

OPTIMIZATION OF STIFFENER CONCEPTS FOR HIGH ASPECT RATIO WINGS: STRUCTURAL WEIGHT, LOAD REDUCTION, AND AEROELASTIC PERFORMANCE

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Abstract

High aspect ratio wings provide significant aerodynamic benefits and improved fuel efficiency. However, their slender geometries generate high structural loads and present critical challenges including buckling and flutter susceptibility. Passive load alleviation is therefore essential to achieve acceptable structural performance and realize these aerodynamic benefits.

Skin-Stiffened panel construction helps maintain structural integrity against buckling, efficiently. Different stiffener concepts have different characteristics with respect to manufacturing, weight, and elastic properties. Backward swept wings imply a passive load alleviation due to a coupling of bending and twist. Higher flexibility result in downward twist of the aerodynamic profile, which results in less local load. E.g. I-stiffener in a wing box have higher flexibility compared to commonly used T-stiffener, while fulfilling all design guidelines.

Therefore, this study evaluates multiple stiffener concepts on the D2AE high aspect ratio wing configuration across three performance metrics: (1) structural weight, (2) passive load reduction effectiveness, and (3) flutter speed, which supports design decisions that balance structural efficiency with aeroelastic stability.

The analysis employs a coupled computational framework combining structural optimization with comprehensive loads analysis. A Doublet Lattice Method (DLM) is used to compute aerodynamic loads. Various mass models are considering for different Center of Gravity positions, accelerations due to maneuvers and multiple flight points within the flight envelope, which provide the corresponding inertia loads. The Wing is treated flexible and an aeroelastic equilibrium is ensured using elastic mode shapes.

Stiffeners are represented analytically to allow continuous variations in geometry, enabling an efficient gradient-based design with large no. of parameters. The stiffeners are treated as an additional layer to the composite material cover material, which allows a superposition of stiffness similar to classical lamination theory. The structural optimizer refines stiffener dimensions and properties to

minimize weight while satisfying strength as well as global and local buckling criteria.

Coupling the loads analysis and the structural optimization, while ensuring a consistent stiffness model, captures interdependencies between both disciplines while enabling rapid exploration of large design spaces

.A subsequent analysis of the flutter speeds reveals the influence of stiffener concepts choice on the flutter response. The corresponding structural weight allows to access the correlation between minimum weight and flutter characteristics. As such, passive load alleviation is directly considered by the coupled structural design and load analysis. The presented work gives insights into trade-offs between weight minimization, load reduction and aeroelastic stability. Moreover, the structural performance benefits can be traded-off with respect to their production conveniences in design process. A practical guidance for stiffener selection is hence provided, which allows better informed decisions in next-generation high aspect ratio wing design.