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Parametric Study Relating to Buckling of Stringer Stiffened Cylindrical Shells with Cutouts

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The effects of stringer eccentricity, shell length, cutouts, and boundary conditions have been studied for cylindrical shells under axial compression considering four generalized simple support and four clamped boundary conditions. Buckling loads were determined through the STAGS computer code with its linear bifurcation branch and smeared stringer theory incorporating an energy formulation and a finite difference technique. Results of the present theory, when compared to classical linear theory, show that a rigorous prebuckling analysis has a significant influence on the analysis of stringer stiffened cylinders. It was found that cutouts do not significantly change a stringer stiffened shell's sensitivity to in-plane boundary conditions but cause a substantial reduction in critical loads for externally stiffened shells. The detrimental effects of cutouts are less apparent in cylindrical shells with internal stringers. The $u=0$ axial restraint is the most important factor in buckling of axially compressed, stringer stiffened cylinders.

Introduction

THE literature devoted to shell instability is replete with investigations of unstiffened isotropic cylindrical shells. Stiffened shells have also been rigorously studied while shells with cutouts, stiffened or unstiffened, have received less attention. This paper considers the stringer stiffened shell with cutouts under axial compression.

Boundary conditions have been shown to be an important consideration in shell buckling problems. Prior efforts[1] in modeling boundary conditions reveal the difficulties involved; actual boundary conditions were stiffer than the theoretical in some cases while weaker in others. Edge restraints can significantly affect a shell's buckling load. Thus, agreement between theory and experiment not only depends upon accurate theories but also upon an adequate representation of the applicable boundary conditions in experimental tests. Therefore, the authors have carried out this study incorporating eight generalized edge supports. They may be listed as:

SS1	$w=0$	$w_{,xx}=0$	$N_x=0$	$N_{xy}=0$
SS2	$w=0$	$w_{,xx}=0$	$u=0$	$N_{xy}=0$
SS3	$w=0$	$w_{,xx}=0$	$N_x=0$	$v=0$
SS4	$w=0$	$w_{,xx}=0$	$u=0$	$v=0$
CC1	$w=0$	$w_{,x}=0$	$N_x=0$	$N_{xy}=0$
CC2	$w=0$	$w_{,x}=0$	$u=0$	$N_{xy}=0$
CC3	$w=0$	$w_{,x}=0$	$N_x=0$	$v=0$
CC4	$w=0$	$w_{,x}=0$	$u=0$	$v=0$

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where SS = simply and CC = clamped supported. The prebuckling boundary conditions SS1 and CC1 were used for the respective simple support and clamped analyses. By incorporating this spectrum of supports, a full appreciation of the end conditions in conjunction with a cutout can be explored.

Modeling

The stringer, shell, and cutout geometry studied are presented in Fig. 1. Using this geometry and $L=60$ in. and $2a=24$ in., Palazotto[2] had demonstrated that the bifurcation load was within 7% of that of nonlinear collapse analysis. The difference between a smeared vs a discrete analysis was only 4%. It can also be seen in his study that nonlinearities are small even for a cutout size of $2a$ equal to $0.3L$. Based upon his findings the same geometry, except for $2a=12$ in., is used herein. These smaller cutouts will thus allow cylinders of shorter length to be analyzed with similar agreement between theories.

The nondimensional stringer parameters in Fig. 1 are similar to the "medium" stiffened cylinders in Weller's boundary condition study[3] where classical theory was used. The ability of these "medium" stiffened shells without cutouts to exhibit the effects of the in-plane edge restraints was also considered in selecting the present stiffener parameters. Furthermore, a comparison between bifurcation theory and classical theory can be additionally realized.

The internal and external stringers in Fig. 1 have an $A_l/b_lh=0.9333$. This is well within the realm of smeared stiffener theory as noted in Rosen.[1] Thus, local buckling between stringers is not a factor. It should also be observed that an R of 57.2958 in. was used. This facilitates the placement of the stringers as 1 in. on the circumference equates to 1 deg.

Since the cutouts are symmetrically placed upon the shell, only one-eighth of the shell, which serves as the shell model, was considered. The portion analyzed is also depicted in Fig. 1. The simple support and clamped boundary conditions presented earlier are imposed upon the shell ends during the buckling portion of the analysis. For the prebuckling problem, boundary conditions analogous to SS1 and CC1 were used for the respective simple support and clamped cases. These prebuckling boundary conditions will be henceforth referred to as SS1* and CC1* for, in addition to u_0 and v_0 being free, an N_{x_0} arises due to the applied end load. The SS1* and CC1* boundary conditions provide the necessary prebuckling edge restraints while insuring a con-

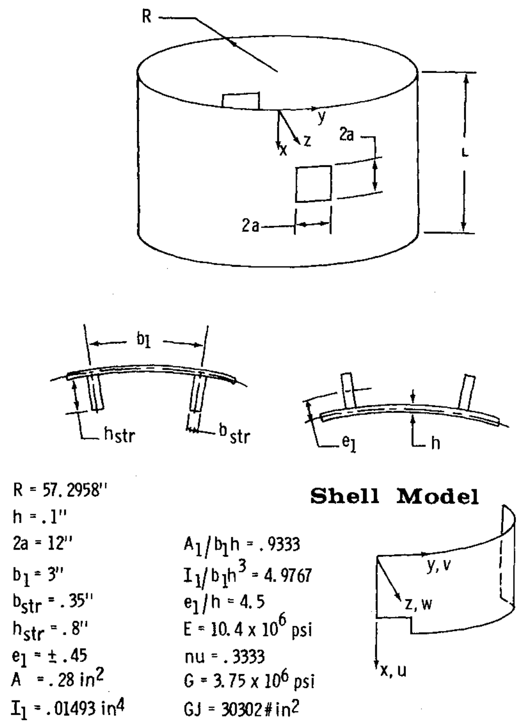

Fig. 1 Shell, stringer geometry and sign convention.

sistent prebuckling analysis for each simple support and clamped case. Thus, only eight sets of boundary conditions need be considered.

Each shell is loaded by imposing a uniform axial displacement which best approximates an experimental load realized under axial compression. Furthermore, the problems that might occur with a line load directly above the cutout are avoided. Since u_0 is free to move in SS1* and CC1*, a conflict in axial displacement is also eliminated while the ends of the shell are initially displaced during loading.

Since STAGS incorporates a finite difference technique, it was necessary to impose a grid arrangement of reference nodes adequately spaced in order to provide the required accuracy. Convergence studies indicate the need for refining the grid close to a cutout and near the shell's boundary, resulting in, over an eighth of the shell shown in Fig. 1, a square grid of 1.5 in. covering a 15 × 15 in. region surrounding the opening and six vertical mesh spaces of 1.0 in. adjacent to the boundary. All other mesh dimensions were set at 3 in.

Discussion

A study of the effects of length, boundary conditions, and stringer eccentricity has been carried out for cylinders incorporating two symmetrically placed 12 × 12 in. square cutouts. In order for the reader to obtain an appreciation of this work some discussion of the results is presented. The conclusion section will relate to the complete study.

The detrimental effects that cutouts have on cylinders with external and internal stringers are demonstrated in Figs. 2 and 3, respectively. For cylinders with external stringers, SS2 and SS4 are the most advantageous boundary conditions since cutouts only decrease the critical load by 15% at small values of L/R. The $u=0$ edge condition in SS2 and SS4 seems to partially compensate for the weakening caused by the cutouts. For $L/R = 0.454$ and SS3, cutouts cause a 30% reduction in P. In Fig. 3 it can be seen that cutouts have a minimal effect on internally stiffened cylinders. For all the simply supported boundary conditions only a 5% decrease in critical load was obtained when cutouts were included in the cylinders.

The trends in Figs. 2 and 3 are best explained by considering the effects that stringers have on cylindrical shells. Due to the

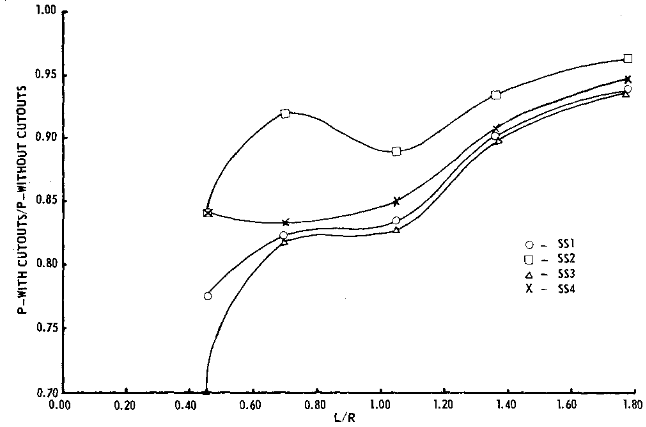

Fig. 2 Effect of cutouts on externally stiffened shells (simply supported).

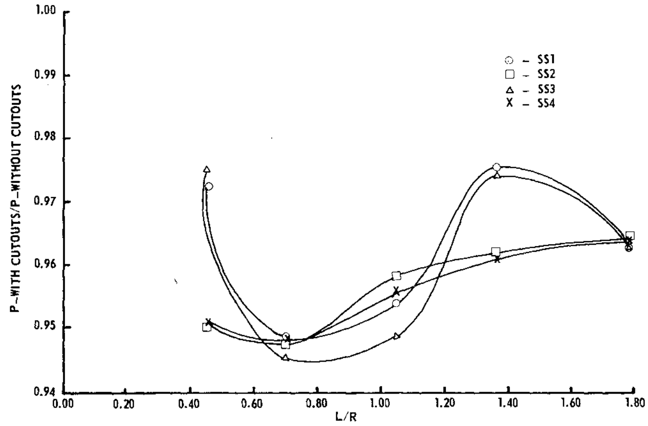

Fig. 3 Effect of cutouts on internally stiffened shells (simply supported).

secondary eccentricity effect, external stringers induce tensile hoop stresses that essentially act like rings in tension that resist buckling. This tension field is negligible for externally stiffened cylinders with large L/R but its magnitude considerably increases for smaller values of L/R. Introducing cutouts into the cylinder eliminates part of this tension field. In shorter shells where the cutouts cover a greater percentage of the shell surface, a greater portion of the tension field is eliminated. Thus, the detrimental effects of cutouts on externally stiffened cylinders become greater as L/R decreases as is demonstrated in Fig. 2. For internally stiffened cylinders, stringers are not as effective in strengthening a shell as external stringers. Removing a portion of the internal stringers encompassed by the perimeter of the cutouts does not weaken the stiffened shell as much as a similar cutout on an externally stiffened cylinder. Therefore, the detrimental effects that cutouts have on a cylinder with internal stringers is not as drastic as equivalent cylinders with external stringers.

The detrimental effect of cutouts on clamped cylinders is demonstrated in Fig. 4 for externally stiffened cylinders while Fig. 5 represents clamped cylinders with internal stringers. In Fig. 4, it can be seen that CC1 and CC3 lessens the detrimental effects of cutouts over that of CC2 and CC4 where externally stiffened shells are concerned. When one studies CC1 and CC3 supported shells, a 20% reduction in critical load is obtained over that of P without cutouts for $L/R = 0.698$. For CC2 and CC4, the cutouts cause a 25% reduction in P at $L/R = 1.407$. Considering internally stiffened shells and $L/R = 0.698$, cutouts have a greater effect on clamped cylinders than simply supported cylinders and can reduce P by 8% for CC2 and CC4, and by 10% for CC1 and CC3. In all the clamped boundary and stringer stiffened

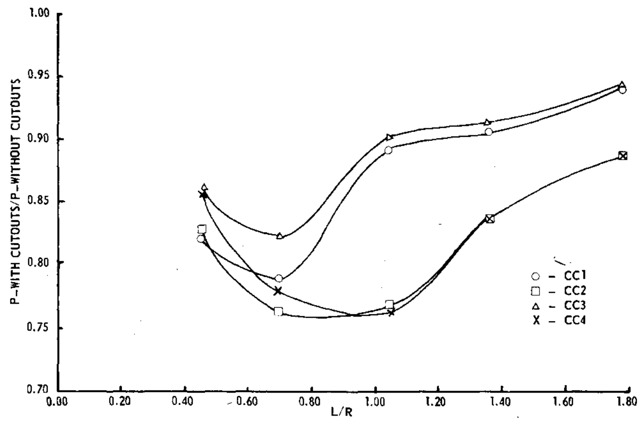

Fig. 4 Effect of cutouts on externally stiffened shells (clamped boundary conditions).

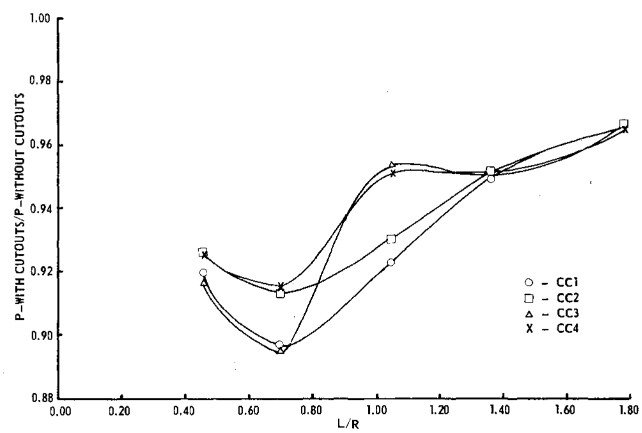

Fig. 5 Effect of cutouts on internally stiffened shells (clamped boundary conditions).

cases, the detrimental effects of the cutouts are minimized in longer shells.

Conclusions

From the analysis undertaken in this study, the following conclusions can be made.

1) Prebuckling deformations and stresses have a significant influence upon the analysis of stringer stiffened cylinders with Z less than 1000 [Batdorf parameter $= (1-\nu^2)^{1/2} (L^2/Rh)$]. The importance of a rigorous prebuckling solution is more apparent in cylinders with internal stringers.

2) If one considers all the simply supported and clamped cylinders with and without cutouts, the $u=0$ axial restraint is the most important factor in buckling of axially compressed cylinders with internal or external stringers. For small values of L/R, the $v=0$ condition gains importance in simply supported stiffened cylinders with and without cutouts.

3) In the studies of simply supported cylinders with and without cutouts, internally stiffened cylinders are more sensitive to in-plane boundary conditions than externally stiffened cylinders. However, for the clamped boundary conditions, cylinders with external stringers are more sensitive to in-plane boundary conditions than cylinders with internal stringers.

4) In general, the addition of two symmetrically placed cutouts, $2a=12$ in., does not significantly change a cylinder's sensitivity to in-plane edge restraints. However, for clamped cylinders with external stringers, the $u=0$ condition is more apparent in shells without cutouts than shells with cutouts.

5) Cutouts have a greater detrimental effect on externally stiffened cylinders than internally stiffened cylinders, irregardless of the simply supported or clamped boundary conditions. However, these detrimental effects diminish in cylinders with increasing values of L/R.

6) Considering shells with external stringers, the $u=0$ condition in SS2 and SS4 reduces the detrimental effects of cutouts over that of SS1 and SS3, whereas the $u=0$ free condition in CC1 and CC3 minimizes the weakening effect of cutouts in clamped cylinders.

7) For the shell geometry considered herein, the influence of cutouts with $2a=12$ in. on the critical loads of stringer stiffened cylinders is analogous to the effects that initial geometric imperfections have on theoretical loads of "perfect" cylinders.

8) Considering the shell and stringer geometry studied herein, cylinders with internal stringers and SS1 and SS3 boundary conditions have critical loads less than unstiffened cylinders of equivalent volume.

9) The advantages of external stringer stiffening over internal stringer stiffening are considerably more significant in simply supported cylinders than clamped cylinders, regardless of the cutouts.

10) The boundary conditions actually realized in experimental tests can be determined by correlating the experimental loads to the theoretical values for various boundary conditions. An agreement between results would then indicate the boundary conditions actually experienced in experimental tests.

11) Considering the detrimental effects of cutouts noticed in this study, reinforcing frames around the cutouts would be more effective in externally stiffened shells than shells with internal stiffening.

12) For all the simply supported and clamped boundary conditions, cutout reinforcement is needed on the externally stiffened shells considered herein. However, for internally stiffened shells, cutout reinforcement is only needed for values of L/R less than 1, where a greater payoff should occur in clamped cylinders.

References

[1]Rosen, A. and Singer, J., "Further Experimental Studies on the Buckling of Integrally Stiffened Cylindrical Shells," T.A.E. Rept. 207, Technion-Israel Institute of Technology, Haifa, Israel, Aug. 1975.

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[3]Weller, T., "Further Studies on the Effect of In-Plane Boundary Conditions on the Buckling of Stiffened Cylindrical Shells," T.A.E. Rept. 120, Technion-Israel Institute of Technology, Haifa, Israel, Aug. 1974.