ICAS-92-5.7.2

POST BUCKLING OF LAMINATED COMPOSITE STIFFENED CURVED PANELS SUBJECTED TO CYCLIC SHEAR AND COMPRESSION

D. Shalev, A. Segal
Israel Aircraft Industries, Ben-Gurion International Airport, Israel

Y. Frostig
Technion - Israel Institute of Technology, Haifa, Israel

ABSTRACT

Results of an experimental study of postbuckling behavior of a composite materials box subjected to a combination of cyclic compression and shear loads is presented. The faces of the box are composite laminated curved panels, stiffened at both longitudinal and transverse directions. Results were recordered visually (Moire shadow fringes) and strain gages were read at over than 100 locations of interest. Still camera pictures of fringe patterns and strain gages plots of behavior presented.

1.0 Introduction

Major structural elements in a flight vehicle are subjected to shear loads which are cyclic in nature. Such elements may be found in a torsion box of a swept wing or in a fuselage. Since composite laminated stiffened panels are increasingly used in today's aircraft structures it is very important to extend the investigations to nonlinear phenomena which enable a wider usage of the material. Such nonlinear phenomena are postbuckling and large deflection. As opposed to the case of metallic structures, composite structures are limited by a relatively poor selection of analytical tools for representing nonlinear phenomena. This region of nonlinear behavior is crucial in respect to weight and efficiency and inability to predict nonlinear behavior puts composite materials sometimes in an inferior position when competing with metallic structures.

The present work introduces an experimental investigation of a composite laminated stiffened cylindrical panel subjected to cyclic shear loads. A combination of shear and compression loading is presented as well. The tested specimen was configured from three panels formed together as a closed triangular torsion box. All panels are made of Graphite Epoxy composite laminates stiffened at both longitudinal and transverse directions by composite laminated stiffeners.

The major objectives of this study were: 1) to examine the static stability of the structure as its complexity might give rise to interesting conclusions. 2) to examine the influence of the combination of shear and compression loading as one is taken constant at certain level while the other is raised incrementaly. 3) to examine the behavior of the stiffened torsion box under fatigue cyclic loads. Stress levels and possible local damage were inspected. 4) to examine the change in the nonlinear performance as the structure accumulates fatigue loading cycles. The literature have many studies on the subject of nonlinear behavior of structures. Both theoretical and experimental investigations have been conducted. The studies range from flat metalic panels via flat composite laminated panels, curved isotropic and anisotropic panels to stiffened panels of all kinds. Buckling and postbuckling results of experiments carried out on composite panels may be seen in [1] - [6]. Stiffened panels are considered [1], [3] and [6]. Curved panels are considered in [2]-[6]. Different types of loadings have been tested for their influence, compression [1], [3], [4], [5] and [6], shear [2], combined shear and compression [7]. Analysis provided relatively good results for components rather than for complete complex structures ([1], [2], [6], [7]) resulting in computer codes and engineering oriented design recommendations [8], [9].

The present work is unique in its kind in presenting results for the response of a structure composed of curved stiffened composite panels subjected to fatigue cyclic shear and compression. A rather complex phenomena was observed in the postbuckling behavior of the panels in that structure changes from one mode shape pattern to another.

2.0 Experimental Program

The experimental program consisted of three stages. In the first stage, a metal cylindrical box was tested in compression and shear for calibration purposes and for examination of the performance of the testing apparatus which was especially designed and built for the tests. In the second stage a box consisting of one curved stiffened composite panel attached to two metal stiffened panels forming altogether a triangular torsion box was tested giving rise to problems of uneven load distribution within the box. Once all problems were solved and overcome a specimen consisting of a torsion box made of three identical curved stiffened composite panels (fig. 1a, 1b and 2) was tested. The results enclosed in this paper are of the third stage only. Three means of inspection were used. There were over 100 strain gages bonded, Moire` shadow grids were placed all around and audio effects of the buckled curved panels helped in tracing the exact times of instabilities. Throughout the experiment the specimen was video filmed all around and at certain times the cyclic loading process was stopped for static strain gage measurements and for camera still shots.

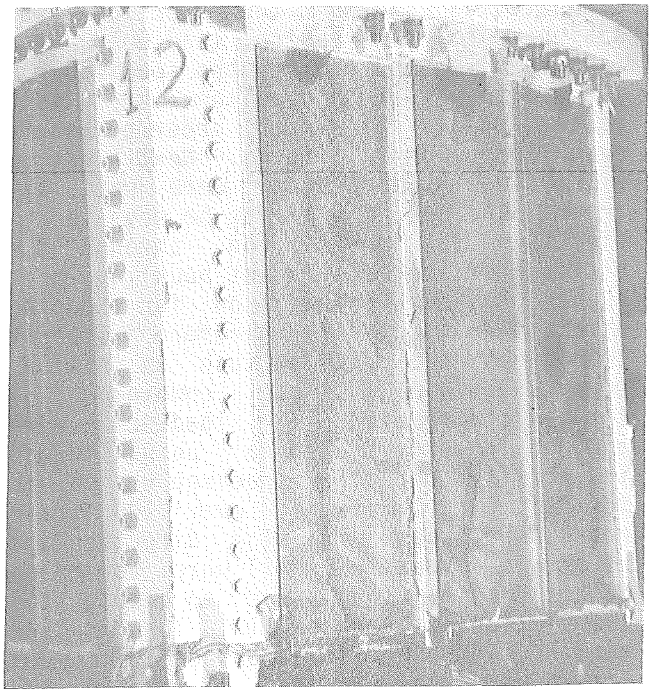

Fig. 1a. Outside view of the tested specimen coated by Moire panels at a buckled position.

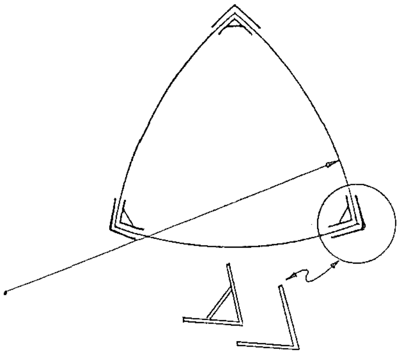

Fig. 1b. Specimen cross section - torsion box built of three curved stiffened composite laminated panels.

2.1 Description of the Testing Apparatus

The testing apparatus, fig. 3a and 3b, consisted of two arms attached to two edges of a massive metal plate which was attached to the upper side of the torsion box through which a torsion moment was applied. An axial loading jack was linked to enable the application of axial compression. The testing fixture as well as the special configuration of the tested torsion box were analyzed and set in a way which enabled pure evenly distributed shear loads in the composite stiffened curved panels when subjected to pure torsion. The entire apparatus enabled static loading of 70 tons in compression and 35 ton-meter in torsion and fatigue loading of 50 tons in compression and 25 ton-meter in torsion. The requirements for the present work as well as anticipated further applications dictated rig dimensions of 2 meters wide, 4.7 meters long and 4 meters high and capacity for accommodation of specimens up to 1.3 meter long and 1.0 meter in diameter.

2.2 Description of the Tested Specimen

The tested specimen was a cylindrical torsion box composed of three identical curved panels, fig. 1a, 1b and 2. The curved composite panels consisted of a curved skin stiffened by 4 longitudinal J shaped stiffeners and 2 transverse I shaped stiffeners. The skin was made of AS4/3502 Gr/Ep prepreg style AW280 fabric laminates oriented (+45,-45,0,-45,+45) to a total thickness of 1.3 mm. The stiffeners were built up from the same fabric material and configuration as the skin , embedding a core of 0 degrees unidirectional AS4/3502 tape. The "J" section stiffeners had a 20mm wide and 2.7 mm thick outer flange and total height of 31mm. The "I" section had a 27mm wide and 1.3 mm thick outer flange and total height of 33mm.

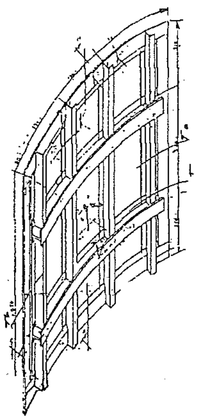

Fig. 2. Typical panel - curved composite skin stiffened by longitudinal "j" section and transverse "I" section stiffeners.

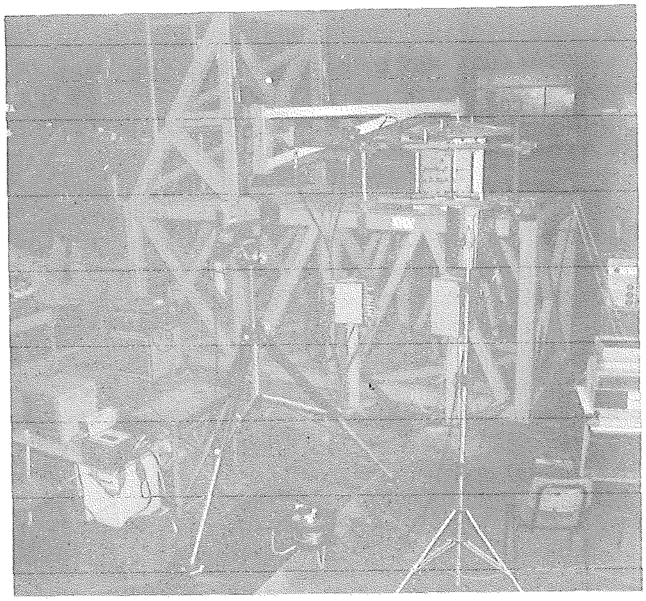

Fig. 3a. Testing apparatus - photo view.

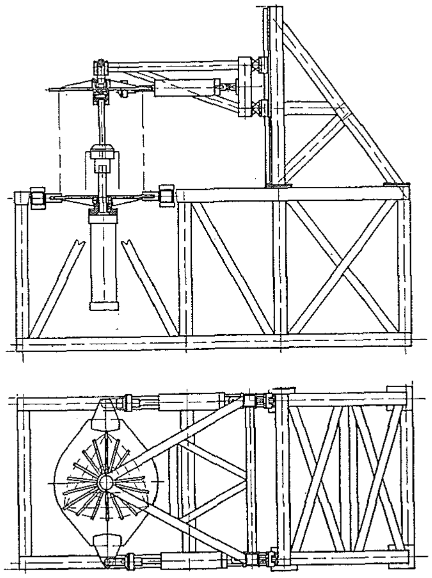

Fig. 3b. Testing apparatus - drawings of side view (on top), top view (at bot.)

2.3 Testing Procedure

Initially a set of 9 strain gages were attached to the specimen at the 9 bays located at the middle of the torsion box circumference (strain gages 1 - 9 in fig. 4). A preliminary calibration was conducted in which the specimen was subjected to compression load only. The massive plate on top of the specimen was matched to meet simultaneously full contact on all panels in order to assure even loading on all faces. Next a set of nine Moire` grid plates were set all around the specimen as may be seen in fig. 1a. The observation through the plates indicated the exact buckling mode shapes providing information for choosing strain gage locations. Therefore different load cases were applied such as torsion, compression and the combined torsion/compression. All loadings were applied in steps to a point beyond instability. Once the specimen was mapped for critical locations, over 100 strain gages were bonded in axial direction and as sets of rosettes. All were bonded on both sides of the skins to enable the examination of both axial loading and bending. The exact locations of the bonded strain gages may be seen in fig. 4. The strain gage numbers appearing in parentheses are for those bonded in the inner face of the skins.

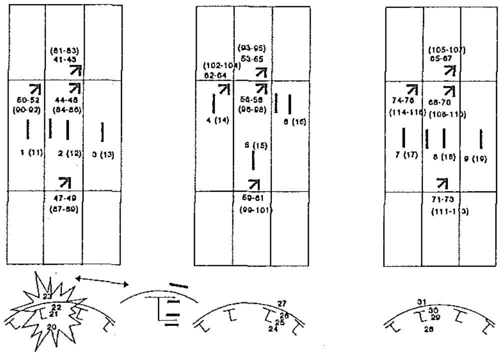

Fig. 4. Strain gage locations on all three panels.

Loadings and measurements were done in stages as follows:

1) Compression load was raised in steps up to 35 tons. Whenever an instability point was inspected visually by the Moire` fringe pattern panels as in fig. 1a and by the audio effect as the buckled curved panel sounded in drum-like fashion, the loading process was paused for strain gage recording.

2) Torsion was applied in steps up to 4.2 ton-meters stopping for strain gages recording as in the previous stage.

3) Compression load of 25 tons was held constant while torsion was raised in steps to 4.2 ton-meters with same method of S.G. recording as before.

4) Same as stage 3 but compression of 35 tons was held constant.

5) Torsion of 2.4 ton-meter was held constant while compression raised in steps to 35 tons.

6) Same as in stage 5 but torsion of 4.2 ton-meters was held constant.

7) The specimen was subjectd to 20000 cycles of fatigue torsion of 0 - 2.4 ton-meters while being constantly compressed at 35 tons.

8) 10000 cycles of 0 - 4.2 ton-meter torstion while applying 35 ton compression.

9) 5000 cycles of 0 - 35 tons compression while constant 2.4 ton-meter torsion.

10) 5000 cycles of 0 - 35 tons compression while constant 4.2 ton-meter torsion.

Throughout the experiment the specimen was video filmed and still camera shots were taken as well. The entire cyclic process was accompanied by drum-like sounds generated by the curved panels when snap-through buckling modes were occured. These sounds may be heard in the video film.

3.0 Test Results

Throughout the entire loading stages the strain gages were recorded for each load step. The load in the cyclic process was raised in steps for S.G. recordings while the other load kept constant. The maximum strains in the static loading stage reached values of 70% of the critical strain for the material, while at the fatigue stage, the maximum strains reached values of 50-60% of the critical strain. During the fatigue cycling the structure was subjected to loads (compression and torsion) of 4 to 5 times the critical loads of initial instability.

Figs. 5 - 8 show results taken before the fatigue loading began. At pure torsion (fig. 5) three diagonal strain gages included in rosettes at the upper portion of the specimen are shown. All locations go through two points of instability showing higher reading in the loading process then at the unloading process when the panels snap back. At the maximum of 6.5tm the panels show high strains of 7000ms. Fig. 6a and 6b show the torsion loading process while compression is held constant at 25t. It is recognized that most strain gages show initial buckling at the constant compression yet when unloaded they do not necessarily get back to the starting point. Here again limit point behavior is recognized. Fig. 7a and 7b show basically the same behavior as traced in 6a and 6b. Fig. 8 shows zero torsion and pure compression. The behavior is again of a limit point. Note that strain gage no. 5/15 (bonded back to back) show two snap backs at the unloading process while this location buckled through one limit point when loaded. Fig. 9a, 9b, 10a, 10b show the behavior throughout the fatigue loading process when stopped for strain gage recordings. It is seen that the snap through and snap back scenarios are again a matter of uncertainty and can not be put in a repetitive scheme. No damage development was observed in either the panels or the stiffeners during the tests. Inspection was carried out by using the ultrasonic detection method.

4.0 Conclusions

A torsion box made of three curved composite laminated plates stiffened by longitudinal J section and transverse I section stiffeners was tested for its fatigue behavior in the postbuckling region. The box was subjected to compression, torsion and the combinations of both. The whole testing process was fully documented in still camera shots, video film and strain gage recordings. The following are the conclusions drawn in the examination of the results:

1) While loaded in the postbuckling region the specimen passes through different buckling mode shapes as areas between stiffeners snap back and forth.
2) Some areas do not buckle at the loading process but do buckle when other areas snap back in the unloading process.
3) Some locations go through instability at certain number of cycles but cease to do that after additional number of cycles is applied.
4) Some locations which started at a certain buckling shape due to the constantly held load did not return to this initial mode after being loaded to buckling again and then unloaded.
5) The number of limit points passed in loading is not necessarily the same as in its counterpart unloading.
6) Strain versus load curves do not go through the same path in the loading and unloading process. This is because the limit point at the loading stage is higher then the limit point at the unloading stage.
7) No analysis known today can predict the phenomena described in items numbers 1 to 5.
8) Quantitative structural design conclusions may be drawn by the loads and strain levels achieved throughout the experiment. It is significantly recognized that the structure successfully held fatigue load levels of 4 to 5 times the critical loads which means that the structure functioned deep in the postbuckling region. It is also important to mention the relatively high strain levels of 50-70% of the critical values of the materials which the panels sucessfully sustained.

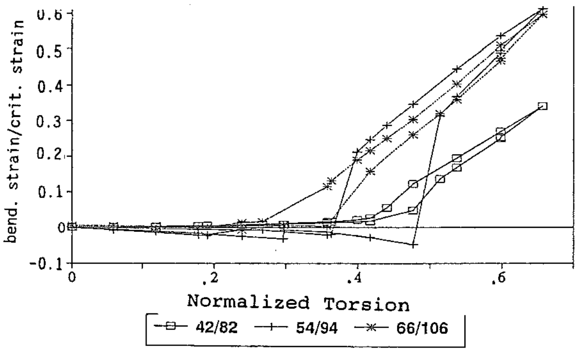

Fig. 5. Cycles = 0, compression = 0 bending strain Vs. torsion

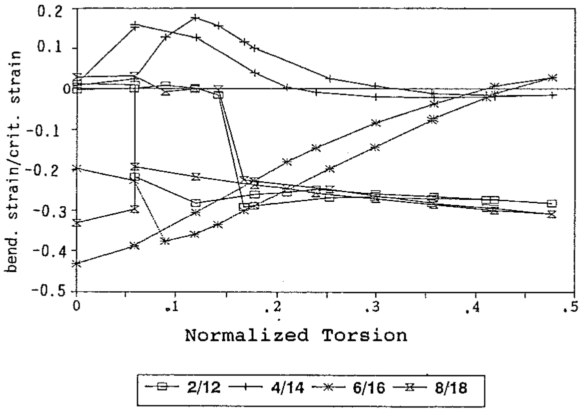

Fig. 6a. Cycles = 0, compression = 25 ton bending strain Vs. torsion

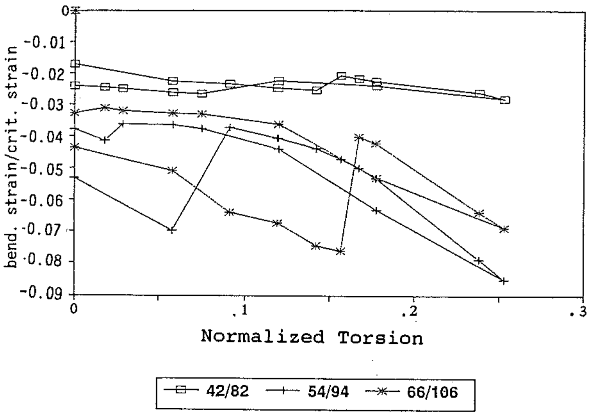

Fig. 6b. Cycles = 0, compression = 25 ton bending strain Vs. torsion

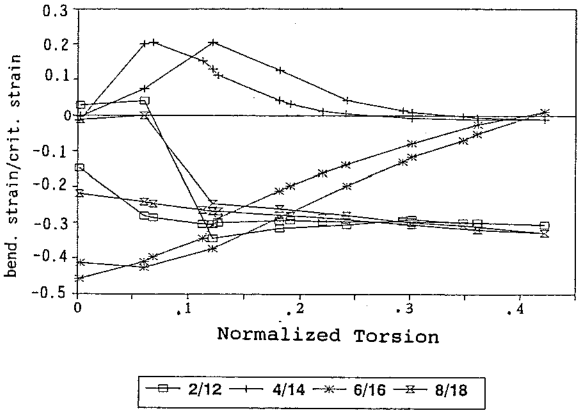

Fig. 7a. Cycles = 0, compression = 35 ton bending strain Vs. torsion

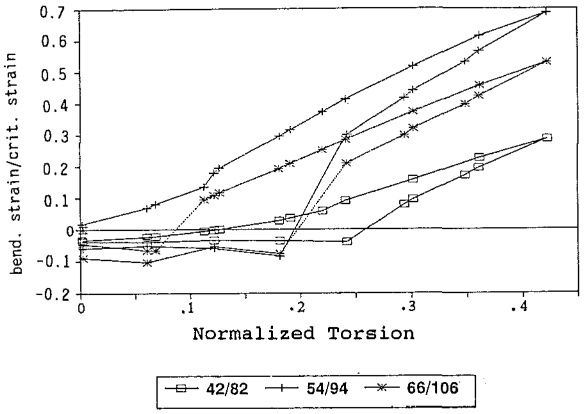

Fig. 7b. Cycles = 0, compression = 35 ton
bending strain Vs. torsion

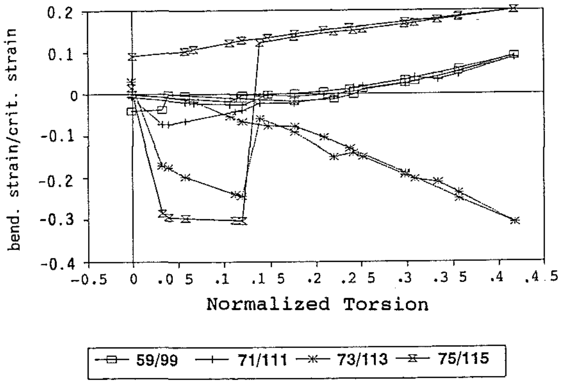

Fig. 9b. Cyc.=20770, compression = 35 ton
5000 cycles of torsion=0-4.2 t-m
bending strain Vs. torsion

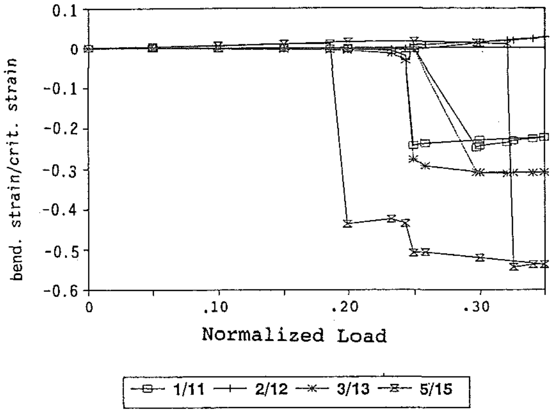

Fig. 8. Cycles = 0, torsion = 0
bending strain Vs. compression

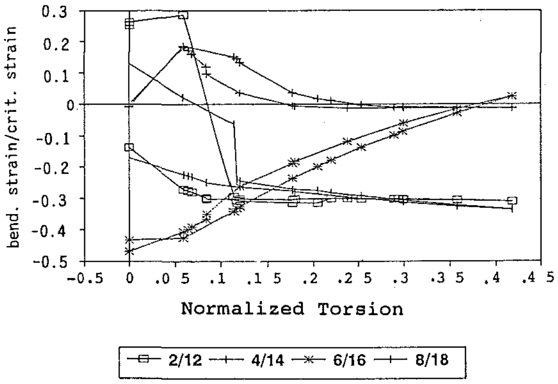

Fig. 10a. Cyc.=40770, torsion=4.2 t-m
5000 cycles compression=0-35 ton
bending strain Vs. torsion

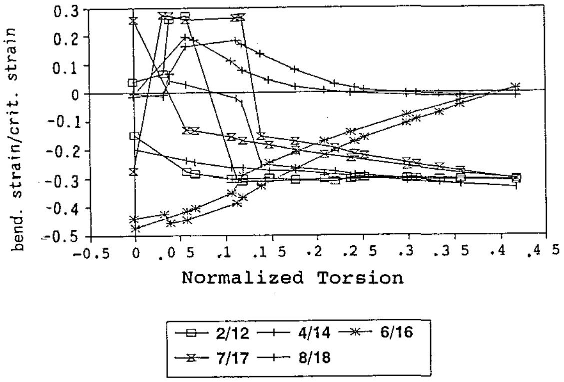

Fig. 9a. Cyc.=20770, compression = 35 ton
5000 cycles of torsion=0-4.2 t-m
bending strain Vs. torsion

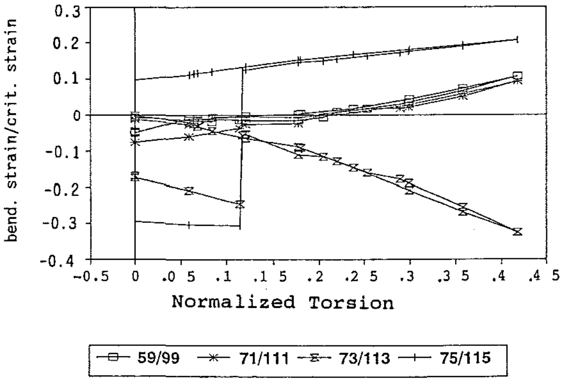

Fig. 10b. Cyc.=40770, torsion=4.2 t-m
5000 cycles compression=0-35 ton
bending strain Vs. torsion

References

1. Stein M. "Postbuckling of Eccentric Open-Section Stiffened Composite Panel", ICAS Proc., ICAS-88-5.6.2, 1988.
2. Wolf K., Kossira H., "The Postbuckling Behavior of Curved CFRP Laminated Shear Panels", ICAS Proc., ICAS-88-5.6.3, 1988.
3. Agrawal B. L., "Postbuckling Behavior of Composite Stiffened Curved Panels Loaded in Compression", Experimental Mechanics, June 1982, pp. 231-236.
4. Wilkins D. J., "Compression Buckling Tests of Laminated Graphite-Epoxy Curved Panels", AIAA Vol. 13, No. 4, April 1975.
5. Becker M. L., Palazotto A. N., Khot N. S., "Experimental Investigation of the Instability of Composite Cylindrical Panels", Experimental Mechanics, October 1982, pp. 372-376.
6. Knight N. F., Starnes J. H., "Postbuckling Behavior of Selected Curved Stiffened Graphite-Epoxy Panels Loaded in Axial Compression" AIAA Paper No. 85-0768-CP, April 1985.
7. Arnold R. R., Parekh J. C., "Buckling Postbuckling and Failure of Flat and Shalow-Curved, Edge-Stiffened Composite Plates Subjected to Combined Axial Compression and Shear Loads", AIAA paper no. 86-1027-CP, pp. 769-782, 1986.
8. Bushnell D., "PANDA - Interactive Program for Minimum Weight Design of Stiffened Cylindrical Panels and Shells", Computers and Structures, Vol. 16 No. 1-4, pp. 167-185, 1983.
9. Dickson J. N., Biggers S. B., "Design and Analysis of a Stiffened Composite Fuselage Panel", NASA Contractor Report 159302, Aug. 1982.