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D-Box Fixture for Testing Stiffened Panels in Compression and Pressure

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A combined loads test machine used to test aircraft primary structures such as fuselage and wing sections is described. The design features of a D-box test fixture that provides a simple test setup with the flexibility to accommodate curved stiffened panels of different radii are presented. Linear finite element analysis results from studies performed to evaluate and to address problems associated with load introduction into a curved panel when tested in the D-box test fixture with compression and internal pressure loading are also presented and discussed. From the analysis results it is determined that by providing cross bars with adjustable lengths in the D-box test fixture, appropriate boundary conditions and the proper load distributions can be simulated for undamaged and damaged curved panels with different frame spacing subjected to internal pressure and axial compression. Nonlinear shell analysis results for both the internal pressure and combined internal pressure and axial compression cases suggest that the deflection and stress states in the panel for these load cases are much larger than those obtained from linear analysis.

Introduction

UNDERSTANDING the response of aircraft structures subjected to combined loading conditions that are representative of the actual operating flight environment is an important aspect of designing aircraft structures. The normal practice in the aircraft industry is to design a test setup specifically to address a particular loading condition. Although this practice may be necessary for certain unique loading conditions, a combined loads test machine with the flexibility to accommodate full-scale and subscale fuselage shells, curved panels, and wing sections together with the capability to apply bending, shear, torsion, and internal pressure load combinations would be of significant value to the aircraft structures community. The NASA Langley Research Center is currently developing such a test capability to help develop validated structures technologies. This test machine is being designed to accommodate a range of fuselage structures and wing sections and subject them to both quasistatic and cyclic loading conditions. Structural tests are being planned to address issues related to the application of composite materials to subsonic transport aircraft primary structures under the advanced composites technology (ACT) program, to address structural integrity issues of metallic aircraft structures under the aircraft structural integrity program (ASIP), to develop high-speed civil transport structures technology under the high-speed research (HSR) program, and to develop high-speed rotorcraft structures technology under the advanced tilt-rotor transport technology (ATTT) program. The combined loads test machine is a part of NASA's combined loads test system (COLTS) and will be capable of testing fuselage barrels of up to 15 ft diameter with combined mechanical, internal pressure, and thermal loads.

One approach for testing curved panels is to mount a panel in a cylindrical shell fixture that has the same radius as the panel and has a cutout to accommodate the test panel. The panel is then subjected to the intended combined loading conditions by loading the cylindrical shell fixture. The correct boundary conditions can be imposed on the test specimen more readily using this approach. In spite of this advantage, this approach is not the preferred approach if the requirement is to test panels of different radii than the cylindrical fixture. Such a requirement would necessitate using cylinders of different radii. There is a need for a test fixture that is inexpensive and that can be used to test curved stiffened panels of different radii and frame spacings. The D-box test fixture concept developed by Lockheed Aeronautical Systems Company to test C-5 transport aircraft fuselage panels in combined compression and shear loading has been adapted for performing combined compression, shear, and internal pressure loads on the fuselage side panels in the combined loads test machine.

The D-box test fixture has been designed to ensure that appropriate boundary conditions are imposed on the curved panel to provide a stress state that is representative of a shell. This requirement is particularly important when investigating the failure of a curved panel and in damage propagation studies. Analytical studies have been performed on a D-box test fixture assembled with a Lockheed C-5 derivative stiffened aluminum fuselage panel. The results from these analytical approaches will be correlated with the experimental results at that time. This panel will be used in the proof-of-concept studies when the test machine is developed and installed at NASA Langley Research Center. For both the undamaged

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and damaged states of the panel, it must be possible to develop stress magnitudes in the curved panel in the D-box test fixture that are comparable to the stress state in a shell.

This article will describe the combined loads test machine and the D-box test fixture. Results from a linear finite element analysis will be presented for both a cylindrical shell and a curved panel in the D-box test fixture to address the load introduction issues associated with testing of a curved panel in the D-box test fixture for combinations of internal pressure and axial compression load conditions. A practical design approach that has been adapted for the D-box test fixture for testing curved panels without and with damage will be illustrated. Also, results from nonlinear finite element analyses will be presented for a cylindrical shell to demonstrate the importance of nonlinear effects for the previous loading conditions.

Description of Test Machine

Combined Loads Test Machine

An end view of the combined loads test machine is illustrated in Fig. 1a. The loading platen is suspended from a gantry that can traverse forward or backward to accommodate test articles of different lengths. Compression and bending loads are applied to the test articles by six 450-kip hydraulic actuators located parallel to the specimen (along the x axis), side shear load is applied by two 300-kip actuators located along the y axis, and a torsional moment is applied by means of two 300-kip actuators located in the z direction. This test machine will be located in a concrete pit that is approximately 32 ft deep, 47 ft wide, and 72 ft long. This arrangement is to ensure that pressured structural testing can be performed safely. A plan view of the test machine is shown in Fig. 1b. This figure illustrates the drive motor and lead screw mechanism that is used to reconfigure the test machine to test structures of 10-, 15-, 25-, 30, 42- and 45-ft lengths. The interior length of the concrete pit is also shown in the figure. The length of the axial actuators is extended by means of tubular extensions to connect the loading platen with the load reacting platen in order to test specimens that are longer than 10 ft.

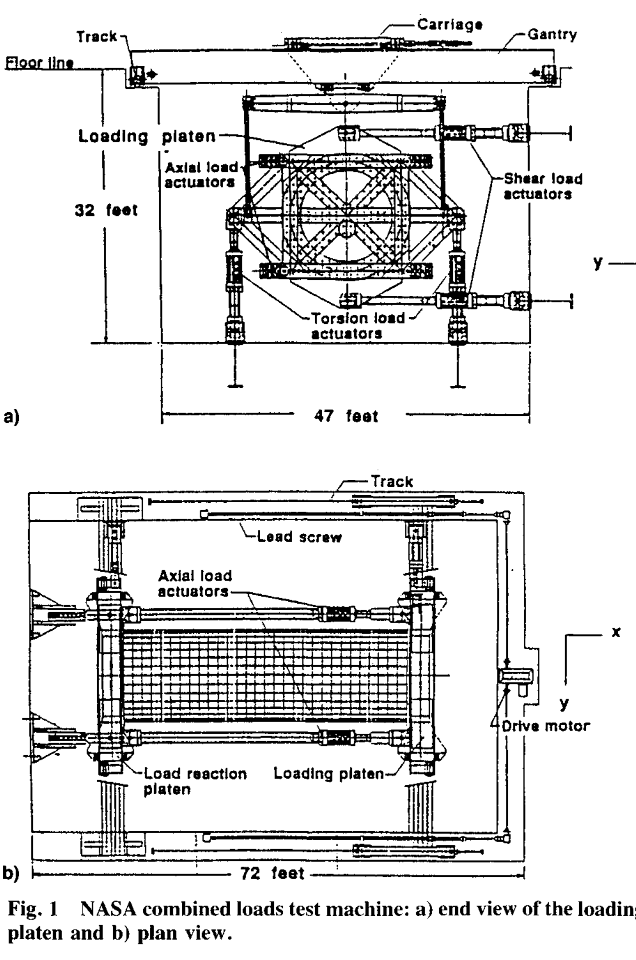


Fig. 1 NASA combined loads test machine: a) end view of the loading platen and b) plan view.

D-Box Test Fixture

One of the design requirements for the D-box test fixture is to provide proper support conditions to a curved panel such that the stress state in the panel will be the same as for the corresponding cylindrical shell for a given load condition.

The D-box test fixture shown in Fig. 2a must have adequate radial stiffness to support the pressure load and have a small axial stiffness compared to the test panel. The small axial stiffness of the D-box test fixture allows the test panel to experience most of the applied axial load and also minimizes the shift in the c.p. of the assembly in the event of test panel buckling. The low axial stiffness of the D-box test fixture is accomplished by constructing the fixture from an assembly of curved I-beams, a cross section of which is shown in the inset. The I-beam sections are 8.0 in. deep and 15 of these sections are used to construct the D-box test fixture. The axial stiffness of the D-box test fixtures is 5% of the D-box test fixture assembled with the curved stiffened panel. The axial stiffness of the curved panel is assumed to be 1.1×10^6 lb/in., which is representative of the stiffness of a typical fuselage shell. This D-box test fixture is designed to test curved panels with 60–130-in. radii and 20- and 22-in. frame spacings. The panels are attached to the D-box test fixture with the hinge fittings shown in the figure. Thirteen of these hinge fittings are provided between the I-beams for this purpose. A cross section of the D-box test fixture is presented in Fig. 2b that shows the details of the hinge fittings. When the D-box assembly is internally pressurized, the assembly expands in a manner that forms an axisymmetric shape, which causes the hinge supports to move inward. This deformation will result in the test panel bending in a way that is not representative of the response of an internally pressurized shell. To prevent this undesirable

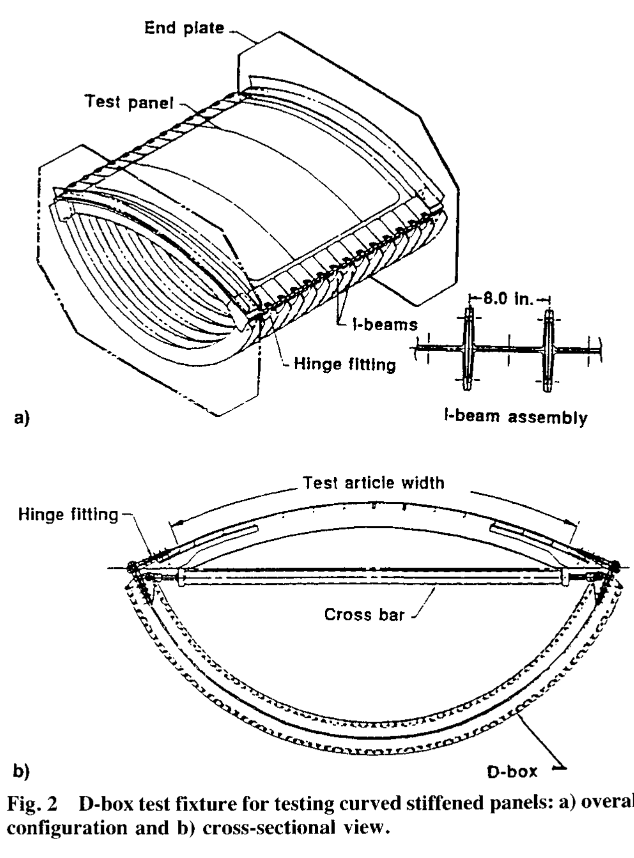


Fig. 2 D-box test fixture for testing curved stiffened panels: a) overall configuration and b) cross-sectional view.

deformation, cross bars are mounted between the hinge points as shown in the figure such that the distance between the hinge points can be held constant or adjusted as needed to induce the appropriate stress state in the test panel.

Analytical Results and Discussion

Two important design details significantly influence the stress state in a curved stiffened panel tested in a D-box fixture. The first design detail is the load introduction region that attaches the curved panel to the D-box fixture. If the hoop load in the panel resulting from internal pressurization of the D-box assembly is reacted at the panel boundary only by the skin, the panel will be subjected to bending moments that result at the hinge attachment point. Part of the hinge fitting that attaches the test panel to the D-box fixture has to be designed so that load is reacted through the frame as well as the skin. The analytical results used in the selection of a hinge fitting design are presented in Ref. 1. The second design detail is the support conditions along the two straight edges of the panel. Appropriate boundary conditions must be imposed so that the panel response compares with the shell response for a given loading condition. More specifically, the cross bars have to be designed to apply forces that negate unwanted radial displacements at the hinge locations that result in panel bending. Finite element analyses have been performed to help address these design details. Finite element models for the cylindrical shell and the D-box test fixture with test panel were generated using Patran (Ref. 2) and linear and nonlinear structural analysis was performing using Nastran (Ref. 3). The nonlinear analysis for the pressure load case and the combined pressure and axial load case has been performed only for the cylindrical shell case to understand the influence and magnitude of nonlinear effects so that, in the future, appropriate nonlinear analysis may be performed on the D-box assembly to determine the exact magnitudes of the crossbar forces.

The shell is modeled using quadrilateral plate elements and has 25,973 degrees of freedom (DOF). The D-box test fixture assembly with the curved panel is modeled with plate, bar, beam, and spring elements totaling 6773 elements and 33,130 DOF. To simulate the cylindrical shell subjected to internal pressure, the curved panel for the D-box test fixture is analyzed with boundary conditions along the straight edges that permit only radial displacements. To simulate the 20-in.-long longitudinal crack in the panel, two rows of nodes generated along the panel centerline with zero distance between them are disconnected through a length of 20 in.

Boundary Conditions to Simulate Shell Load Distributions in a Curved Panel—Linear Analysis

Finite element analysis results for internal pressure load cases and a combination of internal pressure with axial compression loads are presented herein for both undamaged and damaged curved panels. The internal pressure case is studied for the D-box test fixture design since the entire hoop load developed in the panel due to internal pressurization must be supported by the D-box test fixture with minimum boundary effects on the panel. When a stiffened curved panel is tested in a D-box test fixture, the D-box fixture should provide proper support conditions to the panel to induce a stress state that is representative of a shell structure. For this reason, cylindrical shell results will be compared with the corresponding curved panel results for internal pressure load cases without and with an axial compression load. The panel used for the following analytical studies is an aluminum panel that is a derivative of the Lockheed C-5 fuselage lower side panel. This panel configuration is being designed to be tested as a proof test article in the D-box test fixture using the combined loads test machine. The frame spacing for the panel is 20 in. and the stringer spacing is 6.85 in. The panel is 96 in. wide and 120 in. long, and has a radius of 120 in. For the damaged case, a 20-in.-long longitudinal crack through the frame at the midsection of the structure is used, which represents penetration damage in an aircraft fuselage. The response of a panel with this damage condition will also be studied during actual panel testing.

Internal Pressure Load Case

For the internal pressure loading case, two specimen and pressure combinations are considered. The first combination is the undamaged panel subjected to an internal pressure condition of 18 psig that is representative of the burst pressure (ultimate load) condition in a transport aircraft fuselage. The second combination is a panel with 20-in.-long penetration damage subjected to a limit load condition of about 9 psig. The panel has a severed frame and skin to simulate penetration damage.

Linear finite element analysis results for the D-box assembly subjected to an internal pressure of 18 psig are shown in Fig. 3 and compared with results for the cylindrical shell case. The resulting hoop stress state in the shell (Fig. 3a) is uniform in the skin and frame regions with a load distribution that has 46% of the total load in the skin elements and 54% of the total load in the frame elements. A maximum hoop stress resultant of 3500 lb/in. is realized on the skin surface opposite to the frame location and 1600 lb/in. is realized on the inside flange of the frame. The corresponding stress state in the curved panel supported in the D-box test fixture with rigid cross bars (no relative displacement between the hinge points connected by the cross bar) is shown in Fig. 3b. The load is not uniform among the panel skin bays, and the load distribution between the frame and the skin is 47 and 53% of the total load, respectively. The middle of the panel experiences a bending component in addition to the membrane tension component. This undesirable bending moment can be corrected by applying a compressive preload to the cross bars, which results in a bending moment in the opposite direction. This correction is accomplished in the analysis by applying a uniform temperature to the cross bars. At a temperature of 150°F, the cross bars apply an equal and opposite bending

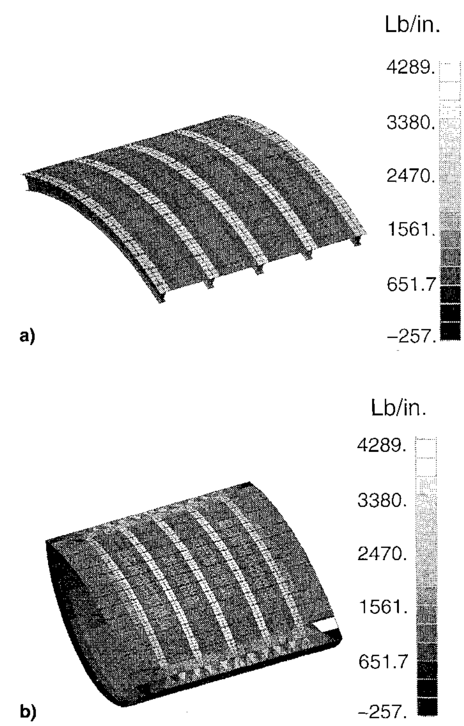


Fig. 3 Comparison of hoop stress resultant distributions for the cylindrical shell and the curved stiffened panel for an internal pressure of 18 psig: a) cylindrical shell and b) curved panel in the D-box test fixture with rigid cross bars.

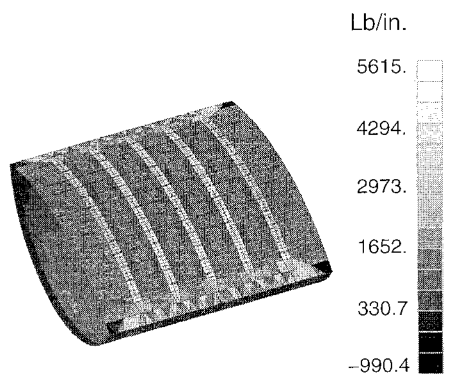


Fig. 4 Hoop stress resultant distributions for the curved panel in the D-box test fixture with preloaded cross bars for an internal pressure of 18 psig.

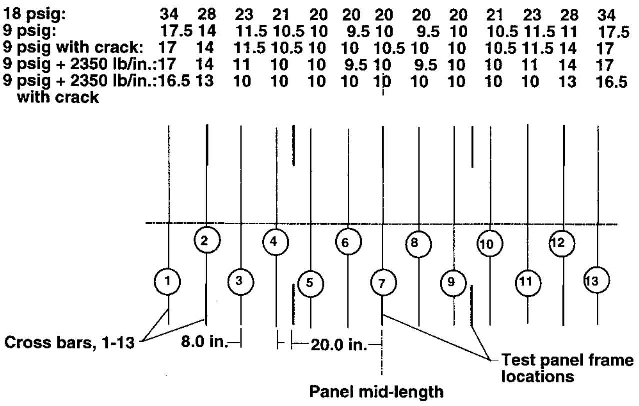


Fig. 5 Distribution of axial forces in the cross bars along the D-box test fixture length for several load cases.

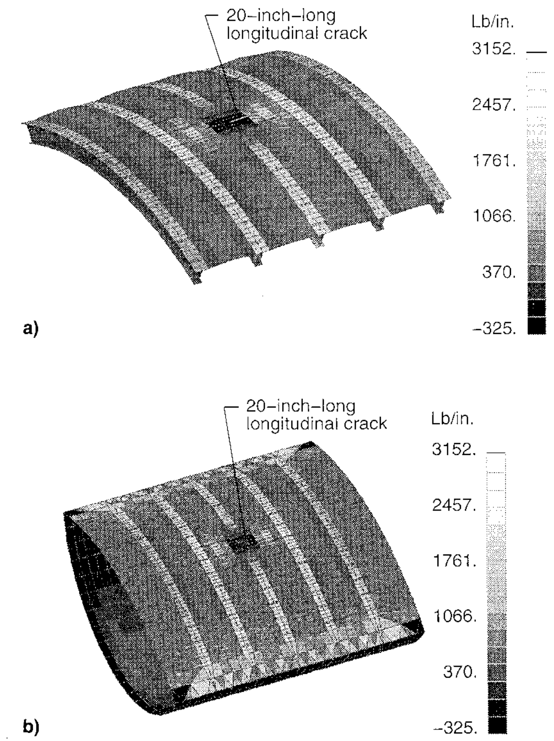


Fig. 6 Comparison of hoop stress resultant distributions for the cylindrical shell and the curved stiffened panel with a 20-in.-long longitudinal crack for an internal pressure of 9 psig: a) cylindrical shell and b) curved panel in a D-box test fixture with loaded cross bars.

moment to the test panel to provide a uniform membrane stress state between the skin bays. The load distribution between the frames and skin are also comparable to the cylindrical shell case for this 18-psig internal pressure condition. This result is shown in Fig. 4. The distribution of axial forces in the cross bars along the length of the D-box test fixture corresponding to the preloaded cross bars are shown in Fig. 5. The cross bars are numbered and the frame locations are represented by a thicker vertical line. The frame locations that do not coincide with the cross-bar locations can be seen in this figure. The axial forces in the cross bars are symmetric about the midlength of the D-box test fixture and vary in magnitude from 20 to 34 kips. The cross bars between the three midframe locations have a uniform load of 20 kips and the load increases as the support platens are approached. This load increase is due to the constraint imposed by the stiff platens in the direction of cross-bar axial forces. For an actual test, the cross bars will be replaced by hydraulic actuators that can apply a controlled force to induce a stress state in the panel that is representative of the shell stress state. This 18-psig pressure load condition essentially determines the capacity of the hydraulic actuators.

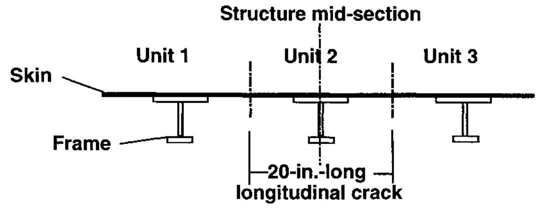
Analytical results are presented in Fig. 6 for a panel with a 20-in.-long longitudinal crack that extends from the center of one skin bay to the center of the next skin bay severing the frame in between. For this damaged panel case, the applied pressure load is 9 psig, which is the limit pressure condition for the fuselage. The load distribution for the shell is shown in Fig. 6a, which indicates that there is a 25% increase in the stress level for the frames adjoining the damaged frame compared to the undamaged panel case. This load condition can be simulated in a curved panel in the D-box test fixture as shown in Fig. 6b by readjusting the loads in the cross bars.

The distribution of load between the frame and skin elements in the three central units of the curved panel and cylindrical shell are summarized in Table 1. For all the pressure-loaded undamaged panel cases considered herein, the load share between the frame and skin elements is 56 and 44 percent, respectively. When the panel is damaged, the load carried by unit 2 is redistributed to the two outer units. This load redistribution results in a 22% increase in the load for skin elements and approximately a 25% increase in the load for frame elements in units 1 and 3. The total load values carried by the frame and skin elements suggest that a 12% load shifts from the frames to the skin.

Combined Internal Pressure and Axial Compression Load Case

Linear analysis has been performed on the shell and the curved panel in the D-box test fixture to determine the loads that need to be applied through the cross bars to simulate the stress state in a shell by the stress state in the curved panel in the D-box test fixture. For both the undamaged and damaged panels the load condition considered is 9-psig internal pressure with an axial compression loading of approximately 2300 lb/in. The compression load is applied to the D-box assembly after applying the internal pressure. The hoop stress resultants in the undamaged shell for this load condition are compared with the curved panel results in Fig. 7 for an applied cross bar load distribution shown in Fig. 5. The stress resultant distributions between the curved panel and the shell compare very well and so do the load distributions between the frame and the skin regions as summarized in Table 1. When an axial compression load of 1600 lb/in. is applied in addition to the pressure loading, the skin carries a smaller load due to its reduced stiffness in the postbuckled load range and shifts the load to the frames. An increase in axial compression load to 2350 lb/in. further reduces the load carried by the skin. Also, the accentuated out-of-plane displacement of the skin due to a combination of axial compression and internal pressure exerts a radially outward force on the frames, resulting in an additional tensile load in the frames. These response mech-

Table 1 Summary of hoop load results for frames and skins of a cylindrical shell and a curved panel in the D-box test fixture



	Hoop load, kips									
	Unit 1		Unit 2		Unit 3		Total		Percent load	
Load case	Frame	Skin	Frame	Skin	Frame	Skin	Frame	Skin	Frame	Skin
Curved panel: linear analysis, 9-psig internal pressure										
Undamaged	12.84	10.32	12.63	9.95	12.84	10.32	38.31	30.59	56	44
Damaged	15.78	12.53	2.67	9.77	15.78	12.53	34.23	34.83	50	50
Cylindrical shell: linear analysis, 9-psig internal pressure										
Undamaged	11.63	10.01	11.63	10.04	11.64	10.03	34.90	30.08	54	46
Damaged	14.75	12.03	2.29	9.39	14.76	12.04	31.80	33.46	49	51
Curved panel: linear analysis, 9-psig internal pressure and 2350-lb/in. axial load										
Undamaged	16.93	5.04	18.22	5.50	16.93	5.04	52.08	15.58	77	23
Damaged	20.30	7.52	5.70	6.00	20.30	7.52	46.30	21.04	69	31
Cylindrical shell: linear analysis, 9-psig internal pressure and 1607-lb/in. axial load										
Undamaged	15.38	5.95	15.66	6.15	15.38	5.95	46.41	18.04	72	28
Damaged	18.96	8.17	4.40	6.11	18.97	8.12	42.33	22.35	65	35
Cylindrical shell: linear analysis, 9-psig internal pressure and 2350-lb/in. axial load										
Undamaged	16.77	4.42	17.17	4.68	16.77	4.41	50.70	13.51	79	21
Damaged	20.54	6.65	5.20	4.88	20.54	6.65	46.28	18.18	72	28
Cylindrical shell: nonlinear analysis, 9-psig internal pressure										
Undamaged	12.88	8.73	12.88	8.73	12.88	8.73	38.64	26.19	60	40
Damaged	16.39	11.60	−0.16	9.02	16.39	11.69	32.62	32.31	50	50
Cylindrical shell: nonlinear analysis, 9-psig internal pressure and 1607-lb/in. axial load										
Undamaged	14.60	6.98	14.59	6.98	14.60	6.98	43.79	20.94	68	32
Damaged	15.53	10.90	0.70	11.15	15.53	10.90	31.76	32.95	49	51

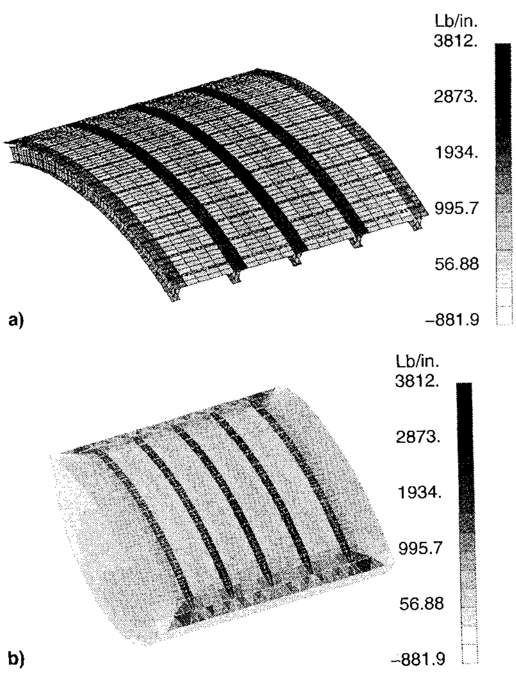


Fig. 7 Comparison of hoop stress resultant distributions for the cylindrical shell and the curved stiffened panel for a combined internal pressure of 9 psig and an axial loading of 2350 lb/in.: a) cylindrical shell and b) curved panel in a D-box test fixture with loaded cross bars.

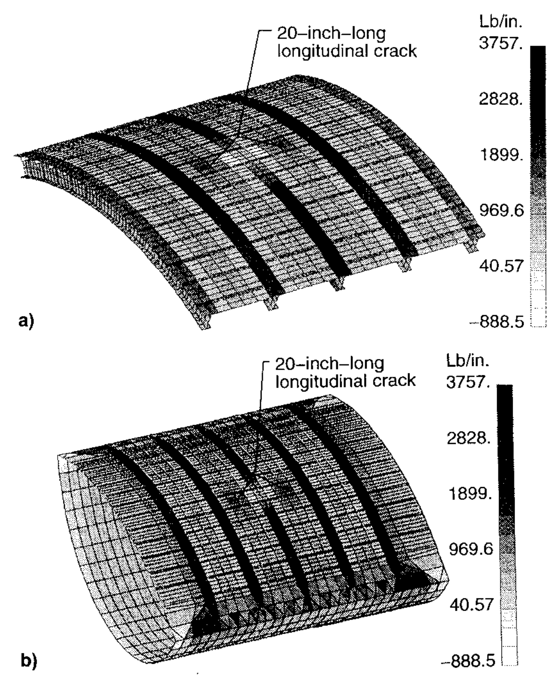


Fig. 8 Comparison of hoop stress resultant distributions for the cylindrical shell and the curved stiffened panel with 20-in.-long longitudinal crack for a combined internal pressure of 9 psig and 2350-lb/in. axial loading: a) cylindrical shell and b) curved panel in a D-box test fixture with loaded cross bars.

anisms for this combined load case result in approximately 78% of the hoop load being supported by the frames and 22% by the skin as summarized in Table 1.

The hoop stress results for a shell with a 20-in.-long longitudinal crack and loaded with 2350 lb/in. of axial compression and 9 psig of internal pressure are compared with a corresponding case for the damaged curved panel in Fig. 8. The stress resultant distribution are comparable for the two structures as shown in this figure when the cross-bar forces summarized in Fig. 5 are applied for this load case. As indicated from results in Fig. 5, the influence of a 20-in.-long longitudinal crack or axial compression load is approximately the same on the loads in the cross bars. Also, the load carried by unit 2 reduces considerably for this load case as the load is redistributed to the outer shell units. For the combined load case, the frame loads in the outer shell units increase by about 20% and the skin element loads increase by about 50%. This change in loads results in a load share of about 70 and 30% between the frames and skin, respectively.

Nonlinear Analysis of the Cylindrical Shell

During the actual proof test of the panel in the combined loads test machine, the panel will be loaded in compression to levels beyond buckling. Reductions in curved panel stiffness in the postbuckling load range require results from a nonlinear analysis to understand better the panel response and the associated boundary conditions that must be imposed on the test panel in the D-box test fixture. Also, even for the internal pressure case, skin pillowing introduces nonlinear interactions between skin and stringers that need to be understood. Shell analyses have been performed for the pressure and combined pressure and axial loading conditions to provide insight into the influence of nonlinear effects on structural response. Although analyzing a complete shell is the preferred approach in general to generate shell combined load response results, a shell segment is used for the analyses. The resulting small model size minimizes computational times associated with the nonlinear analysis. Since the structure is planned to be loaded beyond buckling, dimensions of this shell segment that represents the shell response in compression loading needs to be determined first. The cyclic symmetry technique in MSC/Nastran (Ref. 3) has been used to perform a linear buckling analysis to determine the size of this shell segment. The lowest eigenvalue for this shell was determined to be for a skin buckling mode with the skin between frames buckling along the shell circumference into 48 half-waves at a total load of 773 lb/in. A shell segment that includes two stringer spacings has been chosen to correspond to this harmonic result. The length of the shell segment was chosen to include three frames to facilitate studies of shell response with a 20-in.-long longitudinal crack through the midframe. Interactions from the boundaries of the shell segment on the internal stress states is expected to be a minimum for this structural size.

Internal Pressure Load Case

Nonlinear analyses were performed for the undamaged and damaged shell cases to determine the magnitude and nature of the differences in stresses and deflections due to nonlinear response of the panel. Since the change in the radial displacement results in the hoop stress results for the panel with 20-in.-long longitudinal crack are more pronounced compared to the undamaged panel case, only these results are discussed herein. The nonlinear hoop stress (in lb/in.^{2}) results for the damaged shell for a 9-psig internal pressure case are compared in Fig. 9. The stress level in the vicinity of the crack is 47%

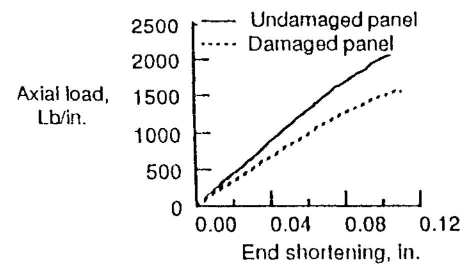


Fig. 10 Load vs end-shortening results from nonlinear analysis for a cylindrical shell without and with 20-in.-long longitudinal crack.

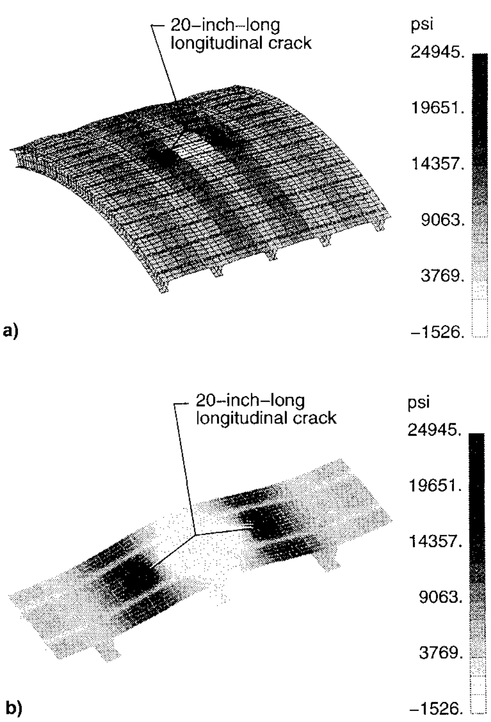


Fig. 9 Comparisons of hoop stress distributions for the cylindrical shell with 20-in.-long longitudinal crack for an internal pressure of 9 psig: a) linear and b) nonlinear analysis.

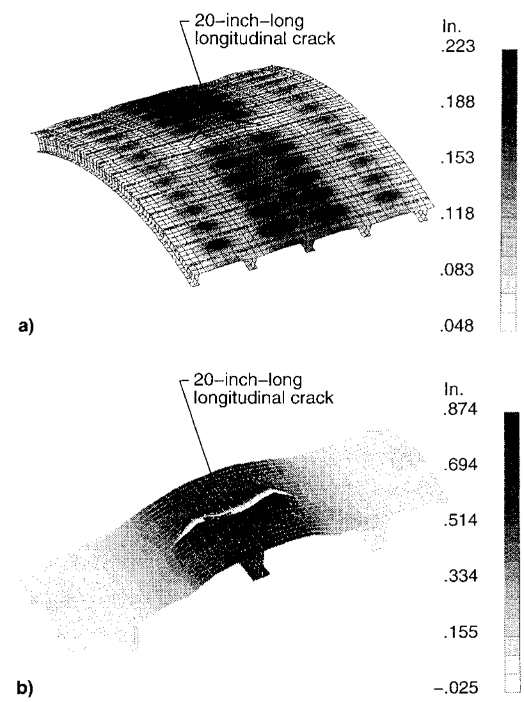


Fig. 11 Comparison of out-of-plane displacement contours for the cylindrical shell with 20-in.-long longitudinal crack for combined 9-psig internal pressure and 1600-lb/in. axial compression loading: a) linear and b) nonlinear analysis.

more than the corresponding stress for the linear case as a consequence of accentuated local bending gradients associated with a larger crack opening. The load distribution between the frames and the skin obtained from nonlinear analysis is listed in Table 1. The nonlinear analysis results show that, even in the undamaged state, the skin elements carry a smaller load than the frames due to the interaction of the skin and frame. The amount of load carried by the frame and skin elements are determined to be approximately the same as the linear analysis results for the damaged panel.

Combined Internal Pressure and Axial Compression Load Case

Load vs end-shortening curves for the shell segment for the combined load case are presented in Fig. 10 for both the undamaged and damaged cases. The shell without damage exhibits nonlinear behavior when a compressive loading of 1675 lb/in. is applied with the pressure load of 9 psig. For the shell with damage, this compressive load level is 905 lb/in. with a more pronounced nonlinear response than the undamaged shell. The deflected shapes from linear and nonlinear analyses for the damaged shell subjected to 9-psig internal pressure and an axial compression load of 1600 lb/in. are compared in Fig. 11. The load distribution between the skin and frame elements from nonlinear analysis at this load are summarized in Table 1. The hoop stress states (in lb/in.^{2}) for the damaged shell for this combined load case are presented in Fig. 12. The nonlinear analysis results indicate significantly larger out-of-plane deformations for both the undamaged and damaged shells. The maximum values for out-of-plane deflection occur in the vicinity of the crack tip. The magnitudes of these deflections are 0.26 and 0.59 in. from the linear and nonlinear analyses, respectively. The maximum hoop stress values from the nonlinear analysis results are also twice that of the linear analysis results. The load distributions between the skin and the frame elements for both the undamaged and damaged shell cases obtained from nonlinear analysis results suggest that stiffening of the skin due to large deformations enable the skin to carry more load. The nonlinear analysis results for this lower axial load case suggest that the skin carried 50% of the total load in the damaged state compared to 35% obtained from linear analysis.

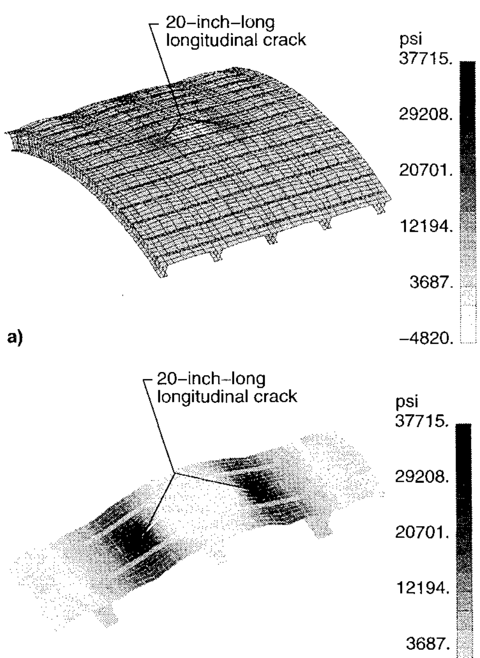


Fig. 12 Comparison of hoop stress distributions for the cylindrical shell with 20-in.-long longitudinal crack for combined 9-psig internal pressure and 1600-lb/in. axial compression loading: a) linear and b) nonlinear analysis.

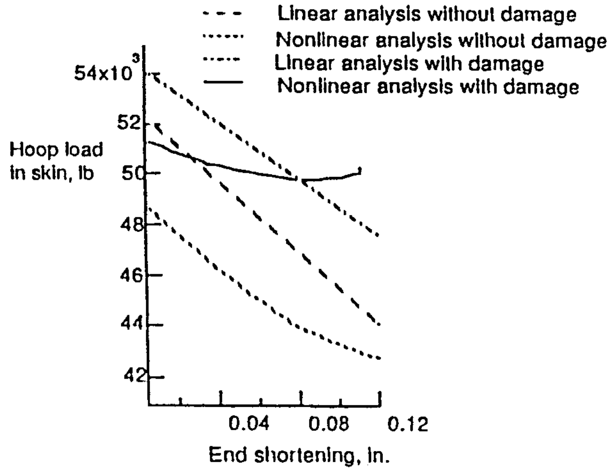


Fig. 13 Load vs end-shortening results for skin of the undamaged and damaged panels subjected to combined axial compression and 9-psig internal pressure.

The differences between linear and nonlinear analysis results for the load-carrying capability of the skin elements with and without damage for the combined pressure and axial load cases are explained by means of Fig. 13. The change in stiffness of the skin is summarized in this figure as the end-shortening corresponding to an axial compression load is increased for the pressure loaded panel. Both the linear and nonlinear analysis results suggest that as the compression load is increased, stiffness reduction for the skin in the undamaged state is more than that for the skin in the damaged state. The nonlinear results suggest that for end-shortening values greater than 0.70 and 0.55 in. for the undamaged and damaged panels, respectively, the skin exhibits a stiffening behavior that results in the skin carrying more load compared to the value obtained from the linear analysis.

These analysis results suggest that curved panels subjected to internal pressure and axial compression can be tested in the D-box test fixture to study the response of full-scale shell structures.

Concluding Remarks

This article describes a combined loads test machine that is part of a new NASA COLTS. A design concept for a D-box test fixture that can be used for testing curved stiffened panels subjected to internal pressure and mechanical loads has been presented. Finite element analyses have been performed to determine load distributions in undamaged and damaged curved panels assembled in the D-box test fixture and are compared with cylindrical shell analysis results for corresponding load cases.

The analysis results indicate that curved panels subjected to internal pressure or a combination of internal pressure and axial compression load can be tested in the D-box test fixture to study the response of full-scale shell structures. The finite element analysis results for the cylindrical shell and the D-box assembly suggest that it is possible to simulate the stress state in a cylindrical shell with a curved stiffened panel assembled in the D-box test fixture by adjusting the preload in the D-box test fixture cross bars. The magnitudes of the cross bar forces are determined primarily by the pressure load case. The cross-bar forces are only slightly different for the panel with a 20-in.-long longitudinal crack compared to the undamaged panel for the 9-psig internal pressure case. The cross bars in the D-box test fixture may be replaced by hydraulic actuators with load capacities determined from the 18-psig internal pressure case and predetermined actuator loads may be applied to the D-box test fixture in order to simulate the shell stress state in the test panel. The nonlinear analysis results for the cylindrical shell suggest that for the combinations of load cases and the damage scenario considered in this article, the panel stress states need to be determined from nonlinear analysis for failure assessment. For determination of reaction loads in the skin and frame elements for the pressure load condition, however, linear analysis results are comparable to the nonlinear analysis results.

References

[1]Ambur, D. R., Cerro, J. A., and Dickson, J. N., "Analysis of a D-Box Fixture for Testing Curved Stiffened Aircraft Fuselage Panels in Axial Compression and Internal Pressure," AIAA Paper 94-1345, April 1994.

[2]Anon., "PATRAN Plus User Manual—Release 2.4," PDA Engineering, Publication 2191023, Sept. 1989.

[3]Anon., "MSC/NASTRAN Handbook for Linear Analysis—Version 64," Macneal-Schwendler Corp., Aug. 1985.