Static Aeroelastic Stiffness Optimization and Investigation of Forward Swept Composite Wings

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Forward swept wings with their beneficial influence on laminar flow, and therefore drag reduction and performance increase, have recently seen a resurgence in interest from the research community and industry. The unfavorable structural behavior as a result of coupling of bending and torsion, however, aggravates the design of a wing that can aerodynamically outperform classical designs. In this paper we present a detailed investigation of the aeroelastic optimization of swept forward composite wings. The wing is allowed to have variable stiffness, i.e., a varying thickness and stiffness matrices in the wing skins, and the use of balanced and unbalanced laminates is considered. Aside from common mass and stress responses, also aeroelastic responses like aileron effectiveness, divergence and twist are considered.

The geometry and finite element models of the load carrying wing box are generated in the parametric model generator ModGen, as is the corresponding doublet lattice model for the computation of aeroelastic loads. The structural model comprises shell representations for skins, spars and ribs, and beam elements for the stringers. Masses other than the ones covered by the wing box are included as point masses, distributed along the span. This also includes a generic fuel model. Instead of representing the skin properties as stacking of single layers, membrane and bending stiffness matrices and the corresponding skin thickness are modeled. The wing skin is split up in design fields, each comprising its own set of stiffness matrices and a thickness. Elements in the stiffness matrices and the thickness serve as design variables in the stiffness optimization process. The finite element solver is used to generate the required responses and sensitivities. A generic flight and aeroelastic envelop is constructed, serving as a guideline for the specification of relevant load cases for sizing, aileron effectiveness, divergence and twist considerations. The responses to be included in the optimization - mass, strength and buckling failure, aileron effectiveness, divergence, twist - are approximated as linear and/or reciprocal function of the membrane and bending stiffness matrices and linear function of the thickness. The design variables are updated after a successful minimization of the approximated sub-problem and new responses and sensitivities are generated. This is repeated till a convergence of the objective function is reached.

With mass as objective function, different sets of constraints on the structural and aeroelastic responses are investigated. The influence of minimum aileron effectiveness, divergence pressure and twist on the wing skin mass is analyzed. Load alleviation is a direct consequence of the mass objective and inherent to the optimization with aeroelastic loads. It is therefore not required to be considered explicitly as a response.

The essential difference of balanced and unbalanced laminates with their effects on mass and stiffness distribution is presented, and the influence of leading edge sweep angle on the optimized skin masses is investigated, subject again to variable sets of constraints.