Engineering Notes

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Shear Buckling of Composite Cylindrical Panels Considering Material Degradation

A.D. Straw* and A.N. Palazzotto†
Air Force Institute of Technology
Wright-Patterson Air Force Base, Ohio

Introduction

DUE to their excellent performance characteristics, advanced composite materials have been gaining wide use in aerospace structures. However, it is recognized that the absorption of moisture and exposure to thermal environments can have undesirable effects on the mechanical properties of polymeric matrix composites. Shirrell et al.[1] reported that, unless these effects are accounted for in designing a system, the service life and reliability of a polymeric matrix composite may be compromised. Moisture absorption affects the composite in several different ways. First, the resin swells, causing a change in the residual stresses of the composite and possibly microcrack formation. Second, the resin may be plasticized, thus causing an increase in the elongation of the resin near failure. This also has an affect on the damping of the material. This plasticization is the result of the lowering of the glass transition temperature T_g. Third, the interface between the fiber and resin may be affected, thus influencing the composite's strength and toughness. The fibers are not affected by either moisture absorption or moderate thermal environments that might be encountered during a normal aircraft service life. These changes in the resin have been found to result in a decrease in the tensile properties[2] and a reduction in the transverse and shear moduli[3-5] of the composite material. Also a slight increase in the longitudinal elastic modulus was reported in Ref. 3.

A numerical finite-element study was performed to evaluate the effects of moisture and temperature on the bifurcation loads of graphite/epoxy composite cylindrical panels subjected to a simple shear load. A square, cylindrical panel was chosen for this analysis to represent a skin panel found on an aircraft fuselage.

Predictions of Moisture Absorption

Fick's second law of diffusion[6] has been used for evaluating the moisture concentrations through the laminate at specific time values. The use of this relationship, as related to composite material, has been published in Refs. 7 and 8 and will not be shown here. It is suffice to say that the E_2 and G_{12} material parameters are assumed to vary, while E_1 and υ_{12} remain constant. The overall material variation is carried out for an AS4/3501 graphite/epoxy considering two moisture boundary conditions: one in which a given panel face has a 1.05% moisture concentration, while the other face has zero, and a second in which both faces have a 1.05% moisture concentration. These concentration values are referred to as C_1 and C_2 in subsequent figures. They represent the increase in weight due to moisture divided by the weight of dry material per unit volume. The effect of temperature is also included.

Finite-Element Model

The composite panel modeled consisted of eight plies. Each ply was assumed to be 0.005 in. thick, giving a total laminate thickness of 0.04 in. The panel had a radius, vertical length, and circumferential distance between supports of 12 in. Two ply orientations were examined, $[0/45/-45/90]_s$ and $[45/-45]_{2s}$. The finite-element model consisted of 324 elements and 361 nodes. The geometric boundary conditions are discussed fully in Ref. 8 and were selected to represent simple shear as related to a flat plate. The overall analysis was carried out using STAGS-C1,[9] including its prebuckling and bifurcation characteristics.

Results and Discussion

The evaluation of the data for a panel loaded in shear indicates that the degradation of the E_2 and G_{12} moduli due to moisture and temperature effects results in a reduction of the panel's bifurcation load N_{xy}. Figures 1 and 3 show the shear loading results of the STAGS-C1 runs, while Fig. 2 shows the results found by Snead and Palazotto[7] for a similar panel acting under compressive loads. In these plots, $\bar{N}_{xy_{\mathrm{orig}}}$ and $\bar{N}_{x_{\mathrm{orig}}}$ represents the bifurcation loads for a panel at 80°F and a dimensionless time of $t^*=0.00$ when loaded in shear and axial compression, respectively. (See Table 1.) These values are unaffected by either temperature or moisture degradations. Dimensionless time t^* in this study was varied (0.001–0.5). This is a variation of 0.35–176 days in real time.

As was expected, the panel's bifurcation load decreased with increasing temperature and absorbed moisture. Comparing Figs. 1 and 2, it can be observed that a similarity in trends occurs for the reduced bifurcation loads considering the $[45/-45]_{2s}$ laminate with the curves for the shear loading shifted above those for axial loading. For example, at a temperature of 300°F and moisture condition 2, the reduction for shear was 35%, while for axial compression it was 43%, a difference of 8%. If one were to look at the same phenomenon for the $[0/45-45/90]_s$ laminate (Fig. 3), it would be observed that the reduction for shear at 300°F is 25.6%, while from Ref. 6 the compression bifurcation load is reduced by 22% for the same moisture and temperature condition. This indicates, as expected, that the $[45/-45]_{2s}$ laminate is better suited to resist shear loads, while the $[0/45-45/90]_s$ laminate is more suited for resisting compressive loading. A point should be made that even though the percent reductions are similar, the actual values for the

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*Graduate Student, Department of Aeronautics and Astronautics.
†Professor, Department of Aeronautics and Astronautics. Associate Fellow AIAA.

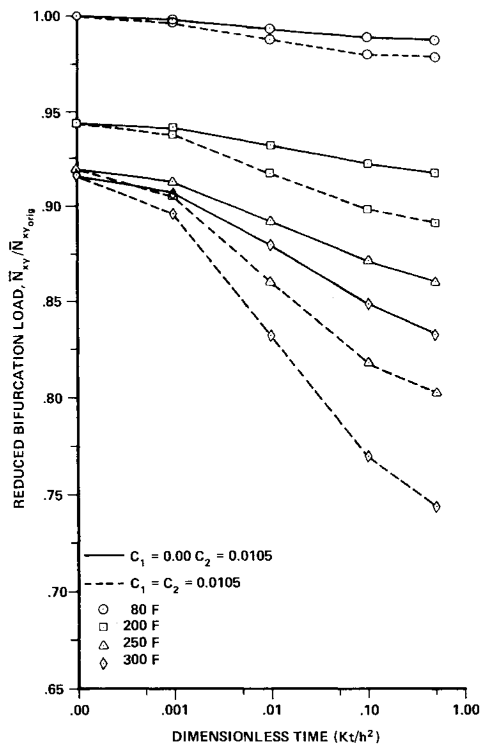

Fig. 1 Degradation in $\bar{N}_{xy}$ for the $[45/-45]_{2s}$ laminate.

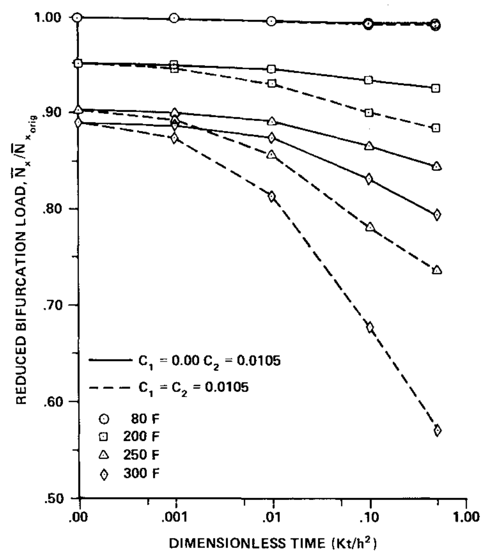

Fig. 2 Degradation in $\bar{N}_x$ for the $[45/-45]_{2s}$ laminate.

bifurcation loads differ considerably. See Table 1 for examples.

A similarity to Snead and Palazotto's[7] work is that for moisture condition 1 reduction in the bifurcation load $\bar{N}_{xy}$ was not as great as it was for moisture condition 2, even though moisture condition 1 causes the initially symmetric laminate to become unsymmetric, which introduces bending-extension coupling. The symmetric moisture condition 2 has a much greater influence on both laminates. This is due to an overall general reduction in the material properties as moisture is absorbed into the panel symmetrically.

Examination of the prebuckled displacements (not shown here)[10] indicate that as the moisture content and temperature increase the laminate becomes softer. This is illustrated by an increase in the prebuckled displacements as t^* increases and

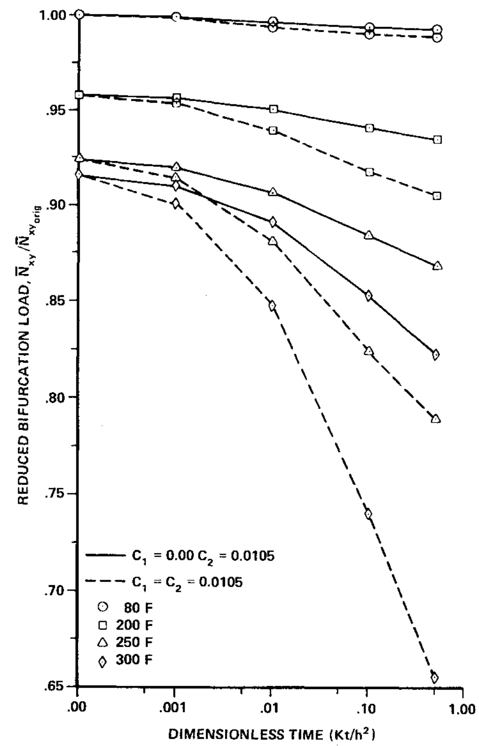

Fig. 3 Degradation in $\bar{N}_{xy}$ for the $[0/45/-45/90]_s$ laminate.

Table 1 Comparison of bifurcation loads, lb/in. at 80°F, $t^* = 0.0$

Laminate	Axial compression,[7] $\bar{N}_{x_{orig}}$	Shear, $\bar{N}_{xy_{orig}}$
$[0/45/-45/90]_s$	514.8	123.4
$[45/-45]_{2s}$	428.9	160.9

also as the temperature increases. This increase in displacement for a given initial load also indicates that the bifurcation load should decrease, since it will require a lower load to obtain the same prebuckled displacement.

Conclusions

The following conclusions can be made for cylindrical, graphite/epoxy panels subject to moisture exposure and elevated temperatures, when loaded in simple shear:

1) The bifurcation load of a composite panel, with a resin material whose elastic moduli are reduced by absorbed moisture and elevated temperature, will degrade with increasing moisture concentrations and temperatures.

2) The trend for the reduction in bifurcation load of a composite panel subjected to a simple shear load is comparable to that found for an axial compression load at a given radius.

3) The extent of the degradation in the bifurcation load is influenced by the moisture concentration, the temperature, and the panel's ply orientation. At 300°F, a radius of 12 in., and a symmetric moisture weight gain of 1.05%, the $[0/45/-45/90]_s$ panel experienced a 25.6% degradation and the $[45/-45]_{2s}$ panel a 34.5% degradation.

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Full-Potential Circular Wake Solution of a Twisted Rotor Blade in Hover

Hans R. Aggarwal*
Helicopter Aerodynamics and Noise
Mountain View, California

Introduction

An exact solution to the flow past a rotor blade is quite difficult because of the nonuniform, complicated flow in its vicinity. A few approximate solutions, employing both transonic small disturbance and full-potential aerodynamic theories with prescribed wakes, have been obtained in the past.[1-5] This Note uses a modified version of the full-potential code ROT22 and presents, employing a simple, circular wake, a solution for the transonic flow past a twisted rotor blade in hover. The flow is also evaluated for a fixed-wing-type straight wake, previously used in Ref. 1, and the results of the two calculations are compared. The results of the circular wake solution are also compared with those for a cambered section obtained on the basis of a general two-dimensional wake.[5] It is shown that the circular wake and the general two-dimensional wake solutions have similar characteristics.

Flow Equations and ROT22

Consider a helicopter hovering with a rotational speed ω. Let $O(x,y,z)$ be a (clockwise) orthogonal blade-fixed Cartesian coordinate system with the z axis running along the blade span and the x axis running parallel to a blade-section chord pointing towards the trailing edge. For a full-potential (nonconservative, irrotational, isentropic) quasisteady flow, the equations governing the flow in the blade-fixed (rotating) coordinate system, reduce to

$$(a^2-q_1^2)\phi_{xx}+(a^2-q_2^2)\phi_{yy}+(a^2-q_3^2)\phi_{zz}-2q_1q_2\phi_{xy}$$
$$-2q_2q_3\phi_{yz}-2q_3q_1\phi_{zx}+\omega^2(x\phi_x+z\phi_z)=0 \tag{1}$$

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*Senior Research Associate.

and the Bernoulli equation

$$\omega(z\phi_x-x\phi_z)+\tfrac{1}{2}(\phi_x^2+\phi_y^2+\phi_z^2)+[a^2/(\gamma-1)]=\text{const} \tag{2}$$

where a is the local speed of sound, ϕ the full-velocity potential, q_i, $(i=1,2,3)$, the x,y,z components of the local velocity vector q defined by

$$q_1=\phi_x+\omega z \qquad q_2=\phi_y \qquad q_3=\phi_z-\omega x \tag{3}$$

γ is the ratio of specific heats. Equation (2) relates the local speed of sound to the velocity potential. The equations are quasisteady in the sense that the time derivatives in the flow equations are ignored. To complete the formulation of the problem, several boundary conditions are necessary. On the blade surface, the flow is tangential and, therefore, requires that $q\cdot\nabla F(x,y,z)=0$, where $F(x,y,z)=0$ is the equation of the blade surface. To satisfy the Kutta condition, an inviscid wake, taken as a vortex sheet, is assumed to lie on a surface continued smoothly behind the trailing edge of the rotor. It is also assumed that the jump in velocity potential along the circular trajectory, traced by a given point on the trailing edge, remains constant during the flow; and the velocity-potential gradient vanishes at large distances from the rotor.

The code ROT22, originally adapted from Jameson's fixed-wing code FLO22,[6] was modified to allow for the variable twist of the rotor blade. The implementation of the circular wake requires locating the point on the trailing edge that last passed through a given point of the wake. If (r,θ) are the polar coordinates of a point P in the wake, referred to in the current position of the leading edge as the initial line, and (x_0,z_0) the Cartesian coordinates of the point P_0 on the trailing edge that was at P at some earlier time t, then the two sets of coordinates are related by the equations

$$x_0=r\sin(\theta+\omega t) \qquad z_0=r\cos(\theta+\omega t) \tag{4}$$

Equations (4), together with the equation of the trailing edge, uniquely determine the coordinates (x_0,z_0) in any given revolution of the blade. This root finding is achieved through a newly developed subroutine C wake. It may be remarked in passing that the subroutine C wake may be extended without any difficulty to noncircular trajectories corresponding to an advancing helicopter. The solution for a given tip Mach number (TMN) on any mesh is obtained iteratively until the maximum correction in the velocity potential is reduced to less than $1.0E-5$.

The model example considered is that of a 1/7th scale UH−1H NACA 0012 profile, single, straight, rotor with input parameters taken as blade outer radius, $R_0=1.045$ m; blade inner radius, $R_i=0.151$ m; and blade chord, $c=0.0762$ m. The twist along the rotor was assumed linear and given by the equation

$$\alpha=10(1-z/R_0) \tag{5}$$

prescribing a washout of 10 deg at the blade root. The fluid density ρ_0 of the undisturbed medium, assumed at 60°F, was taken as 1.225 kg/m.

Results and Discussion

Figure 1 exhibits the distribution of the local lift coefficient C_L defined by

$$C_L=\frac{2}{\rho_0\omega^2z^2c}\int(p_\ell-p_u)\,\mathrm{d}x \tag{6}$$

for TMN = 0.9 along the blade span, as predicted by the circular and straight wakes. In Eq. (6), p_ℓ and p_u are the lower and upper surface pressures, respectively, at span station z. Figure 1 shows that the effect of the curvature of the wake is