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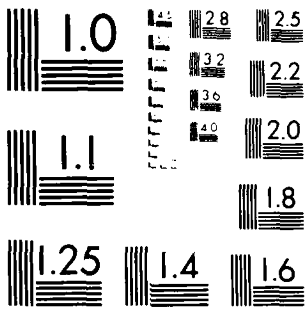

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AFWAL-TR-83-4041

AN APPLE COMPUTER PROGRAM FOR THE ANALYSIS OF COMPOSITE LAMINATES

HERZL CHAI
Universal Energy Systems, Inc.
Dayton, OH 45432

March 1983

Approved for public release; distribution unlimited.

MATERIALS LABORATORY
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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

STEPHEN W. TSAI, Chief
Mechanics & Surface Interactions Branch
Nonmetallic Materials Division

FOR THE COMMANDER

FRANKLIN D. CHERRY, Chief
Nonmetallic Materials Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The proposed numerical code which is based on lamination plate theory is capable of determining characteristics of general laminates with cores. The laminate may be subjected to mechanical or hygrothermal loadings. The main features of this program are:

a) calculating stiffness and compliance matrices;

b) calculating effective stresses and moments resulting from temperature or moisture content change;

(over)

c) calculating on-axis and off-axis interlaminar strains arising from mechanical or hygrothermal effects

d) conducting strength analysis using the Tsai-Hill or maximum strain criterion.

The program is in Applesoft and can be executed from an Apple computer terminal. It is saved on a disk* obtainable from Dr. S. W. Tsai, AFWAL/MLBM, Wright-Patterson AFB, Ohio 45433, Tel: (513) 255-3068. Material properties for five commonly used composites are stored in the program. Output is displayed on a CRT screen as well as on a "hard copy" using a surface printer.

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* Different disks are available for Apple I and Apple II computers.

FOREWORD

This report is an inhouse effort conducted in the Mechanics and Surface Interactions Branch, Nonmetallic Materials Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, (AFWAL/MLBM), under the Visiting Scientist program with Universal Energy Systems, Inc., Air Force Contract #F33615-82-C-5001. This work was performed during the period of Oct. 82 to Dec. 82.

The writer is grateful to Dr. S.W. Tsai for supporting this work and for valuable discussions.

TABLE OF CONTENTS

I. INTRODUCTION

The behavior of a composite laminate depends on variety of characteristics including stiffness, strength and behavior under environmental changes. The large number of parameters and the extensive amount of calculations involved in the characterization of composite laminates suggest the use of electronic computers. Algorithms for solutions of laminate problems in various computing facilities are given in [1-3]*. In the present work an algorithm for the solution of the general laminate shown in Figure 1 is provided using an Apple computer.

A review of relevant equations is provided in Section II which includes modulus and compliance analysis, hygrothermal effects, strain computation, and strength analysis. This material is based on a book by S. W. Tsai and H. T. Hahn, [4].

Instruction for program running and control is given in Section III. This includes data input procedure and printout control.

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* 1. S. W. Tsai, R. Aoki, "TI-59 Magnetic Card Calculator Solutions to Composite Materials Formulas", AFML-TR-79-4040.

2. Som R. Soni, "A Digital Algorithm for Composite Laminate Analysis-Fortran", AFWAL-TR-81-4073.

3. Won J. Park, "Radio Shack TRS-80 Pocket Computer Solutions to Composite Materials Formulas", AFWAL-TR-81-4074.

4. S. W. Tsai, H. T. Hahn, "Introduction to Composite Materials", Technomic Publishing Co., Westport, CT 06880, July 1980.

II. REVIEW OF EQUATIONS

A short review of relevant equations is given in this section. For a detailed derivation the reader is referred to reference 4.

1. Modulus and Compliance Analysis

With deformation prescribed, the effective loads are found from*

$$\begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ M_1 \\ M_2 \\ M_3 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & B_{11} & B_{12} & B_{13} \\ & A_{22} & A_{23} & B_{21} & B_{22} & B_{23} \\ & & A_{33} & B_{31} & B_{32} & B_{33} \\ & & & D_{11} & D_{12} & D_{13} \\ & \text{SYM.} & & & D_{22} & D_{23} \\ & & & & & D_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_1^o \\ \varepsilon_2^o \\ \varepsilon_3^o \\ k_1 \\ k_2 \\ k_3 \end{bmatrix} \text{ or } \begin{bmatrix} \underset{\sim}{N} \\ \underset{\sim}{M} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{A} & \underset{\sim}{B} \\ \underset{\sim}{B} & \underset{\sim}{D} \end{bmatrix} \begin{bmatrix} \underset{\sim}{\varepsilon}^o \\ \underset{\sim}{k} \end{bmatrix} \tag{1.1}$$

where ε_i^o and k_i, $i = 1\text{-}3$, are mid-surface strain and curvature components, respectively, and N_i, M_i, $i = 1\text{-}3$, are average forces per unit length and average moments per unit length, respectively. Referring to Figure 1 for notation, the stiffness matrices in (1.1) are given by

	V_{0x}	U_2	U_3
x_{11}	U_1	V_{1x}	V_{2x}
x_{22}	U_1	$-V_{1x}$	V_{2x}
x_{12}	U_4		$-V_{2x}$
x_{33}	U_5		$-V_{2x}$
x_{13}		$V_{3x/2}$	V_{4x}
x_{23}		$V_{3x/2}$	$-V_{4x}$

, $x = A, B, D$ (1.2)

---

* For convenience the axis "6" in reference 4 is replaced in this work by "3"

where

$$[V_{iA}, V_{iB}, V_{iD}] = \int_{-h/2}^{h/2} \phi \cdot f_i [1, z, z^2] dz \ , \ i = 0\text{-}4$$

$f_0 = 1, \quad f_1 = \cos 2\theta, \quad f_2 = \cos 4\theta, \quad f_3 = \sin 2\theta, \quad f_4 = \sin 4\theta$

$$\phi = 0 \text{ for } {}^{-h}/_2 + Mh_0 \leqslant z \leqslant {}^{-h}/_2 + Mh_0 + h_c \ , \quad \phi = 1 \text{ otherwise} \qquad (1.3)$$

h_0, h_c, h = ply, core, and laminate thickness, respectively

M = number of plies below core

$$\begin{aligned} U_1 &= (3Q + 2Q_{xy} + 4Q_{ss}) / 8 \\ U_2 &= (Q_{xx} - Q_{yy}) / 2 \\ U_3 &= (Q - 2Q_{xy} - 4Q_{ss}) / 8 \\ U_4 &= (Q + 6Q_{xy} - 4Q_{ss}) / 8 \\ U_5 &= (Q - 2Q_{xy} + 4Q_{ss}) / 8 \\ Q &= Q_{xx} + Q_{yy} \end{aligned} \qquad (1.4)$$

$Q_{xx} = m_0 E_x$, E_x = longitudinal Young's modulus

$Q_{yy} = m_0 E_y$, E_y = transverse Young's modulus

$Q_{xy} = Q_{yx} = m_0 E_y \nu_x$, ν_x = longitudinal Poisson's ratio (1.5)

$Q_{ss} = E_s$, E_s = longitudinal shear modulus

$$m_0 = 1/(1 - \nu_x^2 E_y / E_x)$$

With the aid of (1.1), the deformation can be expressed in terms of effective loads

$$\begin{bmatrix} \underset{\sim}{\varepsilon}^0 \\ \underset{\sim}{k} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{\alpha} & \underset{\sim}{\beta} \\ \underset{\sim}{\beta}^T & \underset{\sim}{\delta} \end{bmatrix} \begin{bmatrix} \underset{\sim}{N} \\ \underset{\sim}{M} \end{bmatrix} \qquad (1.6)$$

where $\underset{\sim}{\alpha} = \underset{\sim}{A}^{-1} - \underset{\sim}{\beta}\underset{\sim}{B}\underset{\sim}{A}^{-1}$, $\underset{\sim}{\beta} = -\underset{\sim}{A}^{-1}\underset{\sim}{B}\underset{\sim}{\delta}$, $\underset{\sim}{\delta} = (\underset{\sim}{D} - \underset{\sim}{B}\underset{\sim}{A}^{-1}\underset{\sim}{B})^{-1}$ (1.7)

It is possible to normalize (1.1) and (1.6) with respect to the total laminate thickness, h. The results are:

$$\begin{bmatrix} \underset{\sim}{N}^* \\ \underset{\sim}{M}^* \end{bmatrix} = \begin{bmatrix} \underset{\sim}{A}^* & \underset{\sim}{B}^* \\ 3\underset{\sim}{B}^* & \underset{\sim}{D}^* \end{bmatrix} \begin{bmatrix} \underset{\sim}{\varepsilon}^{o*} \\ \underset{\sim}{k}^* \end{bmatrix} \tag{1.8}$$

$$\begin{bmatrix} \underset{\sim}{\varepsilon}^{o*} \\ \underset{\sim}{k}^* \end{bmatrix} \begin{bmatrix} \underset{\sim}{\alpha}^* & \underset{\sim}{\beta}^*/3 \\ \underset{\sim}{\beta}^{*T} & \underset{\sim}{\delta}^* \end{bmatrix} \begin{bmatrix} \underset{\sim}{N}^* \\ \underset{\sim}{M}^* \end{bmatrix} \tag{1.9}$$

where

$$\begin{aligned} &\underset{\sim}{A}^* = \underset{\sim}{A}/h, \quad \underset{\sim}{B}^* = 2\underset{\sim}{B}/h^2, \quad \underset{\sim}{D}^* = 12\underset{\sim}{D}/h^3 \\ &\underset{\sim}{\alpha}^* = \underset{\sim}{\alpha}h, \quad \underset{\sim}{\beta}^* = \underset{\sim}{\beta}\, h^2/2, \quad \underset{\sim}{\delta}^* = \underset{\sim}{\delta}h^3/12 \\ &\underset{\sim}{N}^* = \underset{\sim}{N}/h, \quad \underset{\sim}{M}^* = 6\underset{\sim}{M}/h^2 \\ &\underset{\sim}{\varepsilon}^{o*} = \underset{\sim}{\varepsilon}^{o}, \quad \underset{\sim}{k}^* = \underset{\sim}{k}h/2 \end{aligned} \tag{1.10}$$

2. Hygrothermal Analysis

The effective loads generated by temperature change, ΔT, and moisture content change, C, are determined using the following procedure:

(i) The nonmechanical strain components, e_i, are given by

$$e_i = \alpha_i \Delta T + \beta_i C, \quad i = x,y \;, \; e_s = 0 \tag{2.1}$$

where α_i and β_i are coefficients of thermal expansion and swelling, respectively.

(ii) The stresses required to produce these strains, σ_j^N, are found from

$$\sigma_j^N = Q_{jk} e_k, \quad J,k = x,y \;, \; \sigma_s^N = 0 \tag{2.2}$$

where the superscript "N" has been assigned to indicate nonmechanical stresses.

(iii) The on-axis stresses in (2.2) can be transformed to off-axis stresses using (2.3)

$$\begin{array}{c|c|c|}
 & p^N & q^N \\ \hline
\sigma_1^N & 1 & \cos 2\theta \\
\sigma_2^N & 1 & -\cos 2\theta \\
\sigma_3^N & & \sin 2\theta \\ \hline
\end{array} \tag{2.3}$$

where $p^N = (\sigma_x^N + \sigma_y^N)/2,\ q^N = (\sigma_x^N - \sigma_y^N)/2$

(iv) The effective nonmechanical forces and moments are given by

$$[N_i^N, M_i^N] = \int_{-h/2}^{h/2} \phi \cdot \sigma_i^N [1,z]\, dz,\ i = 1 - 3$$

or

$$\begin{array}{c|c|c|}
 & p^N & q^N \\ \hline
N_1^N\ ,\ M_1^N & V_{0A},\ V_{0B} & V_{1A},\ V_{1B} \\
N_2^N\ ,\ M_2^N & V_{0A},\ V_{0B} & -V_{1A},\ -V_{1B} \\
N_3^N\ ,\ M_3^N & & V_{3A},\ V_{3B} \\ \hline
\end{array} \tag{2.4}$$

where the V's and ϕ are defined in (1.3)

3. Strain Analysis

The object here is to determine on-axis and off-axis interlaminar strains from prescribed loadings (mechanical or nonmechanical).

Assuming a linear strain variation across the laminate thickness, i.e.

$$\underset{\sim}{\varepsilon} = \underset{\sim}{\varepsilon}^{o} + z\underset{\sim}{k} \tag{3.1}$$

and using (1.6) in (3.1), the off-axis strains at z is given by

$$\underset{\sim}{\varepsilon} = \underset{\sim}{\alpha}\underset{\sim}{N} + \underset{\sim}{\beta}\,\underset{\sim}{M} + z\,(\underset{\sim}{\beta}^{T}\underset{\sim}{N} + \underset{\sim}{\delta}\,\underset{\sim}{M}) \tag{3.2}$$

Next, the on-axis strains are found using the transformation in (3.3)

	p	q	r
ε_x	1	$\cos 2\theta$	$\sin 2\theta$
ε_y	1	$-\cos 2\theta$	$-\sin 2\theta$
ε_s		$-2\sin 2\theta$	$2\cos 2\theta$

(3.3)

where $p = (\varepsilon_1 + \varepsilon_2)/2$, $q = (\varepsilon_1 - \varepsilon_2)/2$, $r = \varepsilon_3/2$

4. Strength Analysis

In this work laminate strength is examined using two failure criteria , i.e. the Tsai-Hill and the Maximum Strain.

In the maximum strain criterion failure is assumed when one of the six conditions below met first

$$\begin{aligned} &\varepsilon_x, \varepsilon_y, \varepsilon_s > 0: (\varepsilon_x, \varepsilon_y, \varepsilon_s)\Big|_{\text{allowed}} = (X/E_x, Y/E_y, S/E_s) \\ &\varepsilon_x, \varepsilon_y, \varepsilon_s < 0: \quad - \quad '' \quad - \qquad = (-X'/E_x, -Y'/E_y, -S/E_s) \end{aligned} \tag{4.1}$$

where X and X' are longitudinal tensile and compressive strength, respectively, Y and Y' are transverse tensile and compressive strength, respectively, and S is the shear strength.

Defining strength ratio R as

$$R = \varepsilon_{i|allowed}/\varepsilon_{i|imposed}, \quad i = x, y, s \tag{4.2}$$

and assuming nonmechanical strain as well as mechanical strain exist, then, with superscript "M" assigned for mechanical strain

$$\varepsilon_{i|allowed} = R\,\varepsilon_i^M + \varepsilon_i^N - e_i \tag{4.3}$$

using (4.3) in (4.1), one has

$$R = \min. \left[\left(\frac{\bar{X}}{E_x} - \varepsilon_x^N + e_x \right)/\varepsilon_x^M ,\ \left(\frac{\bar{Y}}{E_y} - \varepsilon_y^N + e_y \right)/\varepsilon_y^M ,\ \left(\frac{\bar{S}}{E_s} - \varepsilon_s^N \right)/\varepsilon_s^M \right] \tag{4.4}$$

where $\bar{X}$, $\bar{Y}$, $\bar{S}$ = X, Y, S for positive ε_i^M, i = x, y, s

and $\bar{X}$, $\bar{Y}$, $\bar{S}$ = -X', -Y', -S for negative ε_i^M, i = x, y, s

In the Tsai-Hill criterion failure occurs when

$$G_{ij}\,\varepsilon_{i|allowed}\,\varepsilon_{j|allowed} + G_i\,\varepsilon_{i|allowed} - 1 = 0, \quad i,j = x, y, s \tag{4.5}$$

where the nonvanishing terms in (4.5) are

$$G_i = F_j\,Q_{ij}$$

$$G_{kl} = F_{ij}\,Q_{ik}\,Q_{jl}, \quad i, j, k, l = x, y \tag{4.6}$$

$$G_{ss} = (Q_{ss}/S)^2$$

$$F_x = 1/X - 1/X', \quad F_y = 1/Y - 1/Y'$$

$$F_{xx} = 1/(XX'), \quad F_{yy} = 1/(YY'), \quad F_{xy} = F_{xy}^{*}\,(F_{xx}F_{yy})^{1/2} \tag{4.7}$$

Introducing (4.3) in (4.5), one finds two roots for R, one positive and the other negative. Only the positive solution is given (the negative root corresponds tc a reverse straining).

III PROGRAM CONTROL

The program language is in "Applesoft" ("BASIC" with some additions) and it is described in the Apple instruction manual. The program flow diagram is shown in Table I. Terminology for input and ouput data is given in Table II and computer memory allocation in Table III. The program listing and illustrative examples are shown in page 15 and 21, respectively. Program control and data input procedure are summarized below.

1. Running the program

With the disk inserted into the disk drive, the program "composite" is loaded automatically into the computer memory once the computer is turned on. Note that the disk contains a subprogram used for printing data in scientific format. This program is also automatically loaded into the computer memory.

2. Data Input Procedure

Data are inputted through both program line editing (before running the program) and computer keyboard during program run, according to the procedure outlined in Table I.

For convenience, material properties for five composites and aluminum are stored in the program according to the following scheme:

Program Line	Material Type	Material Identification
40	40	T300/5208 (graphite/epoxy)
50	50	B(4)/5505 (boron/epoxy)
60	60	AS/3501 (graphite/epoxy)
70	70	Scotchply 1002 (glass/epoxy)
80	80	Kevlar 49/epoxy (aramid/epoxy)
90	90	Aluminum

Material selection is achieved through keyboard by inputting the material type number in the table above. Other materials can be analyzed by introducing appropriate material properties in either program line 40 to 90.

Mechanical forces and moments on a per unit length basis are inputted in program lines 940 and 950, respectively. The current values are $N_1 = 1/10^9$ M·GPa, $N_2 = N_3 = M_1 = M_2 = M_3 = 0$. The strength parameter F^*_{xy} is inputted in line 1580. Its current value is -0.5.

3. Printout Control

If a "hard copy" printout is desired the printer should be activated prior to running the program. The display and printing format requires that both the CRT screen and the printer page width should be set to at least 80 character.

For some applications a printout of all output data blocks indicated in Table I may be excessive. A selective output printout is possible using the CN(I), I = 1-8, array in program line 20, as described in Table I. For instance, if in program line 20 we have "CN(1)=0: CN(2)=0: CN(3)=0: CN(4)=0: CN(5)=1: CN(6)=0: CN(7)=0: CN(8)=0", then only on-axis strains will be printed. The current values are CN(I)=1, I = 1-8.

4. Program Pause

As indicated in Table I, after each block printout the program pauses to give the user an ample time to observe the output on the CRT screen. This is accompanied by cursor flashing. To resume computer operation press the "RETURN" key. To eliminate program pause the user should delete the "Get G$" statements in program lines 2130 and 2190.

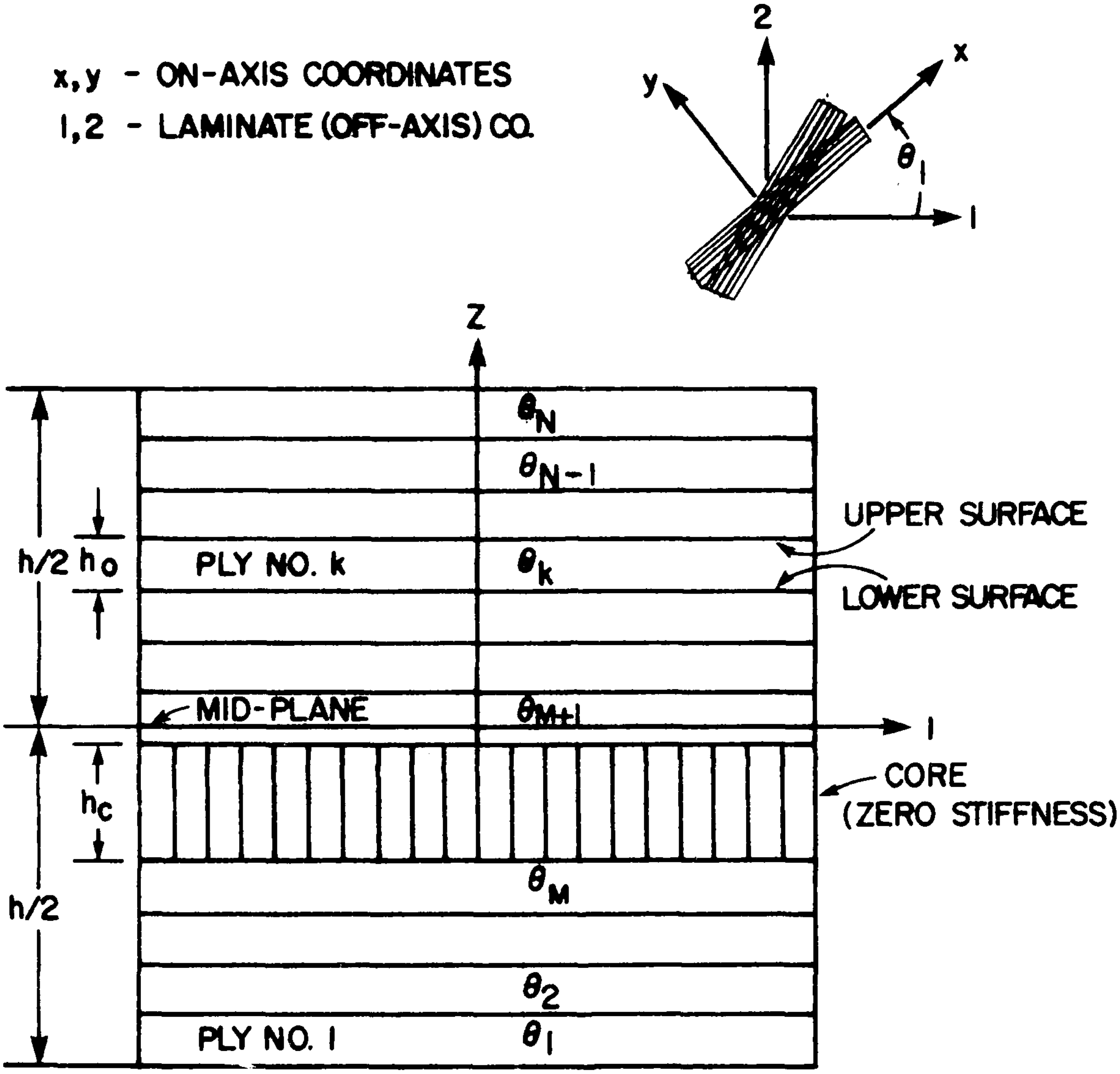

Figure 1. Notation for General Laminate with Core.

TABLE I - FLOW DIAGRAM

NOTATION

- PROGRAM LINE DATA INPUT

- KEY BOARD DATA INPUT (TYPE THE INPUT VALUE AND THEN "RETURN")

CN(I), I=1-8. - DATA PRINTOUT CONTROL PARAMETERS GIVEN IN PROGRAM LINE 20. CN(I)=1 FOR PRINT, CN(I)=0 FOR NO PRINT

- DATA BLOCK PRINTOUT

- PROGRAM PAUSES. PRESS "RETURN" TO CONTINUE

NOTE: SEE FIGURE 1 AND TABLE II FOR OTHER NOTATION

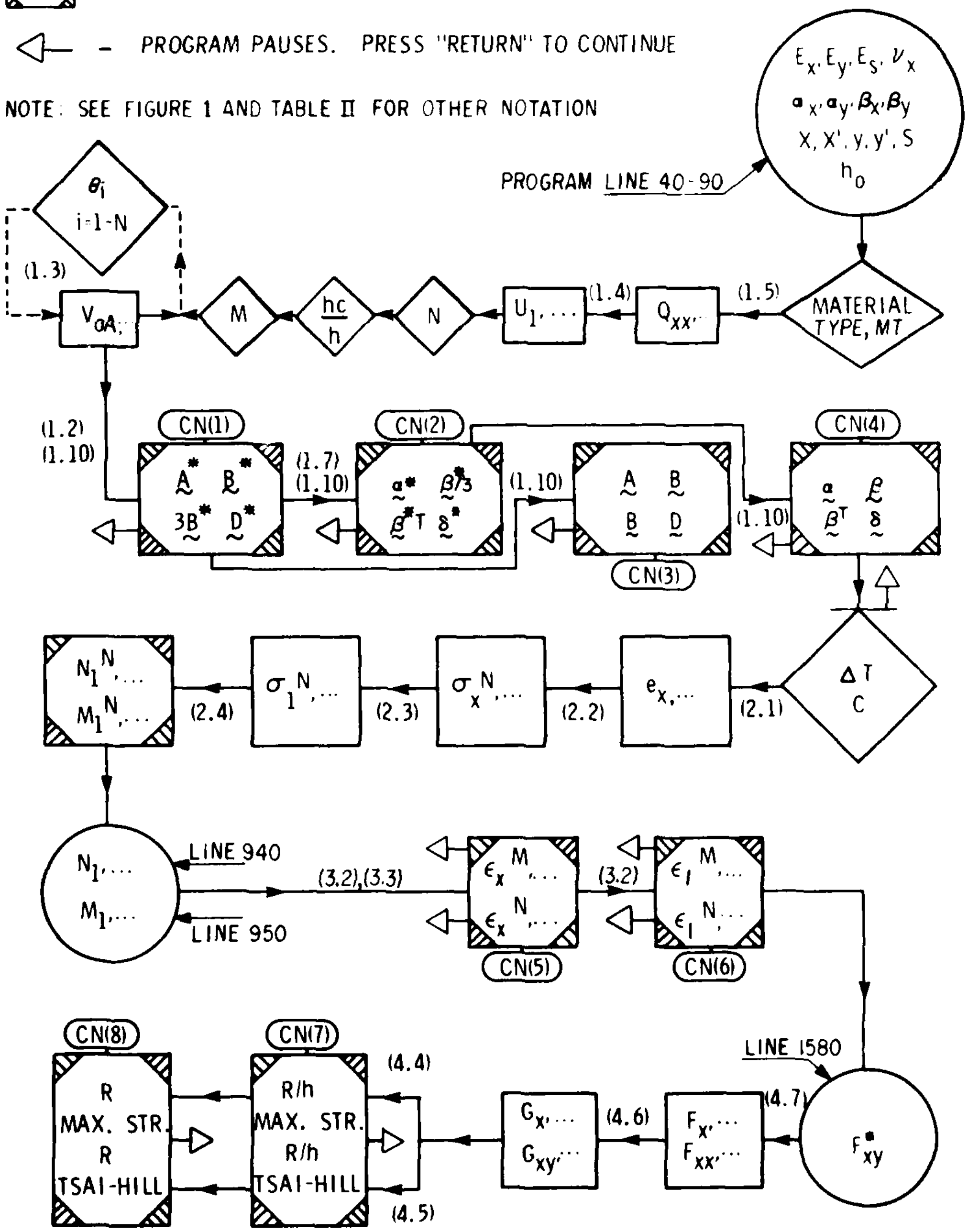

TABLE II

TERMINOLOGY FOR DATA INPUT AND OUTPUT

Data Input

C (C)* - moisture content

h_o, h_c (HO, HC) - ply and core thickness, respectively, (M)**

N, M (N, M) - number of plies in laminate and number of plies below core, respectively

N_i^M, M_i^M (N(I,0), M(I,0), I = 1-3)- effective mechanical force and effective mechanical moment components (on a per unit length basis), respectively, (M·Gpa, M^2·Gpa)

Material Type (MT) - see table in page 8

E_x, E_y (EX, EY) - longitudinal and transverse Young's modulus, respectively, (Gpa)

E_s (ES) - longitudinal shear modulus, (Gpa)

S (S) - longitudinal shear strength, (Gpa)

X, X' (X, XC) - longitudinal tensile and compressive strength, respectively, (Gpa)

Y, Y' (Y, YC) - transverse tensile and compressive strength, respectively, (Gpa)

F_{xy}* (FXY STAR) - Parameter related to material strength (See (4.7))

α_x, α_y (AX, AY) - coefficient of thermal expansion along x and y direction, respectively, (1/K^o)

β_x, β_y (BX, BY) - swelling coefficient in x and y direction, respectively

ν_x (PX) - longitudinal Poisson's ratio = $-\varepsilon_y/\varepsilon_x$

ΔT (DT) - temperature difference, (K^o)

θ_i (O(I)) - orientation of i^{th} ply (Deg.)

Data Output

$\underset{\sim}{A}$, $\underset{\sim}{B}$, $\underset{\sim}{D}$ (A, B, D) - stiffness matrices, (M·Gpa, M^2·Gpa, M^3·Gpa)

$\underset{\sim}{A}$*, $\underset{\sim}{B}$*, $\underset{\sim}{D}$*(A*, B*, D*) - normalized stiffness matrices, (Gpa)

---

*Quantities in parenthesis indicate program variables

**Dimension : M - Meter, pa - paschall, Gpa - 10^9pa, K^o - deg. Kelvin

TABLE II

TERMINOLOGY FOR DATA INPUT AND OUTPUT (CONTINUED)

$\underset{\sim}{N}^M$(N), $\underset{\sim}{N}^N$(NN) - Mechanical and nonmechanical force/unit length Vector, respectively, (M·Gpa)

$\underset{\sim}{M}^M$(M), $\underset{\sim}{M}^N$(MN) - Mechanical and nonmechanical moment/unit length Vector, respectively, (M^2·Gpa)

$\underset{\sim}{N}^{*M}$(N*), $\underset{\sim}{N}^{*N}$(NN*) - normalized mechanical and nonmechanical force/unit length Vector, respectively, (Gpa)

$\underset{\sim}{M}^{*M}$(M*), $\underset{\sim}{M}^{*N}$(MN*) - normalized mechanical and nonmechanical moment/unit length Vector, respectively, (Gpa)

$\underset{\sim}{\alpha}$, $\underset{\sim}{\beta}$, $\underset{\sim}{\beta}^T$, $\underset{\sim}{\delta}$ (ALPHA, BETA, TRBETA, DELTA) - compliance matrices,

(1/M·Gpa, 1/M^2·Gpa, 1/M^2·Gpa, 1/M^3·Gpa)

$\underset{\sim}{\alpha}^*$, $\underset{\sim}{\beta}^*$, $\underset{\sim}{\beta}^{*T}$, $\underset{\sim}{\delta}^*$ (ALPHA*, BETA*, TRBETA*, DELTA*) - normalized compliance matrices, (1/Gpa)

R (R) - strength ratio

TABLE III

COMPUTER MEMORY STORAGE

Modulus and Compliance Components

$X(I, J, 0) \longleftrightarrow \underset{\sim}{A}^*(I, J,)$ $I, J = 1\text{-}3$

$X(I, J, 1) \longleftrightarrow \underset{\sim}{B}^*$

$X(I, J, 2) \longleftrightarrow \underset{\sim}{D}^*$

$X(I, J, 3) \longleftrightarrow \underset{\sim}{\alpha}^*$

$X(I, J, 4) \longleftrightarrow \underset{\sim}{\beta}^*$

$X(I, J, 5) \longleftrightarrow \underset{\sim}{\beta}^{*T}$

$X(I, J, 6) \longleftrightarrow \underset{\sim}{\delta}^*$

Strain Components

$E\ (k, I, 0) \longleftrightarrow \varepsilon^M(I)$ in the k^{th} ply

$E\ (k, I, 1) \longleftrightarrow \varepsilon^N(I)$ in the k^{th} ply

I = 1-3 : on-axis strain components at lower ply surface

I = 4-6 : on-axis strain components at upper ply surface

I = 7-9 : off-axis strain components at lower ply surface

I = 10-12 : off-axis strain components at upper ply surface

Strength Ratio

R1 (k, o)	k^{th} ply, $R_{Tsai\text{-}Hill}$, lower surface
R1 (k, 1)	k^{th} ply, $R_{Tsai\text{-}Hill}$, upper surface
RM (k, o)	k^{th} ply, $R_{Max\ strain}$, lower surface
RM (k, 1)	k^{th} ply, $R_{Max\ strain}$, upper surface

IV. PROGRAM LISTING

```
10  DIM CN(10)
20 CN(1) = 1:CN(2) = 1:CN(3) = 1:CN(4) = 1:CN(5) = 1:CN(6) = 1:CN(7) = 1:C
    N(8) = 1
30  INPUT "MATERIAL TYPE, MT=";MT
40 EX = 181:EY = 10.3:PX = .28:ES = 7.17:HO = .000125:X = 1.5:XC = 1.5:Y =
    .04:YC = .246:S = .068:AX = .02 / 1E6:AY = 22.5 / 1E6:BX = 0:BY = .6:
     IF MT = 40 THEN  GOTO 100
50 EX = 204:EY = 18.5:PX = .23:ES = 5.59:HO = .000125:X = 1.26:XC = 2.5:Y =
    .061:YC = .202:S = .067:AX = 6.1 / 1E6:AY = 30.2 / 1E6:BX = 0:BY = .6
    0: IF MT = 50 THEN  GOTO 100
60 EX = 138:EY = 8.96:PX = .3:ES = 7.1:HO = .000125:X = 1.447:XC = 1.447:Y
     = .0517:YC = .206:S = .093:AX = - .3 / 1E6:AY = 28.1 / 1E6:BX = 0:B
    Y = .44: IF MT = 60 THEN  GOTO 100
70 EX = 38.6:EY = 8.27:PX = .26:ES = 4.14:HO = .000125:X = 1.026:XC = .61:
    Y = .031:YC = .118:S = .072:AX = 8.6 / 1E6:AY = 22.1 / 1E6:BX = 0:BY =
    .6: IF MT = 70 THEN  GOTO 100
80 EX = 76:EY = 5.5:PX = .34:ES = 2.3:HO = .000125:X = 1.4:XC = .275:Y = .
    012:YC = .053:S = .034:AX = - 4.0 / 1E6:AY = 79 / 1E6:BX = 0:BY = .6
    : IF MT = 80 THEN  GOTO 100
90 EX = 69:EY = 69:PX = .3:ES = 26.5:HO = .000125:X = .4:XC = .4:Y = .4:YC
     = .4:S = .23:AX = 22.5 / 1E6:AY = AX:BX = 0:BY = 0: IF MT = 90 THEN
     GOTO 100
100 MP = 1 / (1 - PX * PX * EY / EX)
110  DIM Q(3,3)
120 A$ = "#.##^^^^ "
130 Q(1,1) = MP * EX:Q(2,2) = MP * EY:Q(2,1) = MP * PX * EY
140 Q(1,2) = Q(2,1):Q(3,3) = ES
150 Q = Q(1,1) + Q(2,2)
160 U1 = (3 * Q + 2 * Q(1,2) + 4 * Q(3,3)) / 8
170 U2 = (Q(1,1) - Q(2,2)) / 2
180 U3 = (Q - 2 * Q(1,2) - 4 * Q(3,3)) / 8
190 U4 = (Q + 6 * Q(1,2) - 4 * Q(3,3)) / 8
200 U5 = (Q - 2 * Q(1,2) + 4 * Q(3,3)) / 8
210  INPUT "NUMBER OF PLIES, N=";N
220  INPUT "NORMALIZED CORE THICKNESS, HC/H=";HC
230 H = N * HO / (1 - HC):HN = (1 - HC) / N
240  IF HC = 0 THEN M = N: GOTO 260
250  INPUT "NUMBER OF PLIES BETWEEN Z=-H/2 AND CORE, M=";M
260  PRINT : PRINT "PLY ORIENTATION (FROM Z=-H/2 TO Z=H/2)"
270  DIM O(60),P(60,4),X(3,3,9),V(4,2),W1(60)
```

```
280 D = 0:FK = 1
290  FOR I = 1 TO N
300  INPUT "PLY ANGLE =";O(I)
310  IF N = M THEN  GOTO 330
320  IF I = M THEN  PRINT "CORE, "; INT (( - N + 1 / HN) * 100  + .5) / 100
     ;" PLY THICK"
330 O(I) = O(I) * 3.1415926535 / 180
340 P(I,0) = 1
350 P(I,1) =  COS (2 * O(I))
360 P(I,2) =  COS (4 * O(I))
370 P(I,3) =  SIN (2 * O(I))
380 P(I,4) =  SIN (4 * O(I))
390  IF I > M THEN D = 1
400 W1(I) =  - .5 + D * HC + (I - 1) * HN
410  NEXT I
420  FOR K = 0 TO 2:K1 = K + 1: IF K = 2 THEN FK = 4
430  FOR I = 1 TO N
440  IF K = 0 THEN TT = HN
450  IF K = 1 THEN TT = HN * (HN + 2 * W1(I))
460  IF K = 2 THEN TT = (W1(I) + HN) ^ 3 - W1(I) ^ 3
470  FOR J = 0 TO 4
480 V(J,K) = V(J,K) + P(I,J) * TT * FK
490  NEXT J
500  NEXT I
510 C1 = V(0,K) * U1:C2 = V(1,K) * U2:C3 = V(2,K) * U3:C4 = V(3,K) * U2 /
     2:C5 = V(4,K) * U3
520 X(1,1,K) = C1 + C2 + C3
530 X(1,2,K) = V(0,K) * U4 - C3
540 X(1,3,K) = C4 + C5
550 X(2,1,K) = X(1,2,K)
560 X(2,2,K) = C1 - C2 + C3
570 X(2,3,K) = C4 - C5
580 X(3,1,K) = X(1,3,K)
590 X(3,2,K) = X(2,3,K)
600 X(3,3,K) = V(0,K) * U5 - C3
610  NEXT K
620 LI = 0:LO = 9: GOSUB 2310
630 F = 1:LA = 9:LB = 1:LC = 7: GOSUB 2420
640 F = 1:LA = 1:LB = 9:LC = 8: GOSUB 2420
650 F =  - 3:LA = 1:LB = 7:LC = 6: GOSUB 2420
660 LA = 2:LB = 6:LC = 6: GOSUB 2520
670 LI = 6:LO = 6: GOSUB 2310
680 F =  - 3:LA = 7:LB = 6:LC = 4: GOSUB 2420
690 F =  - 1:LA = 4:LB = 8:LC = 3: GOSUB 2420
700 LA = 9:LB = 3:LC = 3: GOSUB 2520
710  FOR I = 1 TO 3
720  FOR J = 1 TO 3
730 X(J,I,5) = X(I,J,4)
740  NEXT J
750  NEXT I
760  IF CN(1) = 0 THEN  GOTO 800
```

```
770 X$ = "A*":Y$ = "B*":V$ = "(GPA)":Z$ = "3B*":W$ = "D*": GOSUB 2150
780 X1 = 1:X2 = 1:K = 0: GOSUB 2220
790 X1 = 3:X2 = 1:K = 1: GOSUB 2220
800  IF CN(2) = 0 THEN  GOTO 840
810 X$ = "ALPHA*":Y$ = "BETA*/3":V$ = "(1/GPA)":Z$ = "TRBETA*":W$ = "DELT
    A*": GOSUB 2150
820 X1 = 1:X2 = 1 / 3:K = 3: GOSUB 2220
830 X1 = 1:X2 = 1:K = 5: GOSUB 2220
840  IF CN(3) = 0 THEN  GOTO 880
850 X$ = "A":Y$ = "B":V$ = " ":Z$ = "B":W$ = " D": GOSUB 2150
860 X1 = H:X2 = H * H / 2:K = 0: GOSUB 2220
870 X1 = 0.5 * H ^ 2:X2 = H ^ 3 / 12:K = 1: GOSUB 2220
880  IF CN(4) = 0 THEN  GOTO 920
890 X$ = "ALPHA":Y$ = "BETA":Z$ = "TRBETA":W$ = "DELTA": GOSUB 2150
900 X1 = 1 / H:X2 = 2 / H ^ 2:K = 3: GOSUB 2220
910 X1 = 2 / H ^ 2:X2 = 12 / H ^ 3:K = 5: GOSUB 2220
920 X$ = "STRAIN ANALYSIS":Y$ = " ":Z$ = " ":W$ = " ": GOSUB 2150
930  DIM N(3,1),M(3,1),E(60,12,1),S1(3,1),S2(3,1),ET(3)
940 N(1,0) = 1 / 1E9:N(2,0) = 0:N(3,0) = 0
950 M(1,0) = 0:M(2,0) = 0:M(3,0) = 0
960  FOR I = 1 TO 3
970 N(I,0) = N(I,0) / H
980 M(I,0) = M(I,0) / (H * H / 6)
990  NEXT I
1000  INPUT "TEMP. DIFFERENCE (IN K), DT=";DT: INPUT "MOISTURE CONTENTS, C
    =";C: PRINT
1010 ET(1) = AX * DT + BX * C:ET(2) = AY * DT + BY * C
1020 JJ = 1: IF  ABS (DT) +  ABS (C) = 0 THEN JJ = 0
1030  IF JJ = 0 THEN  GOTO 1130
1040 SX = Q(1,1) * ET(1) + Q(1,2) * ET(2)
1050 SY = Q(2,1) * ET(1) + Q(2,2) * ET(2)
1060 PN = .5 * (SX + SY):QN = .5 * (SX - SY)
1070 N(1,1) = PN * V(0,0) + QN * V(1,0)
1080 N(2,1) = PN * V(0,0) - QN * V(1,0)
1090 N(3,1) = QN * V(3,0)
1100 M(1,1) = 3 * (PN * V(0,1) + QN * V(1,1))
1110 M(2,1) = 3 * (PN * V(0,1) - QN * V(1,1))
1120 M(3,1) = 3 * QN * V(3,1)
1130  PRINT  TAB( 8);"EFFECTIVE STRESSES"; TAB( [illegible]);"EFFECTIVE MOMENTS"
1140 EJ$(0) = "MECHANICAL":EJ$(1) = "NON-MECHANICAL"
1150 A$(1,0) = "N* ":A$(2,0) = "M* ":A$(3,0) = "N  ":A$(4,0) = "M  "
1160 A$(1,1) = "NN*":A$(2,1) = "MN*":A$(3,1) = "NN ":A$(4,1) = "MN "
1170  FOR J = 0 TO JJ:X1 = 1:X2 = 1
1180  PRINT  TAB( 27);EJ$(J)
1190  FOR L = 0 TO 1: PRINT A$(1 + 2 * L,J);
1200  FOR I = 1 TO 3: &  PRINT USEA$;X1 * N(I,J);
1210  NEXT I: PRINT "  ";A$(2 + 2 * L,J);:X1 = X1 * H
1220  FOR I = 1 TO 3: &  PRINT USEA$;X2 * M(I,J);
1230  NEXT I:X2 = X2 * H * H / 6: PRINT
1240  NEXT L
1250  NEXT J
```

```
1260 FOR P = 0 TO JJ
1270 GOSUB 2580: NEXT P
1280 FOR K = 1 TO N
1290 FOR L = 0 TO 1
1300 FOR J = 0 TO JJ
1310 FOR I = 1 TO 3
1320 E(K,I + 3 * L,J) = S1(I,J) + 2 * (W1(K) + L * HN) * S2(I,J)
1330 E(K,I + 3 * L + 6,J) = E(K,I + 3 * L,J)
1340 NEXT I
1350 NEXT J
1360 FOR J = 0 TO JJ
1370 GOSUB 2660
1380 NEXT J
1390 NEXT L
1400 NEXT K
1410 PRINT : PRINT "PLY"; TAB( 5 );"LOWER PLY SURFACE"; [illegible];"UPPER P
    LY SURFACE"
1420 IF CN(5) + CN(6) = 0 THEN GOTO 1560
1430 Z$(0,0) = "ON AXIS MECHANICAL STRAIN":Z$(0,1) = "OFF AXIS MECHANICAL
    STRAIN":Z$(1,0) = "ON AXIS NON-MECHANICAL STRAIN":Z$(1,1) = "OFF AXIS
     NON-MECHANICAL STRAIN"
1440 FOR J = 0 TO JJ
1450 PRINT : FOR M6 = 1 - CN(6) TO CN(6): PRINT TAB( 20);Z$(J,M6): GET C
    $
1460 FOR K = 1 TO N: PRINT K; TAB( 5)
1470 FOR L = 0 TO 1
1480 FOR I = 1 TO 3
1490 ? PRINT USEA$;E(K,I + 3 * L + M6 * 6,J);
1500 NEXT I: PRINT "  ";
1510 NEXT L
1520 PRINT
1530 NEXT K
1540 NEXT M6
1550 NEXT J
1560 IF CN(7) + CN(8) = 0 THEN GOTO 2140
1570 DIM F(2,2),G(3,3),EX(6),U(3),CM(60,1),R1(60,1),RM(60,1),F(3)
1580 FXYSTAR = - 0.5
1590 F(1,1) = 1 / (X * XC):F(2,2) = 1 / (Y * YC)
1600 F(1,2) = FXYSTAR * SQR (F(1,1) * F(2,2)):F(2,1) = F(1,2)
1610 FX = 1 / X - 1 / XC:FY = 1 / Y - 1 / YC
1620 EX(1) = X / EX:EX(2) = Y / EY:EX(3) = S / ES:EX(4) = - XC / EX:EX(5)
     = - YC / EY:EX(6) = - S / ES
1630 GX = FX * Q(1,1) + FY * Q(1,2)
1640 GY = FX * Q(1,2) + FY * Q(2,2)
1650 FOR K = 1 TO 2
1660 FOR F = 1 TO 2
1670 G(K,F) = 0
1680 FOR I = 1 TO 2
1690 FOR J = 1 TO 2
1700 G(K,F) = G(K,F) + F(I,J) * Q(I,K) * Q(J,F)
1710 NEXT J
1720 NEXT I
1730 NEXT F
1740 NEXT K
1750 G(3,3) = (Q(3,3) / S) ^ 2
```

```
1760  FOR K = 1 TO N
1770  FOR L = 0 TO 1
1780 A = 0:B = 0:C = 0
1790  FOR I = 1 TO 3:IL = I + 3 * L:BB = 0
1800  IF E(K,IL,0)   0 THEN BB = 3
1810 U(I) = E(K,IL,1)   ET(1): IF E(K,IL,0) = 0 THEN E(K,IL,0) = E(K,IL,0)
      + 1E   30
1820 R(I) = (EX(I + BB)  - U(I)) / E(K,IL,0): IF I = 1 THEN  GOTO 1840
1830  IF R(I)   RM(K,L) THEN  GOTO 1850
1840 RM(K,L) = R(I):CM(K,L) = I
1850  NEXT I
1860  FOR I = 1 TO 3:IL = I + 3 * L
1870  FOR J = 1 TO 3:JL = J + 3 * L
1880 A = A + G(I,J) * E(K,IL,0) * E(K,JL,0): IF JJ = 0 THEN  GOTO 1910
1890 B = B + G(I,J) * (E(K,IL,0) * U(J) + E(K,JL,0) * U(I))
1900 C = C + G(I,J) * U(I) * U(J)
1910  NEXT J
1920  NEXT I
1930 B = B + GX * E(K,1 + 3 * L,0) + GY * E(K,2 + 3 * L,0)
1940 C = C + GX * U(1) + GY * U(2) - 1
1950 V2 =  SQR (B ^ 2 - 4 * A * C)
1960 R1(K,L) = ( - B + V2) / 2 / A
1970  NEXT L
1980  NEXT K
1990 X$ = "STRENGTH ANALYSIS":Y$ = " ":V$ = " ":Z$ = " ":W$ = " ": GOSUB 2
      150
2000  FOR I = 1 TO 2
2010  PRINT "     ";"TSAI-HILL";"  ";"MAX. STR.";"  ";"STR. COMP.";
2020  NEXT I
2030  PRINT : PRINT
2040 X1 = H:K$(1) = "STRENGTH RATIO, R":K$(0) = "NORMALIZED STRENGTH RATIO
      , R/H"
2050  FOR K = 1 - CN(7) TO CN(8)
2060  PRINT  TAB( 20);K$(K);: PRINT
2070  FOR I = 1 TO N: PRINT I; TAB( 5);
2080  FOR L = 0 TO 1
2090  &  PRINT USEA$;R1(I,L) / X1;: PRINT "  ";: &  PRINT USEA$;RM(I,L) /
      X1;: PRINT "     ";CM(I,L);       ;" ";
2100  NEXT L
2110  PRINT
2120  NEXT I
2130 X1 = 1: GET G$: NEXT K
2140  END
2150  PRINT
2160  PRINT "**************************************"
2170  PRINT  TAB( 15);X$;"       ";Y$;"         ";V$
2180  PRINT  TAB( 15);Z$;"      ";W$
2190  GET G$
2200  PRINT
2210  RETURN
```

```
2220  FOR I = 1 TO 3:XM = X1
2230  FOR L = K TO K + 1: IF L = K + 1 THEN XM = X2
2240  FOR J = 1 TO 3
2250  &  PRINT USEA$;XM * X(I,J,L);
2260  NEXT J
2270  NEXT L
2280  PRINT
2290  NEXT I
2300  RETURN
2310 A = X(1,1,LI):B = X(1,2,LI):C = X(1,3,LI):D = X(2,2,LI):E = X(2,3,LI)
     :F = X(3,3,LI)
2320 DET = A * (D * F - E * E) + B * (2 * E * C - F * B) - D * C * C
2330 X(1,1,LO) = (D * F - E * E) / DET
2340 X(1,2,LO) = (C * E - B * F) / DET
2350 X(2,1,LO) = X(1,2,LO)
2360 X(1,3,LO) = (B * E - D * C) / DET
2370 X(3,1,LO) = X(1,3,LO)
2380 X(2,2,LO) = (A * F - C * C) / DET
2390 X(2,3,LO) = (B * C - A * E) / DET:X(3,2,LO) = X(2,3,LO)
2400 X(3,3,LO) = (A * D - B * B) / DET
2410  RETURN
2420  FOR I = 1 TO 3
2430  FOR J = 1 TO 3
2440 SU = 0
2450  FOR K = 1 TO 3
2460 SU = SU + X(I,K,LA) * X(K,J,LB)
2470  NEXT K
2480 X(I,J,LC) = F * SU
2490  NEXT J
2500  NEXT I
2510  RETURN
2520  FOR I = 1 TO 3
2530  FOR J = 1 TO 3
2540 X(I,J,LC) = X(I,J,LA) + X(I,J,LB)
2550  NEXT J
2560  NEXT I
2570  RETURN
2580  FOR I = 1 TO 3
2590 S1(I,P) = 0:S2(I,P) = 0
2600  FOR J = 1 TO 3
2610 S1(I,P) = S1(I,P) + X(I,J,3) * N(J,P) + X(I,J,4) * M(J,P) / 3
2620 S2(I,P) = S2(I,P) + X(I,J,5) * N(J,P) + X(I,J,6) * M(J,P)
2630  NEXT J
2640  NEXT I
2650  RETURN
2660 P = .5 * (E(K,1 + 3 * L,J) + E(K,2 + 3 * L,J))
2670 Q = .5 * (E(K,1 + 3 * L,J) - E(K,2 + 3 * L,J))
2680 R = .5 * E(K,3 + 3 * L,J)
2690 E(K,1 + 3 * L,J) = P + Q * P(K,1) + R * P(K,3)
2700 E(K,2 + 3 * L,J) = P - Q * P(K,1) - R * P(K,3)
2710 E(K,3 + 3 * L,J) = 2 * R * P(K,1) - 2 * Q * P(K,3)
2720  RETURN
```

V. ILLUSTRATIVE EXAMPLES

Problem #1

```
[illegible]
MATERIAL TYPE, MT=4[illegible]
NUMBER OF PLIES, N=4
NORMALIZED CORE THICKNESS, HC/H=[illegible]

PLY ORIENTATION (FROM Z=-H/2 TO Z=H/2)
PLY ANGLE =0
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =0

**********************************************
                    A*         B*          [illegible]
                    TB*        [illegible]

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

**********************************************
                    ALPHA        [illegible]         [illegible]
                    TRBETA*      DELTA*

[illegible]
[illegible]
0.00E+00 0.00E+00 1.39E+01 0.00E+00 0.00E+00 0.00E+00
0.00E+00 0.00E+00 0.00E+00 [illegible] [illegible] 0.00E+00
[illegible] [illegible] 0.00E+00 [illegible] 3.15E+00 [illegible]
[illegible] 0.00E+00 [illegible] 0.00E+00 [illegible] 1.39E+[illegible]

**********************************************
                    A          [illegible]
                    B          [illegible]

[illegible]
[illegible] 4.20E+02 0.00E+00 0.00E+00 0.00E+00 [illegible]
[illegible] 0.00E+00 3.59E+07 [illegible] 0.00E+00 [illegible]
0.00E+00 0.00E+00 0.00E+00 [illegible] 3.02E-11 [illegible]
[illegible] [illegible] 0.00E+00 [illegible] 3.31E-1[illegible] [illegible]
0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 [illegible]E-11

**********************************************
```

```
        ALPHA          BETA
        GAMMA          DELTA

[illegible]
[illegible] 2.08E+[illegible] 0.00E+00 0.00E+00 0.00E+[illegible] [illegible]
[illegible] 0.00E+00 [illegible]9E+0[illegible] [illegible]
[illegible] 0.00E+00 [illegible]
[illegible] 0.00E+00 [illegible]
[illegible]

*************************************
         STRAIN ANALYSIS

 [illegible]
 [illegible]

      EFFECTIVE STRESSES                EFFECTIVE MOMENTS
                          MECHANICAL
[illegible] 0.00E+00          MX  0.00E+00 [illegible]
N[illegible] 0.00E+00 [illegible] 0.00E+00   M[illegible] 0.00E+00 [illegible]

[illegible]   LOWER PLY SURFACE           UPPER PLY SURFACE

                     ON AXIS MECHANICAL STRAIN
1  [illegible] 0.00E+00   2.08E-08 [illegible]
2  [illegible] 0.00E+00   -.63E-09 2.08E-08 [illegible]
3  [illegible]-09 2.08E-08 0.00E+00   -.63E-09 2.08E-08 0.00E+00
4  [illegible]-08 [illegible]-09 0.00E+00   2.08E-08 -.63E-09 0.00E+00
                     OFF AXIS MECHANICAL STRAIN
1  2.08E-0[illegible] [illegible]-09 0.00E+00   2.08E-08 -.63E-09 0.00E+00
2  [illegible]-09 0.00E+00   2.08E-08 -.63E-09 0.00E+00
3  2.08E-09 [illegible]-09 0.00E+00   2.08E-08 -.63E-09 0.00E+00
4  [illegible]-08 [illegible]-09 0.00E+00   2.08E-08 -.63E-09 0.00E+00

*************************************
         STRENGTH ANALYSIS

   TSAI-HILL   MAX. STR.  STR. COMP.    TSAI-HILL  MAX. STR.  STR. COMP.

                     NORMALIZED STRENGTH RATIO, R/H
1  6.[illegible]E+08   [illegible]E+08    1         6.82E+08   7.96E+0[illegible]   [illegible]
2  3.[illegible]E+08   [illegible]E+08    2         3.[illegible]E+08   3.73E+08   2
3  3.73E+08   [illegible]E+08    [illegible]         3.73E+08   3.[illegible]E+08   [illegible]
4  6.91E+08   [illegible]E+08    1         6.82E+08   7.[illegible]6E+08
                     STRENGTH RATIO, R
1  3.41E+05   [illegible]E+05    1         3.41E+05   3.98E+05   1
2  1.87E+05   1.9[illegible]E+05    2         1.87E+05   1.86E+05   [illegible]
3  1.8[illegible]E+05   1.94E+0[illegible]    2         1.87E+05   1.86E+05   [illegible]
4  3.41E+05   3.98E+0[illegible]    1         3.41E+05   3.98E+05   1
```

Problem #2

[illegible]
[illegible]TERIAL TYPE, MT=4[illegible]
NUMBER OF PLIES, N=6
NORMALIZED CORE THICKNESS, HC/H=0.[illegible]
NUMBER OF PLIES BETWEEN Z=-H/2 AND CORE, M [illegible]

PLY ORIENTATION (FROM Z=-H/2 TO Z=H/2)
PLY ANGLE 0
PLY ANGLE -[illegible]
[illegible] PLY THICK
[illegible]Y ANGLE -4[illegible]
PLY ANGLE [illegible]
PLY ANGLE -30
[illegible] ANGLE [illegible]

****
A* B* (GPa)
TB* D*

[illegible]	[illegible]	[illegible].00E+00	[illegible].78E+00	8.[illegible]4E+00	[illegible]E+01
[illegible]E+01	[illegible]	[illegible]E+00	8.24E+00	-.62E+01	[illegible]E+01
[illegible]	[illegible]	[illegible]E+01	[illegible]E+01	-.1[illegible]E+01	8.[illegible]E+00
[illegible]E+01	[illegible]	[illegible]E+01	9.98E+01	1.82E+01	-[illegible]E+01
[illegible]E+01	[illegible]	-.47E+01	1.9[illegible]E+01	4.45E+01	[illegible]E+01
[illegible]E+01	[illegible]	7.57E+01	-.34E+01	-.44E+0[illegible]	[illegible]E+01

****
[illegible]* BETA[illegible] (1/GPa)
[illegible]* DELTA*

[illegible]	[illegible]E+01	[illegible]E-02	[illegible]	-.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-.44E[illegible]	[illegible]	[illegible]
[illegible]	-.24E-02	[illegible].99E-02	.56E[illegible]	[illegible]	[illegible]E-01
[illegible]	.13E[illegible]01	.17E-02	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]E-02	6.78E-04	[illegible].76E-02	[illegible]	[illegible]
[illegible]	7.57[illegible]	[illegible].12E+00	[illegible].46E[illegible]03	3.5[illegible]	9.4[illegible]

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           A        B
           B        D

6.55E-02 1.94E-02 0.00E+00 2.77E-06 5.22E-06 [illegible]
1.94E-02 4.41E-02 0.00E+00 5.22E-06 -.39E-05 -.98E-06
0.00E+00 0.00E+00 2.26E-02 -.15E-05 -.98E-06 [illegible]
2.77E-06 5.22E-06 -.15E-05 1.18E-08 2.17E-09 -.99E-09
5.22E-06 -.39E-05 -.98E-06 2.17E-09 5.28E-09 -.53E-09
-.15E-05 -.98E-06 5.42E-06 -.99E-09 -.53E-09 [illegible]

***************************************
           ALPHA        BETA
           BBETA        DELTA

-.19E+01 -.13E+02 -.37E+01 7.44E+02 -.34E+05 1.12E+04
-.13E+02 3.56E+01 .21E+01 -.21E+05 4.89E+04 [illegible]
[illegible] [illegible] 8.08E+01 [illegible] [illegible] [illegible]
7.44E+02 -.21E+05 -.27E+04 1.06E+09 -.54E+08 [illegible]
-.34E+05 4.89E+04 1.07E+03 -.64E+08 2.93E+09 [illegible]
1.12E+04 1.20E+04 -.19E+06 2.92E+07 [illegible] [illegible]

***************************************
           STRAIN ANALYSIS


TEMP. DIFFERENCE (IN K), DT=0
MOISTURE CONTENTS, C=0

       EFFECTIVE STRESSES               EFFECTIVE MOMENTS
                        MECHANICAL
 * 1.39E-07 0.00E+00 0.00E+00     M* [illegible]
 N  1.00E-09 0.00E+00 0.00E+00     M  0.00E+00 0.00E+00 [illegible]

PLY       LOWER PLY SURFACE               UPPER PLY SURFACE

                    ON AXIS MECHANICAL STRAIN
1    1.77E-08 5.37E-09 -.99E-08     1.86E-08 1.62E-09 -.86E-08
2    1.62E-09 1.86E-08 8.55E-09     -.26E-08 1.95E-08 7.15E-09
3    1.97E-09 4.73E-09 -.38E-07     1.00E-09 1.57E-09 -.42E-07
4    2.57E-09 1.00E-09 4.29E-08     2.04E-10 3.90E-11 4.81E-08
5    1.21E-08 -.12E-07 -.42E-07     1.22E-08 -.15E-07 -.46E-07
6    1.12E-08 -.14E-07 4.63E-09     1.03E-08 -.17E-07 2.20E-09
                    OFF AXIS MECHANICAL STRAIN
1    1.77E-08 5.37E-09 -.99E-08     1.86E-08 1.62E-09 -.86E-08
2    1.86E-08 1.62E-09 -.86E-08     1.95E-08 -.26E-08 -.72E-08
3    2.23E-08 .15E-07 -.30E-08     2.33E-08 -.20E-07 -.16E-08
4    2.33E-08 .20E-07 -.16E-08     2.42E-08 .24E-07 .17E-09
5    2.41E-08 .24E-07 -.17E-09     2.51E-08 .29E-07 1.23E-09
6    2.51E-08 .28E-07 1.23E-09     2.60E-08 -.32E-07 2.62E-09
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                STRENGTH ANALYSIS
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	TSAI-HILL	MAX. STR.	STR. COMP.	TSAI-HILL	MAX. STR.	[illegible]
			NORMALIZED STRENGTH RATIO, [illegible]			
1	2.46E+09	4.17E+08	1	2.91E+08	2.96E+0[illegible]	[illegible]
2	1.79E+09	[illegible].05E+08	2	1.75E+08	1.77E+08	[illegible]
3	[illegible].91E+08	2.23E+08	3	1.83E+08	1.9[illegible]E+08	[illegible]
4	1.98E+08	1.96E+08	3	1.75E+08	1.75E+08	[illegible]
5	2.21E+08	2.02E+08	3	2.11E+08	1.85E+08	[illegible]
6	2.96E+08	1.80E+08	3	1.92E+08	1.62E+08	[illegible]
			STRENGTH RATIO, R			
1	2.72E+05	4.69E+05	1	3.28E+05	4.46E+05	[illegible]
2	[illegible]0E+05	3.09E+05	2	1.97E+05	1.99E+05	[illegible]
3	2.15E+05	2.51E+05	3	2.06E+05	2.21E+05	[illegible]
4	2.12E+05	2.21E+05	3	1.97E+05	1.97E+05	[illegible]
5	2.49E+05	2.27E+05	3	2.18E+05	2.08E+05	[illegible]
6	2.[illegible]E+05	2.0[illegible]E+05	3	2.16E+05	1.82E+05	[illegible]

Problem #3

```
RUN
MATERIAL TYPE, M =4
NUMBER OF PLIES, N=16
NORMALIZED CORE THICKNESS, HC/H=0

PLY ORIENTATION (FROM Z=-H/2 TO Z=H/2)
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =0
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90
PLY ANGLE =90

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[illegible]
[illegible] 9.[illegible] [illegible] 0.00E+00 [illegible] 4.[illegible] [illegible]
[illegible] .17E+0[illegible] [illegible]
[illegible] 9.[illegible]E+01 2.90E+00 [illegible]
[illegible] 1.[illegible] [illegible] 2.9[illegible] [illegible]
[illegible] 0.00E+00 [illegible] 0.00E+00 [illegible]

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[illegible]
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PLY	LOWER PLY SURFACE			UPPER PLY SURFACE		
			ON AXIS MECHANICAL STRAIN			
1	-.44E-08	-.39E-09	0.00E+00	-.22E-08	.39E-09	[illegible]
2	-.22E-08	-.39E-09	0.00E+00	-.50E-10	.39E-09	[illegible]
3	-.50E-10	-.39E-09	0.00E+00	2.12E-09	-.39E-09	[illegible]
4	2.12E-09	-.39E-09	0.00E+00	4.28E-09	-.39E-09	[illegible]
5	4.28E-09	-.39E-09	0.00E+00	6.45E-09	-.39E-09	[illegible]
6	6.45E-09	-.39E-09	0.00E+00	8.62E-09	-.39E-09	[illegible]
7	8.62E-09	-.39E-09	0.00E+00	1.08E-08	-.39E-09	[illegible]
8	1.08E-08	-.39E-09	0.00E+00	1.29E-08	-.39E-09	[illegible]
9	-.39E-09	1.29E-08	0.00E+00	-.39E-09	1.51E-08	[illegible]
10	-.39E-09	1.51E-08	0.00E+00	-.39E-09	1.73E-08	[illegible]
11	-.39E-09	1.73E-08	0.00E+00	-.39E-09	1.94E-08	[illegible]
12	-.39E-09	1.94E-08	0.00E+00	-.39E-09	2.16E-08	[illegible]
13	-.39E-09	2.16E-08	0.00E+00	-.39E-09	2.38E-08	[illegible]
14	-.39E-09	2.38E-08	0.00E+00	-.39E-09	2.59E-08	[illegible]
15	-.39E-09	2.59E-08	0.00E+00	.39E-09	2.81E-08	[illegible]
16	-.39E-09	2.81E-08	0.00E+00	.39E-09	[illegible]	[illegible]
			OFF AXIS MECHANICAL STRAIN			
1	-.44E-08	.39E-09	0.00E+00	-.22E-08	.39E-09	[illegible]
2	-.22E-08	.39E-09	0.00E+00	-.50E-10	.39E-09	[illegible]
3	-.50E-10	.39E-09	0.00E+00	2.12E-09	.39E-09	[illegible]
4	2.12E-09	-.39E-09	0.00E+00	4.28E-09	.39E-09	[illegible]
5	4.28E-09	.39E-09	0.00E+00	6.45E-09	-.39E-09	[illegible]
6	6.45E-09	.39E-09	0.00E+00	8.62E-09	-.39E-09	0.00E+00
7	8.62E-09	.39E-09	0.00E+00	1.08E-08	-.39E-09	[illegible]
8	1.08E-08	.39E-09	0.00E+00	1.29E-08	-.39E-09	0.00E+00
9	1.29E-08	.39E-09	0.00E+00	1.51E-08	.39E-09	[illegible]
10	1.51E-08	.39E-09	0.00E+00	1.73E-08	-.39E-09	0.00E+00
11	1.73E-08	.39E-09	0.00E+00	1.94E-08	-.39E-09	[illegible]
12	1.94E-08	.39E-09	0.00E+00	2.16E-08	-.39E-09	0.00E+00
13	2.16E-08	-.39E-09	0.00E+00	2.38E-08	-.39E-09	0.00E+00
14	2.38E-08	.39E-09	0.00E+00	2.59E-08	.39E-09	0.00E+00
15	2.59E-08	.39E-09	0.00E+00	2.81E-08	.39E-09	[illegible]
16	2.81E-08	.39E-09	0.00E+00	3.03E-08	-.39E-09	0.00E+00
			ON AXIS NON-MECHANICAL STRAIN			
1	5.17E-05	.22E-03	0.00E+00	3.43E-05	-.21E-03	0.00E+00
2	3.43E-05	.21E-03	0.00E+00	1.67E-05	-.19E-03	[illegible]
3	1.67E-05	-.19E-03	0.00E+00	-.86E-06	-.18E-03	[illegible]
4	-.86E-06	.18E-03	0.00E+00	-.18E-04	-.16E-03	[illegible]
5	.18E-04	.16E-03	0.00E+00	-.36E-04	-.14E-03	[illegible]
6	.36E-04	.14E-03	0.00E+00	.54E-04	.12E-03	[illegible]
7	-.54E-04	.12E-03	0.00E+00	-.71E-04	-.11E-03	[illegible]
8	-.71E-04	.11E-03	0.00E+00	-.89E-04	-.89E-04	[illegible]
9	-.89E-04	-.89E-04	0.00E+00	-.71E-04	-.11E-03	[illegible]
10	-.71E-04	.11E-03	0.00E+00	-.54E-04	-.12E-03	[illegible]
11	-.54E-04	.12E-03	0.00E+00	-.36E-04	-.14E-03	[illegible]
12	-.36E-04	.14E-03	0.00E+00	-.18E-04	-.16E-03	[illegible]
13	.18E-04	.16E-03	0.00E+00	-.86E-06	-.18E-03	[illegible]
14	.86E-06	.18E-03	0.00E+00	1.67E-05	-.19E-03	[illegible]
15	1.67E-05	.19E-03	0.00E+00	3.43E-05	.21E-03	[illegible]
16	3.43E-05	.21E-03	0.00E+00	5.17E-05	.22E-03	[illegible]

[illegible]

* *

[illegible]

		NORMALIZED	[illegible]			
1	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.93E+09	1.95E+09	1	[illegible]	9.69E+0[illegible]	[illegible]
5	[illegible]	[illegible]	1	5.52E+08	[illegible]	
6	5.51E+08	[illegible]	1	[illegible]	4.84E+0[illegible]	1
7	4.02E+08	[illegible]	1	[illegible]	[illegible]	
8	[illegible]	3.97E+08	1	2.69E+08	[illegible]	
9	1.39E+08	[illegible]	2	1.20E+08	1.20E+08	
10	[illegible]	[illegible]	2	1.05E+08	[illegible]	
11	[illegible]	1.05E+08	2	[illegible]	[illegible]	
12	9.40E+07	[illegible]	2	8.49E+07	[illegible]	
13	8.49E+07	8.49E+07	[illegible]	7.75E+07	[illegible]	
14	7.75E+07	7.75E+07	2	7.13E+07	7.1[illegible]E+07	2
15	7.13E+07	7.1[illegible]E+07	2	[illegible]	[illegible]	
16	6.61E+07	6.62E+07	2	[illegible]	6.17E+07	2
		STRENGTH RATIO, R				
1	[illegible]	1.90E+06	1	[illegible]	[illegible]	1
2	[illegible]	[illegible]	1	[illegible]	[illegible]	
3	6.72E+07	6.16E+07	2	[illegible]	[illegible]	
4	[illegible]	[illegible]	1	[illegible]	1.94E+0[illegible]	
5	1.70E+06	1.91E+06	[illegible]	[illegible]	1.29E+06	
6	1.10E+06	1.29E+06	1	[illegible]	[illegible]	
7	8.10E+05	9.69E+05	1	[illegible]	7.75E+05	1
8	6.49E+05	7.75E+05	1	5.38E+05	[illegible]	1
9	2.79E+05	2.73E+05	1	2.40E+05	2.39E+05	
10	2.40E+05	2.39E+05	2	[illegible]	[illegible]	2
11	2.11E+05	[illegible]	2	1.88E+05	1.88E+05	2
12	1.88E+05	1.89E+05	2	1.70E+05	1.70E+05	
13	1.70E+05	1.70E+05	2	1.55E+05	1.55E+05	2
14	1.55E+05	1.55E+05	2	1.47E+05	[illegible]	
15	[illegible]	1.47E+05	2	[illegible]	1.32E+05	
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

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8