A Unified Multidisciplinary Shape Optimization Methodology for Composite Aircraft Structures

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Motivation and objectives
Due to increasing emission norms, the aerospace industry aims to improve fuel efficiency. To achieve this, each aircraft component needs to be optimized, in particular with respect to weight reduction. Here, aircraft wings are the crucial components. Shape optimization of the internal components combined with optimization of modern composite materials can considerably reduce the weight of the wing box.

Approach
In the first part of the research project, a parametric geometry of the wing structure is developed, which allows to modify efficiently global wing architectures. Global parameters of the wing, like sweep angle of the outer wing, dihedral angle, airfoil parameters, and twist of the wing, are introduced. Additional wing box parameters, e.g. number and location of ribs/spars/stringers and cross-sectional shape parameters of stringers enable automatic adaptation for arbitrary outer shell geometries (Figs 1-2).

Fig. 1: Examples of different wing shapes illustrating the adaptivity of the wing box components.

Fig. 2: Example of tapered thicknesses changing for spars (left) and different types of stringer cross-sections (right).
Several load types are considered, including acceleration load, engine loads and aero loads. The latter are calculated via ANSYS Fluent CFD or by the simplified XFOIL 2D code. The flow simulation is calculated for fixed external shapes; the resulting pressure distribution is mapped automatically to the structural model in ANSYS Mechanical (Fig. 3).

Fig. 3: Pressure distribution for a wing obtained by ANSYS Fluent (left), XFOIL software (right).

A two-stage approach for wing box parametrization is proposed: at first, the spacing density of the ribs is described in each wing section as a linear function with two parameters to identify rapidly approximate rib layouts (only 4 design parameters). At the second stage, the obtained rib positions are varied, also allowing changing the rib angle individually, in order to refine to an optimal layout. The objective is to reduce the wing weight with constraints on maximum local skin deflection between each pair of ribs and also on wing tip displacement, Fig. 4.

Fig. 4: Convergence for skin deflection constraint (left), coarse model (middle), and refined optimization (right)

For detailed rib optimization, a novel rib stiffener parametrization is proposed, well-suited for direct search methods (e.g. evolutionary algorithms). It enables topology-like shape optimization and includes various constraints within the optimization (e.g. concerning displacements, stresses, buckling, etc.), which is not possible in standard density-based topology optimization.

Fig. 5: Example of Point-Angle-Width (a), topology optimal result (b) and shape optimal result (c)

Finally, a new approach for fiber-steered composite optimization is developed and integrated. Here, the Maximum Fiber Curvature Constraint (MFCC) is added to the optimization process. As example, a 4-layer steered-fiber fuselage section with a window optimized for buckling loads is shown in Fig. 6.

Fig. 6: Problem example (left), optimal iso-lines obtained by 9 parameters (middle), optimal fiber placement for [±α]s laminate with MFCC = 10 m-1 at each layer of laminate (right)

References