Aeroelastic tailoring for gust load alleviation

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Summary: In this paper, the structural optimisation process of a wing that is designed for gust load alleviation is presented. The optimisation process is built around the equivalent static loads method and Nastran.

Introduction:

Load alleviation has been a field of research which has received more and more attention over the past decade due to the development of light-weight highly flexible wings used in modern airliners as well as for high altitude long endurance (HALE) uninhabited aerial vehicles (UAVs). It has been identified as an efficient way to reduce structural fatigue and to improve aircraft handling as well as passenger comfort. Instead of active load control using ailerons and spoilers which has been around since forty years, composite materials can also be used to obtain a flexible wing that can deform in such way that it will passively relieve itself from the loads. But flexibility also means that unwanted interactions can occur between the control surfaces, leading to control efficiency problems. In this paper, the structural optimisation process of a wing that is designed for passive gust load alleviation and also complies with constraints related to structural strength and stiffness, aeroelastic instability (flutter, divergence) and minimum control effectiveness over the entire flight envelope, is presented. To perform this optimisation, a gradient-based approach is preferred as the number of design variables is relatively large (> 100). However the required sensitivity computation over a transient response is not an easy task [1]. The equivalent static loads (ESL) method recently formalised by Park [2] is used to bypass this issue, and has already been applied to similar problems [3], [4]. It is combined with existing aeroelastic and structural optimisation framework, and can be extended to non-linear cases [5]. Although this technique only provides a weak coupling between the design variables and the loads, its main advantage resides in its ease of implementation.

Preliminary results:

Preliminary results show that the ESL method can provide accurate static loads to the optimisation routine by reproducing the strain field from the dynamic simulation into a static case. This is sufficient to achieve convergence within the required constraints. For this first study, a transport aircraft wing that can freely move in plunge is hit by a "1-cosine gust". The objective function is the structural mass and only the strength constraints are applied. The loads are extracted from the transient aeroelastic NASTRAN solution [6] while the sizing is performed within the NASTRAN optimisation module [7]. A custom-built MATLAB script is used for the data transfer between the two solvers. Thicknesses of several panels of the wing box are used as design variables, and the convergence is reached after 25 iterations, providing a significant reduction root bending moment and weight saving (see Figure 1).

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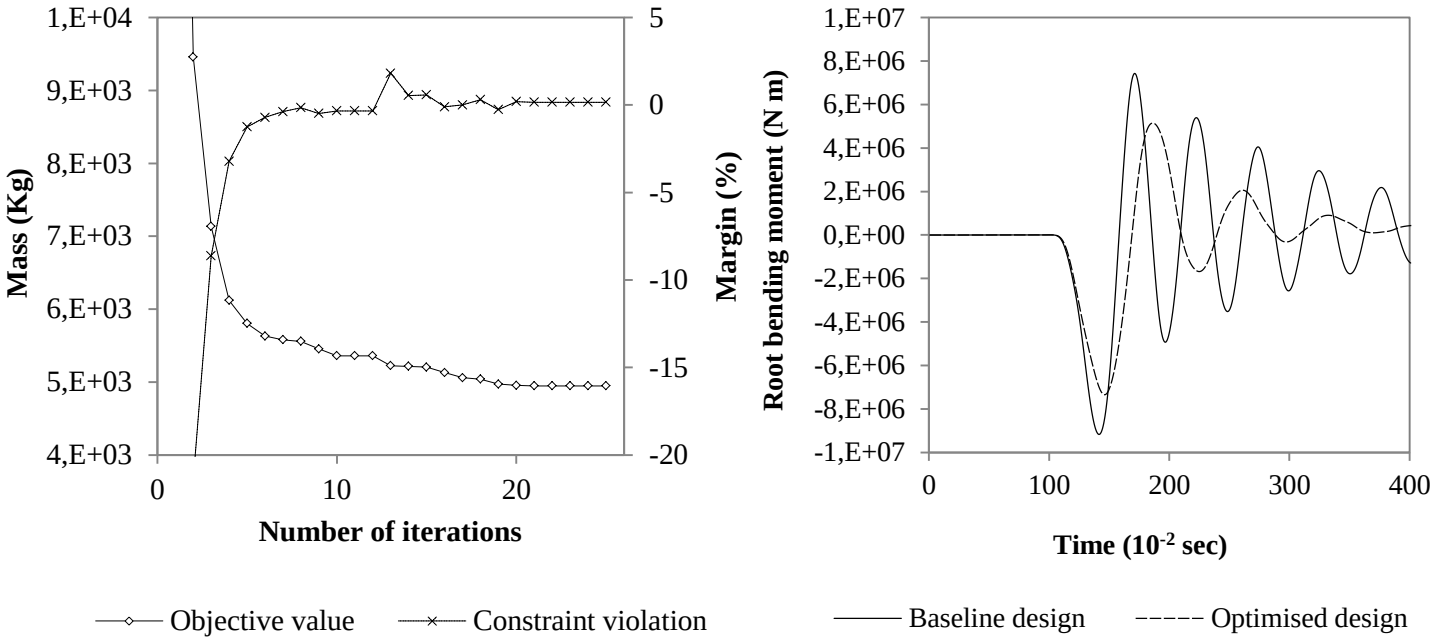

Figure 1: Optimisation results of a wing hit by a 1-cos gust.

In order to assess the limitations of the ESL methodology and the number of iterations required to reach convergence, test cases with different gust scenarios, wing geometries and boundary conditions will be performed (clamped or free pitch and/or plunge). Design variables will be extended to composite laminate properties and additional constraints will be added regarding aeroelastic instability and control effectiveness. The results will be presented in the completed paper. Finally, a trade-off study will be introduced between wing flexibility and effectiveness of different load alleviation strategies.

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