CFRP Fuselage Structures – Postbuckling Permitted

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CFRP (carbon fibre reinforced plastics) fuselage structures are expected to be realized with future generations of aircraft. Going into the postbuckling regime with these structures requires improved, fast and reliable procedures for analysis and design of stiffened fibre composite panels. The EC project POSICOSS, which was started in the year 2000, develops such procedures. This article deals with the main objectives of the project, the theoretical and experimental work to be carried out, and with first results.

eduction of weight by about 20% in 10 years without prejudice to costs and structural life is one main objective for the design of the next generation of aircraft structures (GROWTH Work Programme, Objective 4.2, Section 4.2.2). How to achieve that aim? *Figure 1* shows the problem to be solved. The diagram shows the 'criterion space' for the design criteria reduction of weight and simultaneous increase of structural life. The dotted area is called the 'feasible space', and each dot stands for one specific structural design which satisfies the constraints the design task is subjected to (feasible design). The upper horizontal line and the left hand vertical line characterize the upper limit of weight and the lower limit of structural life, respectively. Only such solutions make sense, which are lying on the lower limiting line of the feasible space, because with them improvements in both criteria at the same time – decrease of weight and increase of structural life – is not possible. Decrease of weight has to be paid by loss of structural life and increase of structural life is for account of weight. The final choice among all the designs on this line must be done by the decision maker according to his preference. If it is assumed that actual designs are already very close to this line, then the objective to reduce weight by 20% without reduction of structural life can only be met by shifting this line downward (cf. dashed line). This can be done for instance by alleviating design constraints or by fundamental innovations like application of high performance materials. A possible contribution to cope with that demand for fuselage structures is to permit postbuckling under ultimate load (alleviation of design constraints) and at the same time to use CFRP material.

Postbuckling

What does it mean, postbuckling? It is explained by the results of computations for a thin-walled stiffened CFRP cylindrical shell, which are shown in *figure 2*. The shell is loaded by compression, and it undergoes shortening. At a certain value

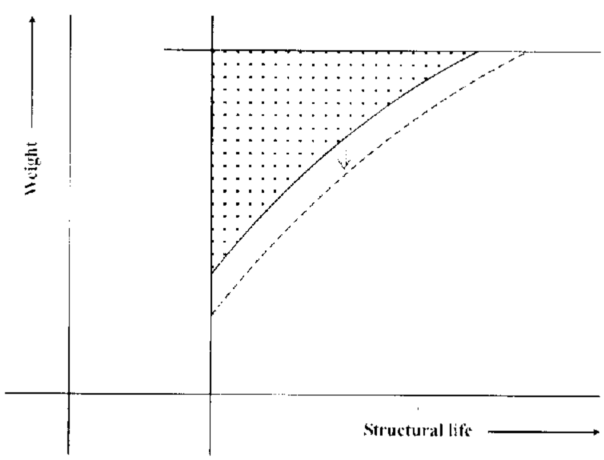

Figure 1. *Criterion space for structural design.*

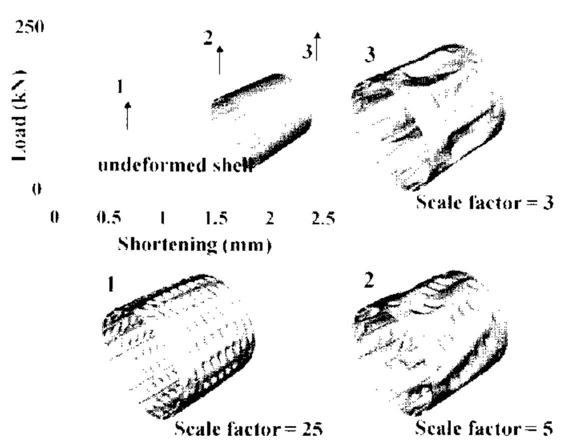

Figure 2. *Buckling and postbuckling behaviour.*

of shortening, transverse deflections occur all in a sudden - this is called buckling: A deflection pattern falls in like that belonging to point 1 in the load-shortening-curve. The behaviour of the shell, if it is loaded beyond buckling, is called postbuckling. The points 2 and 3 indicate postbuckling patterns. Of course, only local buckling and postbuckling with small deformations will be permitted.

In this context the issue has to be raised, whether thin-walled structures made of carbon fibre reinforced plastics tolerate repeated buckling without damage. Experiments performed in former times at Technion and DLR with stiffened plane panels and unstiffened cylinders made of that material showed, that the test structures sustained repeated buckling without any change in their buckling behaviour. They were compressed in axial direction until buckling, then deloaded, loaded again, deloaded, and so on. Even repeated buckling with high frequency (20 Hz) was tolerated by the shell: No change of buckling load and no change of buckling pattern. However, it still has to be found out, how far loading can go into the postbuckling regime without damage of the structure.

The European Union is funding within the 5th Framework Programme the project POSICOSS, which copes with the above mentioned demand to design fibre composite fuselage structures for postbuckling under ultimate load. POSICOSS means 'Improved POstbuckling SImulation for Design of Fibre COmposite Stiffened Fuselage Structures'. The project started 1 January 2000, and will run until the end of 2003. It merges knowledge and capabilities of seven partners from industry and research: The German Aerospace Center (DLR) - which also acts as coordinator – and the Technical University RWTH Aachen from Germany, Agusta and the Politecnico di Milano from Italy, IAI and the Technion from Israel, and the Technical University of Riga from Latvia.

POSICOSS objectives

The main objective of the work to be done is the development of improved, fast and reliable procedures for analysis and design of fibre composite stiffened panels of future fuselage structures. They are unconditionally needed, because so far postbuckling calculations are extremely time consuming and as such not applicable for design. In addition, comprehensive experimental data bases will be created for the purpose of validation.

The partners cooperate in six technical work packages:

- *WP1: Benchmarking for postbuckling and collapse analysis:* This work is performed in order to collect existing benchmarks for software evaluation purposes, as well as to identify in detail the abilities and deficiencies of the tools available. As with postbuckling the computations are on highly non-linear problems and as fast software actually does not exist, the benchmark computations are very time consuming;
- *WP2: Design of stiffened, fibre composite verification structures:* The objectives and constraints are mainly defined in view of the requirements from benchmarking according to the shortcomings of existing tools and benchmarks; thus the verification structures are designed as to specific limiting aspects of application of the software to be verified, e.g. type of shell theory (design going into the limits of the theory), type of buckling before postbuckling (local or global), mild or strong stiffness reduction in postbuckling regime, multiple or single modes of buckling limit before postbuckling. For designing, material properties have to be known. Hence the required properties are characterized by coupon testing for the fibre composite materials used;
- *WP3: Manufacturing and testing of verification structures:* The objective is to extend the data base for evaluation of improved software tools by results of buckling tests until collapse. At least a total of 26 verification structures will be manufactured and inspected non-destructively. The tests are carried out with shortening control, thus enabling control of how far going into the postbuckling regime. This is important, because with one structure several tests must be performed. Different loading conditions are applied (compression, torsion or shear, and critical combinations of them). A basic problem in testing as reference to computations is, that the material properties realized in the structure may vary from those found by coupon testing. Thus efforts are taken to identify the most important material properties as they are realized in the verification structures;
- *WP4: Development of improved simulation procedures and preliminary design guidelines:* New tools are developed and existing ones for metallic structures are modified. After verification by means of the extended data base, the tools then are used for parametric studies in order to derive preliminary design guidelines for stringer stiffened fibre composite panels;
- *WP5: Design, analysis, manufacture, inspection and testing of fibre composite industrial panels:* The industrial panels are designed in regard to industrial aspects, to being best for application as part of real industrial fuselage structures, thus being result of optimisation considering minimum weight and favourable postbuckling behaviour as objectives, taking full advantage of experience of the industrial partners, always taking into account manufacture constraints and efficiency and cost of production. 30 industrial panels are manufactured, inspected and tested. Again, realised material properties are identified;
- *WP6: Design guidelines for stiffened fibre composite panels:* Existing experience and practice of industry, as well as the lessons learned from the project work, are combined in order to carry out final design guidelines.

First results

WP1 is finished. Benchmarks which fulfil all requirements for the verification structures were not found. *Figure 3* compares computational results from benchmarking, which were obtained by different partners and by use of different software products. It shows load

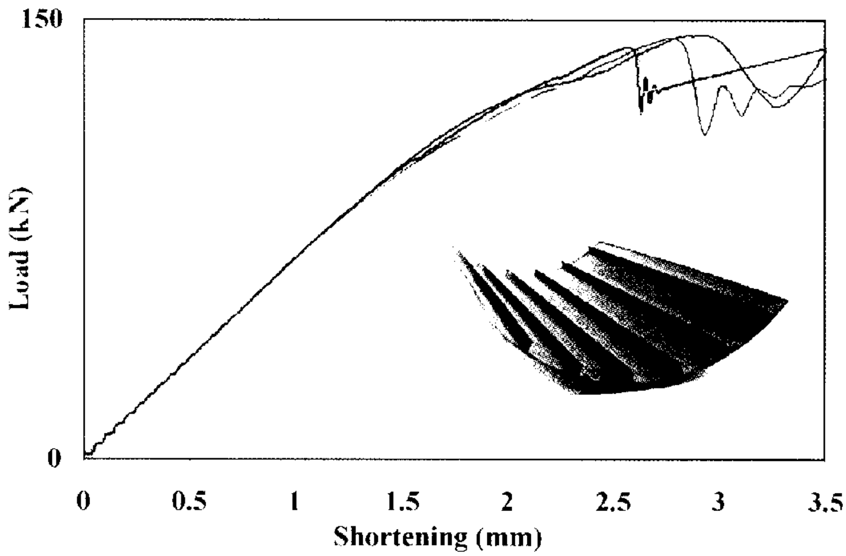

Figure 3. Load-shortening-curves of CFRP benchmark panel.

shortening curves diverging in their non-linear parts. Obviously, without reliable test results it can not be said, which curve is the correct one. The test to be performed under WP2 and 3 will confirm which computational method is more precise. This emphasizes the importance of WP2 and 3 on verification structures.

With WP2 and WP3 the material characterization by coupon tests is nearly finished, and design and manufacture of verification structures have been started. *Figure 4* shows the predicted load shortening curves of three different verification panels with 5 stiffeners, each designed for a substantial postbuckling regime before collapse. In addition, the figure gives an impression of one of these panels at the end of manufacturing. The results of testing will be available in July 2002, and the verification procedure within WP4 will be completed at the end of that year.

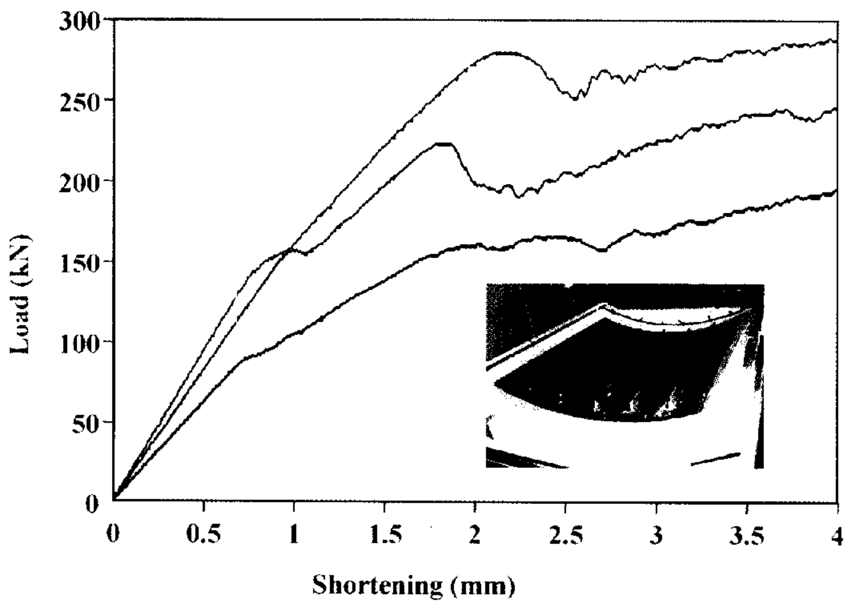

Figure 4. Load-shortening-curves of verification structures.

Expected results

Improved fast and reliable tools for simulation of postbuckling behaviour of fibre composite stiffened panels, which are a major component of next generation of fuselage structures, are developed, and guidelines for their design are prepared. Due to participation of industrial partners their development takes into account industrial needs from the beginning. The results will be ready for immediate industrial application; they will not only reduce weight, but also diminish design and analysis time by an order of magnitude. Thus they contribute to concurrent engineering, and they improve substantially response-to-market time. In addition, a comprehensive experimental data base is created, which will guide and help research for future development of design technologies. Sharing of simulation tools and respective technical information strengthens current trends to develop and use joint simulation tools within the European Aerospace sector, and furthers introduction of common European standards. The consortium is going to establish a Users Group. ■

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For more information on the project and on the partners, the web site http://www.posicoss.de can be consulted.