A CONTROL-ORIENTED AEROELASTIC MODELLING FRAMEWORK FOR COMPLIANT WINGS WITH TRAILING-EDGE MORPHING

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ABSTRACT

Morphing wing concepts offer significant potential for improving aerodynamic performance and load alleviation by enabling continuous adaptation of the wing shape during flight. In particular, trailing-edge morphing provides a practical means of reshaping the spanwise lift distribution, allowing trade-offs to be made between aerodynamic efficiency and structural load levels, such as wing-root bending moments. Exploiting these capabilities in a dynamic environment requires modelling and simulation tools that are sufficiently accurate to capture aeroelastic effects, yet efficient enough to support control-oriented analysis and model-based controller design.

This paper presents a computationally efficient aeroelastic modelling framework for morphing wings with span-wise trailing-edge morphing, specifically developed to generate reduced-order models suitable for control design. The framework couples an unsteady aerodynamic model based on the unsteady vortex lattice method with a linear structural model formulated using Euler–Bernoulli beam elements, modeling both spanwise bending and torsional modes. Morphing is introduced through a dedicated kinematic mesh, which acts as an intermediate layer between the structural and aerodynamic meshes. This kinematic layer enables chordwise shape changes to be prescribed at discrete sections distributed along the wing span, independently of the structural discretisation, while ensuring consistent displacement and load transfer between the structural and aerodynamic domains.

Time-domain simulations of the coupled aeroelastic system are used to generate data over selected operating conditions. These data are subsequently processed using the Dynamic Mode Decomposition with control method to identify linear, discrete-time state-space models. The resulting models capture the dominant aeroelastic dynamics and the influence of morphing actuation on aerodynamic forces and structural response, while remaining sufficiently low-order for use in model-based control synthesis. Validation of the aerodynamic and aeroelastic response is carried out through comparison with classical two-dimensional unsteady aerodynamic solutions based on the Wagner function, as well as against selected transient CFD simulations with prescribed mesh motion.

The primary objective of the proposed framework is not high-fidelity aeroelastic prediction, but rather the efficient generation of control-oriented models that retain the essential physics of morphing wing behaviour. Compared to fully coupled CFD–CSD fluid–structure interaction simulations, the presented approach requires a relatively small number of parameters, exhibits low computational cost, and enables rapid exploration of design and control trade-offs. These characteristics make the framework particularly suitable for iterative controller development, parametric studies, and preliminary design phases.

The paper demonstrates the applicability of the framework through representative numerical examples and discusses its potential for the design of multi-objective controllers that balance aerodynamic performance enhancement with the suppression of undesirable structural oscillations.