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Can we use buckling to design adaptive composite wings?

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Abstract. In aeronautics, buckling has long been considered as a structural phenomenon to be avoided, because characterized by large out-of-plane displacements and therefore by losing the ability to sustain the designed loads. Several recent studies show the possibility to allow composite stiffened panels of primary aeronautical components to work in the post-buckling field so to potentially reduce the structural weight. The present study aims to control buckling behavior of composite structural components for future adaptive wings using novel tailorable and effective mechanisms. Instead of the traditional design against buckling, the idea is to use the nonlinear post-buckling response to control stiffness changes which redistribute the load in the wing structure. Numerical studies are at first conducted on a composite plate and then implemented in a simplified thin-walled composite wing box, where stiffness changes is controlled using buckling.

Introduction

The development of aviation has always been characterized by the search for maximum efficiency in a holistic and multidisciplinary way, through optimal structural, aerodynamic and propulsive efficiency characteristics. Two contrasting challenges have recently become evident: on one side the growth of air traffic, which implies the need to increase transport capacity and reduce travel times while maintaining or improving the level of safety, and on the other the search for a reduction of the environmental impacts of air transport. The Advisory Council for Aviation Research and Innovation in Europe (ACARE) provided a Strategic Research and Innovation Agenda (SRIA), that contains the roadmap for aviation research, development and innovation for reaching the so-called "Clean Aviation" [1], that is part of the European Green Deal.

It is evident that a simple evolutionary improvement of aircraft technologies will not be sufficient to fulfil the challenging targets requested in terms of environmental impact reduction.

In the last years, a few papers appeared in literature showing how buckling could be used for innovative applications, but in aeronautics they are mainly devoted to use buckling for the design of energy harvesters or for bistable structures with limited morphing applications [2-3].

The project NABUCCO (New Adaptive and BUCkling-driven COmposite aerospace structures), funded by the European Union through an ERC Advanced Grant, is proposing to design new adaptive buckling-driven composite structural concepts for the next generation of aircraft configurations, that will impact on two of the biggest levels for reduction of fuel burn needed for future clean aviation: reduced weight and increased efficiency.

NABUCCO Project

The NABUCCO project aims to design new adaptive buckling-driven composite structures for next generation of aircraft configurations. The project is proposing a paradigm shift in aerospace design concepts, considering buckling no more as a phenomenon to be avoided, but as a favorable behavior to be actively exploited.

Let's suppose for a moment to change radically the traditional design approach, and to analyze what happens if from the beginning a structure is designed to exhibit buckling, and not to avoid it.

The main drawbacks that are commonly seen towards buckling in the design of composite aerospace structures are summarized in Table 1, together with the way they are seen positively in NABUCCO.

Table 1. From drawbacks to advantages of buckling.

Buckling must be avoided because…	Buckling can be exploited because…
Buckling produces stiffness reduction.	The stiffness reduction can be used for shape variation, load redistribution and dynamic response change.
Buckling generates large nonlinear deformations.	The large nonlinear deformations can be exploited to significantly change the structural shape with a minimum amount of provided energy.
The transition from pre- to post-buckling can be instantaneous (snap-through).	The fast structural response can be adopted for passive control of peak loads, such as those due to heavy gust excitation or maneuvers.
Buckling strongly depends on geometrical imperfections, material variability, external loads, boundary conditions.	The potential design space can become very large, allowing for many and unusual combinations of structural configurations to obtain pre-defined shapes.

The composite structures have the capability to work safely in the deep post-buckling field with large out-of-plane displacement, as shown for example in [4]. Besides, if appropriately designed, these structures can undergo repeated loading-unloading-loading cycles remaining in the elastic field for the different post-buckling configurations.

The idea of the NABUCCO project is to modify and adapt the aircraft wing shape during the flight mission by the direct use of the buckling phenomena, taking advantage of their typical large nonlinear displacements and stiffness redistribution (Fig. 1).

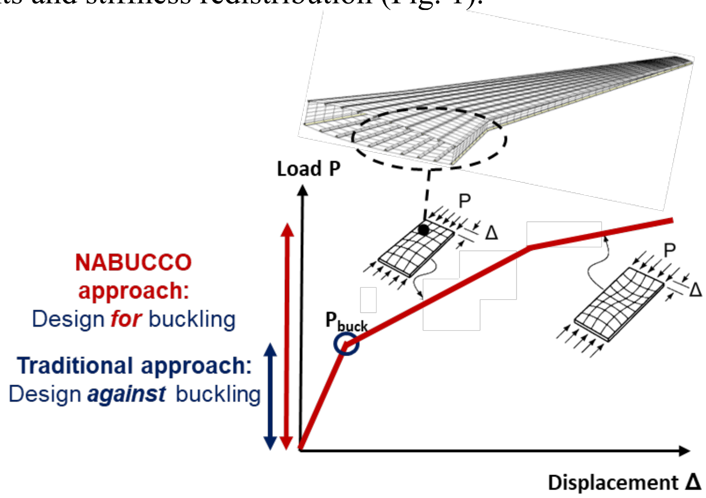

Fig. 1. Approach of NABUCCO project:
Design for buckling of composite aeronautical components.

Buckling-driven Mechanisms for Composite Adaptive Structures

All the potentialities offered by composite materials are used, thanks also to novel manufacturing processes, and the boundary conditions are modified to govern when buckling occurs so to tune multiple non-traditional post-buckling stable configurations.

Buckling-driven mechanisms are developed to obtain different stable configurations changing the boundary conditions, that require only small forces to be reconfigured. In this way it is possible

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to induce controlled buckling, to obtain local stiffness increase or reduction, infinite number of shapes variation, and load redistribution.

The first steps of the buckling-driven methodology under development consisted in the numerical investigation of a composite plate and then of a simplified thin-walled composite wing box, where stiffness changes were controlled using three buckling-driven mechanisms by restraining the out-of-plane buckling deformation using point, area and maximum displacement constraints [5]. In particular, in the investigation of the composite wing box, the post-buckling behavior of the spar web was controlled by out-of-plane deflection constraints, so that the wing twisting performances were tailored by the relative stiffness of the spar web compared to the rest of the structure. In this way, the nonlinear post-buckling response is used to control stiffness changes, as shown in Fig. 2.

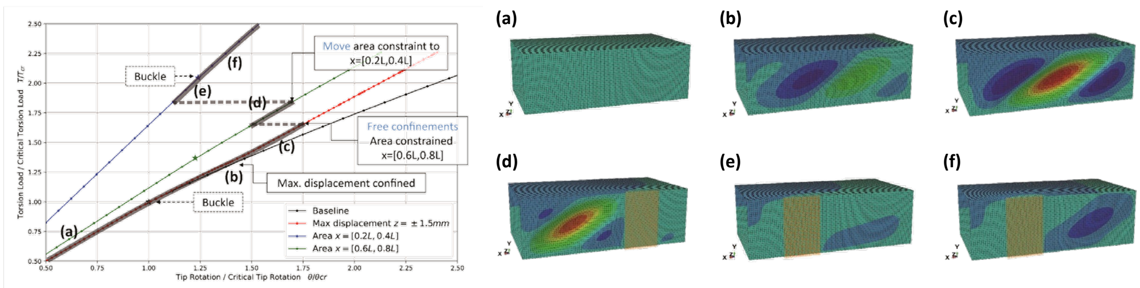

Fig. 2. Adaptive multi-stable composite wingbox:
controlled torque-rotation load path and corresponding wingbox deformation.

In this way, the load in the wing structure is redistributed controlling the stiffness changes, and the methodology allows to gain the real-time controllability of the post-buckling behavior and to enhance the adaptivity of the wing structure to meet multi-stable tailorable situations, with a limited amount of load and actuation energy.

The investigated structures still requires an extensive research of feasibility as they need to be validated experimentally. For this reason NABUCCO is developing a strongly coupled computational-experimental framework, to demonstrate the feasibility of designing aircraft components with controllable buckling, starting from simple composite panel, and then increasing complexity considering a wingbox, and later an adaptive wing for morphing application, as shown in Fig. 3.

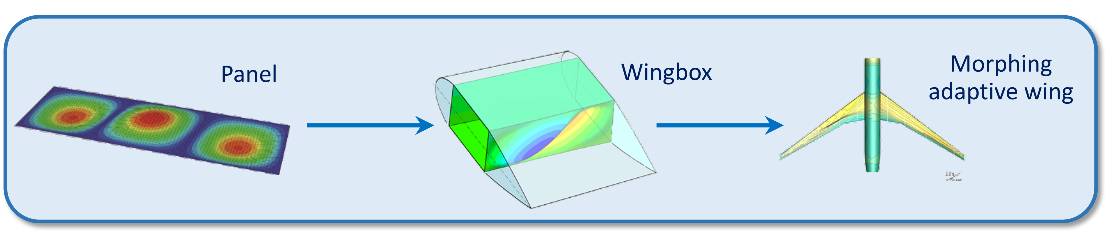

Fig. 3. Increasing complexity of the composite structures investigated in the NABUCCO project.

The first steps of the buckling-driven methodology under development for composite structures show that the design space is significantly enlarged and the designer can identify, manage and control the buckling phenomena.

Summary

The next generation aircraft will require to be lighter, more flexible and sustainable, with the same or increased level of safety. The relaxation of some of the established design constraints, together with the use of new lightweight and recyclable materials, can contribute to the development of new breakthrough technologies and design philosophies.

Structures designed to work in the post-buckling field and able to adapt their shape during different flight conditions are under development. The first steps of the methodology consisted in the numerical investigation of a composite plate and then of a simplified thin-walled composite wing box, where the post-buckling behavior of the structural component is controlled by out-of-plane deflection constraints.

Even if the investigated configurations still require an extensive research of feasibility as they need to be validated experimentally, they show the capability of controlling the stiffness changes through the nonlinear post-buckling response and to enhance the adaptivity of the wing structure to meet multi-stable tailorable situations, with a limited amount of load and actuation energy. These new composite structures will act on two of the biggest levers for the future of clean aviation: reduced weight and increased efficiency.

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References

[1] Clean Aviation, Strategic Research and Innovation Agenda, December 2021. Information on https://clean-aviation.eu/sites/default/files/2022-01/CAJU-GB-2021-12-16-SRIA_en.pdf

[2] A. F. Arrieta, I. K. Kuder, M. Rist, T. Waeber, P. Ermanni, Passive load alleviation aerofoil concept with variable stiffness multi-stable composites, Composite Structures. 116 (2014) 235-242. https://doi.org/10.1016/j.compstruct.2014.05.016

[3] Y. Li, S. Pellegrino, A theory for the design of multi-stable morphing structures, Journal of the Mechanics and Physics of Solids. 136 (2020) 103772. https://doi.org/10.1016/j.jmps.2019.103772

[4] K. S. van Dooren, B.H.A.H. Tijs, J.E.A. Waleson, C. Bisagni, Skin-stringer separation in post-buckling of butt-joint stiffened thermoplastic composite panels, Composite Structures, 304 (2023) 116294304. https://doi.org/10.1016/j.compstruct.2022.116294

[5] J. Zhang, C. Bisagni, Buckling-driven mechanisms for twisting control in adaptive composite wings, Aerospace Science and Technology, 118 (2021) 107006. https://doi.org/10.1016/j.ast.2021.107006