Engineering Notes

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Collapse Analysis of Cylindrical Composite Panels with Cutouts

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Introduction

IN the aircraft industry, various studies have been conducted both experimentally and analytically[1-3] on the buckling of composite panels and plates under axial compression However, very little information on composite panels with cutouts can be found There have been studies done on cutout reinforcement in composite shells[4] and on flat rectangular graphite epoxy plates with either surface damage or cutouts [5,6] No studies were found relating the effect of cutouts on curved composite panels

A nonlinear analysis using the STAGS C 1 computer code has been used herein [7] In addition, a study has been made to evaluate the effect of ply layup with two cutout sizes and three different composite panel ply orientations

Modeling

Panel Properties

This study has modeled a graphite epoxy composite panel as shown in Fig 1 The ply orientations studied are listed on the top of Fig 2 A boundary condition has been assumed in which the top of the panel is clamped with only the u degree of freedom (DOF) free and the bottom of the panel is totally clamped with no free DOFs. The vertical sides of the panel are simply supported with u, v, and rotation about x free The panel is loaded into compression with a controlled distribution load N_x along the top edge The material properties of each ply are $E_1 = 20{,}500$ ksi, $E_2 = 1300$ ksi, $G_{12} = 750$ ksi, and $\nu_{12} = 0\ 335$

Grid Selection

The first panel modeled has a 2×2 in ^{2} opening located in the center of the panel There are two grid sizes (13 x 13 and 25 x 25) with constant spacing that will be used to model this panel The critical load for nonlinear collapse was computed for both grid sizes The coarser grid completed its collapse load calculations in only 20% of the CPU time of the finer grid Since both grid sizes were very close to each other in stiffness with only a 12 5% difference in the collapse load, the coarser grid size has been used, as the phenomenon of collapse is the important part of this study not the exact numerical comparisons

A compatability problem at the junction of elements will arise when modeling a curved panel with flat elements The 411 element (a rectangular 32 DOF element) in STAGS has been developed specifically so that the displacement compatability can be incorporated for flat elements meeting at a nonzero angle [7]

Discussion and Results

A graph of the top edge load vs the top edge displacement is shown in Fig 2 for the panels with and without cutouts When considering just the linear bifurcation of the panels, it can be seen that the presence of a cutout greatly reduces the load bearing capability of the panel and its stiffness The linear bifurcation of the panels shown in Fig 2 is for a $[0, +45, -45, 90]_s$ ply layup with the indicated cutout By changing the orientation of the 45 deg plies with each other, one did not find a change in the bifurcation load or top edge displacement However, their load bearing capability is reduced Because the axial stiffness is the same for the two panels, the plots of the top edge load vs the top-edge displacement overlay one another One notices that the $[90, +45, -45, 0]_s$ panels with the 2×2 in cutouts have the bifurcation load reduced to 81% of the $[0, +45, -45, 90]_s$ panels bifurcation load The 4×4 in cutout $[90, +45, -45, 0]_s$ panel had its bifurcation load lower than the $[0, +45, -45, 90]_s$ In other words, it can be seen from the linear bifurcation results that the different ply layup did not affect the axial stiffness of the panel However, the load bearing capability of the panel with the zero degree outside ply was greater

The panels with the three different ply layups and 2 in ^{2} cutouts all had the same top edge displacement of 0 0103 in at their respective collapse loads The nonlinear collapse load for the $[0, +45, -45, 90]_s$ panel was exactly the same as the $[0, -45, +45, 90]_s$ panel at a load of 215 9 lb/in The collapse load for the $[90, +45, -45, 0]_s$ panel was a little higher (3 4%) at 223 6 lb/in Since they are so close to one another, they are represented in Fig 2 as the same curve for the nonlinear analysis The zero degree outside ply panels had a collapse lower than the linear bifurcation load However, the panel with the 90 deg outside ply had a collapse load higher than its respective linear bifurcation

This item can be explained by considering the stiffness matrix for the panels and the effects a small cutout has on a nonlinear collapse analysis In the linear bifurcation, the panels had the same axial stiffness The panels with the zero degree outside plies have a greater bending stiffness and were able to withstand the higher load When the nonlinear collapse analysis was progressing, the radial displacements and the nonlinearity of the cutout started to come into play Since the load is applied in the zero degree direction (axial compression), the cutting of this ply orientation by the cutout produces a reduced bending stiffness Therefore, the panel with the zero degree outside plies allowed the panel to displace radially more than the panels with the 90 deg outside plies Taking this into account the panels with the 90 deg outside

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plies will have a higher collapse load Thus compared to the linear bifurcation analysis the load bearing capability for the 90 deg outside play panels will increase in the nonlinear collapse analysis This is the reason why the nonlinear collapse analysis of the 2×2 in cutout is very close to being the same for both ply orientations and why it falls in between the two linear bifurcations

The nonlinear collapse load of the 4×4 in cutout was higher than both of the indicated bifurcation loads This appears to be due to the fact that in the nonlinear collapse analysis the radial displacements along the cutout edges play a greater role in absorbing energy than in the 2×2 in cutout and the linear bifurcation of the 4×4 in cutout panel By having the larger cutout radial displacements along the cutout edges are less constrained in the radial direction and will allow a greater amount of bending Thus, the panel will be able to absorb more energy (higher collapse load) than the linear bifurcation value and will have a larger top edge displacement

The w component displacement contours of the panels with a 2×2 in cutout (small cutout) prior to or at the collapse load were given in Ref 8 A difference in the displacement pattern than that experienced by isotropic panels[2 4] was found; that

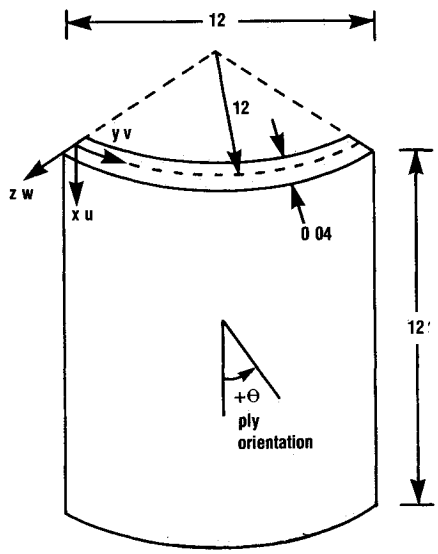

Fig 1 Panel notation

●[0, +45 −45, 90]$_S$ Panels
—[90 +45, −45 0]$_S$ Panel

Cutout Size	Ply Layup	Collapse Load	Linear Bifurcation
2X2	[0 +45 −45 90]$_S$	215 9	252 14
2X2	[0, −45, +45, 90]$_S$	215 9	252 14
2X2	[90 +45 −45 0]$_S$	223 6	205 0
4X4	[0 +45, −45 90]$_S$	131 2	113 2
4X4	[0, −45, +45, 90]$_S$	131 2	113 2
4X4	[90 +45 −45 0]$_S$		74 32

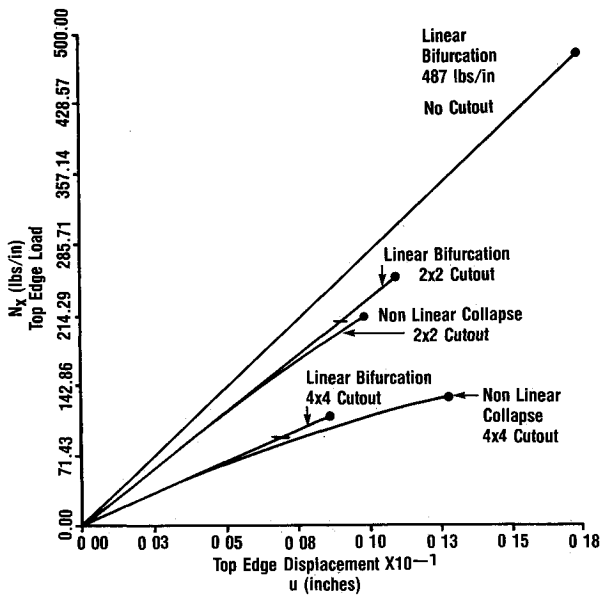

Fig 2 Top edge load vs top edge displacements

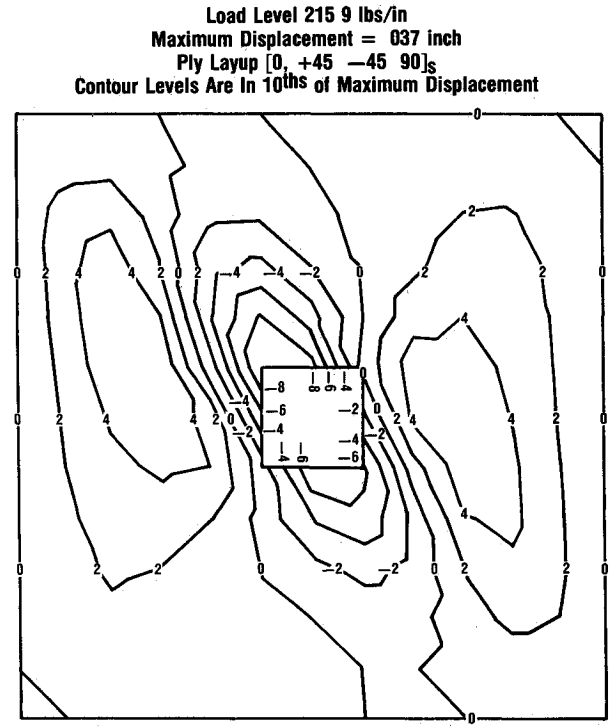

Fig 3 W component displacement contours 2 in cutout.

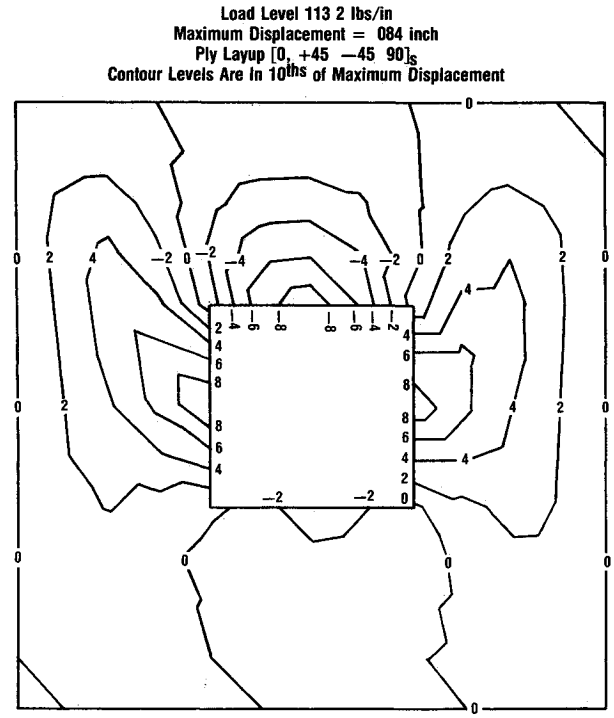

Fig 4 W component displacement contours 4 in cutout

is, at collapse the symmetry about the cutout is lost (see Fig 3). This loss of symmetry is due to the larger radial displacements, hence the larger moments With the greater radial displacements, the bending stiffness matrix (D matrix) has a greater effect Therefore, the D_{11} and D_{22} will have an effect on the displacement pattern A further review of the history of the displacement pattern and the plots of eigen vectors were given in Ref 8

Figure 4 shows the contours of the radial displacements at collapse load (131.2 lb/in) for the $[0, +45, -45, 90]_s$ panel The collapse displacement function for the $[0, -45, +45, 90]_s$ panel is the mirror image of that shown in Fig 4 It can be seen that with a 4 × 4 in cutout the displacement pattern at collapse is more symmetric about the circumferential and longitudinal axis than the panel with a 2 × 2 in cutout This is because the larger cutout produces the bending effects earlier and the moment change is more spread out; therefore, a more symmetric displacement pattern However, the slight amount of nonsymmetry shown at the center of the cutout's vertical edges can be seen to change sides when the ply layup is changed by switching the 45 deg plies The same phenomenon was experienced with the smaller cutouts The w component eigenvector contour plots of the 4×4 in cutout panels and the physical interpretation of results were contained in Ref 8

Conclusions

The following statements and conclusions are based on the analysis presented in this paper

1) Collapse characteristics of composite panels are depen dent on the ply layup and the size of the cutouts

2) The 2×2 cutouts (less than 5% of the panel surface area) have a displacement pattern at the collapse load that is different than the larger cutouts. The 2×2 cutouts displacement pattern build symmetrically about the cutout and at the collapse load, snap into the displacement pattern of the eigenvector. The 4×4 cutout had a displacement pattern that stayed fairly symmetric at collapse and was close to the isotropic collapse pattern

3) The load bearing capability of a composite panel is very sensitive to the presence and size of a cutout

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Flutter Characteristics of High Aspect Ratio Tailless Aircraft

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Introduction

ONE of the examples of high aspect ratio slender wing aircraft is sailplanes In the next context of their continuing development a tailless design study[1] at Cranfield has claimed an overall performance gain of 10% over con ventional types achieved mainly from reduction in the parasite drag Sailplanes, because of their high aspect ratios and slender wings, are prone to aeroelastic problems such as flutter, even at low speeds Furthermore the complexity increases in the absence of a tail when the damping in pitch becomes very low This makes the longitudinal dynamics of the aircraft a formidable problem because it involves an aerodynamic coupling of the rigid body motion with the elastic modes of distortion Using the basic data for the class of tailless sailplanes given in the design study[1] at Cranfield, this Note investigates such interactions from a selection of extracted results from Ref 2

The particular class of tailless sailplane under investigation is called the Ricochet[1,2] and a major section of results is compared with those of an existing class of tailed sailplane the Kestrel-22m Figure 1 and Table 1 together give the basic details of the two aircraft, whereas Fig 2 shows the structural and aerodynamic properties of their respective wings

Method of Analysis

The use of generalized coordinates in flutter analysis has been reported earlier by a number of authors [3-6] The same method involving normal modes is implemented herein to express mass, stiffness and aerodynamic matrices of the aircraft in terms of the generalized coordinates The finite element method[7] is used to obtain the mass stiffness matrix and the normal modes, whereas strip theory based on Theodorsen expressions[3] for unsteady airfoil motion is employed to form the aerodynamic matrix. The flutter matrix is formed by algebraically summing the generalized mass, stiffness, and aerodynamic matrices

The solution of the flutter determinant is a complex eigenvalue problem because the determinant is primarily a complex function of two unknown variables, the airspeed and the frequency The method used selects an airspeed and evaluates the real and imaginary parts of the flutter deter minant for a range of frequencies The process is repeated for a range of airspeeds until both the real and imaginary parts of the flutter determinant vanish completely Once the flutter speed and frequency are established, the corresponding vector, i e , the flutter mode is found in the classical way by deleting one row of, say, the nth order determinant and solving for $(n-1)$ of the coordinates in terms of the nth

Results of Computation

The first few wing modes in the symmetric motion obtained from PAFEC[7] analysis are shown for the Ricochet (four

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