[7]Pearson, D., "Dynamic Behavior of Helical Springs," *Shock and Vibration Digest,* Vol. 20, No. 7, 1988, pp. 3–9.

[8]Dick, J., "Shock-Waves in Helical Springs," *The Engineer,* Vol. 204, Aug. 9, 1957, pp. 193–195.

[9]Gross, S. C., "Coil Spring Performance," *Automobile Engineering,* 1959.

[10]Curran, J. P. S., "Further Considerations in Injector Design for High Specific Output Diesel Engines," *I. Mech. E. Symp,* Critical Factors in the Application of Diesel Engines, Southhampton Univ., 1970.

[11]Phillips, J. W., and Costello, G. A., "Large Deflections of Impacted Helical Springs," *Journal of the Acoustical Society of America,* Vol. 51, No. 3, Pt. 2, 1972, pp. 967–973.

[12]Costello, G. A., "Radial Expansion of Impacted Helical Springs," *Journal of Applied Mechanics, Transactions of the ASME,* Vol. 42, Dec. 1975, pp. 789–792.

[13]Sinha, S. K., and Costello, G. A., "The Numerical Solution of the Dynamic Response of Helical Springs," *International Journal for Numerical Methods in Engineering,* Vol. 12, 1978, pp. 949–961.

[14]Jiang, W., Jones, W. K., Wang, T. L., and Wu, K. H., "Free Vibration of Helical Springs," *Journal of Applied Mechanics, Transactions of ASME,* Vol. 58, No. 1, 1991, pp. 222–228.

Collapse Characteristics of Cylindrical Composite Panels Under Axial Loads

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Introduction

LAMINATED composites are well suited for membrane applications, but structurally optimizing an elastic shell makes it susceptible to buckling or collapse. Shells such as stiffened fuselage panels contain many discontinuities, such as square cutouts, which cause local stress and displacement gradients that influence structural performance. The phenomenon of buckling of flat composite panels or plates is well documented and not discussed herein. The instability of curved composite panels is attracting a smaller amount of documented research,[1,2] and only recently are there articles including work on composite shells requiring nonlinear analysis due primarily to the inclusion of geometric discontinuities (such as cutouts) within their structure.[3] In this Note, the static response of a laminated graphite/epoxy cylindrical shell subjected to an axially distributed load considering cutout positioning is investigated. A 36-degree-of-freedom (DOF) two-dimensional curved, rectangular finite element, including through-the-thickness transverse shear, is incorporated in this study. A modified Newton-Raphson (MNR) iterative technique traces equilibrium through to the collapse load and comparisons are made to experimentation.

Numerical Modeling

Comparable theories incorporating higher-order transverse shear effects for laminated shells were presented by Reddy and Liu[4] and Dennis and Palazotto.[5] The code, with a 36-DOF element mentioned previously and referred to as SHELL, is used herein. SHELL's theory is thoroughly discussed in Ref. 5. An important aspect of the present study is to determine the effect of transverse shear strain (while considering large displacements and rotations) on a cylindrical shell. Transverse shear strain β_s is defined as

$$\beta_s = |\Psi_s| - |w_{,s}| \tag{1}$$

where Ψ_s is the rotation due to the bending, β_s the rotation due to transverse shear, and $w_{,s}$ the slope of the elastic curve. Since Ψ_s and $w_{,s}$ are degrees of freedom calculated by SHELL, the difference of their magnitudes must equal the change in the slope of the elastic curve in the presence of transverse shear strain.

A convergence study was conducted using the 36-DOF element. This study led to the refined mesh shown for the two basic panels (see Fig. 1). In considering imperfections (cutouts) of the 4 in. × 4 in. size, circumferential eccentricity of 1 in. was included in the study, as shown in Fig. 2. The mesh size used in this study resulted in a general set of active DOF equal to approximately 2750 for the 8-in. panel and 3300 for the 12-in. panel.

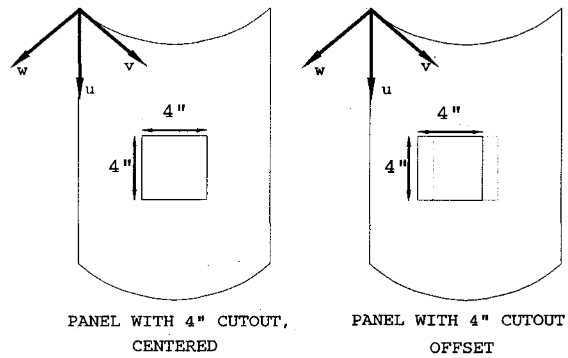

Fig. 1 Location of cutouts studied.

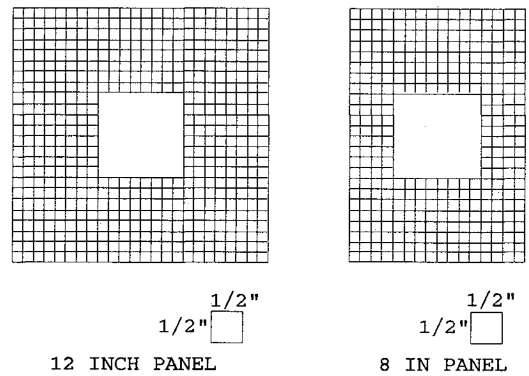

Fig. 2 Refined meshes for 8 × 12 in. and 12 × 12 in.

Results and Discussion

References 6 and 7 discuss the experimental test setup and the axial compression procedure in detail. Graphite/epoxy panels (Hercules AS4-3501-6) were studied with the following properties:

$$E_1 = 20.461 \times 10^6 \text{ psi}$$

$$G_{12} = 0.883 \times 10^6 \text{ psi}$$

$$E_2 = E_3 = 1.468 \times 10^6 \text{ psi}$$

$$G_{13} = G_{23} = 0.441 \times 10^6 \text{ psi}$$

$$\nu_{12} = 0.28$$

with a ply-lay up of $[0, \mp 45, 90]_s$.

Received Oct. 15, 1990; revision received July 23, 1991; accepted for publication July 31, 1991.

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Table 1 Numerical transverse shear effect with boundary conditions

Shell	Collapse load, %	β_s, rad[a]	$w,_s$ %
12-in. simply supported	91.2	0.00452	7.3
12-in. unsupported	94.5	0.00860	15.7
8-in. simply supported	98.1	0.00448	8.9
8-in. unsupported	97.6	0.00790	13.8

[a] β_s and $w,_s$ are the maximum values found in the shell.

Table 2 Numerical eccentricity effect on collapse load

Shell	Cutout, lb	Offset cutout, lb	Delta, %
12-in. simply supported	2450	2501	+2.1
12-in. unsupported	1177	1204	+2.3
8-in. simply supported	1878	1965	+4.6
8-in. unsupported	436	447	+2.4

Table 3 Comparison of collapse load, numerical vs experimental results

Shell	Numerical, lb	Experimental, lb	Percent error
12-in. no cutout	2143	2045	4.6
12-in. centered cutout	1177	1093	7.7
12-in. offset cutout	1204	1127	6.8
8-in. no cutout	1322	1311	0.8
8-in. centered cutout	436	400	8.3
8-in. offset cutout	447	403	9.8

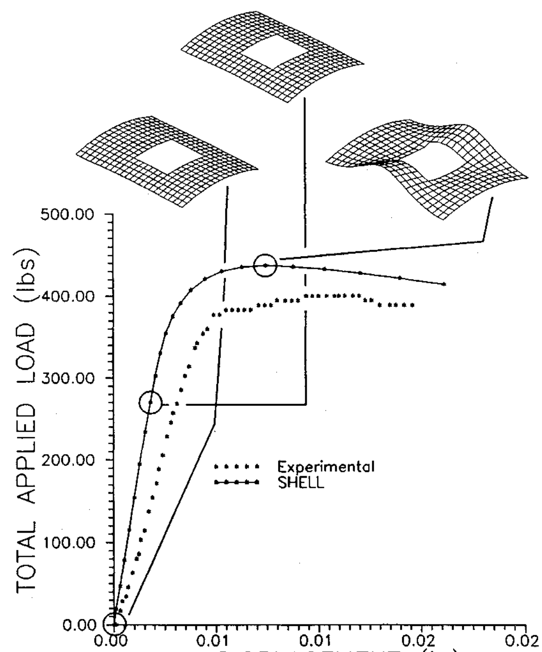

Fig. 3 *U* displacement at midpoint of top edge vs total applied load *P* for unsupported panel.

Numerical Effect of Transverse Shear Strain

Two boundary conditions were examined: 1) the top and bottom edges are clamped ($u = v = w = w,_x = w,_s = \Psi_x = \Psi_s = 0$) while the vertical edges are unsupported and, 2) the top and bottom edges are clamped while the vertical edges are simply supported ($v = w = w,_s = \Psi_s = 0$). For the unsupported panels, transverse shear strain β_s along the vertical edge is increasingly important. Table 1 lists the maximum value of β_s produced for each type of panel for comparable loads. At low initial loads, when the membrane is initially compressed, very little β_s is developed due to the lack of presence of any bending moment and, thereby, any significant rotations. However, as collapse is achieved, significant variances are noticed; bending rotations significantly dominate the shell's response over membrane activity. Hence, as the amount of rotation increases, the percentage of shear strain rotation β_s is increased. Since quasi-isotropic panels have a large in-plane shear stiffness (A_{66}) when compared to the transverse shear stiffness terms (A_{44} and A_{55}), the amount of β_s produced as a by-product of rotation is significant.

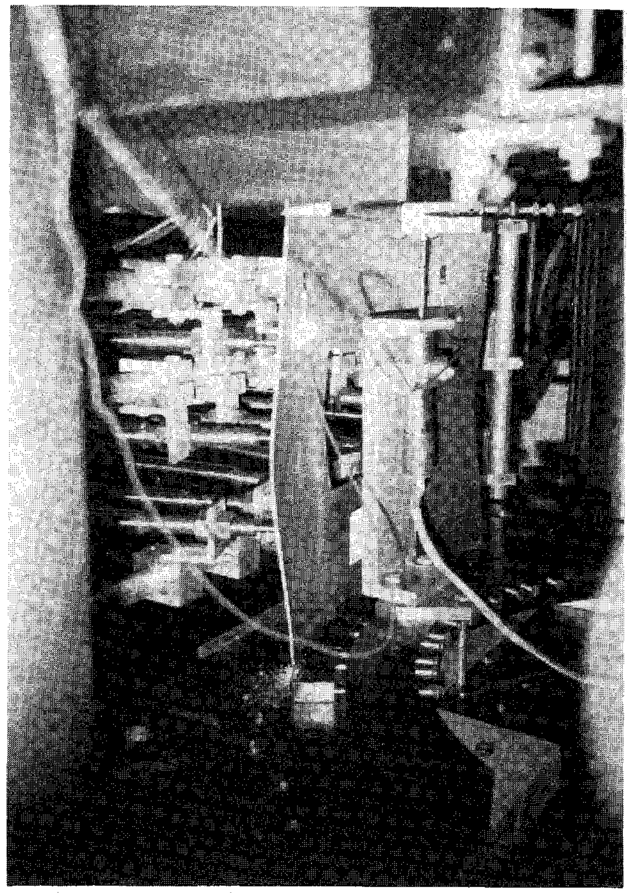

Fig. 4 Unsupported panel in experimental test fixture of total collapse.

Numerical Effects of Cutout Eccentricity

It is rare when geometric imperfections such as cutouts are symmetric with respect to the shell. Hence, the effect of circumferential eccentricity of the cutout is addressed herein. For this effort, cutout eccentricity is defined as offsetting the cutout in the circumferential direction by 1 in. (refer to Fig. 2). An unexpected result was the slight increase in the total collapse load for those shells having circumferential eccentricity. This is attributed to the larger column of the eccentric panel carrying more load compared to the columns of the panel with a centered cutout. The increase in collapse load varied from 2.1 to 4.6%, as shown in Table 2.

Comparisons with Experimental Results

As expected, the numerical results from the finite element code, SHELL, are stiffer than experimental results. Figure 3 compares displacements for the unsupported vertical edged shells. Table 3 lists the collapse loads for shells with no vertical support from numerical results and experimental tests. It is observed that the numerical results closely follow the experimental tests. Both deflection and loading are represented well by the finite element model (see Figs. 3 and 4).

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Conclusions

The nonlinear response of a laminated shell including transverse shear and collapse was studied. Offsetting the cutout increases stiffness and strength (compared to shells with a centered cutout). Transverse shear strain significantly influences the response of a laminated shell undergoing large rotations (in excess of 15 deg) and is greater with increased width and reduced circumferential boundary conditions. This indicates that an approach not including transverse shear is less conservative for large rotations due to the presence of large transverse shear strains.

References

[1]Knight, N. F., and Starnes, J. H., "Postbuckling Behavior of Axially Compressed Graphite-epoxy Cylindrical Panels with Circular Holes," *Collapse Analysis of Structures*, edited by L. H. Sobel and K. Thomas, PVP-Vol. 84, American Society of Mechanical Engineers, New York, 1984, pp. 13-167.

[2]Palazotto, A. N., Hinrichson, R. L., and Witt, W. P., "Inter-Ply Rotational Compatibility for Composite Plates," *Journal of Composite Structures*, Vol. 11, No. 3, 1989, pp. 167-182.

[3]Palazotto, A. N., and Tisler, T. W., "Insight into the Collapse of Composite Cylindrical Panels with Cutouts: Analysis and Experimentation," *Recent Advances in Structural Dynamics*, ASME PVP-Vol. 124, 1987, pp. 55-61.

[4]Reddy, J. N., and Liu, C. F., "A Higher Order Shear Deformation Theory of Laminted Composite Shells," *International Journal of Engineering Science*, Vol. 23, No. 3, 1985, pp. 319-330.

[5]Dennis, S. T., and Palazotto, A. N., "Large Displacement and Rotational Formulations for Laminated Shells Including Parabolic Transverse Shells," *International Journal of Non-Linear Mechanics*, Vol. 25, No. 1, 1990, pp. 67-85.

[6]Becker, M. L., Palazotto, A. N., and Khot, N. S., "Experimental Investigation of the Instability of Composite Cylindrical Panels," *Experimental Mechanics*, Vol. 22, No. 10, 1982, pp. 372-376.

[7]Palazotto, A. N., "An Experimental Study of Curved Composite Panel with a Cutout," *ASTM STP 972*, American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 191-202.

Book Review

Automatic Control of Aircraft and Missiles

John H. Blakelock, 2nd Ed., Wiley, New York, 1991, 646 pp., $74.95

This book is a second edition of a volume originally published in 1965. The first volume competed with books such as those by Etkin or Seckel in the areas of airplane dynamics and controls, but was somewhat unique in its inclusion of missile dynamics and control. This edition is apparently intended to update aspects of the first edition, particularly in the inclusion of modern control theory and pilot modeling. In this light, it partially competes with Roskam's text or Etkin's second book, or newer books incorporating a treatment of "modern" control such as that by Stengel, but again the inclusion of missiles sets it apart from books that consider only aircraft. The text seems to be at about the right level for a first-year graduate course in flight dynamics and controls, but would be hampered in this regard by the lack of suggested exercises.

The book is composed of 13 chapters and 10 appendices. Chapters 1-4 deal with the equations of motion for aircraft, the development of longitudinal and lateral autopilots, inertial coupling, and "adaptive" autopilots, and are largely unchanged from the first edition. This constancy is both good and bad. The autopilot designs are clearly presented in terms of "classic" root-locus procedures, with engineering tradeoffs well identified—a characteristic sadly lacking in many textbooks and almost always missing in modern control textbooks. The time history responses, however, appear to have been carried over, and could not be presented with orthogonal grids rather than those dictated by the analog computers apparently used for the first edition. In addition, the use of stability axes, while typical of practice during the time of the first edition, is largely eschewed today for most flight analyses because of large angles of attack in many applications of interest; also, dimensional derivatives, rather than the "classic" nondimensionalization used here, are often more appropriate.

To this reviewer, Chapters 2 and 4, which present several designs in exemplary fashion and include some new material in lateral autopilots, are particularly good. Less successful for today's audience, perhaps, is Chapter 6 on adaptive autopilots, which is carried over from the previous edition; the material here is over 20 years old, and has effectively been superseded.

Chapter 7, again largely carried over from the first edition, deals with missile dynamics and control, whereas Chapter 8 is new and presents guidance design information. Again the presentation of the concepts is clear, and the designs are understandable. Chapter 8, which was particularly instructive for this reviewer, includes bank-to-turn design information that is appropriate for modern missiles. Chapter 9, another new chapter, returns to the aircraft application for an integrated flight-fire-control system design, including both longitudinal and lateral dynamics plus those of a gimballed tracker and movable gun. This chapter is unique compared with most books on aircraft dynamics because of its presentation of this fairly complex integrated "real-world" design problem, and should be very useful for students in developing an understanding of how rapidly the complexities grow.

Chapter 9 is also unique in the book in that it introduces, in this context only, the use of digital design procedures into the analysis. The design is considered from both a "direct" digital point of view, which uses z transforms, and the "emulation" point of view, which is in the Laplace domain but includes a Pade approximation to represent the digital delay. The author considers the results for these two digital methods to be equivalent, for the example selected, but this assessment would not