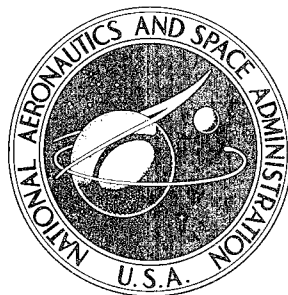


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NOLIN - A NONLINEAR
LAMINATE ANALYSIS PROGRAM

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16. Abstract A nonlinear, plane-stress, laminate analysis program, NOLIN, has been developed which accounts for laminae nonlinearity under inplane shear and transverse extensional stress. The program determines the nonlinear stress-strain behavior of symmetric laminates subjected to any combination of inplane shear and bi-axial extensional loadings. The program has the ability to treat different stress-strain behavior in tension and compression, and predicts laminate failure using any or all of maximum stress, maximum strain, and quadratic interaction failure criteria. This document provides a brief description of the program including discussion of the flow of information and details of the input required. Sample problems and a complete listing of the program is also provided.					
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NOLIN
A NONLINEAR LAMINATE ANALYSIS PROGRAM

by
John J. Kibler

SUMMARY

A nonlinear, plane-stress, laminate analysis program, NOLIN, has been developed which accounts for laminae nonlinearity under inplane shear and transverse extensional stress. The program determines the nonlinear stress-strain behavior of symmetric laminates subjected to any combination of inplane shear and biaxial extensional loadings. The program has the ability to treat different stress-strain behavior in tension and compression, and predicts laminate failure using any or all of maximum stress, maximum strain, and quadratic interaction failure criteria.

A second program, UNI, has been developed which computes elastic constants and thermal coefficients of expansion for laminae, from constituent properties, to aid in compiling input for the NOLIN program. Laminae properties can be computed for isotropic or transversely isotropic fibers in an isotropic matrix. In addition, the nonlinear inplane shear stress-strain curves are computed for the laminae by computing the Ramberg-Osgood shear stress parameter.

This document provides brief descriptions of both programs, a description of the flow of information through the NOLIN program, and detailed descriptions of the input required for each program. Sections are provided with sample problems and sample program output, along with complete listings of each program.

1. NOLIN Program Description

1.1 Introduction

The NOLIN program codifies a nonlinear, plane-stress, laminate analysis wherein the nonlinear behavior of the laminae under inplane shear and transverse extensional stresses are taken into account. Both the underlying analytical development and the computer program are sufficiently general to enable the user to study the nonlinear behavior of a symmetric laminate subjected to any combination of inplane shear and biaxial extensional loadings. Contained in this document are a detailed description of the input required to use the NOLIN program, as well as a description of the theoretical developments upon which the program is based. For a complete theoretical description the reader is referred to Ref. 1.

In unidirectional, fiber-reinforced laminae, the transverse extensional and, particularly, the inplane shear stress-strain relationships cannot be accurately characterized as linear. The NOLIN program allows for nonlinear representations by permitting these stress-strain relationships to take the form of Ramberg-Osgood nonlinear relationships. The introduction of these nonlinear, Ramberg-Osgood type constitutive relationships into a laminate analysis then leads to a set of nonlinear equations involving the laminae stress components as unknowns. The program then solves this set of equations by means of a generalized, Newton-Raphson procedure to give the laminae stresses and strains corresponding to the applied boundary stresses.

The theoretical development for this nonlinear, laminate analysis incorporates total deformation theory with Ramberg-Osgood type stress-strain characterizations to formulate the governing nonlinear equations. At the outset the compliance tensor is assumed to be the sum of two tensors, the components of one are the usual components associated with linear,

orthotropic, plane-stress elasticity theory, while the second tensor contains the nonlinear elements. By assuming a quadratic interaction of the stress components, and requiring the constitutive relationship to reduce to the relationships for the uniaxial stress cases of inplane shear and transverse extension, the elements of the nonlinear compliance tensor are explicitly determined.

Having the nonlinear laminae constitutive relations, the usual methods of laminate theory are then utilized to obtain the governing, nonlinear equations for the laminate. As in linear, laminate theory, the strains of the individual laminae are first rotated to a common set of laminate axis, and the laminate compatibility relations requiring the corresponding strains of the individual laminae to be equal are then employed. In addition, equilibrium at the laminate boundaries is invoked. In this way the required number of equations involving the unknown laminae stresses are formulated.

The program solution procedure for the set of nonlinear equations involving the laminae stress components is a Newton-Raphson technique generalized to accomodate systems of equations. The starting point for the solution procedure is taken as the solution of the associated, linear laminate problem, where the associated linear problem is obtained by ignoring all nonlinear terms.

Incorporated into the program are three different failure criteria, maximum stress, maximum strain and a quadratic interaction criteria. Any or all of these may be employed by the program user. Unfortunately, the nonlinear aspects of this program preclude the generation of strength envelopes since linear extrapolation is not valid here. Instead a sequence of combined loadings may be run.

The governing equations are formulated so that the three stress components in each lamina are the unknowns. Thus, for an N-layered laminate, the problem is formulated in terms of 3N unknowns. To obtain solutions, 3N equations are then required, and these equations consist of three equilibrium equations and 3(N-1) compatibility equations satisfying strain compatibility between adjacent laminae. The three equations of equilibrium for a laminate under a combined state of stress are,

$$\begin{aligned} \sum_{k=1}^N \sigma_{11}^{(k)} t_k &= N_{11} \\ \sum_{k=1}^N \sigma_{22}^{(k)} t_k &= N_{22} \\ \sum_{k=1}^N \sigma_{12}^{(k)} t_k &= N_{12} \end{aligned} \quad (6)$$

Where N_{11} , N_{22} and N_{12} are the applied stress resultants, t_k the thickness of the kth lamina, and subscripts 1 and 2 denote the laminate axes. The 3(N-1) equations of strain compatibility are,

$$\begin{aligned} \epsilon_{11}^{(k)} &= \epsilon_{11}^{(k-1)} \\ \epsilon_{22}^{(k)} &= \epsilon_{22}^{(k-1)} \\ \epsilon_{12}^{(k)} &= \epsilon_{12}^{(k-1)} \end{aligned} \quad (7)$$

$$k = 2, 3, \dots, N$$

Equations (6) and (7) are the 3N equations required for the solution of the nonlinear laminate problem. When the stress-strain relations given by equations (2), (4) and (5) are transformed to the laminate reference axes and substituted into equations (7), the governing equations can be expressed

in functional form as,

$$F_k (\sigma_1, \sigma_2, \dots, \sigma_1^2, \dots) = 0 \quad (8)$$

$$k = 1, 2, \dots, 3N$$

1.3 Method of Solution

Solutions of equations (8) for the 3N stress components are obtained by employing a Newton-Raphson iterative scheme. The functions F_k are first expanded in Taylor series about an approximate set of initial stresses, σ_j^0 . Considering only the first order terms of these series,

$$F_k = F_k^0 + \left(\frac{\partial F_k}{\partial \sigma_j} \right) \bigg|_{\sigma_j^0} \cdot \Delta \sigma_j \quad (9)$$

$$j, k = 1, 2, \dots, 3N$$

By writing,

$$\Delta \sigma_j = \sigma_j - \sigma_j^0$$

where σ_j are the solution values, equations (9) can be rewritten to give

$$\sigma_j = \sigma_j^0 - \left(\frac{\partial F_k}{\partial \sigma_j} \right) \cdot F_k^0 \quad (10)$$

$$j, k = 1, 2, \dots, 3N$$

For clarity, the notation in equations (10) is, in expanded form,

$$\sigma_j = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \vdots \\ \sigma_N \end{bmatrix} \quad (11)$$

$$\sigma_j^\circ = \begin{bmatrix} \sigma_1^\circ \\ \sigma_2^\circ \\ \cdot \\ \cdot \\ \cdot \\ \sigma_N^\circ \end{bmatrix} \quad (12)$$

$$F_k^\circ = \begin{bmatrix} F_1^\circ \\ F_2^\circ \\ \cdot \\ \cdot \\ \cdot \\ F_N^\circ \end{bmatrix} \quad (13)$$

and,

$$\left(\frac{\partial F_k}{\partial \sigma_j} \right) \sigma_j^\circ = \begin{vmatrix} \frac{\partial F_1}{\partial \sigma_1} & \frac{\partial F_1}{\partial \sigma_2} & \dots \\ \frac{\partial F_2}{\partial \sigma_1} & \frac{\partial F_2}{\partial \sigma_2} & \dots \\ \cdot & & \\ \cdot & & \\ \cdot & & \end{vmatrix} \sigma_j^\circ = \sigma_j^\circ \quad (14)$$

The solution for σ_j in equation (10) may be taken as the approximate, initial stress values for the next iteration step, and this process repeated until a result is obtained within some desired accuracy. After the stresses are obtained and transformed to the laminae natural axes, the corresponding laminae strains are determined from equations (1), (2) and (5).

1.4 Computer Program

The flow chart for the computer program is shown in Fig. 1. The major sections of the program are the formation of the governing equations, the Newton-Raphson solution procedure and the failure checks.

Using the computer program notation, the governing equations take the form,

$$[A] \cdot \overline{SG} + \overline{B} = \overline{SGO} \quad (15)$$

Where $\overline{SG}$ and $\overline{SGO}$ are the stress solution vector and the applied stress vector, respectively. A is a matrix of constant elements which are the coefficients of the linear terms in the solution, and $\overline{B}$ is a vector containing the nonlinear terms in the solution. The set of equations (15) are equivalent to equations (8). If in equation (15) the vector $\overline{B}$ is set to zero, the resulting equation

$$[A] \cdot \overline{SG} = \overline{SGO} \quad (16)$$

is the linear laminate solution. The stress vector, $\overline{SG}$, as determined from equation (16) is taken as the initial approximation for the stress vector in the Newton-Raphson procedure.

For the Newton-Raphson procedure it is necessary to formulate the derivative of $([A] \cdot \overline{SG} + \overline{B})$ in equation (15) with respect to σ_j as well as the vector

$$\overline{DC} = ([A] \cdot \overline{SGO} + \overline{B} - \overline{SGO}) \quad (17)$$

The vector $\overline{DC}$ corresponds to the vector $\overline{F}_f^o$ in equation (10), and an explicit evaluation of $\overline{DC}$ is obtained by using the current, approximate value for the solution stress vector, $\overline{SC}$. The derivative of $([A] \cdot \overline{SG} + \overline{B})$ is designated $\overline{DB}$ in the computer program, and is equivalent to the matrix $(\partial F_k / \partial \sigma_j) \sigma_j^o$ in equation (10). An explicit evaluation of $\overline{DB}$ is also obtained by using the current, approximate value for the solution stress vector, $\overline{SG}$.

In the program, the external loading is applied in increments. The approximate solution stress vector for the first load increment and the first Newton-Raphson iteration is determined from equation (16). For the second and third load increments, the approximate solution stress vectors for the first iteration are taken as the final solution stress vectors from the previous increments. Solutions for subsequent load increments are initiated by the following algorithm:

$$\begin{aligned} (SG_{i+1})_{\text{INITIAL}} &= (SG_i)_{\text{FINAL}} * (\text{FACTOR}) \\ (\text{FACTOR}) &= \frac{i(i-2)}{(i-1)^2} \frac{(SG_i)_{\text{FINAL}} - (SG_{i-1})_{\text{FINAL}}}{(SG_i)_{\text{FINAL}}} \end{aligned} \quad (18)$$

The convergence and divergence criteria employed in the program are contained in the following expressions:

$$\begin{aligned} |(SG_{i+1} - SG_i)/SG_i| &\leq \epsilon \\ |(SG_{i+1} - SG_i)/SG_i| &< \lambda \end{aligned} \quad (19)$$

Where SG_i and SG_{i+1} are the solution vectors obtained from the i^{th} and $i+1^{\text{th}}$ iterations. Usually values of 10^{-3} and 10^{-4} are taken for ϵ and λ , respectively. However, the other values may be input as data to the program. In addition, the maximum number of iterations to be allowed is input as data. Ten iterations have been found to be sufficient for most problems.

The program contains three failure criteria, maximum strain, maximum stress, and a quadratic interaction criteria. After a solution is obtained for each load increment any or all of these failure criterias may be applied to check for laminae failure.

The maximum stress and maximum strain failure criteria check, respectively, the laminae stress or strain values in

the fiber, and transverse fiber directions against the material allowables. These allowables are input to the program as data. The quadratic criteria is given by

$$A_{11} \sigma_{LL}^2 + A_{22} \sigma_{TT}^2 + A_{44} \sigma_{LT}^2 + A_{12} \sigma_{LL} \sigma_{TT} + B_1 \sigma_{LL} + B_2 \sigma_{TT} = 1 \quad (20)$$

where the coefficients are functions of the allowable stress

$$\begin{aligned} A_{11} &= \frac{1}{F_L^T F_L^C} & B_{11} &= \frac{1}{F_L^T} - \frac{1}{F_L^C} \\ A_{22} &= \frac{1}{F_T^T F_T^C} & B_{22} &= \frac{1}{F_T^T} - \frac{1}{F_T^C} \\ A_{44} &= \frac{1}{(F^S)^2} \end{aligned} \quad (21)$$

F_L^t and F_L^c are the allowable tension and compression stresses in the longitudinal direction, F_T^t and F_T^c are the allowable tension and compression stresses in the transverse direction, and F^S is the allowable shear stress. The coefficient A_{12} is input as data to the program, or a default null value is used.

If a failure criteria is satisfied at the end of a load increment, the program determines the failure load through linear interpolation. If all failure criteria are being checked, and not all indicate failure during the same load increment, the program continues loading until all criteria indicate failure.

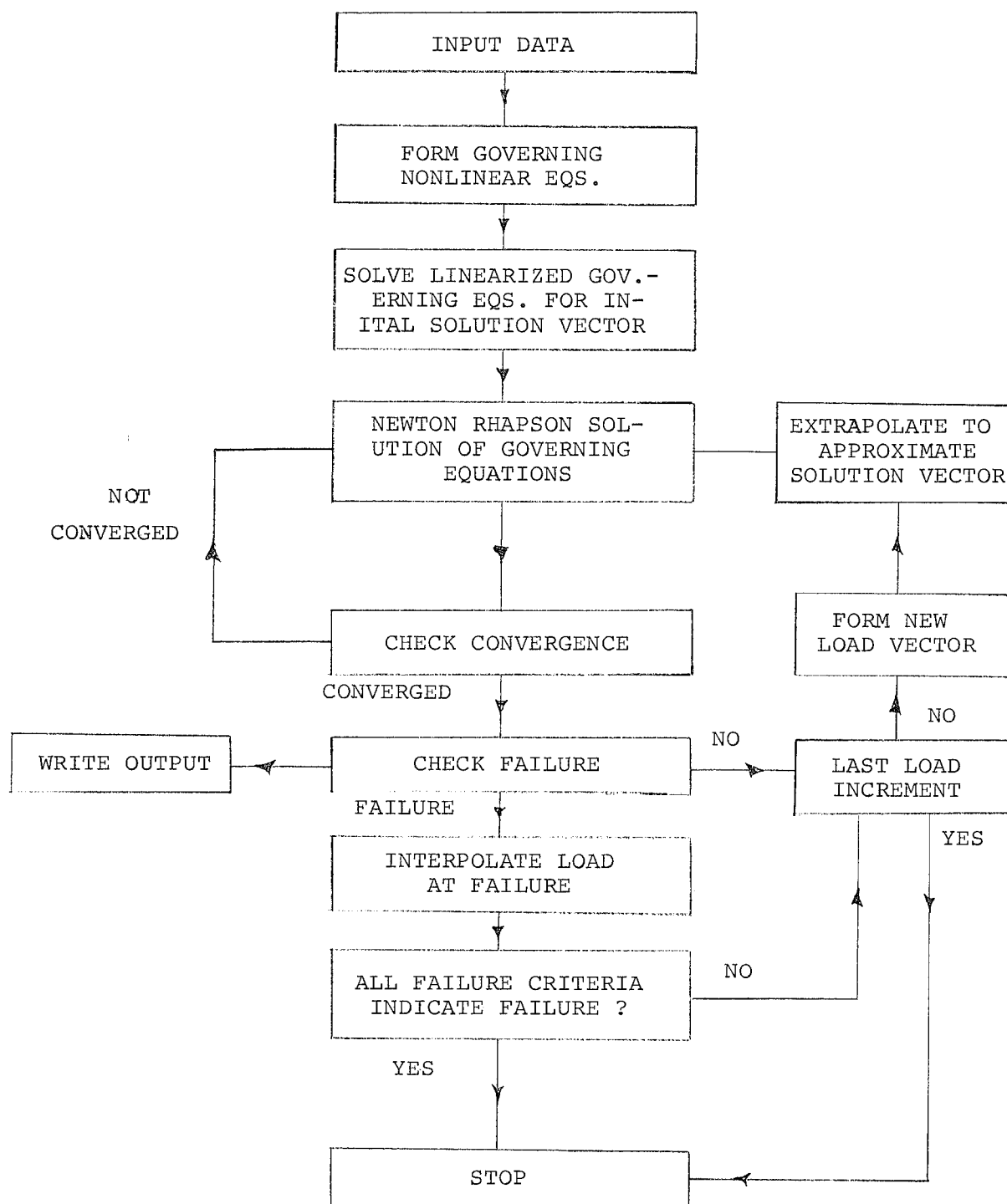


Figure 1 - Solution flow Chart

2. NOLIN PROGRAM USERS GUIDE

2.1 Program Description

This section describes the input data requirements for NOLIN (version 2 mod 2). Input procedures have been streamlined wherever possible by using one NAMELIST statement, hence eliminating any input under format control.

The input flow diagram and input description provide all information necessary to specify input data sets capable of exercising all program options.

2.2 Input Description

The initial data required is a message of five cards of alphanumeric descriptive information describing the problem being solved and printed as a title on the output. These five cards may be left blank, but must be included ahead of the first NAMELIST deck in the data. This descriptive message is read only once at the beginning of the program execution. The multiple case feature of running successive computations is accomplished by supplying multiple NAMELIST data sets with the changed variables indicated.

The following is a description of the input variables required for execution of the program. Where appropriate, default or suggested values are indicated. The following data are supplied through NAMELIST "DATA":

Program Option Parameters

IOPT:	Ramberg-Osgood parameter sentinel.
	IOPT=1: Input R-O parameter directly.
	IOPT=2: Determine parameters from stress-strain curve-fit routine.
COPT:	Curve-fit sentinel, (exercised if IOPT=2)
	COPT=1: Same stress-strain data for each layer.
	COPT=2: Different sets of data for each layer.

EOPT: Exponent option, (exercised if IOPT=2)
EOPT=1: Determine exponents from curve-fit routine.
EOPT=2: Input exponents to curve-fit routine.

Solution Accuracy Parameters

KSGM: No. of load increments, maximum = 50 increments.
SMLT: Load increment multiple, maximum number of Newton-Raphson iterations, default is 100.
EPS: Convergence criteria for Newton-Raphson analysis, default value is 10^{-3} .
UPBD: Divergence criteria during Newton-Raphson analysis, default value is 20000.
INMT: Incrementation estimate method, default value is 2.

Layer Description

NLAY: Number of laminate layers (max. is 20).
THICK(LAY): Thickness of each layer.
THETA(LAY): Orientation of each layer in degrees.
MATYPE(LAY): Material kind of each layer (maximum number of different materials is 20).

Material Description

E11 (MATYPE): Lamina longitudinal modulus.
E22 " Lamina transverse modulus.
G12 " Lamina shear modulus.
V12 " Lamina major Poisson's ratio.
S11T " Lamina longitudinal tensile strength.
S11C " Lamina longitudinal compressive strength.
S22T " Lamina transverse tensile strength.

S22C (MATYPE):		Lamina transverse compressive strength.
S12	"	Lamina in-plane shear strength.
EP11T	"	Lamina longitudinal tensile strain.
EP11C	"	Lamina longitudinal compressive strain.
EP22T	"	Lamina transverse tensile strain.
EP22C	"	Lamina transverse compressive strain.
GAMA	"	Lamina in-plane shear strain.
A12	"	Lamina interaction term for quadratic interaction criteria - default value is 0.0.
STY	"	Ramberg-Osgood tension constant
SCY	"	Ramberg-Osgood compression constant
TY	"	Ramberg-Osgood shear constant.
XM	"	Ramberg-Osgood shear exponent (default value is 3.0).
XN	"	Ramberg-Osgood tension exponent (default value is 3.0).

Stress-Strain Data (input in IOPT=2)

IPTS:		Number of stress-strain data points.
SIG11(I,MATYPE):		IPTS values of longitudinal lamina stresses for each material type.
SIG22	"	IPTS values to transverse lamina stresses for each material type.
SIG12	"	IPTS values of in-plane shear stresses for each material type.
EPS11	"	IPTS values of longitudinal lamina strains for each material type.
EPS22	"	IPTS values of transverse lamina strains for each material type.
EPS12	"	IPTS values of in-plane shear strain for each material type.

Applied Loading and Failure Criteria

SO11: Initial axial stress applied to laminate.
SO22: Initial transverse stress applied to
laminate.
SO12: Initial shear stress applied to laminate.
IFCN: Failure criteria sentinel
IFCN=1: ultimate stress
IFCN=2: ultimate strain
IFCN=3: quadratic interaction
IFCN=4: all failure criteria
STIFF: Ratio of final to initial laminate
stiffness which constitutes failure
due to stiffness reduction, default
value is 0.10.

3. UNI PROGRAM

3.1 Description

Program UNI computes the elastic properties, thermal expansion coefficients and the Ramberg-Osgood shear stress parameter for the unidirectional fiber bundle or the lamina. The fiber may be isotropic or transversely isotropic and the matrix is isotropic. The effective elastic properties of the composite are calculated from the composite cylinder assemblage model proposed by Hashin and Rosen [2] and the thermal expansion coefficients from the analytical results of Ref. [3]. The program also calculates the Ramberg-Osgood shear stress parameter of the matrix as outlined in Ref. [1].

The UNI program takes constituent properties as input and computes laminae properties as output. The output properties provide all the information required as input to the NOLIN program. The program accepts families of fiber and matrix materials such that an array of laminae properties can be generated. This feature can be especially useful for sensitivity analyses. All input to UNI is accomplished through a single NAMELIST statement "UNID".

3.2 Input Description

The following describes the variables required for the execution of UNI through NAMELIST "UNID".

Program Control Variables

NF:	No. of fibers, max. is 20.
NM:	No. of matrices, max. is 20.
NVM:	No. of matrix vol. fractions, max. is 20.

Matrix Properties, J=1, NM

EM(J): Young's modulus for Jth matrix.
RHOM(J): Density of Jth matrix.
ANUM(J): Poisson ratio for Jth matrix.
ALPM(J): Coef. of thermal expansion for Jth
matrix required only if ISTS=1.
ROMS(J): Shear stress Ramberg-Osgood parameter
for Jth matrix required only if
NONLIN = 1.

Isotropic Fiber Properties, J=1, NF

The following variables are required when ISOT=1:

EF(J): Young's modulus for Jth fiber.
ANUF(J): Poisson ratio for Jth fiber.
RHOF(J): Density of Jth fiber.
ALPF(J): Coef. of thermal expansion for Jth
fiber (required only if ISTS=1).

Transversely Isotropic Fiber Properties, J=1 NF

The following variables are required when ISOT=2:

EFA(J): Axial Young's modulus for Jth fiber.
EFT(J): Transverse Young's modulus for Jth fiber.
ANUFA(J): Axial Poisson ratio for Jth fiber.
GFA(J): Axial shear modulus for Jth fiber.
ANUFT(J): Transverse Poisson ratio for Jth fiber.
ALPF(J): Axial thermal expan. coef. for Jth
fiber (required only if ISTS=1).
ALPFT(J): Transverse thermal exp. coef. for Jth fiber.
(required only if ISTS=1).

Laminae Volume Fractions, J=1, NVM

VM(J): Jth volume fraction of matrix material.

The UNI program computes laminae properties for all combinations of fibers, matrix materials, and volume fractions which are supplied as input. That is, there are a total of $NF \times NM \times NVM$ materials formed from the input. Within a given run the total number of materials ($NF \times NM \times NVM$) must be less than 200.

The following is a description of the properties computed by UNI and printed as output:

Calculated Thermo-Elastic Constituent Parameters

GFT(J): Transverse shear modulus for Jth fiber.
GF(J): Shear modulus for Jth fiber.
GM(J): Shear modulus for Jth matrix.
AKF(J): Plane strain bulk modulus for Jth fiber.
AKM(J): Plane strain bulk modulus for Jth matrix.

Effective Thermo-Elastic Parameters

AKTS(J): Effective trans. bulk modulus for Jth material.
EAS(J): Effective axial Young's modulus for Jth material.
ETS(J): Effective trans. Young's modulus for Jth material.
ANUAS(J): Eff. Poisson ratio (unidirectional axial stress) for Jth material.
ANUTS(J): Eff. Poisson ratio (in transverse plane) for Jth material.
GAS(J): Eff. shear modulus (in fiber planes) for Jth material.
GTS(J): Eff. shear modulus (in trans. planes) for Jth material.

ALPAS(J): Eff. (fiber direction) thermal exp.
coef. for Jth material.
ALPTS(J): Eff. (trans. direction) thermal exp. coef.
for Jth material.
RHOS(J): Bulk density for Jth material.
ROCOMP(J): Ramberg-Osgood shear stress parameter
for Jth material.

4. SAMPLE PROBLEMS

The purpose of this section is to present several sample problems which illustrate the capabilities of both the UNI and the NOLIN programs. Both the program input and output are listed at the end of this section to aid in understanding the program.

4.1 UNI - Sample Problems

4.1.1 Laminae properties for Thornel 50 fibers in two carbon matrices have been determined. The transversely isotropic fiber option has been used to model the Thornel 50 fibers, and a Ramberg-Osgood shear stress parameter is included for the two matrix materials.

The input data and the resulting output data are given in sections 4.1.2 and 4.1.3. Note that the constituent properties are mirrored in the program output along with the required computed constituent properties. The effective thermoelastic properties for the 1-D laminae are printed on the second page of output. Units are consistent throughout the program such that the units need only be consistent for the constituent properties, in this case properties were input as MN/M^2 .

The second sample problem combines KEVLAR-49 fibers with a range of matrix properties to obtain the 1-D composite properties. A list of input data for this case and the corresponding program output are shown in sections 4.1.2 and 4.1.3. It is interesting to note that an order of magnitude change in matrix modulus results in a factor of five change in transverse modulus and transverse shear modulus.

4.1.2 UNI SAMPLE PROBLEMS - INPUT CARDS

C UNI DATA

\$DATAONE

NF=1, NM=2, NV=1,
EFA(1)=3.8E+03, EFT(1)=7.23E+03, GFA(1)=.38E+04,
ANUEFA(1)=0.1, ANUEFT(1)=0.1,
RHOF(1)=1.,
EM(1)=1.7E+14, 3.4E+14,
ANUM(1)=2*0.2,
RHUM(1)=2*1.,
VM(1)=0.4,0.6,
ROMS(1)=2*3.0,
ALPF(1)=5.E-07,
ALPFT(1)=3.6E-06,
ALPM(1)=2*1.4E-16

\$DATAONE

NF=1, NM=10, NV=1,
EFA(1)=1.3E+03, EUEFA(1)=1.2, RHCF(1)=1.,
EFT(1)=9.78E+03, ANUEFT(1)=0.2, GFA(1)=.17E+03,
EM(1)=.5E+03, 1.E+03, 1.5E+03, 2.E+03, .7E+03, 3.E+03,
3.5E+03, 4.E+03, 4.5E+03, 5.E+03,
ANUM(1)=10*1.2, RHUM(1)=10*1.,
VM(1)=0.4,
ALPF(1)=.6.1E-17, ALPFT(1)=3.83E-06,
ALPM(1)=10*1.39E-16

4.1.3 UNI SAMPLE PROBLEM OUTPUT NO. 1

FIBER NO.	E(F)	NU(F)	G(F)	K(F)	RHO(F)	ALPHA(F)
1	3.60000E+05	.10000	13800	4018.4	1.0000	5.00000E-07
1	7230.0	.10000	4286.4	4018.4	1.0000	3.60000E-06

MATRIX NO.	E(M)	NU(M)	G(M)	K(M)	RHO(M)	ALPHA(M)
1	17000	.20000	7033.3	11606	1.0000	1.40000E-06
2	34000	.20000	14167	23611	1.0000	1.40000E-06

MATRIX NO.	R-O-S(M)
1	3.0000
2	3.0000

EFFECTIVE THERMO-ELASTIC PARAMETERS

F	M	MATERIAL	V(M)	E(M)* E(T)*	NU(M)* NU(T)*	G(M)* G(T)*	K(T)* RHO*	ALPHA(A)* ALPHA(T)*
1	1	1	.40000	2.34833E+05 10303	.15351 .16120	15471 4475.1	6210.6 1.00000	5.23229E-07 2.51547E-06
				R-O PARAMETER = 3.11794E+00				
1	1	2	.60000	1.62270E+05 13302	.17215 .18709	9175.0 5241.3	7667.0 1.0000	5.52901E-07 2.13356E-06
				R-O PARAMETER = 2.76561E+00				
1	2	3	.40000	2.41649E+05 14403	.16535 .17125	13946 6180.8	8778.4 1.00000	5.46548E-07 2.27233E-06
				R-O PARAMETER = 3.11794E+00				
1	2	4	.60000	1.72441E+05 10563	.18093 .19209	14019 8199.3	12234 1.0000	6.01735E-07 1.94690E-06
				R-O PARAMETER = 2.96541E+00				

PROBLEM NO. 2 OUTPUT

FIRER NO.	E(F)	NU(F)	S(F)	K(F)	RHO(F)	ALPHA(F)
1	1.30000E+05	.20000	1170.0	6158.8	1.0000	-6.10000E-07
1	9780.0	.20000	4075.0	6158.8	1.0000	1.83000E-06

MATRIX NO.	E(M)	NU(M)	S(M)	K(M)	RHO(M)	ALPHA(M)
1	500.00	.20000	208.33	347.22	1.0000	1.39000E-05
2	1000.0	.20000	416.67	694.44	1.0000	1.39000E-05
3	1500.0	.20000	625.00	1041.7	1.0000	1.39000E-05
4	2000.0	.20000	833.33	1388.9	1.0000	1.39000E-05
5	2500.0	.20000	1041.7	1736.1	1.0000	1.39000E-05
6	3000.0	.20000	1250.0	2083.3	1.0000	1.39000E-05
7	3500.0	.20000	1458.3	2430.6	1.0000	1.39000E-05
8	4000.0	.20000	1666.7	2777.8	1.0000	1.39000E-05
9	4500.0	.20000	1875.0	3125.0	1.0000	1.39000E-05
10	5000.0	.20000	2083.3	3472.2	1.0000	1.39000E-05

MATRIX NO.	P-O-S(M)
1	3.00*0
2	3.00*0
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.

EFFECTIVE THERMO-ELASTIC PARAMETERS

F	M	MATERIAL	V(M)	E(A)* E(T)*	NU(A)* NU(T)*	G(A)* G(T)*	K(T)* RHO*	ALPHA(A)* ALPHA(T)*
1	1	1	.40000	78200 4596.5	.20000 .21564	508.35 656.64	1019.8 1.00000	-5.72890E-09 6.33022E-06
				R=0 PARAMETER = 3.11794E+00				
1	2	2	.40000	78000 2803.9	.20000 .21802	748.63 1151.0	1799.4 1.00000	-5.35969E-07 6.42491E-06
				R=0 PARAMETER = 3.11794E+00				
1	3	3	.40000	78600 3760.0	.20000 .21920	903.44 1542.0	2419.6 1.00000	-4.99237E-07 6.51767E-06
				R=0 PARAMETER = 0.				
1	4	4	.40000	78800 4543.4	.20000 .21973	1020.2 1862.4	2928.7 1.00000	-4.62690E-07 6.60856E-06
				R=0 PARAMETER = 0.				
1	5	5	.40000	79000 5202.6	.20000 .21990	1116.8 2132.4	3357.3 1.00000	-4.26329E-07 6.69761E-06
				R=0 PARAMETER = 0.				
1	6	6	.40000	79200 5769.5	.20000 .21985	1201.4 2364.8	3725.5 1.00000	-3.90152E-07 6.78490E-06
				R=0 PARAMETER = 0.				
1	7	7	.40000	79400 6265.5	.20000 .21969	1278.2 2568.5	4047.5 1.00000	-3.54156E-07 6.87046E-06
				R=0 PARAMETER = 0.				
1	8	8	.40000	79600 6706.1	.20000 .21945	1349.8 2749.6	4333.1 1.00000	-3.18342E-07 6.95435E-06
				R=0 PARAMETER = 0.				
1	9	9	.40000	79800 7102.3	.20000 .21917	1417.6 2912.8	4589.8 1.00000	-2.82707E-07 7.03662E-06
				R=0 PARAMETER = 0.				
1	10	10	.40000	80000 7462.7	.20000 .21887	1482.7 3061.3	4822.9 1.00000	-2.47250E-07 7.11730E-06
				R=0 PARAMETER = 0.				

***** R=0 PARAMETER TERMINATED *****

4.2 NOLIN Sample Problems

4.2.1 The sample problems for the NOLIN program have been chosen to exercise several options of the program. Graphite/Epoxy and Boron/Aluminum laminates have been modeled, employing material properties derived from the Air Force Composites Design Guide.

The initial problem is a $\pm 30^\circ$ Boron/Aluminum laminate under uniaxial tensile loading. Ramberg-Osgood parameters were input, with exponents set equal to 3.0, and a maximum strain failure criteria was employed. The input data and the program output follow in sections 4.2.2 and 4.2.3 respectively. A graph of the axial stress-strain curve for the laminate is given in Figure 2. Note that the laminate exhibits a non-linear stress-strain behavior from loading onset to failure.

The second sample nonlinear laminate analysis problem is a $0, \pm 45$ Graphite/Epoxy laminate under combined tension and shear loading. In this case the Ramberg-Osgood parameters were determined by the curve-fit routine from uniaxial stress-strain data supplied as input. The input data and program output listing are given in sections 4.2.2 and 4.2.3 respectively. Output of the program is plotted in the form of axial stress versus axial strain for this case in Figure 3.

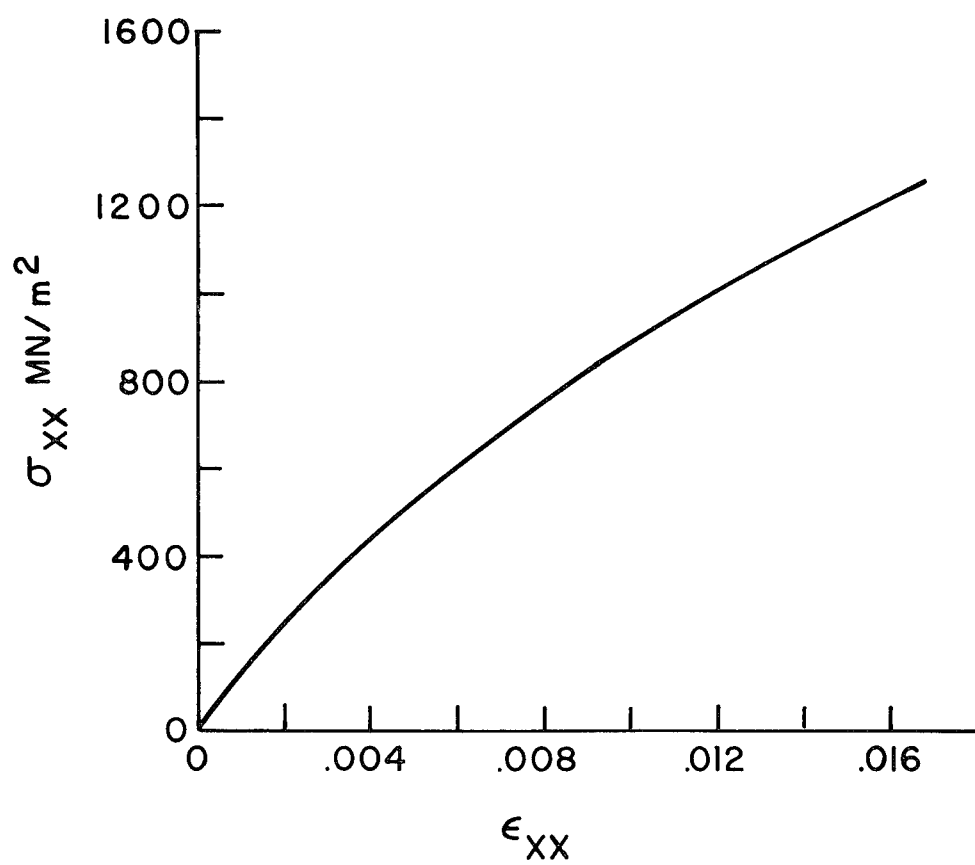


Figure 2 - +30° Boron/Aluminum Laminate - Axial Stress-Strain Behavior.

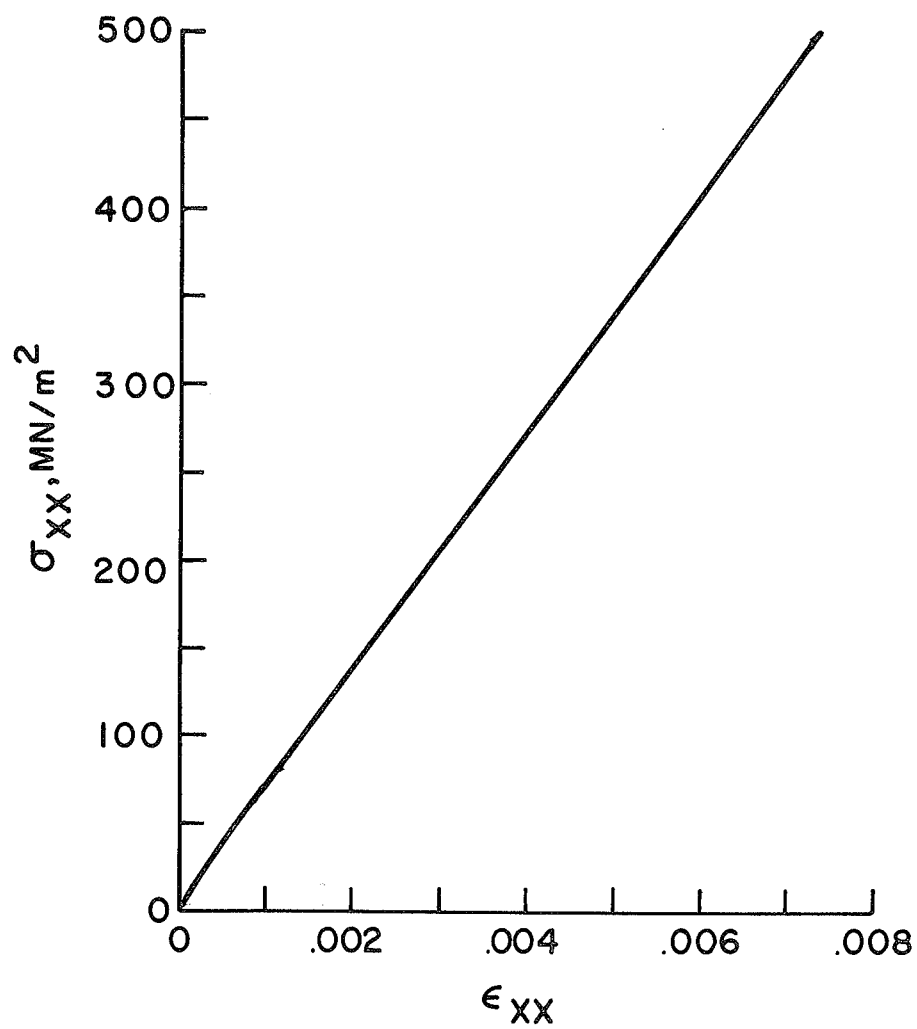


Figure 3 - Axial Stress-Strain Response of [0+45] Graphite-Epoxy Laminate under Axial and Shear Loading.

4.2.2 NOLIN SAMPLE PROBLEM INPUT CARDS

C NOLIN DATA

```

*
*      NOLIN SAMPLE PROBLEMS                      VERS 2 MOD 3
*
*      1.  0,+45,-45 LAMINATE. FULL R-O PARAM CURVE-FIT. ALL FAIL CRIT,
*      2.  +30,-30 LAMINATE. R-O PARAM INPUT. STRAIN FAIL CRIT.
$DATA
NLAY=3,
E11(1)=3*1.982E+05,
E22(1)=3*1.900E+04,
V12(1)=3*0.255E+00,
G12(1)=3*5.770E+03,
THICK(1)=0.25,0.5,0.25,
THETA(1)=45.,0,0,-45.,
IOPT=2,EOPT=1,COPT=1,
IPTS=10,
SIG11(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,
          48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS11(1,1)=1.1E-03,2.6E-03,4.E-03,5.7E-03,7.6E-03,1.E-02,1.31E-02,
          1.65E-02,2.15E-02,2.84E-02,
SIG22(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,
          48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS22(1,1)=1.1E-03,2.6E-03,4.E-03,5.7E-03,7.6E-03,1.E-02,1.31E-02,
          1.65E-02,2.15E-02,2.84E-02,
SIG12(1,1)=6.89E+00,13.78E+00,20.67E+00,27.56E+00,34.45E+00,41.34E+00,

```

NOLIN SAMPLE INPUT CARDS CONT.

```

      48.23E+00,55.12E+00,62.01E+00,68.90E+00,
EPS12(1,1)=2.2E-03,6.2E-03,8.E-03,11.4E-03,15.2E-03,2.E-02,2.62E-02,
3.30E-02,4.30E-02,5.68E-02,
SQ11=+5.0E+00,SQ22=-2.5E+00,SQ12=0.0,
IFCN=4,IPRINT=1,
MATYPE(1)=1,1,1,
S11T(1)=1.32E03,S22T(1)=7.16E+01,S12(1)=1.05E+02,EP11T(1)=6.68E-03,
EP22T(1)=3.77E-03,GAMA(1)=1.827E-02,S11C(1)=2.43E+03,S22C(1)=2.75E+02,
EP11C(1)=1.227E-02,EP22C(1)=1.45E-02,
STIFF=0.100,
A12(1)= 3*-2.8623E-06,
KSGM=50,SMLT=3.0,IT=10,INMT=2%
$DATA
NLAY=2,
E11(1)=2*2.20E+05,
E22(1)=2*1.24E+05,
V12(1)=2*0.01E+00,
G12(1)=2*2.60E+04,
THICK(1)=2*0.50,
THETA(1)=30.0,-30.0,
IOPT=1,
STY(1)=2*1109,E+00,
SCY(1)=2*1467,E+00,
TY(1)=2*93.0E+00,
XM=3.00,XN=3.00,
SQ11=50.,
SQ22=0.,
SQ12=0.,
IFCN=2,
S11T(1)=1100.0,S22T(1)=103.0,S12(1)=93.0,EP11T(1)=0.7E-02,
EP22T(1)=2.0E-02,GAMA(1)=3.0E-02,S11C(1)=1480.0,S22C(1)=160.,
EP11C(1)=0.7E-02,EP22C(1)=0.02,
STIFF=0.100,
KSGM=48,SMLT=4%

```

4.2.3 NOLIN SAMPLE OUTPUT

```

*****
*                                     *
*      NONLINEAR                     *
*      THERMOELASTIC ANALYSTS       *
*      OF                           *
*      FIBROUS COMPOSITES           *
*      AND                           *
*      NON-HOMOGENEOUS LAMINATES    *
*                                     *
*****

```

•VERSION 2 MOD 3 (MAY 74)

•DATE

•PROGRAM IDENTIFICATION

```

*
*   NOLIN SAMPLE PROBLEMS           VERS 2 MOD 3
*
*   1.  0,+45,-45 LAMINATE. FULL R-O PARAM CURVE-FIT. ALL FAIL CRIT.
*   2.  +30,-30 LAMINATE. R-O PARAM INPUT. STRAIN FAIL CRIT.

```

LAMINATE 1

32 NUMBER OF LAYERS = 3

DATA INPUT POINTS FOR CURVE FIT-

6.89000E+00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01
6.20100E+01	6.89000E+01						
1.10000E-03	2.60000E-03	4.00000E-03	5.70000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02
2.15000E-02	2.84000E-02						
6.89000E+00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01
6.20100E+01	6.89000E+01						
1.10000E-03	2.60000E-03	4.00000E-03	5.70000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02
2.15000E-02	2.84000E-02						
6.89000E+00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01
6.20100E+01	6.89000E+01						
2.20000E-03	5.20000E-03	8.00000E-03	1.14000E-02	1.52000E-02	2.00000E-02	2.62000E-02	3.30000E-02
4.30000E-02	5.60000E-02						

LAYER THETA T E11 E22 V12 V21 G12 SGT Y SGC Y TAU Y

1	45.00	2.5000E-01	1.9820E+05	1.9000E+04	2.5500E-01	2.445E-02	5.7700E+03	2.1069E+00	2.1069E+00	6.5456E+01
2	0.00	5.0000E-01	1.9820E+05	1.9000E+04	2.5500E-01	2.445E-02	5.7700E+03	2.1069E+00	2.1069E+00	6.5456E+01
3	-45.00	2.5000E-01	1.9820E+05	1.9000E+04	2.5500E-01	2.445E-02	5.7700E+03	2.1069E+00	2.1069E+00	6.5456E+01

EQUATION PARAMETERS

EXPONENT M = 2.74594E+00
EXPONENT N = 1.47384E+00

EXTERNALLY APPLIED STRESS

NO. OF
INCREMENTS

50

STRESS
INCREMENT

1.50000E+01
-7.50000E+00
0.

INITIAL
STRESS

SG XX 5.00000E+00
SG YY -7.50000E+00
SG XY 0.

LAMINA FAILURE CRITERIA

ALL FAILURE CRITERIA

LAYER	LL	TT	LT
	ULT. STRESS		
	ULT. STRAIN		
NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS			
1	TFNS. COMP.	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
1	TFNS. COMP.	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02
2	TFNS. COMP.	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
2	TFNS. COMP.	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02
3	TFNS. COMP.	7.16000E+01 2.75000E+02	1.05000E+02 1.05000E+02
3	TFNS. COMP.	3.77000E-03 1.45000E-02	1.82700E-02 1.82700E-02

LAYER QUADRATIC INTERACTION TERM (A12)

- 1 -2.86230E-06
- 2 -2.86230E-06
- 3 -2.86230E-06

STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = 2.00000E+04

LAMINATE CONSTANTS (STRESS-STRAIN)

E_{XX} = 1.11891E+05
E_{YY} = 3.49464E+04
V_{YX} = 6.85439E-01
V_{XY} = 2.14203E-01
G_{XY} = 2.89865E+04

APPLIED STRESS ANALYSIS

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+00
SG YY = -2.50000E+00
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-5.44278E+00	-4.36713E-01	-9.62175E-01	6.18445E-05	-1.15643E-04	-7.23315E-13	-2.68992E-05	-2.68992E-05	-8.87437E-05
2	1.19776E+01	-1.09807E+00	0.	6.18445E-05	-1.15643E-04	0.	6.18445E-05	-1.15643E-04	0.
3	-5.44278E+00	-4.36713E-01	9.62182E-01	6.18445E-05	-1.15643E-04	-7.41279E-13	-2.68992E-05	-2.68992E-05	8.87444E-05

EXTERNAL APPLIED STRESS

SG XX = 2.00000E+01
SG YY = -1.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-2.54934E+01	-1.60973E+00	-2.74989E+00	2.61075E-04	-5.14182E-04	2.48289E-11	-1.26554E-04	-1.26554E-04	-3.87628E-04
2	5.08018E+01	-3.69865E+00	0.	2.61075E-04	-5.14182E-04	0.	2.61075E-04	-5.14182E-04	0.
3	-2.54934E+01	-1.60973E+00	2.74964E+00	2.61039E-04	-5.14147E-04	2.48162E-11	-1.26554E-04	-1.26554E-04	3.87593E-04

EXTERNAL APPLIED STRESS

SG XX = 3.50000E+01
SG YY = -1.75000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 4 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-4.87608E+01	-2.72727E+00	-3.22333E+00	4.74559E-04	-9.59587E-04	-2.64055E-12	-2.42514E-04	-2.42514E-04	-7.17073E-04
2	9.25187E+01	-6.03463E+00	0.	4.74559E-04	-9.59587E-04	0.	4.74559E-04	-9.59587E-04	0.
3	-4.87608E+01	-2.72727E+00	3.22336E+00	4.74565E-04	-9.59594E-04	-2.64345E-12	-2.42514E-04	-2.42514E-04	7.17080E-04

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+01

SG YY = -2.50000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.13712E+01	-3.76005E+00	-3.24699E+00	6.93289E-04	-1.42397E-03	-3.78710E-12	-3.65339E-04	-3.65339E-04	-1.05863E-03
2	1.15323E+02	-8.18288E+00	0.	6.93289E-04	-1.42397E-03	0.	6.93289E-04	-1.42397E-03	0.
3	-7.13712E+01	-3.76005E+00	3.24699E+00	6.93302E-04	-1.42398E-03	-3.79320E-12	-3.65339E-04	-3.65339E-04	1.05864E-03

EXTERNAL APPLIED STRESS

SG XX = 6.50000E+01
SG YY = -3.25000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-0.45741E+01	-4.75320E+00	-3.15385E+00	9.13755E-04	-1.89622E-03	-2.15423E-12	-4.91231E-04	-4.91231E-04	-1.40499E-03
2	1.78510E+02	-1.01825E+01	0.	9.13755E-04	-1.89622E-03	0.	9.13755E-04	-1.89622E-03	0.
3	-0.45741E+01	-4.75320E+00	3.15387E+00	9.13745E-04	-1.89623E-03	-2.15636E-12	-4.91231E-04	-4.91231E-04	1.40500E-03

EXTERNAL APPLIED STRESS

SG XX = 8.00000E+01
SG YY = -4.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-1.24105E+02	-5.68706E+00	-3.03740E+00	1.13489E-03	-2.37258E-03	3.92971E-12	-6.18844E-04	-6.18844E-04	-1.75374E-03
2	2.21859E+02	-1.20665E+01	0.	1.13489E-03	-2.37258E-03	0.	1.13489E-03	-2.37258E-03	0.
3	-1.24105E+02	-5.68706E+00	3.03736E+00	1.13487E-03	-2.37256E-03	3.92203E-12	-6.18844E-04	-6.18844E-04	1.75372E-03

EXTERNAL APPLIED STRESS

SG XX = 9.50000E+01
SG YY = -4.75000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

ETC.
ETC.

36.

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.09459E+02	-2.12599E+01	-1.91901E+00	6.02590E-03	-1.31302E-02	2.76945E-12	-3.55214E-03	-3.55214E-03	-9.57806E-03
2	1.18344E+03	-4.27218E+01	0.	6.02590E-03	-1.31302E-02	0.	6.02590E-03	-1.31302E-02	0.
3	-7.09459E+02	-2.12599E+01	1.91900E+00	6.02590E-03	-1.31302E-02	2.75785E-12	-3.55214E-03	-3.55214E-03	9.57801E-03

EXTERNAL APPLIED STRESS

SG XX = 4.25000E+02
SG YY = -2.12500E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.36579E+02	-2.14573E+01	-1.89844E+00	6.24879E-03	-1.36252E-02	2.50081E-12	-3.68822E-03	-3.68822E-03	-9.93701E-03
2	1.22732E+03	-4.34833E+01	0.	6.24879E-03	-1.36252E-02	0.	6.24879E-03	-1.36252E-02	0.
3	-7.36579E+02	-2.14573E+01	1.89843E+00	6.24879E-03	-1.36252E-02	2.49184E-12	-3.68822E-03	-3.68822E-03	9.93696E-03

EXTERNAL APPLIED STRESS

SG XX = 4.40000E+02
SG YY = -2.20000E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.43727E+02	-2.24492E+01	-1.87882E+00	6.47171E-03	-1.41206E-02	2.26652E-12	-3.82443E-03	-3.82443E-03	-1.02961E-02
2	1.27121E+03	-4.50331E+01	0.	6.47171E-03	-1.41206E-02	0.	6.47171E-03	-1.41206E-02	0.
3	-7.43727E+02	-2.24492E+01	1.87881E+00	6.47166E-03	-1.41205E-02	2.25905E-12	-3.82443E-03	-3.82443E-03	1.02961E-02

LAMINATE HAS FAILED+ EP 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT

EXTERNAL APPLIED STRESS

SG XX = 4.55000E+02
SG YY = -2.27500E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS

STRAIN

LAYER	(LAYER AXES)			(LAMINATE AXES)			(LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.40900E+02	-2.34356E+01	-1.86008E+00	6.69466E-03	-1.46162E-02	2.06077E-12	-3.96078E-03	-3.96078E-03	-1.06554E-02
2	1.31511E+03	-4.61719E+01	0.	6.69466E-03	-1.46162E-02	0.	6.69466E-03	-1.46162E-02	0.
3	-7.40900E+02	-2.34356E+01	1.86007E+00	6.69466E-03	-1.46162E-02	2.05438E-12	-3.96078E-03	-3.96078E-03	1.06554E-02

**** LAMINATE ANALYSIS INTERPOLATED TO FAILURE POINT ***

AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.54014E+02
SG YY = -2.27007E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.49113E+02	-2.29972E+01	-1.86128E+00	6.68000E-03	-1.45836E-02	1.07969E-13	-3.95181E-03	-3.95181E-03	-1.06318E-02
2	1.31222E+03	-4.60974E+01	0.	6.68000E-03	-1.45836E-02	0.	6.68000E-03	-1.45836E-02	0.
3	-7.49113E+02	-2.29972E+01	1.86128E+00	6.68000E-03	-1.45836E-02	1.07941E-13	-3.95181E-03	-3.95181E-03	1.06318E-02

LAMINATE HAS FAILED+ SG 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT
EXTERNAL APPLIED STRESS

SG XX = 4.70000E+02
SG YY = -2.35000E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.18099E+02	-2.36168E+01	-1.84215E+00	6.91764E-03	-1.51122E-02	1.87914E-12	-4.09726E-03	-4.09726E-03	-1.10149E-02
2	1.45902E+03	-4.73000E+01	0.	6.91764E-03	-1.51122E-02	0.	6.91764E-03	-1.51122E-02	0.
3	-8.18099E+02	-2.36168E+01	1.84215E+00	6.91764E-03	-1.51121E-02	1.87378E-12	-4.09726E-03	-4.09726E-03	1.10149E-02

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AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.56671E+02
SG YY = -2.28336E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.93930E+02	-2.31006E+01	-1.85804E+00	6.71947E-03	-1.46715E-02	1.96310E-12	-3.97598E-03	-3.97598E-03	-1.06955E-02
2	1.42009E+03	-4.62981E+01	0.	6.71950E-03	-1.46715E-02	0.	6.71950E-03	-1.46715E-02	0.
3	-7.93930E+02	-2.31006E+01	1.85803E+00	6.71947E-03	-1.46715E-02	1.95735E-12	-3.97598E-03	-3.97598E-03	1.06955E-02

EXTERNAL APPLIED STRESS

SG XX = 4.85000E+02
SG YY = -2.42500E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-R.45321E+02	-2.41931E+01	-1.82498E+00	7.14066E-03	-1.56084E-02	1.71832E-12	-4.23386E-03	-4.23386E-03	-1.13745E-02
2	1.40293E+03	-4.84179E+01	0.	7.14066E-03	-1.56084E-02	0.	7.14066E-03	-1.56084E-02	0.
3	-R.45321E+02	-2.41931E+01	1.82498E+00	7.14062E-03	-1.56084E-02	1.71377E-12	-4.23386E-03	-4.23386E-03	1.13745E-02

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+02
SG YY = -2.50000E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-R.72567E+02	-2.47445E+01	-1.80852E+00	7.36370E-03	-1.61049E-02	1.57546E-12	-4.37059E-03	-4.37059E-03	-1.17343E-02
2	1.44686E+03	-4.95259E+01	0.	7.36370E-03	-1.61049E-02	0.	7.36370E-03	-1.61049E-02	0.
3	-R.72567E+02	-2.47445E+01	1.80851E+00	7.36347E-03	-1.61049E-02	1.57158E-12	-4.37059E-03	-4.37059E-03	1.17343E-02

LAMINATE HAS FAILED QUADRATIC INTERACTION FAILURE 2
 QUADRATIC = 1.0320 FOR LAYER 2
 QUADRATIC = .9714 FOR LAYER 2 OF PREVIOUS LOAD

AT FIRST POST-FAILURE LOAD POINT
 EXTERNAL APPLIED STRESS

SG XX = 5.15000E+02
 SG YY = -2.57500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.99834E+02	-2.53313E+01	-1.79271E+00	7.58678E-03	-1.66017E-02	1.44798E-12	-4.50744E-03	-4.50744E-03	-1.20942E-02
2	1.49079E+03	-5.06244E+01	0.	7.58678E-03	-1.66017E-02	0.	7.58678E-03	-1.66017E-02	0.
3	-8.99834E+02	-2.53313E+01	1.79270E+00	7.58675E-03	-1.66016E-02	1.44462E-12	-4.50744E-03	-4.50744E-03	1.20942E-02

*** LAMINATE ANALYSIS INTERPOLATED TO FAILURE POINT ***

AT FAILURE
 EXTERNAL APPLIED STRESS

SG XX = 5.07082E+02
 SG YY = -2.53541E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.95438E+02	-2.50927E+01	-1.90097E+00	7.46902E-03	-1.63394E-02	7.18620E-13	-4.43519E-03	-4.43519E-03	-1.19042E-02
2	1.46760E+03	-5.01457E+01	0.	7.46902E-03	-1.63394E-02	0.	7.46902E-03	-1.63394E-02	0.
3	-8.95438E+02	-2.50927E+01	1.90097E+00	7.46900E-03	-1.63394E-02	7.17842E-13	-4.43519E-03	-4.43519E-03	1.19042E-02

NUMBER OF LAYERS = 2

LAYER	THETA	T	E11	E22	V12	V21	012	S0T Y	S0C Y	TAUY
1	30.00	5.0000E-01	2.2000E+05	1.2400E+05	1.0000E-02	5.6304E-03	2.6000E+04	1.1090E+03	1.4670E+03	9.3000E+01
2	-30.00	5.0000E-01	2.2000E+05	1.2400E+05	1.0000E-02	5.6304E-03	2.6000E+04	1.1090E+03	1.4670E+03	9.3000E+01

EQUATION PARAMETERS

EXPONENT M = 3.00000E+00
EXPONENT N = 3.00000E+00

EXTERNALLY APPLIED STRESS

NO. OF INCREMENTS

INITIAL STRESS	STRESS INCREMENT	NO. OF INCREMENTS
SG XX 5.00000E+01	2.00000E+02	48
SG YY 0.	0.	
SG XY 0.	0.	

LAMINA FAILURE CRITERIA

LAYER	LL	TT	LT
-------	----	----	----

NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

1	TENS. 7.00000E-03	2.00000E-02	3.00000E-02
	COMP. 7.00000E-03	2.00000E-02	3.00000E-02
2	TENS. 7.00000E-03	2.00000E-02	3.00000E-02
	COMP. 7.00000E-03	2.00000E-02	3.00000E-02

STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = 2.00000E+04

LAMINATE CONSTANTS (STRESS-STRAIN)

EXX = 1.31218E+05
EYY = 8.96347E+04

VYX	=	4.42435E-01
VXY	=	3.02224E-01
GXY	=	7.05386E+04

APPLIED STRESS ANALYSIS

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+01
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	5.97302E+01	-3.73016E+00	-1.22801E+01	3.83121E-04	-1.71772E-04	-2.69684E-13	2.44398E-04	-3.3049E-05	-2.40276E-04
2	5.97302E+01	-3.73016E+00	1.22801E+01	3.83121E-04	-1.71772E-04	-1.88746E-13	2.44398E-04	-3.3049E-05	2.40276E-04

EXTERNAL APPLIED STRESS

SG XX = 2.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	2.90731E+02	-3.07312E+01	-5.44261E+01	2.08896E-03	-1.15710E-03	-8.72517E-10	1.27745E-03	-3.45581E-04	-1.40559E-03
2	2.90731E+02	-3.07312E+01	5.44261E+01	2.08896E-03	-1.15710E-03	-6.85787E-10	1.27745E-03	-3.45581E-04	1.40559E-03

EXTERNAL APPLIED STRESS

SG XX = 4.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	5.25892E+02	-7.58573E+01	-8.61013E+01	4.17189E-03	-2.93967E-03	-3.02218E-07	2.39387E-03	-1.10165E-03	-3.07947E-03
2	5.25892E+02	-7.58573E+01	8.60956E+01	4.17132E-03	-2.93967E-03	-2.85248E-07	2.39370E-03	-1.10204E-03	3.07909E-03

EXTERNAL APPLIED STRESS

SG XX = 6.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	7.40039E+02	-1.30051E+02	-1.12556E+02	6.64157E-03	-5.71879E-03	1.41357E-07	3.55154E-03	-2.62876E-03	-5.35216E-03
2	7.40052E+02	-1.30040E+02	1.12556E+02	6.64179E-03	-5.71877E-03	1.19534E-07	3.55160E-03	-2.62868E-03	5.35231E-03

EXTERNAL APPLIED STRESS

SG XX = 8.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.03875E+03	-1.84653E+02	-1.36434E+02	9.53050E-03	-9.66849E-03	-1.48380E-06	4.74018E-03	-4.86807E-03	-8.31382E-03
2	1.03866E+03	-1.84674E+02	1.36422E+02	9.52838E-03	-9.66863E-03	-1.31694E-06	4.72970E-03	-4.86904E-03	8.31222E-03

EXTERNAL APPLIED STRESS

SG XX = 1.05000E+03
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.29984E+03	-2.49716E+02	-1.58904E+02	1.28870E-02	-1.49782E-02	-2.27314E-06	5.91972E-03	-8.01090E-03	-1.20665E-02
2	1.29971E+03	-2.49833E+02	1.58895E+02	1.28838E-02	-1.49784E-02	-1.99637E-06	5.91912E-03	-8.01372E-03	1.20642E-02

LAMINATE HAS FAILED↓ EP 11 EXCEEDS MAXIMUM

AT FIRST POST-FAILURE LOAD POINT
EXTERNAL APPLIED STRESS

SG XX = 1.25000E+03
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS			STRAIN			STRAIN		
--------	--	--	--------	--	--	--------	--	--

LAYER	(LAYER AXES)		(LAMINATE AXES)			(LAYER AXES)			
	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	1.56228E+03	-3.12157E+02	-1.80593E+02	1.67730E-02	-2.18526E-02	-2.67009E-06	7.11545E-03	-1.21950E-02	-1.67260E-02
2	1.56215E+03	-3.12271E+02	1.80581E+02	1.67695E-02	-2.18529E-02	-2.32925E-06	7.11488E-03	-1.21983E-02	1.67234E-02

***** PROGRAM TERMINATED *****

5. Computer Program Listings

Source listings of both the UNI and NOLIN computer programs follow. The UNI program requires 20 K of computer core storage in a CDC 6600 machine, while the NOLIN program requires 60 K of core storage. No peripheral devices are required for either program for intermediate data storage.


```

C GF(J) 1 SHEAR MODULUS FOR JTH FIBER
C GM(J) 1 SHEAR MODULUS FOR JTH MATRIX
C AKF(J) 1 PLANE STRAIN BULK MODULUS FOR JTH FIBER
C AKM(J) 1 PLANE STRAIN BULK MODULUS FOR JTH MATRIX
C
C EFFECTIVE THERMOELASTIC PARAMETERS
C AKTS(J) 1 EFFECTIVE TRANS. BULK MOD. FOR JTH MATERIAL
C EAS(J) 1 EFFECTIVE AXIAL YOUNG'S MOD. FOR JTH MATERIAL
C ETS(J) 1 EFFECTIVE TRANS. YOUNG'S MOD. FOR JTH MATERIAL
C ANUAS(J) 1 EFF. POISSON RATIO (UNIDIRECTIONAL AX. STRESS) FOR JTH MATERIAL
C ANUTS(J) 1 EFF. POISSON RATIO (IN TRANSVERSE PLANE) FOR JTH MATERIAL
C GAS(J) 1 EFF. SHEAR MOD. (IN FIBER PLANES) FOR JTH MATERIAL
C GTS(J) 1 EFF. SHEAR MOD. (IN TRANS. PLANES) FOR JTH MATERIAL
C ALPAS(J) 1 EFF. (FIBER DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
C ALPTS(J) 1 EFF. (TRANS. DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
C RHOS(J) 1 BULK DENSITY FOR JTH MATERIAL
C RCOMP(J) 1 RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR JTH MATERIAL

```

* PROGRAMMING INFORMATION *

```

C UNI MAY BE USED AS A SUBROUTINE
C SUBROUTINES REQUIRED 1 MSUB01,MSUB02

```

INITIALIZE VARIABLES TO ZERO.

```

C NAMELIST/DATAONE/NF,NM,NVM,EF,ANUF,RHOF,EFA,ANUFA,GFA,EFT,ANUFT,
C IEM,ANUM,RHOM,VM,ROMS,ALPF,ALPFT,ALPM

```

```

C DATA EFT/20*0.0/
C DATA ROMS/20*0.0/
C DATA ALPM/20*0.0/

```

171 CONTINUE

```

C READ(5,DATAONE)

```

```

C IF(EOF,5)172,173

```

173 CONTINUE

```

C IF(EFT(1))1012,1012,1014

```

1012 CONTINUE

```

C DO 3 J=1,NF

```

```

C IF (J.NE.1) GO TO 4

```

```

C WRITE(6,202)

```

```

C IF(ALPM(1))5,5,6

```

```

C 5 WRITE(6,203)

```

```

C GO TO 4

```

```

C 6 WRITE(6,204)

```

```

C 4 GF(J) = EF(J)/((1.0+ANUF(J))*2.0)

```

```

C AKF(J) = GF(J)/(1.0-2.0*ANUF(J))

```

```

C IF(ALPM(1))8,8,9

```

```

C 8 WRITE(6,205)(J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J))

```

```

C GO TO 3

```

```

C 9 WRITE(6,206)(J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J),ALPF(J))

```

```

C 3 CONTINUE

```

```

C GO TO 1018

```

```

C 1014 CONTINUE

```

```

C DO 503 J=1,NF

```

```

C IF (J.NE.1) GO TO 504

```

```

00018600
00018700

```

```

00018900
00019000
00019100
00019200
00019300

```

```

00019500
00019600
00019700
00019800

```

```

000122      IF (ALPM(1)) 505, 505, 506
000123      505 WRITE(6, 203)
000127      GO TO 504
000130      506 WRITE(6, 204)
000134      504 CONTINUE
000134      GFT(J) = EFT(J) / ((1.0 + ANUFT(J)) * 2.0)
000141      AKF(J) = EFA(J) * EFT(J) / (2.0 * EFA(J) * (1.0 - ANUFT(J)) - 4.0 * EFT(J) *
1      ANUFA(J) * 2)
000154      IF (ALPM(1)) 508, 508, 509
000155      508 WRITE(6, 205) (J, EFA(J), ANUFA(J), GFA(J), AKF(J), RHOF(J))
000175      WRITE(6, 205) (J, EFT(J), ANUFT(J), GFT(J), AKF(J), RHOF(J))
000215      GO TO 503
000216      509 WRITE(6, 206) (J, EFA(J), ANUFA(J), GFA(J), AKF(J), RHOF(J), ALPF(J))
000240      WRITE(6, 206) (J, EFT(J), ANUFT(J), GFT(J), AKF(J), RHOF(J), ALPFT(J))
000262      503 CONTINUE
000265      1018 CONTINUE
000265      DO 10 J = 1, NM
000267      IF (J.NF.1) GO TO 11
000271      IF (ALPM(1)) 12, 12, 13
000272      12 WRITE(6, 207)
000276      GO TO 11
000277      13 WRITE(6, 208)
000303      11 GM(J) = EM(J) / ((1.0 + ANUM(J)) * 2.0)
000310      AKM(J) = GM(J) / (1.0 - 2.0 * ANUM(J))
000314      IF (ALPM(1)) 14, 14, 15
000315      14 WRITE(6, 205) (J, EM(J), ANUM(J), GM(J), AKM(J), RHOM(J))
000335      GO TO 10
000336      15 WRITE(6, 206) (J, EM(J), ANUM(J), GM(J), AKM(J), RHOM(J), ALPM(J))
000360      10 CONTINUE
C
000363      IF (ROMS(1), .EQ. 0) GO TO 777
000364      WRITE (6, 217)
000367      DO 779 J=1, NM
C
C      CALCULATE THE EFFECTIVE THERMO-ELASTIC PARAMETERS
C
779 WRITE (6, 216) J, ROMS(J)
777 KLINE = 49
L = 0
DO 100 I=1, NF
C      FORM FIBER COMPLIANCE MATRIX
IF (ALPM(1)) 910, 910, 911
911 IF (EFT(1), .EQ. 0) CALL MSUR01(I, EF, EF, ANUF, ANUF, SF)
IF (EFT(1), .NE. 0) CALL MSUR01(I, EFA, EFT, ANUFA, ANUFT, SF)
910 CONTINUE
DO 100 J=1, NM
C      FORM MATRIX COMPLIANCE MATRIX
IF (ALPM(1)) 912, 912, 913
913 CALL MSUR01(J, EM, EM, ANUM, ANUM, SM)
912 CONTINUE
DO 100 K=1, NVM
L = L + 1
MM(L) = J
MF(L) = I
MV(L) = K
VF = 1.0 - VM(K)
000441
000441
00019900
00020000
00020200
00020300
00020400
00020500
00020600
00020800
00021000
00021100
00021300
00021400
00021600
00021700
00021800
00021900
00022000
00022100

```

```

000443 RCOMP(L)=ROMS(J)*SORT(3.*(1.+VF)**3/(3.*13.*VF+VF**2+VF**3))
000463 P1 = VM(K)*AKM(J)*(AKF(I)+GM(J))+VF*AKF(I)*(AKM(J)+GM(J))
000474 Q1 = VM(K)*(AKF(I)+GM(J))+VF*(AKM(J)+GM(J))
000505 AKTS(L) = P1/Q1
000510 IF(LEFT(I))1022,1022,1026
000511 1022 CONTINUE
000511 P2 = 4.0*(ANUF(I)-ANUM(J))*(ANUF(I)-ANUM(J))*VF*VM(K)
000511 Q2 = VM(K)*AKF(I)+VF*AKM(J)+1.0/GM(J)
000520 EAS(L) = VF*EF(I)+VM(K)*EM(J)+P2/Q2
000527 P3 = VF*VM(K)*(ANUF(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000537 Q3 = Q2
000551 ANUAS(L) = VF*ANUF(I)+VM(K)*ANUM(J)+P3/Q3
000553 P4 = VM(K)*GM(J)+(1.0+VF)*GF(I)
000562 Q4 = (1.0+VF)*GM(J)+VM(K)*GF(I)
000571 GAS(L) = GM(J)*P4/Q4
000577 GAMMA = GF(I)/GM(J)
000603 RETAM = 1.0/(3.0-4.0*ANUM(J))
000605 RETAF = 1.0/(3.0-4.0*ANUF(I))
000611 GO TO 1028
000616 1026 CONTINUE
000616 P2 = 4.0*(ANUFA(I)-ANUM(J))*(ANUFA(I)-ANUM(J))*VF*VM(K)
000616 Q2 = VM(K)*AKF(I)+VF*AKM(J)+1.0/GM(J)
000625 EAS(L) = VF*EFA(I)+VM(K)*EM(J)+P2/Q2
000634 P3 = VF*VM(K)*(ANUFA(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000644 Q3 = Q2
000656 ANUAS(L) = VF*ANUFA(I)+VM(K)*ANUM(J)+P3/Q3
000660 P4 = VM(K)*GM(J)+(1.0+VF)*GFA(I)
000667 Q4 = (1.0+VF)*GM(J)+VM(K)*GFA(I)
000676 GAS(L) = GM(J)*P4/Q4
000704 GAMMA = GF(I)/GM(J)
000710 RETAM = 1.0/(3.0-4.0*ANUM(J))
000712 RETAF = 1.0/(3.0-4.0*ANUF(I))
000716 1028 CONTINUE
000723 ALEF = 1.E50
000723 IF(GAMMA.NE.1.0) ALEF = (GAMMA*RETAM)/(GAMMA-1.0)
000725 RP = GAMMA*BETAF
000733 R = (BETAM-RP)/(1.0+RP)
000735 VF3 = VF*VF*VF
000741 VM2 = VM(K)*VM(K)
000742 RETAM2 = RETAM*RETAM
000744 X1 = 1.0+P*VF3
000746 X2 = 3.0*VF*VM2*BETAM2
000751 P5 = (ALEF+BETAM*VF)*X1-X2
000754 Q5 = (ALEF-VF)*X1-X2
000761 IF(GAMMA.EQ.1.0) GTS(L)=GM(J)
000763 IF(GAMMA.NE.1.0) GTS(L)=GM(J)*P5/Q5
000770 P6 = 4.0*AKTS(L)*GTS(L)
000776 Q6 = AKTS(L)+(1.0+4.0*AKTS(L)*ANUAS(L)*ANUAS(L)/EAS(L))*GTS(L)
001001 ETS(L) = P6/Q6
001012 ANUTS(L) = 0.5*(ETS(L)/GTS(L))-1.0
001014 IF(ALPM(I))20,20,920
001020 920 IF(LEFT(I).NE.0)GO TO 921
001021 BIGKM(J) = EM(J)/(3.0*(1.0-2.0*ANUM(J)))
001022 RIGKF(I) = EF(I)/(3.0*(1.0-2.0*ANUF(I)))
001030 BARRK = VM(K)/RIGKM(J)+VF/BIGKF(I)
001035

```

```

001042 ALBAR = VF*ALPFF(I)*VM(K)*ALPM(J)
001046 F1 = 0.0
001047 IF (BIGKM(J).NE.BIGKF(I)) F1 = (ALPM(J)-ALPFF(I))/
1 (1.0/BIGKM(J)-1.0/BIGKF(I))
001061 F2 = (3.0*(1.0 - 2.0* ANUAS(L)))/EAS(L)
001067 ALPHA(1,L) = ALBAR + F1*(F2 - BARRK)
001074 ALPHA(2,L) = ALBAR + F1*(3.0/(2.0*AKTS(L)) - ANUAS(L)*F2 - BARRK)
001106 GO TO 20
001106 921 CONTINUE

C
C FORM COMPOSITE COMPLIANCE MATRIX AND CALCULATE MATERIAL THERMAL
C EXPANSION COEFFICIENTS
C CALL MSUR02(I,J,K,VF,SF,SM)
20 RHOS(L) = VM(K)*RHOM(J)*VF*RHOF(I)
KLINE = KLINE+3
IF (KLINE.LE.48) GO TO 22
KLINE = 0
WRITE(6,215)
IF (ALPM(I)) 23,23,24
23 WRITE(6,209)
GO TO 22
24 WRITE(6,210)
22 IF (ALPM(I)) 25,25,26
25 WRITE(6,211) I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L)
WRITE(6,212) ETS(L),ANUTS(L),GTS(L),RHOS(L)
GO TO 778
26 WRITE(6,213) I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L),ALPHA(1,L)
WRITE(6,214) ETS(L),ANUTS(L),GTS(L),RHOS(L),ALPHA(2,L)
778 IF (RMS.NE.0) WRITE(6,218) RCOMP(L)
100 CONTINUE

C
GO TO 171
172 WRITE(6,1999)
STOP
200 FORMAT(1R14)
201 FORMAT(1P6E12.5)
202 FORMAT(1H1///42X37HCONSTITUENT THERMO-ELASTIC PARAMETERS)
203 FORMAT(///11H FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),
11X6HRHO(F),//)
204 FORMAT(///11H FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),
11X6HRHO(F),9X8HALPHA(F)//)
205 FORMAT(17,7X,5G16.5)
206 FORMAT(17,7X,6G16.5)
207 FORMAT(///12H MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),
11X4HK(M),11X6HRHO(M),//)
208 FORMAT(///12H MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),
11X4HK(M),11X6HRHO(M),9X8HALPHA(M)//)
209 FORMAT(///3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,10X6HNU(A)*,
11X5HG(A)*,11X5HK(T)*,42X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,
21X4HRHO*)
210 FORMAT(///3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,
11X6HNU(A)*,11X5HG(A)*,11X5HK(T)*,9X9HALPHA(A)*,
24X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,11X4HRHO*,10X9HALPHA(T)*,
211 FORMAT(21,17,615.5,4X,4G14.5)
212 FORMAT(34X,4G14.5)

```

00025600

00025800
00025900
0002600000026100
00026200
00026300
00026400
0002650000026700
00026800
0002690000027100
0002720000027400
0002750000027600
0001500000015100
00015200
00015300
00015400
00015500
0001560000015700
00015800
00015900
0001600000016100
00016200
00016300
00016400
00016500
00016600
00016700
00016800
00016900
00017000
00017100

07/09/74

MAIN

RUN VERSION 2.3 --PSR LEVEL 363--

00017200
00017300
00017400

001301 213 FORMAT(/2I4,I7,G15.5,4X,50I6.5)
001301 214 FORMAT(34X,5G16.5)
001301 215 FORMAT(1H1///42X35HEFFECTIVE THERMO-ELASTIC PARAMETERS)
001301 216 FORMAT(I7,7X,G16.5)
001301 217 FORMAT(///12H MATRIX NO.,8X,8HR=0-S(M)///
001301 218 FORMAT(/,38X,16H R=0 PARAMETER =,1E16.5)
001301 1999 FORMAT(///***** PROGRAM TERMINATED *****
1 *****)

PROGRAM TERMINATED

C

END

00028100

```

SUBROUTINE MSUB01(I,A,B,C,D,VAR)
ROUTINE MSUB01 FORMS COMPLIANCE MATRIX FOR CONSTITUENTS
* VARIABLE DICTIONARY *
A(I) : LONGITUDINAL MODULUS FOR ITH FIBER/MATRIX
B(I) : TRANSVERSE MODULUS FOR ITH FIBER/MATRIX
C(I) : LONGITUDINAL POISSON RATIO FOR ITH FIBER/MATRIX
D(I) : TRANSVERSE POISSON RATIO FOR ITH FIBER/MATRIX
VAR(J,K) : COMPLIANCE MATRIX
* PROGRAMMING INFORMATION *
MSUB01 IS CALLED FROM : UNI
*****
DIMENSION A(20),B(20),C(20),D(20),VAR(3,3)
VAR(1,1) = 1./A(I)
VAR(2,2) = 1./B(I)
VAR(3,3) = VAR(2,2)
VAR(1,2) = -C(I)/A(I)
VAR(1,3) = VAR(1,2)
VAR(2,3) = -D(I)/B(I)
RETURN
END

```


5.2 NOLIN LISTING

```

000003      PROGRAM MAIN(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT)
000003      REAL IANG
000003      DIMENSION
1          1 E11(20),E22(20),V12(20),V21(20),G12(20),
2          2 SCY(20),STY(20),TY(20),
3          3 T(20),IANG(20),
4          4 S11(20),S12(20),S21(20),S22(20),S44(20),
          DIMENSION
1          1 SINS(20),COS(20),SIN2(20),COS2(20)
2          2 P11(20),P22(20),P12(20),
          DIMENSION
1          1 EPS11(20),EPS22(20),EPI12(20),
2          2 FPS11(20),FPS22(20),EPS12(20)
          DIMENSION
1          1 AT(60),DC(60),
          DIMENSION
1          1 F(3,20),G(3,20),H(3,20)
          DIMENSION
1          1 A(60,60),DR(60,60),SG(60,1),SGO(60,1),SF(60),
          DIMENSION
1          1 ULT(6,2,20),
          DIMENSION
1          1 SGS(60),SG1(60,1)
          DIMENSION
1          1 STXS( 50),STRN( 50),A0(100),POINTS(50,6,20),
          DIMENSION
1          1 STXX(20,50),STYY(20,50),STXY(20,50)
          DIMENSION
1          1 EXX(50),EYY(50),VXX(50),VYY(50),GXX(50)
          DIMENSION
1          1 A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
          DIMENSION
1          1 EPN(60,1),PS(60)
          DIMENSION MATYPE(20),S11T(20),S22T(20),
1          1 S11C(20),S22C(20),EPI1C(20),EP22C(20),GAMA(20),EPI1T(20),
2          2 EP22T(20),SIG11(50,20),SIG22(50,20),SIG12(50,20)
          COMMON /SET01/ E11,E22,V12,V21,G12
          COMMON /SET02/ TT,T,IANG
          COMMON /SET03/ EPI1,EP22,EPI2
          COMMON /SET04/ S011,S022,S012,SM11,SM22,SM12
          COMMON /SET05/ ULT,STIFF
          COMMON /SET06/ SIN2,COS2,SINS,COSS
          COMMON /SET07/ EPS11,EPS22,EPS12
          COMMON /SET08/ S11,S22,S12,S21
          COMMON /SET09/ LAY,EOPT,COPT,IFCN,KSGM,INMT,RATIO,SENS
          COMMON /SET10/ STY,SCY,TY,XM,XN
          COMMON /SET11/ EPS,UPRO,NIT,IT,SMLT
          COMMON /SET12/ F,G,H
          COMMON /SET13/ EXX,EYY,VXX,STXX,STYY,STXY
          COMMON /SET14/ A11,A22,A44,A12,B1,B2
          COMMON /SET15/ POINTS,IPRINT,IOP1,IP1S,LUP
          COMMON /SET16/ MATYPE,S11T,S11C,S22T,S22C,EPI1T,EPI1C,
1          1 EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
          COMMON /SET17/ MSING,MSINGD
          COMMON /SET18/ EOPT,COPT,SWITCH,AGAIN
          COMMON /SET19/ UFAIL(3)
          COMMON /SET20/ (STXX(1),A0(1))
          LOGICAL
1          1 MSING,MSINGD
          INTEGER
1          1 EOPT,COPT,SWITCH,AGAIN
          INTEGER
1          1 UFAIL(3)
          EQUIVALENCE
1          1 (STXX(1),A0(1))
          C
          LOGICAL
1          1 MSING,MSINGD
          INTEGER
1          1 EOPT,COPT,SWITCH,AGAIN
          INTEGER
1          1 UFAIL(3)
          EQUIVALENCE
1          1 (STXX(1),A0(1))
          C
          ARITHMETIC STATEMENT FUNCTIONS
          PR0(X,Y,N) = 1.0/(X*Y)**(1./(N-1.))
          C
          * PROGRAM REQUIREMENTS *
          C

```

```

C SUBROUTINES
C : LAMTST,OUTPT1,PROP,REGAL,QUADCF,INVRTD,CHAI,
C CONVR,HEADER ANGLE,MMXULD,TRANS,RESET,NRI,
C MATCPL,LAYSUR
C : SINT
C FUNCTION SUBPROGRAM : INITIALIZE VARIABLES IN COMMON SETS
C BLOCK DATA SUBPROGRAM : 01.05,10.11, AND 14
C
C * LIMITATIONS *
C
C * DEFAULT VALUES *
C
C EPS = 1.00E-03
C UPBD = 2.00E+04
C IT = 100
C AL2(I) = 0.00 (FOR ALL LAYERS)
C XM = 3.00E 00
C XN = 3.00E 00
C INMT = 2
C
C * INPUT PARAMETERS *
C
C NST : NO. OF SEPERATE LAMINATES
C IOPT : INPUT OPTION
C      #1: INPUT RAMBERG-OZGOOD PARAMETERS TY,STY,SCY,XM,XN
C      #2: DETERMINE RAMBERG-OZGOOD PARAMETERS FROM CURVE-FIT
C      #3: EXPONENT OPTION FOR CURVE-FIT ROUTINE
C      #4: CURVE-FIT FOR ALL RAMBERG-OZGOOD PARAMETERS
C      #5: INPUT EXPONENTS, XM + XN, CURVE-FIT TY,STY,SLY
C      #6: LAYER OPTION FOR CURVE-FIT ROUTINE
C      #7: USE SAME STRESS-STRAIN DATA FOR ALL LAYERS
C      #8: STRESS-STRAIN DATA INPUT FOR EACH LAYER
C
C LAMINATE PROPERTIES
C LAY : NO. OF LAYERS IN LAMINATE
C F11(I) : AXIAL YOUNG'S MODULUS (LAYER I)
C F22(I) : TRANSVERSE YOUNG'S MODULUS (LAYER I)
C V12(I) : AXIAL-TRANSVERSE POISSON RATIO (LAYER I)
C G12(I) : IN-PLANE SHEAR MODULUS (LAYER I)
C IANG(I) : ANGULAR ORIENTATION (DEGREES) OF ITH LAYER
C T(I) : THICKNESS OF ITH LAYER
C
C CURVE-FIT PARAMETERS
C IPTS : NO. OF DATA POINTS
C STRS(I) : ITH STRESS DATA POINT
C STRN(I) : ITH STRAIN DATA POINT
C
C POINTS --- COMPONENT
C 1 - SIGMA 11
C 2 - EPSILON 11
C 3 - SIGMA 22
C 4 - EPSILON 22
C 5 - SIGMA 12
C 6 - EPSILON 12

```

```

C   LOADING PARAMETERS
C   S011 : AXIAL APPLIED LOAD
C   S022 : TRANSVERSE APPLIED LOAD
C   S012 : APPLIED SHEAR
C   IFCN : FAILURE OPTION
C       =1: ULTIMATE STRESS
C       =2: QUADRATIC INTERACTION
C       =3: ULTIMATE STRAIN
C       =4: ALL FAILURE OPTIONS
C   ULT(I,J,K) : LIMIT VALUE FOR LAYER K IN DIRECTION I (AXIAL, TRANSVERSE,
C               OR SHEAR) UNDER J (TENSION OR COMPRESSION)
C   STIFF : RATIO (TANGENT MODULUS TO INITIAL MODULUS) AT
C           WHICH COMPUTATIONS TERMINATE
C   AL2(I) : QUADRATIC INTERACTION TERM (LAYER I)
C   CONTROL SENTINELS
C   KSGM : INCREMENTATION LIMIT
C   SMLT : MULTIPLICATIVE FACTOR FOR LOAD INCREMENTS
C   IT : ITERATION LIMIT PER NEWTON-RAPHSON ANALYSIS
C   FPS : CONVERGENCE CRITERIA
C   UPRI : DIVERGENCE CRITERIA
C   INMT : INCREMENTATION ESTIMATE METHOD

```

* VARIABLE DICTIONARY *

```

C   A0(I) : CURVE-FIT PARAMETER
C   RBO(X,Y,W) : CONVERSION FUNCTION FROM CURVE-FIT PARAMETERS
C               TO RAMBERG-OSGOOD PARAMETERS
C   TT : TOTAL THICKNESS
C   SG(I,1) : RESULTANT AXIAL STRESS FOR ITH LAYER
C   SG(I,LAY,1) : RESULTANT TRANSVERSE STRESS FOR ITH LAYER
C   SG(I,2*LAY,1) : RESULTANT SHEAR ITH LAYER
C   SGS(I) : AXIAL STRESS (ITH LAYER) FROM PREVIOUS INCREMENT
C   SGS(I+LAY) : TRANSVERSE STRESS (ITH LAYER) FROM PREVIOUS LOAD
C   SGS(I+2*LAY) : SHEAR (ITH LAYER) FROM PREVIOUS LOAD
C   SG0(I,1) : INITIAL LOAD
C   S11(I) : COMPLIANCE TERM
C   S12(I) : COMPLIANCE TERM
C   S21(I) : COMPLIANCE TERM
C   S22(I) : COMPLIANCE TERM
C   S44(I) : COMPLIANCE TERM
C   SINS(I) : SQUARE OF SIN OF ITH LAYER
C   COSI(I) : SQUARE OF COS OF ITH LAYER
C   SIN2(I) : TWICE SIN OF ITH LAYER
C   COS2(I) : TWICE COS OF ITH LAYER
C   A(I,J) : INITIAL TRANSFORMATION MATRIX
C   AB(I,J) : MATRIX OF DERIVATIVE TERMS FOR N-R, APPROX.
C   DC(I) : MULTIPLIER OF DERIVATIVE MATRIX (DB)
C   RT(I) : INCREMENTAL CHANGE IN STRESS SOLUTION BETWEEN
C           N-R ITERATES
C   SG1(I,1) : STRESS SOLUTION FROM PREVIOUS NEWTON-RAPHSON
C               ITERATION FOR A GIVEN LOAD
C   P11(I) : AXIAL STRAIN LAYER AXES (ITH LAYER)
C   P22(I) : TRANSVERSE STRAIN LAYER AXES (ITH LAYER)

```

```

C      P12(I)      : SHEAR STRAIN LAYER AXES (ITH LAYER)
C      EP11(I)     : AXIAL STRAIN LAMINATE AXES (ITH LAYER)
C      EP22(I)     : TRANSVERSE STRAIN LAMINATE AXES (ITH LAYER)
C      EP12(I)     : SHEAR STRAIN LAMINATE AXES (ITH LAYER)
C      SF(I)       : MULTIPLICATION FACTOR USED TO ESTIMATE INITIAL
C                  : STRESS IN SUCCESSIVE LOADS
C      PS(I)       : AXIAL STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C      PS(I+LAV)   : TRAN. STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C      PS(I+2*LAV) : SHEAR STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C      FPS1(I)     : AXIAL STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C      EPS22(I)    : TRAN. STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C      EPS12(I)    : SHEAR STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C      SWITCH      : FAILURE SENTINEL
C                  : =0: NO FAILURE
C                  : =1: FAILURE, INTERPOLATE LOAD TO FAILURE POINT
C      NIT         : NEWTON-RAPHSON ITERATION COUNTER
C      NSR         : NON-STANDARD RETURN. NSR=1 IF AN END-OF-FILE IS TRUE
C      *****
C      INITIALIZE VARIABLES
C      EX=3.
C      INMT=2
C      RATIO=1.E-06
C      SENS=1.E-15
C
C      PRINT PROGRAM HEADER
C      CALL HEADER
C      NST=1
C      423 CONTINUE
C      NSR=0
C      TPRINT=0
C      CALL MATCPL (NSR)
C      IF (NSR.FQ.1) GO TO 424
C      CHANGE ENGINEERING STRAIN TO TENSORIAL STRAIN.
C      425 DO 63 ILKA=1,50
C      DO 63 ILKR=1,20
C      63 POINTS(ILKA,6,ILKR) = POINTS(ILKA,6,ILKR)/2.
C
C      *****
C      * INPUT PER SET *
C      *****
C
C      GO TO (20,30),IOPT
C      INPUT 11
C      20 CONTINUE
C      GO TO 50
C      INPUT 21
C      30 CONTINUE
C      IF (COPT.FQ.1) LUP=1
C      IF (COPT.FQ.2) LUP=LAY
C      DO 40 IL=1,LUP
C      INPUT STRESS-STRAIN DATA AND FIT CURVE OF FORM:

```

```

C
C
000067 STRN = A0 + A1*STRS**EX
000070 WHERE A0 = A*STRS
000071
000077 DO 40 IC=1,3
000104 STRN(IDT)=POINTS(IDT,2*IC-1,LUP)
000111 IF(FC.EQ.1) A0(IDT) = STRS(IDT)/G12(IL)
000114 IF(FC.EQ.2) A0(IDT) = STRS(IDT)/E22(IL)
000123 IF(FC.EQ.3) A0(IDT) = STRS(IDT)/E22(IL)
000126 STRN(IDT) = STRN(IDT) - A0(IDT)
000132 IF(STRN(IDT).LE.1.0E-20) STRN(IDT) = 0.00
35 CONTINUE
C
C LEAST-SQUARES CURVE-FIT FOR STRESS-STRAIN DATA
000135 CALL REGA1(STRS,STRN,IPTS,EOPT,0,A1,EX,0)
000144 IF(FC.EQ.1) TY(IL) = RRO(G12(IL),A1,EX)
000153 IF(FC.EQ.2) XM = EX
000157 IF(FC.EQ.2) STY(IL) = RRO(F22(IL),A1,EX)
000165 IF(FC.EQ.2) XN = EX
000171 IF(FC.EQ.3) SCY(IL) = RRO(E22(IL),A1,EX)
000177 IF(FC.EQ.3) XN = EX
40 CONTINUE
000203 IF(COPT.NE.1) GO TO 50
000210 DO 43 IL=2,LAY
000212 TY(IL) = TY(1)
000213 STY(IL) = STY(1)
000215 SCY(IL) = SCY(1)
43 CONTINUE
000220
50 CONTINUE
C
C INPUT LOADINGS AND FAILURE CRITERIA
000222 INPUT ANALYSIS CONTROL PARAMETERS
C
C PRINT INPUT
C
C CALL OUTPT1(NST,LAY,IFCN,KSGM)
C
C
C *****
C * INITIAL ASSIGNMENTS *
C * AND *
C * COMPUTATIONS *
C *****
C
C ANGLE REDUCTION ROUTINE
000225 CALL ANGLE(LAY,IANG)
C
C SWITCH = 0
000227 TT = 0.0E0
000230 DO 100 T = 1,LAY
000231 TT = TT + T(1)
000232
100 CONTINUE
C
000234
C
000236 UFAIL(1) = 0
000237 UFAIL(2) = 0
000240 UFAIL(3) = 0
000241 AGATN = 0
000242 KSG = 1
000243 LTI = LAY
000244 N = ITI
000245 LP1 = LAY +1

```

MAIN

RUN VERSION 2.3 --PSR LEVEL 363--

```

000247      LT2 = LAY*2
000250      LT2) = LAY*2+1
000251      LT3 = LAY*3
000252      LM1 = LAY -1
C
000253      DO 105 I=1,LT3
000255      SG(I,1) = 9.000E 00
000256      SGS(I) = 0.0E00
000257      SF(I) = 1.0E0
000261      SGO(I,1) = 0.0E0
000262      105 CONTINUE
C
000264      DO 107 I = 1,LAY
000265      S11(I) = 1.0E0/E11(I)
000267      S12(I) = -V12(I)/E11(I)
000272      S21(I) = -V21(I)/E22(I)
000274      107 CONTINUE
C
C PRINT INITIAL ELASTIC LAMINATE CONSTANTS
C CALL PROP(SG*EXX,EYY,VXY,VXX,GXY,KSGM,KSG,LAY,1)
C
C ***** INCREMENTAL *****
C * ANALYSIS *
C *****
C
C RETURN TO 110 FOR NEXT INCREMENTAL STEP
C
000310      110 CONTINUE
000310      MSING = .FALSE.
000311      MSINGD = .FALSE.
000312      NIT = 0
000313      IPT = 0
000314      SGO1 = S011
000315      SGO2 = S022
000317      SGO3 = S012
C
C DO 111 K = 1,LT3
000320      DC(K) = 0.0E0
000322      SGI(K,1) = 0.0F0
000323      DO 111 L=1,LT3
000324      DB(K,L) = 0.0E0
000326      AK,L) = 0.0E0
000331      111 CONTINUE
000334      DO 1115 I=1,N
000341      S22(I) = 1.0F0/E22(I)
000342      S44(I) = 1.0F0/(4.0E0*G12(I))
000344      1115 CONTINUE
C
C AFTER 2ND INCREMENTATION USE MULTIPLICATIVE FACTOR
C AS INITIAL STRESS SOLUTION ESTIMATE
C IF (KSG*GF.3 .AND. IPT.EQ.0) GO TO 120
000351      112 CONTINUE
000360      JF(N.EQ.1) LM1=1
000363      DO 115 I=1,LM1

```

8 RUN VERSION 2.3 --PSR LEVEL 363--

```

000365      SNS = SINS(I)
000367      CSS = COSX(I)
000370      SN2 = SIN2(I)
000372      CS2 = COS2(I)
C
000373      IF(N.EQ.1) GO TO 113
000375      SNSP = SINS(I+1)
000377      CSSP = COSX(I+1)
000400      SN2P = SIN2(I+1)
000402      CS2P = COS2(I+1)
C
000403      113 CONTINUE
000403      A(1,I) = CSSP*(I)
000407      A(1,I+N) = SNSP*(I)
000414      A(1,I+2*N) = -SN2P*(I)
C
000422      A(2,I) = SNSP*(I)
000426      A(2,I+N) = CSSP*(I)
000432      A(2,I+2*N) = SN2P*(I)
C
000440      A(3,I) = SN2P*(I)/2.0E0
000444      A(3,I+N) = -SN2P*(I)/2.0E0
000451      A(3,I+2*N) = CS2P*(I)
000455      IF(N.EQ.1) GO TO 116
C
000457      A(3,I+1,I) = -S11(I)*CSS-S21(I)*SNS
000465      A(3,I+1,I+1) = S11(I+1)*CSSP+S21(I+1)*SNSP
000474      A(3,I+1,I+N) = -S12(I)*CSS-S22(I)*SNS
000503      A(3,I+1,I+N+1) = S12(I+1)*CSSP+S22(I+1)*SNSP
000512      A(3,I+1,I+2*N) = 2.0E0*S44(I)*SN2
000521      A(3,I+1,I+2*N+1) = -2.0E0*S44(I+1)*SN2P
C
000530      A(3,I+2,I) = -S11(I)*SNS-S21(I)*CSS
000536      A(3,I+2,I+1) = S11(I+1)*SNSP+S21(I+1)*CSSP
000545      A(3,I+2,I+N) = -S12(I)*SNS-S22(I)*CSS
000554      A(3,I+2,I+N+1) = S12(I+1)*SNSP+S22(I+1)*CSSP
000563      A(3,I+2,I+2*N) = -2.0E0*S44(I)*SN2
000572      A(3,I+2,I+2*N+1) = 2.0E0*S44(I+1)*SN2P
C
000601      A(3,I+3,I) = -(S11(I)-S21(I))*SN2/2.0E0
000610      A(3,I+3,I+1) = (S11(I+1)-S21(I+1))*SN2P/2.0E0
000620      A(3,I+3,I+N) = -(S12(I)-S22(I))*SN2/2.0E0
000627      A(3,I+3,I+N+1) = (S12(I+1)-S22(I+1))*SN2P/2.0E0
000636      A(3,I+3,I+2*N) = -2.0E0*S44(I)*CS2
000644      A(3,I+3,I+2*N+1) = 2.0E0*S44(I+1)*CS2P
C
000653      115 CONTINUE
C
000655      A(1,N) = CSSP*(N)
000661      A(1,2*N) = SNSP*(N)
000665      A(1,3*N) = -SN2P*(N)
000672      A(2,N) = SNSP*(N)
000676      A(2,2*N) = CSSP*(N)
000702      A(2,3*N) = SN2P*(N)
000706      A(3,N) = SN2P*(N)/2.0E0

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MAIN

RUN VERSION 2.3 --PSR LFVEL 363--

```

000712      A(3,2*N) = -SN2P*T(N)/2.0E0
000716      A(3,3*N) = CS2P*T(N)
000723      116 CONTINUE
000723      IF(MSING) GO TO 117
C
C
C      INVERT MATRIX A
C      CALL INVRTD(A,60,LT3,DET, SFMS ,IRANK,1.00E-30)
C
C      CHECK FOR SINGULAR MATRIX
C      IF(IRANK.EQ.LT3) GO TO 118
C      MSING = .TRUE.
C      WRITE(6,1420) IRANK,DET
C      GO TO 117
000745      117 CONTINUE
000746      WRITE(6,1425) ((A(K1,L1),L1=1,LT3),K1=1,LT3)
000746      MSING = .FALSE.
000766      GO TO 990
000767      118 CONTINUE
000770
C
C      INITIAL LOAD VECTOR
C      IF (SWITCH.EQ.1) GO TO 119
C      SGO(1,1) = S011*TT
C      SGO(2,1) = S022*TT
C      SGO(3,1) = S012*TT
C      119 CONTINUE
C      CALL MMXMDL(A,SGO,SG,60,60,1,LT3,LT3,1)
C
C      RESET STRESS = 0, IF RELATIVE STRESS ) 1.00E-06
C      CALL RESET(LT3,SG, RATIO )
C      GO TO 126
C
C      (MULTIPLICATIVE FACTOR) X (SOLUTION FROM PREVIOUS INCREMENT)
C      120 CONTINUE
C      DO 122 I=1,LT3
C      SG(I,1) = SF(I)*SGS(I)
C      122 CONTINUE
C      GO TO 126
C
C      RETURN TO 125 FOR NEXT ITERATION STEP
C      125 CONTINUE
C      NIT = NIT + 1
C      126 CONTINUE
C      STORE STRESS SOLUTION FOR THIS ITERATION
C      DO 127 I=1,LT3
C      SG(I,1) = SG(I,1)
C      RT(I) = 0.0E 00
C      127 CONTINUE
C
C      130 CONTINUE
C      DO 1305 K=1,LT3
C      DO 1305 L=1,LT3
C      DB(K,L) = 0.0E 00

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MAIN

```

001042      1305 CONTINUE
C
C ***** DERIVATIVE MATRIX *****
C * DERIVATIVE MATRIX *
C * FOR *
C * NEWTON-RAPHSON ANALYSIS *
C *****
C
001046      IF(N.EQ.1) LM1=1
001051      DO 151 I=1,LM1
C      CALCULATION OF TERMS USED IN FORMATION OF DERIVATIVE MATRIX
001053      IF(N.EQ.1) GO TO 1308
001055      CALL NRTRM (LAY,SG,F,G,H,I)
001061      CALL NRTRM (LAY,SG,F,G,H,I+1)
001067      1308 CONTINUE
C
001067      SNS = SINS(I)
001071      CSS = COS(I)
001073      SN2 = SIN2(I)
001074      CS2 = COS2(I)
C
001076      IF(N.EQ.1) GO TO 131
001100      SNSP = SINS(I+1)
001101      CSSP = COS(I+1)
001103      SN2P = SIN2(I+1)
001104      CS2P = COS2(I+1)
C
C 131 CONTINUE
001106      DB(1,I) = CSS*(I)
001106      DB(1,I+N) = SNS*(I)
001112      DB(1,I+2*N) = -SN2*(I)
001117      DB(2,I) = SNS*(I)
001125      DB(2,I+N) = CSS*(I)
001131      DB(2,I+2*N) = SN2*(I)
001135      DB(3,I) = SN2*(I)/2.
001143      DB(3,I+N) = -SN2*(I)/2.
001147      DB(3,I+2*N) = CS2*(I)
001154      IF(N.EQ.1) GO TO 161
001160
C
001162      DB(3*I+1,I) = -F(1,I)
001167      DB(3*I+1,I+1) = F(1,I+1)
001174      DB(3*I+1,I+N) = -F(2,I)
001201      DB(3*I+1,I+N+1) = F(2,I+1)
001207      DB(3*I+1,I+2*N) = -F(3,I)
001215      DB(3*I+1,I+2*N+1) = F(3,I+1)
C
001223      DB(3*I+2,I) = -G(1,I)
001231      DB(3*I+2,I+1) = G(1,I+1)
001236      DB(3*I+2,I+N) = -G(2,I)
001243      DB(3*I+2,I+N+1) = G(2,I+1)
001251      DB(3*I+2,I+2*N) = -G(3,I)
001260      DB(3*I+2,I+2*N+1) = G(3,I+1)
C
001266      DB(3*I+3,I) = -H(1,I)
001274      DB(3*I+3,I+1) = H(1,I+1)
001301      DB(3*I+3,I+N) = -H(2,I)
001306      DB(3*I+3,I+N+1) = H(2,I+1)

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RUN VERSION 2.3 --PSR LEVEL 363--
MAIN
001314 DB(3*I+3,I+2*N) = -H(3,I)
001323 DB(3*I+3,I+2*N+1) = H(3,I+1)
C
001331 151 CONTINUE
001334 DB(1,N) = CSSP*T(N)
001340 DB(1,2*N) = SNSP*T(N)
001344 DB(1,3*N) = -SN2P*T(N)
001351 DB(2,N) = SNSP*T(N)
001355 DB(2,2*N) = CSSP*T(N)
001361 DB(2,3*N) = SN2P*T(N)
001365 DB(3,N) = SN2P*T(N)/2.
001371 DB(3,2*N) = -SN2P*T(N)/2.
001375 DB(3,3*N) = CS2P*T(N)
001402 161 CONTINUE
001402 IF(MSINGN) GO TO 167
C
C INVERT MATRIX DB
C CALL INVRTD(DB,60,LT3,DET, SPNS ,IRANK,1.00E-30)
C
C CHECK FOR SINGULAR MATRIX
C IF(IRANK.EQ.LT3) GO TO 168
C MSINGD = .TRUE.
C WRITE(6,1420) IRANK,DET
C GO TO 130
001424 167 CONTINUE
C WRITE(6,1425) ((DB(K1,L1),L1=1,LT3),K1=1,LT3)
C MSINGD = .FALSE.
C GO TO 999
001446 168 CONTINUE
C
C *****
C * INITIAL VECTOR *
C * FOR *
C * NEWTON-RAPHSON ANALYSIS *
C *****
001447 IF (SWITCH.EQ.1) GO TO 173
001451 DC(1) = -S011*T
001453 DC(2) = -S022*T
001455 DC(3) = -S012*T
001456 GO TO 174
001457 173 CONTINUE
C DC(1) = -S60(1,1)
C DC(2) = -S60(2,1)
C DC(3) = -S60(3,1)
001462 174 CONTINUE
C
C DO 6 I=1,LAY
C SNS = SINS(I)
C CSS = COSI(I)
C SN2 = SIN2(I)
C CS2 = COS2(I)
C DC(1) = DC(1) + SG(I,1)*CSS*T(I) + SG(LAY,I,1)*SNS*T(I)
C -SG(I,LAY,I,1)*SN2*T(I)
C
001464 001464
001466 001466
001470 001470
001473 001473
001474 001474

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COMUN VERSION 2.3 --PSK LEVEL 363--

MAIN

```

001510      DC(2) = DC(2) + SG(I,1)*SNS*T(I) + SG(LAY+I,1)*CSS*T(I)
1          + SG(2*LAY+I,1)*SN2*T(I)
001524      DC(3) = DC(3) + SG(I,1)*T(I)*SN2/2. - SG(LAY+I,1)*T(I)*
1          SN2/2. + SG(2*LAY+I,1)*CS2*T(I)
001540      6 CONTINUE
C
C FORM NON-LINEAR COMPLIANCE TERMS S22 AND S44
001543      DO 7 K=1,N
001544      T125 = (SG(K+2*N,1)/TY(K))*2
001550      IF(SG(K+N,1)-0.0) 1,2,2
001553      1 TS225 = (SG(K+N,1)/SCY(K))*2
001557      GO TO 3
001557      2 TS225 = (SG(K+N,1)/STY(K))*2
001563      3 S125 = T125 + TS225
001565      S22(K) = (1.0E0+S125**((XN-1.)/2.))/E22(K)
001577      S44(K) = (1.0E0+S125**((XM-1.)/2.))/(4.0E0*G12(K))
001612      7 CONTINUE
C
C IF(N.EQ.1) GO TO 5008
001614      DO 8 K=1,LM1
001616      SNS = SINS(K)
001617      CSS = COS5(K)
001621      SN2 = SIN2(K)
001622      CS2 = COS2(K)
001624      SNSP = SINS(K+1)
001625      CSSP = COS5(K+1)
001627      SN2P = SIN2(K+1)
001630      CS2P = COS2(K+1)
001632
001633      DC(3+3*K-2) = -(S11(K)*CSS+S21(K)*SNS)*SG(K,1) -
1          SG(LAY+K,1)*(S12(K)*CSS+S22(K)*SNS) + 2.*S44(K)*SN2*
2          SG(2*LAY+K,1) + (S11(K+1)*CSSP+S21(K+1)*SNSP)*
3          *SG(K+1,1) + (S12(K+1)*CSSP+S22(K+1)*SNSP)*
4          *SG(LAY+K+1,1) - 2.*S44(K+1)*SG(2*LAY+K+1,1)*
5          SN2P + SG(3+3*K-2,1)
001706      DC(3+3*K-1) = -(S11(K)*SNS+S21(K)*CSS)*SG(K,1) - (S12(K)*SNS+
1          S22(K)*CSS)*SG(LAY+K,1) - 2.*S44(K)*SN2*
2          SG(2*LAY+K,1) +
3          (S11(K+1)*SNSP+S21(K+1)*CSSP)*SG(K+1,1) + (S12(K+1)*
4          SNSP+S22(K+1)*CSSP)*SG(LAY+K+1,1) + 2.*S44(K+1)*SN2P*
5          *SG(2*LAY+K+1,1) + SG(3+3*K-1,1)
001761      DC(3+3*K) = -(S11(K)-S21(K))*SN2*SG(K,1)/2. - (S12(K)-S22(K))*
1          SN2*SG(LAY+K,1)/2. - 2.*S44(K)*CS2*SG(2*LAY+K,1) +
2          (S11(K+1)-S21(K+1))*SN2P*SG(K+1,1)/2. + (S12(K+1)-
3          S22(K+1))*SN2P*SG(LAY+K+1,1)/2. + 2.*S44(K+1)*CS2P*
4          *SG(2*LAY+K+1,1) + SG(3+3*K,1)
002035      8 CONTINUE
002037      5008 CONTINUE
C
C DO 9 I=1,LT3
002037      DC(I) = -DC(I)
002041
002043      9 CONTINUE
C
C DO 11 I=1,LT3
002045      DO 11 K=1,LT3
002046

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      MAIN
      RUN VERSION 2.3 --PSR LEVEL 363--
002047 11 RT(I) = RT(I) + DB(I,K)*DC(K)
      C
      C *****
      C * FORM SOLUTION VECTOR *
      C * FOR *
      C * THIS ITERATION *
      C *****
002062 DO 15 I=1,LT3
002063 SG(I,1) = SG(I,1) + RT(I)
002066 15 CONTINUE
      C
002070 RESET STRESS = 0, IF RELATIVE STRESS ) 1.0D-06
002073 CALL RESET(LT3,SG, RATIO )
      IF(NIT.EQ.0) GO TO 125
      C
      C *****
      C * CONVERGENCE CHECK *
      C *****
002074 CALL CONVR(LAY,SG,SG1,KSG,IRTN)
002100 GO TO (495,125,900),IRTN
002107 495 CONTINUE
002107 IF(SWITCH.EQ.0) GO TO 500
002110 SG01 = SG0(1,1)/TT
002112 SG02 = SG0(2,1)/TT
002114 SG03 = SG0(3,1)/TT
002115 500 CONTINUE
      C
002115 DO 540 I = 1,LAY
002117 SNS = SINS(I)
002121 CSS = C0SS(I)
002122 SN2 = SIN2(I)
002124 CS2 = C0S2(I)
      C
      C STRAIN COMPUTATIONS IN FIBER AXES DIRECTIONS
002125 P11(I) = S11(I)*SG(I,1) + S12(I)*SG(I+N,1)
002132 T125 = (SG(I+2*N,1)/TY(I))**2
002136 IF(SG(I+N,1)-C.0) 4,5,5
002142 4 TS225 = (SG(I+N,1)/SCY(I))**2
002146 GO TO 18
002146 5 TS225 = (SG(I+N,1)/STY(I))**2
002152 18 S125 = T125+TS225
002154 P22(I) = S21(I)*SG(I,1) + SG(I+N,1)/E22(I)*(1.0E0+S125**((XN
      1 P12(I) = SG(I+2*N,1)/(2.*G1P(I))*(1.0E0+S125**((XN-1.)/2.))
002173 520 CONTINUE
002211 EPN(I ,1) = P11(I)
002211 EPN(I+ N,1) = P22(I)
002213 EPN(I+2*N,1) = P12(I)
002216
      C
      C STRAIN COMPUTATIONS IN LAMINATE AXES DIRECTIONS
002221 EPN(I) = P11(I)*CSS + P22(I)*SNS - P12(I)*SN2
002227 EPN(I) = P11(I)*SNS + P22(I)*CSS + P12(I)*SN2

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```

002235 C      FPI2(I) = (P11(I)-P22(I))*SN2/2.E0 + P12(I)*CS2
002243 C      540 CONTINUE
002246 IF (AGAIN.EQ.1) GO TO 752
002250 IF (SWITCH.EQ.0) GO TO 610
002251 SWITCH = 0
002251 IPT = 1
002252 GO TO 730

C
C
C *****
C * LAMINATE FAILURE TESTS *
C *****
C
002253 C      610 CONTINUE
002253 CALL LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SWITCH)

C
C *****
C * OUTPUT PER *
C * LOAD INCREMENT *
C *****
C
002266 C      730 CONTINUE
002266 WRITE(6,1525)
002272 WRITE(6,1527) SG01
002300 WRITE(6,1528) SG02
002306 WRITE(6,1529) SG03
002314 WRITE(6,1735) NIT
002322 WRITE(6,1536)
002326 WRITE(6,1537)
002332 WRITE(6,1538)
002336 DO 750 I = 1,LAY
002340 EPI2(I)=EPI2(I)*2.
002342 WRITE(6,1550) I,SG(I,1),SG(I+N,1),SG(I+2*N,1),
1 EPI1(I),EPI2(I),EPI2(I),P11(I),P22(I),P12(I)
002375 FPI2(I)=EPI2(I)/2.
002400 C      750 CONTINUE
002402 IF(IPT.FQ.1) WRITE(6,1990)
002407 IF (IPT.FQ.1) AGAIN=1
002412 IF (IPT.EQ.1) GO TO 110

C
C *****
C * COMPUTE INELASTIC MATERIAL PROPERTIES AND RETAIN AS FUNCTION OF INCREMENT *
C *****
C
002413 C      752 CONTINUE
002413 AGAIN = 0
002414 CALL PROP(SG,EXX,EYY,VXY,VXX,GXY,KSGM,KSG,LAY,2)
002426 DO 755 I=1,LAY
002430 STXX(I,KSG) = SG(I ,1)
002434 STYY(I,KSG) = SG(I+N,1)
002441 STXY(I,KSG) = SG(I+2*N,1)
002446 C      755 CONTINUE

C
C *****
C * CHECK FOR LAMINATE FAILURE, IF FAILURE HAS OCCURED INTERPOLATE LOADS TO *
C * FAILURE POINT AND REEVALUATE *
C *****
C
002450 IF (SWITCH.FQ.0) GO TO 75R
002451 WRITE(6,1555)
002455 WRITE(6,1560)
002461 SG0(1,1) = ((S011-SM11) + FAC*SM11)*TI
002466 SG0(2,1) = ((S022-SM22) + FAC*SM22)*TI

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RUN VERSION 2.3 --PSR LEVEL 363--

```

002472      SG0(3,1) = ((S012-SM12) + FAC*SM12)*TI
002477      GO TO 110
002477      758 CONTINUE
C
C      CHECK FOR INCREMENTATION LIMIT
C      IF (KSGM-KSG) 790,790,760
C
C      *****
C      *      INCREMENTATION      *
C      *      ESTIMATE            *
C      *****
C
002502      760 CONTINUE
002502      GO TO (762,766), INMT
C
C      RATIO OF PREVIOUS SOLUTIONS
C      762 CONTINUE
002510      DO 765 I=1,LT3
002510      IF (KSG.EQ.1) GO TO 770
002512      IF (SGS(I).EQ.0.0E0) GO TO 763
002514      SF(I) = SG(I,1)/SGS(I)
002515      GO TO 745
002517      763 CONTINUE
002520      SF(I) = 1.0E0
002520
002522      765 CONTINUE
002522      GO TO 770
002525
C
002525      766 CONTINUE
002525      DO 768 I=1,LT3
002527      IF (KSG.LT.2) GO TO 767
002527      IF (SG(I,1).EQ.0.0E0) GO TO 767
002531      VKSG = KSG + 1
002533      CONS = VKSG*(VKSG-2)/(VKSG-1)**2
002535      SF(I) = 1.0E0 + CONS*(SG(I,1)-SGS(I))/SG(I,1)
002543      GO TO 768
002543
002551      767 CONTINUE
002551      SF(I) = 1.0E0
002551
002553      768 CONTINUE
C
C      STORE STRESS AND STRAIN VALUES
C      770 CONTINUE
002556      DO 775 I = 1,LAY
002556      SGS(I) = SG(I)
002560      SGS(I+N) = SG(I+N,1)
002562      SGS(I+2*N) = SG(I+2*N,1)
002566      EPS1(I) = EP1(I)
002572      EPS2(I) = EP2(I)
002573      EPS12(I) = EP12(I)
002575      PS(I) = P1(I)
002576      PS(I+N) = P2(I)
002600      PS(I+2*N) = P12(I)
002602
002605      775 CONTINUE
C
C      INCREMENT APPLIED LOADING
C      KSG = KSG + 1
002610

```


SUBROUTINE HEADER

```

C
C ROUTINE HEADER PRINTS HEADER INFORMATION FOR NOLIN V2 M2
C
000002 REAL          MESSAGE(100)
C RETRIEVE JULIAN DATE FROM THE OPERATING SYSTEM.....
C DATE=0
C READ IN 5 CARD PROGRAM IDENTIFICATION
C READ(5,200) (MESSAGE(I),I=1,100)
C      200 FORMAT(20A4)
C WRITE OUT TITLE, DATE, AND PROGRAM IDENTIFICATION
C      1000 FORMAT (1H1,///,41X,41(***).3(/,41X,***,39X,***),/,
C      *      41X,***,14X,***NONLINEAR,16X,***,/,41X,***,39X,***,/,
C      *      41X,***, 8X,***THERMOELASTIC ANALYSIS, 9X,***,/,
C      *      41X,***,39X,***,/,41X,***,18X,***OF,19X,***,/,
C      *      41X,***,39X,***,/,41X,***,10X,***FIBROUS COMPOSITES,
C      *      11X,***,/,41X,***,39X,***,/,41X,***,17X,***AND,19X,***,/,
C      *      41X,***,39X,***,/,41X,***, 6X,
C      *      *NON-HOMOGENEOUS LAMINATES, 8X,***,3(/,41X,***,39X,***),
C      *      /,41X,41(***),//,
C      *      //21X,*.VERSION 2      MOD 3 (MAY 74)*,
C      *      //,21X,*.DATE      *,A10,///,21X,
C      *      *.PROGRAM IDENTIFICATION*//,5(21X,20A4,/,)////)
C
000031 RETURN
000032 END

```

00002200
00002300

00003600

```

000003      SUBROUTINE MATCRL (NSR)
000003      REAL THETA
000003      DIMENSION THETA(20),THICK(20),MATYPE(20),S11T(20),S22T(20),
1      S12(20),S11C(20),S22C(20),EP11T(20),EP22T(20),EP11C(20),
2      EP22C(20),GAMA(20),E11(20),E22(20),G12(20),V12(20),
3      T(20),A12(20),V21(20),TE11(20),TE22(20),TG12(20),
4      TV12(20),TA12(20),TSTY(20),TSCY(20),TY(20),TY(20),
5      STY(20),SCY(20),EP11(20),EP22(20),EP12(20),ULT(62,20),
6      POINTS(50,6,20),EPS11(50,20),EPS22(50,20),EPS12(50,20),
7      TEPS11(50,20),TEPS22(50,20),TEPS12(50,20),
8      SIG11(50,20),SIG22(50,20),SIG12(50,20),A11(20),A22(20),
9      A44(20),B1(20),B2(20),S11(20),S22(20),S21(20),
      /SET01/ E11,E22,V12,V21,G12
      /SET02/TT,THICK,THETA
      /SET03/EP11,EP22,EP12
      /SET04/ S011,S022,S012,S012,SM11,SM22,SM12
      /SET05/ ULT,STIFF
      /SET08/ S11,S22,S12,S21
      /SET09/ NLAY,EOP1,COP1,IFCN,KSGM,INMT,RATIO,SENS
      /SET10/ STY,SCY,TY,XM,XN
      /SET11/ EPS,UPHD,NIT,IT,SMLT
      /SET14/ A11,A22,A44,A12,B1,B2
      /SET15/ POINTS,IPRINT,IOP1,IPIS,LUP
      /SET16/ MATYPE,S11T,S11C,S22T,S22C,EP11T,EP11C,
1     EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
      /SET17/ TE11,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
      INTEGER EOPT,COPT
      NAMELIST/DATA/NLAY,E11,E22,V12,G12,THICK,THETA,IOP1,
1     STY,SCY,TY,XM,XN,EOP1,COPT,IPIS,IPRINT,S011,S022,S012,
2     IFCN,STIFF,A12,KSGM,SM1T,IT,EPS,UPHD,INMT,RATIO,SENS,
3     S11T,S22T,S12,S11C,S22C,EP11T,EP22T,EP11C,EP22C,
4     GAMA,SIG11,SIG22,SIG12,EPS11,EPS22,EPS12,MATYPE
      NSR=0
      READ(5,DATA)
      IF (EOF,5) 424,425
425 DO 10 I=1,20
      TE11(I) = E11(I)
      TE22(I) = E22(I)
      TG12(I) = G12(I)
      TV12(I) = V12(I)
      TA12(I) = A12(I)
      TSTY(I) = STY(I)
      TSCY(I) = SCY(I)
      TTY(I) = TY(I)
      NO 200 I = 1,20
      M = MATYPE(I)
      E11(I) = TE11(M)
      E22(I) = TE22(M)
      G12(I) = TG12(M)
      V12(I) = TV12(M)
      A12(I) = TA12(M)
      STY(I) = TSTY(M)
      SCY(I) = TSCY(M)

```

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MATCRL

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```

100052 TY(I) = ITY(M)
100053 ULT(1,1,I) = S11T(M)
100056 ULT(1,2,I) = S11C(M)
100061 ULT(2,1,I) = S22T(M)
100064 ULT(2,2,I) = S22C(M)
100067 ULT(3,1,I) = S12(M)
100072 ULT(3,2,I) = S12(M)
100075 ULT(4,1,I) = EP11T(M)
100100 ULT(4,2,I) = EP11C(M)
100103 ULT(5,1,I) = EP22T(M)
100106 ULT(5,2,I) = EP22C(M)
100111 ULT(6,1,I) = GAMA(M)
100114 ULT(6,2,I) = GAMA(M)
100117 DO 200 J = 1,IPTS
100121 POINTS(J,1,I) = SIG11(J,M)
100127 POINTS(J,2,I) = EPS11(J,M)
100135 POINTS(J,3,I) = SIG22(J,M)
100143 POINTS(J,4,I) = EPS22(J,M)
100151 POINTS(J,5,I) = SIG12(J,M)
100157 POINTS(J,6,I) = EPS12(J,M)
100171 RETURN
100172 200 NSR=1
100173 424 RETURN
100174 END

```

```

SURROUTINE OUTPT1(NST,LAY,IFCN,KSGM)
C
C ROUTINE OUTPT1 PRINTS OUT ALL PARAMETERS PERTAINING
C TO PROBLEM DEFINITION
C
REAL IANG
DIMENSION
1
2
    DIMENSION
    DIMENSION
    DIMENSION /SET01/ EPS,UPHD,NIT,IT,SMLT
    COMMON /SET02/ TT,T,IANG
    COMMON /SET04/ SOLL,S022,S012,SML1,SM22,SM12
    COMMON /SET05/ ULT,STIFF
    COMMON /SET10/ STY,SCY,TV,XM,XN
    COMMON /SET11/ EPS,UPHD,NIT,IT,SMLT
    COMMON /SET14/ A11,A22,A44,A12,B1,B2
    COMMON /SET15/ POINTS,IPRINT,IOP1,IPTS,LUP
DATA
*
*
*
    SML1 = SMLT*SOLL
    SM22 = SMLT*S022
    SM12 = SMLT*S012
    DO 15 I=1,LAY
        V21(I) = V12(I)*E22(I)/E11(I)
15 CONTINUE
C
WRITE(6,1509) NST
WRITE(6,1510) LAY
IF(ITPRINT.NE.1) GO TO 1112
WRITE(6,1507)
DO 47 IL = 1,LUP
    DO 45 J = 1,5
45 WRITE(6,1553) (POINTS(I,J,IL),I=1,IPTS)
DO 46 IAC = 1,IPTS
46 POINTS(IAC,6,IL) = POINTS(IAC,6,IL)*2.
WRITE(6,1553) (POINTS(I,6,IL),I=1,IPTS)
DO 47 IAD = 1,IPTS
47 POINTS(IAD,6,IL) = POINTS(IAD,6,IL)/2.
1112 WRITE(6,1513)
DO 60 I=1,LAY
    WRITE(6,1515)
        I,IANG(I),T(I),E11(I),E22(I),V12(I),V21(I),
        G12(I),STY(I),SCY(I),TV(I),TY(I)
60 CONTINUE
    WRITE(6,1516)
    WRITE(6,1517) XM
    WRITE(6,1518) XN
    WRITE(6,1520)
    WRITE(6,1524) SOLL,SM11,KSGM
00203
00210
00213
00221
00227
00233

```

UN VERSION 2.3 --PSR LFVEL 363--

```

00247 WRITE(6,1526) S022,SM22
00257 WRITE(6,1528) S012,SM12
00267 IFN = 2*IFCN
00273 IST = IFN-1
00275 WRITE(6,1530) (HOFAIL(IF),IF=IST,IFN)
00307 IF(IFCN.NE.2) WRITE(6,1532)
00322 IF((IFCN.NE.2).OR.(IFCN.EQ.4)) IFS=1
00332 IF((IFCN.EQ.2).OR.(IFCN.EQ.4)) WRITE(6,1533)
00350 IF(IFCN.EQ.2) IFS=4
00353 DO 90 IL=1,LAY
00355 85 CONTINUE
00355 IFE = IFS+2
00355 WRITE(6,1534) IL,((ULT(ID,IM,IL),ID=IFS,IFE),IM=1,2)
00404 IF(IFCN.NE.4) GO TO 90
00411 IF(IFS.EQ.1) IFS=4
00414 IF(IFE.EQ.3) GO TO 85
00416 IFS = 1
00417 90 CONTINUE
00422 IF((IFCN.EQ.1).OR.(IFCN.EQ.2)) GO TO 110
00431 WRITE(6,1535)
00435 DO 95 IL=1,LAY
00441 WRITE(6,1536) IL,A12(IL)
00450 95 CONTINUE
00455 110 CONTINUE
00455 WRITE(6,1538) STIFF
00463 WRITE(6,1540) IT
00467 WRITE(6,1544) IT
00475 WRITE(6,1546) EPS
00503 WRITE(6,1548) UPBD

C
00511 1507 FORMAT(/// ** DATA INPUT POINTS FOR CURVE FIT-*/)
00511 1509 FORMAT (1H1,50X,*LAMINATE*,14,50X,12(/**))
00511 1510 FORMAT (/// ** NUMBER OF LAYERS = *,12)
00511 1513 FORMAT (/ ** LAYER THETA*,6X,*,13X,*E11*, 9X,*E22*, 9X,*
* v12*, 9X,*v21*, 9X,*G12*,8X,*SGT Y*,8X,*SGC Y*,8X,*TAUY*/)
00511 1515 FORMAT (14,3X,F6.2,2X,E11.4,4X,E11.4)
00511 1516 FORMAT (/// ** EQUATION PARAMETERS*)
00511 1517 FORMAT (/ ** EXPONENT M = *,E12.5)
00511 1520 FORMAT (///50X,*EXTERNALLY APPLIED STRESS*/50X,27(/**),
* /30X,*INITIAL*,18X,*STRESS*, 42X,*NO. OF*
* /32X,*STRESS*,17X,*INCHMENT*,37X,*INCREMENTS*/)
00511 1524 FORMAT (15X,*SG XX*,4X,E15.5,11X,E15.5, 37X,15)
00511 1526 FORMAT (15X,*SG YY*,4X,E15.5,11X,E15.5)
00511 1528 FORMAT (15X,*SG XY*,4X,E15.5,11X,E15.5)
00511 1530 FORMAT (///50X,*LAMINA FAILURE CRITERIA*,50X,23(/**),
* /52X,2A10,16X,*LAYER*,18X,*LL*,23X,*TT*,25X, *LT*/)
00511 1532 FORMAT ( 25X,*ULT. STRESS*)
00511 1533 FORMAT (25X,*ULT. STRAIN*/25X,*NOTE: ALL STRAINS ARE ENGINEER*,
* ING COMPONENTS*)
00511 1534 FORMAT (/16X,12, 4X,*TENS.*, 4X,3(E15.5,10X),/22X,*COMP.*,
* 4X,3(E15.5,10X))
00511 1535 FORMAT (/15X,*LAYER*,20X,*QUADRATIC INTERACTION TERM (A12)*/)
00511 1536 FORMAT (16X,12,27X,E15.5)

```

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OUTPUT1

JN VERSION 2.3 --PSR LEVEL 363--

```
00511 1538 FORMAT (/15X,*STIFFNESS = *,E15.5)
00511 1540 FORMAT (/50X,*CONTROL PARAMETERS*/50X,18(*,*)//)
00511 1544 FORMAT (15X,*MAX. NO. OF ITERATIONS = *,I5)
00511 1546 FORMAT (15X,*CONVERGENCE CRITERIA = *,E15.5)
00511 1548 FORMAT (15X,*DIVERGENCE CRITERIA = *,E15.5)
00511 1553 FORMAT(3X,RE14.5/3X,2E14.5//)
```

C

```
00511      RETURN
00512      END
```


PROP

IN VERSION 2.3 --PSK LEVEL 363--

```

.0070 CALL TRANS(TNS,K)
.0072 CALL CMATX(CMT,SG,LAY,K,LPROP)
.0103 CALL MXMULD(CMT,TNS,TMP,3,3,3,3,3,3)
.0114 CALL INVRTD(TNS,3,3,DET,1.0E-12,IRANK,1.0E-30)
.0123 CALL MXMULD(TNS,TMP,CMT,3,3,3,3,3,3)
.0134 DO 110 KI = 1,3
.0141 DO 110 KJ = 1,3
.0142 CSUM(KI,KJ)=CSUM(KI,KJ)+CMT(KI,KJ)*TH(K)
.0152 110 CONTINUE
.0156 150 CONTINUE
C
C INVERT RESULTANT MATRIX
C CALL INVRTD(CSUM,3,3,DET,1.0E-12,IRANK,1.0E-30)
C
.0161 GO TO (175,500), LPROP
.0167 175 CONTINUE
.0201 HEL = 1./A(1,1)*TT
.0204 HET = 1./A(2,2)*TT
.0207 NULT = -A(1,2)/A(1,1)
.0211 NUTL = -A(1,2)/A(2,2)
.0213 HGLT = 1./A(3,3)*TT
.0216 WRITE(6,1510)
.0222 WRITE(6,1522) HEL
.0230 WRITE(6,1524) HET
.0236 WRITE(6,1526) NULT
.0244 WRITE(6,1528) NUTL
.0252 WRITE(6,1532) HGLT
.0260 WRITE(6,1560)
.0264 RETURN
C
.0265 500 CONTINUE
C COMPUTE NONLINEAR PROPERTIES AS FUNCTION OF STRESS
.0266 FXX(ILD) = 1./CSUM(1,1)
.0274 EYY(ILD) = 1./CSUM(2,2)
.0276 VXY(ILD) = -CSUM(1,2)/CSUM(1,1)
.0300 VYX(ILD) = -CSUM(1,2)/CSUM(2,2)
.0303 GXY(ILD) = 1./CSUM(3,3)
.0305 RETURN
C
.0305 1510 FORMAT (//45X,*LAMINATE CONSTANTS (STRESS-STRAIN)*,/45X,36(#+*))
.0305 1522 FORMAT (/48X,*EXX = *,E15.5)
.0305 1524 FORMAT (/48X,*EYY = *,E15.5)
.0305 1526 FORMAT (/48X,*VXY = *,E15.5)
.0305 1528 FORMAT (/48X,*VYX = *,E15.5)
.0305 1532 FORMAT (/48X,*GXY = *,E15.5)
.0305 1560 FORMAT (1H1,50X,*APPLIED STRESS ANALYSIS*/50X,22(#+*))
.0305 END

```



```

SUBROUTINE CMATX(C,SG,N,I,LP,PROP)
C
C ROUTINE CMATX COMPUTES C MATRIX
C
COMMON /SET01/ E11,E22,V12,V21,G12
COMMON /SET10/ STY,SCY,TY,XM,XN
DIMENSION E11(20),E22(20),V12(20),V21(20),G12(20),
1 SCY(20),STY(20),TY(20)
DIMENSION SG(60,1),C(3,3)
DENOM = 1.0-V12(I)*V21(I)
C(1,1) = E11(I)/DENOM
C(2,2) = E22(I)/DENOM
IF(LP,PROP,EQ.1) C(3,3) = 2.*G12(I)
IF(LP,PROP,EQ.2) C(3,3) = G12(I)/(1.0+(SG(I+2*N,1)/TY(I))*2)
C(1,2) = V12(I)*E22(I)/DENOM
C(2,1) = C(1,2)
C(1,3) = 0.0
C(2,3) = 0.0
C(3,1) = 0.0
C(3,2) = 0.0
C
10045 RETURN
10045 END

```

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```

10072 NDELET = NDELET + 1
10074 100 CONTINUE
10077 C
10100 C COMPUTE REGRESSION EQUATION PARAMETERS
10111 M = (SXY - SX*SY/N)/(SX2 - SX**2/N)
10123 A1 = EXP(SY/N - M*SX/N)
10143 C COMPUTE CORRELATION COEFFICIENT (ABS. VAL.)
10144 R = (N*SXY-SX*SY)/SQRT((N*SX2-SX**2)*(N*SY2-SY**2))
GO TO 800
C
10150 C FIT M ONLY
10150 250 CONTINUE
10150 GO TO 800
C
10151 C FIT A1 ONLY
10151 500 CONTINUE
10151 DO 550 I=1,N
10153 YP = Y(I)-A0
10156 XP = X(I)
10160 SNUM = SNUM + YP*XP**M
10166 SDEN = SDEN + XP** (2.*M)
10175 550 CONTINUE
10177 A1 = SNUM/SDEN
10201 R = 1.
C
C PRINT OPTIONS
C 800 CONTINUE
10202 IF (IPRT.EQ.0) RETURN
10204 WRITE(6,1500)
10210 WRITE(6,1510) OPTION(0PT)
10225 WRITE(6,1515) R
10233 WRITE(6,1520) A0
10245 WRITE(6,1524) A1
10257 WRITE(6,1528) M
C
10265 IF (NDELET.NE.0) WRITE(6,1810) NDELET
C
1500 FORMAT (1H1,////49X,*LEAST SQUARES REGRESSION ANALYSIS OF FORM*/
10303 60X,*Y = A0 + A1*X.*M*////)
10303 1510 FORMAT (50X,*FIT PARAMETERS *A10)
10303 1515 FORMAT (50X,*CORRELATION COEFFICIENT OF LOG CURVE = *FA.2//)
10303 1520 FORMAT (50X,*A0 = *.1PE15.5)
10303 1524 FORMAT (50X,*A1 = *.1PE15.5)
10303 1528 FORMAT (50X,* M = *.1PE15.5)
10303 1810 FORMAT (1H1,10X,*CURVE-FIT WARNING*/25X,15,
* DATA POINTS YIELD NEGATIVE LOG ARGUMENTS AND*,
* HAVE BEEN DELETED*)
10303 * RETURN
10304 FND

```

IN VERSION 2.3 --PSR LEVEL 363--

```

C
C
C
C
      SURROUTINE ANGLE(LAY,IANG)
      ROUTINE ANGLE REDUCES ANGLES TO VALUES BETWEEN 0 AND PI/4 FOR
      COMPUTING SIN AND COS
      REAL IANG,IAVAL,IANG2
      DIMENSION SINS(20),COSS(20),SIN2(20),COS2(20),IANG(20)
      COMMON /SET06/ SIN2,COS2,SINS,COSS
      DO 72 I = 1,LAY
      IANG2 = 2*IANG(I)
      ANG = IANG(I)
      ANG2 = IANG2
      RAD = ANG /57.295779513D0
      RAD2 = ANG2/57.295779513D0
      IAVL = ABS(IANG(I))
      IF(IAVAL.EQ.0.0) GO TO 66
      IF(IAVAL.NE.90.0) GO TO 62
      SINS(I) = COS(0.0E0)**2
      COSS(I) = SIN(0.0E0)**2
      SIN2(I) = SIN(0.0E0)
      COS2(I) = - COS(0.0E0)
      GO TO 72
62 CONTINUE
      SGN = IANG(I)/IAVAL
      IF(IAVAL.NE.45.0) GO TO 64
      SIN2(I) = COS(0.0E0)*SGN
      COS2(I) = SIN(0.0E0)
      GO TO 68
64 CONTINUE
      IF(IAVAL.LT.45.0)GO TO 66
      RDA = (2.*IAVAL-90.)/57.295779513
      SIN2(I) = SGN* COS(SGN*RDA)
      COS2(I) = -SGN* SIN(SGN*RDA)
      GO TO 68
66 CONTINUE
      SIN2(I) = SIN(RAD2)
      COS2(I) = COS(RAD2)
68 CONTINUE
      SINS(I) = SIN(RAD)**2
      COSS(I) = COS(RAD)**2
72 CONTINUE
      RETURN
      END
10005
10005
10005
10005
10006
10011
10012
10014
10027
10041
10043
10045
10047
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10056
10062
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10156

```

```

00014 SUBROUTINE MXMULD(A,B,C,NROWA,NCOLA,NCULR,MA,NA,NB) R06D0001
00014 C
00014 C ROUTINE MXMULD MULTIPLIES TWO MATRICES (A + B), STORES RESULT IN C
00014 C
00014 C DIMENSION A(NROWA,NCOLA),B(NCOLA,NCOLB),C(NROWA,NCULR)
00014 C
00014 C REAL
00014 C DO 20 I=1,MA
00014 C DO 20 J=1,NB
00014 C X=0.
00014 C DO 10 K=1,NA
00014 C 10 X=X+A(I,K)*B(K,J)
00014 C 20 C(I,J)=X
00014 C
00014 C RETURN
00014 C
00014 R0
00014 R06D0005
00014 R06D0006
00014 R06D0007
00014 R06D0008
00014 R06D0009
00014 R06D0010
00014 R06D0011

```

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UN VERSION 2.3 --PSR LEVEL 363--

INVRTD

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```

00133 IF (ABS(DELTA).LT.UNDER) DELTA = 0.00E 00
00137 DELTA=PIV*DELTA
00141 IF (ABS(PIV) .LE. TOL) GO TO 150
00143 IR(I)=J
00145 IC(J)=I
00146 PIV = 1.0E0/PIV
00150 A(I,J)=PIV
00153 DO 60 K = 1,N
00155 60 IF (K.NE.J) A(I,K)=A(I,K)*PIV
00166 DO 90 K = 1,N
00167 IF (K.EQ.I) GO TO 90
00171 PIV1 = A(K,J)
00175 DO 80 L = 1,N
00177 IF (ABS(PIV1).LT.UNDER) PIV1=0.0E 00
00203 IF (ABS(A(I,L)).LT.UNDER) A(I,L) = 0.00E 00
00217 80 IF (L.NE.J) A(K,L)=A(K,L)-PIV1*A(I,L)
00235 90 CONTINUE
00240 DO 100 K = 1,N
00241 100 IF (K.NE.I) A(K,J)=-PIV*A(K,J)
00253 S=S+1
00254 IF (S.LT.R) GO TO 30
00256 110 DO 140 I = 1,N
00260 K=IC(I)
00262 M=IR(I)
00263 IF (K.EQ.I) GO TO 140
00265 DELTA=DELTA
00266 DO 120 L = 1,N
00267 TEMP=A(K,L)
00273 A(K,L)=A(I,L)
00302 A(I,L)=TEMP
00306 DO 130 L = 1,N
00307 TEMP=A(L,M)
00314 A(L,M)=A(L,I)
00322 130 A(L,I)=TEMP
00330 IC(M)=K
00332 IR(K)=M
00333 140 CONTINUE
00336 150 IRANK=S
00337 RETURN
00340 END

```

R12D0035
R12D0036
R12D0037
R12D0038
R12D0039
R12D0040
R12D0041
R12D0042
R12D0043
R12D0044
R12D0045
R12D0046

R12D0047
R12D0048
R12D0049
R12D0050
R12D0051
R12D0052
R12D0053
R12D0054
R12D0055
R12D0056
R12D0057
R12D0058
R12D0059
R12D0060
R12D0061
R12D0062
R12D0063
R12D0064
R12D0065
R12D0066
R12D0067
R12D0068
R12D0069
R12D0070

```

SURROUTINE NRTRM(LAY,SG,F,G,H,I)
C
C ROUTINE NRTRM COMPUTES ELEMENTS OF DERIVATIVE MATRIX IN
C NEWTON-RAPHSON ANALYSIS
C
00011 REAL SG(60,1)
00011 REAL E11(20),E22(20),V12(20),V21(20),G12(20),
00011 SCY(20),STY(20),TY(20)
00011 1 DIMENSION
00011 1 S11(20),S12(20),S21(20),S22(20),
00011 2 S1NS(20),COS2(20),S1N2(20),COS2(20),
00011 F(3,20),G(3,20),H(3,20)
00011 COMMON /SET01/ E11,E22,V12,V21,G12
00011 COMMON /SET06/ S1N2,COS2,S1NS,COS2
00011 COMMON /SET08/ S11,S22,S12,S21
00011 COMMON /SET10/ STY,SCY,TY,XM,XN
C
N = LAY
T12S = (SG(I+2*N,1)/TY(I))**2
T12D = SG(I+2*N,1)/TY(I) **2
T22S = (SG(I+N,1)/TY(I))**2
T22D = SG(I+N,1)/TY(I) **2
C12T = SG(I+2*N,1)*SG(I+N,1)/TY(I)**2
IF(SG(I+N,1) = 0.0) 1,2,2
1 VAL = SCY(I)*1.0E-60
RAT = SG(I+2*N,1)*SG(I+N,1)/SCY(I)
VAL = ABS(VAL)
RAT = ABS(RAT)
IF(RAT.LE.VAL) RAT=0.0E00
C12S = RAT/ SCY(I)
TS22S = (SG(I+N,1)/SCY(I))**2
GO TO 3
2 VAL = STY(I)*1.00E-60
RAT = SG(I+2*N,1)*SG(I+N,1)/STY(I)
VAL = ABS(VAL)
RAT = ABS(RAT)
IF(RAT.LE.VAL) RAT=0.0E00
C12S=RAT/STY(I)
TS22S = (SG(I+N,1)/STY(I))**2
3 S12S = T12S +TS22S
IF(ABS(S12S).LT.1.00E-20) GO TO 40
PN12 = S12S**((XM-1.)/2.)
PN32 = S12S**((XM-3.)/2.)
PM12 = S12S**((XM-1.)/2.)
PM32 = S12S**((XM-3.)/2.)
GO TO 80
40 CONTINUE
PN12 = 0.
PN32 = 0.
PM12 = 0.
PM32 = 0.
R0 CONTINUE
C
00164 SNS = S1NS(I)
00166 CSS = COS2(I)

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00167      SN2 = SIN2(I)
00171      CS2 = COS2(I)
      C
00172      F(1,I) = S11(I)*CSS + S21(I)*SNS
00177      F(2,I) = S12(I)*CSS + SNS/F22(I) + SNS/E22(I)*PN12
      1      + SNS*TS22S*(XM-1.)/E22(I)*PN32
      2      - SN2*(XM-1.)/(2.*G12(I))*PM32*CI2S
00227      F(3,I) = -SN2/(2.*G12(I)) - SN2/(2.*G12(I))*PM12
      1      - SN2*TI2S*(XM-1.)/(2.*G12(I))*PM32
      2      + CI2I*(XM-1.)/E22(I)*PN32
00253      G(1,I) = S11(I)*SNS + S21(I)*CSS
00260      G(2,I) = SNS*S12(I) + CSS/F22(I) + PN12*CSS/E22(I)
      1      + CSS * (XM-1.)*PN32/E22(I)*TS22S
      2      + (XM-1.)*CI2S*SN2*PM32/(2.*G12(I))
00310      G(3,I) = SN2/(2.*G12(I)) + SN2*PM12/(2.*G12(I))
      1      + SN2*(XM-1.)/(2.*G12(I))*PM32*TI2S
      2      + (XM-1.)*CI2I*PN32*CSS/F22(I)
00334      H(1,I) = (S11(I)-S21(I))*SN2/2.
00343      H(2,I) = S12(I)*SN2/2. - SN2/(2.*E22(I)) - PN12*SN2
      1      / (2.*E22(I)) - (XM-1.)*PN32*SN2/(2.*E22(I))
      2      + TS22S * (XM-1.)*CI2S*PM32
      3      + CS2/(2.*G12(I))
00373      H(3,I) = CS2/(2.*G12(I)) + PM12*CS2/(2.*G12(I))
      1      + (XM-1.)*PM32 * TI2S*CS2/(2.*G12(I))
      2      - (XM-1.)*CI2I*PN32 * SN2/(2.*E22(I))
      C
00421      RETURN
00422      END

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C      SUBROUTINE CONVR(LAY,SG,SG1,KSG,IRTN)
C      ROUTINE CONVR CHECKS FOR CONVERGED SOLUTION DURING NEWTON-RAPHSON
C      ANALYSIS. ALSO CHECKS ITERATION LIMIT AND DIVERGENCE LIMIT.
C
000010      DIMENSION      SG(60,1),SG1(60,1),DIF(60)
000010      COMMON      /SET11/ EPS,UPRD,NIT,IT,SMLT
C
000010      ICON = 1
000011      N = LAY
000012      LT3 = LAY*3
000013      IRTN=1
C
C      CONVERGENCE CHECK
000014      DO 375 J3=1,LT3
000016      SUR = ABS(SG(J3,1))- ABS(SG1(J3,1))
000024      IF(SG1(J3,1).EQ.0.0E0) GO TO 330
000026      DIF(J3) = ABS(SUB/SG1(J3,1))
000031      GO TO 335
000032      330 CONTINUE
000032      DIF(J3) = SUR
000032      335 CONTINUE
000034      IF(NIF(J3).GT.EPS) GO TO 340
000040      GO TO 375
C
C      ITERATION CHECK
000040      340 CONTINUE
000040      IF((NIT-IT).NE.0) GO TO 350
000042      ICON = 3
000043      IF(NIF(J3).LE.UPRD) GO TO 375
000046      ICON = 4
000047      GO TO 375
C
C      DIVERGENCE CHECK
000050      350 IF(NIF(J3).LE.UPRD) GO TO 370
000053      ICON = 4
000054      GO TO 375
C
C
000055      370 CONTINUE
000055      ICON = 2
000056      375 CONTINUE
C
000061      GO TO (500,400,382,386),ICON
C
C      NON-CONVERGENCE DUMP
000071      382 CONTINUE
000071      WRITE(6,1720)
000075      WRITE(6,1722) EPS
000103      GO TO 395
000107      386 CONTINUE
000107      WRITE(6,1730)
000113      WRITE(6,1722) UPRD
000121      395 CONTINUE

```

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CONVR

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000121      NIT = NIT - 1
000123      WRITE(6,1741) NIT,NITP
000133      WRITE(6,1742)
000137      DO 397 I=1,LAY
000144      WRITE(6,1550) I,SG(I,1),SG(I+N,1),SG(I+2*N,1),SG(I,1),SG(I+N,1),
1          SG(I+2*N,1),DIF(I),DIF(I+N),DIF(I+2*N)
000241      397 CONTINUE
000247      IRTN=3
000250      RETURN
000250      400 IRTN=2
000251      500 RETURN
C
000252      1550 FORMAT (I4,I1X,2(3E13.5,4X),3E13.5)
000252      1720 FORMAT (* SOLUTION FOR STRESS DOES NOT CONVERGE*)
000252      1722 FORMAT (* RELATIVE ERROR .GI.,E15.5)
000252      1730 FORMAT (* SOLUTION FOR STRESS DIVERGES*)
000252      1741 FORMAT (/18X,*ITERATION *,I3,*,*28X,*ITERATION *,I3,*)
000252      1742 FORMAT ( * LAYER*,4X,*SGM XY*,8X,*SGM Y*,8X,*SGM XY*,11X,*SGM X*,
1          AX,*SGM Y*,8X,*SGM XY*,11X,*REL X*,8X,*REL Y*,8X,
2          *REL XY*/)
000252      1      END

```

```

C SURROUTINE LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SW)
C ROUTINE LAMTST PERFORMS FAILURE ANALYSIS*, STIFFNESS TEST, ULTIMATE
C STRESS, ULTIMATE STRAIN, AND QUADRATIC INTERACTION
C
C * VARIABLE DICTIONARY *
C
C UFAIL(I) : INDICATE FAILURE UNDER SEPARATE MODES
C IFCN : FOR MULTI-MODE FAILURE ANALYSIS (I.E., IFCN=4)
C LFAIL : FAILURE ANALYSIS OPTION
C IJJ : FAILURE MODE
C KJJ : ORIENTATION OF STRESS FAILURE
C QIT(I) : ORIENTATION OF STRAIN FAILURE
C QPV(I) : QUADRATIC INTERACTION TERM FOR LAYER I
C FAC : QUADRATIC INTERACTION TERM FOR LAYER I PROV.LOAD
C IST : INTERPOLATION FACTOR
C ISV : STORE LAYER NO. AT FAILURE
C KSV : STORE STRESS ORIENTATION NO. AT FAILURE
C : STORE STRAIN ORIENTATION NO. AT FAILURE
C
C *****
C DIMENSION SG(60,1),SGS(60)
C DIMENSION EPS11(20),FPS22(20),EPS12(20)
C DIMENSION P11(20),P22(20),P12(20),
C 1 ULT(6,2),ULTIMA(6,2,20),
C 1 EP11(20),EP22(20),EP12(20)
C DIMENSION QIT(20),QPV(20)
C DIMENSION A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
C DIMENSION EPN(60,1),PS(60)
C INTEGER UFAIL(3),SW,T
C
C COMMON /SET03/EP11,EP22,EP12
C COMMON /SET04/ S011,S022,S012,SM11,SM22,SM12
C COMMON /SET05/ ULTIMA,STIFF
C COMMON /SET07/EP11,EP22,EP12
C COMMON /SET14/ A11,A22,A44,A12,B1,B2
C
C EVALUATE QUADRATIC INTERACTION COEFFICIENTS IF QUAD. INTER. FAILURE
C IF((IFCN.EQ.3).OR.(IFCN.EQ.4)) CALL QUADCF(LAY)
C IST = 1
C LFAIL = 0
C IPT = 1
C
C 500 CONTINUE
C NO 475 J=IST,LAY
C T = 1
C
C NO 550 II=1,6
C NO 550 JJ=1,2
C ULT(II,JJ) = ULTIMA(II,JJ,I)
C 550 CONTINUE
C
C TEST 1: STIFFNESS TEST

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```

000054 IF(KSG,EQ,1) GO TO 560
000060 IF(S011,EQ,0.0E0) GO TO 560
000061 RATIO = ABS(SW11/EP11(I))-FPS11(I))
000065 IF(RATIO,LT,STIFF) GO TO 677
TEST 2: ULTIMATE STRESS
C      ULT(1,1): MAX. AXIAL TENS.
C      ULT(2,1): MAX. TRAN. TENS.
C      ULT(3,1): MAX. SHEAR
560 CONTINUE
IF(.NOT.((IFCN,EQ,1).OR.(IFCN,EQ,4))) GO TO 570
IF(UFAIL(1),EQ,1).AND.(IFCN,EQ,4)) GO TO 570
IJJ=1
IF(SG(I,1)-0.0) 1,1,2
1 IF(ABS(SG(I,1))-ULT(1,2))3,679,679
2 IF(ABS(SG(I,1))-ULT(1,1))3,679,679
3 K= I+LAY
IJJ=2
IF(SG(K,1)-0.0)4,4,5
4 IF(ABS(SG(K,1))-ULT(2,2))6,679,679
5 IF(SG(K,1))-ULT(2,1))6,679,679
6 K= I+2*LAY
IJJ=3
IF(ABS(SG(K,1))-ULT(3,1))570,679,679
C
TEST 3: ULTIMATE STRAIN
C      ULT(4,1): MAX. AXIAL TENS.
C      ULT(5,1): MAX. TRAN. TENS.
C      ULT(6,1): MAX. SHEAR
570 CONTINUE
IF(.NOT.((IFCN,EQ,2).OR.(IFCN,EQ,4))) GO TO 580
IF(UFAIL(2),EQ,1).AND.(IFCN,EQ,4)) GO TO 580
KJJ=1
IF(EPN(I,1)-0.0) 71,71,72
71 IF(ABS(EPN(I,1))-ULT(4,2))73,689,689
72 IF(ABS(EPN(I,1))-ULT(4,1))73,689,689
73 CONTINUE
K= I+LAY
KJJ=2
IF(EPN(K,1)-0.0) 74,74,75
74 IF(ABS(EPN(K,1))-ULT(5,2))76,689,689
75 IF(EPN(K,1))-ULT(5,1))76,689,689
76 CONTINUE
K= I+2*LAY
KJJ=3
IF(ABS(EPN(K,1))-ULT(6,1))580,689,689
C
TEST 4: QUADRATIC INTERACTION
C
580 CONTINUE
IF(.NOT.((IFCN,EQ,3).OR.(IFCN,EQ,4))) GO TO 590
IF(UFAIL(3),EQ,1).AND.(IFCN,EQ,4)) GO TO 675
GIT(I) = A11(I)*SG(I,1)**2 + A22(I)*SG(I+LAY,1)**2
1      +A44(I)*SG(I+2*LAY,1)**2 + A12(I)*SG(I,1)*SG(I+LAY,1)
2      +A1(I)*SG(I,1) + A2(I)*SG(I+LAY,1)
IF( GIT(I) .GT.1.0) GO TO 699

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000316 C 590 CONTINUE
000317 C
000318 675 CONTINUE
000319 IF (LFAIL.NE.0) GO TO R10
000320 WRITE(6,1995)
000321 RETURN
000322
000323 C SET INDICATOR OF FAILURE MODE
000324 C
000325 677 LFAIL = 1
000326 KSG = KSGM
000327 GO TO 700
000328 679 LFAIL = 2
000329 IST = T
000330 GO TO 700
000331 689 LFAIL = 3
000332 IST = T
000333 GO TO 700
000334 699 LFAIL = 4
000335 IST = T
000336 QPV(T) = A11(T)*SGS(T) **2 + A22(T)*SGS(T+LAY) **2
000337 * +A44(T)*SGS(T+2*LAY) **2 + A12(T)*SGS(T) *SGS(T+LAY)
000338 * +B1(T)*SGS(T) + B2(T)*SGS(T+LAY)
000339
000340 C PRINT FAILURE MODE
000341 C
000342 700 CONTINUE
000343 IF(IPT.EQ.1) WRITE(6,1990)
000344 IPT = 0
000345 IF(IFCN.NE.4) KSG=KSGM
000346 GO TO (701,703,723,743), LFAIL
000347 701 WRITE(6,1450)
000348 GO TO R50
000349 703 CONTINUE
000350 ISV = IJJ
000351 GO TO(704,705,706),IJJ
000352 704 WRITE(6,1452)
000353 GO TO 799
000354 705 WRITE(6,1453)
000355 GO TO 799
000356 706 WRITE(6,1454)
000357 GO TO 799
000358
000359 C 723 CONTINUE
000360 KSV = KJJ
000361 GO TO (724,725,726), KJJ
000362 724 WRITE(6,1462)
000363 GO TO 799
000364 725 WRITE(6,1463)
000365 GO TO 799
000366 726 WRITE(6,1464)
000367 GO TO 799
000368
000369 C 743 WRITE(6,1472) QIT(T),I,QPV(T),T
000370 C 799 CONTINUE
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LAMTST

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000554 IF(IFCN.NE.4) GO TO 850
000562 LFM = LFAIL-1
000564 UFAIL(LFM) = 1
000566 IF((UFAIL(1).EQ.1).AND.(UFAIL(2).EQ.1).AND.(UFAIL(3).EQ.1))
      1 KSG = KSGM
      GO TO 500
000605 R10 CONTINUE
000606 IF (KSG.EQ.1) GO TO 850
000610 SW = 1
000611 IF( LFAIL.EQ.2 ) FAC = SINT(SG,SGS,ISV,1,IST,LAY)
000624 IF( LFAIL.EQ.3 ) FAC = SINT(EPN,PS,KSV,2,IST,LAY)
000637 IF( LFAIL.EQ.4 ) FAC = (1.0-QPV(IST))/(QIT(IST)-QPV(IST))
000646 850 WRITE(6,1495)

C
000652 1450 FORMAT (//* LAMINATE HAS FAILED* STIFFNESS TEST FAILURE*)
000652 1452 FORMAT (//* LAMINATE HAS FAILED* SG 11 EXCEEDS MAXIMUM*)
000652 1453 FORMAT (//* LAMINATE HAS FAILED* SG 22 EXCEEDS MAXIMUM*)
000652 1454 FORMAT (//* LAMINATE HAS FAILED* SG 12 EXCEEDS MAXIMUM*)
000652 1462 FORMAT (//* LAMINATE HAS FAILED* EP 11 EXCEEDS MAXIMUM*)
000652 1463 FORMAT (//* LAMINATE HAS FAILED* EP 22 EXCEEDS MAXIMUM*)
000652 1464 FORMAT (//* LAMINATE HAS FAILED* EP 12 EXCEEDS MAXIMUM*)
000652 1472 FORMAT (//* LAMINATE HAS FAILED* QUADRATIC INTERACTION*)
      * FAILURE*/27X,*QUADRATIC = *F7.4** FOR LAYER *,I2/
      27X,*QUADRATIC = *F7.4** FOR LAYER *,I2*
      *
      * OF PREVIOUS LOAD*)
000652 1495 FORMAT (/* AT FIRST POST-FAILURE LOAD POINT*)
000652 1990 FORMAT (////)
000652 1995 FORMAT (1H0)

C
000652 RETURN
000653 END

```

```

SUBROUTINE QUADCF(LAY)
C
C   COMPUTES QUADRATIC FAILURE CRITERIA COEFFICIENTS
C
000003   DIMENSION      ULTIMA(6,2,20)
000003   DIMENSION      A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
000003   COMMON        /SET05/ ULTIMA,STIFF
000003   COMMON        /SET14/ A11,A22,A44,A12,B1,B2
C
000003   DO 100 IMTALY=1,LAY
000005   A11(IMTALY) = 1./ULTIMA(1,1,IMTALY)*ULTIMA(1,2,IMTALY))
000013   A22(IMTALY) = 1./ULTIMA(2,1,IMTALY)*ULTIMA(2,2,IMTALY))
000017   A44(IMTALY) = (1./ULTIMA(3,1,IMTALY))*2
000023   B1(IMTALY) = 1./ULTIMA(1,1,IMTALY) - 1./ULTIMA(1,2,IMTALY)
000027   B2(IMTALY) = 1./ULTIMA(2,1,IMTALY) - 1./ULTIMA(2,2,IMTALY)
000034   100 CONTINUE
C
000037   RETURN
000037   END

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```

000012 SUBROUTINE LAYSUB (A12,STY,SCY,TY,EP511,EP522,EP512)
000012 DIMENSION E11(20),E22(20),V12(20),V21(20),G12(20),A12(20),
000012 1 STY(20),SCY(20),TY(20),EP511(20),EP522(20),EP512(20)
000012 DIMENSION TEL1(20),TE22(20),TG12(20),TV12(20),TA12(20),TSTY(20),
000012 1 TSCY(20),TTY(20)
000012 COMMON /SET01/ E11,E22,V12,V21,G12
000012 COMMON /SET17/ TEL1,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
000012 DO 10 I = 1,20
000012 E11(I) = TEL1(I)
000013 E22(I) = TE22(I)
000015 G12(I) = TG12(I)
000017 V12(I) = TV12(I)
000021 V12(I) = TA12(I)
000023 STY(I) = TSTY(I)
000025 SCY(I) = TSCY(I)
000027 10 TY(I) = TTY(I)
000031 RETURN
000035 END
000036

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REAL FUNCTION SINT(VAL,PREV,IOR,SS,I,N)
      FUNCTION: SUBPROGRAM SINT DETERMINES INTERPOLATION FACTOR FOR
      STRES OR STRAIN FAILURE
      * VARIABLE DICTIONARY *
      VAL(I,1)      : VALUE OF STRESS OR STRAIN AFTER FAILURE
      PREV(I)       : VALUE OF STRESS OR STRAIN BEFORE FAILURE
      FLEMT         : ELEMENT OF STRESS OR STRAIN ARRAY WHICH HAS FAIL
      SINT          : INTERPOLATION FACTOR
      *****
      DIMENSION      VAL(60,1),PREV(60),ULT(6,2,20)
      COMMON /SET05/ ULT,STIFF
      INTEGER        SS,ELEMT
      *****
      IF (SS.EQ.1)   IOS=IOR
      IF (SS.EQ.2)   IOS=IOR+3
      FLEMT = (IOR-1)*N + I
      ISN=2
      IF (VAL(FLEMT,1).GT.0.00) ISN=1
      NPRV = ABS(PREV(ELEMT))
      DDIF = ABS(VAL(ELEMT,1)-PREV(ELEMT))
      SINT = (ULT(IOS,ISN,1)-DPRV)/DDIF
      *****
      RETURN
      END

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REFERENCES

- (1) Z. Hashin, D. Bagchi and B. W. Rosen, "Non-Linear Behaviour of Fiber Composite Laminates", NASA CR-2313, 1973.
- (2) Z. Hashin and B. W. Rosen, "the Elastic Moduli of Fiber Reinforced Materials", J. Applied Mechanics, Vol. 31, p. 223, 1964.
- (3) B. W. Rosen and Z. Hashin, "Effective Thermal Expansion Coefficients and Specific Heats of Composite Materials", Int. J. Engineering Science, Vol. 8, p. 157, 1970.