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Behavior of curved laminated composite panels and shells under axial compression

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ABSTRACT

The buckling and post-buckling behavior of curved cylindrical stringer-stiffened laminated composite and metal panels had been investigated both numerically and experimentally. The results were compared to those of cylindrical stringer-stiffened laminated composite shells to yield a way of determining the optimal structure to be used for axial compression loading. For the present tested structures, the composite panels showed the best load-weight ratio.

1. Introduction

Thin walled structures are one of the basic elements in aerospace engineering. Curved stringer stiffened cylindrical panels or stringer stiffened shells usually form the fuselage of an aircraft leading to what it is called a semi-monocoque structure. During its lifetime, the fuselage undergoes bending, which causes compressive axial loads that might lead to buckling and collapse phenomena.

Buckling and post-buckling investigations of stringer stiffened shells and panels have been widely dealt and presented in the literature for more than 60 years. The topic included use of both aluminum and laminated composite materials, investigating different aspects such as stability, dynamic behavior, free vibrations, wave propagation, de-bonding, and optimization. Many books, such as [1,2] and review papers, such as [3–7] had been published to cover the complex problem of buckling and post-buckling behavior of shells and panels made of both metal and laminated composite materials.

Two recent European projects, POSICOSS (***PO***stbuckling ***SI***mulation for Design of Fiber ***CO***mposite ***S***tiffened Fuselage ***S***tructures) and COCOMAT (Improved ***MAT***erial Exploitation at Safe Design of ***CO***mposite Airframe Structures by Accurate Simulation of ***CO***llapse) [8] followed by DAEDALOS (***D***ynamics in ***A***ircraft ***E***ngineering ***D***esign and ***A***nalysis for ***L***ight Optimized ***S***tructures) [9] and DESICOS (New Robust ***DESI***gn Guideline for Imperfection Sensitive ***CO***mposite Launcher ***S***tructures) [8] were the drivers behind new important results, both analytical and experimental, on the behavior of stringer stiffened curved panels and shells, mainly built from laminated composite materials [10–29]. These publications as well as other ones [30–39] can be seen as only a short list of references which represent the numerous studies being published, demonstrating the importance being attributed to the buckling and post-buckling behavior of axially-compressed stiffened curved or flat panels and cylindrical shells.

The present manuscript presents new experimental test results for the buckling and post-buckling behavior of various types of curved stiffened cylindrical panels and shells. The results are compared aiming at presenting an optimal structure having the lowest weight and capable of withstanding the highest buckling load. This experimental data base provides new insights on the structural stability of curved stiffened cylindrical panels and shells, and enhances the already existing knowledge on these structures.

2. Test set-up

The test set-up for monitoring and measuring the stability behavior of stiffened curved panels and shells is presented in Fig. 1. It consists of a hydraulic MTS test rig capable of applying up to 500 kN at quasi-static or dynamic loading, with frequencies up to 12–15 Hz. The structure is clamped between two loading plates and the hydraulic piston pushes the lower part towards the upper static bridge of the rig. The loading can be performed either by closing the control loop on force or axial displacement. The

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structure is equipped with back-to-back strain gauges, vertical and horizontal LVDTs capable of measuring out-of-plane displacements and end shortening, respectively. All the data obtained during the tests are managed by the VISHAY 6000 data acquisition system. To enable the visualization of the buckling modes, the Moiré technique is used, and the structures were painted in white to strengthen the visual contrast of the Moiré grid.

3. Test structures

Several tests were performed during the DAEDALOS project. In particular, five different types of curved cylindrical panels and a cylindrical shell are here presented reporting the results of a representative structure for each type.

The first panel is called $D_{COM}1$ and consists of a hybrid curved panel, having a laminated composite skin and two longerons made of aluminum alloy, being bonded and riveted at the long straight sides of the panel. The second and the third panels, $D_{AL}1$ and $D_{AL}3$, are curved stiffened panels made of aluminum alloy with two and three stringers, respectively. The fourth and fifth panels, $D_{str.}2$ and $D_{str.}3$, are laminated composite curved stiffened panels having two stringers and three stringers, respectively. The sixth structures is a laminated composite cylindrical shell, SH1, having four internal stringers.

The properties of the aluminum alloy and of the composite material, of which the panels and the shell were manufactured, are reported in Table 1. The dimension of each structure is given in

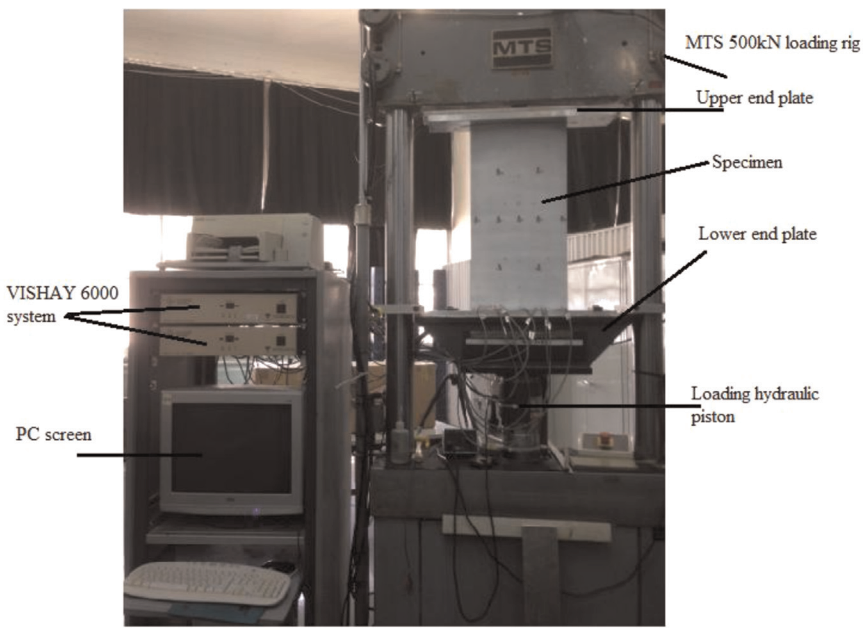

Fig. 1. Test set-up.

Table 1
Material properties of panels $D_{COM}1$, $D_{AL}1$, $D_{AL}3$, $D_{str.}2$, $D_{str.}3$ and shell SH1.

	Term	Value
Single layer property		
Used for $D_{COM}1$ (skin only), $D_{str.}2$, $D_{str.}3$ and shell SH1		
Longitudinal modulus [GPa]	E_1	155.6
Transverse modulus [GPa]	E_2	8.2
In-plane shear modulus [GPa]	G_{12}	4.5
Major Poisson's ratio	ν_{12}	0.34
Density [kg/m^3]	ρ	1550
Longitudinal tensile strength [MPa]	X_T	2650
Longitudinal compressive strength [MPa]	X_C	1550
Transverse tensile strength [MPa]	Y_T	95
Transverse compressive strength [MPa]	Y_C	300
In-plane shear strength [MPa]	S_{12}	100
Thickness [mm]	t	0.125
Aluminum property		
Used for $D_{COM}1$ (longerons only), $D_{AL}1$ and $D_{AL}3$		
Young's modulus [GPa]	E	70
Poisson's ratio	ν	0.3
Density [kg/m^3]	ρ	2700

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