LPV-Based Co-Design of Baseline Flight Control and Active Flutter Suppression with Control Surface Size Optimization

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ABSTRACT

This paper proposes a unified co-design framework that integrates linear parameter-varying (LPV) control synthesis with structural parameter optimization for baseline flight control and active flutter suppression of flexible aircraft. The main objective is to enable a control-oriented, early-stage assessment of aeroelastic stability and control performance while explicitly accounting for the mutual coupling between control law design and control surface geometry. Unlike conventional sequential approaches, where the structure and controller are designed independently, the proposed methodology treats controller synthesis and control surface sizing as a single optimization problem.

The co-design framework is applied to the mini MUTT aircraft. The mini MUTT is a small, remotely piloted test vehicle, which is designed as a research platform for active aeroservoelastic control, exhibiting body freedom flutter. The framework is formulated using a reduced-order polytopic LPV aeroelastic model that captures the dominant dynamics of the flexible aircraft and explicitly represents parametric dependence on airspeed and control surface geometry. The polytopic representation is obtained via Tensor Product (TP) model transformation based on Higher-Order Singular Value Decomposition (HOSVD), enabling an efficient and structured LPV formulation suitable for convex control synthesis. This representation allows the controller to systematically account for variations in both flight condition and structural parameters within a unified mathematical setting.

Within the proposed co-design architecture, a nested optimization strategy is employed. The inner loop performs LPV controller synthesis to ensure closed-loop stability and performance over the achievable flight envelope, addressing both baseline control objectives and flutter suppression requirements. The controller synthesis is carried out using the LPVTools toolbox in MATLAB, resulting in an LPV flutter suppression controller and a gain-scheduled baseline controller parameterized by the structural design variables and sheduled with respect to airspeed. The outer optimization loop explores the influence of control surface size on control authority and performance metrics, enabling a quantitative trade-off analysis between structural design and control effectiveness.

The methodology is demonstrated on the aeroelastic mini MUTT unmanned aerial vehicle, serving as a representative flexible aircraft configuration. Numerical results show that the proposed LPV-based co-design approach can effectively improve flutter robustness while maintaining or enhancing baseline control performance across a range of airspeeds and structural configurations. The results also highlight the strong coupling between control surface sizing and achievable closed-loop performance, underscoring the

importance of integrated design.

Overall, the proposed framework provides a systematic and transparent approach for the concurrent design of structure and control in flexible aircraft. It supports certification-relevant analysis by explicitly addressing robustness over parametric variations and offers a scalable methodology that can be extended to other aeroelastic configurations and advanced flight control architectures.