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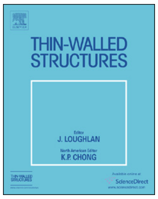

Future structural stability design for composite space and airframe structures

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ABSTRACT

Space and aircraft industry demands for reduced development and operating costs. Structural weight reduction by exploitation of structural reserves in composite space and aerospace structures contributes to this aim, however, it requires accurate and experimentally validated stability analysis. Currently, the potential of composite light weight structures, which are prone to buckling, is not fully exploited as appropriate guidelines in the field of aerospace and space applications do not exist. This paper deals with the state-of-the-art advances and challenges related to coupled stability analysis of composite structures which show very complex stability behaviour. Two types of thin-walled light weight structures endangered by buckling will be considered; imperfection tolerant and imperfection sensitive structures. For both groups improved design guidelines for composites structures are still under development. This paper gives a short state-of-the-art and presents proposals for future design guidelines.

1. Introduction

Reduction of structural weight of primary constructions in the aerospace and space industry is an important contribution to decrease operating costs. Lower structural weight has also an impact on reduced fuel consumption and therefore also a positive effect on the environment. The use of CFRP lightweight structures in future markets is characterised by an annual growth rate of more than 10%. A considerable potential of the fibrous composite materials is based on their lightweight potential as well as on their anisotropic material behaviour. By purposeful combination, arrangement and design of the individual components – fibre and matrix – directionality of the material characteristics can be constructed and used in a way which is suitable for the respective application. Furthermore, the state-of-the-art lightweight material CFRP is characterised by good damping behaviour and by a high specific energy absorption capacity. These additional “degrees of freedom“ lead to a completely new development potential, but also require a more complex and new type of design philosophy as well as interdisciplinary knowledge ranging from the design to the production of fibre composite structures.

The use of CFRP for primary aerospace structures is already accepted. The share of that material in the whole aircraft structure is continuously increasing. The Dreamliner 787, just recently developed by Boeing contains about 50% of CFRP. Airbus is currently designing the Airbus A350, which will contain a similar proportion of composites. Although this is a significant step in the aerospace technology, this first airplane generation do not use the full potential of the composite structures. The reason is that there is still a need for research in different areas as stability, effects of defects, structural health monitoring or automation of the manufacturing processes. Thus, for the future there are possibilities and challenges in further weight reduction as well in bringing more functionality into the structure.

Thin-walled light weight structures endangered by buckling can be for instance divided into two groups: imperfection tolerant and imperfection sensitive structures. For both groups improved design guidelines for composites structures are still under development. This paper gives a short state-of-the-art and presents proposals for future design guidelines.

Stiffened panels used in aircraft applications can be classified in the *Imperfection tolerant structures* group. The ultimate load is quite insensitive with respect to imperfections. Such structures are characterised by a relatively large post-buckling area that is

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currently well explored for designs in metallic structures, but not for composites. The use of the post-buckling area for composites is the research topic of POSICOSS and COCOMAT, two EU projects which will be further discussed in Section 3 of this paper.

Imperfection sensitive structures are for instance unstiffened structures or stiffened structures with a rather dominant skin compared to the stiffeners, commonly used in space applications. For such structures the ultimate load is equal or close to the first buckling load, and the buckling load is highly dependent on initial geometric imperfections. The NASA SP-8007 guideline, published in 1965 and reviewed to the most known version in 1968 [1], consists in a database of tests results from 1930s to 1960s and suggests a lower-bound curve to calculate the knock-down factor (KDF). Originally developed for isotropic materials, this guideline can be applied for the orthotropic case with some approximations, using an equivalent thickness. Section 4 of this paper explains why this approach does not consider the structural behaviour of composite material appropriately

The conservativeness of NASA SP-8007 guideline has been discussed by many authors [2–4]. New methods have been proposed and will be discussed in Section 4.

The “Single Perturbation Load Approach” is a promising concept which is based on the observation that a large enough disturbing single load leads to the worst imperfection: This approach opens a lot of new questions which are investigated in the running EU project DESICOS (New Robust DESIgn Guideline for Imperfection Sensitive COmposite Launcher Structures). The paper presents this approach, some results as well as the challenges for the future.

The ideas for future guidelines presented in this paper are all related to *coupled-stability analysis* as the structures considered show very complex stability behaviour. For the specific case of an unstiffened cylinder with a big enough lateral perturbation load, it will be seen that the global buckling is dominated by the local buckling which was stimulated by the lateral load. This coupled behaviour will be further discussed, it explains the lower imperfection sensitivity after a threshold perturbation load originally called “P1” by Hühne [5].

2. Stability of light weight structures

2.1. *Comparison of imperfection tolerant and imperfection sensitive structures*

Fig. 1 illustrates the typical load shortening curves obtained for stiffened and unstiffened structures. As already discussed these types are imperfection tolerant and imperfection sensitive, respectively. For both groups the design guidelines for composites structures are still under development.

In Fig. 1a it can be seen the large post-buckling area (range between the first buckling load and the first global buckling load). At the first buckling load it is observed skin buckling and the load is redistributed to the stringers. At the global buckling the stringers start to buckle and here degradation starts to take place, verified mainly by skin-stringer separation. Usually, after the global buckling and the onset of collapse the structure cannot withstand much additional load prior to collapse.

Fig. 1b shows a typical example of how imperfection sensitive a thin-walled cylindrical shell can be. This structure is a benchmark cylinder with very high imperfection sensitivity, designed by Zimmermann, 1992 [6] and used by Hühne [5] and Wullschleger [7]. The imperfection pattern used was produced by a lateral-radial load oriented inwards (referred to as a single perturbation load). The radial defect amplitude was measured and when this value is only 0.4 mm a buckling reduction of 35% takes place (KDF of 0.65). The buckling load to be used as a design load is highly dependent on the imperfection level, which makes it difficult to obtain a reliable and realistic prediction of the buckling load at early design phases.

Table 1 shows the design scenario for metallic and orthotropic, stiffened and unstiffened structures. For metallic stiffened structures many design handbooks are available (just to cite some examples: [8–10]) to allow a fast and reliable prediction of the post-buckled behaviour. These handbooks are largely applied in the aerospace industry at both preliminary and more detailed design phases. For metallic unstiffened structures the NASA SP-8007 was developed, but in this paper its conservativeness is not discussed for the metallic case. The Shell Buckling Knockdown Factor (SBKF) Project was established in 2007 by the NASA Engineering and Safety Centre (NESC) in collaboration with NASA's Constellation Program and Exploration Systems Mission Directorate [2]. The SBKF deals with both metallic and composite structures.

For composite structures no guideline for calculating post-buckling in composite is available. Table 1 shows two EU projects that are concluded (POSICOSS – improved post-buckling simulation for design of fibre composite stiffened fuselage structures; COCOMAT – improved material exploitation at safe design of composite airframe structures by accurate simulation of collapse).

Table 1
Design scenario for isotropic and orthotropic stiffened and unstiffened structures.

Material	Imperfection tolerant structures (stiffened):	Imperfection sensitive structures (unstiffened):
Metallic structures:	Conventional guidelines available	NASA SP-8007 NASA SBKF
Composite structures	Developed (e.g. in EU-Projects POSICOSS, COCOMAT)	NASA SBKF, DESICOS

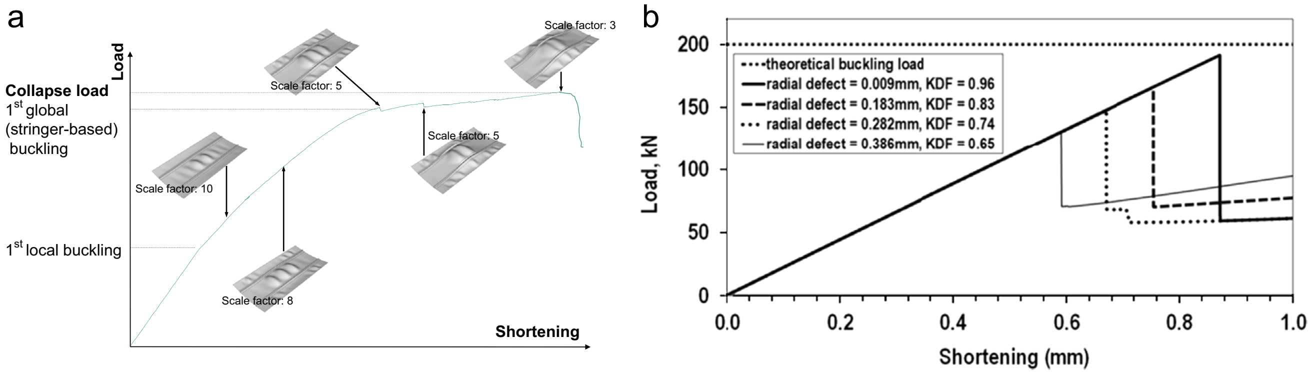

Fig. 1. Structural behaviour of light weight structures: (a) stiffened structures (imperfection tolerant) and (b) unstiffened structures (imperfection sensitive).