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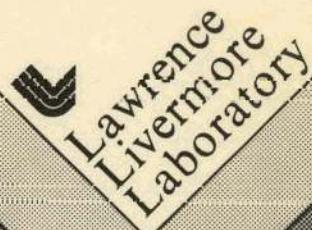
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BILAM[®] A COMPOSITE
LAMINATE FAILURE-ANALYSIS CODE
USING BILINEAR STRESS-STRAIN APPROXIMATIONS

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October 1980



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FOREWORD

This report has been prepared under Lawrence Livermore National Laboratory Subcontract No. 6448409, Mod. 1, with Villanova University. Work accomplished herein is part of the Flywheel Rotor and Containment Technology Task of the Mechanical Energy Storage Project. Professor P. V. McLaughlin, Jr., was the Principal Investigator and Dr. S. V. Kulkarni was the Lawrence Livermore Project Engineer.

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LIST OF SYMBOLS

A_{AA} , A_{TT} , A_{12} ,	Coefficients in quadratic interaction failure equation.
A_S , A_A , A_T	
[\bar{C}]	laminate effective stiffness matrix
E	Young's Modulus
G	Shear Modulus
ϵ	normal strain
γ	shear strain
σ	normal strain
τ	shear stress
ν	Poisson's Ratio

Subscripts

A	axial direction in layer
T	transverse direction in layer
AT	in-plane (axial) shear
x	load direction in laminate
y	transverse to load direction in laminate
I	pre-break-point
II	post-break-point

Superscripts

c	compressive failure
o	shear failure
t	tensile failure
C	in compression
T	in tension

1. INTRODUCTION

This report describes code BILAM which uses constant strain laminate analysis to generate in-plane load/deformation or stress/strain history of composite laminates to the point of laminate failure. The program uses bilinear stress-strain curves to model layer stress-strain behavior.

Efficient design of energy storage flywheels made from fiber composite materials requires ability to reliably predict stress-strain behavior and failure of the constituent material. Previous work performed under the MEST project to develop design data for use by flywheel designers^{1*} showed that linear elastic laminate analysis does not give an accurate quantitative prediction of laminate ultimate strength. This same study showed that use of a bilinear approximation to stress-strain behavior could increase predictive accuracy, especially for composites such as glass/epoxy having low-to-moderate stiffnesses.

Conventional laminate analysis algorithms usually assume linear, elastic material properties.² While this allows fairly accurate predictions of laminate elastic properties, attempts to use this method in conjunction with several different layer failure criteria to analytically predict laminate strengths have been less successful. Past analysis has shown that imperfect correlation exists between experimental results and linear elastic analytical predictions.¹ The discrepancy is attributed to several complex and interacting phenomena which cannot be modelled in a linear laminate analysis; e.g. laminate nonlinear behavior caused by in-plane layer shear nonlinearity, matrix-cracking/crazing, fiber-matrix debonding, fiber micro-buckling, etc. Figure 1 shows the effect of these phenomena on stress-strain behavior of typical, unidirectional, composite laminates. Figure 1 also illustrates the fact that a linear approximation of the stress-strain curve is inadequate to simulate unidirectional layer behavior over the entire loading range.

One solution is to perform an iterative, nonlinear analysis such as developed in ref. 6. While this analysis models the nonlinear behavior, the computing time involved is relatively large compared to linear elastic

*Superscripted numbers identify reference at the end of the report.

analyses. An alternative material modelling method which requires less computing time is to approximate the nonlinear stress-strain curves of Figure 1 with two linear segments. It not only economizes considerably on computing time (over an iterative solution technique); but, as demonstrated in Figure 2, should approximate the nonlinear curves sufficiently closely to provide enough accuracy for engineering purposes.

In this program the stress-strain curves are modelled as shown in Figure 2 by assuming linear response in axial tension while using bilinear approximations (2 linear segments) for stress-strain response to axial compressive, transverse tensile, transverse compressive and axial shear loadings. It should be noted that the program attempts to empirically simulate the effects of the phenomena which cause nonlinear stress-strain behavior, instead of mathematically modelling the micromechanics involved. This bilinear modelling should not be confused with previous modelling of bimodulus materials where compressive modulus is assumed to be different from the tensile modulus.¹¹

This code, therefore, performs a bilinear laminate analysis, and, in conjunction with several user-defined failure interaction criteria (described in Section 2.3), is designed to provide sequential information on all layer failures up to and including the first fiber failure. The modus operandi has been described in Section 2.4.

Code BILAM can be used to:

- (i) predict the load-deformation/stress-strain behavior of a composite laminate subjected to a given combination of in-plane loads.
- (ii) make analytical predictions of laminate strength.

2. THEORY

2.1 BEHAVIOR OF UNIDIRECTIONAL COMPOSITES

A typical unidirectional layer of fiber composite material under in-plane loads is shown in Figure 3. The layer will exhibit different stress-strain and failure behavior when it is in a laminate, and thereby provided with adjacent cross-ply support, than it will if tested separately. A discussion of the differences are provided here as background for the subsequent description of the unidirectional layer behavior modelled in the BILAM program.

2.1.1 Stress-Strain Response

Tests on single unidirectional layers or multi-layer unidirectional laminates typically exhibit the stress-strain response to failure shown in Figure 4. The following points are noteworthy:

Axial Tension: Most fiber-reinforced composites exhibit linear response to axial tensile loading. However, some low-strength fibers exhibit non-linearity when subjected to axial stresses because they fail at random locations, thereby setting up "ineffective zones", causing a cumulative weakening of the material. This has the effect of lowering the modulus^{4,5}.

Axial Compression: Stress-strain response is considerably nonlinear due to:

- (i) Nonlinear response of the matrix material to compressive loads.
- (ii) Micro-buckling of fibers, due to initial curvatures or misalignments, which set up small, local zones where the matrix has undergone either shear-dominated failure or inelastic deformation. The buckled regions have a smaller compressive modulus than intact regions, and the laminate modulus progressively decreases as the buckled zones spread throughout the specimen. Finally inelastic, unstable macro-buckling sets in³.

Transverse Tension: As shown in Figure 4, transverse tensile behavior is approximately linear until brittle failure occurs.

Transverse Compression: Transverse compressive loading causes highly nonlinear response due to:

- (i) Nonlinear inelastic deformation of the matrix material.
- (ii) Localized slippage and crazing at fiber-matrix interfaces due to local matrix shear failures.

Axial Shear: Axial shear loading causes nonlinear response due to:

- (i) Nonlinear and/or inelastic matrix material behavior.
- (ii) Localized debonding at the fiber matrix interface and matrix cracking parallel to the fiber direction.

It should be realized that many of these phenomena interact and are not independent of each other when combined axial, transverse, and shear stresses act at the same time.

Unidirectional layers, when acting in a multidirectional composite laminate, can exhibit different stress-strain response than when treated singly or in unidirectional laminates. Behavior under axial tensile, axial compressive, and transverse compressive loads is believed to be nearly the same as that of unconstrained layers or [0] laminates. However, there are some significant differences in the response to transverse tensile and axial shear loading:

Transverse Tension: Unlike the unconstrained layer response, the constrained layer behavior in a laminate is not linear. This is because the laminate, unlike the layer, does not fall apart at the occurrence of the first matrix crack. Instead, progressive loading continues to trigger a series of matrix cracks, parallel to fiber direction, which follow a statistical, spatial distribution in the laminate. None of these cracks can independently precipitate laminate failure, but they all contribute cumulatively to overall degradation of the laminate modulus by reducing the ability of the matrix to carry transverse stress and resist deformation in the transverse direction. This behavior is best illustrated by comparing the behavior of a [0/90] laminate tested to failure with predicted behavior from unidirectional layer tests. Typical laminate response to transverse tensile loading is shown in Figure 5a. Figure 5b shows the stress-strain curve of a $[0/\pm 90]_S$ laminate tested in tension in the 0 deg. direction. The initial tangent modulus represents laminate response with 90 deg. layers intact. The intermediate zone shows the modulus decay due to matrix cracks while the final portion represents ever-decreasing contributions from 90 deg. layers towards laminate stiffness.^{7, 8}

Axial Shear: Axial-Shear loading causes statistically distributed cracks in the matrix in a manner very similar to that in transverse tensile loading. Shear response of constrained layers in a laminate can be studied by loading

a $[+45]_S$ laminate in the 0 degree direction. Figure 6 shows a typical stress-strain curve. The initial tangent modulus represents response of the laminate with intact matrix. The zone of decreasing modulus represents increased occurrence of matrix cracks or debonded regions. Once the overall layer shear modulus has degenerated, the fibers tend to "scissor" under the load, causing large deformations under little increase in load until fibers re-orient significantly toward the direction of load. At this point, the fiber stiffness begins to contribute significantly to laminate stiffness, thus causing a rise in the modulus.⁹

2.1.2 Failure Behavior

An unconstrained unidirectional layer exhibits the following failure behavior (see Figure 4):

Axial Tension: This failure is a combination of statistical fiber failures (cumulative weakening) and adjacent fiber overstress failures which proceed until the remaining fibers are inadequate to sustain the applied load.

Axial Compression: Failure marks the stress/strain level at which inelastic, unstable macro-buckling of fibers or matrix shear/compressive failure sets in, and is a matrix-dominated phenomenon.

Transverse Tension: The transverse-tension failure is a matrix dominated phenomenon and occurs at very low stress levels since the layer fails, like a chain, on the "weakest link" principle. The first matrix crack will cause layer failure.

Transverse Compression: Failure represents a sufficient number of matrix cracks to enable large scale debonding at fiber-matrix interfaces, and is a statistical phenomenon.

Axial Shear: Failure is normally matrix debonding or matrix cracking parallel to fibers.

As mentioned earlier, it is failure behavior of layers acting together in a laminate that governs laminate failure. Therefore, this behavior needs careful consideration. Failure mechanisms and failure stresses under axial-tensile, axial-compressive and transverse-compressive loadings are nearly the same in a multidirectional laminate as when the layer is tested without angular ply constraint. Only transverse tensile and axial shear behavior are significantly different:

Transverse Tension: The failure level of the constrained layer in a laminate is significantly higher than that of the single layer. Layer failure

is no longer a matter of breaking the "weakest link" but of creating a pattern of large scale statistical cracking which eventually causes the layer to be completely ineffective in transverse tension. In a cross-ply laminate (Figure 5b), ultimate laminate failure does not occur until the 0 deg. layers fail. The 90 deg. layer cracks in transverse tension, but still contributes to laminate stiffness through constraint offered by uncracked portions of the layer. Therefore, the 90 deg. layer has not truly failed, and continues to provide laminate structural support until the 0 deg. layers fail, even though this support continually decreases with increased degree of cracking. As a result, "ultimate" failure of the constrained layer in transverse tension can be hypothesized to occur at very high strain levels.

Axial Shear: As in transverse tensile failure, axial shear failure is a matrix dominated phenomenon which represents the inability of the layer to contribute to the load-carrying capacity of the laminate because of extensive axial shear cracks in the fiber direction. As shown in Figure 6, the layers in angle ply laminates will hold out until very high strain levels have been reached, even though the matrix has long since cracked in many places. Therefore, as in transverse tension, it can be argued that the constrained layer does not "fail" (lose integrity) in shear until extremely high strain values are reached in the laminate.

2.2 BILINEAR MODELLING OF UNI-DIRECTIONAL LAYER (CONSTRAINED) PROPERTIES

As explained earlier, each layer is modelled as a bilinear elastic material. The significance of this scheme can be examined now in the light of the preceding discussion of unidirectional layer behavior when constrained in a laminate. Figures 1, 4, 5, and 6 together indicate that initial matrix-dominated failures will degrade the laminate properties significantly, without completely destroying or disabling the load-bearing capacity of the layer or the laminate. For the purposes of this analysis, these individual initial matrix failures are termed "non-disabling". When matrix failures have occurred in all layers, or fiber failure has occurred in one or more layers, the laminate is considered to have undergone a "disabling" failure (one which causes the laminate to lose its load bearing capacity). It is necessary, therefore, to continue the analysis beyond the first matrix-dominated layer failures, but with new layer elastic properties.⁷

Each bilinear stress-strain curve contains a transition point where the slope is discontinuous (see Fig 2). The transition point is termed for the purposes of this manual as a "break point". The break point, along with the ultimate failure levels and pre- and post-break point elastic properties, form the layer material property inputs to the program. The two

critical states, viz. the break point and failure, are defined in this analysis by specifying the stress levels and corresponding strain levels at which they are presumed to occur.

It is also noted that analytical predictions of the occurrence of break points or failures in a layer have to be made assuming some form of interaction between the failure modes, since the phenomena causing these failures are inter-related. Details of these interaction criteria are discussed in Section 2.3.

The output of the analysis is largely dependent on the proper selection of the inputs and particular attention is therefore required for determining these properties:

2.2.1 Stress-Strain Response

Axial Tension: As previously explained, response of a layer to axial loading does not change significantly when that layer is constrained in a laminate. Thus the stress-strain curve used to determine input properties is chosen to be the experimental stress-strain curve of the unidirectional layer. As mentioned already, this behavior is usually linear, but may, in some cases be slightly nonlinear.

The linear response is modelled by a single straight line whose slope E_A^T is same as the axial tensile modulus of the layer. Since there is no break point in this case, no prediction needs to be made in the analysis of occurrence of break points. This can be numerically ensured by inputting break point stress and strain levels, $[\sigma_{ABP}^T \quad \text{and } \epsilon_{ABP}^T]$ higher than failure stress and strain levels, $[\sigma_A^T \quad \text{and } \epsilon_A^T]$, i.e., $\sigma_{ABP}^T > \sigma_A^T$ and $\epsilon_{ABP}^T > \epsilon_A^T$.

If nonlinear behavior is assumed, bilinear modelling can be performed. The linear segments are selected to fit the experimental data as closely as possible. The intersection point of the two segments defines the break point. This break point does not necessarily have any physical significance.

The failure point is chosen as the coordinates of the actual failure point on the experimental stress-strain curve.

Axial Compression: In-plane response of a layer to axial compressive loading is nearly always nonlinear (Figure 2). Thus, the input bilinear curve is selected on the "best fit" principle from the compressive experimental stress-strain curve of the unidirectional layer. The selection

and interpretation of the break point and failure levels follow the same rationale as in modelling of non-linear response to axial tensile loading, with one exception: It is essential for proper operation of the program that the pre-break point moduli for axial loading be the same in tension and compression, i.e., $E_A^T = E_A^C$ before break point. This is not a serious limitation since composite compressive and tensile moduli are seldom significantly different, and the bilinear approximation will allow sufficiently accurate approximation when they are different. As explained in Section 4.1, built in overrides in the program always ensure that this condition is satisfied.

Transverse Tension: As previously explained, the response of the unconstrained, unidirectional layer to transverse tensile load is only indicative of the response of the layer in a laminate when no matrix failures have occurred. The constrained layer pre-break-point transverse tensile modulus, $E_{T_I}^T$, can be chosen as the transverse tensile modulus of the unconstrained layer. The input post-break point properties however, are determined from the response of the [0/90]_S cross-ply laminate (Fig 5b), in the following manner:

It is assumed that axial Poisson's ratio, ν_A , does not change after transverse matrix failures (see discussion below). As a result, all elastic post-break-point properties of the 0 deg. layer and the axial properties of the 90 deg. layer are known. It is also assumed that under all conditions $\nu_T = \nu_A E_T/E_A$ and this results in only one unknown property:

$E_{T_{II}}^T$: To determine $E_{T_{II}}^T$, two straight lines are used to fit the [0/90]_S tensile stress-strain test results in a manner which most accurately follows the data points. The layer break point strain is chosen as the laminate axial strain where the two lines intersect. The transverse tensile break point stress is then given by the product of break point strain and pre-break point modulus. Next, the layer post-break-point transverse modulus, $E_{T_{II}}^T$, is chosen by trial and error, using linear elastic laminate analysis, to give the [0/90]_S post-post-break point modulus $E_{x_{II}}$ resulting from the bilinear fit. A good first guess can be obtained from a volume fraction-weighted average of layer moduli approximation to laminate modulus, which results in $E_{T_{II}}^T \approx E_A^T - 2E_{x_{II}}$

where E_A^T is the axial tensile modulus of the unidirectional layer. Alternatively, from constant-strain laminate analysis theory, an equation can be derived for the Young's modulus of the post-break point [0/90] laminate, in

terms of known 0 deg. and 90 deg. elastic properties and the unknown E_{TII}^T . The post-break point transverse modulus can then be determined from this equation and the [0/90] experimental data.

It is noted that the transverse tensile break point stress for a constrained [90] layer is normally found to be significantly higher than the transverse tensile failure stress in an unconstrained layer. An analysis¹² of AS-1002 S2-glass epoxy material for which there is complete [0] and [0/90] experimental data,¹⁶ has shown that the break point stress is nearly three times the unconstrained unidirectional transverse tensile failure stress.

As previously discussed, the damaged layer will play an increasingly passive role for further loading, contributing less and less stiffness in the transverse direction. In the program, therefore, it may be meaningless to predict a separate ultimate failure in transverse tension in this layer. Transverse failure can be prevented by inputting very high failure stress and strain levels (several orders of magnitude higher than the break point level).

Transverse Compression: The input parameters for transverse compressive stress can be generated from the experimental stress-strain response of the unidirectional layer subjected to transverse compressive loads in the fashion previously described for axial compressive loading. Using the same procedure as for axial property determination, built in overrides in the program force the pre-break point transverse moduli to be equal in tension and compression, i.e., $E_{TI}^T = E_{TI}^C$.

Axial Shear: As in the case of transverse tensile loading, the response to axial shear loading is not the same in constrained and unconstrained layers. Data is therefore required from layers constrained in a laminate. A strain gaged $[+45]_S$ angle-ply laminate in tension is suggested. The shear stress-shear strain curve can be readily determined from such a specimen, and will resemble the curve of Fig. 7. Thus, the problem reduces to one of selecting two best-fit lines to the data and determining break point and post-break point modulus as shown in Fig. 7. For this laminate, the break point signifies onset of large scale matrix cracking. The layer failure stresses and strains can be computed from the failure values from the experimental shear stress-strain curve of the $[+45]_S$ laminate, although as with transverse tensile failure, they

have little physical significance.

Axial Poisson's Ratio: The pre-break-point axial Poisson's ratio (ν_A)_I of a constrained layer is modelled to be equal to the axial Poisson's ratio of an unconstrained, intact, unidirectional layer. The program has provisions for inputting different axial Poisson's ratios after each of the following break points have been reached in a layer:

<u>BREAK POINT MODE</u>	<u>SUBSEQUENT POISSON'S RATIO</u>
Axial compression	ν_{AII}
Shear and/or transverse tension	ν_{AIII}
Transverse compression	ν_{AIV}
Quadratic interaction (discussed in Section 2.3)	ν_{Av}

However, since the transverse modulus beyond the break point in transverse tension and axial shear is of the order of zero, effect of ν_A past break point under these stresses on laminate behavior will be negligible. This has been numerically verified for [0/90]_S laminates using a linear laminate analysis code. Thus, for transverse tensile and shear loadings, the axial Poisson's ratio need not be altered to simulate post-break-point behavior. The effects of changing axial Poisson's ratio beyond compressive break points have not been investigated.

Transverse Poisson's Ratio (ν_T): This is not an input parameter and therefore need not be modelled by the user. ν_T is computed within the program from the following symmetry relation: $E_A/\nu_A = E_T/\nu_T$. This ensures a symmetric stiffness matrix [\bar{C}] for the laminate; which is important for ease of numerical manipulations of the matrix. As the layer properties keep changing with the occurrence of break points, ν_T is continually updated to maintain the symmetry of the layer and laminate stiffness matrices.

2.3. FAILURE INTERACTION

Predictions of failure and break point occurrences are based on several interaction criteria presented below:

Maximum strain: Failure is assumed to occur when axial normal, transverse normal, or axial shear strains reach critical values in tension or compression, resulting in the following equations:

$$\epsilon_A^t, \text{ or } -\epsilon_A^c = \frac{\sigma_A}{E_A} - \frac{\nu_T}{E_T} \sigma_T$$

$$\epsilon_T^t, \text{ or } -\epsilon_T^c = \frac{\sigma_T}{E_T} - \frac{\nu_A}{E_A} \sigma_A \quad (1 a,b,c)$$

$$\gamma_{AT}^o = \tau_{AT}/G_{AT}$$

where σ is normal stress, τ is shear stress, ϵ is normal strain, γ is shear strain, E is Young's modulus, ν is Poisson's ratio, G is shearing modulus, A is axial (fiber) direction, T is transverse to fiber direction, superscripts t and c indicate failure in tension and compression, respectively, and superscript o indicates failure in shear. The maximum strain failure criterion is shown in Figure 8a for $\tau_{AT} = 0$.

Quadratic interaction: Several researchers⁽¹²⁻¹⁵⁾ have proposed stress polynomial failure criteria which account for unequal properties in tension and compression as well as complicated interaction effects. The simplest of these is a quadratic interaction equation, which, when satisfied, predicts failure:

$$A_{AA} \frac{\sigma_A^2}{A} + A_{TT} \frac{\sigma_T^2}{T} + A_{12} \frac{\sigma_A \sigma_T}{AT} + A_S \frac{\tau_{AT}^2}{G_{AT}} + A_A \frac{\sigma_A}{E_A} + A_T \frac{\sigma_T}{E_T} = 1 \quad (2a)$$

The A 's are constants which depend upon failure stresses in uniaxial and combined stress states. Of the six constants, only A_{AT} (called the quadratic interaction coefficient) requires a layer failure test under combined σ_A and σ_T stress. The rest can be determined from uniaxial data. In the present study, since combined stress data were unavailable, the default quadratic interaction coefficient was assumed to be:

$$A_{12} = -\frac{1}{\sigma_A^c \sigma_T^c} \quad (2b)$$

where σ^c are failure stresses in compression. This assumption agrees reasonably well with experimentally determined interaction coefficients reported in reference 14. The user, however, has the option of inputting any desired value for A_{12} . A typical quadratic failure criterion is shown for $\tau_{AT} = 0$ in Figure 8c.

Maximum stress: Failure is assumed to occur when axial normal, transverse normal, or axial shear stresses reach critical values in tension or compression:

$$\sigma_A = \sigma_A^t - \sigma_A^c$$

$$\sigma_T = \sigma_T^t - \sigma_T^c \quad (3)$$

$$\tau_{AT} = \pm \tau_{AT}^o$$

where τ_{AT}^o is the failure stress in axial shear, and σ^t and σ^c are failure stresses in tension and compression, respectively. The maximum stress failure criterion is shown in Figure 8b for $\tau_{AT} = 0$.

2.4. STRESS-STRAIN AND FAILURE CALCULATIONS WITH BILAM

2.4.1. General Operation

The code initially applies unit loads to the laminate and checks all layers in all modes for occurrence of break point stresses/strains. Once a layer has reached break point in shear and/or transverse tension, axial compression, or transverse compression, the relevant properties of that layer are degraded to post-break-point values. The algorithm then recalculates the stiffness matrix of that layer with the new properties and arrives at a new laminate stiffness matrix. The increment in applied load that will cause the next occurrence of break point is determined. The resulting incremental stresses and strains are added to the initial stresses and strains (at which the first break point occurred) to get the total stresses and strains at the second break point. This stepwise elastic stress-strain computation procedure continues until the occurrence of the first disabling fiber failure. First fiber failure has been shown to be upper bound to laminate failure^{1, 17} and the computations are terminated at this point. Several status messages are also provided as an aid for the user to monitor the state of the laminate:

- (a) The program indicates when all layers have reached "break-point" in shear and/or transverse tension (or in the case of quadratic interaction--when all layers have reached break point). This could provide an effective guide to predict the onset of large-scale delaminations in the laminate.
- (b) The first fiber failure not only terminates the computations but also

triggers a status message declaring the fiber failure.

(c) If the user wishes to determine the state of the laminate at some pre-determined level of applied external stress, he can choose the option to have a status message along with the stresses and strains in the laminate printed when this external stress is reached.

The overall operation of the program is shown schematically in Fig. 9. Appendices 9.1 and 9.2 give a program listing, sample cases, and detailed flowcharts.

2.4.2. Break Point Interactions

Occurrence of break points is assumed to occur according to certain interactions between the stresses or strains in different modes. The user has the option of selecting any of the three interaction criteria, maximum stress, maximum strain or quadratic, detailed in Section 2.3. In the program, this check is referred to as a Break Point Analysis. There is another automatic interaction modelled within the program, i.e., occurrence of a transverse tension break point is assumed to automatically trigger a shear break point and vice-versa. This is because the physical phenomena resulting from these break points are identical.

2.4.3. Failure Interactions

Occurrence of ultimate layer failure is checked assuming the same three user defined interaction criteria used in the break point analysis.

NOTE: The user's options on selection of interaction criteria have been discussed in detail in Section 4.3.

2.5 CONCLUSIONS

It is reiterated at this stage that no effort has been made in this analysis to directly model the micro-mechanics of composite failure with the exception of the automatic occurrence of axial shear and transverse tension break points. Instead, the effects of these phenomena are simulated by controlling layer macroscopic stress-strain and failure properties appropriately. Unlike conventional laminate analysis, this code draws its input data not only from unidirectional laminate behavior, but also from response of $[0/90]_S$ and $[+45]_S$ laminates. The user has been given the maximum possible flexibility of selecting material input properties and interaction criteria, to simulate, as closely as possible, the actual physical interactions in combined stress fields. These choices can become particularly powerful when performing a quadratic interaction analysis. Variations in the interaction

coefficient A_{12} have been found to alter the final predictions of laminate behavior. The accuracy of the analysis is therefore largely dependent on the accuracy of the inputs. For a more complete discussion of this topic, see ref. 10.

Appendix 9.3 presents a comparison of BILAM failure predictions with linear elastic laminate analysis predictions and results of tensile tests of several graphite/epoxy and S2-glass/epoxy laminates. This comparison shows that BILAM analysis provides consistently better qualitative and quantitative agreement with experiment than linear elastic laminate analysis. However, since BILAM only considers in-plane effects (as also does linear elastic laminate analysis), stacking sequence effects are not treated. There is strong evidence (see Appendix 9.3) that these phenomena contribute significantly to laminate failure.

3. PROGRAM CHARACTERISTICS

3.1. TYPE

This is an independent and self-sufficient program. In its present form it cannot be called as a subroutine by any other program, nor does it call any standard, library subroutines. It consists of a main program and twenty subroutines with a maximum of four levels in the program organization, as shown in Figure 10. Date storage is accomplished in twenty common blocks and eight dimension statements as shown in Table 1.

3.2. SOURCE LANGUAGE

Fortran IV

3.3. SYSTEM REQUIRED

This program was written for the IBM VM/370 System, and is designed to run on either of the following compilers:

- (i) WATFIV
- (ii) FORTRAN-F
- (iii) FORTRAN-G

There are no interactive features. It can be run either on-line or batch-mode, from a terminal/card-reader. The output is designed for a logical record length of 132 characters and can be either printed on any standard printer or deprinted on the terminal.

3.4. MISCELLANEOUS

3.4.1. J. C. L.

No J. C. L. statements are included with the program since these are system-dependent. The user must supply the necessary statements according to his requirements.

3.4.2. Storage

The storage requirements are approximately 45,500 Bytes for the dimensional constraints specified in Section 6.1. The object code needs approximately 35,800 Bytes while the rest is taken up for Array allocation.

3.4.3. Running Time

Running time estimates (on IBM 370/VM) are:

- (i) Compilation (a) WATFIV: 5.5 secs.
(b) FORTRAN-C: 4.1 secs.
- (ii) Execution: Approximately 0.6 secs. per loadset per type of analysis.

4. DESCRIPTION OF INPUT

All inputs are format-free and accomplished with NAMELIST commands. Listings of sample inputs are enclosed with this manual (ref. Appendix 9.1). Input arrays/variables are discussed below, by class.

4.1. CLASS ELASTD

Read in subroutine DATA 1. Contains material elastic properties for each layer.

AXE (K, I, L) : Axial Young's Modulus (force/unit area)
TRANE (K, I, L) : Transverse Young's Modulus
G (K, I, L) : Axial Shear Modulus
AXNU (K, I, L) : Axial Poisson's Ratio
SUBSCRIPT K : Material no. (maximum 10)
SUBSCRIPT I : 1 for tension
 2 for compression
SUBSCRIPT L : 1 for pre-break-point properties
 (n+1) for properties after n^{th} break point
 (See Section 2.3 for explanation of break point)
NLAMM : Total number of laminates to be analyzed
 (no limit)
NMATL : Total number of constituent materials
 (maximum 10)

It is noted that the program cannot accomodate different properties in tension and compression for:

- (i) AXE and TRANE before break point
- (ii) G and AXNU at any stage

Statements 4 through 11 of subroutine DATA 1 ensure that the above conditions are never violated. Hence it is not necessary for the user to input:

- (i) pre-break-point compressive values for AXE and TRANE
- (ii) any compressive values for G and AXNU

4.2. CLASS CRITIC

Read in subroutine DATA 2. Contains critical (viz. break point and ultimate) stresses and strains for each layer.

CRITS (J, I, K, L) : Critical stress

CRITE (J, I, K, L) : Critical strain
 SUBSCRIPT J : 1 for axial
 2 for transverse
 3 for shear
 SUBSCRIPT I : 1 for tension
 2 for compression
 SUBSCRIPT K : Material number (maximum 10)
 SUBSCRIPT L : 1 for values at break point
 2 for values at failure

As in subroutine DATA 1, statements 2 through 5 ensure that critical values are same for positive and negative shear. The user need not, therefore, input the critical values for negative shear loading.

NOTE: The user may, for his reference, choose to incorporate negative signs for critical values in compressive loading. The option rests with the user, since the program is designed to operate independently of the input sign. However, the input sign is included in the echo-print of Section 5.2.

4.3. CLASS OPT 1

Read in subroutine LAMANS. Contains three variables to the following user-controller options:

NLOADS : Total Number of load sets for analysis (maximum 16)
 NSTRES (J): Gives the option of printing out the layer stresses and strains at an input level of applied external load.
 = 1 for exercising the option.
 = 0 (by default) to bypass this print-out option.
 SUBSCRIPT J: Load set serial number (maximum = NLOADS)
 NANS : Total types of analyses required for each load-set (maximum 9).
 As indicated in Section 2.3, the user can select all possible combinations of the three available failure criteria for "break-point" analysis and failure analysis. Thus, there will be a total of nine optional types of analyses possible, as shown below:

<u>ANALYSIS NO.</u>	<u>CRITERION FOR BREAK-POINT ANALYSIS</u>	<u>CRITERION FOR FAILURE ANALYSIS</u>
1	Maximum stress	Maximum stress
2	Maximum strain	Maximum strain
3	Quadratic interaction	Quadratic interaction

4	Maximum stress	Maximum strain
5	Maximum stress	Quadratic interaction
6	Maximum strain	Maximum stress
7	Maximum strain	Quadratic interaction
8	Quadratic interaction	Maximum stress
9	Quadratic interaction	Maximum strain

If no value is input for NANS, the program defaults to the first three types of analyses listed above.

A12 (K, L) : Quadratic interaction coefficient (reference Section 2.1.3).
If no value is input, it defaults to the value described in Section 7.2.

SUBSCRIPT K : Material number (maximum 10)

SUBSCRIPT L : 1 for coefficient at break point
2 for coefficient at failure

4.4. CLASS LOAD

Read in subroutine LAMANS. Contains the different load sets (totalling NLOADS) acting on the laminate.

ALOAD (I, J) : Positive for tensile load.

Negative for compressive (or tensorially negative shear) load.
Zero (by default) is there is no load.
If the layer stresses and strains are required to be printed at any predetermined level of external applied stress,
ALOAD (I, J) must be equal to this applied stress level.

SUBSCRIPT (I) : 1 for axial load
2 for transverse load
3 for shear load

SUBSCRIPT (J) : load set serial number (maximum = NLOADS)

4.5. CLASS OPTION

Read in subroutine LAMANS. Called only if user has exercised his option to define the types of analyses required (i.e. if he has input a non-zero value for NANS in OPT1. Reference Section 4.3 for detailed discussion, including default. Also see Section 7.1). Sets the sentinel ISENT for user-defined modes of "break-point"/failure analysis, viz. by maximum stress criterion, maximum strain criterion, or quadratic stress-interaction criterion (reference Section 2.1 for explanation).

ISENT (J, K) : 1 for maximum stress criterion
 2 for maximum strain criterion
 3 for quadratic interaction criterion

SUBSCRIPT J : Analysis number (Maximum = NANS)

SUBSCRIPT K : 1 for "break-point" analysis (see Section 2.3)
 2 for failure analysis (see Section 2.3)

NOTE: 1. If the user has exercised his option to select the type of analysis (i.e. if he has input a non-zero value for NANS), then it is essential to input a value of ISENT (J, K) for all J and all K.
2. Same ISENT values will hold for every load set and every laminate input for a given run.

4.6. CLASS GEOMED

Read in subroutine GEOMET. Contains laminate geometry.

NLAY : Total number of layers in the laminate (maximum 24)

IMATL (I) : Material number for I^{th} layer. User has option of using any material in any layer

ALPHA (I) : Orientation of I^{th} layer (degrees)

DELTA (I)* : Thickness of I^{th} layer

SUBSCRIPT I : Layer number (maximum = NLAY)

NOTE: GEOMED must be repeated NLAMM number of times.

*To generate stress-strain curve instead of load-deformation curve, ensure that $\sum_{i=1}^{NLAY} \text{DELTA}(I) = 1$.

4.7. SAMPLE INPUTS

Sample inputs are presented in Appendix 9.1.

5. DESCRIPTION OF OUTPUT

5.1. MATERIAL ELASTIC PROPERTIES

Echo-print of all input values in ELASTD. Printed in DATA1.

5.2. BREAK POINT AND ULTIMATE STRESSES AND STRAINS

Echo-print of input values in CRITIC. Printed in DATA2.

5.3. LAMINATE SERIAL NO. AND GEOMETRY

Echo-print of input values in GEOMED. Printed in GEOMET and LAMANS.

5.4. LAMINATE LOAD

Echo-print of applied forces/length input in LOAD. Printed in LAMANS.

5.5. ANALYSIS TYPE

Echo-print of the input/default ISENT values. Printed in LAMANS.

5.6. LAMINATE TANGENT STIFFNESS MATRIX

Weighted sum of individual layer stiffness matrices (weight factor being the layer thicknesses). Recalculated at every break point, it gives the local tangent stiffness matrix of the laminate. Printed in LAMSTF.

5.7. LAMINATE TANGENT ELASTIC MODULI AND POISSON'S RATIOS

Calculated at every break point from laminate tangent stiffness matrix. Printed in LAMSTF.

5.8. APPLIED FORCES/LENGTH

The external applied forces/length (in laminate coordinates) at break point/failure level, are printed in BREAK/FAIL.

5.9. LAMINATE TOTAL STRAINS

The cumulative laminate strains in laminate coordinates are printed in BREAK/FAIL.

5.10. LAYER STRESSES IN LAMINATE COORDINATES

Cumulative layer stresses in laminate coordinates are printed in BREAK/FAIL.

5.11. LAYER STRESSES AND STRAINS IN LAYER COORDINATES

Cumulative stresses and strains in the layer at i^{th} break point/failure and at the prescribed level of applied external stress, are printed in BREAK/FAIL.

5.12. STATUS MESSAGES

- (i) Message predicting i^{th} break point/failure, and containing information on:
 - (a) which layers have reached break point/failure, and
 - (b) in what mode.

- (ii) Message indicating that the applied load has reached the prescribed input level.
- (iii) Message indicating when all layers have reached shear and/or transverse tension break point.
- (iv) Message indicating first fiber failure.

5.13. LEGEND

- (i) Explanation of analysis-type numbering, i.e.

1 = maximum stress criterion

2 = maximum strain criterion

3 = quadratic interaction criterion

- (ii) Explanation of mode numbering, i.e.

1 = axial

2 = transverse

3 = shear

5.14. SAMPLE OUTPUTS

Sample outputs are enclosed in appendix 9.1..

6. RESTRICTIONS

6.1. DIMENSIONAL RESTRICTIONS

- (i) Number of materials : 10
- (ii) Number of layers in a laminate : 24
- (iii) Number of load sets : 16
- (iv) Number of analyses/load set : 9
- (v) Number of laminates/run : No limit

6.2. TYPES OF LOADS

This program cannot handle flexural or thermal loads. Only plane stress problems can be analyzed. Therefore, this program cannot be used to analyze non-symmetric laminates since there is no flexural coupling in the program. It is noted that, as a result, computational time and storage space can be reduced when analyzing symmetric laminates by performing an analysis on only one half of the laminate. Since only in-plane stresses and deformations are treated, no flexural deformations are allowed to occur. Therefore, analyzing the total symmetric laminate provides redundant information.

This program can only be used to study laminate behavior under monotonic increasing proportional loading.

6.3. MATERIAL PROPERTIES

Material elastic properties prior to break point are required to be identical in tension and compression. Axial Poisson ratio and shear modulus must be equal in tension and compression both before and after the break point. The program is designed so that input tension values will be used in the above situations for stiffness and stress-strain calculations.

7. OPTIONS AND DEFAULTS

This section summarizes information in user-controlled options, and respective defaults presented in Section 4.

7.1. TYPES OF ANALYSES

The user can select any (or all) possible combinations of the three available failure criteria to check the occurrence of break points and/or failures, viz.

- (i) Maximum stress criterion
- (ii) Maximum strain criterion
- (iii) Quadratic stress-interaction criterion

See Section 2.1 for explanation. The user exercises this option by assigning any desired non-zero value for NANS in OPT1 (reference Section 4.3), and by making an appropriate selection of ISENT values in OPTION, as shown below:

CRITERION	ISENT
Maximum stress	1
Maximum strain	2
Quadratic interaction	3

NOTE: Non-zero ISENT values MUST be input if NANS \neq 0. If NANS = 0 (either by input or by default), the following default analyses will be performed:

ANALYSIS SERIAL NO.	BREAK-POINT ANALYSIS		FAILURE ANALYSIS	
	CRITERION	ISENT VALUE	CRITERION	ISENT VALUE
1	Maximum Strain	ISENT (1, 1) = 1	Maximum Strain	ISENT (1, 2) = 1
2	Maximum Stress	ISENT (2, 1) = 2	Maximum Stress	ISENT (2, 2) = 2
3	Quadratic Interaction	ISENT (3, 1) = 3	Quadratic Interaction	ISENT (3, 2) = 3

7.2. QUADRATIC INTERACTION COEFFICIENT

A_{12} values can be selected by the user in OPT1. In case no value is input, the program defaults to the following value

$$A_{12} = -\frac{1}{\sigma_A^c \sigma_T^c}$$

7.3. INPUT LOADS

If no value is input for ALOAD in LOAD, the program reads it as zero (no load) by default.

7.4. PREDETERMINED APPLIED STRESS LEVEL

The user can opt to have the state of the laminate viz. the stresses and strains in each layer and the local tangent stiffness matrix of the laminate, printed in any desired level of applied stress. This is done by assigning the value 1 to NSTRES in OPT1, and inputting the appropriate stress level ALOAD in LOAD. If no value is entered for NSTRES, the program skips this optional printout.

8. REFERENCES

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Table 1. Data Storage Allocation

<u>LOCATION & VARIABLE/ARRAY</u>	<u>ACCESSED IN SUBROUTINES</u>
1. COMMON/LOC 1/AXE, TRANE, AXNU, G	STIFF, DATA1
2. COMMON/LOC 2/A11, A22, A44, B1, B2, A12	QDRCFS, QRAT
3. COMMON/LOC 3/CRITE, CRITS	DATA2, QDRCFS, RAT
4. COMMON/LOC 4/NLAY, IMATL, ALPHA	GEOMET, LAYSTF, STIFF, LAMSTF, STRESS, RAT, QRAT, FABIG, BRBIG, FAIL, BREAK, LAMANS, APLOAD
5. COMMON/LOC 5/ALOAD, NLOADS, IEL, ELOAD, NSTRES	LAMANS, STRESS, APLOAD, BREAK, FAIL
6. COMMON/LOC 6/BEPS, BSIG, EPSLAY, SIGLAY, EPSLAM, T	STRESS, LAMANS, RAT, FAIL, BREAK, QRAT, APLOAD
7. COMMON/LOC 7/ISENT, IBREAK	LAMANS, RATIO, LAYSTF, BREAK, RAT
8. COMMON/LOC 8/A12	QRAT, QDRGFS, LAMANS
9. COMMON/LOC 9/DELTA	GEOMET, LAMSTF
10. COMMON/LOC 10/IQB, MB1, KB1, ILM	LAYSTF, BREAK, RATIO
11. COMMON/LOC 11/LI, IL, F	STIFF, LAYSTF
12. COMMON/LOC 12/S1	LAMSTF, LAYSTF
13. COMMON/LOC 13/TS, TE, ALPHAR, C3, CALPHA SALPHA	STIFF, TFORM, STRESS, BREAK, FAIL, APLOAD
14. COMMON/LOC 14/SBAR	STIFF, LAMSTF
15. COMMON/LOC 15/FBAR	LAMSTF, LAMPRT, STRESS
16. COMMON/LOC 16/BRATIO, FRATIO	RATIO, RAT, BRBIG, QRAT, LAMANS, FABIG, BREAK, LAYSTF
17. COMMON/LOC 17/DENOM	QRAT, BREAK
18. COMMON/LOC 18/ MF, KF, FBIG, FBIGP, MF1, KF1, IQF	RATIO, FABIG, FAIL
19. COMMON/LOC 19/ MB, KB, BBIG, BEST, BBIGP	RATIO, BRBIG, BREAK
20. COMMON/LOC 20/ALOADB, ALOADF, CELAMB, CELAMF, GSIG	LAMANS, FAIL, BREAK, APLOAD
<u>LOCATION & VARIABLE/ARRAY</u>	<u>ACCESSED IN SUBROUTINES</u>
21. DIMENSION A, B	MATINV
22. DIMENSION X, Y, Z	MXMULT
23. DIMENSION EPSLAM, SLAY, T	STRESS
24. DIMENSION S	LAYSTF
25. DIMENSION QRATIO	QRAT
26. DIMENSION XRATIO	RAT
27. DIMENSION FSIG, FEPS	FAIL
28. DIMENSION TRANU	STIFF
29. DIMENSION APLODB, CAPLAM, APEPS, APSIG	APLOAD

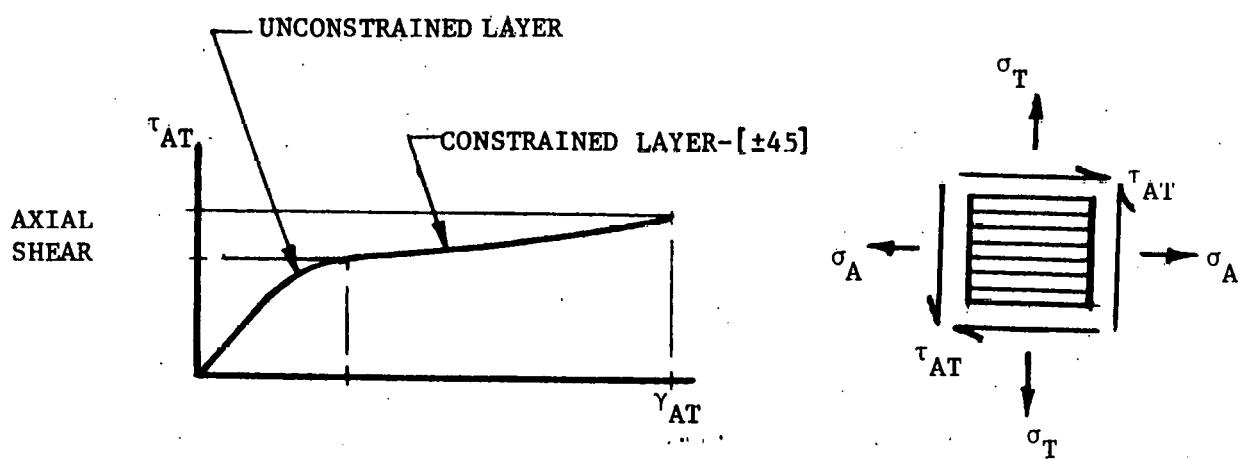
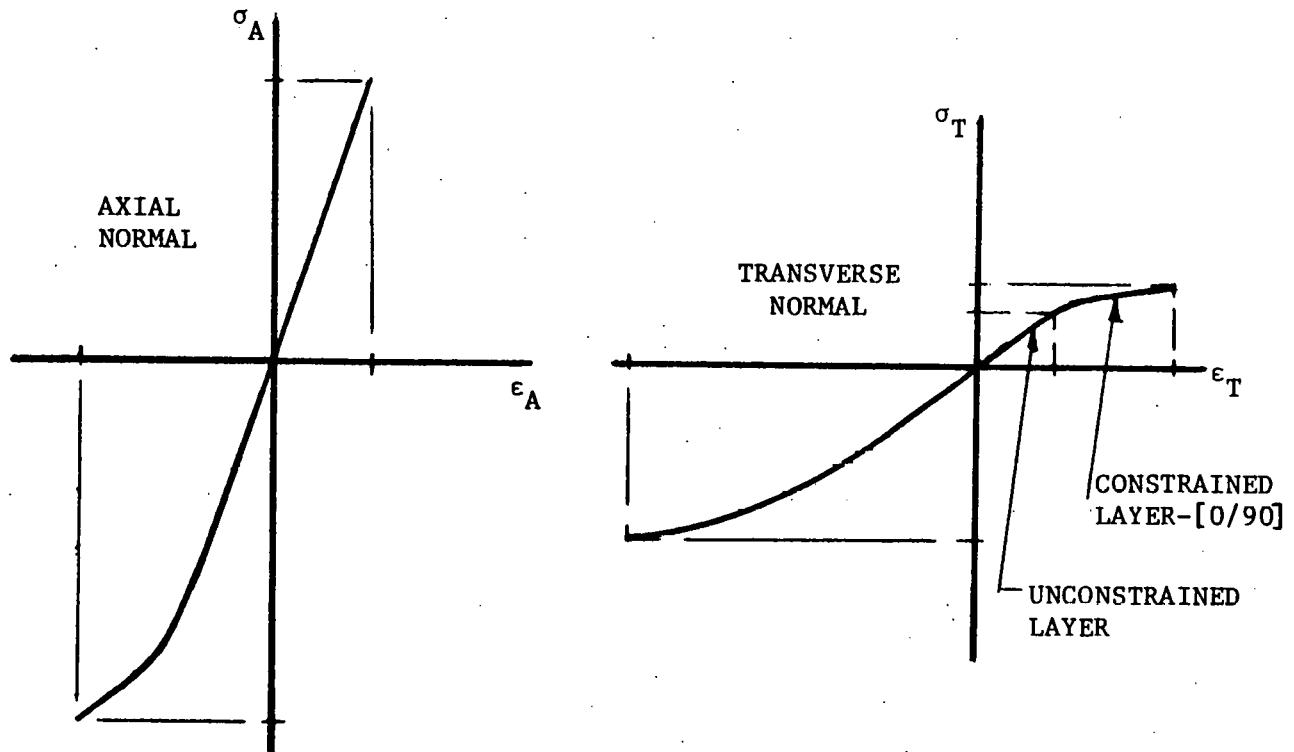


Figure 1. Typical stress-strain curves for unidirectional fiber composites.

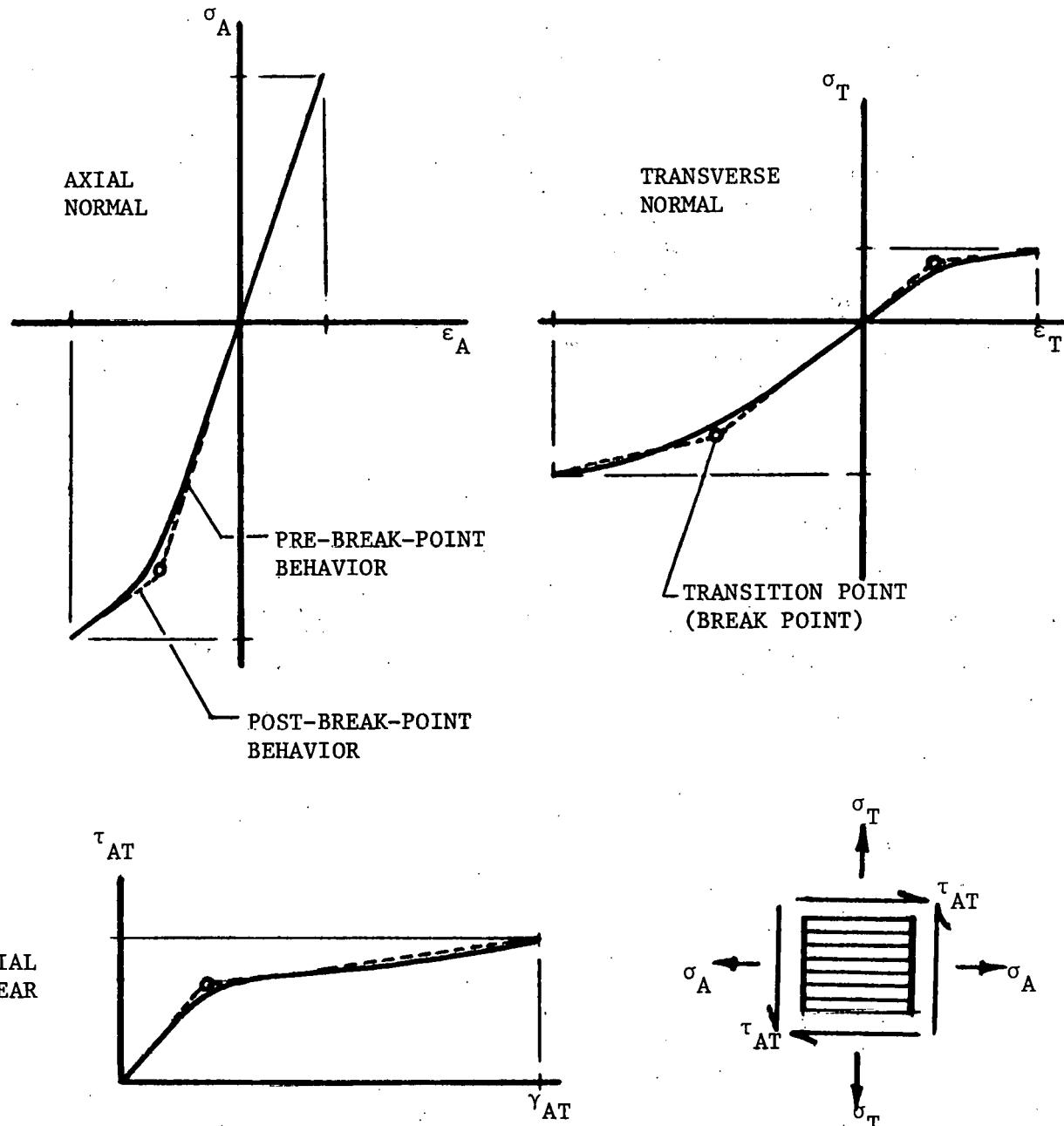


Figure 2. Bilinear approximations of constrained layer nonlinear stress-strain behavior.

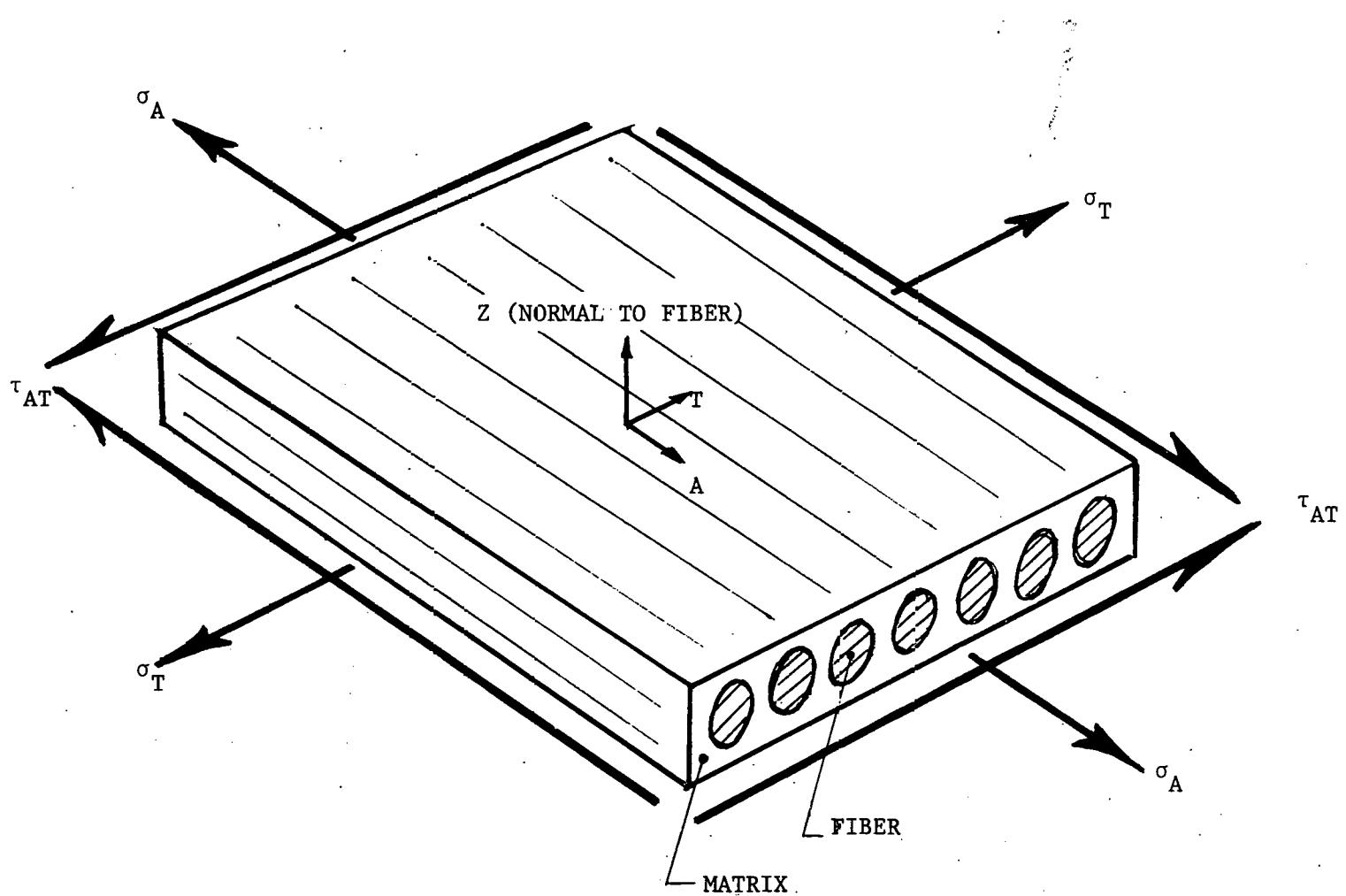


Figure 3. Schematic of composite layer subjected to in-plane stresses.

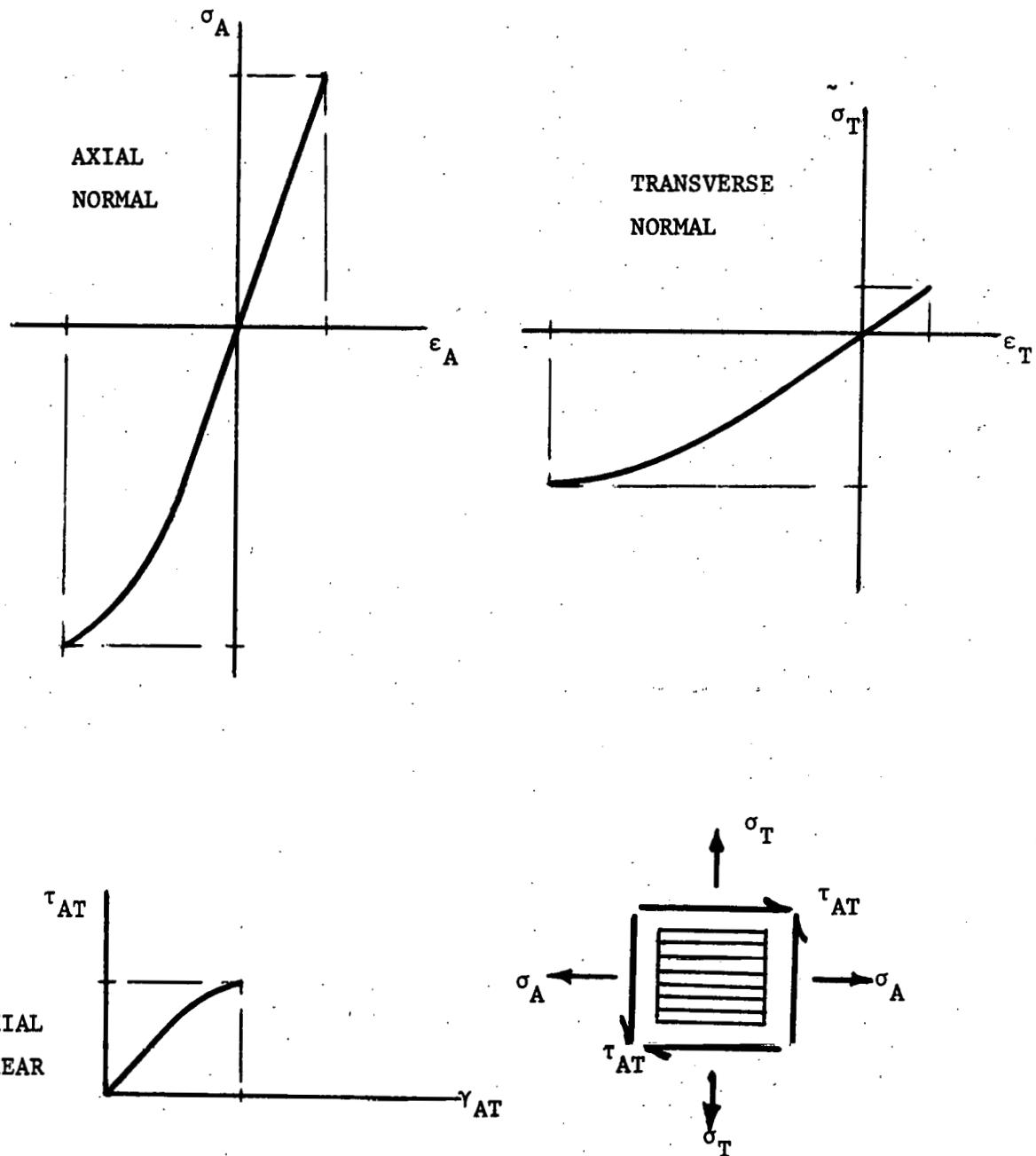


Figure 4. Typical stress-strain curves for unidirectional, unconstrained fiber composites.

TRANSVERSE
STRESS,
 σ_T

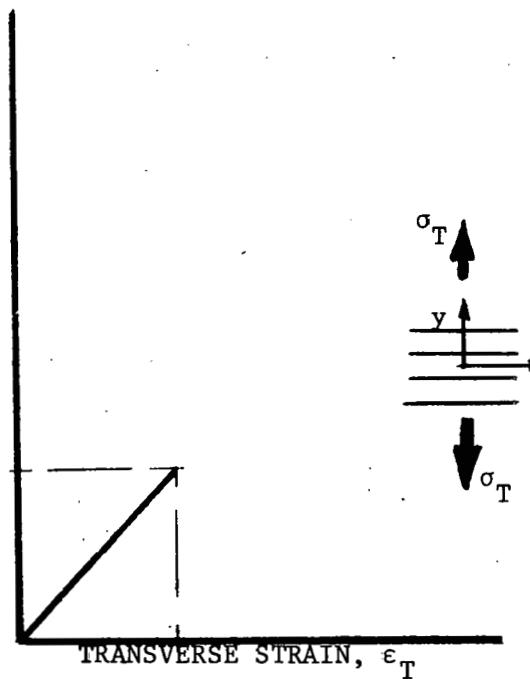


Figure 5a. Stress-strain response of unidirectional laminate subjected to load in transverse direction.

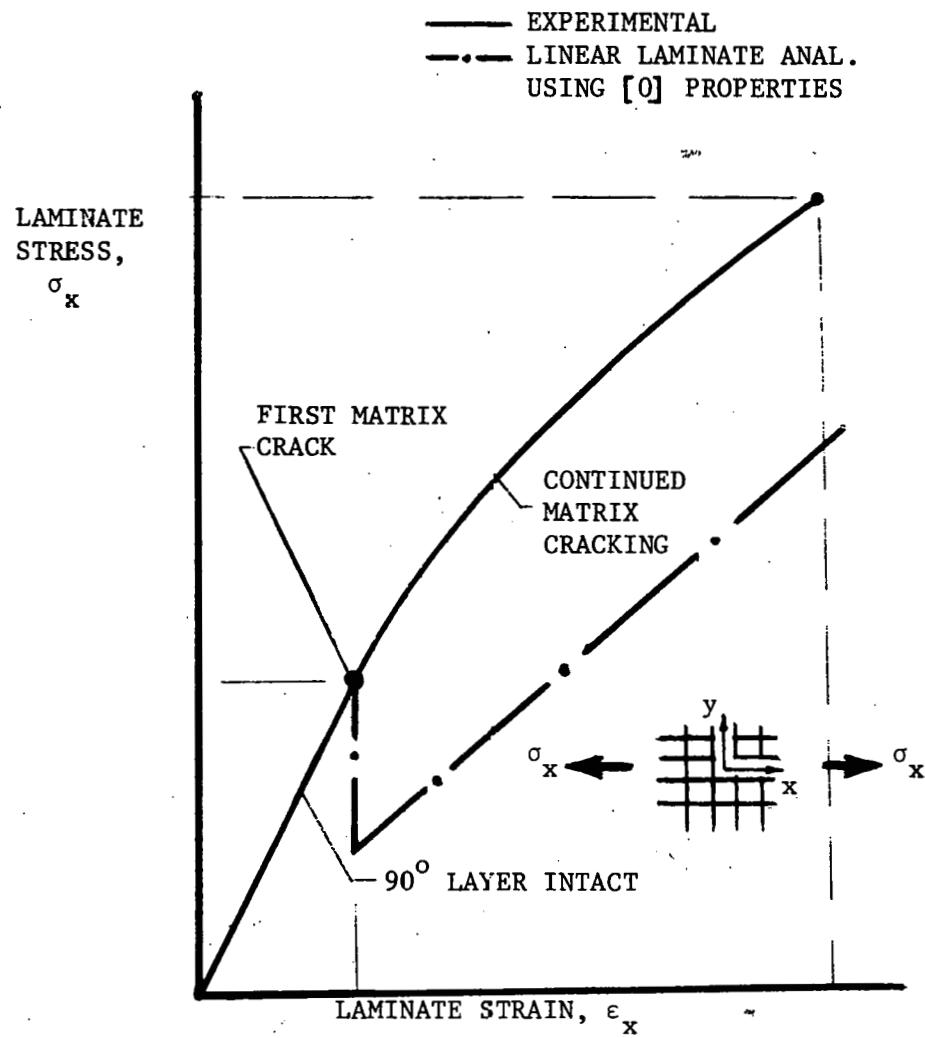
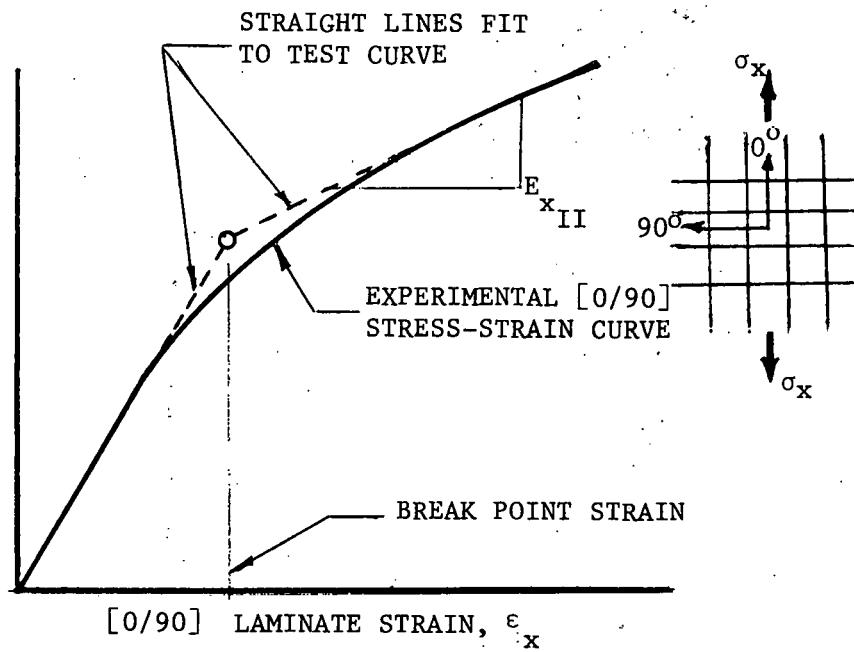


Figure 5b. Stress-strain response of $[0/90]_s$ laminate subjected to unidirectional loading in 0 deg. direction.

[0/90]
LAMINATE
TENSILE
STRESS,
 σ_x



TRANSVERSE
STRESS IN
90° LAYER,
 σ_T

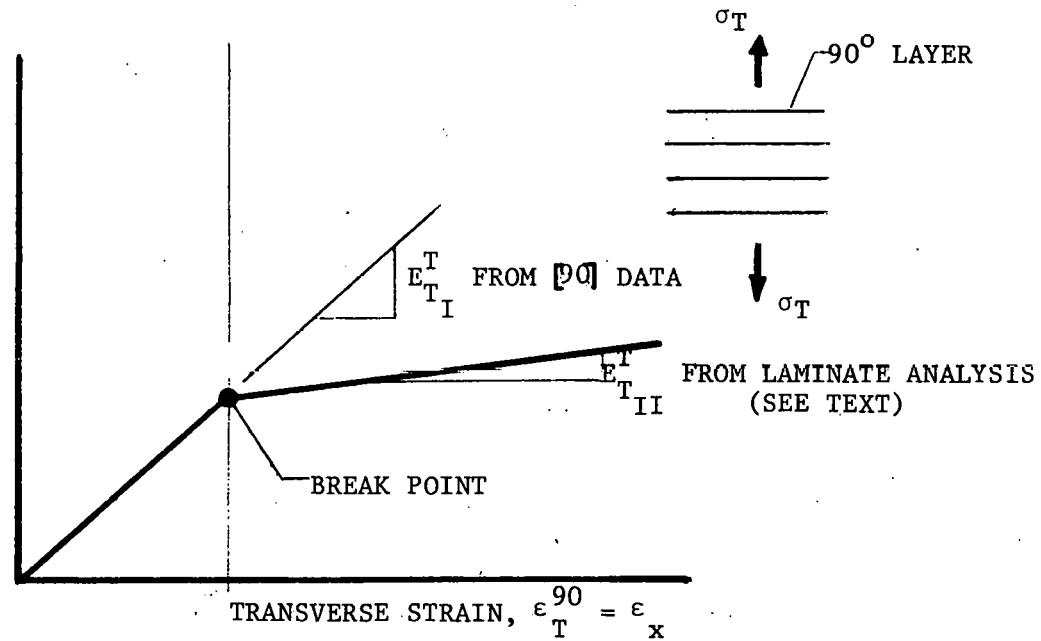


Figure 6. Determination of in-situ [0] transverse tensile behavior from [0/90] stress-strain curve.

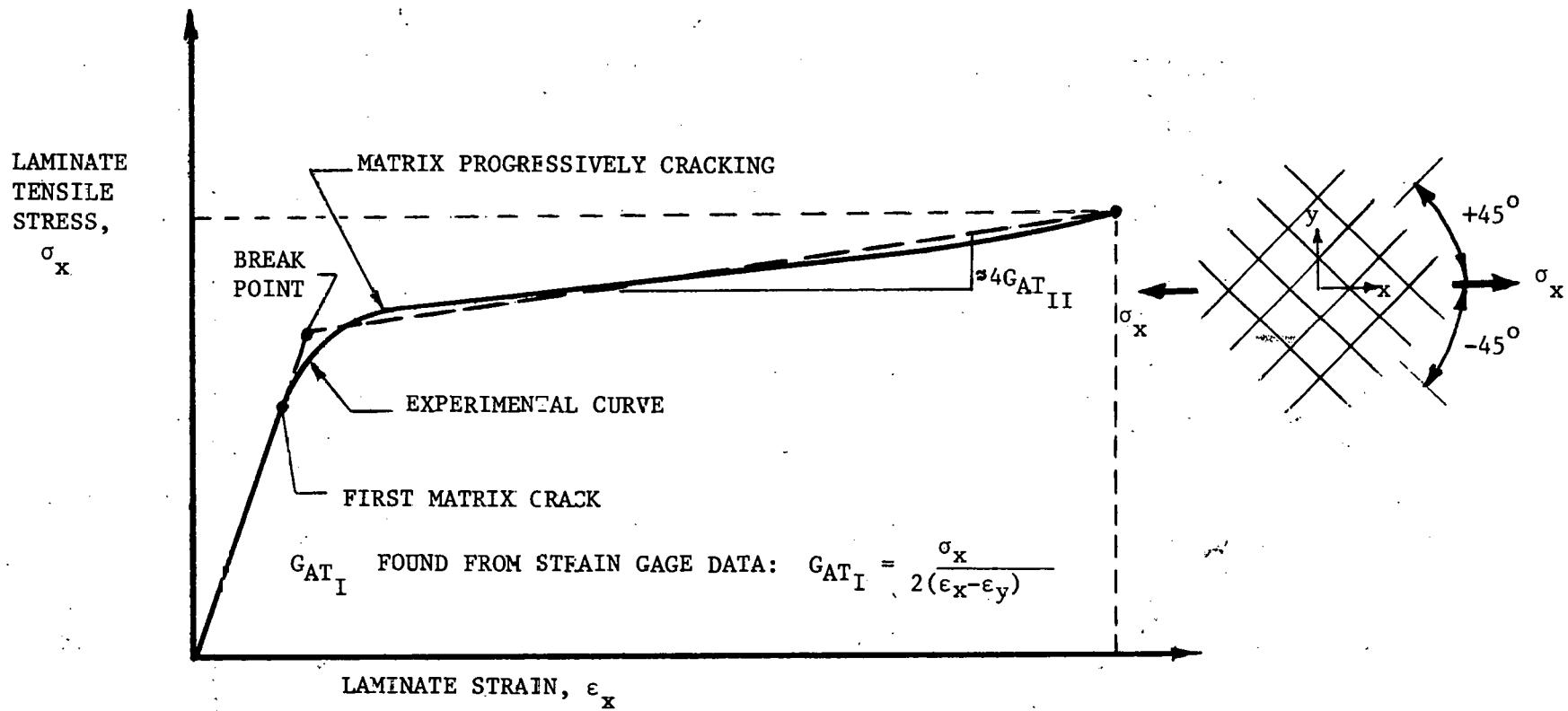
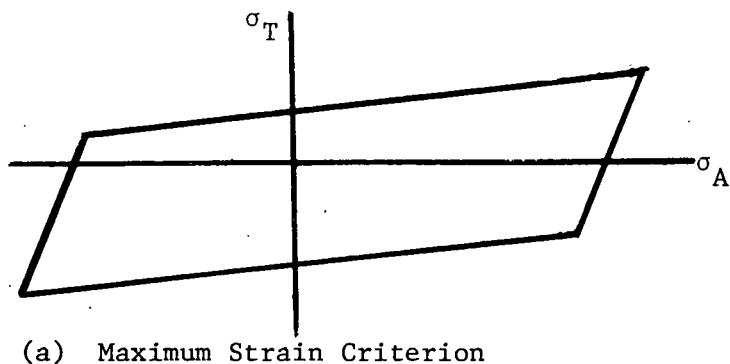
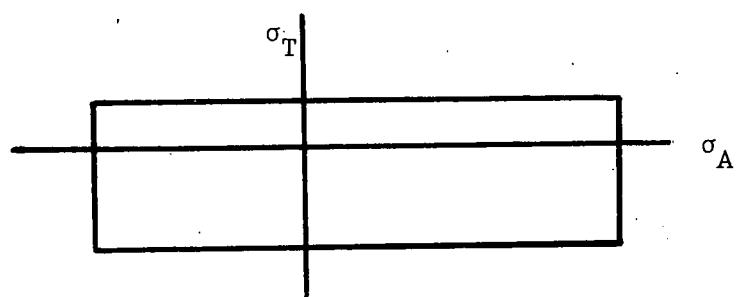


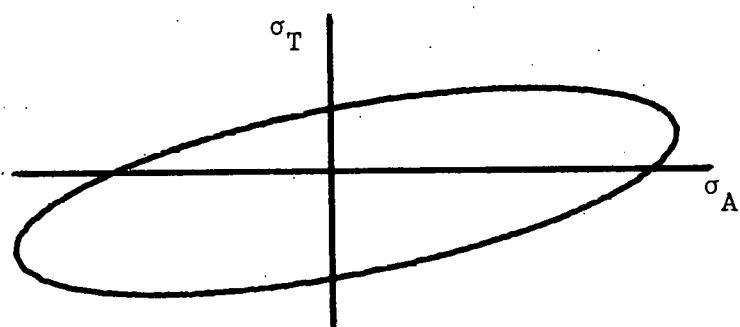
Figure 7. Stress-strain response of $[+45]_s$ laminate to load in 0 deg. direction.



(a) Maximum Strain Criterion



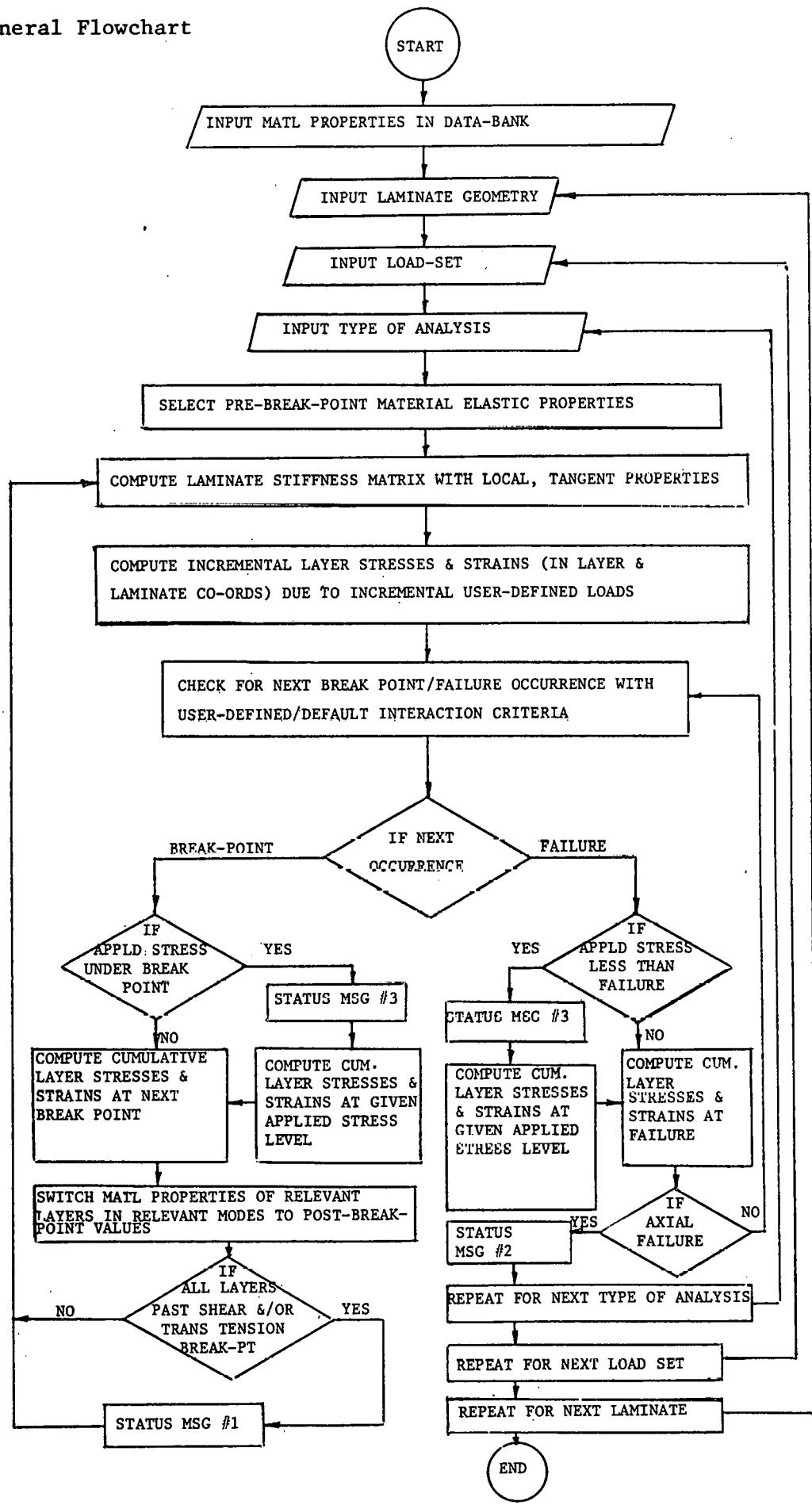
(b) Maximum Stress Criterion



(c) Quadratic Interaction Criterion

Figure 8. Interaction criteria for layer failure.

Figure 9. General Flowchart



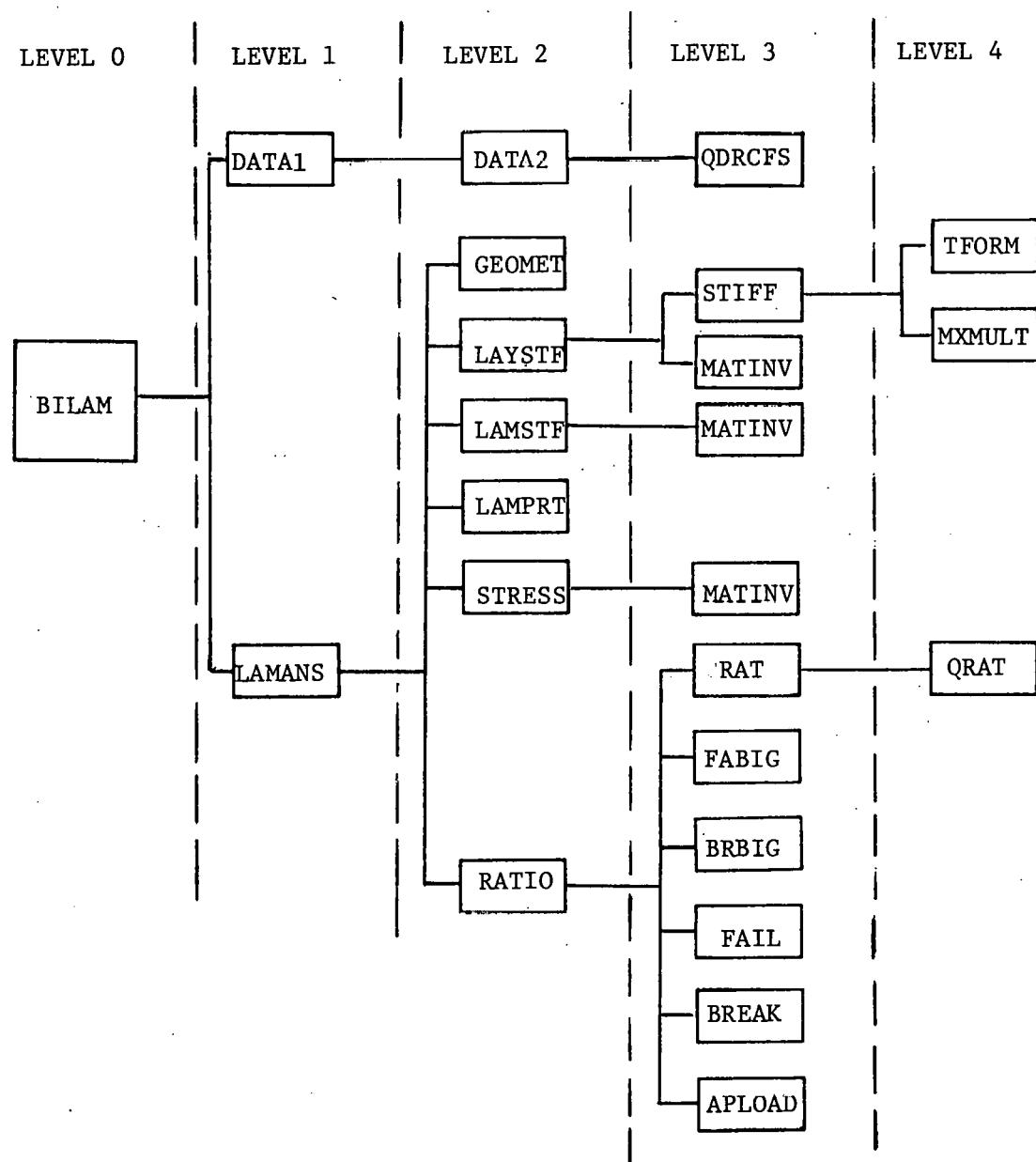


Figure 10. BILAM program organization.

9. APPENDIX

9.1 PROGRAM LISTING AND SAMPLE CASES

9.1.1 BILAM Program Listing

BILAM

```
C-----FORTRAN PROGRAM FOR LAMINATE ANALYSIS OF COMPOSITES ASSUMING BILINEAR
C-----MATERIAL PROPERTIES
C-----MAIN PROGRAM
    CALL DATA1(NLAM,NMATL)
    CALL LAMANS(NLAM,NMATL)
    STOP
    END
C
C
C      SUBROUTINE DATA1(NLAM,NMATL)
C-----THIS SUBROUTINE READS IN THE MATERIAL ELASTIC PROPERTIES
COMMON/LOC1/AXE(10,2,2),TRANE(10,2,2),AXNU(10,2,5),G(10,2,2)
NAMELIST/ELASTD/AXE,TRANE,G,AXNU,NLAMM,NMATLL
READ(5,ELASTD)
NLAM=NLAMM
NMATL=NMATLL
DO 5 K=1,NMATL
    AXE(K,2,1)=AXE(K,1,1)
    TRANE(K,2,1)=TRANE(K,1,1)
    G(K,2,1)=G(K,1,1)
    G(K,2,2)=G(K,1,2)
    DO 5 LI=1,5
        5 AXNU(K,2,LI)=AXNU(K,1,LI)
        WRITE(6,10)
10 FORMAT(//,2X,'MATERIAL ELASTIC PROPERTIES:')
        WRITE(6,20)
20 FORMAT(//,2X,'PROPERTIES BEFORE BREAK-POINT:')
        WRITE(6,30)
30 FORMAT(/,2X,'MATL',6X,'AXIAL YOUNGS MODULUS',6X,'TRANS YOUNGS MODU
*lus',7X,'SHEAR',8X,'AXIAL')
        WRITE(6,40)
40 FORMAT(3X,'NO',59X,'MODULUS',6X,'POISSON')
        WRITE(6,50)
50 FORMAT(5X,2(7X,'TENSION',7X,'COMPR'),21X,'RATIO',/)
        DO 60 K=1,NMATL
60 WRITE(6,70)K,AXE(K,1,1),AXE(K,2,1),TRANE(K,1,1),TRANE(K,2,1),G(K,1
*,1),AXNU(K,1,1)
70 FORMAT(3X,I2,3X,6(E13.4))
        WRITE(6,80)
80 FORMAT(//,2X,'PROPERTIES AFTER BREAK-POINT:')
        WRITE(6,90)
90 FORMAT(/,2X,'MATL',6X,'AXIAL YOUNGS MODULUS',6X,'TRANS YOUNGS MODU
*lus',7X,'SHEAR',13X,'***** AXIAL POISONS RATIO *****')
        WRITE(6,100)
100 FORMAT(3X,'NO',59X,'MODULUS')
        WRITE(6,110)
110 FORMAT(5X,2(7X,'TENSION',7X,'COMPR'),20X,'AX COMPR',3X,'SHEAR/T TE
*NS',3X,'TR COMPR',7X,'QUAD',/)
        DO 120 K=1,NMATL
120 WRITE(6,130)K,AXE(K,1,2),AXE(K,2,2),TRANE(K,1,2),TRANE(K,2,2),G(K,
*,2),AXNU(K,1,2),AXNU(K,1,3),AXNU(K,1,4),AXNU(K,1,5)
130 FORMAT(3X,I2,3X,9(E13.4))
    CALL DATA2(NMATL)
    RETURN
    END
C
C
C      SUBROUTINE DATA2(NMATL)
C-----THIS SUBROUTINE READS IN CRITICAL STRESSES & STRAINS FOR EACH MATERIAL
COMMON/LOC3/CRITE(3,2,10,2),CRITS(3,2,10,2)
NAMELIST/CRITIC/CRITE,CRITS
READ(5,CRITIC)
DO 90 LI=1,2
DO 5 K=1,NMATL
    CRITS(3,2,K,LI)=CRITS(3,1,K,LI)
    5 CRITE(3,2,K,LI)=CRITE(3,1,K,LI)
    IF(LI.EQ.2)GO TO 20
    WRITE(6,10)
10 FORMAT(//,2X,'INPUT BREAK-POINT STRESSES & STRAINS:')
    GO TO 40
20 WRITE(6,30)
30 FORMAT(//,2X,'INPUT ULTIMATE STRESSES & STRAINS:')
40 WRITE(6,50)
50 FORMAT(/,27X,'STRESSES',40X,'STRAINS')
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      WRITE(6,60)
60 FORMAT(//,7X,'MATL',5X,'AXIAL',8X,'TRANS',8X,'SHEAR',16X,'AXIAL',8X
     *, 'TRANS',8X,'SHEAR')
     DO 90 K=1,NMATL
     WRITE(6,70)K,(CRITS(I,1,K,LI),I=1,3),(CRITE(I,1,K,LI),I=1,3)
70 FORMAT(/,2X,'TENS',2X,I2,3(E13.3),8X,3(E13.3))
     WRITE(6,80)(CRITS(I,2,K,LI),I=1,3),(CRITE(I,2,K,LI),I=1,3)
80 FORMAT(2X,'COMP',4X,3(E13.3),8X,3(E13.3))
90 CONTINUE
     CALL QDRCF5(NMATL)
     RETURN
END

C
C
      SUBROUTINE QDRCF5(NMATL)
C-----THIS SUBROUTINE COMPUTES QUADRATIC BREAK-POINT & FAILURE CRITERIA CO-EFFS
COMMON/LOC2/A11(10,2),A22(10,2),A44(10,2),B1(10,2),B2(10,2)
COMMON/LOC3/CRITE(3,2,10,2),CRITS(3,2,10,2)
COMMON/LOC8/A12(10,2)
DO 10 K=1,NMATL
DO 10 LI=1,2
A11(K,LI)=1./(CRITS(1,1,K,LI)*ABS(CRITS(1,2,K,LI)))
A12(K,LI)=-1./(CRITS(1,2,K,LI)*CRITS(2,2,K,LI))
A22(K,LI)=1./(CRITS(2,1,K,LI)*ABS(CRITS(2,2,K,LI)))
A44(K,LI)=(1./CRITS(3,1,K,LI))**2
B1(K,LI)=1./CRITS(1,1,K,LI)-1./ABS(CRITS(1,2,K,LI))
B2(K,LI)=1./CRITS(2,1,K,LI)-1./ABS(CRITS(2,2,K,LI))
10 CONTINUE
     RETURN
END

C
C
      SUBROUTINE LAMANS(NLAM,NMATL)
C-----THIS SUBROUTINE PERFORMS LAMINATE ANALYSIS ON EACH LAMINATE FOR EACH
C-----LOAD-SET.
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC5/ALOAD(3,16),NLOADS,IEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLAM
*(3),T(3,3)
COMMON/LOC7/ISENT(9,2),IBREAK(24)
COMMON/LOC8/A12(10,2)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC20/ALOADB(3),ALOADF(3),CELAMB(3),CELAMF(3),GSIG(3,24)
NAMELIST/OPT1/NLOADS,NANS,A12,NSTRES
NAMELIST/LOAD/ALOAD
NAMELIST/OPTION/ISENT
NANS=0
READ(5,OPT1)
WRITE(6,5)
5 FORMAT(///,5X,'QUADRATIC INTERACTION CO-EFFICIENTS :')
WRITE(6,6)
6 FORMAT(//,5X,'MATERIAL',5X,'BREAK-POINT',5X,'FAILURE',//)
     DO 7 I=1,NMATL
7 WRITE(6,8) I,A12(I,1),A12(I,2)
8 FORMAT(8X,I2,4X,2(5X,E10.3))
     DO 10 I=1,3
     DO 10 L=1,NLOADS
10 ALOAD(I,L)=0.0
     IF(NANS.NE.0)GO TO 40
     NANS=3
     DO 30 J=1,NANS
     DO 30 K=1,2
30 ISENT(J,K)=J
     GO TO 60
40 DO 50 J=1,NANS
     DO 50 K=1,2
50 ISENT(J,K)=0
     READ(5,OPTION)
60 READ(5,LOAD)
     DO 240 NL=1,NLAM
     WRITE(6,70)NL
70 FORMAT(1H1,/,2X,'LAMINATE',I3)
     CALL GEOMET
     DO 240 L=1,NLOADS
     WRITE(6,80)
80 FORMAT(////////,38X,'LONGITUDINAL      TRANSVERSE      SHEAR')
     WRITE(6,90)(ALOAD(I,L),I=1,3)
90 FORMAT(2X,'APPLIED LAMINATE FORCES/LENGTH:',3(5X,E10.3))

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DO 95 I=1,95
IF (ALOAD(I,L).NE.0)GO TO 96
95 CONTINUE
96 IEL=I
DO 98 I=1,3
98 ELOAD(I,L)=ALOAD(I,L)/ALOAD(IEL,L)
DO 240 JA=1,NANS
IFLAG=0
ISTOP=0
WRITE(6,100)JA
100 FORMAT(//,,5X,'ANALYSIS NUMBER',I3,:')
WRITE(6,120)(ISENT(JA,L11),L11=1,2)
120 FORMAT(//,5X,'BREAK-POINT ANALYSIS=',I3,'; FAILURE ANALYSIS=',I3)
DO 122 L11=1,2
IF (ISENT(JA,L11).EQ.0)GO TO 235
122 CONTINUE
WRITE(6,128)
128 FORMAT(//,5X,'(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=
*QUADRATIC INTERACTION CRITERION)')
130 DO 140 K=1,NLAY
IBREAK(K)=0
DO 140 M=1,3
BRATIO(M,K)=-100.0
FRATIO(M,K)=-100.0
BEPS(M,K)=0.0
140 BSIG(M,K)=0.0
DO 145 M=1,3
CELAMB(M)=0.0
CELAMF(M)=0.0
ALOADB(M)=0.0
145 ALOADF(M)=0.0
ERR=0.001
LOOP=1
IPRINT=0
150 CALL LAYSTF(LOOP,K,IFLAG,JA)
IF (IFLAG.NE.2)GO TO 170
IF (IPRINT.EQ.1)GO TO 170
IPRINT=1
IF (ISENT(JA,1).NE.3)GO TO 159
152 WRITE(6,154)
154 FORMAT(//,5X,'QUADRATIC BREAK-POINT REACHED IN EVERY LAYER')
GO TO 170
159 WRITE(6,160)
160 FORMAT(//,5X,'SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY L
*AYER')
170 CALL LAMSTF(ISTOP,NLAY)
IF (ISTOP.EQ.3)GO TO 200
CALL LAMPRT
CALL STRESS(L)
CALL RATIO(LOOP,JA,IFLAG,ERR,L,ISTOP)
IF (ISTOP.EQ.5)GO TO 233
IF (ISTOP.EQ.6)GO TO 231
IF (ISTOP.EQ.7)GO TO 220
IF (IFLAG.EQ.1)GO TO 150
WRITE(6,175)
175 FORMAT(//,5X,'FIRST FIBER FAILURE')
GO TO 240
200 WRITE(6,210)
210 FORMAT(//,5X,'LAMINATE STIFFNESS MATRIX IS SINGULAR')
GO TO 240
220 WRITE(6,225)
225 FORMAT(//,5X,'BOTH QUADRATIC ROOTS ARE OF SAME SIGN. INTERACTION CU
*RVE IS NOT ELLIPTIC')
GO TO 240
231 WRITE(6,232)
232 FORMAT(//,5X,'QUADRATIC ROOTS ARE COMPLEX. RECHECK INPUTS.')
GO TO 240
233 WRITE(6,234)
234 FORMAT(//,5X,'NO AXIAL FAILURES. LAMINATE FAILS DUE TO MATRIX DEGE
*NERATION')
GO TO 240
235 IF (L11.EQ.1)GO TO 238
WRITE(6,237)
237 FORMAT(//,5X,'INVALID OPTION ON CRITERION FOR FAILURE ANALYSIS')
GO TO 240
238 WRITE(6,239)
239 FORMAT(//,5X,'INVALID OPTION ON CRITERION FOR BREAK-POINT ANALYSIS
*')
240 CONTINUE
RETURN
END

```

```

C
C
      SUBROUTINE GEOMET
C-----THIS SUBROUTINE READS IN THE LAMINATE GEOMETRY.
      COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
      COMMON/LOC9/DELTA(24)
      NAMELIST/GEOINED/NLAY,IMATL,ALPHA,DELTA
      READ(5,GEONED)
      WRITE(6,10)
      10 FORMAT(//,2X,'LAYER',2X,'MATERIAL',2X,'THICKNESS',2X,'ANGLE')
      DO 20 K=1,NLAY
      20 WRITE(6,30)K,IMATL(K),DELTA(K),ALPHA(K)
      30 FORMAT(3X,I2,6X,I2,6X,F7.4,3X,F6.2)
      RETURN
      END

C
C
      SUBROUTINE LAYSTF(LOOP,K,IFLAG,JA)
C-----THIS SUBROUTINE COMPUTES LAYER STIFFNESS MATRICES IN LAMINATE CO-ORD
      COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
      COMMON/LOC7/ISENT(9,2),IBREAK(24)
      COMMON/LOC16/IQB,MEL(24),KB1(24),ILM(3,24)
      COMMON/LOC11/LI(4),IL(4),C(3,3)
      COMMON/LOC12/S1(3,3,24)
      COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
      IF(LOOP.EQ.1)GO TO 110
      DO 90 I=1,IQB
      K=KB1(I)
      MBO=MEL(I)
      II=IMATL(K)
      DO 10 N=1,2
      10 IL(M)=ILM(M,K)
      IF(ISENT(JA,1).NE.3)GO TO 30
      DO 20 M=1,3
      20 LI(M)=2
      LI(4)=5
      IBREAK(K)=1
      GO TO 70
      30 IF(MBO.EQ.1)GO TO 60
      IF(ILM(2,K).EQ.1)GO TO 50
      IF(MBO.EQ.3)GO TO 40
      LI(2)=2
      LI(4)=4
      GO TO 70
      40 LI(3)=2
      LI(4)=3
      IBREAK(K)=1
      GO TO 70
      50 LI(2)=2
      LI(3)=2
      LI(4)=3
      IBREAK(K)=1
      GO TO 70
      60 LI(1)=2
      LI(4)=2
      70 CALL STIFF(K)
      DO 90 M=1,3
      DO 90 J=1,3
      S1(M,J,K)=C(M,J)
      90 CONTINUE
      DO 100 K=1,NLAY
      IF(IBREAK(K).EQ.0)GO TO 150
      100 CONTINUE
      IFLAG=2
      GO TO 150
      110 DO 120 M=1,4
      IL(M)=1
      120 LI(M)=1
      DO 130 K=1,NLAY
      CALL STIFF(K)
      DO 130 M=1,3
      DO 130 J=1,3
      130 S1(M,J,K)=C(M,J)
      150 RETURN
      END
C
C

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SUBROUTINE STIFF(K)
C-----THIS SUBROUTINE COMPUTES INDIVIDUAL STIFFNESS TERMS AS PER CONDIT
C-----SET OUT IN SUBROUTINE LAYSTF.
    COMMON/LOC1/AXE(10,2,2),TRANE(10,2,2),AXNU(10,2,5),G(10,2,2)
    COMMON/LOC4/NIAY,IMATL(24),ALPHA(24)
    COMMON/LOC11/LI(4),IL(4),C(3,3)
    COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPHA(24),SALP
*HA(24)
    COMMON/LOC14/SBAR(3,3)
    II=IMATL(K)
    TRANU=AXNU(II,IL(4),LI(4))*TRANE(II,IL(2),LI(2))/AXE(II,IL(1),LI(
    *1))
    DENOM=1.-TRANU*AXNU(II,IL(4),LI(4))
    C(1,1)=AXE(II,IL(1),LI(1))/DENOM
    C(1,2)=TRANU*AXE(II,IL(1),LI(1))/DENOM
    C(1,3)=0.
    C(2,1)=AXNU(II,IL(4),LI(4))*TRANE(II,IL(2),LI(2))/DENOM
    C(2,2)=TRANU*TRANE(II,IL(2),LI(2))/DENOM
    C(2,3)=0.
    C(3,1)=0.
    C(3,2)=0.
    C(3,3)=G(II,IL(3),LI(3))
    ALPHAR(K)=ALPHA(K)*3.1415927/180.
    DO 10 I=1,3
    DO 10 J=1,3
10   C3(I,J,K)=C(I,J)
    CALL TFORM(K)
    CALL MXMULT(C,TE,SBAR,3,3,3)
    CALL MXMULT(TS,SBAR,C,3,3)
    RETURN
    END
C
C
    SUBROUTINE TFORM(K)
C-----THIS SUBROUTINE COMPUTES THE STRESS & STRAIN TRANSFORMATION MATRIX
    COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPHA(24),SALP
*HA(24)
    CALPHA(K)=COS(ALPHAR(K))
    SALPHA(K)=SIN(ALPHAR(K))
    TE(1,1)=CALPHA(K)**2
    TE(1,2)=SALPHA(K)**2
    TE(1,3)=SALPHA(K)*CALPHA(K)
    TE(2,1)=TE(1,2)
    TE(2,2)=TE(1,1)
    TE(2,3)=-TE(1,3)
    TE(3,1)=TE(2,3)*2.
    TE(3,2)=TE(1,3)*2.
    TE(3,3)=TE(1,1)-TE(1,2)
    DO 10 I=1,3
    DO 10 J=1,3
10   TS(I,J)=TE(J,I)
    RETURN
    END
C
C
    SUBROUTINE MXMULT(X,Y,Z,N1,N2,N3)
C-----THIS SUBROUTINE PRE-MULTIPLIES A (N2XN3) MATRIX BY A (N1XN2) MATRIX.
    DIMENSION X(3,3),Y(3,3),Z(3,3)
    DO 10 I=1,N1
    DO 10 J=1,N3
    Z(I,J)=0.0
    DO 10 K=1,N2
10   Z(I,J)=Z(I,J)+X(I,K)*Y(K,J)
    RETURN
    END
C
C
    SUBROUTINE MATINV(A,B,INV,N)
C-----THIS SUBROUTINE INVERTS A (NXN) MATRIX BY GAUSS-JORDAN REDUCTION WITHOUT
C-----PIVOTING
    DIMENSION A(3,3),B(3,3)
    INV=1
    DO 30 K=1,N
    DO 10 J=1,N
    IF(J.EQ.K)GO TO 10
    IF(ABS(A(K,K)).LE.1.0E-20)GO TO 50
    A(K,J)=A(K,J)/A(K,K)
10   CONTINUE
30   CONTINUE
50   CONTINUE
    END

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IF(ABS(A(K,K)).LE.1.0E-20)GO TO 50
A(K,K)=1./A(K,K)
DO 25 I=1,N
IF(I.EQ.K)GO TO 25
DO 26 J=1,N
IF(J.EQ.K)GO TO 26
A(I,J)=A(I,J)-A(K,J)*A(I,K)
20 CONTINUE
25 CONTINUE
DO 30 I=1,N
IF(I.EQ.K)GO TO 30
A(I,K)=-A(I,K)*A(K,K)
30 CONTINUE
INV=1
DO 40 I=1,N
DO 40 J=1,N
40 B(I,J)=A(I,J)
GO TO 60
50 INV=0
60 RETURN
END
C
C
SUBROUTINE LAMSTF(ISTOP,NLAY)
C-----THIS SUBROUTINE COMPUTES LAMINATE STIFFNESS MATRIX IN LAMINATE CO-ORDS.
COMMON/LOC9/DELTA(24)
COMMON/LOC12/S1(3,3,24)
COMMON/LOC14/SBAR(3,3)
COMMON/LOC15/FBAR(3,3)
DO 10 I=1,3
DO 10 J=1,3
SBAR(I,J)=0.0
DO 10 K=1,NLAY
10 SBAR(I,J)=SBAR(I,J)+S1(I,J,K)*DELTA(K)
WRITE(6,20)
20 FORMAT(//,5X,'LAMINATE TANGENT STIFFNESS MATRIX:',/)
DO 30 I=1,3
30 WRITE(6,40)(SBAR(I,J),J=1,3)
40 FORMAT(5X,3(E11.3,3X))
CALL MATINV(SBAR,FBAR,INV,3)
IF(INV.MEQ.0)ISTOP=3
RETURN
END
C
C
SUBROUTINE LAMPRT
C-----THIS SUBROUTINE EVALUATES THE LAMINATE ELASTIC PROPERTIES
COMMON/LOC15/FBAR(3,3)
WRITE(6,10)
10 FORMAT(/,5X,'LAMINATE TANGENT MODULI & POISSON RATIOS:',/)
AXEBAR=1./FBAR(1,1)
TREBAR=1./FBAR(2,2)
ANUBAR=-FBAR(2,1)/FBAR(1,1)
TNUBAR=-FBAR(1,2)/FBAR(2,2)
GBAR=1./FBAR(3,3)
WRITE(6,20)
20 FORMAT(17X,'YOUNGS',8X,'POISSON',8X,'SHEAR')
WRITE(6,30)
30 FORMAT(17X,'MODULUS',8X,'RATIO',8X,'MODULUS')
WRITE(6,40)AXEBAR,ANUBAR,GBAR
40 FORMAT(/,5X,'LONG',2X,3(2X,E13.6))
WRITE(6,50)TREBAR,TNUBAR,GBAR
50 FORMAT(5X,'TRAN',2X,3(2X,E13.6))
RETURN
END
C
C
SUBROUTINE STRESS(L)
C-----THIS SUBROUTINE COMPUTES LAYER STRESSES & STRAINS IN LAYER & LAMINATE
C-----CO-ORDINATES.
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC5/ALOAD(3,16),NLOADS,IEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC6/EPSS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLM
*(3),T(3,3)
COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPEA(24),SALP
*HA(24)
COMMON/LOC15/FBAR(3,3)
DO 10 I=1,3
EPSLM(I)=0.0
DO 10 J=1,3

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10 EPSLM(I)=EPSLM(I)+FBAR(I,J)*ELOAD(J,L)
DO 50 K=1,NLAY
II=IMATL(K)
T(1,1)=CALPHA(K)**2
T(1,2)=SALPHA(K)**2
T(1,3)=SALPHA(K)*CALPHA(K)
T(2,1)=T(1,2)
T(2,2)=T(1,1)
T(2,3)=-T(1,3)
T(3,1)=T(2,3)*2.
T(3,2)=T(1,3)*2.
T(3,3)=T(1,1)-T(1,2)
DO 30 I=1,3
EPSLAY(I,K)=0.0
DO 30 J=1,3
30 EPSLAY(I,K)=T(I,J)*EPSLM(J)+EPSLAY(I,K)
DO 40 I=1,3
SIGLAY(I,K)=0.0
DO 40 J=1,3
40 SIGLAY(I,K)=SIGLAY(I,K)+C3(I,J,K)*EPSLAY(J,K)
50 CONTINUE
70 RETURN
END
C
C
SUBROUTINE RATIO(LOOP,JA,IFLAG,ERR,L,ISTOP)
C----THIS SUBROUTINE CALCULATES & STORES FAILURE & BREAK-POINT RATIOS &
C----COMPARES TO DETECT DOMINANT EFFECT.
COMMON/LOC5/ALOAD(3,16),NLOADSIEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC7/ISENT(9,2),IBREAK(24)
COMMON/LOC10/IQB,MBl(24),KB1(24),ILM(3,24)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC18/NF,KF,FBIG,FBIGP,MFl(24),KF1(24),IQF
COMMON/LOC19/MB,KB,BBIG,BBIGP,BEST(3,24)
COMMON/LOC20/ALOADB(3),ALOADF(3),CELAMB(3),CELAMP(3),GSIG(3,24)
DO 10 L1L=1,2
CALL RAT(L1L,IQRT,JA)
IF(IQRT.EQ.1)GO TO 170
IF(IQRT.EQ.2)GO TO 175
10 CONTINUE
IB=0
IFF=0
IQB=0
30 IQF=0
40 CALL FABIGIFF)
IF(IQF.NE.0)GO TO 120
IF(IB.NE.0)GO TO 60
50 CALL BRBIGIB)
IF(IQB.NE.0)GO TO 70
IF(FBIG.EQ.0.0.AND.BBIG.EQ.0.)GO TO 160
60 IF(FBIG.GT.BBIG)GO TO 110
IF(NSTRES(L).NE.1)GO TO 65
IF((1./((ALOADIEL,L)-ALOADBIEL))).GT.BBIG)CALL ALOAD(L)
65 BBIGP=BBIG
70 IF(ABS((BBIGP-BBIG)/BBIGP).GT.ERR)GO TO 80
IQB=IQR+1
KB1(IQB)=KB
MB1(IQB)=MB
BRATIO(MB,KB)=-100.0
GO TO 50
80 CALL BREAK(LOOP,L,JA)
DO 100 I=1,IQB
KEQ=KB1(I)
DO 100 M=1,3
IF(BEST(M,KBQ).LT.0)GO TO 90
ILM(M,KBQ)=1
GO TO 100
90 ILM(M,KBQ)=2
100 CONTINUE
LOOP=LOOP+1
IFLAG=1
GO TO 180
110 IF(NSTRES(L).NE.1)GO TO 115
IF((1./((ALOADIEL,L)-ALOADBIEL))).GT.FBIG)CALL ALOAD(L)
115 FBIGP=FBIG
120 IF(ABS((FBIGP-FBIG)/FBIGP).GT.ERR)GO TO 130
IQF=IQF+1
KF1(IQF)=KF
MF1(IQF)=MF
FRATIO(MF,KF)=-100.0
GO TO 40

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130 CALL FAIL(L)
DO 140 I=1,IQF
IF(MFL(I).EQ.1)GO TO 150
140 CONTINUE
GO TO 30
150 IFLAG=0
GO TO 180
160 ISTOP=5
GO TO 180
170 ISTOP=6
GO TO 180
175 ISTOP=7
180 RETURN
END
C
C
SUBROUTINE RAT(LIL,IQRT,JA)
C-----THIS SUBROUTINE COMPUTES RATIOS OF BREAK-POINT & FAILURE STRESSES
C-----& STRAINS TO ACTUAL STRESSES & STRAINS.
COMMON/LOC3/CRITE(3,2,10,2),CRITS(3,2,10,2)
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLM
*(3),T(3,3)
COMMON/LOC7/ISENT(9,2),IBREAK(24)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
DIMENSION XRATIO(3,24),ILX(3,24)
IF(ISENT(JA,LIL)-2)50,20,10
10 CALL QRAT(LIL,IQRT)
GO TO 120
20 DO 40 K=1,NLAY
II=IMATL(K)
DO 40 M=1,3
ILX(M,K)=1
IF((EPSLAY(M,K)+BEPS(M,K)).LT.0.) ILX(M,K)=2
IF(ABS(BEPS(M,K)).EQ.ABS(CRITE(M,ILX(M,K),II,LIL)))GO TO 30
XRATIO(M,K)=(EPSLAY(M,K))/((-1)**(ILX(M,K)+1)*ABS(CRITE(M,ILX(M,K),
*,II,LIL))-(BEPS(M,K)))
GO TO 40
30 XRATIO(M,K)=-100.0
40 CONTINUE
GO TO 80
50 DO 70 K=1,NLAY
II=IMATL(K)
DO 70 M=1,3
ILX(M,K)=1
IF((SIGLAY(M,K)+BSIG(M,K)).LT.0.) ILX(M,K)=2
IF(ABS(BSIG(M,K)).EQ.ABS(CRITS(M,ILX(M,K),II,LIL)))GO TO 60
XRATIO(M,K)=(SIGLAY(M,K))/((-1)**(ILX(M,K)+1)*ABS(CRITS(M,ILX(M,K),
*,II,LIL))-(BSIG(M,K)))
GO TO 70
60 XRATIO(M,K)=-100.0
70 CONTINUE
80 IF(LIL.EQ.1)GO TO 100
DO 90 K=1,NLAY
DO 90 M=1,3
90 FRATIO(M,K)=XRATIO(M,K)
GO TO 120
100 DO 110 K=1,NLAY
IF(IBREAK(K).EQ.1)GO TO 104
DO 102 M=1,3
102 BRATIO(M,K)=XRATIO(M,K)
GO TO 110
104 DO 106 M=1,2
106 BRATIO(M,K)=XRATIO(M,K)
DRATIO(3,K)=-100.0
IF(ILX(2,K).EQ.1)BRATIO(2,K)=-100.0
110 CONTINUE
120 RETURN
END
C
C
SUBROUTINE ORAT(LIL,IQRT)
C-----THIS SUBROUTINE EXAMINES BREAK-POINT & FAILURE BY QUADRATIC CRITERIA
COMMON/LOC2/A11(10,2),A22(10,2),A44(10,2),B1(10,2),B2(10,2)
COMMON/LOC4/NLAY,IMATL(24),ALPEA(24)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLM
*(3),T(3,3)
COMMON/LOC7/ISENT(9,2),IBREAK(24)
COMMON/LOC8/A12(10,2)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC17/DENOM(24,2)

```

```

DIMENSION QRATIO(1,24),D(2)
DO 30 K=1,NLAY
IF(IBREAK(K).EQ.1.AND.L11.EQ.1)GO TO 25
IQRT=0
II=IMATL(K)
A=A11(II,L11)*(SIGLAY(1,K)**2)+A22(II,L11)*(SIGLAY(2,K)**2)+A12(II
*,L11)*SICLAY(1,K)*SIGLAY(2,K)+A44(II,L11)*(SIGLAY(3,K)**2)
B=(2.*A11(II,L11)*BSIG(1,K)+A12(II,L11)*BSIG(2,K)+B1(II,L11))*SIGL
*AY(1,K)+(2.*A22(II,L11)*ESIG(2,K)+A12(II,L11)*DSIG(1,K)+E2(II,L11)
*)*SIGLAY(2,K)+2.*A44(II,L11)*BSIG(3,K)*SIGLAY(3,K)
C=A11(II,L11)*(BSIG(1,K)**2)+A12(II,L11)*(BSIG(1,K)*BSIG(2,K)+A22(I
*I,L11)*(BSIG(2,K)**2)+A44(II,L11)*(BSIG(3,K)**2)+B1(II,L11)*BSIG(1
*,K)+B2(II,L11)*BSIG(2,K)-1.
IF(A.EQ.0)GO TO 22
IF((B**2-4.*A*C).LT.0)GO TO 50
DO 29 ICOUNT=1,2
20 D(ICOUNT)=(-B+(-1)**ICOUNT*SQRT(B**2-4.*A*C))/(2.*A)
IF((D(1)*D(2)).GE.0.)GO TO 55
DENOM(K,L11)=D(1)
IF(DENOM(K,L11).LE.0.)DENOM(K,L11)=D(2)
GO TO 24
22 DENOM(K,L11)=-C/B
24 QRATIO(1,K)=1./DENOM(K,L11)
GO TO 30
25 QRATIO(1,K)=-100.0
30 CONTINUE
IF(L11.EQ.1)GO TO 40
DO 35 K=1,NLAY
35 FRATIO(1,K)=QRATIO(1,K)
GO TO 60
40 DO 45 K=1,NLAY
45 BRATIO(1,K)=QRATIO(1,K)
GO TO 60
50 IQRT=1
GO TO 60
55 IQRT=2
60 RETURN
END
C
C SUBROUTINE FABIG(IF)
C-----THIS SUBROUTINE CALCULATES THE BIGGEST FAILURE RATIO.
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC18/MF,KF,FBIG,FBIGP,MF1(24),KF1(24),IQF
FBIG=FRATIO(1,1)
MF=1
KF=1
DO 10 K=1,NLAY
DO 10 M=1,3
DELF=FBIG-FRATIO(M,K)
IF(DELF.GE.0)GO TO 10
FBIG=FRATIO(M,K)
MF=M
KF=K
10 CONTINUE
IFF=1
RETURN
END
C
C SUBROUTINE BREIG(IB)
C-----THIS SUBROUTINE CALCULATES THE BIGGEST BREAK-POINT RATIO.
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC19/MB,KB,BBIG,BBIGP,BEST(3,24)
BBIG=BRATIO(1,1)
MR=1
KB=1
DO 10 K=1,NLAY
DO 10 M=1,3
DELB=BBIG-BRATIO(M,K)
IF(DELB.GE.0)GO TO 10
BBIG=BRATIO(M,K)
MB=M
KB=K
10 CONTINUE
IB=1
RETURN
END

```

```

C
SUBROUTINE FAIL(L)
C-----THIS SUBROUTINE CALCULATES STRESSES & STRAINS IN EACH LAYER AT FAILURE
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC5/ALOAD(3,16),NLOADS,IEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLAM
*(3),T(3,3)
COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPHA(24),SALP
*HA(24)
COMMON/LOC18/MF,KF,FBIGP,MF1(24),KF1(24),IQF
COMMON/LOC20/ALOADB(3),ALOADF(3),CELAMB(3),CELMF(3),GSIG(3,24)
DIMENSION FSIG(3,24),FEPS(3,24)
WRITE(6,10)
10 FORMAT(/,5X,'FAILURE PREDICTED IN FOLLOWING LAYERS: ',/)
WRITE(6,15)
15 FORMAT(5X,'(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)')
WRITE(6,20)
20 FORMAT(5X,'MODE',4X,'LAYER')
DO 30 I=1,IQF
30 WRITE(6,40)MF1(I),KF1(I)
40 FORMAT(2(6X,I2))
DO 42 M=1,3
42 ALOADF(M)=ALOADB(M)+ELOAD(M,L)/FBIGP
WRITE(6,44)
44 FORMAT(/,43X,'LONGITUDINAL TRANSVERSE SHEAR')
WRITE(6,45)(ALOADF(M),M=1,3)
45 FORMAT(5X,'APPLIED FORCES/LENGTH AT FAILURE:',2X,3(4X,E10.3))
DO 46 M=1,3
46 CELMF(M)=CELAMB(M)+EPSLAM(M)/FBIGP
WRITE(6,47)(CELMF(M),M=1,3)
47 FORMAT(/,5X,'LAMINATE TOTAL STRAINS:',14X,3(2X,E10.3,2X))
WRITE(6,50)
50 FORMAT(/,5X,'LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE
*:')
WRITE(6,60)
60 FORMAT(/,12X,'ORIENTATION',15X,'STRESSES',31X,'STRAINS')
WRITE(6,70)
70 FORMAT(5X,'LAYER',5X,'ANGLE',3X,2('LONGITUDINAL',2X,'TRANSVERSE',5
*X,'SHEAR',5X))
DO 100 K=1,NLAY
DO 80 M=1,3
FEPS(M,K)=BEPS(M,K)+EPSLAY(M,K)/FBIGP
FSIG(M,K)=BSIG(M,K)+SIGLAY(M,K)/FBIGP
80 CONTINUE
WRITE(6,90)K.ALPHA(K),(FSIG(M,K),M=1,3),(FEPS(M,K),M=1,3)
90 FORMAT(6X,I2,6X,F6.2,3X,6(E11.4,2X))
100 CONTINUE
WRITE(6,110)
110 FORMAT(/,5X,'LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:')
WRITE(6,112)
112 FORMAT(/,12X,'ORIENTATION',15X,'STRESSES')
WRITE(6,114)
114 FORMAT(5X,'LAYER',5X,'ANGLE',3X,'LONGITUDINAL TRANSVERSE SHEA
*R')
DO 130 K=1,NLAY
T(1,1)=CALPHA(K)**2
T(1,2)=SALPHA(K)**2
T(1,3)=-2.*CALPHA(K)*SALPHA(K)
T(2,1)=T(1,2)
T(2,2)=T(1,1)
T(2,3)=-T(1,3)
T(3,1)=CALPHA(K)*SALPHA(K)
T(3,2)=-CALPHA(K)*SALPHA(K)
T(3,3)=T(1,1)-T(1,2)
DO 120 M=1,3
GSIG(M,K)=0.0
DO 120 J=1,3
120 GSIG(K,K)=GSIG(M,K)+T(M,J)*FSIG(J,K)
130 WRITE(6,140)K,ALPHA(K),(GSIG(M,K),M=1,3)
140 FORMAT(6X,I2,6X,F6.2,3X,3(E11.4,2X))
RETURN
END
C
C

```

```

SUBROUTINE BREAK(LOOP,L,JA)
C-----THIS SUBROUTINE CALCULATES LAYER STRESSES & STRAINS IN LAYER CO-CRDS. AT
C-----EACH BREAK-POINT.
COMMON/LOC3/CRITE(3,2,10,2),CRITS(3,2,10,2)
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC5/ALOAD(3,16),NLOADS,IEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLM
*(3),T(3,3)
COMMON/LOC7/ISENT(9,2),IBREAK(24)
COMMON/LOC10/IQB,MB1(24),KB1(24),ILM(3,24)
COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPHA(24),SALP
*HA(24)
COMMON/LOC16/BRATIO(3,24),FRATIO(3,24)
COMMON/LOC17/DENON(24,2)
COMMON/LOC19/NB,KB,BBIGP,BEST(3,24)
COMMON/LOC20/ALOADB(3),ALOADF(3),CELAmb(3),CELMF(3),GSIG(3,24)
WRITE(6,10) LOOP
10 FORMAT(/,5X,'BREAK-POINT NO.',I3,' PREDICTED IN FOLLOWING LAYERS:'
*,/)
WRITE(6,15)
15 FORMAT(5X,'(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)')
WRITE(6,20)
20 FORMAT(5X,'MODE',4X,'LAYER')
DO 30 I=1,IQB
30 WRITE(6,40) MB1(I),KB1(I)
40 FORMAT(2(6X,I2))
DO 42 M=1,3
42 ALOADB(M)=ALOADB(M)+ELOAD(M,L)/BBIGP
WRITE(6,44)
44 FORMAT(/,43X,'LONGITUDINAL TRANSVERSE SHEAR')
WRITE(6,45)(ALOADB(M),M=1,3)
45 FORMAT(5X,'APPLIED FORCES/LENGTH AT BREAK-POINT:',3(2X,E10.3,2X))
DO 46 M=1,3
46 CELAMB(M)=CELAmb(M)+EPSLM(M)/BBIGP
WRITE(6,47)(CELAmb(M),M=1,3)
47 FORMAT(/,5X,'LAMINATE TOTAL STRAINS:',14X,3(2X,E10.3,2X))
WRITE(6,50)
50 FORMAT(/,5X,'LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-P
*OINT:')
WRITE(6,60)
60 FORMAT(/,12X,'ORIENTATION',15X,'STRESSES',31X,'STRAINS')
WRITE(6,70)
70 FORMAT(5X,'LAYER',5X,'ANGLE',3X,2('LONGITUDINAL',2X,'TRANSVERSE',5
*X,'SHEAR',5X))
DO 80 K=1,NLAY
DO 80 M=1,3
BEPS(M,K)=BEPS(M,K)+EPSLAY(M,K)/BBIGP
BSIG(M,K)=BSIG(M,K)+SIGLAY(M,K)/BBIGP
80 CONTINUE
IF(ISENT(JA,1)-2)85,100,120
85 DO 90 I=1,IQB
II=IMATL(KB1(I))
IL=1
IF(BSIG(MB1(I),KB1(I)).LT.0.)IL=2
BSIG(MB1(I),KB1(I))=(-1)**(IL+1))*ABS(CRITS(MB1(I),IL,II,1))
DO 90 M=1,3
90 BEST(M,KB1(I))=BEIG(M,KB1(I))
GO TO 140
100 DO 110 I=1,IQB
II=IMATL(KB1(I))
IL=1
IF(BEPS(MB1(I),KB1(I)).LT.0.)IL=2
REPS(MB1(I),KB1(I))=(-1)**(IL+1))*ABS(CRITE(MB1(I),IL,II,1))
DO 110 M=1,3
110 BEST(M,KB1(I))=BEPS(M,KB1(I))
GO TO 140
120 DO 130 I=1,IQB
II=IMATL(KB1(I))
DO 130 M=1,3
130 BEST(M,KB1(I))=BSIG(M,KB1(I))
140 DO 150 K=1,NLAY
150 WRITE(6,160)K,ALPHA(K),(BSIG(M,K),M=1,3),(BEPS(K,K),M=1,3)
160 FORMAT(6X,I2,6X,F6.2,3X,6(E11.4,2X))
WRITE(6,170)
170 FORMAT(/,5X,'LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:')
WRITE(6,172)
172 FORMAT(/,12X,'ORIENTATION',15X,'STRESSES')
WRITE(6,174)
174 FORMAT(5X,'LAYER ANGLE LONGITUDINAL TRANSVERSE SHEAR')
DO 190 K=1,NLAY
T(1,1)=CALPHA(K)**2

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T(1,2)=SALPHA(K)**2
T(1,3)=-2.*CALPHA(K)*SALPHA(K)
T(2,1)=T(1,2)
T(2,2)=T(1,1)
T(2,3)=-T(1,3)
T(3,1)=CALPHA(K)*SALPHA(K)
T(3,2)=-CALPHA(K)*SALPHA(K)
T(3,3)=T(1,1)-T(1,2)
DO 180 M=1,3
GSIG(M,K)=0.0
DO 180 J=1,3
180 GSIG(M,K)=GSIG(M,K)+T(M,J)*BSIG(J,K)
190 WRITE(6,200)K,ALPHA(K),(GSIG(M,K),M=1,3)
200 FORMAT(6X,I2,6X,F6.2,3X,3(E11.4,2X))
RETURN
END

C
C
SUBROUTINE APLOAD(L)
C-----THIS SUBROUTINE COMPUTES STRESSES & STRAINS IN EACH LAYER AT ANY
C-----PREDETERMINED LEVEL OF APPLIED LAMINATE STRESS.
COMMON/LOC4/NLAY,IMATL(24),ALPHA(24)
COMMON/LOC5/ALOAD(3,16),NLOADSIEL,ELOAD(3,16),NSTRES(16)
COMMON/LOC6/BEPS(3,24),BSIG(3,24),EPSLAY(3,24),SIGLAY(3,24),EPSLM
*(3),T(3,3)
COMMON/LOC13/TS(3,3),TE(3,3),ALPHAR(24),C3(3,3,24),CALPHA(24),SALP
*IHA(24)
COMMON/LOC20/ALOADB(3),ALOADF(3),CELAMB(3),CELAMF(3),GSIG(3,24)
DIMENSION APLODB(3,16),CAPLAM(3),APEPS(3,24),APSIG(3,24)
WRITE(6,10)
10 FORMAT(//,5X,'LAMINATE LOAD HAS REACHED PREDEFINED LEVEL')
WRITE(6,20)
20 FORMAT(//,43X,'LONGITUDINAL TRANSVERSE SHEAR')
DEF=ALOAD(IEL,L)-ALOADB(IEL)
DO 30 N=1,3
30 APLODB(M,L)=ALOADB(M)+ELOAD(M,L)*DEF
WRITE(6,40)(APLODB(M,L),M=1,3)
40 FORMAT(5X,'APPLIED FORCES/LENGTH:',13X,3(4X,E10.3))
DO 50 M=1,3
50 CAPLAM(M)=CELAMB(M)+EPSLM(M)*DEF
WRITE(6,60)(CAPLAM(M),M=1,3)
60 FORMAT(//,5X,'LAMINATE TOTAL STRAINS:',14X,3(2X,E10.3,2X))
WRITE(6,70)
70 FORMAT(//,5X,'LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT PREDEFI
*NED LAMINATE LOAD LEVEL:')
WRITE(6,80)
80 FORMAT(//,12X,'ORIENTATION',15X,'STRESSES',31X,'STRAINS')
WRITE(6,90)
90 FORMAT(5X,'LAYER',5X,'ANGLE',3X,2('LONGITUDINAL',2X,'TRANSVERSE',5
*X,'SHEAR',5X))
DO 120 K=1,NLAY
DO 100 M=1,3
APEPS(M,K)=BEPS(M,K)+EPSLAY(M,K)*DEF
APSIG(M,K)=BSIG(M,K)+SIGLAY(M,K)*DEF
100 CONTINUE
WRITE(6,110)K,ALPHA(K),(APSIG(M,K),M=1,3),(APEPS(M,K),M=1,3)
110 FORMAT(6X,I2,6X,F6.2,3X,6(E11.4,2X))
120 CONTINUE
WRITE(6,130)
130 FORMAT(//,5X,'LAYER STRESSES IN LAMINATE CO-ORDS AT APPLIED LOAD:')
WRITE(6,140)
140 FORMAT(//,12X,'ORIENTATION',15X,'STRESSES')
WRITE(6,150)
150 FORMAT(5X,'LAYER ANGLE LONGITUDINAL TRANSVERSE SHEAR')
DO 170 K=1,NLAY
T(1,1)=CALPHA(K)**2
T(1,2)=SALPHA(K)**2
T(1,3)=-2.*CALPHA(K)*SALPHA(K)
T(2,1)=T(1,2)
T(2,2)=T(1,1)
T(2,3)=-T(1,3)
T(3,1)=CALPHA(K)*SALPHA(K)
T(3,2)=-T(3,1)
T(3,3)=T(1,1)-T(1,2)
DO 160 M=1,3
GSIG(M,K)=0.0
DO 160 J=1,3
160 GSIG(M,K)=GSIG(M,K)+T(M,J)*APSIG(J,K)
170 WRITE(6,180)K,ALPHA(K),(GSIG(M,K),M=1,3)
180 FORMAT(6X,I2,6X,F6.2,3X,3(E11.4,2X))
RETURN
END

```

9.1.2 Sample Cases

Case 1:

- $[0/\pm 45/90]_s$ G1/Ep laminate.
- Same material in all layers.
- All nine possible types of break point/failure analyses performed.
- Quadratic interaction coefficient selected by user.
- No. of load-sets: 1.
- Stress print-out not requested at any specified laminate load.
- Post-break-point modulus in transverse tension input negative to demonstrate capability of program to model stress-strain curve with negative slope.

```

EELASTD NLAMM=1,NMATLL=1,
AXE(1,1,1)=6.20E 06,
AXE(1,2,1)=4.5E 03,
TRANE(1,1,1)=1.650E 06,
TRANE(1,2,1)=2.00E 06,
GL(1,1,1)=0.63E 06,
AXNU(1,1,1)=0.3,
AXE(1,1,2)=6.20E 06,
AXE(1,2,2)=1.31E 06,
TRANE(1,1,2)=-0.20E 00,
TRANE(1,2,2)=0.140E 06,
GL(1,2)=0.0475E 06,
AXNU(1,1,2)=0.3,
AXNU(1,1,3)=0.3,
AXNU(1,1,4)=0.3,
AXNU(1,1,5)=0.3,
&END
&CRITIC
CRITS(1,1,1,1)=2300.E 03, CRITS(1,2,1,1)=100.0E 03,
CRITS(2,1,1,1)=73.10E 03, CRITS(2,2,1,1)=20.0E 03,
CRITS(3,1,1,1)=6.62E 03, CRITS(3,2,1,1)=6.62E 03,
CRITS(1,1,1,2)=229.0E 03, CRITS(1,2,1,2)=134.0E 03,
CRITS(2,1,1,2)=25.0E+07, CRITS(2,2,1,2)=25.0E+07,
CRITS(3,1,1,2)=66.2E 03, CRITS(3,2,1,2)=66.2E 03,
CRITE(1,1,1,1)=370.E-03, CRITE(1,2,1,1)=16.1E-03,
CRITE(2,1,1,1)=14.00E-03, CRITE(2,2,1,1)=12.1E-03,
CRITE(3,1,1,1)=10.5E-03, CRITE(3,2,1,1)=10.5E-03,
CRITE(1,1,1,2)=37.00E-03, CRITE(1,2,1,2)=22.0E-03,
CRITE(2,1,1,2)=2.90E 03, CRITE(2,2,1,2)=70.0E-03,
CRITE(3,1,1,2)=130.0E-03, CRITE(3,2,1,2)=130.0E-03,
&END
&OPT1 NLOADS=1,A12(1,1)=16*0.0,NANS=9
&END
&OPTION ISENT(1,1)=1,ISENT(1,2)=1,
ISENT(2,1)=1,ISENT(2,2)=2,
ISENT(3,1)=1,ISENT(3,2)=3,
ISENT(4,1)=2,ISENT(4,2)=1,
ISENT(5,1)=2,ISENT(5,2)=2,
ISENT(6,1)=2,ISENT(6,2)=3,
ISENT(7,1)=3,ISENT(7,2)=1,
ISENT(8,1)=3,ISENT(8,2)=2,
ISENT(9,1)=3,ISENT(9,2)=3,
&END
&LOAD
ALOAD(1,1)=1.0,ALOAD(2,1)=1.0,
&END
&GEOED NLAY=8,IMATL=8*1,
ALPHA(1)=0.0,ALPHA(2)=45.0,ALPHA(3)=-45.0,ALPHA(4)=90.0,
ALPHA(5)=90.0,ALPHA(6)=-45.0,ALPHA(7)=45.0,ALPHA(8)=-0.0,
DELTA=8*0.125
&END

```

MATERIAL ELASTIC PROPERTIES:

PROPERTIES BEFORE BREAK-POINT:

MATL NO	AXIAL YOUNGS MODULUS		TRANS YOUNGS MODULUS		SHEAR MODULUS	AXIAL PCISSCN RATIO
	TENSION	COMPR	TENSION	COMPR		
1	0.6200E 07	0.6200E 07	0.1650E 07	0.1650E 07	0.6300E 06	0.3000E 00

PROPERTIES AFTER BREAK-POINT:

MATL NO	AXIAL YOUNGS MODULUS		TRANS YOUNGS MODULUS		SHEAR MODULUS
	TENSION	COMPR	TENSION	COMPR	
1	0.6200E 07	0.1310E 07	-0.2000E 00	0.1400E 06	0.4750E 05

1.2

***** AXIAL POISSONS RATIO *****

AX COMPR	SHEAR/T TENS	TR COMPR	QUAD
0.3000E 00	0.3000E 00	0.3000E 00	0.3000E 00

INPUT BREAK-POINT STRESSES & STRAINS:

STRESSES				STRAINS			
MATL	AXIAL	TRANS	SHEAR	AXIAL	TRANS	SHEAR	
TENS	1	0.230E 07	0.231E 05	0.662E 04	0.370E 00	0.140E-01	0.105E-01
COMP		0.100E 06	0.200E 05	0.662E 04	0.161E-01	0.121E-01	0.105E-01

INPUT ULTIMATE STRESSES & STRAINS:

STRESSES				STRAINS			
MATL	AXIAL	TRANS	SHEAR	AXIAL	TRANS	SHEAR	
TENS	1	0.229E 06	0.250E 09	0.662E 05	0.370E-01	0.290E 04	0.130E 00
COMP		0.134E 06	0.250E 09	0.662E 05	0.220E-01	0.700E-01	0.130E 00

QUADRATIC INTERACTION CO-EFFICIENTS :

MATERIAL	BREAK-POINT	FAILURE
1	0.0	0.0

LAMINATE 1

LAYER	MATERIAL	THICKNESS	ANGLE
1	1	0.1250	0.0
2	1	0.1250	45.00
3	1	0.1250	-45.00
4	1	0.1250	90.00
5	1	0.1250	90.00
6	1	0.1250	-45.00
7	1	0.1250	45.00
8	1	0.1250	0.0

APPLIED LAMINATE FORCES/LENGTH:	LONGITUDINAL 0.100E 01	TRANSVERSE 0.100E 01	SHEAR 0.0
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ANALYSIS NUMBER 1:

BREAK-POINT ANALYSIS= 1; FAILURE ANALYSIS= 1

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

1.3

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT:	LONGITUDINAL	TRANSVERSE	SHEAR
	0.476E 05	0.476E C5	0.0

LAMINATE TOTAL STRAINS: 0.105E-01 0.105E-01 -0.138E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	STRESSES	SHEAR	LONGITUDINAL	STRAINS	TRANSVERSE	SHEAR
1		0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-C1	0.1051E-01	-0.1376E-07	
2		45.00	0.7210F 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
3		-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051F-01	0.1051E-01	-0.6562E-14	
4		90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-C1	0.1051E-01	0.1376F-07	
5		90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-01	0.1051E-01	0.1376E-07	
6		-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
7		45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051F-01	0.1051E-01	-0.6562E-14	
8		0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-01	0.1051E-01	-0.1376E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	STRESSES	SHEAR
1		0.0	0.7210E 05	0.2310E 05	-0.8669E-02
2		45.00	0.4760E 05	0.4760F 05	0.2450E C5
3		-45.00	0.4760E 05	0.4760E 05	-0.2450E C5
4		90.00	0.2310E 05	0.7210E 05	0.5344E-01
5		90.00	0.2310E 05	0.7210E 05	0.5344E-C1
6		-45.00	0.4760E 05	0.4760E 05	-0.2450E C5
7		45.00	0.4760E 05	0.4760E 05	0.2450E 05
8		0.0	0.7210E 05	0.2310E 05	-0.8669E-02

SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625F-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E C6

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1 3
1 6
1 4
1 5
1 1
1 8
1 2
1 7

1.4

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
0.126E 06 0.126E 06 0.0
LAMINATE TOTAL STRAINS: 0.358E-01 0.358E-01 -0.771E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION		STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	0.3582E-01	0.3582E-01	-0.7713E-07	
2	45.00	0.2290E 06	0.2310E 05	0.1271E-02	0.3582E-01	0.3582E-01	0.2676E-07	
3	-45.00	0.2290E 06	0.2310E 05	-0.1271E-02	0.3582E-01	0.3582E-01	-0.2676E-07	
4	90.00	0.2290E 06	0.2310E 05	0.1168E-01	0.3582E-01	0.3582E-01	0.7713E-07	
5	90.00	0.2290E 06	0.2310E 05	0.1168E-01	0.3582E-01	0.3582E-01	0.7713E-07	
6	-45.00	0.2290E 06	0.2310E 05	-0.1271E-02	0.3582E-01	0.3582E-01	-0.2676E-07	
7	45.00	0.2290E 06	0.2310E 05	0.1271E-02	0.3582E-01	0.3582E-01	0.2676E-07	
8	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	0.3582E-01	0.3582E-01	-0.7713E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	
2	45.00	0.1260E 06	0.1260E 06	0.1029E 06	
3	-45.00	0.1260E 06	0.1260E 06	-0.1029E 06	
4	90.00	0.2310E 05	0.2290E 06	0.2493E 00	
5	90.00	0.2310E 05	0.2290E 06	0.2493E 00	
6	-45.00	0.1260E 06	0.1260E 06	-0.1029E 06	
7	45.00	0.1260E 06	0.1260E 06	0.1029E 06	
8	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	

FIRST FIBER FAILURE

ANALYSIS NUMBER 2:

BREAK-POINT ANALYSIS= 1; FAILURE ANALYSIS= 2

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT: 0.476E 05 LONGITUDINAL TRANSVERSE SHEAR 1.5

LAMINATE TOTAL STRAINS: 0.105E-01 0.105E-01 -0.138E-07

LAYER STRESSES & STRAINS IN LAYER CO-CRDS. AT BREAK-POINT:

ORIENTATION		STRESSES			STRAINS		
LAYER	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-01	0.1051E-01	-0.1376E-07
2	45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14
3	-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14
4	90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-01	0.1051E-01	0.1376E-07
5	90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-01	0.1051E-01	0.1376E-07
6	-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14
7	45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14
8	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-01	0.1051E-01	-0.1376E-07

LAYER STRESSES IN LAMINATE CO-CRDS AT BREAK-POINT:

ORIENTATION		STRESSES		
LAYER	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.7210E 05	0.2310E 05	-0.8669E-02
2	45.00	0.4760E 05	0.4760E 05	0.2450E 05
3	-45.00	0.4760E 05	0.4760E 05	-0.2450E 05
4	90.00	0.2310E 05	0.7210E 05	0.5344E-01
5	90.00	0.2310E 05	0.7210E 05	0.5344E-01
6	-45.00	0.4760E 05	0.4760E 05	-0.2450E 05
7	45.00	0.4760E 05	0.4760E 05	0.2450E 05
8	0.0	0.7210E 05	0.2310E 05	-0.8669E-02

SHEAR & OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULE & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	3
1	6
1	4
1	5
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR

LAMINATE TOTAL STRAINS: 0.370E-01 0.370E-01 -0.801E-07

LAYER STRESSES & STRAINS IN LAYER CO-CRDS. AT FAILURE:

ORIENTATION		STRESSES			STRAINS		
LAYER	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2363E 06	0.2310E 05	-0.1182E-01	0.3700E-01	0.3700E-01	-0.8009E-07
2	45.00	0.2363E 06	0.2310E 05	0.1330E-02	0.3700E-01	0.3700E-01	0.2801E-07
3	-45.00	0.2363E 06	0.2310E 05	-0.1330E-02	0.3700E-01	0.3700E-01	-0.2801E-07
4	90.00	0.2363E 06	0.2310E 05	0.1182E-01	0.3700E-01	0.3700E-01	0.8009E-07
5	90.00	0.2363E 06	0.2310E 05	0.1182E-01	0.3700E-01	0.3700E-01	0.8009E-07
6	-45.00	0.2363E 06	0.2310E 05	-0.1330E-02	0.3700E-01	0.3700E-01	-0.2801E-07
7	45.00	0.2363E 06	0.2310E 05	0.1330E-02	0.3700E-01	0.3700E-01	0.2801E-07
8	0.0	0.2363E 06	0.2310E 05	-0.1182E-01	0.3700E-01	0.3700E-01	-0.8009E-07

LAYER STRESSES IN LAMINATE CO-CRDS AT FAILURE:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.2363E 06	0.2310E 05	-0.1192E-01	
2	45.00	0.1297E 06	0.1297E 06	0.1066E 06	
3	-45.00	0.1297E 06	0.1297E 06	-0.1066E 06	
4	90.00	0.2310E 05	0.2363E 06	0.2585E 00	
5	90.00	0.2310E 05	0.2363E 06	0.2585E 00	
6	-45.00	0.1297E 06	0.1297E 06	-0.1066E 06	
7	45.00	0.1297E 06	0.1297E 06	0.1066E 06	
8	0.0	0.2363E 06	0.2310E 05	-0.1192E-01	

1.6

FIRST FIBER FAILURE

ANALYSIS NUMBER 3:

BREAK-POINT ANALYSIS= 1; FAILURE ANALYSIS= 3

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL 0.476E 05 TRANSVERSE 0.476E 05 SHEAR 0.0

LAMINATE TOTAL STRAINS: 0.105E-01 0.105E-01 -0.138E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-01	0.1051E-01	-0.1376E-07	
2	45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
3	-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
4	90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-01	0.1051E-01	0.1376E-07	
5	90.00	0.7210E 05	0.2310E 05	0.8669E-02	0.1051E-01	0.1051E-01	0.1376E-07	
6	-45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
7	45.00	0.7210E 05	0.2310E 05	-0.4134E-08	0.1051E-01	0.1051E-01	-0.6562E-14	
8	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	0.1051E-01	0.1051E-01	-0.1376E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	
2	45.00	0.4760E 05	0.4760E 05	0.2450E 05	
3	-45.00	0.4760E 05	0.4760E 05	-0.2450E 05	
4	90.00	0.2310E 05	0.7210E 05	0.5344E-01	
5	90.00	0.2310E 05	0.7210E 05	0.5344E-01	
6	-45.00	0.4760E 05	0.4760E 05	-0.2450E 05	
7	45.00	0.4760E 05	0.4760E 05	0.2450E 05	
8	0.0	0.7210E 05	0.2310E 05	-0.8669E-02	

SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

1.7

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1	3
1	4
1	5
1	6
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR

0.126E 06 0.126E 06 0.0

LAMINATE TOTAL STRAINS: 0.358E-01 0.358E-01 -0.771E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION	STRESSES	STRAINS				
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	0.3582E-01	0.3582E-01	-0.7713E-07
2	45.00	0.2290E 06	0.2310E 05	0.1271E-02	0.3582E-01	0.3582E-01	0.2676E-07
3	-45.00	0.2290E 06	0.2310E 05	-0.1271E-02	0.3582E-01	0.3582E-01	-0.2676E-07
4	90.00	0.2290E 06	0.2310E 05	0.1168E-01	0.3582E-01	0.3582E-01	0.7713E-07
5	90.00	0.2290E 06	0.2310E 05	0.1168E-01	0.3582E-01	0.3582E-01	0.7713E-07
6	-45.00	0.2290E 06	0.2310E 05	-0.1271E-02	0.3582E-01	0.3582E-01	-0.2676E-07
7	45.00	0.2290E 06	0.2310E 05	0.1271E-02	0.3582E-01	0.3582E-01	0.2676E-07
8	0.0	0.2290E 06	0.2310E 05	-0.1168E-01	0.3582E-01	0.3582E-01	=0.7713E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ORIENTATION	STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.2310E 05	-0.1168E-01
2	45.00	0.1260E 06	0.1260E 06	0.1029E 06
3	-45.00	0.1260E 06	0.1260E 06	-0.1029E 06
4	90.00	0.2310E 05	0.2290E 06	0.2493E 00
5	90.00	0.2310E 05	0.2290E 06	0.2493E 00
6	-45.00	0.1260E 06	0.1260E 06	-0.1029E 06
7	45.00	0.1260E 06	0.1260E 06	0.1029E 06
8	0.0	0.2290E 06	0.2310E 05	-0.1168E-01

FIRST FIBER FAILURE

ANALYSIS NUMBER 4:

BREAK-POINT ANALYSIS= 2; FAILURE ANALYSIS= 1

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
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LONG 0.312623E 07 0.309647E 00 0.119354E 07
 TRAN 0.312623E 07 0.309647E 00 0.119354E 07

1.8

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR
 0.634E 05 0.634E 05 0.0

LAMINATE TOTAL STRAINS: 0.140E-01 0.140E-01 -0.183E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

ORIENTATION		STRESSES			STRAINS		
LAYER	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07
2	45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
3	-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
4	90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07
5	90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07
6	-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
7	45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
8	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

ORIENTATION		STRESSES		
LAYER	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.9603E 05	0.3077E 05	-0.1155E-01
2	45.00	0.6340E 05	0.6340E 05	0.3263E 05
3	-45.00	0.6340E 05	0.6340E 05	-0.3263E 05
4	90.00	0.3077E 05	0.9603E 05	0.7118E-01
5	90.00	0.3077E 05	0.9603E 05	0.7118E-01
6	-45.00	0.6340E 05	0.6340E 05	-0.3263E 05
7	45.00	0.6340E 05	0.6340E 05	0.3263E 05
8	0.0	0.9603E 05	0.3077E 05	-0.1155E-01

SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
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LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1	3
1	4
1	5
1	6
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
 0.130E 06 0.130E 06 0.0

LAMINATE TOTAL STRAINS: 0.354E-01 0.354E-01 -0.720E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

1.9

LAYER	ORIENTATION ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.3077E 05	-0.1410E-01	0.3545E-01	0.3545E-01	-0.7203E-07
2	45.00	0.2290E 06	0.3077E 05	0.1077E-02	0.3545E-01	0.3545E-01	0.2268E-07
3	-45.00	0.2290E 06	0.3077E 05	-0.1077E-02	0.3545E-01	0.3545E-01	-0.2268E-07
4	90.00	0.2290E 06	0.3077E 05	0.1410E-01	0.3545E-01	0.3545E-01	0.7203E-07
5	90.00	0.2290E 06	0.3077E 05	0.1410E-01	0.3545E-01	0.3545E-01	0.7203E-07
6	-45.00	0.2290E 06	0.3077E 05	-0.1077E-02	0.3545E-01	0.3545E-01	-0.2268E-07
7	45.00	0.2290E 06	0.3077E 05	0.1077E-02	0.3545E-01	0.3545E-01	0.2268E-07
8	0.0	0.2290E 06	0.3077E 05	-0.1410E-01	0.3545E-01	0.3545E-01	-0.7203E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ORIENTATION ANGLE	STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.3077E 05	-0.1410E-01
2	45.00	0.1299E 06	0.1299E 06	0.9912E 05
3	-45.00	0.1299E 06	0.1299E 06	-0.9912E 05
4	90.00	0.3077E 05	0.2290E 06	0.2372E 00
5	90.00	0.3077E 05	0.2290E 06	0.2372E 00
6	-45.00	0.1299E 06	0.1299E 06	-0.9912E 05
7	45.00	0.1299E 06	0.1299E 06	0.9912E 05
8	0.0	0.2290E 06	0.3077E 05	-0.1410E-01

FIRST FIBER FAILURE

ANALYSIS NUMBER 5:

BREAK-POINT ANALYSIS= 2; FAILURE ANALYSIS= 2

{ 1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION}

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT: 0.634E 05 0.634E 05 0.0

LAMINATE TOTAL STRAINS: 0.140E-01 0.140E-01 -0.183E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07
2	45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
3	-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
4	90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07
5	90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07
6	-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
7	45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14
8	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	
2	45.00	0.6340E 05	0.6340E 05	0.3263E 05	
3	-45.00	0.6340E 05	0.6340E 05	-0.3263E 05	
4	90.00	0.3077E 05	0.9603E 05	0.7118E-01	
5	90.00	0.3077E 05	0.9603E 05	0.7118E-01	
6	-45.00	0.6340E 05	0.6340E 05	-0.3263E 05	
7	45.00	0.6340E 05	0.6340E 05	0.3263E 05	
8	0.0	0.9603E 05	0.3077E 05	-0.1155E-01	

SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	3
1	6
1	4
1	5
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE:	LONGITUDINAL	TRANSVERSE	SHEAR
	0.135E 06	0.135E 06	0.0
LAMINATE TOTAL STRAINS:	0.370E-01	0.370E-01	-0.759E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION			STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.2386E 06	0.3077E 05	-0.1428E-01	0.3700E-01	0.3700E-01	-0.7592E-07		
2	45.00	0.2386E 06	0.3077E 05	0.1155E-02	0.3700E-01	0.3700E-01	0.2432E-07		
3	-45.00	0.2386E 06	0.3077E 05	-0.1155E-02	0.3700E-01	0.3700E-01	-0.2432E-07		
4	90.00	0.2386E 06	0.3077E 05	0.1428E-01	0.3700E-01	0.3700E-01	0.7592E-07		
5	90.00	0.2386E 06	0.3077E 05	0.1428E-01	0.3700E-01	0.3700E-01	0.7592E-07		
6	-45.00	0.2386E 06	0.3077E 05	-0.1155E-02	0.3700E-01	0.3700E-01	-0.2432E-07		
7	45.00	0.2386E 06	0.3077E 05	0.1155E-02	0.3700E-01	0.3700E-01	0.2432E-07		
8	0.0	0.2386E 06	0.3077E 05	-0.1428E-01	0.3700E-01	0.3700E-01	-0.7592E-07		

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ORIENTATION			STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.2386E 06	0.3077E 05	-0.1428E-01		
2	45.00	0.1347E 06	0.1347E 06	0.1039E 06		
3	-45.00	0.1347E 06	0.1347E 06	-0.1039E 06		
4	90.00	0.3077E 05	0.2386E 06	0.2492E 00		
5	90.00	0.3077E 05	0.2386E 06	0.2492E 00		
6	-45.00	0.1347E 06	0.1347E 06	-0.1039E 06		
7	45.00	0.1347E 06	0.1347E 06	0.1039E 06		
8	0.0	0.2386E 06	0.3077E 05	-0.1428E-01		

FIRST FIBER FAILURE

ANALYSIS NUMBER 6:

1.11

BREAK-POINT ANALYSIS= 2; FAILURE ANALYSIS= 3

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	2
2	4
2	5
2	7
2	8
2	3
2	6

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR
0.634E 05 0.634E 05 0.0

LAMINATE TOTAL STRAINS: 0.140E-01 0.140E-01 -0.183E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	STRAINS	SHEAR
1		0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07	
2		45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14	
3		-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14	
4		90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07	
5		90.00	0.9603E 05	0.3077E 05	0.1155E-01	0.1400E-01	0.1400E-01	0.1833E-07	
6		-45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14	
7		45.00	0.9603E 05	0.3077E 05	-0.5506E-08	0.1400E-01	0.1400E-01	-0.8739E-14	
8		0.0	0.9603E 05	0.3077E 05	-0.1155E-01	0.1400E-01	0.1400E-01	-0.1833E-07	

LAYER STRESSES IN LAMINATE CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1		0.0	0.9603E 05	0.3077E 05	-0.1155E-01
2		45.00	0.6340E 05	0.6340E 05	0.3263E 05
3		-45.00	0.6340E 05	0.6340E 05	-0.3263E 05
4		90.00	0.3077E 05	0.9603E 05	0.7118E-01
5		90.00	0.3077E 05	0.9603E 05	0.7118E-01
6		-45.00	0.6340E 05	0.6340E 05	-0.3263E 05
7		45.00	0.6340E 05	0.6340E 05	0.3263E 05
8		0.0	0.9603E 05	0.3077E 05	-0.1155E-01

SHEAR &/OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

1.12

MODE	LAYER
1	3
1	6
1	1
1	4
1	5
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE:	LONGITUDINAL	TRANSVERSE	SHEAR
	0.130E 06	0.130E 06	0.0

LAMINATE TOTAL STRAINS: 0.354E-01 0.354E-01 -0.720E-07

LAYER STRESSES & STRAINS IN LAYER CO-CORDS. AT FAILURE:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	STRAINS
1	0.0	0.0	0.2290E 06	0.3077E 05	-0.1410E-01	0.3545E-01	0.3545E-01	-0.7203E-07
2	45.00	45.00	0.2290E 06	0.3077E 05	0.1077E-02	0.3545E-01	0.3545E-01	0.2268E-07
3	-45.00	-45.00	0.2290E 06	0.3077E 05	-0.1077E-02	0.3545E-01	0.3545E-01	-0.2268E-07
4	90.00	90.00	0.2290E 06	0.3077E 05	0.1410E-01	0.3545E-01	0.3545E-01	0.7203E-07
5	90.00	90.00	0.2290E 06	0.3077E 05	0.1410E-01	0.3545E-01	0.3545E-01	0.7203E-07
6	-45.00	-45.00	0.2290E 06	0.3077E 05	-0.1077E-02	0.3545E-01	0.3545E-01	-0.2268E-07
7	45.00	45.00	0.2290E 06	0.3077E 05	0.1077E-02	0.3545E-01	0.3545E-01	0.2268E-07
8	0.0	0.0	0.2290E 06	0.3077E 05	-0.1410E-01	0.3545E-01	0.3545E-01	-0.7203E-07

LAYER STRESSES IN LAMINATE CO-CORDS AT FAILURE:

LAYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.0	0.2290E 06	0.3077E 05	-0.1410E-01
2	45.00	45.00	0.1299E 06	0.1299E 06	0.9912E 05
3	-45.00	-45.00	0.1299E 06	0.1299E 06	-0.9912E 05
4	90.00	90.00	0.3077E 05	0.2290E 06	0.2372E 00
5	90.00	90.00	0.3077E 05	0.2290E 06	0.2372E 00
6	-45.00	-45.00	0.1299E 06	0.1299E 06	-0.9912E 05
7	45.00	45.00	0.1299E 06	0.1299E 06	0.9912E 05
8	0.0	0.0	0.2290E 06	0.3077E 05	-0.1410E-01

FIRST FIBER FAILURE

ANALYSIS NUMBER 7:

BREAK-POINT ANALYSIS= 3; FAILURE ANALYSIS= 1

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULUS & POISSON RATIOS:

YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG 0.312623E 07	0.309647E 00	0.119354E 07
TRAN 0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	1
1	2
1	4
1	5
1	7
1	8
1	3
1	6

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR 1.13
 0.641E 05 0.641E 05 0.0

LAMINATE TOTAL STRAINS: 0.142E-01 0.142E-01 -0.185E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07	
2	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
3	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-C1	0.1416E-01	-0.8842E-14	
4	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-C1	0.1854E-07	
5	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-01	0.1854E-07	
6	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-C1	0.1416E-01	-0.8842E-14	
7	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	
2	45.00	0.6414E 05	0.6414E 05	0.3301E 05	
3	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05	
4	90.00	0.3113E 05	0.9715E 05	0.7201E-01	
5	90.00	0.3113E 05	0.9715E 05	0.7201E-01	
6	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05	
7	45.00	0.6414E 05	0.6414E 05	0.3301E 05	
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-C1	

QUADRATIC BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULE & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E C6

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	3
1	4
1	5
1	6
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
 0.130E 06 0.130E 06 0.0

LAMINATE TOTAL STRAINS: 0.354E-C1 0.354E-C1 -0.718E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION		STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	0.3543E-C1	0.3543E-01	-0.7179E-07	
2	45.00	0.2290E 06	0.3113E 05	0.1068E-02	0.3543E-01	0.3543E-01	0.2248E-07	
3	-45.00	0.2290E 06	0.3113E 05	-0.1068E-02	0.3543E-01	0.3543E-01	-0.2248E-07	
4	90.00	0.2290E 06	0.3113E 05	0.1421E-C1	0.3543E-C1	0.3543E-C1	0.7179E-07	
5	90.00	0.2290E 06	0.3113E 05	0.1421E-01	0.3543E-01	0.3543E-01	0.7179E-07	
6	-45.00	0.2290E 06	0.3113E 05	-0.1068E-02	0.3543E-01	0.3543E-01	-0.2248E-07	
7	45.00	0.2290E 06	0.3113E 05	0.1068E-02	0.3543E-01	0.3543E-C1	0.2248E-07	
8	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	0.3543E-01	0.3543E-01	-0.7179E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ANGLE	LONGITUDINAL	STRESSES		
			TRANSVERSE	SHEAR	
1	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	
2	45.00	0.1301E 06	0.1301E 06	0.9894E 05	
3	-45.00	0.1301E 06	0.1301E 06	-0.9894E 05	
4	90.00	0.3113E 05	0.2290E 06	0.2366E 00	
5	90.00	0.3113E 05	0.2290E 06	0.2366E 00	
6	-45.00	0.1301E 06	0.1301E 06	-0.9894E 05	
7	45.00	0.1301E 06	0.1301E 06	0.9894E 05	
8	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	

1.14

FIRST FIBER FAILURE

ANALYSIS NUMBER 8:

BREAK-POINT ANALYSIS= 3; FAILURE ANALYSIS= 2

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	1
1	2
1	4
1	5
1	7
1	8
1	3
1	6

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR
 0.641E 05 0.641E 05 0.0

LAMINATE TOTAL STRAINS: 0.142E-01 0.142E-01 -0.185E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ANGLE	LONGITUDINAL	STRESSES			STRAINS		
			TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07	
2	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
3	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
4	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-01	0.1854E-07	
5	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-01	0.1854E-07	
6	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
7	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14	
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ANGLE	LONGITUDINAL	STRESSES		
			TRANSVERSE	SHEAR	
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	
2	45.00	0.6414E 05	0.6414E 05	0.2301E 05	
3	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05	
4	90.00	0.3113E 05	0.9715E 05	0.7201E-01	
5	90.00	0.3113E 05	0.9715E 05	0.7201E-01	
6	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05	
7	45.00	0.6414E 05	0.6414E 05	0.2301E 05	
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	

QUADRATIC BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)
 MODE LAYER

1	3
1	6
1	4
1	5
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
 0.135E 06 0.135E 06 0.0

LAMINATE TOTAL STRAINS: 0.370E-01 0.370E-01 -0.757E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2387E 06	0.3113E 05	-0.1440E-01	0.3700E-01	-0.7572E-07	
2	45.00	0.2387E 06	0.3113E 05	0.1147E-02	0.3700E-01	0.2414E-07	
3	-45.00	0.2387E 06	0.3113E 05	-0.1147E-02	0.3700E-01	-0.2414E-07	
4	90.00	0.2387E 06	0.3113E 05	0.1440E-01	0.3700E-01	0.7572E-07	
5	90.00	0.2387E 06	0.3113E 05	0.1440E-01	0.3700E-01	0.7572E-07	
6	-45.00	0.2387E 06	0.3113E 05	-0.1147E-02	0.3700E-01	-0.2414E-07	
7	45.00	0.2387E 06	0.3113E 05	0.1147E-02	0.3700E-01	0.2414E-07	
8	0.0	0.2387E 06	0.3113E 05	-0.1440E-01	0.3700E-01	-0.7572E-07	

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ANGLE	STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2387E 06	0.3113E 05	-0.1440E-01
2	45.00	0.1349E 06	0.1349E 06	0.1038E 06
3	-45.00	0.1349E 06	0.1349E 06	-0.1038E 06
4	90.00	0.3113E 05	0.2387E 06	0.2488E 00
5	90.00	0.3113E 05	0.2387E 06	0.2488E 00
6	-45.00	0.1349E 06	0.1349E 06	-0.1038E 06
7	45.00	0.1349E 06	0.1349E 06	0.1038E 06
8	0.0	0.2387E 06	0.3113E 05	-0.1440E-01

FIRST FIBER FAILURE

ANALYSIS NUMBER 9:

BREAK-POINT ANALYSIS= 3; FAILURE ANALYSIS= 3

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.150E 01
0.625E-01	0.150E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312623E 07	0.309647E 00	0.119354E 07
TRAN	0.312623E 07	0.309647E 00	0.119354E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

1.16

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1	1
1	2
1	4
1	5
1	7
1	8
1	3
1	6

APPLIED FORCES/LENGTH AT BREAK-POINT: 0.641E 05 LONGITUDINAL TRANSVERSE SHEAR
0.641E 05 0.0

LAMINATE TOTAL STRAINS: 0.142E-01 0.142E-01 -0.185E-07

LAYER STRESSES & STRAINS IN LAYER CO-CROS. AT BREAK-POINT:

LAYER	ORIENTATION	STRESSES			STRAINS		
		ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07
2	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14
3	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14
4	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-01	0.1854E-07
5	90.00	0.9715E 05	0.3113E 05	0.1168E-01	0.1416E-01	0.1416E-01	0.1854E-07
6	-45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14
7	45.00	0.9715E 05	0.3113E 05	-0.5570E-08	0.1416E-01	0.1416E-01	-0.8842E-14
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-01	0.1416E-01	0.1416E-01	-0.1854E-07

LAYER STRESSES IN LAMINATE CO-CROS AT BREAK-POINT:

LAYER	ORIENTATION	STRESSES		
		ANGLE	LONGITUDINAL	TRANSVERSE
1	0.0	0.9715E 05	0.3113E 05	-0.1168E-01
2	45.00	0.6414E 05	0.6414E 05	0.3301E 05
3	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05
4	90.00	0.3113E 05	0.9715E 05	0.7201E-01
5	90.00	0.3113E 05	0.9715E 05	0.7201E-01
6	-45.00	0.6414E 05	0.6414E 05	-0.3301E 05
7	45.00	0.6414E 05	0.6414E 05	0.3301E 05
8	0.0	0.9715E 05	0.3113E 05	-0.1168E-01

QUADRATIC BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.194E 01
0.625E-01	0.194E 01	0.799E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210846E 07	0.319851E 00	0.798750E 06
TRAN	0.210846E 07	0.319851E 00	0.798750E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1	3
1	4
1	5
1	6
1	1
1	8
1	2
1	7

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
0.130E 06 0.130E 06 0.0

LAMINATE TOTAL STRAINS: 0.354E-01 0.354E-01 -0.718E-07

LAYER STRESSES & STRAINS IN LAYER CO-CRDS. AT FAILURE:

1.17

LAYER	ORIENTATION			STRESSES			STRAINS		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	0.3543E-01	0.3543E-01	-0.7179E-07		
2	45.00	0.2290E 06	0.3113E 05	0.1068E-02	0.3543E-01	0.3543E-01	0.2248E-07		
3	-45.00	0.2290E 06	0.3113E 05	-0.1068E-02	0.3543E-01	0.3543E-01	-0.2248E-07		
4	90.00	0.2290E 06	0.3113E 05	0.1421E-01	0.3543E-01	0.3543E-01	0.7179E-07		
5	90.00	0.2290E 06	0.3113E 05	0.1421E-01	0.3543E-01	0.3543E-01	0.7179E-07		
6	-45.00	0.2290E 06	0.3113E 05	-0.1068E-02	0.3543E-01	0.3543E-01	-0.2248E-07		
7	45.00	0.2290E 06	0.3113E 05	0.1068E-02	0.3543E-01	0.3543E-01	0.2248E-07		
8	0.0	0.2290E 06	0.3113E 05	-0.1421E-01	0.3543E-01	0.3543E-01	-0.7179E-07		

LAYER STRESSES IN LAMINATE CO-CRDS AT FAILURE:

LAYER	ORIENTATION			STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.2290E 06	0.3113E 05	-0.1421E-01		
2	45.00	0.1301E 06	0.1301E 06	0.9894E 09		
3	-45.00	0.1301E 06	0.1301E 06	-0.9894E 09		
4	90.00	0.3113E 05	0.2290E 06	0.2366E 00		
5	90.00	0.3113E 05	0.2290E 06	0.2366E 00		
6	-45.00	0.1301E 06	0.1301E 06	-0.9894E 09		
7	45.00	0.1301E 06	0.1301E 06	0.9894E 09		
8	0.0	0.2290E 06	0.3113E 05	-0.1421E-01		

FIRST FIBER FAILURE

9.1.2 Sample Cases (cont'd)

Case 2:

- $[0/\pm 30/\pm 60/90]_S$ G1/Ep laminate.
- Same material in all layers.
- Breakpoint and failure stresses and strains in compression are input with a negative sign to illustrate that it does not affect the analysis.
- Types of break point/failure analyses: default.
- Quadratic interaction coefficient: default..
- Number of load sets: 2.
- Option exercised to print layer stresses and strains at predetermined level of input laminate loads.

```

&ELASTD NLAMM=1,NMATLL=1,
AXE(1,1,1)=6.20E 06,
AXE(1,2,1)=4.5E 03,
TRANE(1,1,1)=1.650E 06,
TRANE(1,2,1)=2.00E 06,
G(1,1,1)=0.63E 06,
AXNU(1,1,1)=0.3,
AXE(1,1,2)=6.20E 06,
AXF(1,2,2)=1.31E 06,
TRANE(1,1,2)=-0.20E 00,
TRANE(1,2,2)=0.140E 06,
G(1,1,2)=0.0475E 06,
AXNU(1,1,2)=0.3,
AXNU(1,1,3)=0.3,
AXNU(1,1,4)=0.3,
AXNU(1,1,5)=0.3,
&END
&CRITIC
CRITS(1,1,1,1)=2300.E 03, CRITS(1,2,1,1)=-100.0E 03,
CRITS(2,1,1,1)=23.10E 03, CRITS(2,2,1,1)=-20.0E 03,
CRITS(3,1,1,1)=6.62E 03, CRITS(3,2,1,1)=-6.62E 03,
CRITS(1,1,1,2)=229.0E 03, CRITS(1,2,1,2)=-134.0E 03,
CRITS(2,1,1,2)=25.0E+07, CRITS(2,2,1,2)=-25.0E+07,
CRITS(3,1,1,2)=66.2E 03, CRITS(3,2,1,2)=-66.2E 03,
CRITE(1,1,1,1)=370.E-03, CRITE(1,2,1,1)=-16.1E-03,
CRITE(2,1,1,1)=14.00E-03, CRITE(2,2,1,1)=-12.1E-03,
CRITE(3,1,1,1)=10.5E-03, CRITE(3,2,1,1)=-10.5E-03,
CRITE(1,1,1,2)=37.00E-03, CRITE(1,2,1,2)=-22.0E-03,
CRITE(2,1,1,2)=2.90E -03, CRITE(2,2,1,2)=-70.0E-03,
CRITE(3,1,1,2)=130.0E-03, CRITE(3,2,1,2)=-130.0E-03,
&END
&OPT1 NLOADS=2,NSTRES(1)=1
&END
&LOAD
ALLOAD(1,1)=5.0E 04,ALLOAD(1,2)=6.3E 04,ALLOAD(2,2)=6.3E 04
&END
&GEOMED NLAY=12, NMATL=12*I,
ALPHA(1)=0.0,ALPHA(2)=30.0,ALPHA(3)=-30.0,ALPHA(4)=60.0,
ALPHA(5)=-60.0,ALPHA(6)=90.0,ALPHA(7)=90.0,ALPHA(8)=-60.0,
ALPHA(9)=60.0,ALPHA(10)=-30,ALPHA(11)=30.0,ALPHA(12)=0.0,
DELTA=12*0.0833
&END

```

MATERIAL ELASTIC PROPERTIES:

PROPERTIES BEFORE BREAK-POINT:

MATL NO	AXIAL YOUNGS MODULUS		TRANS YOUNGS MODULUS		SHEAR MODULUS	AXIAL POISSON RATIO
	TENSION	COMPR	TENSION	COMPR		
1	0.6200E 07	0.6200E 07	0.1650E 07	0.1650E 07	0.6300E 06	0.3000E 00

PROPERTIES AFTER BREAK-POINT:

MATL NO	AXIAL YOUNGS MODULUS		TRANS YOUNGS MODULUS		SHEAR MODULUS
	TENSION	COMPR	TENSION	COMPR	
1	0.6200E 07	0.1310E 07	-0.2000E 00	0.1400E 06	0.4750E 05

***** AXIAL POISONS RATIO *****

AX COMPR	SHEAR/TENS	TR COMPR	QUAD
0.3000E 00	0.3000E 00	0.3000E 00	0.3000E 00

INPUT BREAK-POINT STRESSES & STRAINS:

STRESSES							STRAINS		
MATL	AXIAL	TRANS	SHEAR	AXIAL	TRANS	SHEAR			
TENS	1	0.230E 07	0.231E 05	0.662E 04	0.370E 00	0.140E-01	0.105E-01		
COMP		-0.100E 06	-0.200E 05	0.662E 04	-0.161E-01	-0.121E-01	0.105E-01		

2.2

INPUT ULTIMATE STRESSES & STRAINS:

STRESSES							STRAINS		
MATL	AXIAL	TRANS	SHEAR	AXIAL	TRANS	SHEAR			
TENS	1	0.229E 06	0.250E 09	0.662E 05	0.370E-01	0.290E 04	0.130E 00		
COMP		-0.134E 06	-0.250E 09	0.662E 05	-0.220E-01	-0.700E-01	0.130E 00		

QUADRATIC INTERACTION CO-EFFICIENTS :

MATERIAL	BREAK-POINT	FAILURE
1	-0.500E-09	-0.299E-13

LAMINATE 1

LAYER	MATERIAL	THICKNESS	ANGLE
1	1	0.0833	0.0
2	1	0.0833	30.00
3	1	0.0833	-30.00
4	1	0.0833	60.00
5	1	0.0833	-60.00
6	1	0.0833	90.00
7	1	0.0833	90.00
8	1	0.0833	-60.00
9	1	0.0833	60.00
10	1	0.0833	-30.00
11	1	0.0833	30.00
12	1	0.0833	0.0

APPLIED LAMINATE FORCES/LENGTHS:	LONGITUDINAL 0.500E 05	TRANSVERSE 0.0	SHEAR 0.0
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ANALYSIS NUMBER 1:

BREAK-POINT ANALYSIS= 1; FAILURE ANALYSIS= 1

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIOS	SHEAR MODULUS
LONG	0.312498E 07	0.309647E 00	0.119306E 07
TRAN	0.312498E 07	0.309647E 00	0.119306E 07

2.3

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

3	4
3	5
3	8
3	9
3	2
3	3
3	10
3	11

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR

0.290E 05 0.0 0.0

LAMINATE TOTAL STRAINS: 0.926E-02 -0.287E-02 0.192E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION	STRESSES	STRAINS				
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.5740E 05	-0.1511E 03	0.1209E-02	0.9265E-02	-0.2869E-02	0.1919E-08
2	30.00	0.3967E 05	0.3438E 04	-0.6620E 04	0.6231E-02	0.1646E-03	-0.1051E-01
3	-30.00	0.3967E 05	0.3438E 04	0.6620E 04	0.6231E-02	0.1646E-03	0.1051E-01
4	60.00	0.4206E 04	0.1062E 05	-0.6620E 04	0.1646E-03	0.6231E-02	-0.1051E-01
5	-60.00	0.4206E 04	0.1062E 05	0.6620E 04	0.1646E-03	0.6231E-02	0.1051E-01
6	90.00	-0.1352E 05	0.1421E 05	-0.2059E-01	-0.2869E-02	0.9265E-02	-0.3268E-07
7	90.00	-0.1352E 05	0.1421E 05	-0.2059E-01	-0.2869E-02	0.9265E-02	-0.3268E-07
8	-60.00	0.4206E 04	0.1062E 05	0.6620E 04	0.1646E-03	0.6231E-02	0.1051E-01
9	60.00	0.4206E 04	0.1062E 05	-0.6620E 04	0.1646E-03	0.6231E-02	-0.1051E-01
10	-30.00	0.3967E 05	0.3438E 04	0.6620E 04	0.6231E-02	0.1646E-03	0.1051E-01
11	30.00	0.3967E 05	0.3438E 04	-0.6620E 04	0.6231E-02	0.1646E-03	-0.1051E-01
12	0.0	0.5740E 05	-0.1511E 03	0.1209E-02	0.9265E-02	-0.2869E-02	0.1919E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION	STRESSES	STRAINS	
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.5740E 05	-0.1511E 03	0.1209E-02
2	30.00	0.3634E 05	0.6762E 04	0.1238E 05
3	-30.00	0.3634E 05	0.6762E 04	-0.1238E 05
4	60.00	0.1475E 05	0.7557E 02	0.5336E 03
5	-60.00	0.1475E 05	0.7556E 02	-0.5336E 03
6	90.00	0.1421E 05	-0.1352E 05	-0.1456E-01
7	90.00	0.1421E 05	-0.1352E 05	-0.1456E-01
8	-60.00	0.1475E 05	0.7556E 02	-0.5336E 03
9	60.00	0.1475E 05	0.7557E 02	0.5336E 03
10	-30.00	0.3634E 05	0.6762E 04	-0.1238E 05
11	30.00	0.3634E 05	0.6762E 04	0.1238E 05
12	0.0	0.5740E 05	-0.1511E 03	0.1209E-02

LAMINATE TANGENT STIFFNESS MATRIX:

0.265E 07	0.920E 06	0.625E-01
0.920E 06	0.265E 07	0.100E 01
0.625E-01	0.100E 01	0.993E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIOS	SHEAR MODULUS
LONG	0.233602E 07	0.346518E 00	0.992519E 06
TRAN	0.233601E 07	0.346517E 00	0.992519E 06

BREAK-POINT NO. 2 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

2	6
2	7

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR

0.427E 05 0.0 0.0

LAMINATE TOTAL STRAINS: 0.151E-01 -0.490E-02 0.360E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

2.4

LAYER	ORIENTATION	STRESSES			STRAINS		
		ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE
1	0.0	0.9366E 05	-0.6128E 03	0.2268E-02	0.1514E-01	-0.4903E-02	0.3599E-08
2	30.00	0.6381E 05	0.3438E 04	-0.6945E 04	0.1013E-01	0.1065E-03	-0.1735E-01
3	-30.00	0.6381E 05	0.3438E 04	0.6945E 04	0.1C13E-01	0.1065E-03	0.1735E-01
4	60.00	0.3846E 04	0.1062E 05	-0.6945E 04	0.1066E-03	0.1013E-01	-0.1735E-01
5	-60.00	0.3846E 04	0.1062E 05	0.6945E 04	0.1065E-03	0.1013E-01	0.1735E-01
6	90.00	-0.2347E 05	0.2310E 05	-0.3427E-01	-0.4903E-02	0.1514E-01	-0.5440E-07
7	90.00	-0.2347E 05	0.2310E 05	-0.3427E-01	-0.4903E-02	0.1514E-01	-0.5440E-07
8	-60.00	0.3846E 04	0.1062E 05	0.6945E 04	0.1065E-03	0.1013E-01	0.1735E-01
9	60.00	0.3846E 04	0.1062E 05	-0.6945E 04	0.1066E-03	0.1013E-01	-0.1735E-01
10	-30.00	0.6381E 05	0.3438E 04	0.6945E 04	0.1013E-01	0.1065E-03	0.1735E-01
11	30.00	0.6381E 05	0.3438E 04	-0.6945E 04	0.1C13E-C1	0.1065E-03	-0.1735E-01
12	0.0	0.9366E 05	-0.6128E 03	0.2268E-02	0.1514E-01	-0.4903E-02	0.3599E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION	STRESSES		
		ANGLE	LONGITUDINAL	TRANSVERSE
1	0.0	0.9366E 05	-0.6128E 03	0.2268E-02
2	30.00	0.5473E 05	0.1252E 05	0.2267E 05
3	-30.00	0.5473E 05	0.1252E 05	-0.2267E 05
4	60.00	0.1494E 05	-0.4760E 03	0.5404E 03
5	-60.00	0.1494E 05	-0.4760E 03	-0.5404E 03
6	90.00	0.2310E 05	-0.2347E 05	-0.2476E-01
7	90.00	0.2310E 05	-0.2347E 05	-0.2476E-01
8	-60.00	0.1494E 05	-0.4760E 03	-0.5404E 03
9	60.00	0.1494E 05	-0.4760E 03	0.5404E 03
10	-30.00	0.5473E 05	0.1252E 05	-0.2267E 05
11	30.00	0.5473E 05	0.1252E 05	0.2267E 05
12	0.0	0.9366E 05	-0.6128E 03	0.2268E-02

LAMINATE TANGENT STIFFNESS MATRIX:

0.237E 07	0.835E 06	0.625E-01
0.835E 06	0.263E 07	0.131E 01
0.625E-01	0.131E 01	0.895E 06

LAMINATE TANGENT MODULI & POTISSON RATIOS:

YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS	
		LONG	TRAN
0.210771E 07	0.317725E 00	0.895475E 06	
0.233533E 07	0.352037E 00	0.895475E 06	

LAMINATE LOAD HAS REACHED PREDEFINED LEVEL

APPLIED FORCES/LENGTH:	LONGITUDINAL			TRANSVERSE		SHEAR	
	0.500E 05	0.0	0.0	0.186E-01	-0.601E-02	0.498E-08	
LAMINATE TOTAL STRAINS:							

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT PREDEFINED LAMINATE LOAD LEVEL:

LAYER	ORIENTATION	STRESSES			STRAINS		
		ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE
1	0.0	0.1152E 06	-0.7170E 03	0.3135E-02	0.1861E-01	-0.6009E-02	0.4977E-08
2	30.00	0.7828E 05	0.3438E 04	-0.7134E 04	0.1246E-01	0.1473E-03	-0.2132E-01
3	-30.00	0.7828E 05	0.3438E 04	0.7134E 04	0.1246E-01	0.1473E-C3	0.2132E-01
4	60.00	0.4098E 04	0.1062E 05	-0.7134E 04	0.1473E-03	0.1246E-01	-0.2132E-01
5	-60.00	0.4098E 04	0.1062E 05	0.7134E 04	0.1473E-03	0.1246E-01	0.2132E-01
6	90.00	-0.3032E 05	0.2310E 05	-0.3489E-01	-0.6009E-02	0.1861E-C1	-0.6740E-07
7	90.00	-0.3032E 05	0.2310E 05	-0.3489E-01	-0.6009E-02	0.1861E-01	-0.6740E-07
8	-60.00	0.4098E 04	0.1062E 05	0.7134E 04	0.1473E-C3	0.1246E-01	0.2132E-01
9	60.00	0.4098E 04	0.1062E 05	-0.7134E 04	0.1473E-03	0.1246E-01	-0.2132E-01
10	-30.00	0.7828E 05	0.3438E 04	0.7134E 04	0.1246E-01	0.1473E-03	0.2132E-01
11	30.00	0.7828E 05	0.3438E 04	-0.7134E 04	0.1246E-01	0.1473E-03	-0.2132E-01
12	0.0	0.1152E 06	-0.7170E 03	0.3135E-02	0.1861E-01	-0.6009E-02	0.4977E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT APPLIED LOAD:

LAYER	ORIENTATION	STRESSES		
		ANGLE	LONGITUDINAL	TRANSVERSE
1	0.0	0.1152E 06	-0.7170E 03	0.3135E-02
2	30.00	0.6575E 05	0.1597E 05	0.2984E C5
3	-30.00	0.6575E 05	0.1597E 05	-0.2884E 05
4	60.00	0.1517E 05	-0.4499E 03	0.7440E 03
5	-60.00	0.1517E 05	-0.4499E 03	-0.7440E 03

6 90.00 0.2310E 05 -0.3032E 05 -0.3283E-01
 7 90.00 0.2310F 05 -0.3032F 05 -0.3283E-01
 8 -60.00 0.1517E 05 -0.4499E 03 -0.7440E C3
 9 60.00 0.1517E 05 -0.4499E 03 0.7440E 03
 10 -30.00 0.6575E 05 0.1597E 05 -0.2884E C5
 11 30.00 0.6575F 05 0.1597E 05 0.2884E C5
 12 0.0 0.1152E 06 -0.7170E 03 0.3135E-02

2.5

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1 1
1 12

APPLIED FORCES/LENGTH AT FAILURE:	0.887E 05	0.0	0.0
LAMINATE TOTAL STRAINS:	0.370E-01	-0.118E-01	0.123E-07

AYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	-0.1268E 04	0.7720E-02	0.3700E-01	-0.1185E-01	0.1225E-07
2	30.00	0.1547F 06	0.3438F 04	-0.8130F 04	0.2479F-01	0.3624F-03	=0.4230E-01
3	-30.00	0.1547E 06	0.3438E 04	0.8130E 04	0.2479E-01	0.3624E-03	0.4230E-01
4	60.00	0.5433E 04	0.1062E 05	-0.8130E 04	0.3625E-03	0.2479E-01	-0.4230E-01
5	-60.00	0.5433E 04	0.1062E 05	0.8130E 04	0.3625E-03	0.2479E-01	0.4230E-01
6	90.00	-0.6653E 05	0.2310E 05	-0.3815F-01	-0.1185E-01	0.3700E-01	-0.1361E-06
7	90.00	-0.6653E 05	0.2310E 05	-0.3815E-01	-0.1185E-01	0.3700E-01	-0.1361E-06
8	-60.00	0.5433E 04	0.1062E 05	0.8130E 04	0.3625E-03	0.2479E-01	0.4230E-01
9	60.00	0.5433E 04	0.1062E 05	-0.8130E 04	0.3625E-03	0.2479E-01	-0.4230E-01
10	-30.00	0.1547E 06	0.3438E 04	0.8130E 04	0.2479E-01	0.3624E-03	0.4230E-01
11	30.00	0.1547E 06	0.3438E 04	-0.8130E 04	0.2479E-01	0.3624E-03	-0.4230E-01
12	0.0	0.2290E 06	-0.1268E 04	0.7720E-02	0.3700E-01	-0.1185E-01	0.1225E-07

AYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ANGLE	STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	-0.1268E 04	0.7720E-02
2	30.00	0.1239E 06	0.3421E 05	0.6143E 05
3	-30.00	0.1239E 06	0.3421E 05	-0.6143E 05
4	60.00	0.1636E 05	-0.3121E 03	0.1820E 04
5	-60.00	0.1636E 05	-0.3122E 03	-0.1820E 04
6	90.00	0.2310F 05	-0.6653E 05	-0.7547E-01
7	90.00	0.2310E 05	-0.6653E 05	-0.7547E-01
8	-60.00	0.1636E 05	-0.3122E 03	-0.1820E 04
9	60.00	0.1636E 05	-0.3121E 03	0.1820E 04
10	-30.00	0.1239E 06	0.3421F 04	-0.4141E-05
11	30.00	0.1239E 06	0.3421E 05	0.4141E-05
12	0.0	0.2290E 06	-0.1268E 04	0.7720F-02

FIRST FIBER FAILURE

ANALYSIS NUMBER 2:

BREAK-POINT ANALYSIS= 2: FAILURE ANALYSIS= 2

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312498E 07	0.309647E 00	0.119306E 07
TRAN	0.312498E 07	0.309647E 00	0.119306E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

3 4

3 5
 3 9
 3 9
 3 3
 3 10
 3 2
 3 11

2.6

APPLIED FORCES/LENGTH AT BREAK-POINT: 0.289E 05 LONGITUDINAL TRANSVERSE SHEAR
 LAMINATE TOTAL STRAINS: 0.926E-02 -0.297E-02 0.192E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ANGLE	ORIENTATION			STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.5735E 05	-0.1510E 03	0.1208E-02	0.9258E-02	-0.2867E-02	0.1918E-08			
2	30.00	0.3964E 05	0.3436E 04	-0.6615E 04	0.6227E-02	0.1645E-03	-0.1050E-01			
3	-30.00	0.3964E 05	0.3436E 04	0.6615E 04	0.6227E-02	0.1645E-03	0.1050E-01			
4	60.00	0.4203E 04	0.1061E 05	-0.6615E 04	0.1645E-03	0.6227E-02	-0.1050E-01			
5	-60.00	0.4203E 04	0.1061E 05	0.6615E 04	0.1645E-03	0.6227E-02	0.1050E-01			
6	90.00	-0.1351E 05	0.1420E 05	-0.2057E-01	-0.2867E-02	0.9258E-02	-0.3266E-07			
7	90.00	-0.1351E 05	0.1420E 05	-0.2057E-01	-0.2867E-02	0.9258E-02	-0.3266E-07			
8	-60.00	0.4203E 04	0.1061E 05	0.6615E 04	0.1645E-03	0.6227E-02	0.1050E-01			
9	60.00	0.4203E 04	0.1061E 05	-0.6615E 04	0.1645E-03	0.6227E-02	-0.1050E-01			
10	-30.00	0.3964E 05	0.3436E 04	0.6615E 04	0.6227E-02	0.1645E-03	0.1050E-01			
11	30.00	0.3964E 05	0.3436E 04	-0.6615E 04	0.6227E-02	0.1645E-03	-0.1050E-01			
12	0.0	0.5735E 05	-0.1510E 03	0.1208E-02	0.9258E-02	-0.2867E-02	0.1918E-08			

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ANGLE	ORIENTATION			STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.5735E 05	-0.1510E 03	0.1208E-02			
2	30.00	0.3631E 05	0.6757E 04	0.1237E 05			
3	-30.00	0.3631E 05	0.6757E 04	-0.1237E 05			
4	60.00	0.1474E 05	0.7551E 02	0.5332E 03			
5	-60.00	0.1474E 05	0.7551E 02	-0.5332E 03			
6	90.00	0.1420E 05	-0.1351E 05	-0.1455E-01			
7	90.00	0.1420E 05	-0.1351E 05	-0.1455E-01			
8	-60.00	0.1474E 05	0.7551E 02	-0.5332E 03			
9	60.00	0.1474E 05	0.7551E 02	0.5332E 03			
10	-30.00	0.3631E 05	0.6757E 04	-0.1237E 05			
11	30.00	0.3631E 05	0.6757E 04	0.1237E 05			
12	0.0	0.5735E 05	-0.1510E 03	0.1208E-02			

LAMINATE TANGENT STIFFNESS MATRIX:

0.265E 07	0.920E 06	0.625E-01
0.920E 06	0.265E 07	0.100E 01
0.625E-01	0.100E 01	0.993E 06

LAMINATE TANGENT MODULUS & POISSON RATIOS:

YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
0.233602E 07	0.346518E 00	0.992519E 06
0.233601E 07	0.346517E 00	0.992519E 06

BREAK-POINT NO. 2 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)
 MODE LAYER
 2 6
 2 7

APPLIED FORCES/LENGTH AT BREAK-POINT:	LONGITUDINAL			TRANSVERSE			SHEAR		
	0.400E 05	0.0	0.0	0.400E 05	0.0	0.0	0.400E 05	0.0	0.0
LAMINATE TOTAL STRAINS:	0.140E-01	-0.451E-02	0.327E-08						

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ANGLE	ORIENTATION			STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.8664E 05	-0.5239E 03	0.2063E-02	0.1400E-01	-0.4510E-02	0.3275E-08			
2	30.00	0.5914E 05	0.3436E 04	-0.6878E 04	0.9373E-02	0.1176E-03	-0.1603E-01			
3	-30.00	0.5914E 05	0.3436E 04	0.6878E 04	0.9373E-02	0.1176E-03	-0.1603E-01			
4	60.00	0.3912E 04	0.1061E 05	-0.6878E 04	0.1176E-03	0.9372E-02	-0.1602E-01			
5	-60.00	0.3912E 04	0.1061E 05	0.6878E 04	0.1176E-03	0.9372E-02	0.1603E-01			
6	90.00	-0.2155E 05	0.2138E 05	-0.3163E-01	-0.4510E-02	0.1400E-01	-0.5020E-07			
7	90.00	-0.2155E 05	0.2138E 05	-0.3163E-01	-0.4510E-02	0.1400E-01	-0.5020E-07			

8	-60.00	0.3912E 04	0.1061E 05	0.6878E 04	0.1176E-03	0.9372E-02	0.1603E-01
9	60.00	0.3912E 04	0.1061E 05	-0.6878E 04	0.1176E-03	0.9372E-02	-0.1603E-01
10	-30.00	0.5914E 05	0.3436E 04	0.6878E 04	0.9373E-02	0.1176E-03	0.1603E-01
11	30.00	0.5914E 05	0.3436E 04	-0.6878E 04	0.9373E-02	0.1176E-03	-0.1603E-01
12	0.0	0.8664E 05	-0.5239E 03	0.2063E-02	0.1400E-01	-0.4510E-02	0.3275E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ANGLE	STRESSES			2.7
		LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.8664E 05	-0.5239E 03	0.2063E-02	
2	30.00	0.5117E 05	0.1141E 05	0.2068E 05	
3	-30.00	0.5117E 05	0.1141E 05	-0.2068E 05	
4	60.00	0.1489E 05	-0.3700E 03	0.5387E 03	
5	-60.00	0.1489E 05	-0.3700E 03	-0.5387E 03	
6	90.00	0.2138E 05	-0.2155E 05	-0.2279E-01	
7	90.00	0.2138E 05	-0.2155E 05	-0.2279E-01	
8	-60.00	0.1489E 05	-0.3700E 03	-0.5387E 03	
9	60.00	0.1489E 05	-0.3700E 03	0.5387E 03	
10	-30.00	0.5117E 05	0.1141E 05	-0.2068E 05	
11	30.00	0.5117E 05	0.1141E 05	0.2068E 05	
12	0.0	0.8664E 05	-0.5239E 03	0.2063E-02	

LAMINATE TANGENT STIFFNESS MATRIX:

0.237E 07	0.835E 06	0.625E-01
0.835E 06	0.267E 07	0.131E 01
0.625E-01	0.131E 01	0.895E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210771E 07	0.317725E 00	0.895475E 06
TRAN	0.233533E 07	0.352037E 00	0.895475E 06

LAMINATE LOAD HAS REACHED PREDEFINED LEVEL

APPLIED FORCES/LENGTH:	LONGITUDINAL	TRANSVERSE		SHEAR
		0.500E 05	0.0	
LAMINATE TOTAL STRAINS:	0.187E-01	-0.602E-02	0.515E-08	

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT PREDEFINED LAMINATE LOAD LEVEL:

LAYER	ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.1160E 06	-0.6659E 03	0.3245E-02	0.1874E-01	-0.6016E-02	0.5152E-08
2	30.00	0.7885E 05	0.3436E 04	-0.7135E 04	0.1255E-01	0.1731E-03	-0.2144E-01
3	-30.00	0.7885E 05	0.3436E 04	-0.7135E 04	0.1255E-01	0.1731E-03	0.2144E-01
4	60.00	0.4256E 04	0.1061E 05	-0.7135E 04	0.1731E-03	0.1255E-01	-0.2144E-01
5	-60.00	0.4256E 04	0.1061E 05	-0.7135E 04	0.1731E-03	0.1255E-01	0.2144E-01
6	90.00	-0.3089E 05	0.2138E 05	-0.3247E-01	-0.6016E-02	0.1874E-01	-0.6792E-07
7	90.00	-0.3089E 05	0.2138E 05	-0.3247E-01	-0.6016E-02	0.1874E-01	-0.6792E-07
8	-60.00	0.4256E 04	0.1061E 05	-0.7135E 04	0.1731E-03	0.1255E-01	0.2144E-01
9	60.00	0.4256E 04	0.1061E 05	-0.7135E 04	0.1731E-03	0.1255E-01	-0.2144E-01
10	-30.00	0.7885E 05	0.3436E 04	-0.7135E 04	0.1255E-01	0.1731E-03	0.2144E-01
11	30.00	0.7885E 05	0.3436E 04	-0.7135E 04	0.1255E-01	0.1731E-03	-0.2144E-01
12	0.0	0.1160E 06	-0.6659E 03	0.3245E-02	0.1874E-01	-0.6016E-02	0.5152E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT APPLIED LOAD:

LAYER	ANGLE	STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.1160E 06	-0.6659E 03	0.3245E-02
2	30.00	0.6617E 05	0.1611E 05	0.2909E 05
3	-30.00	0.6617E 05	0.1611E 05	-0.2909E 05
4	60.00	0.1520E 05	-0.3345E 03	0.8162E 03
5	-60.00	0.1520E 05	-0.3345E 03	-0.8162E 03
6	90.00	0.2138E 05	-0.3089E 05	-0.3378E-01
7	90.00	0.2138E 05	-0.3089E 05	-0.3378E-01
8	-60.00	0.1520E 05	-0.3345E 03	-0.8162E 03
9	60.00	0.1520E 05	-0.3345E 03	0.8162E 03
10	-30.00	0.6617E 05	0.1611E 05	-0.2909E 05
11	30.00	0.6617E 05	0.1611E 05	0.2909E 05
12	0.0	0.1160E 06	-0.6659E 03	0.3245E-02

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	1
1	12

APPLIED FORCES/LENGTH AT FAILURE:	0.885E 05	LONGITUDINAL	TRANSVERSE	SHEAR
LAMINATE TOTAL STRAINS:	0.370E-01	0.0	0.0	

2.8

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ANGLE	STRESSES			STRAINS		
		LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	-0.1213E 04	0.7800E-02	0.3700E-01	-0.1182E-01	0.1238E-07
2	30.00	0.1548E 06	0.3436E 04	-0.8124E 04	0.2480E-01	0.3868E-03	-0.4228E-01
3	-30.00	0.1548E 06	0.3436E 04	0.8124E 04	0.2480E-01	0.3868E-03	0.4228E-01
4	60.00	0.5581E 04	0.1061E 05	-0.8124E 04	0.3868E-03	0.2480E-01	-0.4228E-01
5	-60.00	0.5581E 04	0.1061E 05	0.8124E 04	0.3868E-03	0.2480E-01	0.4228E-01
6	90.00	-0.6686E 05	0.2138E 05	-0.3571E-01	-0.1182E-01	0.3700E-01	-0.1361E-06
7	90.00	-0.6686E 05	0.2138E 05	-0.3571E-01	-0.1182E-01	0.3700E-01	-0.1361E-06
8	-60.00	0.5581E 04	0.1061E 05	0.8124E 04	0.3868E-03	0.2480E-01	0.4228E-01
9	60.00	0.5581E 04	0.1061E 05	-0.8124E 04	0.3868E-03	0.2480E-01	-0.4228E-01
10	-30.00	0.1548E 06	0.3436E 04	0.8124E 04	0.2480E-01	0.3868E-03	0.4228E-01
11	30.00	0.1548E 06	0.3436E 04	-0.8124E 04	0.2480E-01	0.3868E-03	-0.4228E-01
12	0.0	0.2290E 06	-0.1213E 04	0.7800E-02	0.3700E-01	-0.1182E-01	0.1238E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ANGLE	STRESSES		
		LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	-0.1213E 04	0.7800E-02
2	30.00	0.1240E 06	0.3423E 05	0.6146E 05
3	-30.00	0.1240E 06	0.3423E 05	-0.6146E 05
4	60.00	0.1639E 05	-0.1976E 03	0.1885E 04
5	-60.00	0.1639E 05	-0.1977E 03	-0.1885E 04
6	90.00	0.2138E 05	-0.6686E 05	-0.7614E-01
7	90.00	0.2138E 05	-0.6686E 05	-0.7614E-01
8	-60.00	0.1639E 05	-0.1977E 03	-0.1885E 04
9	60.00	0.1639E 05	-0.1976E 03	0.1885E 04
10	-30.00	0.1240E 06	0.3423E 05	-0.6146E 05
11	30.00	0.1240E 06	0.3423E 05	0.6146E 05
12	0.0	0.2290E 06	-0.1213E 04	0.7800E-02

FIRST FIBER FAILURE

ANALYSIS NUMBER 3:

BREAK-POINT ANALYSIS= 3; FAILURE ANALYSIS= 3

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS	
LONG	0.312498E 07	0.309647E 00	0.119306E 07
TRAN	0.312498E 07	0.309647E 00	0.119306E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	4
1	9
1	5
1	8

APPLIED FORCES/LENGTH AT BREAK-POINT:	0.275E 05	LONGITUDINAL	TRANSVERSE	SHEAR
LAMINATE TOTAL STRAINS:	0.882E-02	0.0	0.0	

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES			STRAINS			2.9
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.5461E 05	-0.1438E 03	0.1150E-02	0.8815E-02	-0.2730E-02	0.1826E-08		
2	30.00	0.3774E 05	0.3272E 04	-0.6299E 04	0.5929E-02	0.1566E-03	-0.9998E-02		
3	-30.00	0.3774E 05	0.3272E 04	0.6299E 04	0.5929E-02	0.1566E-03	0.9998E-02		
4	60.00	0.4002E 04	0.1010E 05	-0.6299E 04	0.1566E-03	0.5929E-02	-0.9998E-02		
5	-60.00	0.4002E 04	0.1010E 05	0.6299E 04	0.1566E-03	0.5929E-02	0.9998E-02		
6	90.00	-0.1287E 05	0.1352E 05	-0.1959E-01	-0.2730E-02	0.8815E-02	-0.3109E-07		
7	90.00	-0.1287E 05	0.1352E 05	-0.1959E-01	-0.2730E-02	0.8815E-02	-0.3109E-07		
8	-60.00	0.4002E 04	0.1010E 05	0.6299E 04	0.1566E-03	0.5929E-02	0.9998E-02		
9	60.00	0.4002E 04	0.1010E 05	-0.6299E 04	0.1566E-03	0.5929E-02	-0.9998E-02		
10	-30.00	0.3774E 05	0.3272E 04	0.6299E 04	0.5929E-02	0.1566E-03	0.9998E-02		
11	30.00	0.3774E 05	0.3272E 04	-0.6299E 04	0.5929E-02	0.1566E-03	-0.9998E-02		
12	0.0	0.5461E 05	-0.1438E 03	0.1150E-02	0.8815E-02	-0.2730E-02	0.1826E-08		

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.5461E 05	-0.1438E 03	0.1150E-02	
2	30.00	0.3458E 05	0.6434E 04	0.1178E 05	
3	-30.00	0.3458E 05	0.6434E 04	-0.1178E 05	
4	60.00	0.1403E 05	0.7191E 02	0.5077E 03	
5	-60.00	0.1403E 05	0.7190E 02	-0.5077E 03	
6	90.00	0.1352E 05	-0.1287E 05	-0.1386E-01	
7	90.00	0.1352E 05	-0.1287E 05	-0.1386E-01	
8	-60.00	0.1403E 05	0.7190E 02	-0.5077E 03	
9	60.00	0.1403E 05	0.7191E 02	0.5077E 03	
10	-30.00	0.3458E 05	0.6434E 04	-0.1178E 05	
11	30.00	0.3458E 05	0.6434E 04	0.1178E 05	
12	0.0	0.5461E 05	-0.1438E 03	0.1150E-02	

LAMINATE TANGENT STIFFNESS MATRIX:

0.293E 07	0.995E 06	0.625E-01
0.995E 06	0.318E 07	0.100E 01
0.625E-01	0.100E 01	0.109E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LNG	0.261642E 07	0.312557E 00	0.109279E 07
TRAN	0.284547E 07	0.339919E 00	0.109279E 07

BREAK-POINT NO. 2 PREDICTED IN FOLLOWING LAYERS:

MODE 1=AXIAL;	MODE 2=TRANSVERSE;	MODE 3=SHEAR
MODE	LAYER	
1	3	
1	10	
1	2	
1	11	

APPLIED FORCES/LENGTH AT BREAK-POINT:	0.347E 05	0.0	SHEAR
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LAMINATE TOTAL STRAINS:	0.116E-01	-0.359E-02	0.245E-08
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LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES			STRAINS			SHEAR
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR		
1	0.0	0.7158E 05	-0.2019E 03	0.1545E-02	0.1156E-01	-0.3586E-02	0.2453E-08		
2	30.00	0.4946E 05	0.4278E 04	-0.8261E 04	0.7770E-02	0.1993E-03	-0.1311E-01		
3	-30.00	0.4946E 05	0.4278E 04	0.8261E 04	0.7770E-02	0.1993E-03	0.1311E-01		
4	60.00	0.4266E 04	0.1010E 05	-0.6447E 04	0.1993E-03	0.7770E-02	-0.1311E-01		
5	-60.00	0.4266E 04	0.1010E 05	0.6447E 04	0.1993E-03	0.7770E-02	0.1311E-01		
6	90.00	-0.1692E 05	0.1772E 05	-0.2573E-01	-0.3586E-02	0.1156E-01	-0.4084E-07		
7	90.00	-0.1692E 05	0.1772E 05	-0.2573E-01	-0.3586E-02	0.1156E-01	-0.4084E-07		
8	-60.00	0.4266E 04	0.1010E 05	0.6447E 04	0.1993E-03	0.7770E-02	0.1311E-01		
9	60.00	0.4266E 04	0.1010E 05	-0.6447E 04	0.1993E-03	0.7770E-02	-0.1311E-01		
10	-30.00	0.4946E 05	0.4278E 04	0.8261E 04	0.7770E-02	0.1993E-03	0.1311E-01		
11	30.00	0.4946E 05	0.4278E 04	-0.8261E 04	0.7770E-02	0.1993E-03	-0.1311E-01		
12	0.0	0.7158E 05	-0.2019E 03	0.1545E-02	0.1156E-01	-0.3586E-02	0.2453E-08		

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION		STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	
1	0.0	0.7158E 05	-0.2019E 03	0.1545E-02	
2	30.00	0.4532E 05	0.8418E 04	0.1543E 05	
3	-30.00	0.4532E 05	0.9418E 04	-0.1543E 05	

4	60.00	0.1423E 05	0.1424E 03	0.6964E 03
5	-60.00	0.1423E 05	0.1423E 03	-0.6964E 03
6	90.00	0.1772E 05	-0.1692E 05	-0.1817E-01
7	90.00	0.1772E 05	-0.1692E 05	-0.1817E-01
8	-60.00	0.1423E 05	0.1423E 03	-0.6964E 03
9	60.00	0.1423E 05	0.1424E 03	0.6964E 03
10	-30.00	0.4532E 05	0.8418E 04	-0.1543E 05
11	30.00	0.4532E 05	0.8418E 04	0.1543E 05
12	0.0	0.7158E 05	-0.2019E 03	0.1545E-02

2.10

LAMINATE TANGENT STIFFNESS MATRIX:

0.265F 07	0.920E 06	0.625E-01
0.920E 06	0.265E 07	0.100E 01
0.625E-01	0.100E 01	0.993E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.233602E 07	0.346518E 00	0.992519E 06
TRAN	0.233601E 07	0.346517E 00	0.992519E 06

BREAK-POINT NO. 3 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)
MODE LAYER

1	6
1	7

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR
 0.366E 05 C.0 0.0

LAMINATE TOTAL STRAINS: 0.124E-01 -0.387E-02 0.269E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	STRESSES	STRAINS	
			LONGITUDINAL	TRANSVERSE	SHEAR
1		0.0	0.7662E 05	-0.2660E 03	0.1692E-02
2		30.00	0.5281E 05	0.4278E 04	-0.8306E 04
3		-30.00	0.5281E 05	0.4278E 04	0.8306E 04
4		60.00	0.4216E 04	0.1010E 05	-0.6492E 04
5		-60.00	0.4216E 04	0.1010E 05	0.6492E 04
6		90.00	-0.1830E 05	0.1895E 05	-0.2763E-01
7		90.00	-0.1830E 05	0.1895E 05	-0.2763E-01
8		-60.00	0.4216E 04	0.1010E 05	0.6492E 04
9		60.00	0.4216E 04	0.1010E 05	-0.6492E 04
10		-30.00	0.5281E 05	0.4278E 04	0.8306E 04
11		30.00	0.5281E 05	0.4278E 04	-0.8306E 04
12		0.0	0.7662E 05	-0.2660E 03	0.1692E-02

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

LAYER	ORIENTATION	ANGLE	STRESSES	SHEAR
			LONGITUDINAL	TRANSVERSE
1		0.0	0.7662E 05	-0.2660E 03
2		30.00	0.4787E 05	0.9217E 04
3		-30.00	0.4787E 05	0.9217E 04
4		60.00	0.1425F 05	0.6582E 02
5		-60.00	0.1425E 05	0.6581E 02
6		90.00	0.1895E 05	-0.1830E 05
7		90.00	0.1895E 05	-0.1830E 05
8		-60.00	0.1425E 05	0.6581E 02
9		60.00	0.1425F 05	0.6582E 02
10		-30.00	0.4787E 05	0.9217E 04
11		30.00	0.4787E 05	0.9217E 04
12		0.0	0.7662E 05	-0.2660E 03

LAMINATE TANGENT STIFFNESS MATRIX:

0.237E 07	0.835E 06	0.625E-01
0.835E 06	0.181E 07	0.313E 00
0.625E-01	0.313E 00	0.895E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.198855E 07	0.460357E 00	0.895475E 06
TRAN	0.152066E 07	0.352037E 00	0.895475E 06

LAMINATE LOAD HAS REACHED PREDEFINED LEVEL

2.11

APPLIED FORCES/LENGTH:	LONGITUDINAL 0.500E 05	TRANSVERSE 0.0	SHEAR 0.0
LAMINATE TOTAL STRAINS:	0.191E-01	-0.697E-02	0.330E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT PREDEFINED LAMINATE LOAD LEVEL:

LAYER	ORIENTATION	STRESSES			STRAINS		
		ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE
1	0.0	0.1178E 06	-0.2090E 04	0.2077E-02	0.1910E-01	-0.6966E-02	0.3298E-08
2	30.00	0.7929E 05	0.4278E 04	-0.8711E 04	0.1258E-01	-0.4497E-03	-0.2257E-01
3	-30.00	0.7929E 05	0.4278E 04	0.8711E 04	0.1258E-01	-0.4497E-03	0.2257E-01
4	60.00	0.2424E 03	0.1010E 05	-0.6896E 04	-0.4497E-03	0.1258E-01	-0.2257E-01
5	-60.00	0.2424E 03	0.1010E 05	0.6896E 04	-0.4497E-03	0.1258E-01	0.2257E-01
6	90.00	-0.2236E 05	0.1895E 05	-0.2884E-01	-0.6966E-02	0.1910E-01	-0.6938E-07
7	90.00	-0.2236E 05	0.1895E 05	-0.2884E-01	-0.6966E-02	0.1910E-01	-0.6938E-07
8	-60.00	0.2424E 03	0.1010E 05	0.6896E 04	-0.4497E-03	0.1258E-01	0.2257E-01
9	60.00	0.2424E 03	0.1010E 05	-0.6896E 04	-0.4497E-03	0.1258E-01	-0.2257E-01
10	-30.00	0.7929E 05	0.4278E 04	0.8711E 04	0.1258E-01	-0.4497E-03	0.2257E-01
11	30.00	0.7929E 05	0.4278E 04	-0.8711E 04	0.1258E-01	-0.4497E-03	-0.2257E-01
12	0.0	0.1178E 06	-0.2090E 04	0.2077E-02	0.1910E-01	-0.6966E-02	0.3298E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT APPLIED LOAD:

LAYER	ORIENTATION	STRESSES			SHEAR
		ANGLE	LONGITUDINAL	TRANSVERSE	
1	0.0	0.1178E 06	-0.2090E 04	0.2077E-02	
2	30.00	0.6808E 05	0.1549E 05	0.2813E 05	
3	-30.00	0.6808E 05	0.1549E 05	-0.2813E 05	
4	60.00	0.1361E 05	-0.3265E 04	-0.8214E 03	
5	-60.00	0.1361E 05	-0.3265E 04	0.8214E 03	
6	90.00	0.1895E 05	-0.2236E 05	-0.2352E-01	
7	90.00	0.1895E 05	-0.2236E 05	-0.2352E-01	
8	-60.00	0.1361E 05	-0.3265E 04	0.8214E 03	
9	60.00	0.1361E 05	-0.3265E 04	-0.8214E 03	
10	-30.00	0.6808E 05	0.1549E 05	-0.2813E 05	
11	30.00	0.6808E 05	0.1549E 05	0.2813E 05	
12	0.0	0.1178E 06	-0.2090E 04	0.2077E-02	

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	1
1	12

APPLIED FORCES/LENGTH AT FAILURE:	LONGITUDINAL 0.861E 05	TRANSVERSE 0.0	SHEAR 0.0
LAMINATE TOTAL STRAINS:	0.373E-01	-0.153E-01	0.495E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION	STRESSES			STRAINS		
		ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE
1	0.0	0.2290E 06	-0.7017E 04	0.3118E-02	0.3727E-01	-0.1533E-01	0.4949E-08
2	30.00	0.1508E 06	0.4278E 04	-0.9802E 04	0.2412E-01	-0.2181E-02	-0.4556E-01
3	-30.00	0.1508E 06	0.4278E 04	0.9802E 04	0.2412E-01	-0.2181E-02	0.4556E-01
4	60.00	-0.1049E 05	0.1010E 05	-0.7988E 04	-0.2181E-02	0.2412E-01	-0.4556E-01
5	-60.00	-0.1049E 05	0.1010E 05	0.7988E 04	-0.2181E-02	0.2412E-01	0.4556E-01
6	90.00	-0.3332E 05	0.1895E 05	-0.3212E-01	-0.1533E-01	0.3727E-01	-0.1383E-06
7	90.00	-0.3332E 05	0.1895E 05	-0.3212E-01	-0.1533E-01	0.3727E-01	-0.1383E-06
8	-60.00	-0.1049E 05	0.1010E 05	0.7988E 04	-0.2181E-02	0.2412E-01	0.4556E-01
9	60.00	-0.1049E 05	0.1010E 05	-0.7988E 04	-0.2181E-02	0.2412E-01	-0.4556E-01
10	-30.00	0.1508E 06	0.4278E 04	0.9802E 04	0.2412E-01	-0.2181E-02	0.4556E-01
11	30.00	0.1508E 06	0.4278E 04	-0.9802E 04	0.2412E-01	-0.2181E-02	-0.4556E-01
12	0.0	0.2290E 06	-0.7017E 04	0.3118E-02	0.3727E-01	-0.1533E-01	0.4949E-08

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

LAYER	ORIENTATION	STRESSES			SHEAR
		ANGLE	LONGITUDINAL	TRANSVERSE	
1	0.0	0.2290E 06	-0.7017E 04	0.3118E-02	
2	30.00	0.1227E 06	0.3243E 05	0.5856E 05	
3	-30.00	0.1227E 06	0.3243E 05	-0.5856E 05	
4	60.00	0.1187E 05	-0.1226E 05	-0.4924E 04	
5	-60.00	0.1187E 05	-0.1226E 05	0.4924E 04	
6	90.00	0.1895E 05	-0.3332E 05	-0.3414E-01	
7	90.00	0.1895E 05	-0.3332E 05	-0.3414E-01	
8	-60.00	0.1187E 05	-0.1226E 05	0.4924E 04	
9	60.00	0.1187E 05	-0.1226E 05	-0.4924E 04	
10	-30.00	0.1227E 06	0.3243E 05	-0.5856E 05	
11	30.00	0.1227E 06	0.3243E 05	0.5856E 05	
12	0.0	0.2290E 06	-0.7017E 04	0.3118E-02	

FIRST FIBER FAILURE

APPLIED LAMINATE FORCES/LNGTH: LONGITUDINAL TRANSVERSE SHEAR
 0.630E 05 0.630E 05 0.0

2.12

ANALYSIS NUMBER 1:

BREAK-POINT ANALYSIS= 1; FAILURE ANALYSIS= 1

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LNG	0.312498E 07	0.309647E 00	0.119306E 07
TRAN	0.312498E 07	0.309647E 00	0.119306E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	12
2	2
2	3
2	4
2	6
2	7
2	9
2	10
2	11
2	5
2	8

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL TRANSVERSE SHEAR
 0.476E 05 0.476E 05 0.0

LAMINATE TOTAL STRAINS: 0.105E-01 0.105E-01 -0.936E-08

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

AYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	STRESSES	LONGITUDINAL	TRANSVERSE	STRAINS	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1		0.0	0.7210E 05	0.2310E 05	-0.5897E-02	0.1051E-01	0.1051E-01	-0.9361E-08				
2		30.00	0.7210E 05	0.2310E 05	0.7275E-02	0.1051E-01	0.1051E-01	0.1155E-07				
3		-30.00	0.7210E 05	0.2310E 05	-0.1317E-01	0.1051E-01	0.1051E-01	-0.2091E-07				
4		60.00	0.7210E 05	0.2310E 05	0.1317E-01	0.1051E-01	0.1051E-01	0.2091E-07				
5		-60.00	0.7210E 05	0.2310E 05	-0.7275E-02	0.1051E-01	0.1051E-01	-0.1155E-07				
6		90.00	0.7210E 05	0.2310E 05	0.5897E-02	0.1051E-01	0.1051E-01	0.9361E-08				
7		90.00	0.7210E 05	0.2310E 05	0.5897E-02	0.1051E-01	0.1051E-01	0.9361E-08				
8		-60.00	0.7210E 05	0.2310E 05	-0.7275E-02	0.1051E-01	0.1051E-01	-0.1155E-07				
9		60.00	0.7210E 05	0.2310E 05	0.1317E-01	0.1051E-01	0.1051E-01	0.2091E-07				
10		-30.00	0.7210E 05	0.2310E 05	-0.1317E-01	0.1051E-01	0.1051E-01	-0.2091E-07				
11		30.00	0.7210E 05	0.2310E 05	0.7275E-02	0.1051E-01	0.1051E-01	0.1155E-07				
12		0.0	0.7210E 05	0.2310E 05	-0.5897E-02	0.1051E-01	0.1051E-01	-0.9361E-08				

LAYER STRESSES IN LAMINATE CO-ORDS. AT BREAK-POINT:

AYER	ORIENTATION	ANGLE	LONGITUDINAL	TRANSVERSE	STRESSES	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1		0.0	0.7210E 05	0.2310E 05	-0.5897E-02				
2		30.00	0.5985E 05	0.3535E 05	0.2122E 05				
3		-30.00	0.5985E 05	0.3535E 05	-0.2122E 05				
4		60.00	0.3535E 05	0.5985E 05	0.2122E 05				
5		-60.00	0.3535E 05	0.5985E 05	-0.2122E 05				
6		90.00	0.2310E 05	0.7210E 05	0.5622E-01				
7		90.00	0.2310E 05	0.7210E 05	0.5622E-01				
8		-60.00	0.3535E 05	0.5985E 05	-0.2122E 05				
9		60.00	0.3535E 05	0.5985E 05	0.2122E 05				
10		-30.00	0.5985E 05	0.3535E 05	-0.2122E 05				
11		30.00	0.5985E 05	0.3535E 05	0.2122E 05				
12		0.0	0.7210E 05	0.2310E 05	-0.5897E-02				

SHEAR & OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.131E 01
0.625E-01	0.131E 01	0.798E 06

LAMINATE TANGENT MODULUS & POISSON RATIOS:

	YOUNGS MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210762E 07	0.319852E 00	0.798430E 06
TRAN	0.210761E 07	0.319851E 00	0.798430E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	5
1	6
1	7
1	8
1	3
1	10
1	4
1	9
1	1
1	12
1	2
1	11

APPLIED FORCES/LENGTH AT FAILURE:	LONGITUDINAL	TRANSVERSE	SHEAR
	0.126E 06	0.126E 06	0.0

LAMINATE TOTAL STRAINS:	0.358E-01	0.358E-01	-0.529E-07
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LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

LAYER	ORIENTATION	STRESSES	STRAINS				
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.2310E 05	-0.7968E-02	0.3582E-01	0.3582E-01	-0.5294E-07
2	30.00	0.2290E 06	0.2310E 05	0.8145E-02	0.3582E-01	0.3582E-01	0.2988E-07
3	-30.00	0.2290E 06	0.2310E 05	-0.1611E-01	0.3582E-01	0.3582E-01	-0.8282E-07
4	60.00	0.2290E 06	0.2310E 05	0.1590E-01	0.3582E-01	0.3582E-01	0.7836E-07
5	-60.00	0.2290E 06	0.2310E 05	-0.7934E-02	0.3582E-01	0.3582E-01	-0.2542E-07
6	90.00	0.2290E 06	0.2310E 05	0.7968E-02	0.3582E-01	0.3582E-01	0.5294E-07
7	90.00	0.2290E 06	0.2310E 05	0.7968E-02	0.3582E-01	0.3582E-01	0.5294E-07
8	-60.00	0.2290E 06	0.2310E 05	-0.7934E-02	0.3582E-01	0.3582E-01	-0.2542E-07
9	60.00	0.2290E 06	0.2310E 05	0.1590E-01	0.3582E-01	0.3582E-01	0.7836E-07
10	-30.00	0.2290E 06	0.2310E 05	0.1611E-01	0.3582E-01	0.3582E-01	-0.8282E-07
11	30.00	0.2290E 06	0.2310E 05	0.8145E-02	0.3582E-01	0.3582E-01	0.2988E-07
12	0.0	0.2290E 06	0.2310E 05	-0.7968E-02	0.3582E-01	0.3582E-01	-0.5294E-07

LAYER STRESSES IN LAMINATE CO-ORDS. AT FAILURE:

LAYER	ORIENTATION	STRESSES		
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2290E 06	0.2310E 05	-0.7968E-02
2	30.00	0.1775E 06	0.7457E 05	0.8916E 05
3	-30.00	0.1775E 06	0.7457E 05	-0.8916E 05
4	60.00	0.7458E 05	0.1775E 06	0.8916E 05
5	-60.00	0.7458E 05	0.1775E 06	-0.8916E 05
6	90.00	0.2310E 05	0.2290E 06	0.2530E 00
7	90.00	0.2310E 05	0.2290E 06	0.2530E 00
8	-60.00	0.7458E 05	0.1775E 06	-0.8916E 05
9	60.00	0.7458E 05	0.1775E 06	0.8916E 05
10	-30.00	0.1775E 06	0.7457E 05	-0.8916E 05
11	30.00	0.1775E 06	0.7457E 05	0.8916E 05
12	0.0	0.2290E 06	0.2310E 05	-0.7968E-02

FIRST FIBER FAILURE

ANALYSIS NUMBER 2:

BREAK-POINT ANALYSIS= 2; FAILURE ANALYSIS= 2

{1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION}

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

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	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.312498E 07	0.309647E 00	0.119306E 07
TRAN	0.312498E 07	0.309647E 00	0.119306E 07

BREAK-POINT NO. 1 PREDICTED IN FOLLOWING LAYERS:

(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
2	1
2	12
2	2
2	3
2	4
2	9
2	10
2	11
2	5
2	6
2	7
2	8

APPLIED FORCES/LENGTH AT BREAK-POINT: LONGITUDINAL 0.634E 05 TRANSVERSE 0.634E 05 SHEAR 0.0

LAMINATE TOTAL STRAINS: 0.140E-01 0.140E-01 -0.125E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT BREAK-POINT:

AYER	ORIENTATION	ANGLE	LONGITUDINAL	STRESSES	SHEAR	LONGITUDINAL	TRANSVERSE	STRAINS	SHEAR
1	0.0	0.9603E 05	0.3077E 05	-0.7855E-02	0.1400E-01	0.1400E-01	-0.1247E-07		
2	30.00	0.9603E 05	0.3077E 05	0.9689E-02	0.1400E-01	0.1400E-01	0.1538E-07		
3	-30.00	0.9603E 05	0.3077E 05	-0.1754E-01	0.1400E-01	0.1400E-01	-0.2785E-07		
4	60.00	0.9603E 05	0.3077E 05	0.1754E-01	0.1400E-01	0.1400E-01	0.2785E-07		
5	-60.00	0.9603F 05	0.3077E 05	-0.9689E-02	0.1400E-01	0.1400E-01	-0.1538E-07		
6	90.00	0.9603E 05	0.3077E 05	0.7855E-02	0.1400E-01	0.1400E-01	0.1247E-07		
7	90.00	0.9603E 05	0.3077E 05	0.7855E-02	0.1400E-01	0.1400E-01	0.1247E-07		
8	-60.00	0.9603E 05	0.3077E 05	-0.9689E-02	0.1400E-01	0.1400E-01	-0.1538E-07		
9	60.00	0.9603E 05	0.3077E 05	0.1754E-01	0.1400E-01	0.1400E-01	0.2785E-07		
10	-30.00	0.9603E 05	0.3077E 05	-0.1754E-01	0.1400E-01	0.1400E-01	-0.2785E-07		
11	30.00	0.9603E 05	0.3077E 05	0.5689E-02	0.1400E-01	0.1400E-01	0.1538E-07		
12	0.0	0.9603E 05	0.3077E 05	-0.7855E-02	0.1400E-01	0.1400E-01	-0.1247E-07		

LAYER STRESSES IN LAMINATE CO-ORDS AT BREAK-POINT:

AYER	ORIENTATION	ANGLE	LONGITUDINAL	STRESSES	SHEAR
1	0.0	0.9603E 05	0.3077E 05	-0.7855E-02	
2	30.00	0.7971E 05	0.4708E 05	0.2826E 05	
3	-30.00	0.7971E 05	0.4708E 05	-0.2826E 05	
4	60.00	0.4708E 05	0.7971E 05	0.2826E 05	
5	-60.00	0.4708E 05	0.7971E 05	-0.2826E 05	
6	90.00	0.3077E 05	0.9603E 05	0.7487E-01	
7	90.00	0.3077E 05	0.9603F 05	0.7487E-01	
8	-60.00	0.4708E 05	0.7971E 05	-0.2826E 05	
9	60.00	0.4708E 05	0.7971E 05	0.2826E 05	
10	-30.00	0.7971E 05	0.4708E 05	-0.2826E 05	
11	30.00	0.7971E 05	0.4708E 05	0.2826E 05	
12	0.0	0.9603E 05	0.3077E 05	-0.7855E-02	

SHEAR & OR TRANSVERSE BREAK-POINT REACHED IN EVERY LAYER

LAMINATE TANGENT STIFFNESS MATRIX:

0.235E 07	0.751E 06	0.625E-01
0.751E 06	0.235E 07	0.131E 01
0.625E-01	0.131E 01	0.798E 06

LAMINATE TANGENT MODULI & POISSON RATIOS:

	YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG	0.210762E 07	0.319852E 00	0.798430E 06
TRAN	0.210761E 07	0.319851E 00	0.798430E 06

FAILURE PREDICTED IN FOLLOWING LAYERS:

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(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE LAYER

1	6
1	7
1	5
1	8
1	3
1	10
1	4
1	9
1	1
1	12
1	2
1	11

APPLIED FORCES/LENGTH AT FAILURE: LONGITUDINAL TRANSVERSE SHEAR
 0.135E 06 0.135E 06 0.0

LAMINATE TOTAL STRAINS: 0.370E-01 0.370E-01 -0.521E-07

LAYER STRESSES & STRAINS IN LAYER CO-CRDS. AT FAILURE:

LAYER	ORIENTATION	STRESSES	STRAINS				
	ANGLE	LONGITUDINAL	TRANSVERSE	SHEAR	LONGITUDINAL	TRANSVERSE	SHEAR
1	0.0	0.2386 E 06	0.3077 E 05	-0.9736 E -02	0.3700 E -01	0.3700 E -01	-0.5208 E -07
2	30.00	0.2386 E 06	0.3077 E 05	0.1048 E -01	0.3700 E -01	0.3700 E -01	0.3204 E -07
3	-30.00	0.2386 E 06	0.3077 E 05	-0.2022 E -01	0.3700 E -01	0.3700 E -01	-0.8411 E -07
4	60.00	0.2386 E 06	0.3077 E 05	0.2002 E -01	0.3700 E -01	0.3700 E -01	0.8006 E -07
5	-60.00	0.2386 E 06	0.3077 E 05	-0.1029 E -01	0.3700 E -01	0.3700 E -01	-0.2799 E -07
6	90.00	0.2386 E 06	0.3077 E 05	0.9736 E -02	0.3700 E -01	0.3700 E -01	0.5208 E -07
7	90.00	0.2386 E 06	0.3077 E 05	0.9736 E -02	0.3700 E -01	0.3700 E -01	0.5208 E -07
8	-60.00	0.2386 E 06	0.3077 E 05	-0.1029 E -01	0.3700 E -01	0.3700 E -01	-0.2799 E -07
9	60.00	0.2386 E 06	0.3077 E 05	0.2002 E -01	0.3700 E -01	0.3700 E -01	0.8006 E -07
10	-30.00	0.2386 E 06	0.3077 E 05	-0.2022 E -01	0.3700 E -01	0.3700 E -01	-0.8411 E -07
11	30.00	0.2386 E 06	0.3077 E 05	0.1048 E -01	0.3700 E -01	0.3700 E -01	0.3204 E -07
12	0.0	0.2386 E 06	0.3077 E 05	-0.9736 E -02	0.3700 E -01	0.3700 E -01	-0.5208 E -07

LAYER STRESSES IN LAMINATE CO-CRDS AT FAILURE:

LAYER	ORIENTATION	STRESSES	SHEAR
	ANGLE	LONGITUDINAL	TRANSVERSE
1	0.0	0.2386 E 06	0.3077 E 05
2	30.00	0.1867 E 06	0.8273 E 03
3	-30.00	0.1867 E 06	0.8273 E 05
4	60.00	0.8273 E 05	0.1867 E 06
5	-60.00	0.8273 E 05	0.1867 E 06
6	90.00	0.3077 E 05	0.2386 E 06
7	90.00	0.3077 E 05	0.2386 E 06
8	-60.00	0.8273 E 05	0.1867 E 06
9	60.00	0.8273 E 05	0.1867 E 06
10	-30.00	0.1867 E 06	0.8273 E 05
11	30.00	0.1867 E 06	0.8273 E 05
12	0.0	0.2386 E 06	0.3077 E 05

FIRST FIBER FAILURE

ANALYSIS NUMBER 3:

BREAK-POINT ANALYSTS= 3; FAILURE ANALYSIS= 3

(1=MAX STRESS CRITERION; 2=MAX STRAIN CRITERION; 3=QUADRATIC INTERACTION CRITERION)

LAMINATE TANGENT STIFFNESS MATRIX:

0.346E 07	0.107E 07	0.625E-01
0.107E 07	0.346E 07	0.100E 01
0.625E-01	0.100E 01	0.119E 07

LAMINATE TANGENT MODULI & POISSON RATIOS:

YOUNG'S MODULUS	POISSON RATIO	SHEAR MODULUS
LONG 0.312498E 07	0.309647E 00	0.119306E 07
TRAN 0.312498E 07	0.309647E 00	0.119306E 07

FAILURE PREDICTED IN FOLLOWING LAYERS:

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(MODE 1=AXIAL; MODE 2=TRANSVERSE; MODE 3=SHEAR)

MODE	LAYER
1	6
1	7
1	5
1	8
1	3
1	4
1	9
1	10
1	1
1	2
1	11
1	12

APPLIED FORCES/LENGTH AT FAILURE:	LONGITUDINAL	TRANSVERSE	SHEAR
	0.151E 06	0.151E 06	0.0

LAMINATE TOTAL STRAINS: 0.334E-01 0.334E-01 -0.297E-07

LAYER STRESSES & STRAINS IN LAYER CO-ORDS. AT FAILURE:

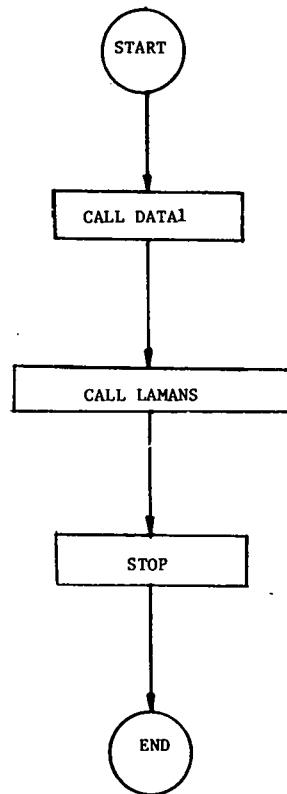
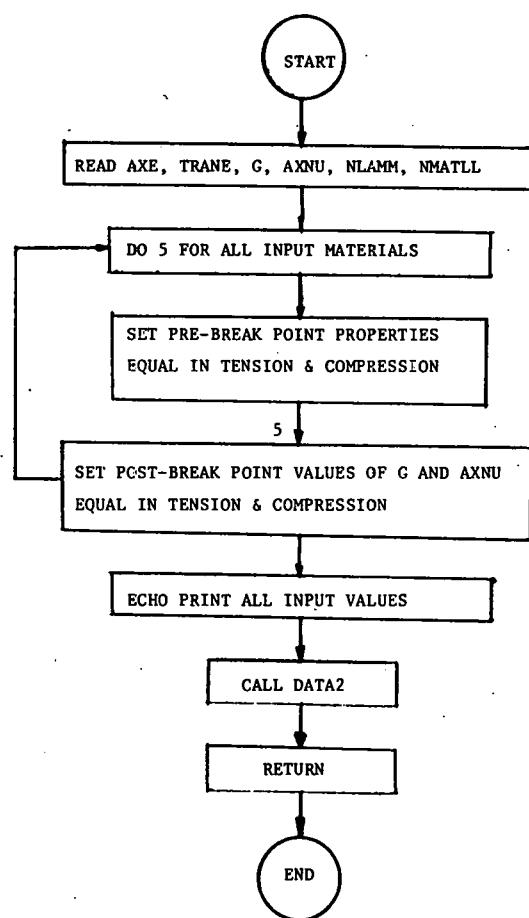
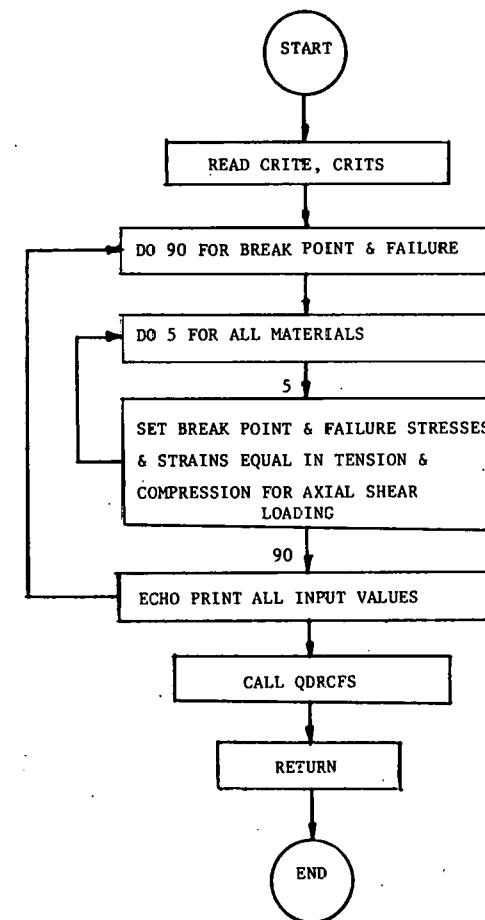
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2	30.00	0.2290E 06	0.7338E 05	0.2311E-01	0.3339E-01	0.3339E-01	0.3668E-07
3	-30.00	0.2290E 06	0.7338E 05	-0.4184E-01	0.3339E-01	0.3339E-01	-0.6642E-07
4	60.00	0.2290E 06	0.7338E 05	0.4184E-01	0.3339E-01	0.3339E-01	0.6642E-07
5	-60.00	0.2290E 06	0.7338E 05	-0.2311E-01	0.3339E-01	0.3339E-01	-0.3668E-07
6	90.00	0.2290E 06	0.7338E 05	0.1873E-01	0.3339E-01	0.3339E-01	0.2974E-07
7	90.00	0.2290E 06	0.7338E 05	0.1873E-01	0.3339E-01	0.3339E-01	0.2974E-07
8	-60.00	0.2290E 06	0.7338E 05	-0.2311E-01	0.3339E-01	0.3339E-01	-0.3668E-07
9	60.00	0.2290E 06	0.7338E 05	0.4184E-01	0.3339E-01	0.3339E-01	0.6642E-07
10	-30.00	0.2290E 06	0.7338E 05	-0.4184E-01	0.3339E-01	0.3339E-01	-0.6642E-07
11	30.00	0.2290E 06	0.7338E 05	0.2311E-01	0.3339E-01	0.3339E-01	0.3668E-07
12	0.0	0.2290E 06	0.7338E 05	-0.1873E-01	0.3339E-01	0.3339E-01	-0.2974E-07

LAYER STRESSES IN LAMINATE CO-ORDS AT FAILURE:

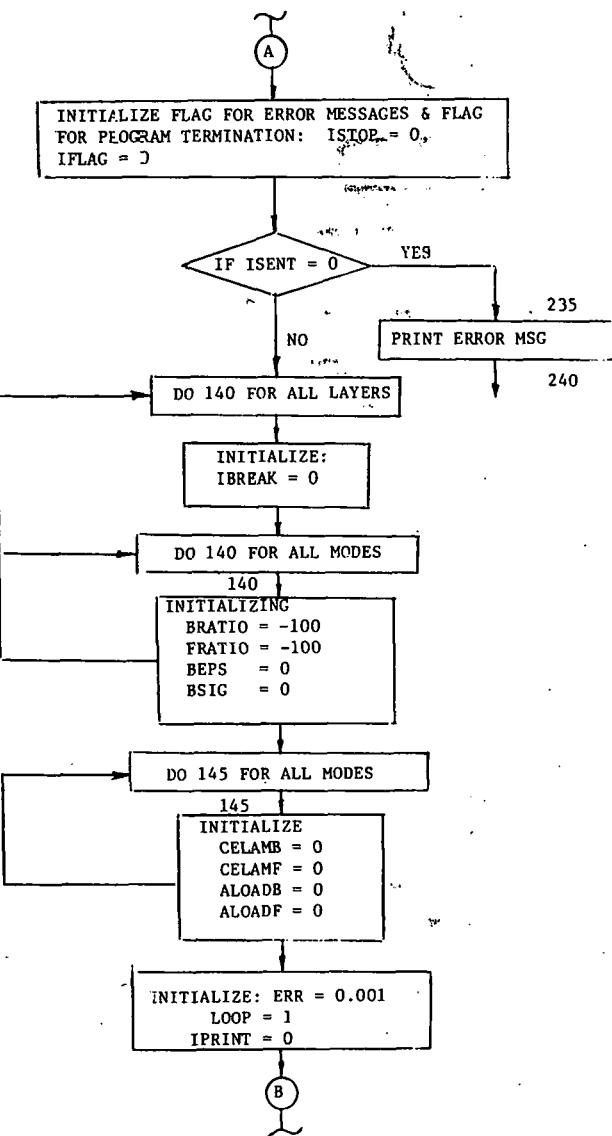
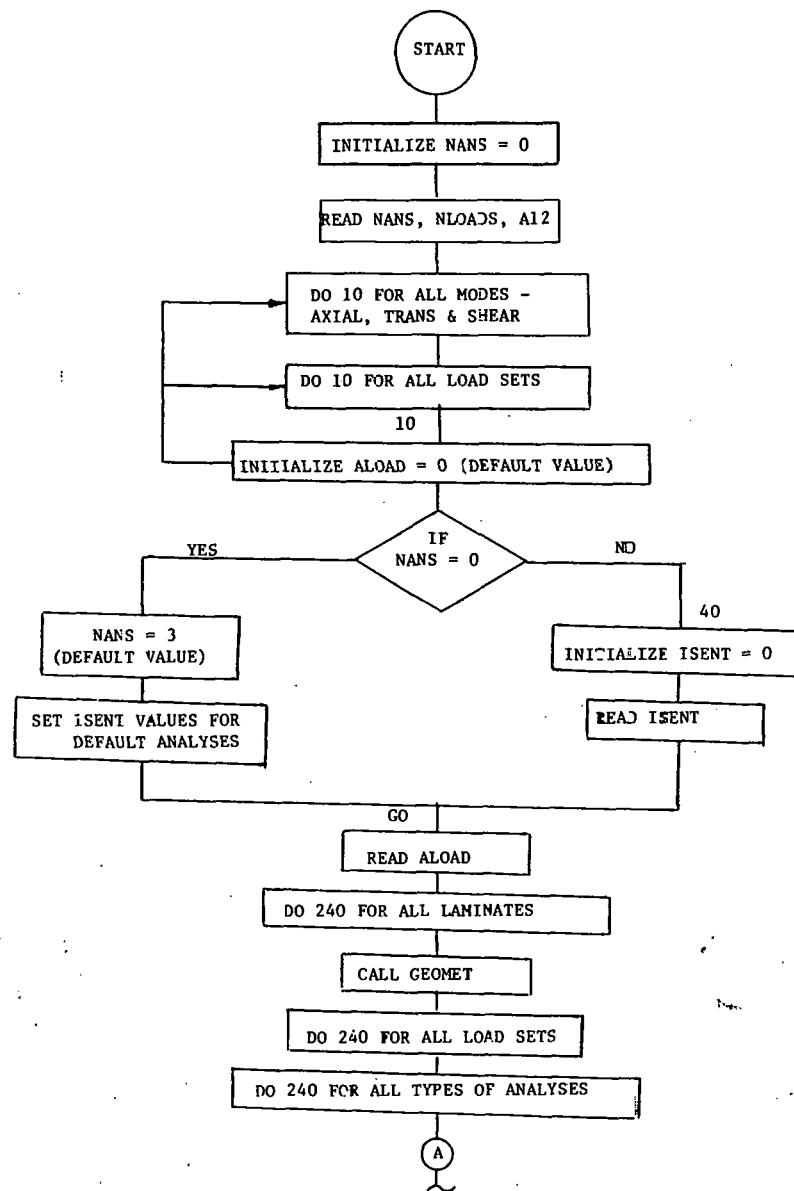
LAYER	ORIENTATION	STRESSES		
		ANGLE	LONGITUDINAL	TRANSVERSE
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2	30.00	0.1901E 06	0.1123E 06	0.6740E 05
3	-30.00	0.1901E 06	0.1123E 06	-0.6740E 05
4	60.00	0.1123E 06	0.1901E 06	0.6740E 05
5	-60.00	0.1123E 06	0.1901E 06	-0.6740E 05
6	90.00	0.7338E 05	0.2290E 06	0.1786E 00
7	90.00	0.7338E 05	0.2290E 06	0.1786E 00
8	-60.00	0.1123E 06	0.1901E 06	-0.6740E 05
9	60.00	0.1123E 06	0.1901E 06	0.6740E 05
10	-30.00	0.1901E 06	0.1123E 06	-0.6740E 05
11	30.00	0.1901E 06	0.1123E 06	0.6740E 05
12	0.0	0.2290E 06	0.7338E 05	-0.1873E-01

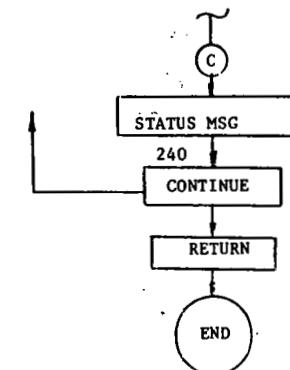
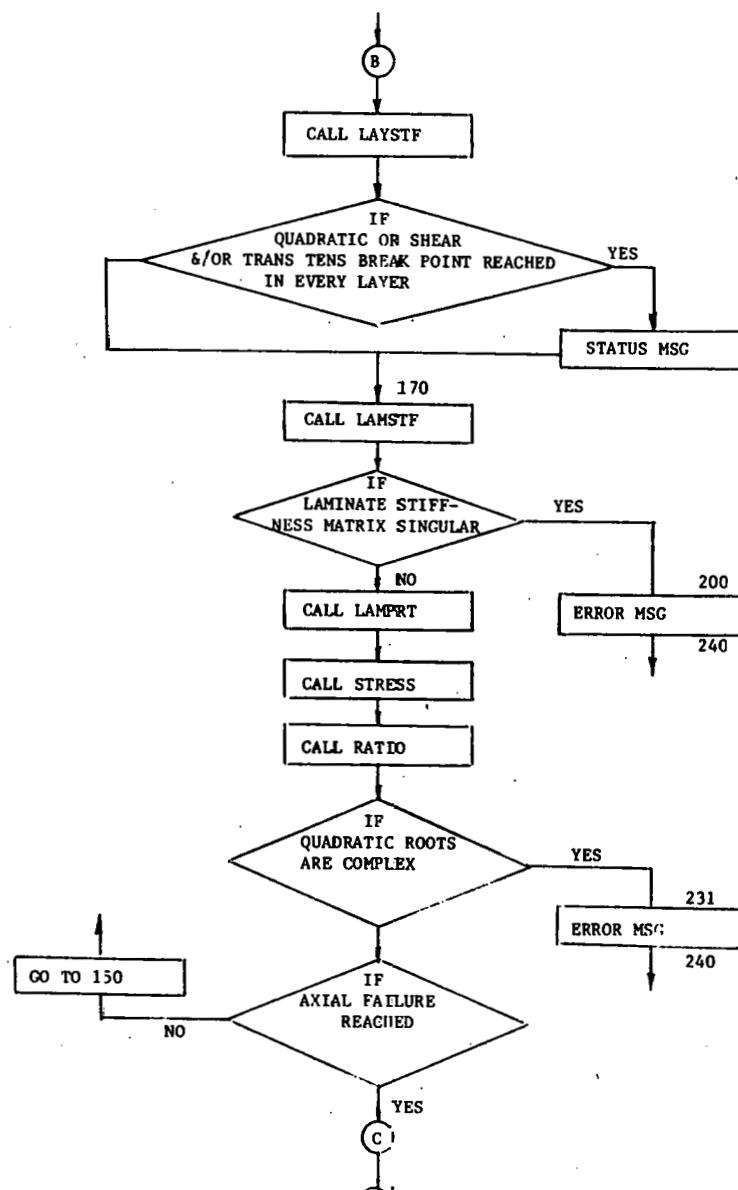
FIRST FIBER FAILURE

9.2 DETAILED FLOWCHARTS

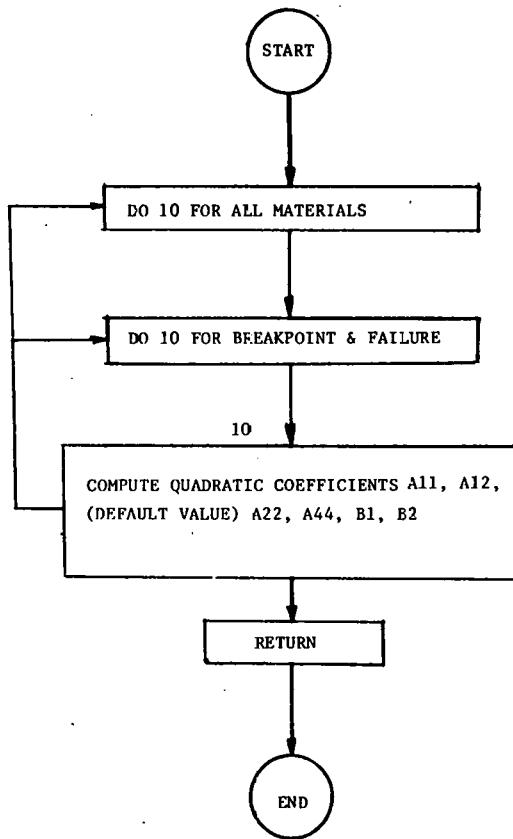
MAIN PROGRAMSUBROUTINE DATA1SUBROUTINE DATA2

SUBROUTINE LAMANS

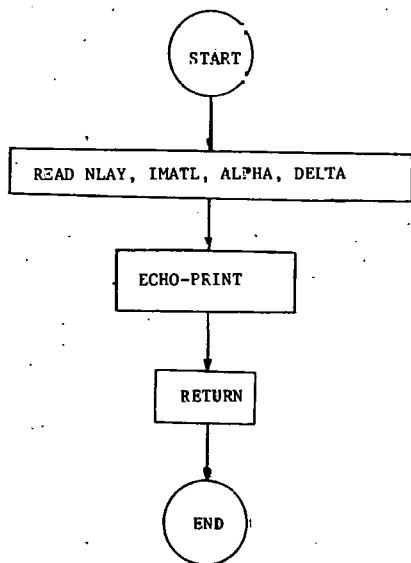




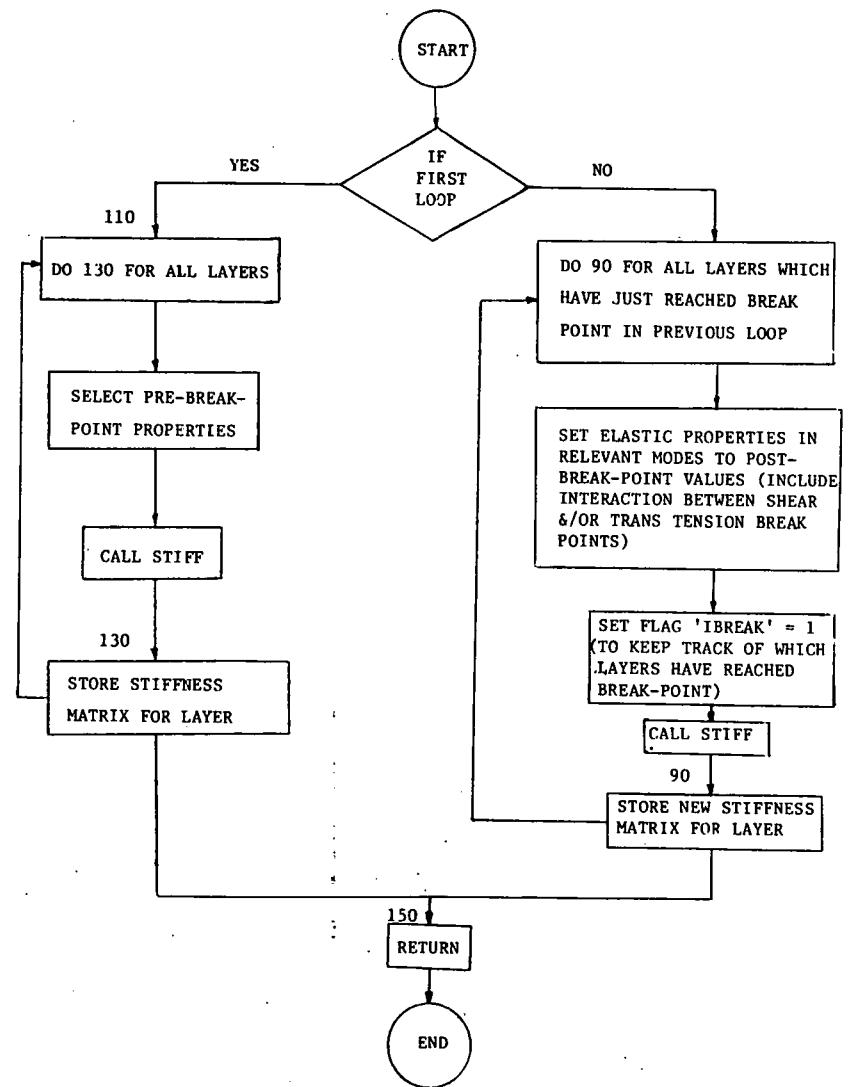
SUBROUTINE QDRCFS



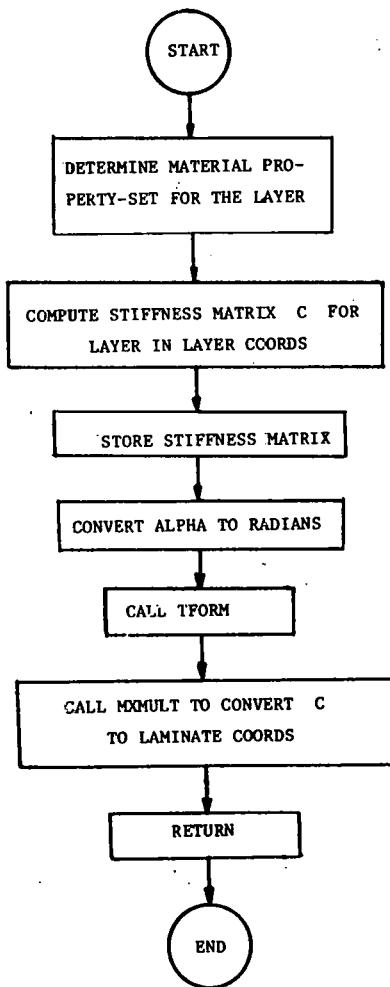
SUBROUTINE GEOMET



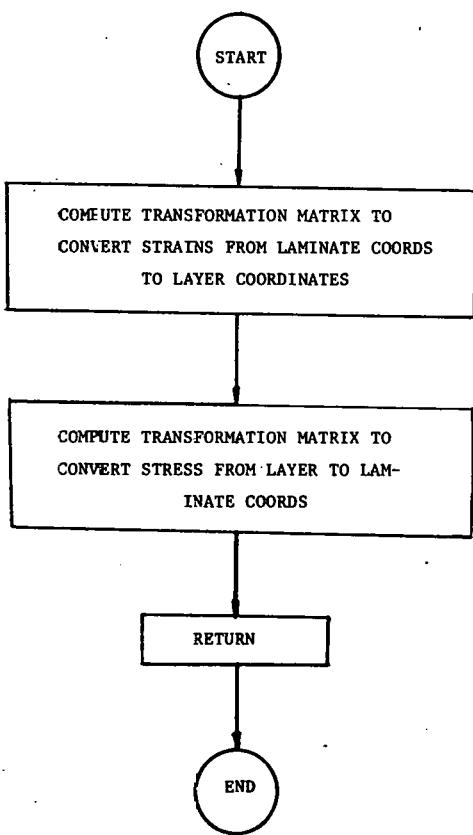
SUBROUTINE LAYSTF



SUBROUTINE STIFF



SUBROUTINE TFORM



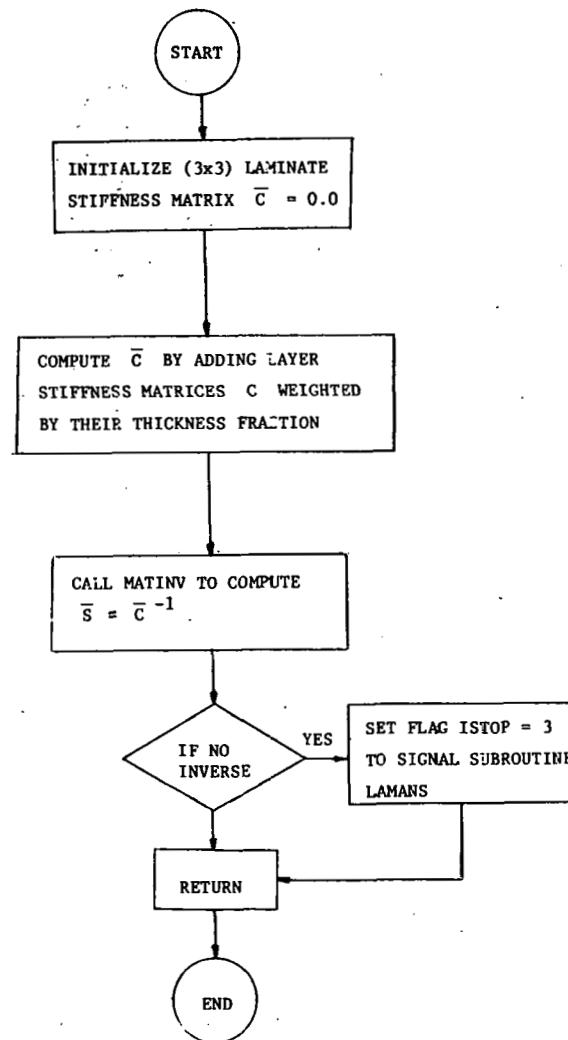
SUBROUTINE MXMULT

This subroutine pre-multiplies a ($N_2 \times N_3$) matrix by a ($N_1 \times N_2$) matrix.

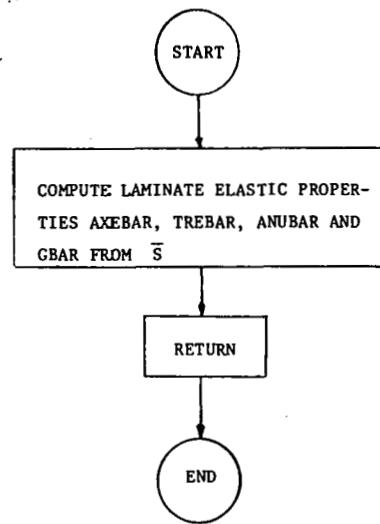
SUBROUTINE MATINV

This subroutine inverts a ($N \times N$) matrix by Gauss-Jordan reduction without pivoting. A check has been incorporated to detect any singularities in the matrix. If the matrix cannot be inverted, the subroutine will return a value of 0 for the flag INV. INV=1 if the matrix is not singular.

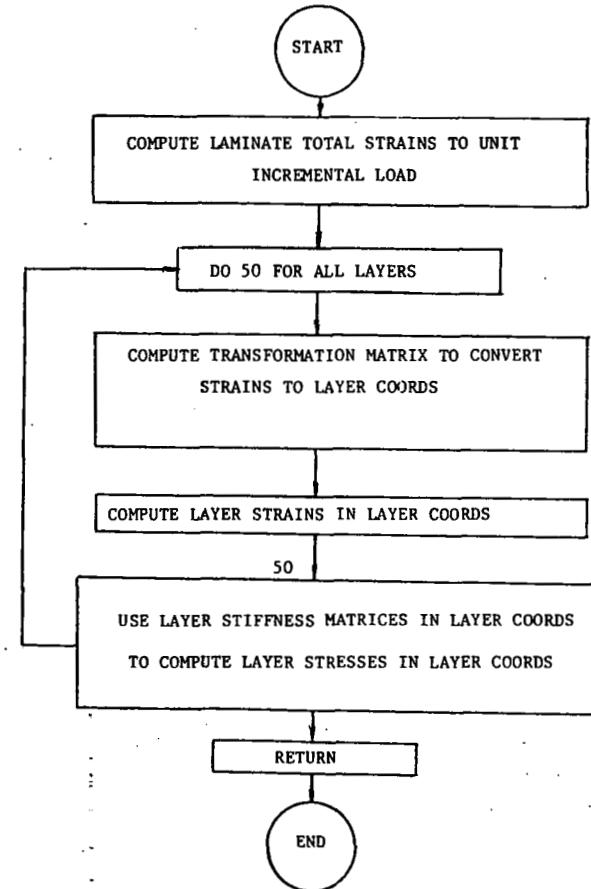
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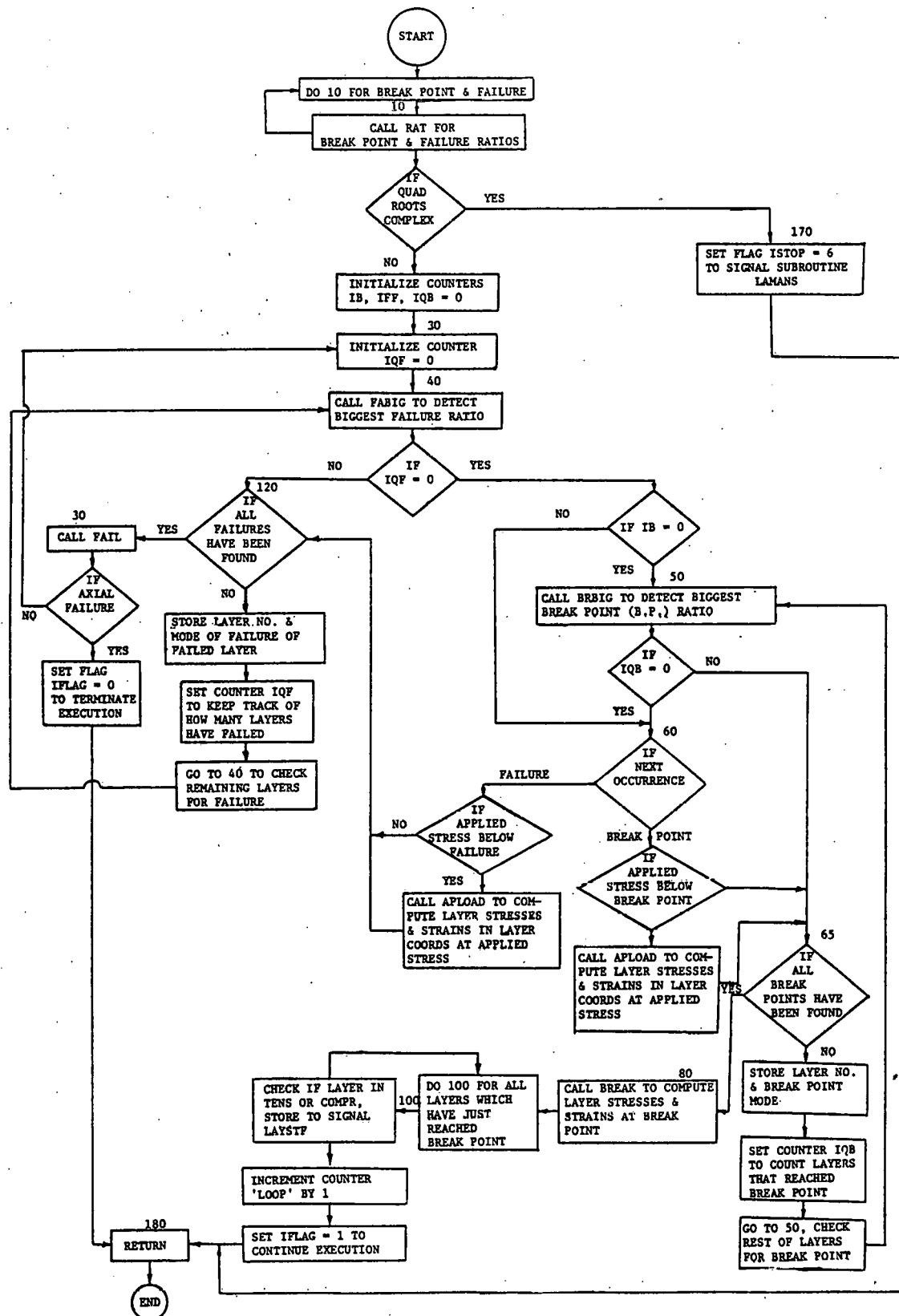
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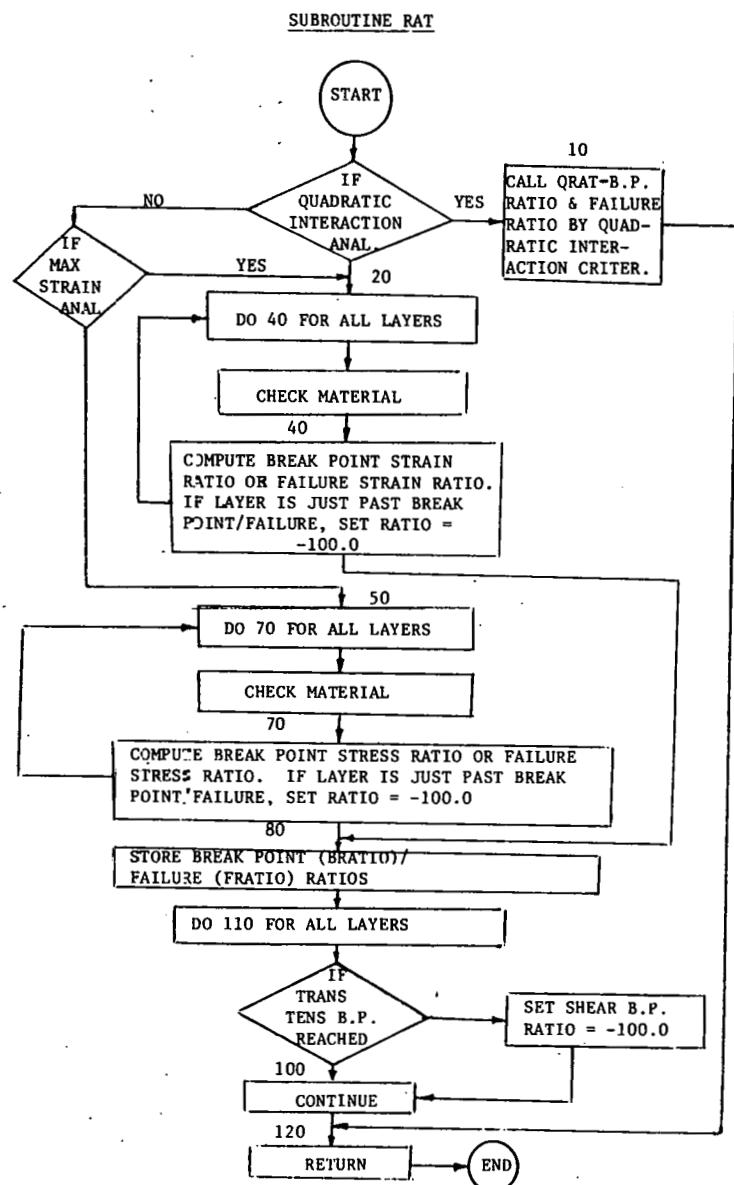
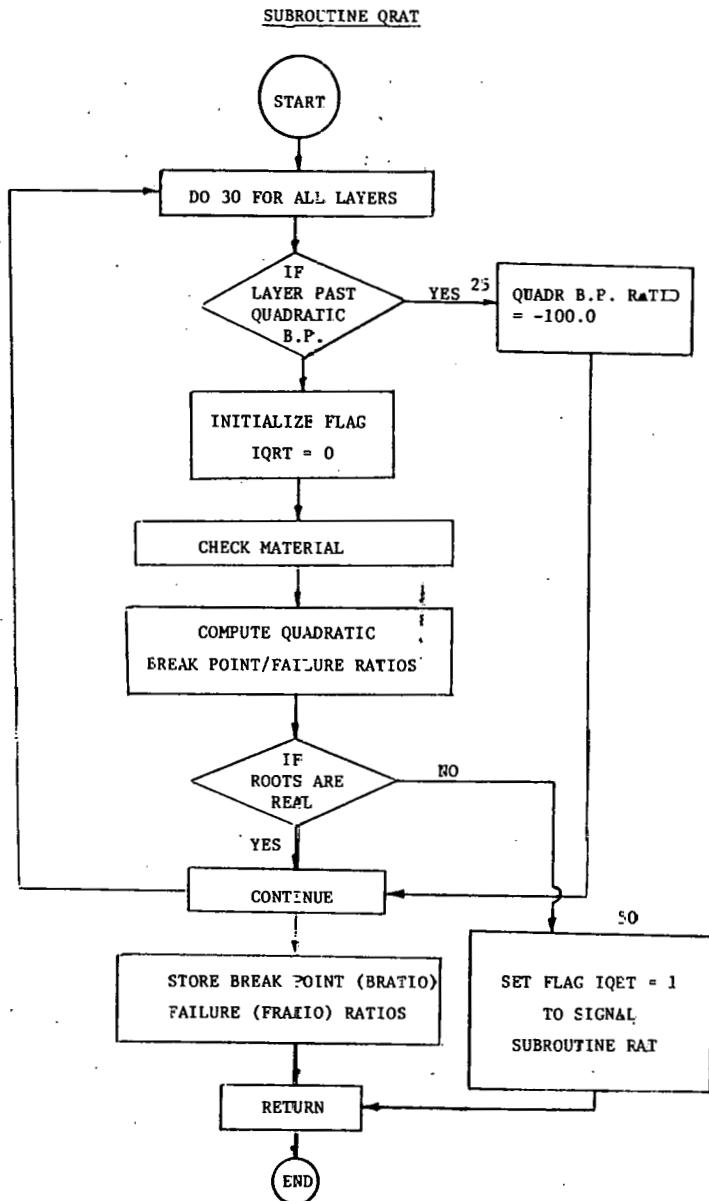


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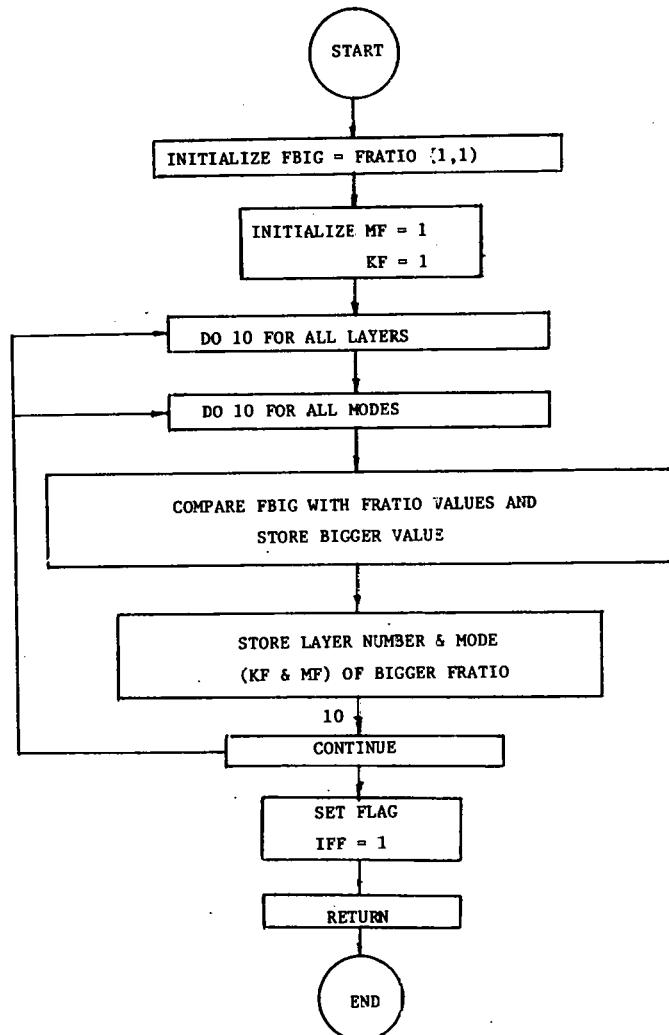


SUBROUTINE RATIO

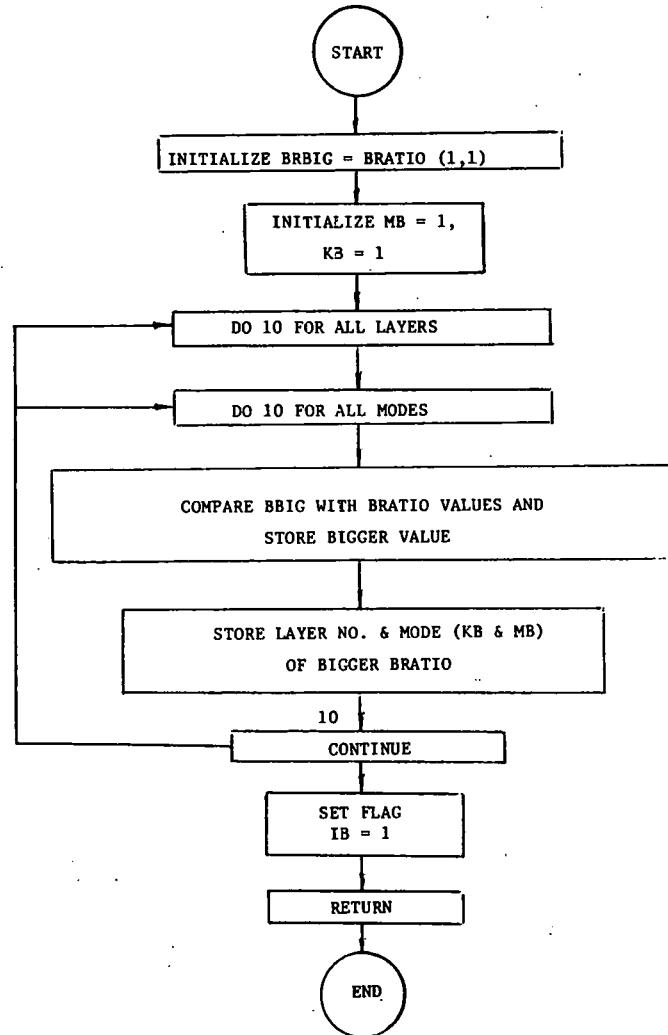


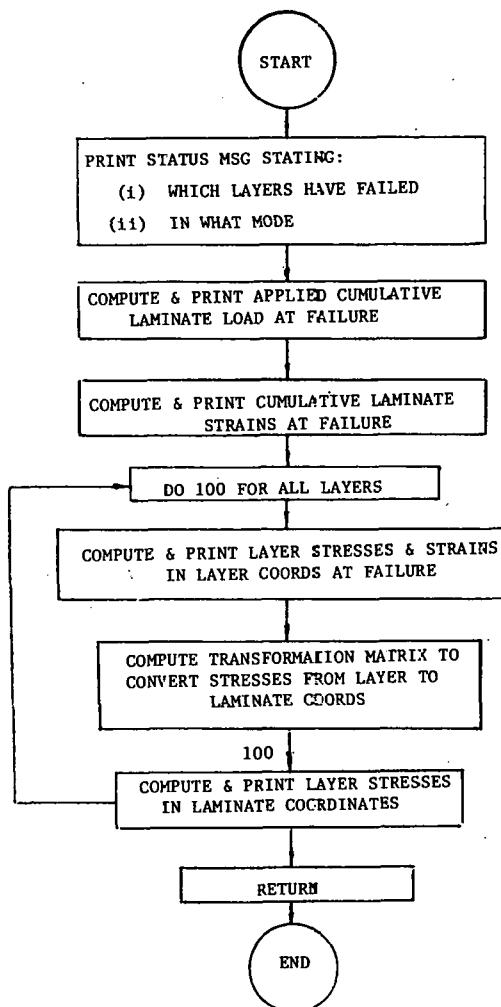
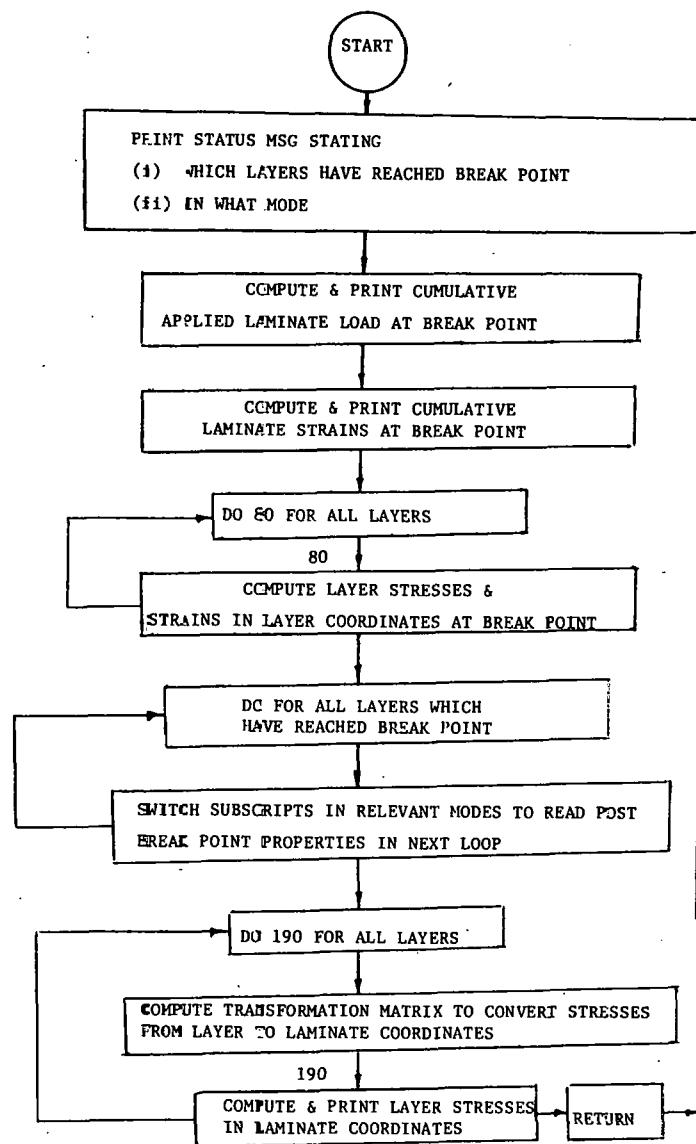
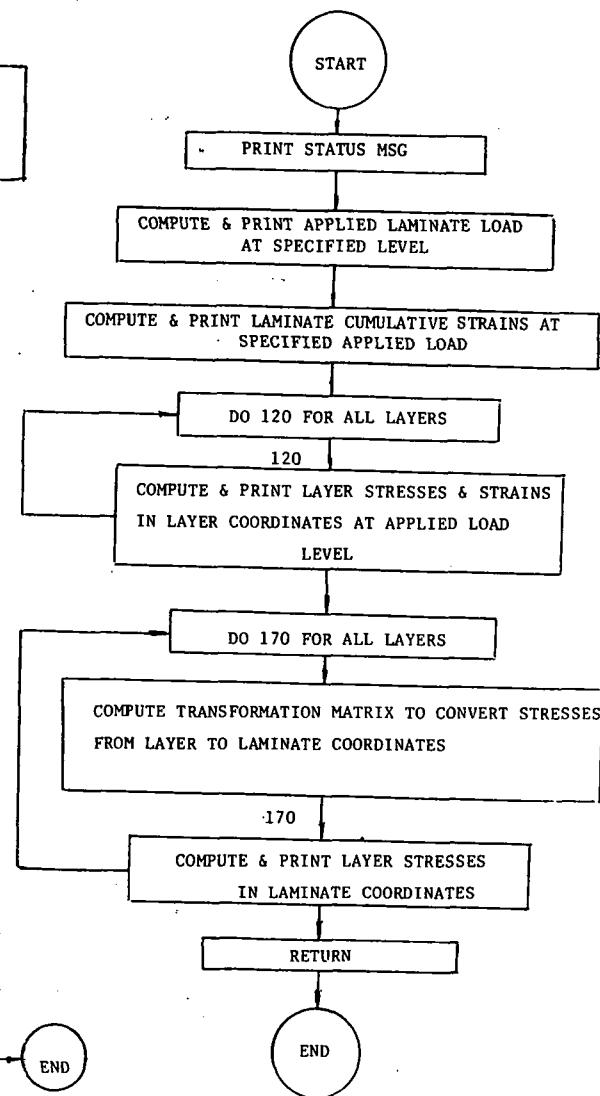


SUBROUTINE FABIG



SUBROUTINE BRBIG



SUBROUTINE FAILSUBROUTINE BREAKSUBROUTINE AFLOAD

9.3 COMPARISON OF BILAM RESULTS WITH LINEAR ELASTIC ANALYSIS

9.3.1 Introduction

Comparisons have been made between failure predictions using the BILAM code and those made by traditional linear elastic laminate analysis. Since material properties are crucial to accurate analyses, two material systems were chosen which have undergone considerable material testing under the LLNL-operated Mechanical Energy Storage Project - namely, autoclave cured 3M SP250-S2 S2-glass/epoxy and Celion 6000/Narmco 5213 graphite/epoxy. In spite of the large amount of information available on these materials, there were several tests required for BILAM analysis which had not been performed. These tests were performed at Villanova as a part of the current program, and the results were used in making the analytical laminate failure calculations.

The laminates analyzed for linear elastic and BILAM failure predictions were those for which failure data under uniaxial tension were available: $[0/\pm 45/90]$, $[0/\pm 30/\pm 60/90]$, and $[\alpha-9]$ (ref. 9.3-11) layups of the S2-glass/epoxy; and $[0/\pm 45/90]$ and $[0/\pm 30/\pm 60/90]$ graphite epoxy (see ref. (9.3-1) at the end of this section). All laminates were analyzed under tensile load parallel to a fiber direction (along axis loading) and bisecting fiber directions (off-axis loading). Details of the analyses and results are discussed below.

9.3.2 Material Property Determination

Inputs to linear elastic laminate analysis are the usual initial tangent moduli of a unidirectional laminate in axial normal (E_A), transverse normal (E_T), and axial shear (G_{AT}) modes; axial and transverse Poisson's ratios (ν_{AT} , ν_{TA}); failure stresses and strains in axial normal, transverse normal, and axial shear loading; and a quadratic interaction coefficient (A_{12}) if a quadratic interaction failure prediction is to be made. The graphite/epoxy properties used in the present elastic laminate analysis are those developed for a previous laminate failure study, ref. (9.3-2), to which the reader is referred for more detail. The S2-glass/epoxy properties

have been modified slightly from ref. (9.3-2) to reflect new experimental results, but were obtained in a fashion similar to that described in ref. (9.3-2). All properties used in the linear elastic laminate analysis are presented in Table 9.3.1.

Determination of accurate unidirectional layer properties for the BILAM code was more difficult because of the lack of certain test data required for the analysis. Poisson's ratios and initial tangent moduli were readily available for both S2-glass/epoxy and graphite/epoxy and are the same as those used in the linear elastic analysis. However, the "break-point" stresses and strains (see main body of report) and failure stresses and strains required testing, analysis, and engineering judgment.

Break-point stresses and strains and post-break-point moduli are found from tests of $[+45]$ tension (for shear properties), $[0]$ axial compression, $[0]$ transverse compression, and $[0/90]$ tension (for $[0]$ transverse tension properties). For both the S2-glass/epoxy and graphite/epoxy materials, $[+45]$ test results were available (refs. 9.3-1,3,4,5). Complete compressive stress-strain curves were not available, and the $[0]$ axial and transverse compression break points of both materials had to be estimated using qualitative information from compression tests of other materials (refs. 9.3-6,7). However, since axial and transverse compressive layer stresses were not large in any of the laminates analyzed, these stresses were not close to break-point and the break-point properties were not critical to the analysis. Transverse tensile break-point properties and post-break-point moduli are extremely important to failure analysis. Since no $[0/90]$ laminate test results were available, tests were performed on several $[0/90]$ samples of 3M SP-250-S2 S2-glass/epoxy and Celion 6000/Narmco 5213 graphite/epoxy. Break-point stresses and strains and post-break-point moduli were determined by fitting a bilinear curve to the resulting data. It is noted that for the S2-glass/epoxy, the ratio of break-point stress to initial transverse tensile failure stress (the latter found from $[0]$ layer transverse tensile tests) was about 3.0. This agrees very closely with a similar break-point-

Table 9.3.1 - Unidirectional Laminate Properties Used in Linear Elastic Laminate Analysis.

[0] PROPERTY	MATERIAL		
	3M SP-250-S2 S2-G1/Ep	Celion 6000/Narmco 5213 Gr/Ep	
<u>MODULI</u> (msi)	AXIAL, E_A TRANS, E_T SHEAR, G_{AT}	6.5 1.7 0.56	21.0 1.4 0.7
<u>AXIAL POISSON'S RATIO</u> , ν_{AT}		0.3	0.3
<u>FAILURE STRESSES</u> (ksi)	AXIAL TENS AXIAL COMPR TRANS TENS TRANS COMPR AXIAL SHEAR	218 134 7.9 28.0 12.3	259 177 7.0 20.0 10.4
<u>FAILURE STRAINS</u> (10^3 in/in)	AXIAL TENS AXIAL COMPR TRANS TENS TRANS COMPR AXIAL SHEAR	33.5 22.0 4.67 11.8 134.0	12 11 5.2 30 110
<u>QUADRATIC INTERACTION COEFFICIENT</u> , A_{12} (10^{-10} psi $^{-2}$)		-2.67	-2.82

to-initial-failure ratio obtained on a different glass epoxy material - Scotchply Type 1002 (ref. 9.3-8). The transverse tensile break-point-to-initial-failure ratio found for the graphite/epoxy was about 1.9. It is also noted that negative post-break-point transverse tensile moduli were required to fit the [0/90] data for both materials.

Failure stress and strain inputs to BILAM must be carefully chosen as discussed in the main body of this report. In transverse tension and axial shear, there is no "failure" other than matrix cracking which has already been modelled in the break-point. Since input transverse tensile failure values will affect other failure modes through maximum strain and quadratic interaction failure equations, arbitrary values cannot be chosen. For the laminates analyzed, choices were made which gave realistic layer failure predictions under combined axial shear and axial and transverse tension or compression. It is again noted that compressive properties were not important to this analysis since compressive layer stresses were well below break-points in all layers.

Table 9.3.2 presents material properties used for BILAM input data.

9.3.3 Failure Criteria

Two of the most popular layer failure criteria used in laminate failure analysis are the maximum strain criterion and the quadratic interaction criterion. For the linear elastic analysis, both layer failure criteria were used. Two laminate failure methodologies were analyzed for each failure criterion. For quadratic interaction layer criterion, the two laminate failure methodologies were:

- 1) Laminate failure occurs at first layer failure.
- 2) Laminate failure occurs when all layers have failed.

For the maximum strain criterion, the two laminate failure methodologies were:

- 1) Laminate failure occurs at first layer failure.
- 2) Laminate failure occurs when either all layers have failed in transverse tension or shear, or the first fiber failure occurs.

Table 9.3.2 - Unidirectional Laminate Properties Used in BILAM Analysis

[0] PROPERTY	MATERIAL			
	3M SP-250-S2, S2 G1/Ep		Celion 6000/Narmco 5213, Gr/Ep	
<u>MODULI</u> (msi)	<u>Pre-Break-Point</u>	<u>Post-Break-Point</u>	<u>Pre-Break-Point</u>	<u>Post-Break-Point</u>
AXIAL TENS	6.5	6.5	21	21
AXIAL COMPR	6.5	5.14	21	12.3
TRANS TENS	1.7	- 0.68	1.4	- 4.0
TRANS COMPR	1.7	0.114	1.4	2.6
SHEAR, G_{AT}	0.56	0.046	0.70	0.0376
<u>AXIAL POISSON'S RATIO</u> , ν_{AT}	0.30	0.30	0.30	0.30
<u>CRITICAL STRESSES</u> (ksi)	<u>Break-Point</u>	<u>Failure</u>	<u>Break-Point</u>	<u>Failure</u>
AXIAL TENS	327	218	390	259
AXIAL COMPR	100	134	100	177
TRANS TENS	23.8	26.0	13.3	16.5
TRANS COMPR	20.0	28.0	15.0	20.0
AXIAL SHEAR	6.68	12.3	6.3	10.4
<u>CRITICAL STRAINS</u> (10^{-3} in/in)	<u>Break-Point</u>	<u>Failure</u>	<u>Break-Point</u>	<u>Failure</u>
AXIAL TENS	50.3	33.5	18.6	12.3
AXIAL COMPR	15.4	22.0	4.76	11.0
TRANS TENS	14.0	2.9×10^6	9.48	2.9×10^6
TRANS COMPR	11.8	70.0	10.7	30.0
AXIAL SHEAR	11.9	134	9.0	110
<u>QUADRATIC INTERACTION COEFFICIENT</u> , A_{12} $(10^{-10} \text{ psi}^{-2})$	<u>Break-Point</u>	<u>Failure</u>	<u>Break-Point</u>	<u>Failure</u>
	0	-2.67	0	-2.82

BILAM has the option of three break-point criteria and three failure criteria. Under the types of laminates and loadings considered, break-points occur in transverse tension and axial shear. Other modes do not appear. Since the transverse tension and axial shear break-points are caused by the same failure phenomena, viz. cracks in matrix material parallel to fibers, a quadratic interaction criterion was chosen for break-point occurrence. Failure in transverse tension and axial shear has no meaning past the break-point, so a non-interactive maximum strain failure criterion was chosen for layer failure.

It is noted that a first layer failure methodology which uses [0] transverse tensile and axial shear failure stresses will yield the same result from either linear elastic or BILAM analysis, since these failure stresses are well below break-points. Results of this layer failure analysis for linear and BILAM models are therefore presented together.

9.3.4 Results and Discussion

Results of failure analyses for the S2-glass/epoxy and graphite/epoxy laminates are shown in Table 9.3.3 with experimental results. The following points are noteworthy for the S2-glass/epoxy results:

- 1) For S2-glass/epoxy, first failure predicted by BILAM and linear elastic analysis represent first matrix cracking, but do not predict laminate failure.
- 2) First layer break-point stresses from BILAM are considerably below failure stresses.
- 3) All linear elastic laminate failure predictions for tensile load parallel to fiber direction along-axis are much too high.
- 4) The all-layers-failure laminate failure predictions by linear elastic analysis exhibit qualitative but not quantitative agreement with test results.
- 5) The BILAM laminate failure predictions from the all-layers-break-point/first-fiber-failure methodology show good qualitative and reasonable quantitative

Table 9.3.3 - Failure Analysis Results for S2-Glass/Epoxy and Graphite/Epoxy Laminates. All Stress in ksi.

LAMINATE	FIRST FAILURE (LINEAR ELASTIC AND BILAM)		LINEAR ELASTIC			BILAM		TEST RESULTS**	
	QUAD	MAX ϵ	QUAD ALF*	MAX ϵ 1st FIB*	MAX ϵ ALM/FF*	QUADRATIC BREAK PT., MAX ϵ FAILURE	1st BP*		
				1st BP*	ALBP/FF*	1st BP*	ALBP/FF*		
TENSILE LOAD PARALLEL TO FIBER DIRECTION (ALONG-AXIS)									
3M SP-250-S2 S2 G1/Ep	[0/ \pm 45/90]	15	15	107	107	107	30	80	84
	[0/ \pm 30/ \pm 60/90]	16	15	107	107	107	31	80	71
	[\alpha-9]	16	15	108	107	107	31	80	-
TENSILE LOAD BISECTING FIBER DIRECTION (OFF-AXIS)									
3M SP-250-S2 S2 G1/Ep	[0/ \pm 45/90]	18	18	61	132	45	33	43	44
	[0/ \pm 30/ \pm 60/90]	17	16	81	117	64	30	56	49
	[\alpha-9]	16	15	94	111	94	29	73	41- 80
TENSILE LOAD PARALLEL TO FIBER DIRECTION (ALONG-AXIS)									
Cellion 6000/ Narmco 5213 Gr/Ep	[0/ \pm 45/90]	40	42	99	96	96	60	88	70- 79
	[0/ \pm 30/ \pm 60/90]	40	42	99	96	96	55	88	74
TENSILE LOAD BISECTING FIBER DIRECTION (OFF-AXIS)									
Cellion 6000/ Narmco 5213 Gr/Ep	[0/ \pm 45/90]	45	52	84	119	100	56	85	47- 50
	[0/ \pm 30/ \pm 60/90]	42	46	92	106	106	59	95	50

*KEY:

ALF = ALL LAYERS FAILED

1st FIB = FIRST FIBER FAILURE (AXIAL TENSION)

ALM/FF = ALL LAYERS MATRIX FAILURES, OR FIRST FIBER FAILURE

1st BP = FIRST BREAK-POINT

ALBP/FF = ALL LAYERS TRANSVERSE TENSILE OR AXIAL SHEAR BREAK-POINT
OR FIRST FIBER FAILURE

** See Refs. 9.3-1, 9.3-9, 9.3-10.

agreement with experimental data for both along-axis and off-axis S2-glass/epoxy.

For the graphite/epoxy laminates, the following results are evident:

- 1) Graphite/epoxy laminates loaded along-axis exhibit strengths which are most closely matched by the BILAM all-layers-break-point/first-fiber-failure predictions. The all layers failure predictions from linear elastic analysis are significantly higher than BILAM results, but the difference is not as great as for the glass. This is expected since ratio of unidirectional transverse Young's modulus to axial Young's modulus is much less for graphite.
- 2) Linear elastic first failure stresses and BILAM's first break-point stresses are much lower than along-axis test results.
- 3) Off-axis test results are closely approximated by BILAM first break-point and the BILAM/linear elastic first failure predictions. All-layers-failure predictions by BILAM and linear elastic analysis are too high.

A note of caution must be inserted at this point. Data on material properties have been obtained from many sources and may or may not represent material properties of laminates used for failure analysis comparisons. It has been determined that variations in moduli, break-point stresses and strains, and failure stresses used as inputs can cause large differences in failure predictions by BILAM and linear elastic analyses. Therefore, the results presented here should be digested with the realization that a carefully obtained experimental set of input material properties was not available for this analysis.

9.3.5 Conclusions

In general, it is seen that reasonable qualitative and quantitative agreement with test data is obtained with the BILAM analysis. The BILAM predictions are consistently closer to experimental data than are the predictions of linear elastic laminate analysis.

It is evident that BILAM and linear elastic failure predictions differ most greatly when transverse and axial moduli of unidirectional layers are of the same order of magnitude, as with S2-glass/epoxy. For such laminates, BILAM analysis gives good qualitative and quantitative predictions of laminate failure by an all-layers-break-point/first fiber failure methodology.

For laminates where layer axial modulus is considerably greater than transverse modulus, BILAM and linear elastic analysis predictions are closer together, but BILAM is nearer to test data. Along-axis test results are best approximated by BILAM all-layers/first-fiber laminate analysis predictions, but results are high. Off-axis test results are best predicted by first layer cracking or first layer break-point, indicating that interlaminar stresses or stress concentrations due to matrix cracks may be initiating failure.

As a result of these comparisons, it can be concluded that BILAM analysis represents a significant improvement over linear elastic laminate analysis provided that care is taken to obtain accurate input properties. A secondary conclusion is that a complete ability to model the failure mechanics of composite laminates still does not exist, and perhaps it will be necessary to include the effects of interlaminar stresses and adjacent layer overstresses when predicting laminate failure. This is supported by the range of test results for off-axis [α -9] laminates where the lower (41 ksi) failure stress was for a specimen designed to contain large interlaminar stresses, while the higher (80 ksi) failure stress resulted when the stacking sequence was selected to minimize interlaminar stresses.

9.3.6 References

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- 9.3-2 McLaughlin, P. V., Jr., Dasgupta, A., and Chun, Y. W., "Composite Failure Analysis for Flywheel Design Applications", Report No. UCRL-15296, Lawrence Livermore National Laboratory, March, 1980.
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- 9.3-4 Davis, J. W., 3M Company, Personal Communication.
- 9.3-5 Kliger, Howard, Celanese Corporation, Personal Communication.

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- 9.3-7 Advanced Composites Design Guide, Third Edition, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, 1973.
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9.4 FEASIBILITY STUDY OF THERMAL STRESS ANALYSIS

9.4.1 Introduction

Code BILAM analyzes response of composite laminates to mechanical, in-plane loads. This appendix examines the feasibility of extending BILAM's capability to include the in-plane effects of thermal loading, and makes recommendations for its implementation.

9.4.2. Feasibility Analysis:

A generalized analysis of thermal stresses would typically have the following capabilities:

- (i) Temperature-dependent material elastic properties.
- (ii) Provisions for applying thermal and mechanical loads either simultaneously or sequentially.
- (iii) Sequential loading that would include all possible load histories, i.e., mechanical loading followed by thermal or vice-versa, or any other arbitrary sequence of applied mechanical and thermal loads.

The following subsections analyze these possible capabilities for inclusion in the current BILAM code:

Temperature dependence of material properties

Investigations made indicate that it would not be feasible to incorporate temperature dependence of material elastic properties in BILAM's analysis method since such a change would necessitate a non-linear, incremental analysis, altering the material thermo-elastic properties at small increments of temperature. This incremental procedure would defeat BILAM's purpose of reducing analysis complexity by eliminating iterative techniques in favor of a bilinear analysis. It is therefore recommended that the elastic properties be treated as independent of temperature in BILAM.

Method of application of mechanical and thermal loads

Since BILAM uses a finite increment loading scheme, simultaneous application of mechanical and thermal loads would be possible only if some combined loading scheme were defined between the temperature

and mechanical load increments. This could be accomplished by describing either load as a function of the other, or by describing each as a function of a third independent parameter, e.g., time. Such a numerical procedure would require extensive restructuring of the input routines and subroutine STRESS, and is therefore not recommended. Besides, since most physical loading situations actually involve sequential loading, a simultaneous loading scheme appears to be unwarranted. Consider for example, a composite flywheel rotor where sustained operation would add frictional heating (thermal load) to an existent centrifugal stress field. This could be achieved in BILAM by letting the mechanical load build up to operating stresses and then applying thermal load increments until operating temperatures are attained. The reverse loading sequence would be true in a cruising aircraft where air-friction will set up a thermal field to which mechanical stresses will be added when maneuvering such as diving, banking, etc., are performed. In the program this could be simulated by applying the mechanical loads after the thermal load.

Selection of a sequence for load application

The sequence in which mechanical and thermal loads are applied would be significant in determining the state of the laminate if the material properties were to be considered temperature-dependent. However, since temperature dependence is considered unfeasible to incorporate, elastic properties will be considered temperature-invariant in BILAM's analysis.

For proportional loading, or if the unloading path of stress and strain is required to be the same as that during loading, the sequence in which mechanical and thermal loads are applied is irrelevant. However, since BILAM is designed to continue to failure, it could be of importance to decide which load (mechanical or thermal) to apply last, i.e., which load should be continued to failure in order to simulate as closely as possible, actual loading conditions. It would be desirable from this point of view to give BILAM's users some degree of

flexibility in selecting the loading sequence. It can be shown that the two alternative sequences listed below will enable the user to simulate any loading condition:

- (i) Mechanical loads applied to preset level - thermal load applied to preset level and continued proportionately until laminate fails.
- (ii) Thermal loads applied to preset level - mechanical loads applied to preset level and continued proportionately until laminate fails.

To illustrate the versatility of these sequences, consider a situation where specified mechanical loads are followed by specified thermal loads and proportional mechanical loading is resumed until failure occurs. Since the laminate state is path independent, it is irrelevant whether the preset mechanical load precedes the preset thermal load or follows it. This load sequence therefore, reduces to (ii) above. By the same rationale, the following loading sequence can be recognized to be the same as option (i) above: Thermal load to preset level followed by mechanical load to preset level followed by thermal loading to failure.

If the user wishes to analyze only for mechanical loading, option (ii) could be used by setting the input thermal load to zero (i.e., defining layer temperatures same as ambient). Option (i) similarly, would allow application of only thermal loads if input mechanical loads are set to zero.

It is noted that restricting loading paths and unloading paths to the same stress-strain curve may not be physically realistic. If it is desired to have a more accurate description of stress-strain properties during thermal changes which cause mechanical unloading, the above arguments concerning path independence cannot be made. To cover general combinations of sequential mechanical and thermal loads would then require development of a sequential loading scheme which can incorporate different material properties in loading and unloading. This situation is clearly most representative of the actual physical behavior, and should produce the most accurate results.

Recommended applications

It is noted that code BILAM is designed specifically for laminate response to in-plane loads and no flexural coupling has been incorporated in the stiffness matrix. This will enable BILAM to examine either transient thermal fields that are symmetric about the laminate midplane (applicable only to symmetric laminates) or arbitrary thermal fields acting on a laminate where flexure is mechanically prevented, e.g., a laminate sandwiched between two rigid plates. Arbitrary thermal fields acting on a laminate free to flex cannot be analyzed by this code.

The following section discusses briefly the modifications required in the code to include thermal analysis:

9.4.3 Recommended Program Modification:

The stiffness matrix in subroutine STIFF would need several modifications:

- (i) The thermal expansion terms would need to be included.
- (ii) It is noted that thermal loads, though monotonic, if imposed on an existing stress field could cause stress (and/or strain) reversals in some layers. This makes it necessary to define a physically realistic return path (i.e., a set of elastic moduli and Poisson's ratios) for the stress reversal to follow. It is recommended that in BILAM the "current" secant moduli be used to analyze such reversals. The term "current" refers to the instantaneous secant moduli at the stress (or strain) level at which the reversal occurs. (ref. fig. 9.4.1.). Thus, provisions must be made to compute an alternate modulus (equal to the ratio of existing stress to existing strain) for the layer in which the stresses (and /or strains) have reversed. Subroutine LAYSTF would also require appropriate modification to ensure the selection of the right set of moduli. Subroutine STRESS would need to be modified to enable it to apply the input thermal loads to the laminate.

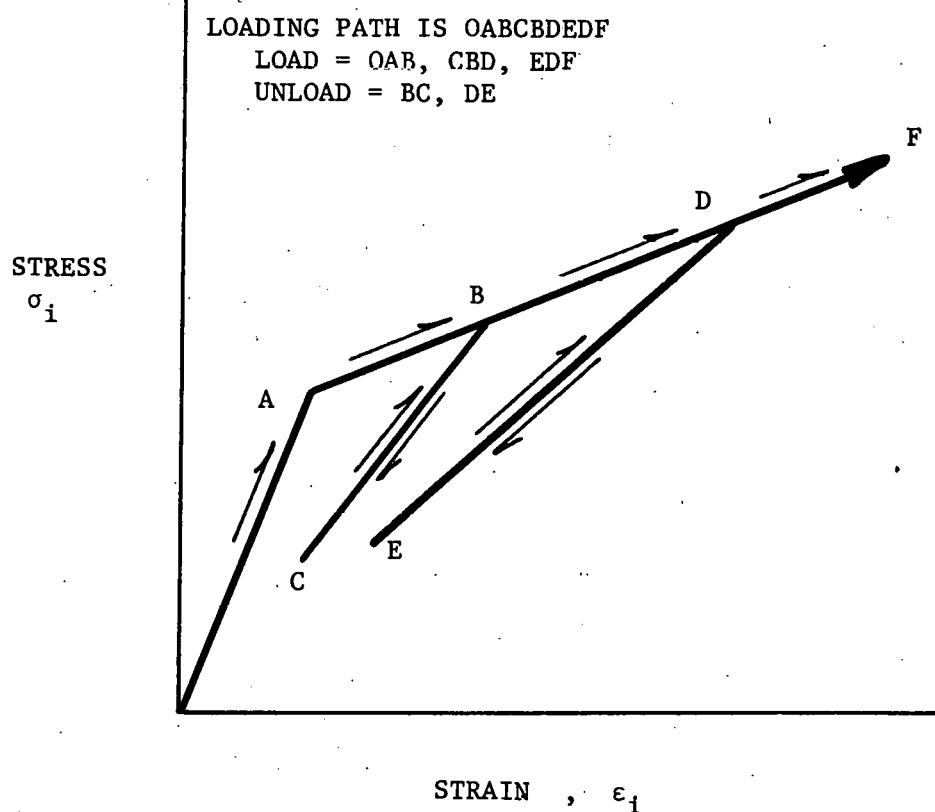


Fig. 9.4.1 Current secant modulus model for constrained fiber composite layer undergoing loading and unloading past break point A.

The input classes ELASTD, OPT1, and LOAD in subroutines DATA1 and LAMANS respectively would need the following modifications:

CLASS ELASTD: A new array would be required to define the thermal expansion coefficients for each input material in each mode (axial and transverse). Zero value (by default) would serve to bypass thermal analysis.

CLASS OPT1: Similar to array NSTRES, an array NTEMP could be used to monitor the laminate state at a predefined thermal load level. NTEMP = 0 (by default) would automatically bypass this option. Now, however, these variables would also have the additional function of triggering the changeover from one load type to another, e.g., NSTRES would set the user-defined stress (or strain level) at which mechanical loading would stop and thermal loading would commence. A new array (e.g., ISEQ) would be required to establish the sequence of application of the mechanical and thermal loads.

CLASS LOAD: Thermal loads could be input using array ATEMP (similar to ALOAD) which would specify the average temperature of each layer. A zero value (by default) would bypass the thermal analysis while a zero value (by default again) for ALOAD would bypass the mechanical analysis.

9.4.4. Conclusions

The recommended capabilities for thermal analysis are summarized below:

Thermal analysis could be performed at the user's option if (i) the thermal field is symmetric about the midplane of a symmetric laminate, or (ii) the thermal field is not symmetric, but zero curvature is externally enforced on the laminate. The user would have the option of applying the thermal and mechanical loads in any sequence but not simultaneously. Average, temperature independent, elastic properties would be used since modelling of their thermal dependence is not advisable for this program. In addition, constraints already existing on mechanical loads (e.g., monotonic, proportional loading only) will also hold for thermal loading. It is estimated that BILAM could be modified with moderate effort to include the capability of analysing thermal loads subject to the above constraints.

A significant outcome of these modifications would be the capability of BILAM to compute an effective stiffness matrix for analyzing load reversals. However, for handling non-monotonic loading, several additional modifications would also be required; e.g., (i) an alternative scheme for terminating the analysis since the loads could reverse thereby preventing laminate failure (which is used as the current terminator) (ii) an effective modulus for counter-reversal, i.e., resuming the original loading after a temporary load reversal, and so on.

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