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FUTURE DESIGN FOR COMPOSITE SPACE AND AIRFRAME STRUCTURES

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Summary. *European 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 of real structures under realistic loading conditions. This paper presents different advances from the area of computational stability analysis of composite aerospace structures which contribute to that field. For stringer stiffened panels, as used in aerospace main results of the finished EU project COCOMAT and objectives of the running EU project MAAXIMUS are given. Aim is the exploitation of reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling and collapse. For unstiffened and highly imperfection sensitive cylindrical composite shells as more used in space applications, a proposal for a new and efficient design method is presented. It takes the advantages of composite materials in an efficient way into account.*

1 INTRODUCTION

Thin-walled light weight structures endangered by buckling can be mainly divided into two groups: imperfection tolerant and imperfection sensitive structures. For both groups 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.

Imperfection tolerant structures are for instance stiffened panels as used in aeronautic applications (e.g. fuselage or wing). They are characterised by a relatively large postbuckling area (load carrying capacity between maximum load and first, in most cases local buckling) which may be usually used for design. The maximum load is quite insensitive with respect geometrical or loading imperfections. The finished EU project COCOMAT (Improved MATerial Exploitation at Safe Design of COmposite Airframe Structures by Accurate

Simulation of COllapse) investigated the postbuckling and collapse behaviour of this kind of structures. The running EU project MAAXIMUS (More Affordable Aircraft Structure through eXtended, Integrated, and Mature nUmerical Sizing) builds up on these results and goes one step further on fuselage barrel level. This paper presents an overview about main COCOMAT results which demonstrates the potential of the postbuckling behaviour of stiffened CRFP panels and gives the strategy of the running MAAXIMUS project.

Imperfection sensitive structures are for instance unstiffened structures or stiffened structures with a more dominant skin compared to the stiffeners. For such structures the maximum load is equal or close to the first buckling load and is imperfection sensitive. These types of structures are more used in space applications. The currently applied design guidelines were developed only for metallic structures and are from 1968. For composites structures no guidelines exist. To fill this gap DLR developed a promising “Single Pertubation Approach” which promises high potential for a future application. The paper presents the approach and the challenges for the future.

2 IMPERFECTION TOLERANT STRUCTURES

Panels stiffened by stringers and frames as used for aircrafts are one example for imperfection tolerant structures. For metallics the structural behaviour in the postbuckling area is traditionally already exploited, for composites intense research and development work is ongoing. For this material the structural behaviour was significantly studied in the finished EU project COCOMAT which demonstrated that composites also allow exploitation reserve capacities resulting in significantly weight reduction. In the running EU project MAAXIMUS the findings are further developed and the applications to a full composite fuselage barrels are investigated. The concepts and design tools, which are mainly developed for applications in aeronautics, are also transferable to other industrial fields as automotive or civil engineering.

2.1 EU project COCOMAT

The EU project COCOMAT (2004-2008) aimed at allowing for a structural weight reduction by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling and collapse ([1, 2]). COCOMAT improved existing slow and fast simulation tools and set up design guidelines for stiffened panels taking skin stringer separation and material degradation into account. Reliable fast tools allow for an economic design process, whereas very accurate but necessarily slow tools are required for the final certification. The project results comprise a substantially extended data base on material properties and on collapse of undamaged and pre-damaged structures subjected to static and low cycle loading, degradation models, improved slow and fast computation tools as well as design guidelines.

COCOMAT mainly strives for accomplishing the large step from the current to a future design scenario of typical stringer stiffened composite panels. Figure 1 demonstrates the aspired achievements by means of a simplified load-shortening curve including buckling, postbuckling behaviour and collapse. The left graph illustrates the current industrial design scenario. Three different regions can be specified. Region I covers loads allowed under operating flight conditions and is bounded by Limit Load (LL); region II is the safety region and extends up to Ultimate Load (UL); region III comprises the not allowed area which reaches up to Collapse. In aircraft design Ultimate Load amounts to 150% of Limit Load. There is still a large unexploited structural reserve capacity between the current Ultimate Load and Collapse. The right graph of Figure 2 depicts the design scenario aspired in future, where Ultimate Load is shifted towards Collapse as close as possible. Through that move the onset of degradation appears no longer in the not allowed region III but already in the safety region II. This is comparable to metallic structures where plasticity is permitted in the safety region.

Although, with respect to loads and characteristic dimensions, this project was oriented towards an application in the fields of fuselage structures, the results are transferable to structures from other engineering field as well. Main project outcome can be downloaded at www.cocomat.de. The papers [4] to [7] presented some selected results.

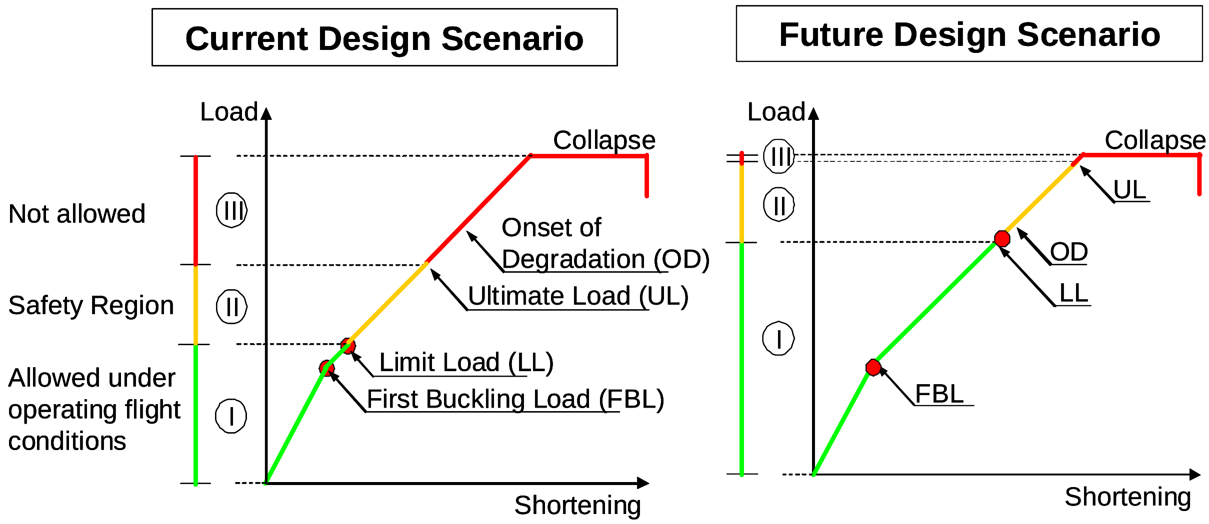

FIGURE 2. Structural behaviour of stiffened thin-walled light weight structures (e.g. stringer stiffened CFRP panel).

3.1 EU project MAAXIMUS

The running EU project MAAXIMUS (2008 – 2013, 67 Mio Euros total costs, 57 partners) aims to demonstrate the fast development and right-first-time validation of a highly-optimised composite airframe. The high level objectives are:

1. Highly-Optimised Composite Fuselage:
   - Enable a high-production rate: 50% reduction of the assembly time
   - Reduce the manufacturing and assembly recurring costs by 10% compared to the ALCAS equivalent reference

- Reducing weight by 10%, compared to best available solutions on similar fuselage sections (F7X, A320 and TANGO fuselage)

2. Faster Development
   - Reduce by 20% the current development timeframe of aircraft composite structures from preliminary design up to full-scale test
   - Reduce by 10% the non-recurring cost of aircraft composite structures from preliminary design up to full-scale test (ALCAS reference)
3. Right-First-Time Structure
   - Reduce the airframe development costs by 5% compared with the equivalent development steps in an industrial context
   - These objectives will be achieved through coordinated developments on the following two platforms (cf. Figure 4):
   - A physical platform, to develop and validate the appropriate composite technologies for low weight aircraft
   - A virtual structure development platform, to identify faster and validate earlier the best solutions

More details of the project are given in [3].

2 IMPERFECTION SENSITIVE STRUCTURES

Currently, imperfection sensitive structures prone to buckling are designed according the NASA SP 8007 guideline using the conservative lower bound curve (cf. Figure 3a). The guideline dates from 1968, and the structural behaviour of composite material is not considered appropriately, in particular since the imperfection sensitivity of CFRP shells **depends on the lay-up design. The buckling loads of composite structures may vary by a factor of about 3 just by changing the lay-up. This is not considered in the NASA SP 8007, which allows designing only "black metal" structures. “Black metal” means in this context** copy of typical metal design and disregarding the influence of stacking (homogenisation). There is a high need for a new, improved and fast design guideline for imperfection sensitive composite structures which allows significant reduction of structural weight as well as development time. For that purpose, DLR developed the promising new approach presented in the next section.

Single Perturbation Load Approach (SPLA)

This approach, recently developed at DLR [8], assumes that a single buckle initiated by a perturbation load (cf. Figure 3b) is the worst imperfection mode and leads directly to the load carrying capacity of the structure. No further information about the imperfections of the unstiffened structure is needed. Figure 3b shows also experimentally obtained buckling loads dependent of the magnitude of a single perturbation load. Each test result is represented by a dot. It can be seen that beyond a certain limit P1 the buckling load is almost independent of the perturbation magnitude. This structural behaviour promises to determine the design buckling load F1 directly using a sufficiently large perturbation load, independent of the kind of imperfection. Numerical analyses, which do not consider any imperfections, lead to the same results as the experimental findings if the perturbation loads are assumed to be large enough. If that observation holds in general, information about imperfections (e.g. detailed geometrical deviations) is no longer needed for the design of an imperfection sensitive cylinder. A recent investigation [9] approved previous findings and demonstrated for an axially loaded unstiffened cylinder a 80% higher buckling load compared with the respective NASA SP 8007 design by means of homogenisation of the composite stacking. This demonstrates the high potential of composites. The SPLA is a promising concept of a future design scenario which will be further investigated in follow-up projects.

Current design scenario (NASA SP 8007)	Future design scenario (SPLA)

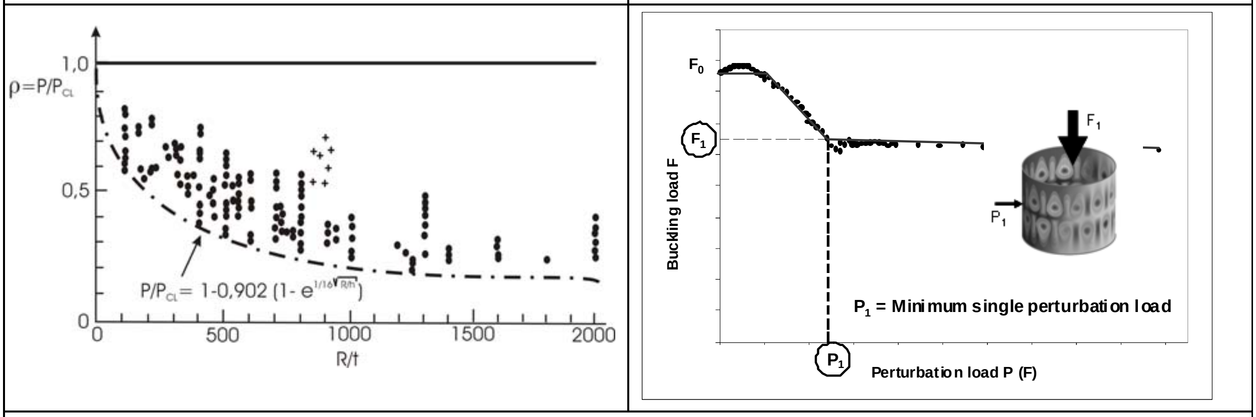

FIGURE 3. Current (a) and future (b) design scenarios for imperfection sensitive structures

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