Topology and Size Optimization of Modular Ribs in Aircraft Wings

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Abstract

Semi-monocoque construction currently followed for ribs with full-depth web in aircraft wings requires extensive elastic analysis to ensure adequate stiffness, strength, and stability against local buckling while reducing the weight. In this work, we address this problem by developing a modular design enabled by fewer components than current design. As a result, the cost and complexity of manufacturing the components as well as the overall assembly reduce. Furthermore, the design process of the overall wing becomes computationally efficient. Optimality is achieved by topology and size optimisation techniques. A systematic three-stage procedure for rib design for any given aircraft wing is developed, as explained next. Structural analysis and design optimization studies were carried out using commercial software Altair Optistruct.

The three stages in the proposed design procedure include two stages of optimization followed by modular design of the rib. Step 1 involves topology optimization of a few selected ribs for which the mean compliance is minimized subject to volume constraint. As the loads and length of the ribs are proportional to the chord, the pattern repeatability of the internal structure was achieved by maintaining the same area-ratio between design and non-design areas for all the ribs. The non-design material region exist all along the periphery of the rib.

Step 2 involves size optimization of the ribs obtained through topology optimization in the first step. The objective here is to minimize the mass subject to stress and buckling constraints. Each topology-optimized rib is thus improved by determining the cross-section dimensions of the beam segments in the rib.

Step 3 is the modular design of the intermediate ribs. As the pattern repeatability is achieved through topology optimization, the internal members of the rib can be located proportionally as per the chord-length using non-dimensional analysis. Non-dimensional stiffness, stress, and other parameters help design any intermediate rib with standard available beam segments by maintaining the area and moment of inertia as obtained from the two-stage optimization procedure.

The modular rib design is “satisficing” in nature in that it satisfies all the design and manufacturing requirements but is only nearly optimal. However, the unique feature of this procedure is the modular design wherein the internal members of all the ribs are decided as per their position in the wing. As a result, the design is amenable for economical manufacturing and is more efficient as compared to current practices in terms of weight and performance.

The proposed modular design concept was successfully demonstrated on a typical light transport aircraft wing ribs. The modular rib design is 22% lighter as compared to conventional design with three times more buckling factor.