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NOLIN - A NONLINEAR LAMINATE ANALYSIS PROGRAM

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16. Abstract

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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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TABLE OF CONTENTS

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 in-plane 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 envoked. 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.

1.2 Derivation of Governing Equations

In the usual, plane-stress, linear, laminate analysis, the laminae stress-strain relationships are first written with respect to the longitudinal and transverse fiber directions. These laminae relationships are then transformed to a common set of laminate axes and the laminate constitutive relationships are then developed by enforcing strain compatibility. In this nonlinear laminate analysis an entirely analogous procedure is followed. The laminae nonlinear, stress-strain relationships are first written for the N lamina with reference to their respective natural axes, and then transformed to a common set of laminate axes. Enforcement of compatibility between adjacent laminae as well as equilibrium at the laminate boundaries leads to the governing, nonlinear equations.

Let the strains be separable into linear and nonlinear parts,

$$
\begin{aligned}
\varepsilon_{LL} &= \varepsilon'_{LL} + \varepsilon''_{LL} \\
\varepsilon_{TT} &= \varepsilon'_{TT} + \varepsilon''_{TT} \\
\varepsilon_{LT} &= \varepsilon'_{LT} + \varepsilon''_{LT}
\end{aligned}
\tag{1}
$$

Where primes designate the linear parts and the double primes designate the nonlinear parts, and the subscripts L and T refer to the longitudinal and transverse directions, respectively. The linear parts of the strain components are related to the stress components by the usual orthotropic, plane-stress elasticity constitutive relationship,

$$
\begin{aligned}
\varepsilon_{LL} &= \frac{1}{E_L}\,\sigma_{LL} + \frac{\nu_{LT}}{E_L}\,\sigma_{TT} \\
\varepsilon'_{TT} &= \frac{\nu_{LT}}{E_{TT}}\,\sigma_{LL} + \frac{1}{E_{TT}}\,\sigma_{TT} \\
\varepsilon'_{LT} &= \frac{1}{2G_{LT}}\,\sigma_{LT}
\end{aligned}
\tag{2}
$$

For the uniaxial stress states of transverse extension and inplane shear, the nonlinear parts of the strain components are related to the stress components by the relationships,

$$\varepsilon_{TT}'' = \frac{\sigma_{TT}}{E_T}\left(\frac{\sigma_{TT}}{f_1}\right)^{n-1}$$
$$\varepsilon_{LT}'' = \frac{\sigma_{LT}}{2G_{LT}}\left(\frac{\sigma_{LT}}{f_2}\right)^{n-1} \tag{3}$$

Where the values of n, m, f_1 and f_2 are obtained from curve fitting unidirectional, experimental data. It is assumed that in the longitudinal direction, the nonlinear part of the strain component is zero.

$$\varepsilon_{LL}'' = 0 \tag{4}$$

The relationships between the nonlinear parts of the strain components and the stress components for cases of combined transverse-extension and inplane-shear stresses are determined by using a generalization of J_2 theory in addition to the requirement that these relationships reduce to equations (3) for uniaxial states of stress. The resulting equations are,

$$\varepsilon_{TT}'' = \frac{\sigma_{TT}}{E_T}\left[\left(\frac{\sigma_{TT}}{f_1}\right)^2 + \left(\frac{\sigma_{LT}}{f_2}\right)^2\right]^{\frac{n-1}{2}}$$
$$\varepsilon_{LT}'' = \frac{\sigma_{LT}}{2G_{LT}}\left[\left(\frac{\sigma_{TT}}{f_1}\right)^2 + \left(\frac{\sigma_{LT}}{f_2}\right)^2\right]^{\frac{m-1}{2}} \tag{5}$$

Equations (2) and (5) comprise the total, nonlinear, stress-strain relationship for the laminae.

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,

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

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,

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

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

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,

$$F_k\ (\sigma_1,\ \sigma_2,\ \ldots,\ \sigma_1{}^2,\ \ldots) = 0 \qquad (8)$$
$$k = 1, 2, \ldots, 3N$$

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, $\overset{\circ}{\sigma}_j$. Considering only the first order terms of these series,

$$F_k = F_k^\circ + \left(\frac{\partial F_k}{\partial \sigma_j}\right)\Bigg|_{\sigma_j^\circ} \cdot \Delta\,\sigma_j \qquad (9)$$
$$j, k = 1, 2, \ldots, 3N$$

By writing,

$$\Delta\,\sigma_j = \sigma_j - \sigma_j^\circ$$

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

$$\sigma_j = \sigma_j^\circ - \left(\frac{\partial F_k}{\partial \sigma_j}\right) \cdot F_k^\circ \qquad (10)$$
$$j, k = 1, 2, \ldots, 3N$$

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

$$\sigma_j = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \cdot \\ \cdot \\ \cdot \\ \sigma_N \end{bmatrix} \qquad (11)$$

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

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

and,

$$\left(\frac{\partial F_k}{\partial \sigma_j}\right)\hat{}\,\sigma_j^\circ = \left| \begin{matrix} \dfrac{\partial F_1}{\partial \sigma_1} & \dfrac{\partial F_1}{\partial \sigma_2} & \cdots \\ \dfrac{\partial F_2}{\partial \sigma_1} & \dfrac{\partial F_2}{\partial \sigma_2} & \cdots \\ \cdot & & \\ \cdot & & \\ \cdot & & \end{matrix} \right|_{\sigma_j = \sigma_j^\circ} \tag{14}$$

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,

$$[A] \cdot \overline{SG} + \overline{B} = \overline{SGO} \tag{15}$$

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

$$[A] \cdot \overline{SG} = \overline{SGO} \tag{16}$$

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

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

The vector $\overline{DC}$ corresponds to the vector F_f° 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 $(\partial F_k / \partial \sigma_j)\ \sigma_j^\circ$ 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:

$$(SG_{i+1})_{INITIAL} = (SG_i)_{FINAL} * (FACTOR)$$
$$(FACTOR) = \frac{i\ (i-2)}{(i-1)^2} \quad \frac{(SG_i)_{FINAL} - (SG_{i-1})_{FINAL}}{(SG_i)_{FINAL}} \tag{18}$$

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

$$\left|(SG_{i+1} - SG_i)/SG_i\right| \leq \varepsilon$$
$$\left|(SG_{i+1} - SG_i)/SG_i\right| < \lambda \tag{19}$$

Where SG_i and SG_{i+1} are the solution vectors obtained from the i^{th} and $i+1^{th}$ 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

$$A_{11}\,\sigma_{LL}^{2} + A_{22}\,\sigma_{TT}^{2} + A_{44}\,\sigma_{LT}^{2} + A_{12}\,\sigma_{LL}\,\sigma_{TT} + B_{1}\,\sigma_{LL} + B_{2}\,\sigma_{TT} = 1 \tag{20}$$

where the coefficients are functions of the allowable stress

$$A_{11} = \frac{1}{F_L^T F_L^c} \qquad B_{11} = \frac{1}{F_L^T} - \frac{1}{F_L^c}$$

$$A_{22} = \frac{1}{F_T^T F_T^c} \qquad B_{22} = \frac{1}{F_T^T} - \frac{1}{F_T^c} \tag{21}$$

$$A_{44} = \frac{1}{(F^s)^2}$$

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.

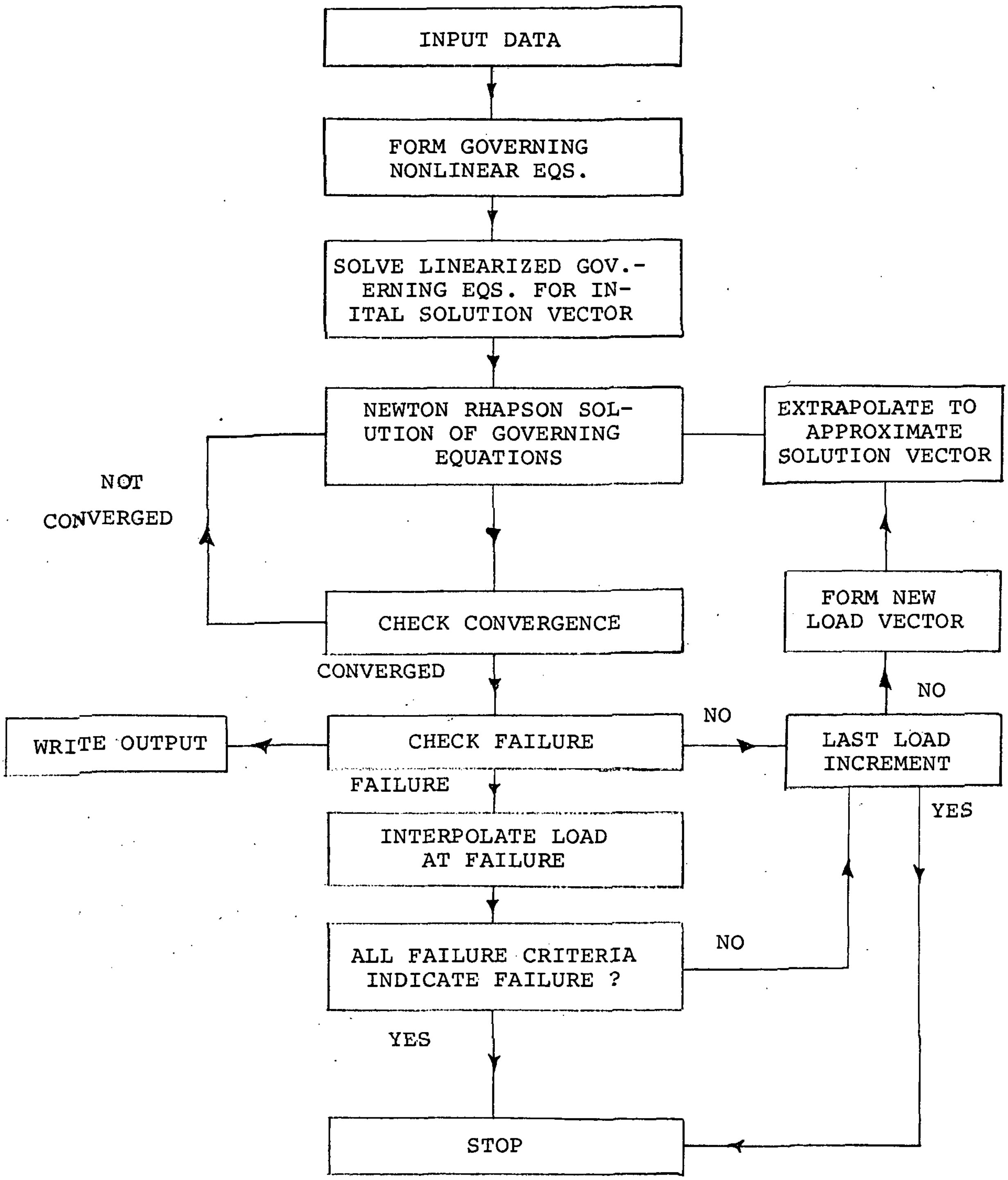

Figure 1 - Solution flow Chart

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 exectuion. 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 incrememts, 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).

<u>Stress-Strain Data (input in IOPT=2)</u>

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 x NM x NVM materials formed from the input. Within a given run the total number of materials (NFxNMxNVM) 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 mdoulus 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 mdoulus (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

 $DATAONE
 NF=1,   NM=2,   NV=2,
 EFA(1)=3.8E+05,    EFT(1)=7.23E+03,    GFA(1)=[illegible].38E+04,
 ANUFA(1)=0.1,    ANUFT(1)=0.1,
 RHOF(1)=1.,
 EM(1)=1.7E+04,  3.4E+04,
 ANUM(1)=2*0.2,
 RHOM(1)=2*1.,
 VM(1)=0.4,0.6,
 ROMS(1)=2*3.0,
 ALPF(1)=5.E-07,
 ALPFT(1)=3.0E-06,
 ALPM(1)=2*1.4E-05$
 $DATAONE
 NF=1,    NM=10,   NV=1,
 EFA(1)=1.3E+05,    ANUFA(1)=0.2,    RHOF(1)=1.,
 EFT(1)=9.78E+03,    ANUFT(1)=0.2,    GFA(1)=1.27E+03,
 EM(1)=.5E+03, 1.E+03,  1.5E+03,  2.E+03,  2.5E+03,  3.E+03,
        3.5E+03,  4.E+03,  4.5E+03,  5.E+03,
 ANUM(1)=10*0.2,  RHOM(1)=10*1.,
 VM(1)=0.4,
 ALPF(1)= -6.1E-07,   ALPFT(1)=3.83E-06,
 ALPM(1)=10*1.39E-05$
```

4.1.3 UNI SAMPLE PROBLEM OUTPUT NO. 1

FIBER NO.	E(F)	NU(F)	G(F)	K(F)	RHO(F)	ALPHA(F)
1	3.80000E+05	.10000	13800	4018.4	1.0000	5.00000E-07
1	7230.0	.10000	3286.4	4018.4	1.0000	3.60000E-06

MATRIX NO.	E(M)	NU(M)	G(M)	K(M)	RHO(M)	ALPHA(M)
1	17000	.20000	7083.3	11806	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 THERMOELASTIC 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	2.34833E+05	.15351	10471	6210.6	5.23229E-07
				10393	.16120	4475.1	1.00000	2.51547E-06
				R-O PARAMETER =	3.11794E+00			
1	1	2	.60000	1.62230E+05	.17215	9175.0	7667.0	5.52901E-07
				12382	.18709	5211.3	1.0000	2.13356E-06
				R-O PARAMETER =	2.96561E+00			
1	2	3	.40000	2.41649E+05	.16535	13946	8778.4	5.46548E-07
				14403	.17125	6186.8	1.00000	2.27233E-06
				R-O PARAMETER =	3.11794E+00			
1	2	4	.60000	1.72441E+05	.18093	14019	12234	6.01723E-07
				19563	.19299	8199.3	1.0000	1.94690E-06
				R-O PARAMETER =	2.96561E+00			

PROBLEM NO. 2 OUTPUT

FIBER NO.	E(F)	NU(F)	G(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	6158.6	1.0000	1.83000E-06

MATRIX NO.	E(M)	NU(M)	G(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	3.0000
2	3.0000
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 1596.5	.20000 .21564	5[illegible]8,35 656,64	1019,8 1,00000	-5,72890E-09 6,33022E-06
				R-O PARAMETER =	3,11794E+00			
1	2	2	.40000	78400 2803,9	.20000 .21802	748,63 1151,0	1799,4 1,00000	-5,35969E-07 6,42491E-06
				R-O 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-O 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-O 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-O 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-O 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-O 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-O 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-O 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-O PARAMETER =	0.			

++++++++++++++++++++++++ PROGRAM 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 $\pm 30°$ 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, ± 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.

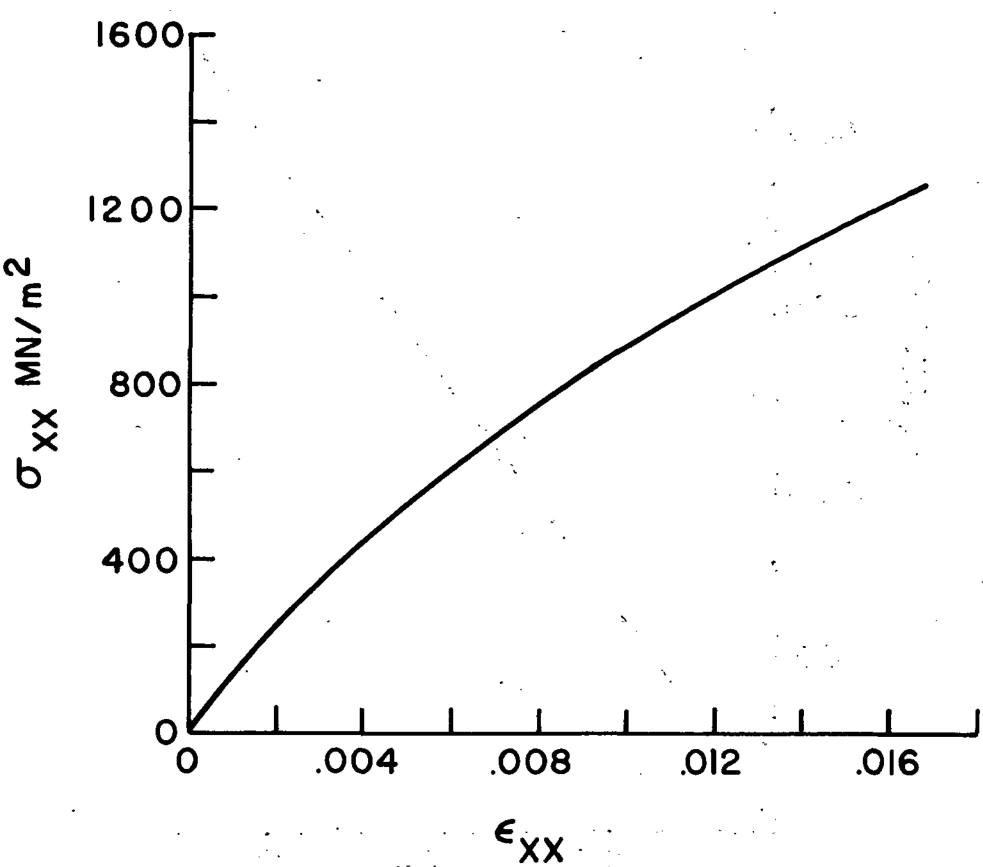

Figure 2 - +30° Boron/Aluminum Laminate - Axial Stress-Strain Behavior.

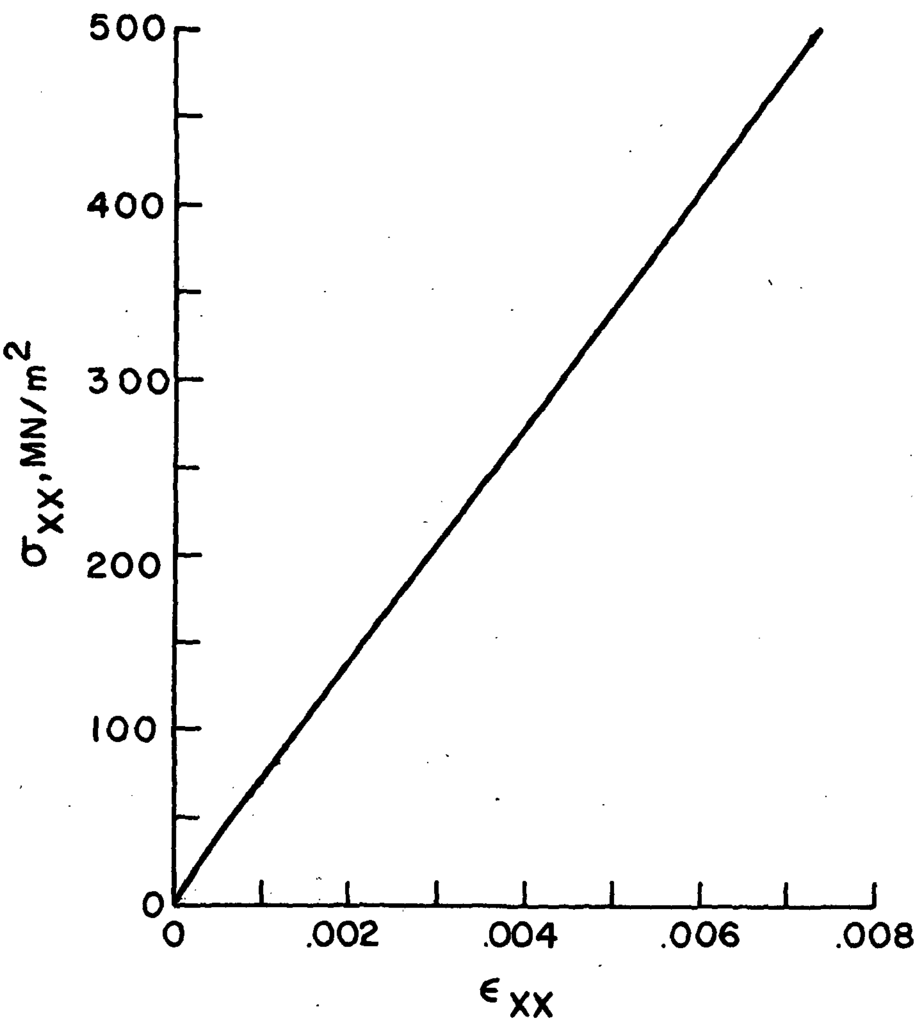

Figure 3 - Axial Stress-Strain Response of [0+45] Graphite-Epoxy Laminate under Axial and Shear Loading.

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-03,5.2E-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,
S011=+5.0E+00,S022=-2.5E+00,S012=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$
$DATA
NLAY=2,
E11(1)=2*2.20E+05,
E22(1)=2*1.24E+05,
V12(1)=2*0.01E+00,
G12(1)=2*2.60E+04,
THICK(1)=2*0.50,
THETA(1)=30.0,-30.0,,
IOPT=1,
STY(1)=2*1109.E+00,
SCY(1)=2*1467.E+00,
TY(1)=2*93.0E+00,
XM=3.00,XN=3.00,
S011=50.,
S022=0.,
S012=0.,
IFCN=2,
S11T(1)=1100.0,S22T(1)=103.0,S12(1)=93.0,EP11T(1)=0.7E-02,
EP22T(1)=2.0E-02,GAMA(1)=3.0E-02,S11C(1)=1480.0,S22C(1)=160.,
EP11C(1)=0.7E-02,EP22C(1)=0.02,
STIFF=0.100,
KSGM=48,SMLT=4$
```

4.2.3 NOLIN SAMPLE OUTPUT

```
+++++++++++++++++++++++++++++++++++++++++
+                                       +
+                                       +
+              NONLINEAR                +
+                                       +
+       THERMOELASTIC ANALYSIS          +
+                                       +
+                 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
                                     ************

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   5.68000E-02

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

  1     45.00   2.5000E-01    1.9820E+05  1.9000E+04  2.5500E-01  2.4445E-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  2.4445E-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  2.4445E-02  5.7700E+03  2.1069E+00  2.1069E+00  6.5456E+01

EQUATION  PARAMETERS

   EXPONENT M =  2.74596E+00
   EXPONENT N =  1.47386E+00

                                     EXTERNALLY APPLIED STRESS
                                     **************************

                 INITIAL               STRESS                                    NO. OF
                  STRESS               INCREMENT                               INCREMENTS

      SG XX     5.00000E+00          1.50000E+01                                   50
      SG YY    -2.50000E+00         -7.50000E+00
      SG XY     0.                   0.

                                     LAMINA FAILURE CRITERIA
```

```
                         **********************
                         ALL FAILURE CRITERIA

LAYER                LL                        TT                         LT

         ULT. STRESS
         ULT. STRAIN

         NOTE:  ALL STRAINS ARE ENGINEERING COMPONENTS

  1    TENS.       1.32000E+03           7.16000E+01            1.05000E+02
       COMP.       2.43000E+03           2.75000E+02            1.05000E+02

  1    TENS.       6.68000E-03           3.77000E-03            1.82700E-02
       COMP.       1.22700E-02           1.45000E-02            1.82700E-02

  2    TENS.       1.32000E+03           7.16000E+01            1.05000E+02
       COMP.       2.43000E+03           2.75000E+02            1.05000E+02

  2    TENS.       6.68000E-03           3.77000E-03            1.82700E-02
       COMP.       1.22700E-02           1.45000E-02            1.82700E-02

  3    TENS.       1.32000E+03           7.16000E+01            1.05000E+02
       COMP.       2.43000E+03           2.75000E+02            1.05000E+02

  3    TENS.       6.68000E-03           3.77000E-03            1.82700E-02
       COMP.       1.22700E-02           1.45000E-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)
                    **********************************

                      EXX  =    1.11891E+05
                      EYY  =    3.49664E+04
                      VYX  =    6.85439E-01
                      VXY  =    2.14203E-01
                      GXY  =    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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	6.18452E-05	-1.15644E-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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	2.45162E-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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-4.87608E+01	-2.72327E+00	-3.22333E+00	4.74559E-04	-9.59587E-04	-2.64055E-12	-2.42514E-04	-2.42514E-04	-7.17073E-04
2	9.75187E+01	-6.03463E+00	0.	4.74559E-04	-9.59587E-04	0.	4.74559E-04	-9.59587E-04	0.
3	-4.87608E+01	-2.72327E+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   2  ITERATIONS

                    STRESS                                    STRAIN                                        STRAIN
                 (LAYER AXES)                             (LAMINATE AXES)                               (LAYER AXES)
LAYER    SG 11        SG 22        SG 12           EP XX        EP YY        EP XY            EP 11        EP 22        EP 12

  1  -7.33712E+01 -3.76905E+00 -3.24695E+00     6.93289E-04 -1.42397E-03 -3.78710E-12    -3.65339E-04 -3.65339E-04 -1.05863E-03
  2   1.45323E+02 -8.18288E+00  0.              6.93289E-04 -1.42397E-03  0.              6.93289E-04 -1.42397E-03  0.
  3  -7.33712E+01 -3.76905E+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

                    STRESS                                    STRAIN                                        STRAIN
                 (LAYER AXES)                             (LAMINATE AXES)                               (LAYER AXES)
LAYER    SG 11        SG 22        SG 12           EP XX        EP YY        EP XY            EP 11        EP 22        EP 12

  1  -9.85741E+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  -9.85741E+01 -4.75320E+00  3.15387E+00     9.13765E-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

                    STRESS                                    STRAIN                                        STRAIN
                 (LAYER AXES)                             (LAMINATE AXES)                               (LAYER AXES)
LAYER    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.
⋮

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	2.76845E-12	-3.55216E-03	-3.55216E-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	6.02585E-03	-1.31302E-02	2.75785E-12	-3.55216E-03	-3.55216E-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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.36579E+02	-2.18573E+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	-4.38833E+01	0.	6.24879E-03	-1.36252E-02	0.	6.24879E-03	-1.36252E-02	0.
3	-7.36579E+02	-2.18573E+01	1.89843E+00	6.24874E-03	-1.36252E-02	2.49188E-12	-3.68822E-03	-3.68822E-03	9.93696E-03

EXTERNAL APPLIED STRESS

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

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.63727E+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	-7.63727E+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 STRAIN

	(LAYER AXES)			(LAMINATE AXES)			(LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.90900E+02	-2.30356E+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	-7.90900E+02	-2.30356E+01	1.86007E+00	6.69462E-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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-7.89113E+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	-4.65974E+01	0.	6.68000E-03	-1.45836E-02	0.	6.68000E-03	-1.45836E-02	0.
3	-7.89113E+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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	1.35902E+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	6.91761E-03	-1.51121E-02	1.87378E-12	-4.09726E-03	-4.09726E-03	1.10149E-02

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

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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	6.71950E-03	-1.46715E-02	1.96310E-12	-3.97598E-03	-3.97598E-03	-1.06955E-02
2	1.32000E+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	-1.46714E-02	1.95735E-12	-3.97598E-03	-3.97598E-03	1.06984E-02

EXTERNAL APPLIED STRESS

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

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.45321E+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	-8.45321E+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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.72567E+02	-2.47645E+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	-8.72567E+02	-2.47645E+01	1.80851E+00	7.36367E-03	-1.61049E-02	1.57158E-12	-4.37059E-03	-4.37059E-03	1.17343E-02

LAMINATE HAS FAILED. QUADRATIC INTERACTION FAILURE
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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	-5.06245E+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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.85438E+02	-2.50327E+01	-1.80097E+00	7.46902E-03	-1.63394E-02	7.18620E-13	-4.43519E-03	-4.43519E-03	-1.19042E-02
2	1.46760E+03	-5.00457E+01	0.	7.46902E-03	-1.63394E-02	0.	7.46902E-03	-1.63394E-02	0.
3	-8.85438E+02	-2.50327E+01	1.80097E+00	7.46900E-03	-1.63394E-02	7.17842E-13	-4.43519E-03	-4.43519E-03	1.19042E-02

LAMINATE 2

NUMBER OF LAYERS = 2

LAYER	THETA	T	E11	E22	V12	V21	G12	SGT Y	SGC Y	TAUY
1	30.00	5.0000E-01	2.2000E+05	1.2400E+05	1.0000E-02	5.6364E-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	5.6364E-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

	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

ULTIMATE STRESS

LAYER		LL	TT	LT

ULT. STRAIN

NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

LAYER		LL	TT	LT
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 = 8.96343E+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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	5.37302E+01	-3.73016E+00	-1.22801E+01	3.83121E-04	-1.71772E-04	-2.69684E-13	2.44398E-04	-3.30489E-05	-2.40276E-04
2	5.37302E+01	-3.73016E+00	1.22801E+01	3.83121E-04	-1.71772E-04	-1.88746E-13	2.44398E-04	-3.30489E-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

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	2.80731E+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	2.80731E+02	-3.07313E+01	5.44261E+01	2.08896E-03	-1.15710E-03	-6.95787E-10	1.27745E-03	-3.45583E-04	1.40558E-03

EXTERNAL APPLIED STRESS

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

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	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	-1.16165E-03	-3.07947E-03
2	5.25854E+02	-7.58890E+01	8.60956E+01	4.17132E-03	-2.93969E-03	-2.85248E-07	2.39370E-03	-1.16208E-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

                  STRESS                                 STRAIN                                  STRAIN
               (LAYER AXES)                         (LAMINATE AXES)                           (LAYER AXES)

LAYER    SG 11          SG 22         SG 12          EP XX        EP YY         EP XY          EP 11        EP 22         EP 12

  1   7.80039E+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   7.80052E+02 -1.30040E+02  1.12558E+02    6.64179E-03 -5.71877E-03  1.19534E-07    3.55160E-03 -2.62858E-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

                  STRESS                                 STRAIN                                  STRAIN
               (LAYER AXES)                         (LAMINATE AXES)                           (LAYER AXES)

LAYER    SG 11          SG 22         SG 12          EP XX        EP YY         EP XY          EP 11        EP 22         EP 12

  1   1.03875E+03 -1.88653E+02 -1.36434E+02    9.53059E-03 -9.66849E-03 -1.48380E-06    4.73018E-03 -4.86807E-03 -8.31382E-03
  2   1.03865E+03 -1.88747E+02  1.36422E+02    9.52838E-03 -9.66863E-03 -1.31694E-06    4.72970E-03 -4.86995E-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

                  STRESS                                 STRAIN                                  STRAIN
               (LAYER AXES)                         (LAMINATE AXES)                           (LAYER AXES)

LAYER    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 -1.58908E+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 AXES)			(LAMINATE AXES)			(LAYER AXES)		
LAYER	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.

5.1 UNI LISTING


```
                  PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
            C
            C     UNI
            C     UNI COMPUTES UNIDIRECTIONAL FIBER BUNDLE PROPERTIES, EXPANSION
            C      COEFFICIENTS AND RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR THE
            C       UNIDIRECTIONAL FIBER BUNDLF
            C
            C     PRESENT VERSION INCLUDES:
            C      1 : TRANSVERSELY ISOTROPIC FIBER/ISOTROPIC MATRIX
            C      2 : AXIAL AND TRANSVERSE FIBER BUNDLE EXPANSION COEFFICIENTS
            C      3 : RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR THE UNIDIRECTIONAL
            C       COMPOSITE AS DERIVED FROM THE RAMBERG-OSGOOD SHEAR STRESS PARAMETER
            C        FOR THE MATRIX
            C
            C                                   * INPUT PARAMETERS *
            C
            C      NF        : NO. OF FIBERS IN COMPOSITE
            C      NM        : NO. OF MATRICES IN COMPOSITE
            C      NVM       : NO. OF MATRIX VOL. FRACTIONS
            C      EF(J)     : YOUNG#S MOD. FOR JTH FIBER
            C      EM(J)     : YOUNG#S MOD. FOR JTH MATRIX
            C      ANUF(J)   : POISSON RATIO FOR JTH FIBER
            C      ANUM(J)   : POISSON RATIO FOR JTH MATRIX
            C      RHOF(J)   : DENSITY OF JTH FIBER
            C      RHOM(J)   : DENSITY OF JTH MATRIX
            C      ALPH(J)   : COEF. OF THERMAL EXPANSION FOR JTH MATRIX
            C      VM(J)     : VOL. FRACTION FOR JTH MATRIX
            C      ROMS(J)   : SHEAR STRESS RAMBERG OSGOOD PARAMETER FOR JTH MATRIX
            C      ALPF(J)   : COEF. OF THERMAL EXPANSION FOR JTH FIBER
            C      ALPFT(J)  : TRANSVERSE THERMAL EXP. COEF. FOR JTH FIBER
            C      EFA(J)    : AXIAL YOUNG#S MOD. FOR JTH FIBER
            C      EFT(J)    : TRANSVERSE YOUNG#S MOD. FOR JTH FIBER
            C      ANUFA(J)  : AXIAL POISSON RATIO FOR JTH FIBER
            C      GFA(J)    : AXIAL SHEAR MODULUS FOR JTH FIBER
            C      ANUFT(J)  : TRANSVERSE POISSON RATION FOR JTH FIBER
            C
000003             COMMON    /AREA01/EAS(200),ETS(200),ANUAS(200),GAS(200),GTS(200),
                  1               AKTS(200),ANUTS(200)
000003             COMMON    /AREA02/L
000003             COMMON    /AREA03/RHOS(200),ALPHA(3,200)
000003             COMMON    /AREA06/EM(20),GM(20),VM(20),ANUM(20),ALPM(20),AKM(20)
000003             COMMON    /AREA07/AKF(20),ALPF(20),ALPFT(20)
000003             COMMON    /AREA10/RIGKM(20),RIGKF(20)
000003             COMMON     /AREA11/MF(200),MV(200),MM(200)
000003             COMMON    /AREA20/ROCOMP(200),ROMS(20)
000003             DIMENSION         EF(20),ANUF(20),RHOF(20),RHOM(20),GF(20)
000003             DIMENSION         SM(3,3),SF(3,3)
000003             DIMENSION      EFA(20),EFT(20),ANUFA(20),ANUFT(20),GFA(20),GFT(20)
000003             FQUIVALENCE       (EF(1),EFA(1)),(GF(1),GFA(1)),(ANUF(1),ANUFA(1))
            C
            C                                   * VARIABLE DICTIONARY *
            C
            C      CALCULATED THERMO-ELASTIC CONSTITUENT PARAMETERS
            C      GFT(J)    : TRANSVERSE SHEAR MODULUS FOR JTH FIBER
```

```
        C      GF(J)    : SHEAR MODULUS FOR JTH FIBER
        C      GM(J)    : SHEAR MODULUS FOR JTH MATRIX
        C      AKF(J)   : PLANE STRAIN BULK MODULUS FOR JTH FIBER
        C      AKM(J)   : PLANE STRAIN BULK MODULUS FOR JTH MATRIX
        C
        C      EFFECTIVE THERMOELASTIC PARAMETERS
        C      AKTS(J) : EFFECTIVE TRANS. BULK MOD. FOR JTH MATERIAL
        C      EAS(J)   : EFFECTIVE AXIAL YOUNG#S MOD. FOR JTH MATERIAL
        C      ETS(J)   : EFFECTIVE TRANS. YOUNG#S MOD. FOR JTH MATERIAL
        C      ANUAS(J): EFF. POISSON RATIO (UNIDIRECTIONAL AX. STRESS) FOR JTH MATERIAL
        C      ANUTS(J): EFF. POISSON RATIO (IN TRANSVERSE PLANE) FOR JTH MATERIAL
        C      GAS(J)   : EFF. SHEAR MOD. (IN FIBER PLANES) FOR JTH MATERIAL
        C      GTS(J)   : EFF. SHEAR MOD. (IN TRANS. PLANES) FOR JTH MATERIAL
        C      ALPAS(J): EFF. (FIBER DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
        C      ALPTS(J): EFF. (TRANS. DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
        C      RHOS(J)  : BULK DENSITY FOR JTH MATERIAL
        C      ROCOMP(J): RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR JTH MATERIAL
        C
        C                                * PROGRAMMING INFORMATION *
        C
        C      UNI MAY BE USED AS A SUBROUTINE
        C      SUBROUTINES REQUIRED    : MSUB01,MSUB02
        C
        C      ***********************************************************************
        C
        C  INITIALIZE VARIABLES TO ZERO.
000003         NAMELIST/DATAONE/NF,NM,NVM,EF,ANUF,RHOF,EFA,ANUFA,GFA,EFT,ANUFT,
              1EM,ANUM,RHOM,VM,ROMS,ALPF,ALPFT,ALPM
000003         DATA      EFT/20*0.0/
000003         DATA      ROMS/20*0.0/
000003         DATA      ALPM/20*0.0/
000003    171  CONTINUE
000003         READ(5,DATAONE)
000006         IF(EOF,5)172,173
000011    173  CONTINUE
000011         IF(EFT(1))1012,1012,1014
000013    1012 CONTINUE
000013         DO 3 J=1,NF
000015         IF (J.NE.1) GO TO 4                                              00018600
000017         WRITE(6,202)                                                     00018700
000022         IF(ALPM(1))5,5,6
000024       5 WRITE(6,203)                                                     00018900
000030         GO TO 4                                                          00019000
000031       6 WRITE(6,204)                                                     00019100
000035       4 GF(J) = EF(J)/((1.0+ANUF(J))*2.0)                                00019200
000042         AKF(J) = GF(J)/(1.0-2.0*ANUF(J))                                 00019300
000046         IF(ALPM(1))8,8,9
000050       8 WRITE(6,205)(J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J))               00019500
000070         GO TO 3                                                          00019600
000071       9 WRITE(6,206)(J,EF(J),ANUF(J),GF(J),AKF(J),RHOF(J),ALPF(J))       00019700
000113       3 CONTINUE                                                         00019800
000116         GO TO 1018
000116    1014 CONTINUE
000116         DO 503 J=1,NF
000120         IF (J.NE.1) GO TO 504
```

```
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.*EFA(J)*(1.-ANUFT(J))-4.*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                                                    00019900
000267         IF (J.NE.1) GO TO 11                                              00020000
000271         IF(ALPM(1))12,12,13
000272      12 WRITE(6,207)                                                      00020200
000276         GO TO 11                                                          00020300
000277      13 WRITE(6,208)                                                      00020400
000303      11 GM(J) = EM(J)/((1.0+ANUM(J))*2.0)                                 00020500
000310         AKM(J) = GM(J)/(1.0-2.0*ANUM(J))                                  00020600
000314         IF(ALPM(1))14,14,15
000315      14 WRITE(6,205)(J,EM(J),ANUM(J),GM(J),AKM(J),RHOM(J))                00020800
000335         GO TO 10
000336      15 WRITE(6,206)(J,EM(J),ANUM(J),GM(J),AKM(J),RHOM(J),ALPM(J))        00021000
000360      10 CONTINUE                                                          00021100
        C
000363         IF(ROMS(1).EQ.0)GO TO 777
000364         WRITE (6,217)
000367         DO 779 J=1,NM
        C      CALCULATE THE EFFECTIVE THERMO-ELASTIC PARAMETERS                 00021300
        C                                                                        00021400
000371     779 WRITE (6,216) J,ROMS(J)
000403     777 KLINE = 49
000404         L= 0                                                              00021600
000405         DO 100 I=1,NF                                                     00021700
        C      FORM FIBER COMPLIANCE MATRIX
000407         IF(ALPM(1))910,910,911
000410     911 IF(EFT(1).EQ.0)CALL MSUB01(I,EF,EF,ANUF,ANUF,SF)
000415         IF(EFT(1).NE.0)CALL MSUB01(I,EFA,EFT,ANUFA,ANUFT,SF)
000422     910 CONTINUE
000422         DO 100 J=1,NM                                                     00021800
        C      FORM MATRIX COMPLIANCE MATRIX
000424         IF(ALPM(1))912,912,913
000425     913 CALL MSUB01(J,EM,EM,ANUM,ANUM,SM)
000431     912 CONTINUE
000431         DO 100 K=1,NVM                                                    00021900
000433         L= L+1                                                            00022000
000435         MM(L) = J
000437         MF(L) = I
000440         MV(L) = K
000441         VF = 1.0-VM(K)                                                    00022100
```

```
000443         ROCOMP(L)=ROMS(J)*SQRT(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(EFT(1))1022,1022,1026
000511   1022  CONTINUE
000511         P2 = 4.0*(ANUF(I)-ANUM(J))*(ANUF(I)-ANUM(J))*VF*VM(K)
000520         Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
000527         EAS(L) = VF*EF(I)+VM(K)*EM(J)+P2/Q2
000537         P3 = VF*VM(K)*(ANUF(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000551         Q3 = Q2
000553         ANUAS(L) = VF*ANUF(I)+VM(K)*ANUM(J)+P3/Q3
000562         P4 = VM(K)*GM(J)+(1.0+VF)*GF(I)
000571         Q4 = (1.0+VF)*GM(J)+VM(K)*GF(I)
000577         GAS(L) = GM(J)*P4/Q4
000603         GAMMA = GF(I)/GM(J)
000605         BETAM = 1.0/(3.0-4.0*ANUM(J))
000611         BETAF = 1.0/(3.0-4.0*ANUF(I))
000616         GO TO 1028
000616   1026  CONTINUE
000616         P2 = 4.0*(ANUFA(I)-ANUM(J))*(ANUFA(I)-ANUM(J))*VF*VM(K)
000625         Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
000634         EAS(L) = VF*EFA(I)+VM(K)*EM(J)+P2/Q2
000644         P3 = VF*VM(K)*(ANUFA(I)-ANUM(J))*(1.0/AKM(J)-1.0/AKF(I))
000656         Q3 = Q2
000660         ANUAS(L) = VF*ANUFA(I)+VM(K)*ANUM(J)+P3/Q3
000667         P4 = VM(K)*GM(J)+(1.0+VF)*GFA(I)
000676         Q4 = (1.0+VF)*GM(J)+VM(K)*GFA(I)
000704         GAS(L) = GM(J)*P4/Q4
000710         GAMMA = GFT(I)/GM(J)
000712         BETAM = 1.0/(3.0-4.0*ANUM(J))
000716         BETAF =  1.0/(1.0 + (2.0*GFT(I))/AKF(I))
000723   1028  CONTINUE
000723         ALEF = 1.E50
000725         IF(GAMMA.NE.1.0) ALEF = (GAMMA+BETAM)/(GAMMA-1.0)
000733         RP = GAMMA*BETAF
000735         R = (BETAM-RP)/(1.0+RP)
000741         VF3 = VF*VF*VF
000742         VM2 = VM(K)*VM(K)
000744         BETAM2 = BETAM*BETAM
000746         X1 = 1.0+R*VF3
000751         X2 = 3.0*VF*VM2*BETAM2
000754         P5 = (ALEF+BETAM*VF)*X1-X2
000761         Q5 = (ALFF-VF)*X1-X2
000763         IF(GAMMA.EQ.1.0) GTS(L)=GM(J)
000770         IF(GAMMA.NE.1.0) GTS(L)=GM(J)*P5/Q5
000776         P6 = 4.0*AKTS(L)*GTS(L)
001001         Q6 = AKTS(L)+(1.0+4.0*AKTS(L)*ANUAS(L)*ANUAS(L)/EAS(L))*GTS(L)
001012         ETS(L) = P6/Q6
001014         ANUTS(L)= 0.5*(ETS(L)/GTS(L))-1.0
001020         IF(ALPM(1))20,20,920
001021    920  IF(EFT(1).NE.0)GO TO 921
001022         BIGKM(J) = EM(J)/(3.0*(1.0-2.0*ANUM(J)))
001030         BIGKF(I) = EF(I)/(3.0*(1.0-2.0*ANUF(I)))
001035         BARRK = VM(K)/BIGKM(J)+VF/BIGKF(I)
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RUN VERSION 2.3 --PSR LEVEL 363--                MAIN                         07/09/74
001042          ALBAR = VF*ALPF(I)+VM(K)*ALPM(J)                              00025600
001046          F1 = 0.0
001047          IF(BIGKM(J).NE.BIGKF(I)) F1 = (ALPM(J)-ALPF(I))/
               1 (1.0/BIGKM(J)-1.0/BIGKF(I))
001061          F2 = (3.0*(1.0 - 2.0* ANUAS(L)))/EAS(L)                       00025800
001067          ALPHA(1,L)= ALBAR + F1*(F2 - BARRK)                           00025900
001074          ALPHA(2,L)= ALBAR + F1*(3./(2.*AKTS(L)) - ANUAS(L)*F2 - BARRK)  00026000
001106          GO TO 20
001106      921 CONTINUE
           C
           C    FORM COMPOSITE COMPLIANCE MATRIX AND CALCULATE MATERIAL THERMAL
           C    EXPANSION COEFFICIENTS
001106          CALL MSUB02(I,J,K,VF,SF,SM)
001112       20 RHOS(L) = VM(K)*RHOM(J)+VF*RHOF(I)                            00026100
001120          KLINE = KLINE+3                                               00026200
001122          IF (KLINE.LE.48) GO TO 22                                     00026300
001124          KLINE = 0                                                     00026400
001125          WRITE(6,215)                                                  00026500
001130          IF(ALPM(1))23,23,24
001132       23 WRITE(6,209)                                                  00026700
001136          GO TO 22                                                      00026800
001137       24 WRITE(6,210)                                                  00026900
001143     22   IF(ALPM(1))25,25,26
001145       25 WRITE(6,211)I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L)        00027100
001171          WRITE(6,212)ETS(L),ANUTS(L),GTS(L),RHOS(L)                    00027200
001205          GO TO 778
001206       26 WRITE(6,213)I,J,L,VM(K),EAS(L),ANUAS(L),GAS(L),AKTS(L),ALPHA(1,L) 00027400
001235          WRITE(6,214)ETS(L),ANUTS(L),GTS(L),RHOS(L),ALPHA(2,L)         00027500
001254    778   IF(ROMS.NE.0)WRITE(6,218) ROCOMP(L)
001263      100 CONTINUE                                                      00027600
           C                                                                  00015000
001273          GO TO 171
001273    172   WRITE(6,1999)
001277          STOP
001301      200 FORMAT(18I4)                                                  00015100
001301      201 FORMAT(1P6E12.5)                                              00015200
001301      202 FORMAT(1H1///42X37HCONSTITUENT THERMO-ELASTIC PARAMETERS)     00015300
001301      203 FORMAT(///11H  FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),00015400
               111X6HRHO(F),//)                                               00015500
001301      204 FORMAT(///11H  FIBER NO.,11X4HE(F),12X5HNU(F),11X4HG(F),12X4HK(F),00015600
               111X6HRHO(F),9X8HALPHA(F)//)                                   00015700
001301      205 FORMAT(I7,7X,5G16.5)                                          00015800
001301      206 FORMAT(I7,7X,6G16.5)                                          00015900
001301      207 FORMAT(///12H  MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),     00016000
               112X4HK(M),11X6HRHO(M),//)                                     00016100
001301      208 FORMAT(///12H  MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M),     00016200
               112X4HK(M),11X6HRHO(M),9X8HALPHA(M)//)                         00016300
001301      209 FORMAT(///3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,10X6HNU(A)*00016400
               1,11X5HG(A)*,11X5HK(T)*,/42X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,    00016500
               211X4HRHO*)                                                    00016600
001301      210 FORMAT(///3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*,       00016700
               110X6HNU(A)*,11X5HG(A)*,           11X5HK(T)*,9X9HALPHA(A)*,/  00016800
               242X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,11X4HRHO*,10X9HALPHA(T)*)   00016900
001301      211 FORMAT(/2I4,I7,G15.5,4X,4G16.5)                               00017000
001301      212 FORMAT(34X,4G16.5)                                            00017100
```

```
001301      213 FORMAT(/2I4,I7,G15.5,4X,5G16.5)                              00017200
001301      214 FORMAT(34X,5G16.5)                                           00017300
001301      215 FORMAT(1H1///42X35HEFFECTIVE THERMO-ELASTIC PARAMETERS)      00017400
001301      216 FORMAT(I7,7X,G16.5)
001301      217 FORMAT(///12H  MATRIX NO.,8X,8HR-O-S(M)//)
001301      218 FORMAT(/,38X,16H R-O PARAMETER =,1E16.5)
001301     1999 FORMAT(///*++++++++++++++++++++++++   PROGRAM TERMINATED   ++++
              1++++++++++++++++++++*)
          C
001301          END                                                          00028100
```

```
                SUBROUTINE MSUB01(I,A,B,C,D,VAR)
          C
          C     ROUTINE MSUB01 FORMS COMPLIANCE MATRIX FOR CONSTITUENTS
          C
          C                                 * VARIABLE DICTIONARY *
          C
          C     A(I)          : LONGITUDINAL MODULUS FOR ITH FIBER/MATRIX
          C     B(I)          : TRANSVERSE MODULUS FOR ITH FIBER/MATRIX
          C     C(I)          : LONGITUDINAL POISSON RATIO FOR ITH FIBER/MATRIX
          C     D(I)          : TRANSVERSE POISSON RATION FOR ITH FIBER/MATRIX
          C     VAR(J,K)      : COMPLIANCE MATRIX
          C
          C                                 * PROGRAMMING INFORMATION *
          C
          C     MSUB01 IS CALLED FROM  : UNI
          C
          C     ***********************************************************************
          C
000011          DIMENSION       A(20),B(20),C(20),D(20),VAR(3,3)
000011          VAR(1,1) = 1./A(I)
000013          VAR(2,2) = 1./B(I)
000015          VAR(3,3) = VAR(2,2)
000017          VAR(1,2) = -C(I)/A(I)
000022          VAR(1,3) = VAR(1,2)
000023          VAR(2,3) = -D(I)/B(I)
          C
000026          RETURN
000027          END
```

RUN VERSION 2.3 --PSR LEVEL 363--   07/09/74

```
                 SUBROUTINE MSUB02(I,J,K,VF,SF,SM)
           C
           C     ROUTINE MSUB02 FORMS COMPOSITE COMPLIANCE MATRIX FOR FIBER BUNDLES
           C     DEFINED IN ROUTINE UNI    AND CALCULATES MATERIAL THERMAL
           C     EXPANSION COEFFICIENTS FOR TRANSVERSELY ISOTROPIC FIBER
           C
           C                                     * VARIABLE DICTIONARY *
           C
           C
           C                                     * PROGRAMMING INFORMATION *
           C
           C     MSUB02 IS CALLED FROM  : UNI
           C
000011           COMMON   /AREA01/EAS(200),ETS(200),ANUAS(200),GAS(200),GTS(200),
                1              AKTS(200),ANUTS(200)
000011           COMMON   /AREA02/L
000011           COMMON   /AREA03/RHO(200),ALPHA(3,200)
000011           COMMON   /AREA06/EM(20),GM(20),VM(20),ANUM(20),ALPM(20),AKM(20)
000011           COMMON   /AREA07/AKF(20),ALPF(20),ALPFT(20)
000011           COMMON   /AREA10/BIGKM(20),BIGKF(20)
000011           COMMON    /AREA11/MF(200),MV(200),MM(200)
000011           DIMENSION       SF(3,3),SM(3,3),SC(3,3,200)
000011           DIMENSION       SV(3,3),S(3,3),SD(3,3),ABAR(2)
           C
           C     ************************************************************************
           C
           C     CALCULATE ALPHA FOR ANISOTROPIC FIBER CASE
000011           SC(1,1,L) = 1./EAS(L)
000014           SC(2,2,L) = 1./ETS(L)
000017           SC(3,3,L) = SC(2,2,L)
000023           SC(1,2,L) = -ANUAS(L)/EAS(L)
000026           SC(1,3,L) = SC(1,2,L)
000031           SC(2,3,L) = -ANUTS(L)/ETS(L)
           C
000034           EXP1 = SC(1,1,L) - SM(1,1)
000036           EXP2 = SF(2,2)   + SF(2,3)    - SM(2,2)   - SM(2,3)
000043           EXP3 = SM(1,2)   - SC(1,2,L)
000046           EXP4 = SF(1,2)   - SM(1,2)
000051           EXP5 = SF(1,1)   - SM(1,1)
000053           EXP6 = SC(2,2,L) + SC(2,3,L) - SM(2,2)   - SM(2,3)
000061           DAA = ALPF(I) - ALPM(J)
000064           DAT = ALPFT(I) - ALPM(J)
           C
000067           ALPHA(1,L) = (DAA * (EXP1*EXP2 + 2.*EXP3*EXP4)
                *              +2.*DAT * (-EXP1*EXP4 - EXP3*EXP5) ) /
                *              (EXP5*EXP2 - 2.*EXP4*EXP4)
000107           ALPHA(1,L) = ALPHA(1,L) + ALPM(J)
000112           ALPHA(2,L) = (DAA * (-EXP3*EXP2 - EXP4*EXP6) +
                *               DAT * (EXP5*EXP6 + 2.*EXP4*EXP3) ) /
                *              (EXP5*EXP2 - 2.*EXP4*EXP4)
000132           ALPHA(2,L) = ALPHA(2,L) + ALPM(J)
           C
000135           RETURN
000135           END
```

```
                    PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
000003              REAL IANG
000003              DIMENSION         E11(20),E22(20),V12(20),V21(20),G12(20),
                  1                   SCY(20),STY(20),TY(20),
                  2                   T(20),IANG(20),
                  3                   S11(20),S12(20),S21(20),S22(20),S44(20),
                  4                   SINS(20),COSS(20),SIN2(20),COS2(20)
000003              DIMENSION         P11(20),P22(20),P12(20),
                  1                   EP11(20),EP22(20),EP12(20),
                  2                   EPS11(20),EPS22(20),EPS12(20)
000003              DIMENSION         HT(60),DC(60),
                  1                   F(3,20),G(3,20),H(3,20)
000003              DIMENSION         A(60,60),DR(60,60),SG(60,1),SG0(60,1),SF(60),
                  1                   ULT(6,2,20),
                  1                   SGS(60),SG1(60,1)
000003              DIMENSION         STRS( 50),STRN( 50),A0(100),POINTS(50,6,20),
                  1                   STXX(20,50),STYY(20,50),STXY(20,50)
000003              DIMENSION         EXX(50),EYY(50),VXY(50),VYX(50),GXY(50)
000003              DIMENSION         A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
000003              DIMENSION         EPN(60,1),PS(60)
000003              DIMENSION MATYPE(20),S11T(20),S22T(20),
                  1    S11C(20),S22C(20),EP11C(20),EP22C(20),GAMA(20),EP11T(20),
                  2    EP22T(20),SIG11(50,20),SIG22(50,20),SIG12(50,20)
             C
000003              COMMON    /SET01/ E11,E22,V12,V21,G12
000003              COMMON    /SET02/ TT,T,IANG
000003              COMMON    /SET03/EP11,EP22,EP12
000003              COMMON    /SET04/ S011,S022,S012,SM11,SM22,SM12
000003              COMMON    /SET05/ ULT,STIFF
000003              COMMON    /SET06/ SIN2,COS2,SINS,COSS
000003              COMMON    /SET07/EPS11,EPS22,EPS12
000003              COMMON    /SET08/ S11,S22,S12,S21
000003              COMMON    /SET09/LAY,EOPT,COPT,IFCN,KSGM,INMT,RATIO,SENS
000003              COMMON    /SET10/ STY,SCY,TY,XM,XN
000003              COMMON    /SET11/ EPS,UPBD,NIT,IT,SMLT
000003              COMMON    /SET12/ F,G,H
000003              COMMON    /SET13/ EXX,EYY,VXY,STXX,STYY,STXY
000003              COMMON    /SET14/ A11,A22,A44,A12,B1,B2
000003              COMMON    /SET15/ POINTS,IPRINT,IOPT,IPIS,LUP
000003              COMMON    /SET16/ MATYPE,S11T,S11C,S22T,S22C,EP11T,EP11C,
                  1                   EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
             C
000003              LOGICAL           MSING,MSINGD
000003              INTEGER           EOPT,COPT,SWITCH,AGAIN
000003              INTEGER           UFAIL(3)
             C
000003              EQUIVALENCE       (STXX(1),A0(1))
             C
             C
             C      ARITHMETIC STATEMENT FUNCTIONS
000003              PBO(X,Y,W) = 1.0/(X*Y)**(1./(W-1.))
             C
             C                              * PROGRAM REQUIREMENTS *
             C
```

```
C     SUBROUTINES              : LAMTSI,OUTPT1,PROP,REGA1,QUADCF,INVRTD,CMATX,
C                                CONVR,HEADER ANGLE,MXMULD,TRANS,RESET,NRIRM,
C                                MATCRL,LAYSUB
C     FUNCTION SUBPROGRAM      : SINT
C     BLOCK DATA SUBPROGRAM    : INITIALIZE VARIABLES IN COMMON SETS
C                                01,05,10,11, AND 14
C
C                                       * LIMITATIONS *
C
C     LAYERS                   : 20
C     CURVE-FIT DATA POINTS    : 50
C     INCREMENTS               : 50
C
C                                       * DEFAULT VALUES *
C
C     EPS      = 1.00E-03
C     UPBD     = 2.00E+04
C     IT       = 100
C     A12(I)   = 0.00           (FOR ALL LAYERS)
C     XM       = 3.00E 00
C     XN       = 3.00E 00
C     INMT     = 2
C
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     EOPT          : EXPONENT OPTION FOR CURVE-FIT ROUTINE
C                     =1: CURVE-FIT FOR ALL RAMBERG-OZGOOD PARAMETERS
C                     =3: INPUT EXPONENTS, XM + XN, CURVE-FIT TY,STY,SLY
C     COPT          : LAYER OPTION FOR CURVE-FIT ROUTINE
C                     =1: USE SAME STRESS-STRAIN DATA FOR ALL LAYERS
C                     =2: STRESS-STRAIN DATA INPUT FOR EACH LAYER
C     LAMINATE PROPERTIES
C     LAY           : NO. OF LAYERS IN LAMINATE
C     E11(I)        : AXIAL YOUNG#S MODULUS (LAYER I)
C     E22(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     CURVE-FIT PARAMETERS
C     IPTS          : NO. OF DATA POINTS
C     STRS(I)       : ITH STRESS DATA POINT
C     STRN(I)       : ITH STRAIN DATA POINT
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
```

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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       A12(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       EPS             : CONVERGENCE CRITERIA
C       UPBD            : DIVERGENCE CRITERIA
C       INMT            : INCREMENTATION ESTIMATE METHOD
C
C
C                                    * VARIABLE DICTIONARY *
C
C
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       COSS(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       DB(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)
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        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+  LAY)               : TRAN. STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
        C      PS(I+2*LAY)               : SHEAR STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
        C      EPS11(I)                  : AXIAL STRAIN LAMIN.AXES (ITH LAYER) PREVIOUS LOAD
        C      EPS22(I)                  : TRAN. STRAIN LAMIN.AXES (ITH LAYER) PREVIOUS LOAD
        C      EPS12(I)                  : SHEAR STRAIN LAMIN.AXES (ITH LAYER) PREVIOUS LOAD
        C
        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      ******************************************************************
        C      INITIALIZE VARIABLES
        C
000020         EX=3.
000022         INMT=2
000023         RATIO=1.E-06
000024         SENS=1.E-15
        C
        C
        C      PRINT PROGRAM HEADER
000026         CALL HEADER
000027         NST=1
000030     423 CONTINUE
000030         NSR=0
000031         IPRINT=0
000032         CALL MATCRL (NSR)
000033         IF(NSR.EQ.1) GO TO 424
        C      CHANGE ENGINEERING STRAIN TO TENSORIAL STRAIN.
000035     425 DO 63 ILKA=1,50
000037         DO 63 ILKB=1,20
000040      63 POINTS(ILKA,6,ILKB) = POINTS(ILKA,6,ILKB)/2.
        C
        C
        C                                ******************************
        C                                *         INPUT PER SET      *
        C                                ******************************
000050         GO TO (20,30),IOPT
        C      INPUT  1:
000056      20 CONTINUE
000056         GO TO 50
        C      INPUT 2:
000057      30 CONTINUE
000057         IF(COPT.EQ.1)  LUP=1
000062         IF(COPT.EQ.2)  LUP=LAY
000065         DO 40 IL=1,LUP
        C      INPUT STRESS-STRAIN DATA AND FIT CURVE OF FORM:
```

```
          C                 STRN = A0 + A1*STRS**EX
          C                 WHERE  A0 = A*STRS
000067          DO 40 IC=1,3
000070          DO 35 IDT=1,IPTS
000071          STRN(IDT)=POINTS(IDT,2*IC,LUP)
000077          STRS(IDT)=POINTS(IDT,2*IC-1,LUP)
000104          IF(IC.EQ.1)  A0(IDT) = STRS(IDT)/G12(IL)
000111          IF(IC.EQ.2)  A0(IDT) = STRS(IDT)/E22(IL)
000116          IF(IC.EQ.3)  A0(IDT) = STRS(IDT)/E22(IL)
000123          STRN(IDT) = STRN(IDT) -A0(IDT)
000126          IF(STRN(IDT).LE.1.0E-20)  STRN(IDT) = 0.00
000132       35 CONTINUE
          C     LEAST-SQUARES CURVE-FIT FOR STRESS-STRAIN DATA
000135          CALL REGA1(STRS,STRN,IPTS,EOPT,0.,A1,EX,0)
000144          IF(IC.EQ.1)    TY(IL) = RRO(G12(IL),A1,EX)
000153          IF(IC.EQ.1)         XM = EX
000157          IF(IC.EQ.2)  STY(IL) = RRO(E22(IL),A1,EX)
000165          IF(IC.EQ.2)         XN = EX
000171          IF(IC.EQ.3)  SCY(IL) = RRO(E22(IL),A1,EX)
000177          IF(IC.EQ.3)         XN = EX
000203       40 CONTINUE
000210          IF(COPT.NE.1)  GO TO 50
000212          DO 43 IL=2,LAY
000213          TY(IL)  = TY(1)
000215          STY(IL) = STY(1)
000216          SCY(IL) = SCY(1)
000220       43 CONTINUE
000222       50 CONTINUE
          C     INPUT LOADINGS AND FAILURE CRITERIA
          C     INPUT ANALYSIS CONTROL PARAMETERS
          C     PRINT INPUT
000222          CALL OUTPT1(NST,LAY,IFCN,KSGM)
          C
          C                             ******************************
          C                             *     INITIAL ASSIGNMENTS    *
          C                             *            AND             *
          C                             *        COMPUTATIONS        *
          C                             ******************************
          C     ANGLE  REDUCTION  ROUTINE
000225          CALL ANGLE(LAY,IANG)
          C
000227          SWITCH = 0
000230          TT     =  0.0E0
000231          DO 100 I = 1,LAY
000232          TT     =  TT + T(I)
000234      100 CONTINUE
          C
000236          UFAIL(1) = 0
000237          UFAIL(2) = 0
000240          UFAIL(3) = 0
000241          AGAIN = 0
000242          KSG  =  1
000243          LT1  =  LAY
000244          N    =  LT1
000245          LP1  =  LAY  +1
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000247         LT2  =  LAY*2
000250         LT21 =  LAY*2+1
000251         LT3  =  LAY*3
000252         LM1  =  LAY  -1
          C
000253         DO 105 I=1,LT3
000255         SG(I,1) =  0.000E 00
000256         SGS(I) =  0.0E00
000257         SF(I) =  1.0E0
000261         SG0(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
000276         CALL PROP(SG,EXX,EYY,VXY,VYX,GXY,KSGM,KSG,LAY,1)
          C
          C                        ******************************
          C                        *          INCREMENTAL       *
          C                        *           ANALYSIS         *
          C                        ******************************
          C
          C    RETURN TO 110 FOR NEXT INCREMENTAL STEP
000310     110 CONTINUE
000310         MSING = .FALSE.
000311         MSINGD = .FALSE.
000312         NIT  =  0
000313         IPT = 0
000314         SG01 = S011
000315         SG02 = S022
000317         SG03 = S012
          C
000320         DO 111 K = 1,LT3
000322         DC(K)  =  0.0E0
000323         SG1(K,1) =  0.0E0
000324         DO 111 L=1,LT3
000326         DB(K,L)=  0.0E0
000331         A(K,L)   =  0.0E0
000334     111 CONTINUE
000341         DO 1115 I=1,N
000342         S22(I) =  1.0E0/E22(I)
000344         S44(I) =  1.0E0/(4.0E0*G12(I))
000347    1115 CONTINUE
          C
          C    AFTER  2ND  INCREMENTATION  USE  MULTIPLICATIVE  FACTOR
          C    AS  INITIAL  STRESS  SOLUTION  ESTIMATE
000351         IF (KSG.GE.3 .AND. IPT.EQ.0)  GO TO 120
000360     112 CONTINUE
000360         IF(N.EQ.1)  LM1=1
000363         DO 115 I=1,LM1
          C
```

```
000365          SNS  =  SINS(I)
000367          CSS  =  COSS(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 =  COSS(I+1)
000400          SN2P =  SIN2(I+1)
000402          CS2P =  COS2(I+1)
        C
000403      113 CONTINUE
000403          A(1,I    ) =  CSS*T(I)
000407          A(1,I+N  ) =  SNS*T(I)
000414          A(1,I+2*N) = -SN2*T(I)
        C
000422          A(2,I    ) =  SNS*T(I)
000426          A(2,I+N  ) =  CSS*T(I)
000432          A(2,I+2*N) =  SN2*T(I)
        C
000440          A(3,I    ) =  SN2*T(I)/2.0E0
000444          A(3,I+N  ) = -SN2*T(I)/2.0E0
000451          A(3,I+2*N) =  CS2*T(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*T(N)
000661          A(1,2*N) =  SNSP*T(N)
000665          A(1,3*N) = -SN2P*T(N)
000672          A(2,N  ) =  SNSP*T(N)
000676          A(2,2*N) =  CSSP*T(N)
000702          A(2,3*N) =  SN2P*T(N)
000706          A(3,N  ) =  SN2P*T(N)/2.0E0
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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
          C    INVERT  MATRIX  A
000725         CALL INVRTD(A,60,LT3,DET, SENS   ,IRANK,1.00E-30)
          C
          C    CHECK  FOR  SINGULAR  MATRIX
000733         IF(IRANK.EQ.LT3)  GO TO 118
000735         MSING = .TRUE.
000736         WRITE(6,1420) IRANK,DET
000745         GO TO 112
000746     117 CONTINUE
000746         WRITE(6,1425) ((A(K1,L1),L1=1,LT3),K1=1,LT3)
000766         MSING = .FALSE.
000767         GO TO 999
000770     118 CONTINUE
          C
          C    INITIAL LOAD VECTOR
000770         IF (SWITCH.EQ.1)  GO TO 119
000772         SG0(1,1) =  S011*TT
000774         SG0(2,1) =  S022*TT
000776         SG0(3,1) =  S012*TT
000777     119 CONTINUE
000777         CALL MXMULD(A,SG0,SG,60,60,1,LT3,LT3,1)
          C
          C    RESET  STRESS = 0.  IF  RELATIVE  STRESS ) 1.0D-06
001010         CALL RESET(LT3,SG, RATIO )
001013         GO TO 126
          C
          C    (MULTIPLICATIVE FACTOR) X (SOLUTION FROM PREVIOUS INCREMENT)
001014     120 CONTINUE
001014         DO 122 I=1,LT3
001016         SG(I,1) =  SF(I)*SGS(I)
001021     122 CONTINUE
001023         GO TO 126
          C
          C    RETURN  TO  125  FOR  NEXT  ITERATION  STEP
001023     125 CONTINUE
001023         NIT =  NIT + 1
001025     126 CONTINUE
          C    STORE STRESS SOLUTION FOR THIS ITERATION
001025         DO 127 I=1,LT3
001027         SG1(I,1) =  SG(I,1)
001031         BT(I) =  0.0E 00
001032     127 CONTINUE
          C
          C
001034     130 CONTINUE
001034         DO 1305 K=1,LT3
001036         DO 1305 L=1,LT3
001037         DB(K,L) =  0.0E 00
```

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001042     1305 CONTINUE
          C                              ******************************
          C                              *    DERIVATIVE MATRIX       *
          C                              *           FOR              *
          C                              *    NEWTON-RAPHSON ANALYSIS *
          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  =  COSS(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 =  COSS(I+1)
001103          SN2P =  SIN2(I+1)
001104          CS2P =  COS2(I+1)
          C
001106      131 CONTINUE
001106          DB(1,I)       =  CSS*T(I)
001112          DB(1,I+N)     =  SNS*T(I)
001117          DB(1,I+2*N)   = -SN2*T(I)
001125          DB(2,I)       =  SNS*T(I)
001131          DB(2,I+N)     =  CSS*T(I)
001135          DB(2,I+2*N)   =  SN2*T(I)
001143          DB(3,I)       =  SN2*T(I)/2.
001147          DB(3,I+N)     = -SN2*T(I)/2.
001154          DB(3,I+2*N)   =  CS2*T(I)
001160          IF(N.EQ.1)  GO TO 161
          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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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(MSINGD)  GO TO 167
          C
          C     INVERT  MATRIX  DB
001404          CALL INVRTD(DB,60,LT3,DET, SENS  ,IRANK,1.00E-30)
          C
          C     CHECK  FOR  SINGULAR  MATRIX
001412          IF(IRANK.EQ.LT3)  GO TO 168
001414          MSINGD = .TRUE.
001415          WRITE(6,1420) IRANK,DET
001424          GO TO 130
001425      167 CONTINUE
001425          WRITE(6,1425) ((DB(K1,L1),L1=1,LT3),K1=1,LT3)
001445          MSINGD = .FALSE.
001446          GO TO 999
001447      168 CONTINUE
          C
          C                                 ******************************
          C                                 *        INITIAL VECTOR      *
          C                                 *             FOR            *
          C                                 *   NEWTON-RAPHSON ANALYSIS  *
          C                                 ******************************
          C
          C
001447          IF (SWITCH.EQ.1)  GO TO 173
001451          DC(1)          = -S011*TT
001453          DC(2)          = -S022*TT
001455          DC(3)          = -S012*TT
001456          GO TO 174
001457      173 CONTINUE
001457          DC(1)          = -SG0(1,1)
001461          DC(2)          = -SG0(2,1)
001462          DC(3)          = -SG0(3,1)
001464      174 CONTINUE
          C
001464          DO 6 I=1,LAY
001466          SNS  =  SINS(I)
001470          CSS  =  COSS(I)
001471          SN2  =  SIN2(I)
001473          CS2  =  COS2(I)
001474          DC(1)          =  DC(1) + SG(I,1)*CSS*T(I) + SG(LAY+I,1)*SNS*T(I)
               1                  -SG(2*LAY+I,1)*SN2*T(I)
```

```
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          T12S =  (SG(K+2*N,1)/TY(K))**2
001550          IF(SG(K+N,1)-0.0) 1,2,2
001553        1 TS22S =(SG(K+N,1)/SCY(K))**2
001557          GO  TO  3
001557        2 TS22S =(SG(K+N,1)/STY(K))**2
001563        3 S12S  = T12S +TS22S
001565          S22(K) =  (1.0E0+S12S**((XN-1.)/2.))/E22(K)
001577          S44(K) =  (1.0E0+S12S**((XM-1.)/2.))/(4.0E0*G12(K))
001612        7 CONTINUE
          C
001614          IF(N.EQ.1)  GO TO 5008
001616          DO 8 K=1,LM1
001617          SNS  =  SINS(K)
001621          CSS  =  COSS(K)
001622          SN2  =  SIN2(K)
001624          CS2  =  COS2(K)
001625          SNSP =  SINS(K+1)
001627          CSSP =  COSS(K+1)
001630          SN2P =  SIN2(K+1)
001632          CS2P =  COS2(K+1)
          C
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 + SG0(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) + SG0(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) + SG0(3+3*K,1)
002035        8 CONTINUE
002037     5008 CONTINUE
          C
002037          DO 9 I=1,LT3
002041          DC(I) = -DC(I)
002043        9 CONTINUE
          C
002045          DO 11 I=1,LT3
002046          DO 11 K=1,LT3
```

```
002047        11 BT(I) =  BT(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) =  SG1(I,1) + BT(I)
002066        15 CONTINUE
           C
           C     RESET  STRESS = 0,  IF  RELATIVE  STRESS ) 1.0D-06
002070           CALL RESET(LT3,SG, RATIO )
002073           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
           C                                  ******************************
           C                                  *     STRAIN COMPUTATIONS    *
           C                                  ******************************
002115           DO 540 I = 1,LAY
002117           SNS  =  SINS(I)
002121           CSS  =  COSS(I)
002122           SN2  =  SIN2(I)
002124           CS2  =  COS2(I)
           C
           C     STRAIN COMPUTATIONS IN FIBER AXES DIRECTIONS
002125           P11(I) =  S11(I)*SG(I,1) + S12(I)*SG(I+N,1)
002132           T12S =  (SG(I+2*N,1)/TY(I))**2
002136           IF(SG(I+N,1)-C.0) 4,5,5
002142         4 TS22S =(SG(I+N,1)/SCY(I))**2
002146           GO TO 18
002146         5 TS22S=(SG(I+N,1)/STY(I))**2
002152        18 S12S=T12S+TS22S
002154           P22(I) =  S21(I)*SG(I,1) + SG(I+N,1)/E22(I)*(1.0E0+S12S**((XN
                1        -1.)/2.))
002173           P12(I) =  SG(I+2*N,1)/(2.*G12(I))*(1.0E0+S12S**((XM-1.)/2.))
002211       520 CONTINUE
002211           EPN(I    ,1) = P11(I)
002213           EPN(I+  N,1) = P22(I)
002216           EPN(I+2*N,1) = P12(I)
           C
           C     STRAIN COMPUTATIONS IN LAMINATE AXES DIRECTIONS
002221           EP11(I) =  P11(I)*CSS + P22(I)*SNS - P12(I)*SN2
002227           EP22(I) =  P11(I)*SNS + P22(I)*CSS + P12(I)*SN2
```

```
002235            FP12(I) =  (P11(I)-P22(I))*SN2/2.E0 + P12(I)*CS2
              C
002243        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                             *    LAMINATE FAILURE TESTS   *
              C                             ******************************
002253        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                             ******************************
002266        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            EP12(I)=EP12(I)*2.
002342            WRITE(6,1550) I,SG(I,1),SG(I+N,1),SG(I+2*N,1),
                 1              EP11(I),EP22(I),EP12(I),P11(I),P22(I),P12(I)
002375            FP12(I)=FP12(I)/2.
002400        750 CONTINUE
002402            IF(IPT.EQ.1)  WRITE(6,1990)
002407            IF (IPT.EQ.1)  AGAIN=1
002412            IF(IPT.EQ.1)  GO TO 110
              C
              C   COMPUTE INELASTIC MATERIAL PROPERTIES AND RETAIN AS FUNCTION OF INCREMENT
002413        752 CONTINUE
002413            AGAIN = 0
002414            CALL PROP(SG,EXX,EYY,VXY,VYX,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        755 CONTINUE
              C
              C   CHECK FOR LAMINATE FAILURE, IF FAILURE HAS OCCURED INTERPOLATE LOADS TO
              C   FAILURE POINT AND REEVALUATE
002450            IF (SWITCH.EQ.0)  GO TO 758
002451            WRITE(6,1555)
002455            WRITE(6,1560)
002461            SG0(1,1) = ((S011-SM11) + FAC*SM11)*TT
002466            SG0(2,1) = ((S022-SM22) + FAC*SM22)*TT
```

```
002472           SG0(3,1) = ((S012-SM12) + FAC*SM12)*TT
002477           GO TO 110
002477       758 CONTINUE
        C
        C        CHECK FOR INCREMENTATION LIMIT
002477           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
002510       762 CONTINUE
002510           DO 765 I=1,LT3
002512           IF(KSG.EQ.1)  GO TO 770
002514           IF(SGS(I).EQ.0.0E0)  GO TO 763
002515           SF(I) =  SG(I,1)/SGS(I)
002517           GO TO 765
002520       763 CONTINUE
002520           SF(I) =  1.0E0
002522       765 CONTINUE
002525           GO TO 770
        C
002525       766 CONTINUE
002525           DO 768 I=1,LT3
002527           IF(KSG.LT.2)  GO TO 767
002531           IF(SG(I,1).EQ.0.0E0)  GO TO 767
002533           VKSG =  KSG + 1
002535           CONS  =  VKSG*(VKSG-2)/(VKSG-1)**2
002543           SF(I) =  1.0E0 + CONS*(SG(I,1)-SGS(I))/SG(I,1)
002551           GO TO 768
002551       767 CONTINUE
002551           SF(I) =  1.0E0
002553       768 CONTINUE
        C
        C        STORE  STRESS  AND  STRAIN  VALUES
002556       770 CONTINUE
002556           DO 775 I = 1,LAY
002560           SGS(I     ) =  SG(I     ,1)
002562           SGS(I+  N) =  SG(I+  N,1)
002566           SGS(I+2*N) =  SG(I+2*N,1)
002572           EPS11(I) =  EP11(I)
002573           EPS22(I) =  EP22(I)
002575           EPS12(I) =  EP12(I)
002576           PS(I     ) = P11(I)
002600           PS(I+  N) = P22(I)
002602           PS(I+2*N) = P12(I)
002605       775 CONTINUE
        C
        C        INCREMENT  APPLIED  LOADING
002610           KSG  =  KSG + 1
```

```
002611            S011 =  S011 + SM11
002613            S022 =  S022 + SM22
002615            S012 =  S012 + SM12
002617            GO TO 110
002620        790 CONTINUE
           C
           C      LEAST-SQUARES CURVE-FIT OF FXX, EYY, AND VXY AGAINST SXX, SYY, AND SXY
002620        900 CONTINUE
002620            NST=NST+1
           C
002622        999 CONTINUE
002622            CALL LAYSUB (A12,STY,SCY,TY,EPS11,EPS22,EPS12)
002631            GO TO 423
002632        424 WRITE(6,1999)
002636            STOP
           C
           C
           C
           C
           C
           C
002640       1420 FORMAT (//* MATRIX  IS  SINGULAR  OF  RANK  =  *,I2,
                *          *+   DETERMINANT  =  *,E15.5/)
002640       1425 FORMAT (6E15.5)
002640       1525 FORMAT (* EXTERNAL APPLIED STRESS*/)
002640       1527 FORMAT (* SG XX  = *,E13.5)
002640       1528 FORMAT (* SG YY  = *,E13.5)
002640       1529 FORMAT (* SG XY  = *,E13.5)
002640       1536 FORMAT (/22X,*STRESS*,38X,*STRAIN*,37X,*STRAIN*)
002640       1537 FORMAT (19X,*(LAYER AXES)*,31X,*(LAMINATE AXES)*,
                *          29X,*(LAYER AXES)*)
002640       1538 FORMAT ( /* LAYER*,4X,*SG 11*,8X,*SG 22*,8X,*SG 12 *,11X,*EP XX*,
                1          8X,*EP YY*,8X,*EP XY *,11X,*EP 11*,8X,*EP 22*,8X,
                2          *EP 12 */)
002640       1550 FORMAT (I4,1X,2(3E13.5,4X),3E13.5)
002640       1555 FORMAT (////40X,*****  LAMINATE ANALYSIS INTERPOLATED TO *,
                *          *FAILURE POINT  *****//)
002640       1560 FORMAT (* AT  FAILURE*)
002640       1735 FORMAT (/* SOLUTION  FOR  STRESS  CONVERGES  WITHIN*,I4,
                *          *  ITERATIONS*/)
002640       1990 FORMAT (////)
002640       1999 FORMAT(///*************************   PROGRAM TERMINATED   ******
                1*******************)
002640            END
```

```
                 SUBROUTINE HEADER
          C
          C      ROUTINE HEADEP PRINTS HEADER INFORMATION FOR NOLIN V2 M2
          C
000002           REAL              MESSAG(100)
          C      RETRIEVE JULIAN DATE FROM THE OPERATING SYSTEM.....
000002           DATE=0
          C      READ IN 5 CARD PROGRAM IDENTIFICATION
000003           READ(5,200) (MESSAG(I),I=1,100)                                      00002200
000015       200 FORMAT(20A4)                                                         00002300
          C      WRITE OUT TITLE, DATE, AND PROGRAM IDENTIFICATION
000015           WRITE(6,1000) DATE, (MESSAG(J),J=1,100)
000031      1000 FORMAT (1H1,///,41X,41(*+*),3(/,41X,*+*,39X,*+*),/,
               *         41X,*+*,14X,*NONLINEAR*,16X,*+*,/,41X,*+*,39X,*+*,/,
               *         41X,*+*, 8X,*THERMOELASTIC ANALYSIS*, 9X,*+*,/,
               *         41X,*+*,39X,*+*,/,41X,*+*,18X,*OF*,19X,*+*,/,
               *         41X,*+*,39X,*+*,/,41X,*+*,10X,*FIBROUS COMPOSITES*,
               *         11X,*+*,/,41X,*+*,39X,*+*,/,41X,*+*,17X,*AND*,19X,*+*,/,
               *         41X,*+*,39X,*+*,/,41X,*+*, 6X,
               *         *NON-HOMOGENEOUS LAMINATES*, 8X,*+*,3(/,41X,*+*,39X,*+*),
               *         /,41X,41(*+*),//,
               *         //21X,*.VERSION 2     MOD 3  (MAY 74)*,
               *                         //,21X,*.DATE           *,A10,///,21X,
               *         *.PROGRAM IDENTIFICATION*,//,5(21X,20A4,/),///)
          C                                                                           00003600
000031           RETURN
000032           END
```

```
                 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),TTY(20),TY(20),
               5           STY(20),SCY(20),EP11(20),EP22(20),EP12(20),ULT(6,2,20),
               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)
000003           COMMON   /SET01/ E11,E22,V12,V21,G12
000003           COMMON   /SET02/TT,THICK,THETA
000003           COMMON   /SET03/EP11,EP22,EP12
000003           COMMON   /SET04/ SO11,SO22,SO12,SM11,SM22,SM12
000003           COMMON   /SET05/ ULT,STIFF
000003           COMMON   /SET08/ S11,S22,S12,S21
000003           COMMON   /SET09/ NLAY,EOPT,COPT,IFCN,KSGM,INMT,RATIO,SENS
000003           COMMON   /SET10/ STY,SCY,TY,XM,XN
000003           COMMON   /SET11/ EPS,UPHD,NIT,IT,SMLT
000003           COMMON   /SET14/ A11,A22,A44,A12,B1,B2
000003           COMMON   /SET15/ POINTS,IPRINT,IOPT,IPTS,LUP
000003           COMMON   /SET16/ MATYPE,S11T,S11C,S22T,S22C,EP11T,EP11C,
               1                  EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
000003           COMMON   /SET17/ TE11,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
000003           INTEGER  EOPT,COPT
000003           NAMELIST/DATA/NLAY,E11,E22,V12,G12,THICK,THETA,IOPT,
               1   STY,SCY,TY,XM,XN,EOPT,COPT,IPTS,IPRINT,SO11,SO22,SO12,
               2   IFCN,STIFF,A12,KSGM,SMLT,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
000003           NSR=0
000004           READ(5,DATA)
000006           IF(EOF,5) 424,425
000012       425 DO 10 I=1,20
000014           TE11(I) = E11(I)
000016           TE22(I) = E22(I)
000017           TG12(I) = G12(I)
000021           TV12(I) = V12(I)
000022           TA12(I) = A12(I)
000024           TSTY(I) = STY(I)
000025           TSCY(I)= SCY(I)
000027           TSCY(I) = SCY(I)
000030        10 TTY(I)  = TY(I)
000033           DO 200 I = 1,20
000035           M = MATYPE(I)
000037           E11(I) = TE11(M)
000041           E22(I) = TE22(M)
000042           G12(I) =TG12(M)
000044           V12(I) = TV12(M)
000045           A12(I) = TA12(M)
000047           STY(I) = TSTY(M)
000050           SCY(I) = TSCY(M)
```

```
000052         TY(I) = TTY(M)
000053         ULT(1,1,I) = S11T(M)
000056         ULT(1,2,I) = S11C(M)
000061         ULT(2,1,I) = S22T(M)
000064         ULT(2,2,I) = S22C(M)
000067         ULT(3,1,I) = S12(M)
000072         ULT(3,2,I) = S12(M)
000075         ULT(4,1,I) = EP11T(M)
000100         ULT(4,2,I) = EP11C(M)
000103         ULT(5,1,I) = EP22T(M)
000106         ULT(5,2,I) = EP22C(M)
000111         ULT(6,1,I) = GAMA(M)
000114         ULT(6,2,I) = GAMA(M)
000117         DO 200 J = 1,IPTS
000121         POINTS(J,1,I) = SIG11(J,M)
000127         POINTS(J,2,I) = EPS11(J,M)
000135         POINTS(J,3,I) = SIG22(J,M)
000143         POINTS(J,4,I) = EPS22(J,M)
000151         POINTS(J,5,I) = SIG12(J,M)
000157     200 POINTS(J,6,I) = EPS12(J,M)
000171         RETURN
000172     424 NSR=1
000173         RETURN
000174         END
```

```
                 SUBROUTINE OUTPT1(NST,LAY,IFCN,KSGM)
           C
           C     ROUTINE OUTPT1 PRINTS OUT ALL PARAMETERS PERTAINING
           C     TO PROBLEM DEFINITION
           C
00007            REAL IANG
00007            DIMENSION        E11(20),E22(20),V12(20),V21(20),G12(20),
                1                 SCY(20),STY(20),TY(20),
                2                 T(20),IANG(20)
00007            DIMENSION        ULT(6,2,20)
00007            DIMENSION        HDFAIL(8),POINTS (50,6,20)
00007            DIMENSION        A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
00007            COMMON   /SET01/ E11,E22,V12,V21,G12
00007            COMMON   /SET02/ TT,T,IANG
00007            COMMON   /SET04/ S011,S022,S012,SM11,SM22,SM12
00007            COMMON   /SET05/ ULT,STIFF
00007            COMMON   /SET10/ STY,SCY,TY,XM,XN
00007            COMMON   /SET11/ EPS,UPBD,NIT,IT,SMLT
00007            COMMON   /SET14/ A11,A22,A44,A12,B1,B2
00007            COMMON   /SET15/ POINTS,IPRINT,IOPT,IPTS,LUP
00007            DATA             HDFAIL/10HULTIMATE S,10HTRESS     ,
                *                         10HULTIMATE S,10HTRESS     ,
                *                         10HQUAD. INTE,10HRACTION   ,
                *                         10HALL FAILUR,10HE CRITERIA/
           C
00007            SM11 = SMLT*S011
00011            SM22 = SMLT*S022
00013            SM12 = SMLT*S012
00015            DO 15 I=1,LAY
00016            V21(I) = V12(I)*E22(I)/E11(I)
00022         15 CONTINUE
           C
00024            WRITE(6,1509)  NST
00031            WRITE(6,1510) LAY
00042            IF(IPRINT.NE.1) GO TO 1112
00047            WRITE(6,1507)
00052            DO 47 IL = 1,LUP
00056            DO 45 J = 1,5
00057         45 WRITE(6,1553)  (POINTS(I,J,IL),I=1,IPTS)
00102            DO 46 IAC = 1,IPTS
00103         46 POINTS(IAC,6,IL) = POINTS(IAC,6,IL)*2.
00111            WRITE(6,1553)  (POINTS(I,6,IL),I=1,IPTS)
00126            DO 47 IAD = 1,IPTS
00132         47 POINTS(IAD,6,IL) = POINTS(IAD,6,IL)/2.
00142       1112 WRITE(6,1513)
00146            DO 60 I=1,LAY
00152            WRITE(6,1515)   I,IANG(I),T(I),E11(I),E22(I),V12(I),V21(I),
                1               G12(I),STY(I),SCY(I),TY(I)
00203         60 CONTINUE
00210            WRITE(6,1516)
00213            WRITE(6,1517) XM
00221            WRITE(6,1518) XN
00227            WRITE(6,1520)
00233            WRITE(6,1524) S011,SM11,KSGM
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00247          WRITE(6,1526) SO22,SM22
00257          WRITE(6,1528) SO12,SM12
00267          IFN = 2*IFCN
00273          IST = IFN-1
00275          WRITE(6,1530) (HDFAIL(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
00357          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)
00467          WRITE(6,1544) IT
00475          WRITE(6,1546) EPS
00503          WRITE(6,1548) UPBD
        C
        C
00511    1507 FORMAT(///* DATA INPUT POINTS FOR CURVE FIT-*///)
00511    1509 FORMAT (1H1,50X,*LAMINATE*,I4,/50X,12(*+*))
00511    1510 FORMAT (////* NUMBER  OF  LAYERS = *,I2)
00511    1513 FORMAT (/* LAYER   THETA*,6X,*T*,13X,*E11*, 9X,*E22*, 9X,
              *        *V12*, 9X,*V21*, 9X,*G12*,8X,*SGT Y*,8X,*SGC Y*,8X,*TAUY*/)
00511    1515 FORMAT(I4,3X,F6.2,2X,E11.4,4X,8(1X,E11.4))
00511    1516 FORMAT (//* EQUATION  PARAMETERS*)
00511    1517 FORMAT (/*    EXPONENT M = *,E12.5)
00511    1518 FORMAT ( *    EXPONENT N = *,E12.5)
00511    1520 FORMAT (//50X,*EXTERNALLY APPLIED STRESS*,/50X,27(*+*),
              *        //30X,*INITIAL*,18X,*STRESS*, 42X,*NO. OF*
              *        /32X,*STRESS*,17X,*INCREMENT*,37X, *INCREMENTS*/)
00511    1524 FORMAT (15X,*SG XX*,4X,E15.5,11X,E15.5, 37X,I5)
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,I2, 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,I2,27X,E15.5)
```

```
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,8E14.5/3X,2E14.5//)
        C
00511          RETURN
00512          END
```

```
                SUBROUTINE PROP(SG,EXX,EYY,VXY,VYX,GXY,KSGM,ILD,LAY,LPROP)
          C
          C     ROUTINE PROP COMPUTES INITIAL LAMINATE CONSTANTS (LPROP=1)
          C     OR NONLINEAR LAMINATE PROPERTIES AS FUNCTION OF RESULTANT STRESS (LPROP=2)
          C
          C                                * VARIABLE DICTIONARY *
          C
          C     CSUM(I,J)             : THICKNESS WEIGHTED SUM OF LAYER STIFFNESSES
          C                             IN LAMINATE COORDINATES
          C     HEL                   : LONGITUDINAL YOUNG#S MODULUS OF LAMINATE
          C     HET                   : TRANSVERSE YOUNG#S MODULUS OF LAMINATE
          C     NULT                  : POISSON RATIO IN LONG.-TRANS.
          C     NUTL                  : POISSON RATIO IN TRANS.-LONG.
          C     HGLT                  : IN-PLANE SHEAR MODULUS OF LAMINATE
          C
          C     *******************************************************************
          C
0015            DIMENSION        TNS(3,3),CMT(3,3),TMP(3,3),CSUM(3,3),
               1                 EXX(KSGM),EYY(KSGM),VXY(KSGM),VYX(KSGM),GXY(KSGM)
0015            DIMENSION        T(20),SG(60,1),IANG(20)
0015            DIMENSION        H(25),TH(25),A(3,3)
0015            REAL IANG ,NULT,NUTL
0015            EQUIVALENCE      (CSUM(1),A(1))
0015            COMMON   /SET02/ TT,T,IANG
          C
          C     INITIALIZE
0015            DO 30 I=1,3
0016            DO 30 J=1,3
0017            CSUM(I,J) = 0.00
0022         30 CONTINUE
          C
0026            GO TO (50,75), LPROP
0034         50 CONTINUE
0034            T0 = TT/2.
0036            H0 = -T0
0037            TSUM = T(1)
0041            TH(1) = T(1)
0042            H(1) = H0 + T(1)
0044            DO 62 K=2,LAY
0045            TSUM = TSUM + T(K)
0047            H(K) = H0 + TSUM
0052            TH(K) = H(K)-H(K-1)
0055         62 CONTINUE
0057            GO TO 90
          C
0057         75 CONTINUE
0057            DO 85 K=1,LAY
0061            TH(K) = T(K)/TT
0064         85 CONTINUE
0066         90 CONTINUE
          C
          C     GENERATE SIMILARITY MATRIX OF CMT FOR EACH LAYER
          C                          CSIM = TNS**(-1) * CMT * TNS
0066            DO 150 K=1,LAY
```

```
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
0161          CALL INVRTD(CSUM,3,3,DET,1.0E-12,IRANK,1.0E-30)
        C
0167          GO TO (175,500), LPROP
0201      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./(2.*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
0265          EXX(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,*VYX  = *,E15.5)
0305     1528 FORMAT (  48X,*VXY  = *,E15.5)
0305     1532 FORMAT (  48X,*GXY  = *,E15.5)
0305     1560 FORMAT (1H1,50X,*APPLIED STRESS ANALYSIS*/50X,22(*+*))
0305          END
```

```
                SURROUTINE TRANS(T,I)
          C
          C     ROUTINE TRANS COMPUTES TRANSFORMATION MATRIX
          C
 0005           DIMENSION        T(3,3),SIN2(20),COS2(20),SINS(20),COSS(20)
 0005           COMMON   /SET06/ SIN2,COS2,SINS,COSS
          C
 0005           T(1,1) = COSS(I)
 0006           T(2,2) = COSS(I)
 0010           T(1,2) = SINS(I)
 0011           T(2,1) = SINS(I)
 0013           T(1,3) = SIN2(I)
 0014           T(3,1) =-SIN2(I)/2.
 0017           T(3,2) = SIN2(I)/2.
 0020           T(2,3) =-SIN2(I)
 0022           T(3,3) = COSS(I)-SINS(I)
          C
 0024           RETURN
 0025           END
```

```
                SUBROUTINE CMATX(C,SG,N,I,LPROP)
          C
          C     ROUTINE CMATX COMPUTES C MATRIX
          C
 0010           COMMON   /SET01/ E11,E22,V12,V21,G12
 0010           COMMON   /SET10/ STY,SCY,TY,XM,XN
 0010           DIMENSION        E11(20),E22(20),V12(20),V21(20),G12(20),
               1                 SCY(20),STY(20),TY(20)
 0010           DIMENSION        SG(60,1),C(3,3)
          C
 0010           DENOM = 1.0-V12(I)*V21(I)
 0014           C(1,1)   = E11(I)/DENOM
 0016           C(2,2)   = E22(I)/DENOM
 0017           IF(LPROP.EQ.1)  C(3,3)   = 2.*G12(I)
 0023           IF(LPROP.EQ.2)  C(3,3)   = G12(I)/(1.0+(SG(I+2*N,1)/TY(I))**2)
 0033           C(1,2)   = V12(I)*E22(I)/DENOM
 0037           C(2,1)   = C(1,2)
 0041           C(1,3)   = 0.0
 0042           C(2,3)   = 0.0
 0043           C(3,1)   = 0.0
 0044           C(3,2)   = 0.0
          C
 0045           RETURN
 0045           END
```

```
                SUBROUTINE REGA1(X,Y,IPTS,OPT,A0,A1,M,IPRT)
          C
          C     ROUTINE REGA1 PERFORMS LEAST-SQUARES CURVE-FIT TO
          C     GEOMETRIC CURVE OF FORM:  Y = A0 + A1*X**M
          C
          C                                  * VARIABLE DICTIONARY *
          C
          C     OPT = 1: DETERMINE A1 + M.        IPRI = 0: DO NOT PRINT RESULTS
          C         = 2: DETERMINE M                   = 1: PRINT RESULTS
          C         = 3: DETERMINE A1
          C
          C     A0: INTERCEPT   (PASSED TO SUBROUTINE)
          C     A1: COEFFICIENT (PASSED TO/OR DETERMINED BY SUBROUTINE)
          C      M: EXPONENT    (PASSED TO/OR DETERMINED BY SUBROUTINE)
          C
          C     ***********************************************************************
          C
 0013           INTEGER         OPT
 0013           REAL            M
 0013           DIMENSION       X(IPTS),Y(IPTS),OPTION(3)
 0013           EQUIVALENCE     (SX,SNUM),(SY,SDEN)
 0013           DATA            OPTION/10H  A1 AND M,10H    M ONLY,
               *                       10H   A1 ONLY/
          C
          C
 0013           N=IPTS
          C
          C     INITIALIZE PARTIAL SUMS TO ZERO
 0014           SX  = 0.0
 0015           SX2 = 0.0
 0016           SY  = 0.0
 0017           SY2 = 0.0
 0020           SXY = 0.0
 0021           NDELET = 0
          C
          C     CHOSE APPROPRIATE CURVE-FIT OPTION
 0022           GO TO (50,250,500),OPT
          C
          C     FIT M AND A1
 0030        50 CONTINUE
 0030           DO 100 I = 1,N
          C     DELETE DATA POINTS YIELDING NEGATIVE ARGUMENTS
          C     CONVERT TO LOG FORM
 0032           IF((Y(I)-A0).LE.1.E-20)  GO TO 80
 0036           XP =   ALOG(X(I))
 0046           YP =   ALOG(Y(I)-A0)
          C     COMPUTE INTERMEDIATE SUMS, SUM SQUARES, AND CROSS PRODUCT SUMS
 0057           SX  = SX  + XP
 0061           SX2 = SX2 + XP**2
 0063           SY  = SY  + YP
 0065           SY2 = SY2 + YP**2
 0067           SXY = SXY + XP*YP
 0071           GO TO 100
 0072        80 CONTINUE
```

```
10072          NDELET = NDELET + 1
10074      100 CONTINUE
10077          N = N - NDELET
         C     COMPUTE REGRESSION EQUATION PARAMETERS
10100          M = (SXY - SX*SY/N)/(SX2 - SX**2/N)
10111          A1 = EXP(SY/N - M*SX/N)
         C     COMPUTE CORRELATION COEFFICIENT (ABS. VAL.)
10123          R = (N*SXY-SX*SY)/SQRT((N*SX2-SX**2)*(N*SY2-SY**2))
10143          R = ABS(R)
10144          GO TO 800
         C
         C     FIT M ONLY
10150      250 CONTINUE
10150          GO TO 800
         C
         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
         C     PRINT OPTIONS
10202      800 CONTINUE
10202          IF(IPRT.EQ.0) RETURN
10204          WRITE(6,1500)
10210          WRITE(6,1510) OPTION(OPT)
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
         C
10303     1500 FORMAT (1H1,////49X,*LEAST SQUARES REGRESSION ANALYSIS OF FORM*/
              *         60X,*Y = A0 + A1.X..M*////)
10303     1510 FORMAT (50X,*FIT PARAMETERS     *,A10)
10303     1515 FORMAT (50X,*CORRELATION COEFFICIENT OF LOG CURVE = *,F6.2//)
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,I5,
              *         *  DATA POINTS YIELD NEGATIVE LOG ARGUMENTS AND*,
              *         * HAVE BEEN DELETED*)
10303          RETURN
10304          END
```

```
                 SURROUTINE ANGLE(LAY,IANG)
           C
           C     ROUTINE ANGLE REDUCES ANGLES TO VALUES BETWEEN 0 AND PI/4 FOR
           C     COMPUTING SIN AND COS
           C
10005            REAL IANG,IAVAL,IANG2
10005            DIMENSION         SINS(20),COSS(20),SIN2(20),COS2(20),IANG(20)
10005            COMMON   /SET06/ SIN2,COS2,SINS,COSS
10005            DO 72 I = 1,LAY
10006            IANG2 =  2*IANG(I)
10011            ANG    =  IANG(I)
10012            ANG2   =  IANG2
10014            RAD    =  ANG /57.2957795130D0
10027            RAD2   =  ANG2/57.2957795130D0
10041            IAVAL = ABS(IANG(I))
10043            IF(IAVAL.EQ.0.0) GO TO 66
10045            IF(IAVAL.NE.90.0) GO TO 62
10047            SINS(I) =   COS(0.0E0)**2
10052            COSS(I) =   SIN(0.0E0)**2
10056            SIN2(I) =   SIN(0.0E0)
10062            COS2(I) = - COS(0.0E0)
10066            GO TO 72
10070         62 CONTINUE
10070            SGN = IANG(I)/IAVAL
10072            IF(IAVAL.NE.45.0) GO TO 64
10075            SIN2(I) =   COS(0.0E0)*SGN
10101            COS2(I) =   SIN(0.0E0)
10104            GO TO 68
10106         64 CONTINUE
10106            IF(IAVAL.LT.45.0)GO TO 66
10111            RDA      =  (2.*IAVAL-90.)/57.295779513
10114            SIN2(I) =  SGN* COS(SGN*RDA)
10122            COS2(I) = -SGN* SIN(SGN*RDA)
10130            GO TO 68
10132         66 CONTINUE
10132            SIN2(I) =   SIN(RAD2)
10136            COS2(I) =   COS(RAD2)
10142         68 CONTINUE
10142            SINS(I) =   SIN(RAD)**2
10146            COSS(I) =   COS(RAD)**2
10152         72 CONTINUE
10156            RETURN
10156            END
```

```
IN VERSION 2.3 --PSR LEVEL 363--                                                07/23/74

                SUBROUTINE MXMULD(A,B,C,NROWA,NCOLA,NCOLB,MA,NA,NB)            R06D0001
          C
          C     ROUTINE MXMULD MULTIPLIES TWO MATRICES (A * B), STORES RESULT IN C
          C
)0014           DIMENSION A(NROWA,NCOLA),B(NCOLA,NCOLB),C(NROWA,NCOLB)          R0
)0014           REAL           A,B,C,X
)0014           DO 20 I=1,MA
)0015           DO 20 J=1,NB                                                     R06D0005
)0016           X=0.                                                             R06D0006
)0017           DO 10 K=1,NA                                                     R06D0007
)0021        10 X=X+A(I,K)*B(K,J)                                                R06D0008
)0035        20 C(I,J)=X                                                         R06D0009
          C
)0047           RETURN                                                           R06D0010
)0047           END                                                              R06D0011
```

```
                 SUBROUTINE INVRTD(A,NDIM,N,DETA,EPS,IRANK,UNDER)
           C
           C     ROUTINE INVRTD INVERTS AN N X N MATRIX USING GAUSS-JORDAN
           C     ELIMINATION METHOD
           C
           C                                     * VARIABLE DICTIONARY *
           C
           C     A(N,N)                  : MATRIX TO BE INVERTED PASSED,INVERSE RETURNED
           C     NDIM                    : UPPER LIMIT TO MATRIX DIMENSION
           C     N.                      : DIMENSION OF MATRIX
           C     IRANK                   : RANK OF MATRIX
           C     DETA                    : DETERINANT OF MATRIX
           C     EPS                     : ADJUSTABLE TOLERANCE FACTOR COMPARED TO
           C                               VALUE OF PIVOTAL ELEMENT DURING INVERSION
           C     UNDER                   : UNDERFLOW LIMIT (CHECK ON COMPUTED VAR.)
           C
           C     ************************************************************************
           C
 00012           DIMENSION A(NDIM,NDIM)
 00012           INTEGER IR(60),IC(60),R,S
           C     CHECK MATRIX ELEMENTS FOR UNDERFLOW POSSIBILITIES
 00012           DO 5 I=1,N
 00013           DO 5 J=1,N
 00014           IF( ABS(A(I,J)).LT.UNDER)  A(I,J) = 0.0E 00
 00027         5 CONTINUE
 00034           DETA=1.                                                       R12D0006
 00035           SUM=0.                                                        R12D0007
 00036           DO 10 I = 1,N                                                 R12D0008
 00037           DO 10 J = 1,N                                                 R12D0009
 00040        10 SUM=SUM+A(I,J)**2                                             R12D0010
 00052           SUM= SQRT(SUM)                                                R12D0011
 00054           DMA = N**2                                                    R12D0012
 00061           RMS=SUM/DMA                                                   R12D0013
 00063           TOL=EPS*RMS                                                   R12D0014
 00064           DO 20 I = 1,N                                                 R12D0015
 00066           IR(I)=0                                                       R12D0016
 00067        20 IC(I)=0                                                       R12D0017
 00072           S=0                                                           R12D0018
 00073           R = N                                                         R12D0019
 00074        30 I=0                                                           R12D0020
 00075           J=0                                                           R12D0021
 00076           TEST=0.0                                                      R12D0022
 00077           DO 50 K = 1,N                                                 R12D0023
 00100           IF(IR(K).NE.0)GO TO50                                         R12D0024
 00102           DO 40 L = 1,N                                                 R12D0025
 00103           IF(IC(L).NE.0)GO TO40                                         R12D0026
 00105           X= ABS(A(K,L))                                                R12D0027
 00112           IF(X.LT.TEST)GO TO40                                          R12D0028
 00114           I=K                                                           R12D0029
 00116           J=L                                                           R12D0030
 00117           TEST=X                                                        R12D0031
 00120        40 CONTINUE                                                      R12D0032
 00123        50 CONTINUE                                                      R12D0033
 00126           PIV=A(I,J)                                                    R12D0034
```

```
      IF( ABS(DETA).LT.UNDER)  DETA = 0.00E 00
      DETA=PIV*DETA
      IF ( ABS(PIV) .LE. TOL) GO TO 150
      IR(I)=J
      IC(J)=I
      PIV = 1.0E0/PIV
      A(I,J)=PIV
      DO 60 K = 1,N
   60 IF(K.NE.J)A(I,K)=A(I,K)*PIV
      DO 90 K = 1,N
      IF (K.EQ.I) GO TO 90
      PIV1 = A(K,J)
   70 DO 80 L = 1,N
      IF( ABS(PIV1).LT.UNDER)  PIV1=0.0E 00
      IF( ABS(A(I,L)).LT.UNDER)  A(I,L) = 0.00E 00
   80 IF(L.NE.J)A(K,L)=A(K,L)-PIV1*A(I,L)
   90 CONTINUE
      DO 100 K = 1,N
  100 IF(K.NE.I)A(K,J)=-PIV*A(K,J)
      S=S+1
      IF(S.LT.R)GO TO 30
  110 DO 140 I = 1,N
      K=IC(I)
      M=IR(I)
      IF(K.EQ.I)GO TO 140
      DETA=-DETA
      DO 120 L = 1,N
      TEMP=A(K,L)
      A(K,L)=A(I,L)
  120 A(I,L)=TEMP
      DO 130 L = 1,N
      TEMP=A(L,M)
      A(L,M)=A(L,I)
  130 A(L,I)=TEMP
      IC(M)=K
      IR(K)=M
  140 CONTINUE
  150 IRANK=S
      RETURN
      END
```

```
                 SUBROUTINE 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),
                1                    SCY(20),STY(20),TY(20)
00011            DIMENSION           S11(20),S12(20),S21(20),S22(20),
                1                    SINS(20),COSS(20),SIN2(20),COS2(20),
                2                    F(3,20),G(3,20),H(3,20)
00011            COMMON   /SET01/ E11,E22,V12,V21,G12
00011            COMMON   /SET06/ SIN2,COS2,SINS,COSS
00011            COMMON   /SET08/ S11,S22,S12,S21
00011            COMMON   /SET10/ STY,SCY,TY,XM,XN
          C
00011            N =  LAY
00012            T12S =  (SG(I+2*N,1)/TY(I))**2
00016            T12D =   SG(I+2*N,1)/TY(I) **2
00022            T22S =  (SG(I+N,1)/TY(I))**2
00025            T22D =   SG(I+N,1)/TY(I) **2
00031            C12T =  SG(I+2*N,1)*SG(I+N,1)/TY(I)**2
00037            IF(SG(I+N,1)- 0.0) 1,2,2
00043          1 VAL =SCY(I)*1.0E-60
00046            RAT=SG(I+2*N,1)*SG(I+N,1)/SCY(I)
00054            VAL= ABS(VAL)
00056            RAT = ABS(RAT)
00057            IF( RAT.LE.VAL) RAT=0.0E00
00062            C12S = RAT/ SCY(I)
00064            TS22S  =(SG(I+N,1)/SCY(I))**2
00070            GO  TO  3
00071          2  VAL = STY(I)* 1.00E-60
00074             RAT =SG(I+2*N,1)*SG(I+N,1)/STY(I)
00102             VAL = ABS(VAL)
00104             RAT =  ABS(RAT)
00105             IF(RAT.LE.VAL) RAT=0.0E00
00110            C12S=RAT/STY(I)
00112            TS22S  =(SG(I+N,1)/STY(I))**2
00116          3  S12S = T12S +TS22S
00120            IF( ABS(S12S).LT.1.00E-20)  GO TO 40
00123            PN12 =  S12S**((XN-1.)/2.)
00132            PN32 =  S12S**((XN-3.)/2.)
00141            PM12 =  S12S**((XM-1.)/2.)
00150            PM32 =  S12S**((XM-3.)/2.)
00157            GO TO 80
00160         40 CONTINUE
00160            PN12 =  0.
00161            PN32 =  0.
00162            PM12 =  0.
00163            PM32 =  0.
00164         80 CONTINUE
          C
00164            SNS  =  SINS(I)
00166            CSS  =  COSS(I)
```

```
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/E22(I) + SNS/E22(I)*PN12
        1           + SNS*TS22S*(XN-1.)/E22(I)*PN32
        2           - SN2*(XM-1.)/(2.*G12(I))*PM32*C12S
00227         F(3,I) = -SN2/(2.*G12(I)) - SN2/(2.*G12(I))*PM12
        1           - SN2*T12S*(XM-1.)/(2.*G12(I))*PM32
        2                     + C12T*(XN-1.)/E22(I)*PN32
00253         G(1,I) =  S11(I)*SNS + S21(I)*CSS
00260         G(2,I) =  SNS*S12(I) + CSS/E22(I) + PN12*CSS/E22(I)
        1           + CSS     *(XN-1.)*PN32/E22(I)*TS22S
        2           + (XM-1.)*C12S*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*T12S
        2          + (XN-1.)*C12T*PN32*CSS/E22(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)) - (XN-1.)*PN32*SN2/(2.*E22(I))
        2               *TS22S           +(XM-1.)*C12S*PM32
        3               *CS2/(2.*G12(I))
00373         H(3,I)=  CS2/(2.*G12(I))+ PM12*CS2/(2.*G12(I))
        1           + (XM-1.)*PM32              *T12S*CS2/(2.*G12(I))
        2           - (XN-1.)*C12T*PN32              *SN2/(2.*E22(I))
00421         RETURN
        C
00422         END
```

```
                  SUBROUTINE RESET(LT3,SG,RVAL)
          C
          C       ROUTINE RESET SETS RELATIVEY SMALL STRESS TERMS EQUAL TO ZERO,
          C       TO AVOID CONVERGENCE DIFFICULTIES (I.E., VALUES ) RVAL)
          C
          C
000006            DIMENSION        SG(LT3,1)
          C
          C       FIND MAXIMUM STRESS VALUE
000006            SGMX =    ABS(SG(1,1))
000010            DO 318 K=2,LT3
000011            IF( ABS(SG(K,1)).GT.SGMX)   SGMX =    ABS(SG(K,1))
000025        318 CONTINUE
          C       COMPARE EACH RELATIVE STRESS VALUE TO RVAL
000030            DO 319 K=1,LT3
000031            RAT =    ABS(SG(K,1)/SGMX)
000037            IF(RAT.LT.RVAL)      SG(K,1)   =   0.0E 00
000046        319 CONTINUE
000051            RETURN
000051            END
```

```
                    SUBROUTINE CONVR(LAY,SG,SG1,KSG,IRTN)
              C
              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,UPBD,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              SUB =   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) =  SUB
000034          335 CONTINUE
000034              IF(DIF(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(DIF(J3).LE.UPBD)  GO TO 375
000046              ICON =  4
000047              GO TO 375
              C
              C     DIVERGENCE  CHECK
000050          350 IF(DIF(J3).LE.UPBD) 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) UPBD
000121          395 CONTINUE
```

```
000121          NITP =  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),SG1(I,1),SG1(I+N,1),
               1              SG1(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
           C
000252     1550 FORMAT (I4,1X,2(3E13.5,4X),3E13.5)
000252     1720 FORMAT (* SOLUTION  FOR  STRESS  DOES  NOT  CONVERGE+*)
000252     1722 FORMAT (* RELATIVE  ERROR  .GT.*,E15.5)
000252     1730 FORMAT (* SOLUTION  FOR  STRESS  DIVERGES+*)
000252     1741 FORMAT (/18X,*(ITERATION *,I3,*)*,28X,*(ITERATION *,I3,*)*)
000252     1742 FORMAT (  * LAYER*,4X,*SGM X*,8X,*SGM Y*,8X,*SGM XY*,11X,*SGM X*,
               1        8X,*SGM Y*,8X,*SGM XY*,11X,*REL X*,8X,*REL Y*,8X,
               2        *REL XY*/)
000252          END
```

```
                     SUBROUTINE LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SW)
               C
               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 SEPARTE MODES
               C                               FOR MULTI-MODE FAILURE ANALYSIS (I.E., IFCN=4)
               C     IFCN                    : FAILURE ANALYSIS OPTION
               C     LFAIL                   : FAILURE MODE
               C     IJJ                     : ORIEINATION OF STRESS FAILURE
               C     KJJ                     : ORIENTATION OF STRAIN FAILURE
               C     QIT(I)                  : QUADRATIC INTERACTION TERM FOR LAYER I
               C     QPV(I)                  : QUADRATIC INTERACTION TERM FOR LAYER I  PROV.LOAD
               C     FAC                     : INTERPOLATION FACTOR
               C     IST                     : STORE LAYER NO. AT FAILURE
               C     ISV                     : STORE STRESS ORIENTATION NO. AT FAILURE
               C     KSV                     : STORE STRAIN ORIENTATION NO. AT FAILURE
               C
               C     ***********************************************************************
               C
000016               DIMENSION         SG(60,1),SGS(60)
000016               DIMENSION         EPS11(20),EPS22(20),EPS12(20)
000016               DIMENSION         P11(20),P22(20),P12(20),
                    1                  ULT(6,2),ULTIMA(6,2,20),
                    1                  EP11(20),EP22(20),EP12(20)
000016               DIMENSION         QIT(20),QPV(20)
000016               DIMENSION         A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
000016               DIMENSION         EPN(60,1),PS(60)
000016               INTEGER           UFAIL(3),SW,T
               C
000016               COMMON   /SET03/EP11,EP22,EP12
000016               COMMON   /SET04/ SO11,SO22,SO12,SM11,SM22,SM12
000016               COMMON   /SET05/ ULTIMA,STIFF
000016               COMMON   /SET07/EPS11,EPS22,EPS12
000016               COMMON   /SET14/ A11,A22,A44,A12,B1,B2
               C
               C     EVALUATE QUADRATIC INTERACTION COEFFICIENTS IF QUAD. INTER. FAILURE
000016               IF((IFCN.EQ.3).OR.(IFCN.EQ.4))    CALL QUADCF(LAY)
000032               IST = 1
000033               LFAIL = 0
000034               IPT = 1
               C
000035           500 CONTINUE
000035               DO 675 I=IST,LAY
000037               T = I
               C
000040               DO 550 II=1,6
000042               DO 550 JJ=1,2
000043               ULT(II,JJ) = ULTIMA(II,JJ,I)
000052           550 CONTINUE
               C
               C     TEST  1:  STIFFNESS  TEST
```

```
000056          IF(KSG.EQ.1) GO TO 560
000060          IF(SO11.EQ.0.0E0)  GO TO 560
000061          RATIO =  ABS(SM11/(EP11(I)-EPS11(I)))
000065          IF(RATIO.LT.STIFF) GO TO 677
         C      TEST  2:  ULTIMATE STRESS
         C                ULT(1,1):  MAX. AXIAL TENS.       ULT(1,2):  MAX. AXIAL COMP.
         C                ULT(2,1):  MAX. TRAN. TENS.       ULT(2,2):  MAX. TRAN. COMP.
         C                ULT(3,1):  MAX. SHEAR
000070      560 CONTINUE
000070          IF(.NOT.((IFCN.EQ.1).OR.(IFCN.EQ.4)))  GO TO 570
000100          IF((UFAIL(1).EQ.1).AND.(IFCN.EQ.4))  GO TO 570
000107          IJJ=1
000110          IF(SG(I,1)-0.0) 1,1,2
000113        1 IF( ABS(SG(I,1))-ULT(1,2))3,679,679
000120        2 IF(      SG(I,1) -ULT(1,1))3,679,679
000124        3 K= I+LAY
000126          IJJ=2
000127          IF(SG(K,1)-0.0)4,4,5
000132        4 IF( ABS(SG(K,1))-ULT(2,2))6,679,679
000137        5 IF(SG(K,1) -ULT(2,1))6,679,679
000143        6 K= I+2*LAY
000145          IJJ=3
000146          IF( ABS(SG(K,1))-ULT(3,1))570,679,679
         C
         C      TEST  3:  ULTIMATE STRAIN
         C                ULT(4,1):  MAX. AXIAL TENS.       ULT(4,2):  MAX. AXIAL COMP.
         C                ULT(5,1):  MAX. TRAN. TENS.       ULT(5,2):  MAX. TRAN. COMP.
         C                ULT(6,1):  MAX. SHEAR
000153      570 CONTINUE
000153          IF(.NOT.((IFCN.EQ.2).OR.(IFCN.EQ.4)))  GO TO 580
000163          IF((UFAIL(2).EQ.1).AND.(IFCN.EQ.4))  GO TO 580
000173          KJJ = 1
000174          IF(EPN(I,1)-0.0) 71,71,72
000177       71 IF( ABS(EPN(I,1))-ULT(4,2))73,689,689
000204       72 IF(      EPN(I,1)-ULT(4,1))73,689,689
000210       73 CONTINUE
000210          K = I+LAY
000212          KJJ = 2
000213          IF(EPN(K,1)-0.0) 74,74,75
000216       74 IF( ABS(EPN(K,1))-ULT(5,2))76,689,689
000223       75 IF(EPN(K,1)-ULT(5,1))76,689,689
000227       76 CONTINUE
000227          K = I+2*LAY
000231          KJJ = 3
000232          IF( ABS(EPN(K,1))-ULT(6,1))580,689,689
         C
         C
         C      TEST  4:  QUADRATIC INTERACTION
000237      580 CONTINUE
000237          IF(.NOT.((IFCN.EQ.3).OR.(IFCN.EQ.4)))  GO TO 590
000247          IF((UFAIL(3).EQ.1).AND.(IFCN.EQ.4))  GO TO 675
000257          QIT(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         +B1(I)*SG(I,1) + B2(I)*SG(I+LAY,1)
000312          IF(      QIT(I) .GT.1.0)  GO TO 699
```

```
              C
000316          590 CONTINUE
              C
000316          675 CONTINUE
000321              IF (LFAIL.NE.0)  GO TO 810
000322              WRITE(6,1995)
000325              RETURN
              C
              C     SET INDICATOR OF FAILURE MODE
000326          677 LFAIL = 1
000327              KSG = KSGM
000334              GO TO 700
000335          679 LFAIL = 2
000336              IST = T
000340              GO TO 700
000340          689 LFAIL = 3
000341              IST = T
000343              GO TO 700
000343          699 LFAIL = 4
000344              IST = T
000346              QPV(T) = A11(T)*SGS(T) **2 + A22(T)*SGS(T+LAY) **2
                *           +A44(T)*SGS(T+2*LAY )**2 + A12(T)*SGS(T )*SGS(T+LAY)
                *           +B1(T)*SGS(T ) + B2(T)*SGS(T+LAY )
              C
              C     PRINT FAILURE MODE
000401          700 CONTINUE
000401              IF(IPT.EQ.1)  WRITE(6,1990)
000413              IPT = 0
000414              IF(IFCN.NE.4)  KSG=KSGM
000420              GO TO (701,703,723,743), LFAIL
000430          701 WRITE(6,1450)
000434              GO TO 850
000440          703 CONTINUE
000440              ISV = IJJ
000442              GO TO(704,705,706),IJJ
000450          704 WRITE(6,1452)
000454              GO TO 799
000460          705 WRITE(6,1453)
000464              GO TO 799
000470          706 WRITE(6,1454)
000474              GO TO 799
              C
000500          723 CONTINUE
000500              KSV = KJJ
000502              GO TO (724,725,726), KJJ
000510          724 WRITE(6,1462)
000514              GO TO 799
000520          725 WRITE(6,1463)
000524              GO TO 799
000530          726 WRITE(6,1464)
000534              GO TO 799
              C
000540          743 WRITE(6,1472)  QIT(T),T,QPV(T),T
              C
000554          799 CONTINUE
```

```
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
000605          GO TO 500
000606      810 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
```

```
                  SUBROUTINE LAYSUB (A12,STY,SCY,TY,EPS11,EPS22,EPS12)
000012            DIMENSION E11(20),E22(20),V12(20),V21(20),G12(20),A12(20),
                 1   STY(20),SCY(20),TY(20),EPS11(20),EPS22(20),EPS12(20)
000012            DIMENSION  TE11(20),TE22(20),TG12(20),TV12(20),TA12(20),TSTY(20),
                 1             TSCY(20),TTY(20)
000012            COMMON   /SET01/ E11,E22,V12,V21,G12
000012            COMMON   /SET17/ TE11,TE22,TG12,TV12,TA12,TSTY,TSCY,TTY
000012            DO 10 I = 1,20
000013            E11(I) = TE11(I)
000015            E22(I) = TE22(I)
000017            G12(I) = TG12(I)
000021            V12(I) = TV12(I)
000023            A12(I) = TA12(I)
000025            STY(I) = TSTY(I)
000027            SCY(I) = TSCY(I)
000031         10 TY(I)  = TTY(I)
000035            RETURN
000036            END
```

```
                REAL FUNCTION SINT(VAL,PREV,IOR,SS,I,N)
           C
           C    FUNCTION SUBPROGRAM SINT DERTIMINES INTERPOLATION FACTOR FOR
           C    STRES OR STRAIN FAILURE
           C
           C                                    * VARIABLE DICTIONARY *
           C
           C    VAL(I,1)             : VALUE OF STRESS OR STRAIN AFTER FAILURE
           C    PREV(I)              : VALUE OF STRESS OR STRAUN BEFORE FAILURE
           C    FLEMT                : ELEMENT OF STRESS OR STRAIN ARRAY WHICH HAS FAIL
           C    SINT                 : INTERPOLATION FACTOR
           C
           C    ********************************************************************
           C
000011          DIMENSION        VAL(60,1),PREV(60),ULT(6,2,20)
000011          COMMON   /SET05/ ULT,STIFF
000011          INTEGER          SS,ELEMT
           C
           C
000011          IF (SS.EQ.1)  IOS=IOR
000014          IF (SS.EQ.2)  IOS=IOR+3
000020          FLEMT = (IOR-1)*N + I
           C
000023          ISN=2
000024          IF (VAL(FLEMT,1).GT.0.00)  ISN=1
           C
000030          DPRV =  ABS(PREV(ELEMT))
000033          DDIF =  ABS(VAL(ELEMT,1)-PREV(ELEMT))
000036          SINT  = (ULT(IOS,ISN,I)-DPRV)/DDIF
           C
           C
000045          RETURN
000046          END
```

```
                  BLOCK DATA
            C
            C     BLOCK DATA SUBPROGRAM INITIALIZES VARIABLES
            C     IN COMMON SETS 01,05,10,11,14
            C
000002            COMMON    /SET01/ DUM01(100)
000002            COMMON    /SET05/ ULT(240),STIFF
000002            COMMON    /SET10/ DUM10(62)
000002            COMMON    /SET11/ EPS,UPBD,NIT,IT,SMLT
000002            COMMON    /SET14/ A11,A22,A44,A12,B1,B2
000002            COMMON    /SET15/ POINTS,IPRINT,IOPT,IPTS,LUP
000002            DIMENSION         A11(20),A22(20),A44(20),B1(20),B2(20)
000002            DIMENSION         A12(20),POINTS(50,6,20)
000002            DATA              STIFF/0.100/
000002            DATA              A12/20*0.0/
000002            DATA              DUM01/100*0.0/
000002            DATA              ULT/240*0.0/
000002            DATA              DUM10/60*0.00,2*3.00/
000002            DATA              EPS/.001/,UPBD/20000./
000002            DATA              IT/100/
000002            DATA              IPRINT/0/
            C
000002            END
```

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