

SKIN-BUCKLING INDUCED PASSIVE LOAD ALLEVIATION

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ABSTRACT

Weight reduction is an important way to develop more efficient aircraft. Load alleviation limits the wing loading enabling a lighter wing design and due to snowball effects, a lighter aircraft. Passive load alleviation influences the load by deflections initiated by the load itself, without additional sensors and actuators. The author's research in the framework of the cluster of excellence SE²A *sustainable and energy-efficient aviation* investigated concepts of passive load alleviation based on strong structural non-linearities such as buckling to enhance the design space of aeroelastic tailoring. Using the different stiffnesses of pre- and post-buckling states on structural level, corresponding structures are designed, which are relatively stiff around the design point but become more flexible after reaching a critical load, changing the wing shape to counteract the exceeding load, both in manoeuvres and gust encounters. A two-dimensional concept of a decambering aerofoil was presented at IFASD [1]. In addition to the two-dimensional concept a different three-dimensional concept, which allows nonlinear twist in the outer wing region, was developed [2] and evaluated on purely structural level [3].

The current work builds upon the three-dimensional concept, adding improved design variations and high-fidelity simulations including fluid-structure-interactions. This allows to answer the research question of how much load alleviation in terms of bending moments can be expected from this concept. The critical improvement over former publications is the full consideration of fluid-structure-interaction effects of the concept, going beyond the previous evaluation of only nonlinear twist effects resulting from a predefined load distribution.

The passive load alleviation concept is based on tailored rib bays in the outer part of the wing. In these rib bays the upper skins are not stiffened by stringers to allow for larger buckling areas. The anisotropic stiffness properties of the skin's composite layups are purposely designed to achieve a tilted bulge shape with respect to the flight direction in order to non-linearly increase the wing twist in high load scenarios in the post-buckling regime. The tilted bulge acts like a tilted hinge increasing bend-twist coupling. The concept is depicted in figure 1. The wing deformations in 0 g, 1 g, and 2.4 g are shown. The buckling shape is well visible in the 2.4 g case. The 1 g case is below the critical load and thus not in the post-buckling regime.

A finite element model is employed, which is mainly composed of shell elements and built using the commercial solver *Abaqus*. Geometrically non-linear quasi-stationary and transient analyses are used. This model is also used with a predefined lift distribution to investigate the structural behaviour of different design variations prior to coupled simulations, as the coupled simulations are computationally expensive. The fluid model is a finite volume model on a hybrid structured and unstructured mesh using the *DLR TAU-Code* solver. The solver is used to solve the steady and unsteady RANS equations. The models are coupled using the in-house software *ifls*, which provides methods for boundary quantity exchange on non-conformal surface meshes as well as means to control the individual solvers.

The coupled model is evaluated in stationary load cases under design and off-design flight conditions as well as in transient discrete gust encounters. Results show approximately 10% reduction in total wing root bending moment for coherent flow conditions in terms of initial angle of attack and maximum gust event. For cases where the load factor is kept constant through increased angle of attack, a reduction in wing root bending moment of 5% is achieved. Compared to the two-dimensional concept, which is very sensitive to changes of the flight condition from the cruise design point, the three-dimensional concept is more robust to different flight conditions and also alleviates loads in subsonic conditions. This is due to the fact that the 3D concept is driven by the bending moment, which does not change as much as the surface pressure distribution that enables the 2D concept, when going down to subsonic flow conditions.

The full paper will provide details about the used models and coupling schemes, the variations in structural designs and their structural behaviour, as well as simulations of load alleviation during steady manoeuvres and dynamic gust encounters. It will demonstrate the performance of the aforementioned unconventional and challenging nonlinear passive load alleviation concept, specifically of the developed three-dimensional realisation of this concept. Furthermore, it will confirm the assumptions in [2] and [3] about how a nonlinear load-twist behaviour contributes to passive load alleviation.

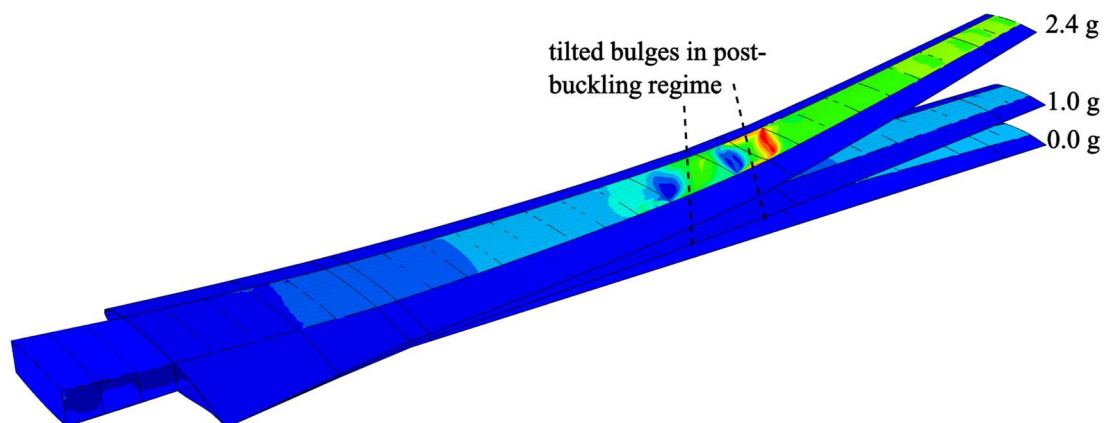


Figure 1: Deformation shapes of the wing with non-linear load alleviation concept based on tilted skin buckling in selected rib bays. Colors represent rotation magnitude.

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