

Aircraft-Level Aeroelastic Optimization Using Global-Local Structural Modeling

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Abstract

This paper presents an aircraft-level aeroelastic structural optimization framework that integrates global–local structural modeling with surrogate-assisted optimization, targeting early design phases where design freedom is high but computational resources are limited. The proposed methodology aims to bridge detailed composite structural modeling at the component level with a full-aircraft aeroelastic analysis capability, enabling physically consistent design exploration across multiple scales.

A parametric half-aircraft model based on a regional aircraft wing configuration, as presented in Figure 1, is developed, incorporating a semi-monocoque composite airframe with geometric and thickness design variables distributed across the wing, fuselage, and tail. The global structural behavior is represented through an aircraft-level finite element model capturing overall stiffness, mass distribution, and load transfer among the various components. Local structural behavior is incorporated through a global-local strategy that couples classical 2D shell finite elements with arbitrarily large refined analysis subdomains. The subdomains are extracted from the most critical regions of the global model and analyzed using high-order Carrera Unified Formulation (CUF) [1, 2] models, while enforcing kinematic consistency at the global-local interface. Within each refined region, layerwise CUF formulations recover through-the-thickness three-dimensional stress fields at a fraction of the cost of full 3D solid discretizations, enabling strength assessment and failure evaluation at the lamina level.

Aerodynamic and aeroelastic loads are computed using the subsonic Source and Doublet Panel Method (SDPM) [3, 4], providing an efficient representation of three-dimensional lifting-surface interactions suitable for conceptual and preliminary design studies. Aeroelastic stability is incorporated directly within the optimization problem through flutter constraints formulated via a Kreisselmeier–Steinhauser aggregation of modal damping ratios, alongside static strength and global buckling constraints.

To render the resulting aircraft-level optimization problem computationally efficient, surrogate modeling techniques based on Kriging are employed. The surrogates provide both response prediction and uncertainty estimates, enabling adaptive sampling of the design space through a constrained Expected Improvement (EI) criterion [5, 6]. This surrogate-assisted strategy

allows the coupled global–local aeroelastic model to be embedded within an iterative optimization framework while maintaining feasible computational cost.

Overall, the proposed framework establishes a unified methodology for combining multiscale composite structural modeling, aircraft-level aeroelastic analysis, and surrogate-assisted optimization during early design. It provides a systematic pathway for treating aeroelastic stability and composite strength as active design constraints, rather than late-stage verification checks, while retaining sufficient local fidelity to support meaningful early-stage sizing decisions and to enable a broader exploration of the design space.

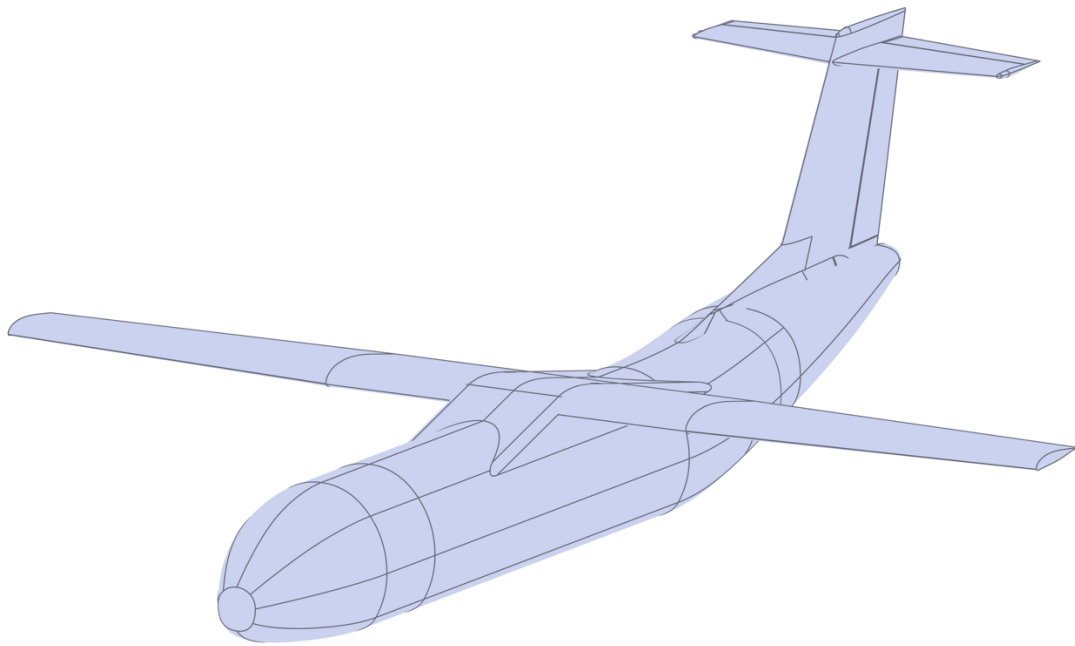


Figure 1. Reference aircraft geometry

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