Experiments on Buckling and Postbuckling Behavior of Laminated Composite Stringer Stiffened Cylindrical Panels

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Summary

The experimental results of nine axially loaded blade stiffened cylindrical graphite-epoxy composite panels are reported. Their buckling and postbuckling behavior demonstrated consistent results. Prior to performing the buckling tests, their initial geometric imperfections were scanned and recorded. The tests were complemented by finite element calculations.

Introduction

It is well known [1] that stiffened panels can have considerable postbuckling reserve strength, enabling them to carry loads significantly in excess of their initial buckling load. If appropriately designed, their load carrying capacity will even appreciably exceed that corresponding to an equivalent weight unstiffened shell (i.e. a shell of identical radius and thicker skin and which is also more sensitive to geometrical imperfections). In these shells, initial buckling of the panel in a local mode takes place, i.e. skin buckling between stiffeners, and not in an overall mode, i.e., an Euler or wide column mode.

The design of aerospace structures places great emphasis on exploiting the behavior and on mass minimization of such panels to reduce lifecycle costs. An optimum (minimum mass) design approach based on initial buckling, stress or strain, and stiffness constraints, typically yields an idealized structural configuration characterized by almost equal critical loads for local and overall buckling. This, of course, results in little postbuckling strength capacity and susceptibility to premature failure. However, the optimum design approach can be modified to produce lower mass designs for a given loading by requiring the initial local buckling to occur considerably below the design load and allowing for the response characteristics known to exist in postbuckled panels[2] ,i.e.

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capability to carry loads higher than their initial buckling load. To meet the requirements of low weight, advanced lightweight laminated composite elements are increasingly being introduced into new designs of modern aerospace structures for enhancing their structural efficiency and performance. In recognition of the numerous advantages that composites offer, there is a steady growth in replacement of metallic components by composite ones in marine structures, ground transportation, robotics, sports and other fields of engineering.

Many theoretical and experimental studies have been performed on buckling and postbuckling behavior of flat stiffened composite panels (see for example Refs.3-5). Recently, a wide body of description and detailed data on buckling and postbuckling tests has been compiled [6] (see chaps.12-14). However, studies on cylindrical composite shells and curved stiffened composite panels are quite scarce in the literature. Most of them have been discussed in detail in Ref. 6 (see chap. 14).

In light of the above considerations, it has been suggested that permitting postbuckling under ultimate load of fuselage structures, i.e. alleviation of design constraints, may provide a means for meeting the objectives for the design of next generation aircraft, where the demand is reduction of weight without prejudice to cost and structural life (see paper Vision 2020 of the European Community). This approach has been undertaken in the present experimental study (Improved **PO**stbuckling **SI**mulation for Design of Fibre **CO**mposite **S**tiffened Fuselage **S**tructures - POSICOSS project) as a part of an ongoing effort for design of low cost low weight airborne structures initiated by the 5th European Initiative Program. It aims at supporting the development of improved, fast and reliable procedures for analysis and simulation of postbuckling behavior of fiber composite stiffened panel of future generation fuselage structures and their design.

Specimen and test set-up

Within the framework of the POSICOSS effort, Israel Aircraft Industries (IAI) has designed and manufactured nine Hexcel IM7 (12K)/8552(33%) graphite-epoxy blade stiffened composite panels, using a co-curing process (see Fig.1) .The nominal radius of each panel was R=938 mm and its total length L=720 mm (which included two end supports having the height of 30 mm ,each, (see Fig. 1). The stringer lay-up was $(\pm45^0, 0^0{}_2)_{3S}$, while the skin lay-up was $(0^0, \pm45^0, 90^0)_S$. Each layer had a nominal thickness of 0.125 mm, (see Fig.1). As can be seen from Table 1, three panels had five blade stringers with a height of 20 mm (panels PSC-1, PSC-2 & PSC-4), three panels had five blade stringers with a height of 15 mm (panels PSC-3,PSC-5&PSC-6),and three panels had six blade stringers with a height of 20 mm (panels PSC-7,PSC-8 &PSC-9). The guidelines of the design were based on the following requirements: the first buckling load of the skin of the panel will coincide with the design limit load of

a. **b.**

Fig.1 A stiffened cylindrical composite panel: **a.** on its tooling, **b.** after being removed

Table 1: Test results on nine stiffened composite cylindrical panels – comparison with MSC-NASTRAN predictions [10]

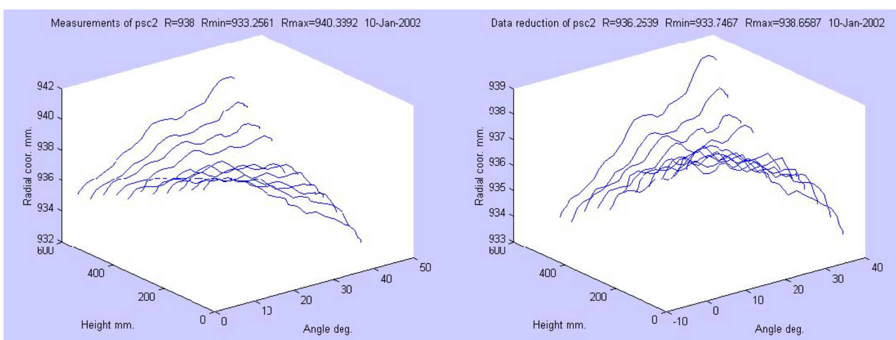
Type of panel			**Theory (MSC NASTRAN)**			**Experiment**		
Panel	# of blades	Blade heigh t [mm]	1^{st} P_{cr} [kN]	$P_{Collapse}$ [kN]	1^{st} natural freq. [Hz]	1^{st} P_{cr} [kN]	$P_{Collapse}$ [kN]	1^{st} natural freq. [Hz]
PSC-1	5	20	92	235	205	131.0	212.7	-
PSC-2	5	20	92	235	205	150.0	227.0	193
PSC-4	5	20	92	235	205	158.5	229.2	-
PSC-3	5	15	89	128	188	136.0	162.0	-
PSC-5	5	15	89	128	188	113.0	152.6	185
PSC-6	5	15	89	128	188	126.0	140.0	-
PSC-7	6	20	139	250	246	228.5	280.0	-
PSC-8	6	20	139	250	246	240.0	270.0	212
PSC-9	6	20	139	250	246	244.0	280.0	-

the structure and the first failure in buckling of the stringers will comply with the ultimate load requirements. This yielded two well defined buckling points, where the ultimate load of the panel is at least 1.5 times its first buckling load (local buckling mode, between the stringers).

Results and Conclusions

The nine panels were then transferred to the Technion and the test program was initiated and performed at the Aerospace Structures Laboratory, (ASL), Faculty of Aerospace Engineering, Technion, and I.I.T., ISRAEL.

All the specimens were equipped with strain gages to monitor the strains on the skin and the stringers of the panels. Prior to the testing, the outer non-stiffened curved surface of the panels was scanned to determine their initial geometric imperfections [7] (see a typical example in Fig.2). Furthermore, the panels were excited and their first natural frequencies were measured and compared with calculated values [7, 8] (see Table 1). Then the panels (see Fig. 4) were placed in a 500 kN MTS loading machine (see Fig. 3), loaded in axial compression and responses of the gages as well as of the end shortening of the panels were monitored and recorded up to comprehensive failure of the panel. To monitor the first local buckling and the developing of the buckles as a function of axial loading, the Moiré technique was employed yielding consistent results (see for example Fig. 4). Finally, each panel was tested to determine its collapse load (see for example Figs. 5a-b).



a. **b.**

Fig.2 Initial geometric imperfections of panel PSC-2: **a.** raw data, **b.** reduced data (eliminating rigid body motions).

A comparison between the ABAQUS [9] finite element predictions of the strains at typical locations on the panel surface, as compared to the experimental results was performed. Good correlation was found though the experimental strains are lower than the predicted ones.

The test results are given in Table 1[7, 8]. The results of the tests have in general demonstrated good correlation with the predicted buckling behavior of the panels. However the predicted local buckling loads under-estimated the test results, while the predicted collapse loads were in good correlation with the test results.

a. **b.**

Fig.3 Panel PSC-1in the testing rig, including the longitudinal fixture plates: **a.** front view, **b.** back view

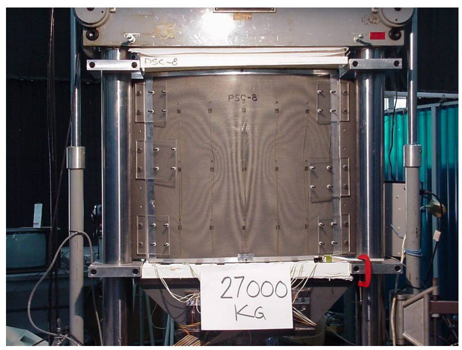


Fig.4 Panel PSC-8 in the 500 kN MTS loading machine. Note the visualization of the buckling waves obtained with the Moiré method (axial loading= 270 kN).

a. **b.**

Fig.5 Panel PSC-2 at various postbuckling axial loads: **a.** at 180 kN (front), **b.** at 225 kN (back).

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