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A DIGITAL ALGORITHM FOR COMPOSITE LAMINATE ANALYSIS - FORTRAN

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October 1983

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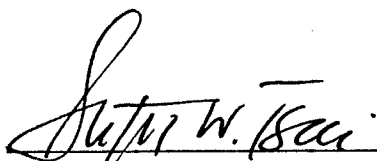
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FOR THE COMMANDER



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Composite Laminates Modulus Compliance Tensor Polynomial Failure Criterion	Classical Laminated Plate Theory Inplane Coupling Ratios Strength Lamina Young's Modulus, Poisson's Ratio	Hybrid Moisture Temperature FORTRAN Plots, CALCOMP
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents a FORTRAN computer code for the solution of composite materials problems. The computer program can conduct the point stress analysis of general laminates including hybrid laminates. The effect of hygrothermal and mechanical loads on the strength of composite laminates can be studied using this program. Strength predictions on the basis of six commonly used failure theories can be done. Plotting capabilities have been included—using CALCOMP Plotter to obtain the failure envelopes in different loading planes for all the failure theories. (Continued on reverse)		

A complete listing of the computer program is given. A number of typical laminates have been treated for numerical and graphical illustrations. Input and output parameters are explained in detail. The algorithm is written in an easily understandable format. Material properties for five different materials are stored in the program (see Table 1). The required material can be used by giving the material name for pure laminates and material property identification number in the layers data card for hybrid laminates. These quantities are given in SI units. If the results are desired in English units (i.e., Psi etc.) a unit identification command has to be used in the appropriate place. This program is a modified version of an earlier program given in AFWAL-TR-81-4073.

unclassified

FOREWORD

This report describes the inhouse effort conducted in the Mechanics and Surface Interactions Branch (MLBM), Nonmetallic Materials Division (MLB), Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under the contract #F33615-83-C-5056 with the University of Dayton Research Institute.

The work reported herein was performed during the period 1 July 1982 to 31 June 1983. Dr. Stephen W. Tsai (AFWAL/MLBM) was the Project Engineer.

This report is a modified version of AFWAL-TR-81-4073.

The author wishes to express his deep sense of gratitude to Dr. S. W. Tsai for his extremely fruitful guidance in the course of this work. Figures 1 - 2 and Tables 1 - 7 have been taken from the book, "Introduction to Composite Materials," by S. W. Tsai and H. T. Hahn with their permission.

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LIST OF SUBROUTINES

1. ADJUST: Adjust the arrays for plots in qr space
2. AMAX: Picks up the maximum value in a vector
3. AMIN: Picks up the minimum value in a vector
4. COEF: Calculate G_{ij} and G_i after transformation
5. FAILCO: Coefficients G_{ij} and G_i for tensor polynomial failure criterion
6. FSFTY: Strength ratios R and $\bar{R}$
7. INVR: Inverse of Q as A
8. LMDT: Contains the values of elastic constants for different materials
9. LMNT: Laminate description
10. MATM: Matrix multiplication, $C = A \times B$
11. MINP: Translates material name to material property identification number
12. MODCM: Off-axis modulus Q_{ij}
13. MODULS: Ply on-axis modulus Q_{ij} and invariants U_i
 ($i = 1,5$)
14. MOLS: Effective in-plane modulus A , Flexural modulus D , and coupling B matrices; nonmechanical stress and moment resultants
15. MTAD: Addition of a matrix to a scalar multiple of another matrix; $C = A + \text{Con} \times B$, Con is scalar
16. MTDM: Translates material properties to each ply
17. MVM: Matrix and vector multiplication $Z = X \times Y$
18. MXSTRN: Strength prediction on the basis of max. strain failure theory
19. MXSTRS: Strength prediction on the basis of max. stress failure theory
20. NMSN: Nonmechanical strain (e_x, e_y, e_{xy})

LIST OF SUBROUTINES (CONTINUED)

- | | | |
|-----|--------|---|
| 21. | NORM: | Effective modulus matrices |
| 22. | NORM1: | Effective compliance matrices |
| 23. | PLT: | Plot subroutine |
| 24. | PLTEN: | Plot engineering constants |
| 25. | ROOTS: | Roots of a quadratic |
| 26. | SETAN: | Sets loads for qr space plot calculations |
| 27. | STRNG: | Calculates strength ratio for each ply |
| 28. | SYM: | Puts the value $X(1,3)$, $X(2,3)$, $X(1,2)$ in a symmetric matrix $X(I,J)$ in place of $X(3,1)$, $X(3,2)$ and $X(2,1)$ |
| 29. | SYMBL: | Notations for failure surface plots |
| 30. | TRE: | Transformation of strain by an angle θ |
| 31. | TRS: | Transformation of stress by an angle θ |
| 32. | US: | Calculates $U(I)$, $I = 1, 5$ |
| 33. | VDI: | Subtraction of vectors $C(I) = A(I) - B(I)$ |
| 34. | VNF: | Negative of a vector |
| 35. | WITE: | Writes two matrices side by side 3×3 each, E format |
| 36. | WITE1: | Writes two matrices side by side F format |
| 37. | WRITE: | Writes one matrix 3×3 |
| 38. | WRT: | Writes a vector $V(I)$, $I = 1,3$ |
| 39. | WRT1: | Writes a vector $V(I)$, $I = 1,3$; F format |

LIST OF FUNCTIONS

VVM = Row Vector to Column Vector Multiplication

SINM = $\sin(\theta)$

COSM = $\cos(\theta)$

SECTION I

INTRODUCTION

This report presents a FORTRAN computer code for the solution of composite materials problems.⁺ The computer program can conduct the point stress analysis of general laminates including hybrid laminates. The effect of hygrothermal and mechanical loads on the strength of composite laminates can be studied using this program. The analytical formulas based on the lamination theory have been used. These formulas are available in Reference 1. For the sake of completeness, the relevant relations are presented in this report. All the notations used in References 1 and 2 are followed. Plotting capabilities to investigate the in-plane strength of layered composites based upon six commonly used failure theories have been incorporated. A large number of options to obtain failure surfaces are included. CALCOMP plotter is used.

This manual has been written to provide the users results for their problems with a minimum of effort. The input instructions are explained in detail and are supported with examples. Material properties of five well-known composite materials are stored in the program and can be used by giving the relevant material name for pure laminates and by giving the material property identification number for hybrid laminates. The material properties which are not included in the program can be used through the input data. In such a case, new material properties will take the storage space provided for already-stored material property data; and, therefore, the corresponding material names or material property identification numbers are to be used for further calculations in that computer run. The new materials are to be supplied in SI units, according to the units used in Table 1, while the output can be obtained in English units. For obtaining results in English units, a command at appropriate place has to be given. For pure materials, this command is ENGLISH at the 11th column of the material card and for hybrid laminates, IUNIT = 2 in the \$LAYERS card.

On the basis of six commonly used failure theories, the in-plane strength characteristics of multidirectional composite laminates can be investigated. In the case of maximum stress and maximum strain failure theories,

⁺Modified version of AFWAL-TR-81-4073 [12]

TABLE 1
MATERIAL PROPERTIES GIVEN IN LAMDATA

LMPI	1	2	3	4	5	6	7
MATERIAL PROPERTY	T300/5208 GRAPH/EP	B4/5505 BORON/EP	AS/3501 GRAPH/EP	SCOTCHPLY 1002 GLASS/EP	KEVLAR49 ARAMID/EP	CORE	ALUMINUM
E_x (GPa)	181.0	204.0	138.0	38.6	76.0	0.0	69.0
E_y (GPa)	10.3	18.5	8.96	8.27	5.5	0.0	69.0
ν_x	0.28	0.23	0.3	0.26	0.34	0.0	0.3
E_s (GPa)	7.17	5.59	7.1	4.14	2.3	0.0	26.5
α_x ($\mu\text{m/m}/^\circ\text{K}$)	0.02	6.1	-0.3	8.6	-4.0	0.01	-
α_y ($\mu\text{m/m}/^\circ\text{K}$)	22.5	30.3	28.1	22.1	79.0	12.5	-
β_x (m/m)	0.0	0.0	0.0	0.0	0.0	0.0	-
β_y (m/m)	0.6	0.6	0.44	0.6	0.6	0.09	-
X (MPa)	1500.0	1260.0	1447.0	1026.0	1400.0	0.09	400.0
X' (MPa)	1500.0	2500.0	1447.0	610.0	235.0	0.09	400.0
Y (MPa)	40.0	61.0	51.7	31.0	12.0	0.09	400.0
Y' (MPa)	246.0	202.0	206.0	118.0	53.0	0.09	400.0
S (MPa)	68.0	67.0	93.0	72.0	34.0	0.09	230.0
h_0 (M)	125E-6	125E-6	125E-6	125E-6	125E-6	0.001	1.0

FOR A SANDWICH CORE IN A LAMINATE LMPI=6. IF NECESSARY NONZERO CORE PROPERTIES CAN BE GIVEN. THESE VALUES ARE TAKEN FROM 'INTRODUCTION TO COMPOSITE MATERIALS' BY S.W. TSAI AND H.T. HAHN.

strength prediction of hygrothermal loads are not included. However, one can calculate that on the basis of mechanical and nonmechanical stress and strain components calculated for other failure theories, or for these failure theories.

A list of other computer codes for composite laminate analysis developed at the Air Force Wright Aeronautical Laboratories, Materials Laboratory is given in the Appendix.

SECTION II

STIFFNESS PROPERTIES

1. UNIDIRECTIONAL LAMINATE STRESS STRAIN RELATIONS

The stiffness of unidirectional composites can be defined by appropriate stress strain relations. These relations can be expressed in terms of engineering constants, compliance components or modulus components. A detailed treatise on mechanics of composites is given in Reference 1. For completeness the relevant relations are given in the present report. All the notations used in Reference 1 are followed in this research.

The two key stress strain relations for a unidirectional composite are given in Tables 2 and 3:

TABLE 2
ON-AXIS STRESS STRAIN RELATIONS - COMPLIANCE

	σ_x	σ_y	σ_s
ϵ_x	S_{xx}	S_{xy}	
ϵ_y	S_{yx}	S_{yy}	
ϵ_s			S_{ss}

TABLE 3
ON-AXIS STRESS STRAIN RELATIONS - MODULUS

	ϵ_x	ϵ_y	ϵ_s
σ_x	Q_{xx}	Q_{xy}	
σ_y	Q_{yx}	Q_{yy}	
σ_s			Q_{ss}

In the foregoing matrix multiplication table, each value in the first column is equal to the sum of products of corresponding row elements with their column headings. This rule should be self-evident.

$$\{\sigma_x, \sigma_y, \sigma_s\} = \{\text{Longitudinal, transverse, shear}\}$$

stress components in the xy - plane

$$\{\epsilon_x, \epsilon_y, \epsilon_s\} = \{\text{Longitudinal, transverse, shear}\}$$

stress components in the xy - plane

$$Q_{ij} = \text{Modulus components}$$

$$S_{ij} = \text{Compliance components}$$

$$S_{xx} = 1/E_x$$

$$S_{yy} = 1/E_y$$

$$S_{xy} = -\nu_y/E_y$$

$$S_{yx} = -\nu_x/E_x$$

$$S_{ss} = 1/E_s$$

$$Q_{xx} = mE_x$$

$$Q_{yy} = mE_y$$

$$Q_{xy} = mE_x \nu_y$$

$$Q_{yx} = mE_y \nu_x$$

$$Q_{ss} = E_s$$

$$m = 1/(1-\nu_y \nu_x)$$

(1)

where

$$E_x = \text{Longitudinal Young's modulus}$$

$$E_y = \text{Transverse Young's modulus}$$

$$\nu_x = \text{Longitudinal Poisson's ratio} = -\frac{\epsilon_y}{\epsilon_x}$$

$$\nu_y = \text{Transverse Poisson's ratio} = -\frac{\epsilon_x}{\epsilon_y}$$

$$E_s = \text{Longitudinal shear modulus} = \frac{\sigma_s}{\epsilon_s}$$

All the material constants of the stress strain relation shown previously are called engineering constants. They are the familiar constants used for conventional materials with subscript added to denote directionality of properties. Thus, the use of engineering constants will often facilitate the use of composites for structural applications. However, it has been found more convenient to use compliance and modulus components of multidirectional composites. In Equation 1 S_{ij} are compliance components and Q_{ij} are modulus components.

Subroutine MODULS calculates the modulus matrix Q_{ij} .

2. TRANSFORMATION OF STRESS AND STRAIN

The change of stiffness of unidirectional composites as a function of ply orientation is a unique feature of composites. These orientational variations of stress and strain are the fundamental underlying issues which must be understood. The relations governing these variations are called transformation equations and are given in Tables 4 and 5:

TABLE 4
STRESS TRANSFORMATION RELATIONS

	σ_1	σ'_2	σ'_6
σ_x	m^2	n^2	$2mn$
σ_y	n^2	m^2	$-2mn$
σ_s	$-mn$	mn	$m^2 - n^2$

$$m = \cos\theta, n = \sin\theta$$

TABLE 5
STRAIN TRANSFORMATION RELATIONS

	ϵ_1	ϵ_2	ϵ_6
ϵ'_x	m^2	n^2	mn
ϵ'_y	n^2	m^2	$-mn$
ϵ'_s	$-2mn$	$2mn$	$m^2 - n^2$

Where $\sigma_1, \sigma_2, \sigma_6$ are off-axis stress components, $\sigma_x, \sigma_y, \sigma_s$, are transformed on-axis stress components and θ is the angle of counter-clockwise rotation of the on-axis laminate (Figure 1).

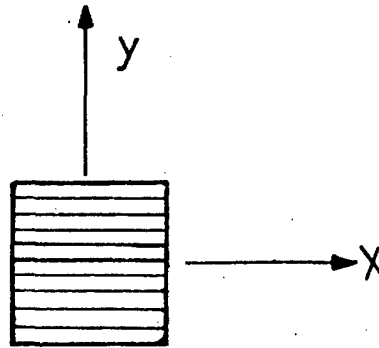


Figure 1(a). Material Symmetry Axis of a Unidirectional Composite

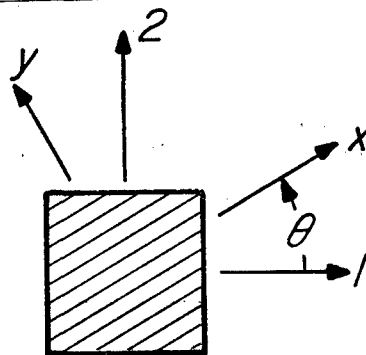


Figure 1(b). Off-Axis Configuration of a Unidirectional Composite, Counter Clockwise Rotation Is Positive

Similarly $\epsilon_1, \epsilon_2, \epsilon_6$ are off-axis and $\epsilon_x, \epsilon_y, \epsilon_s$ are on-axis strain components.

Subroutine TRS calculates the transformed stress components.

Subroutine TRE calculates the transformed strain components.

3. OFF-AXIS MODULUS

Because the composite laminates are made of off-axis and on-axis plies, the stiffness of off-axis ply orientation must be understood. The off-axis modulus of a ply can be determined in three steps: (1) the off-axis to on-axis strain transformation, (2) the on-axis stress strain relation, and (3) the on-axis to off-axis stress transformation. This process is initiated by a given strain in Figure 2(a) and eventually leads us to the induced stress in Figure 2(d). The three transformations mentioned above, when combined together, will yield the required off-axis modulus and off-axis stress strain relations for arbitrary angle of rotation.

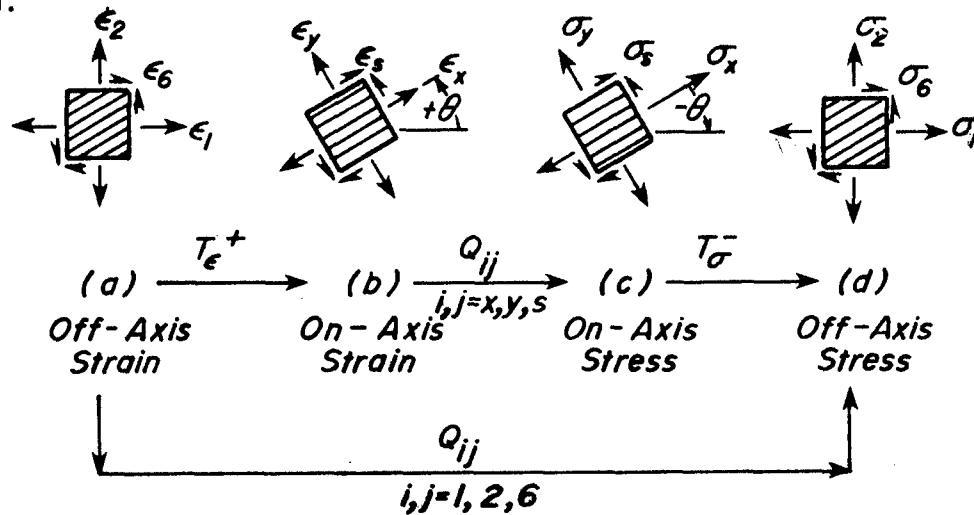


Figure 2. Determination of Off-Axis Modulus

From (a) - (b): Use positive angle θ strain transformations

From (b) - (c): Use the on-axis stress strain relations in modulus

From (c) - (d): Use inverse stress transformation.

Following the above transformations and making some mathematical simplifications, off-axis stress strain relations can be obtained, i.e., Table 6.

TABLE 6
OFF-AXIS STRESS STRAIN RELATIONS

	ϵ_1	ϵ_2	ϵ_6
σ_1	Q_{11}	Q_{12}	Q_{16}
σ_2	Q_{21}	Q_{22}	Q_{26}
σ_6	Q_{61}	Q_{62}	Q_{66}

The off-axis modulus components are given in the matrix form shown in Table 7.

TABLE 7
MODULUS COMPONENTS Q_{ij}

	1	U_2	U_3
Q_{11}	U_1	$\cos 2\theta$	$\cos 4\theta$
Q_{22}	U_1	$-\cos 2\theta$	$\cos 4\theta$
Q_{12}	U_4		$-\cos 4\theta$
Q_{66}	U_5		$-\cos 4\theta$
Q_{16}		$\frac{1}{2} \sin 2\theta$	$\sin 4\theta$
Q_{26}		$\frac{1}{2} \sin 2\theta$	$-\sin 4\theta$

Where

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

4. MODULUS AND COMPLIANCE OF GENERAL LAMINATES

According to the classical laminated plate theory, the strain components are considered to vary linearly along the thickness of the laminate, i.e.,

$$\begin{aligned}\epsilon_1(z) &= \epsilon_1^0 + zk_1 \\ \epsilon_2(z) &= \epsilon_2^0 + zk_2 \\ \epsilon_6(z) &= \epsilon_6^0 + zk_6\end{aligned}\quad (3)$$

where ϵ_i^0 ($i = 1, 2, 6$) are mid plane strain components and k_i ($i = 1, 2, 6$) are the corresponding curvatures.

A general laminate may contain plies of the same material or different materials (hybrid). The effective modulus of the composite laminate is considered to be an arithmetic average of the modulus of the constituent plies. Simple formulas can be derived to compute the effective stress strain relationship in terms of the modulus of constituent plies. The stress strain relation for a general laminate is given by:

$$\begin{bmatrix} N_1 \\ N_2 \\ N_6 \\ M_1 \\ M_2 \\ M_6 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{21} & A_{22} & A_{26} & B_{21} & B_{22} & B_{26} \\ A_{61} & A_{62} & A_{66} & B_{61} & B_{62} & B_{66} \\ & & & D_{11} & D_{12} & D_{16} \\ & & & D_{21} & D_{22} & D_{26} \\ & & & D_{61} & D_{62} & D_{66} \end{bmatrix} \begin{bmatrix} \epsilon_1^0 \\ \epsilon_2^0 \\ \epsilon_6^0 \\ k_1 \\ k_2 \\ k_6 \end{bmatrix} - \begin{bmatrix} N_1^N \\ N_2^N \\ N_6^N \\ M_1^N \\ M_2^N \\ M_6^N \end{bmatrix} \quad (4)$$

where N_1, N_2, N_6 are stress resultants over the thickness (h) of the laminate and M_1, M_2 and M_6 are corresponding moment resultants. These parameters are defined as follows:

$$N_i = \int_{-h/2}^{h/2} \sigma_i dz$$

$$N_i = \int_{-h/2}^{h/2} Q_{ij} \epsilon_j^0 dz + \int_{-h/2}^{h/2} Q_{ij} k_j z dz \quad (i \& j = 1, 2, 6)$$

or

$$N_i = A_{ij} \epsilon_j^0 + B_{ij} k_j \quad (5)$$

and

$$M_i = \int_{-h/2}^{h/2} \sigma_i z dz$$

or

$$M_i = \int_{-h/2}^{h/2} Q_{ij} \epsilon_j^0 z dz + \int_{-h/2}^{h/2} Q_{ij} k_j z^2 dz$$

or

$$M_i = B_{ij} \epsilon_j^0 + D_{ij} k_j \quad (6)$$

$$N_i^N = \int_{-h/2}^{h/2} Q_{ij} e_j dz \quad (7)$$

$$M_i^N = \int_{-h/2}^{h/2} Q_{ij} e_j z dz$$

$$e_i = \Delta T \alpha_i + c \beta_i \quad (i=x, y)$$

$$e_s = 0$$

Where h is the thickness of the laminate and e_i ($i=x, y, s$) are nonmechanical strain components, α_i and β_i are coefficients of thermal expansion and swelling coefficients respectively, ΔT is the temperature difference and

c is the moisture contents. In the foregoing relations the summation over the range of repeated subscript will be understood. Figure 3 shows a reference frame for numbering the layers. The detailed explanation to these equations is given in Reference 1.

Subroutine NMSN calculates the nonmechanical strain components for each layer.

Subroutine MOLS calculates the effective inplane modulus matrix A, effective flexural modulus D, coupling matrix B, nonmechanical stress, and moment resultants.

The constitutive equations (Equation 4) can be rewritten in the following form:

$$\begin{bmatrix} \underline{\underline{\epsilon}}^0 \\ \underline{\underline{k}} \end{bmatrix} = \begin{bmatrix} \underline{\underline{\alpha}} & \underline{\underline{\beta}} \\ \underline{\underline{\beta}}^T & \underline{\underline{\delta}} \end{bmatrix} \times \begin{bmatrix} \underline{\underline{N}} + \underline{\underline{N}}^N \\ \underline{\underline{M}} + \underline{\underline{M}}^N \end{bmatrix} \quad (8)$$

where

$$\begin{aligned} \underline{\underline{\alpha}} &= \text{Inplane compliance} = \underline{\underline{a}} + \underline{\underline{aB}} (\underline{\underline{D-BaB}})^{-1} \underline{\underline{Ba}} \\ \underline{\underline{\beta}} &= \text{Coupling compliance} = -\underline{\underline{aB}} (\underline{\underline{D-BaB}})^{-1} \\ \underline{\underline{\delta}} &= \text{Flexural compliance} = (\underline{\underline{D-BaB}})^{-1} \\ \underline{\underline{a}} &= \underline{\underline{A}}^{-1} \end{aligned}$$

It has been shown (Reference 2), that the use of normalized quantities in the stress strain relations is very helpful in understanding the variation in effective material properties of composite laminates due to the

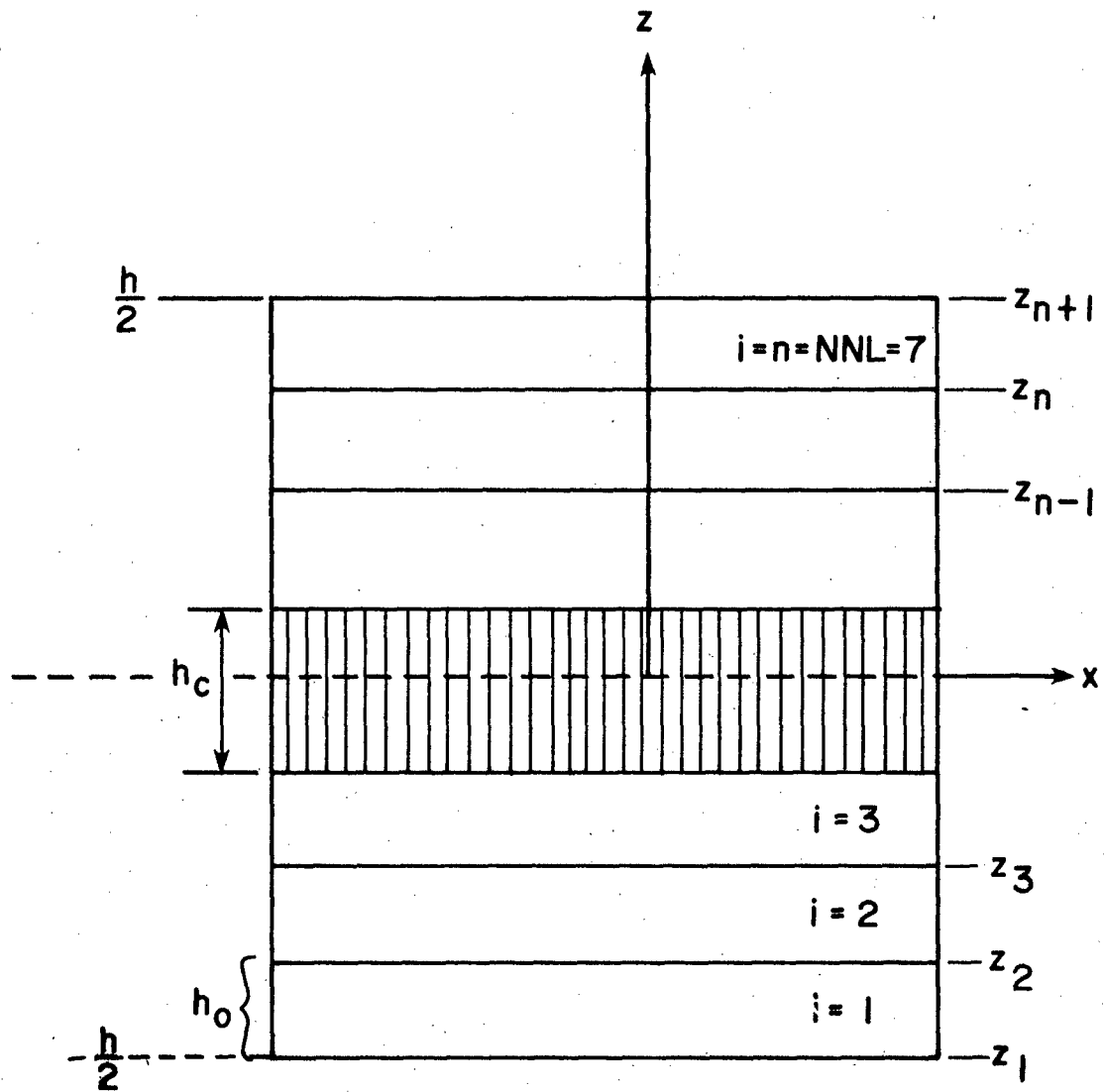


Figure 3. Reference Frame for Locating Different Plies in the Laminate

change in ply properties, orientations or volume fractions. The following normalization has been suggested:

$$\begin{aligned}
 \underline{N^*} &= \frac{1}{h} \underline{N} \\
 \underline{M^*} &= \frac{6}{h^2} \underline{M} \\
 \underline{k^*} &= \frac{h}{2} \underline{k} \\
 \underline{A^*} &= \frac{1}{h} \underline{A} \\
 \underline{D^*} &= \frac{12}{h^3} \underline{D} \\
 \underline{B^*} &= \frac{2}{h^2} \underline{B} \\
 \underline{\alpha^*} &= h \underline{\alpha} \\
 \underline{\beta^*} &= \frac{h^2}{2} \underline{\beta} \\
 \underline{\delta^*} &= \frac{h^3}{12} \underline{\delta} \\
 \underline{N^{N^*}} &= \frac{1}{h} \underline{N^N} \\
 \underline{M^{N^*}} &= \frac{6}{h^2} \underline{M^N}
 \end{aligned} \tag{9}$$

With the aid of these normalized parameters the stress strain relations (Equation 4), reduce to the following form:

$$\begin{bmatrix} \underline{N^*} \\ \underline{M^*} \end{bmatrix} = \begin{bmatrix} \underline{A^*} & \underline{B^*} \\ 3\underline{B^*} & \underline{D^*} \end{bmatrix} \begin{bmatrix} \underline{\epsilon^*} \\ \underline{k^*} \end{bmatrix} - \begin{bmatrix} \underline{N^{N^*}} \\ \underline{M^{N^*}} \end{bmatrix} \tag{10}$$

and

$$\begin{bmatrix} \underline{\epsilon^*} \\ \underline{k^*} \end{bmatrix} = \begin{bmatrix} \underline{\alpha^*} & 1/3 \underline{\beta^*} \\ \underline{\beta^{*T}} & \underline{\delta^*} \end{bmatrix} \begin{bmatrix} \underline{N^*} + \underline{N^{N^*}} \\ \underline{M^*} + \underline{M^{N^*}} \end{bmatrix} \tag{11}$$

In these equations, the multiplying factors 3 and 1/3 are consequent to the normalization factors defined in Equation 9. The well known Kirchhoff's assumption in classical plate theory of the linear strain distribution along the ply thickness, can be stated as:

$$\epsilon_i = \epsilon_i^0 + z^* k_i^* \quad (i = 1, 2, 6) \quad (12)$$

where $z^* = 2z/h$ and $-1 < z^* < 1$

Thus, all the equations required for computing the effective modulus matrix are given.

5. INPLANE AND FLEXURAL ENGINEERING CONSTANTS

a. Inplane

The inplane stress strain relation can be written in the following form:

$$\underline{N}^* = \underline{A}^* \underline{\epsilon}^*$$

or

$$\underline{\epsilon} = \underline{a}^* \underline{N}^*, \quad \underline{a}^* = (\underline{A}^*)^{-1}$$

The typical effective engineering constants are given by:

$$\text{Inplane longitudinal modulus} = E_1^0 = 1/a_{11}^*$$

$$\text{Inplane transverse modulus} = E_2^0 = 1/a_{22}^*$$

$$\text{Inplane shear modulus} = E_6^0 = 1/a_{66}^*$$

$$\text{Inplane Poison's ratio} = \nu_{21}^0 = -\frac{a_{12}^*}{a_{11}^*}$$

b. Flexural

The moment-curvature relation can be written as:

$$\tilde{M}^* = \tilde{D}^* \tilde{k}^*$$

or

$$\tilde{k}^* = \tilde{d}^* \tilde{M}^* \quad , \quad \tilde{d}^* = (\tilde{D}^*)^{-1}$$

The typical effective flexural engineering constants are given by:

$$\text{Longitudinal Young's modulus} = E_1^f = 1/d_{11}^*$$

$$\text{Transverse Young's modulus} = E_2^f = 1/d_{22}^*$$

$$\text{Shear modulus} = E_6^f = 1/d_{66}^*$$

$$\text{Poisson's ratio} = \nu_{21}^f = -d_{12}^*/d_{11}^*$$

In unsymmetric laminates, the effective stress strain relations and moment curvature relations will not be uncoupled. Therefore, in those situations the effective inplane and flexural engineering constants may not give much meaningful information.

6. MATERIAL PROPERTIES FOR FINITE ELEMENT ANALYSIS

The theory used in this report is based upon Kirchhoff's classical plate theory. For the stress analysis of composite laminates by finite element general purpose computer code, NASTRAN, the effective modulus matrix A_{ij}/h is used. In the NASTRAN material property input data card MT2, the numerical values are given such that the notation G_{ij} in the NASTRAN manual represents the effective modulus A_{ij}/h in this report.

SECTION III FAILURE THEORIES

Figure 4 shows the failure criteria survey response obtained by the AIAA composite materials subcommittee [3]. On the basis of this response we have chosen maximum stress, maximum strain and quadratic polynomial (Tsai-Wu [4], Chamis [5], Hoffman [6], and Hill [7]) failure criteria for a comparative treatment in this work. Reference 8 gives an extensive survey of failure theories. The theories considered in this investigation are given in [9,10,11]. For completeness, these theories are restated here

Maximum Stress

$$\sigma_x \leq X$$

$$\sigma_y \leq Y$$

$$\sigma_s \leq S$$

Maximum Strain

$$\epsilon_x \leq \frac{X}{E_x}$$

$$\epsilon_y \leq \frac{Y}{E_y}$$

$$\epsilon_s \leq \frac{S}{E_s}$$

Failure occurs when one of the equalities is met.

Quadratic Polynomial

Four quadratic polynomial failure criteria given in Table 8, have been considered.

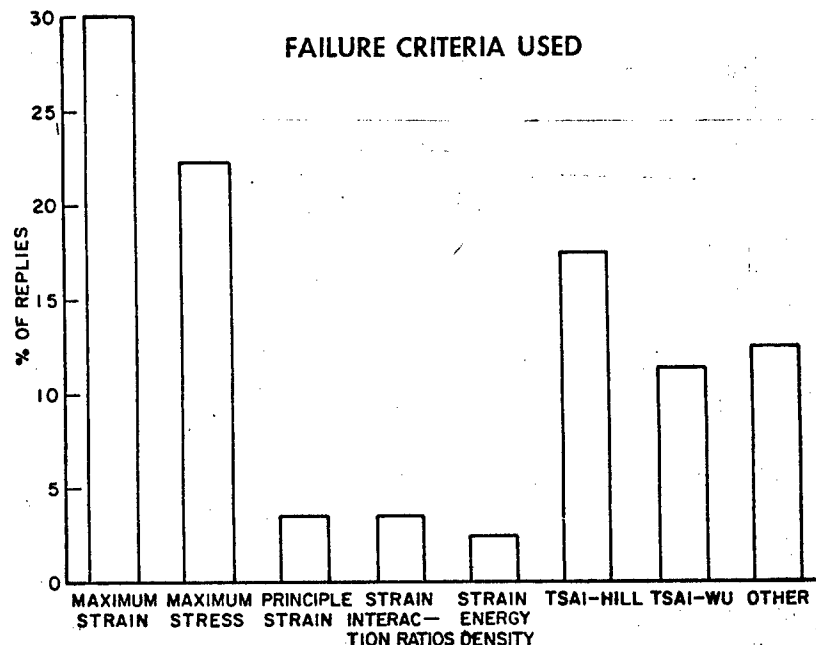


Figure 4. AIAA Failure Criteria Survey.

TABLE 8
QUADRATIC POLYNOMIAL FAILURE CRITERION

Criteria Parameter	Tsai-Wu	Chamis	Hoffman	Hill
Equation	$\sigma^T F \sigma + \bar{F}^T \sigma = 1$	$\sigma^T F \sigma = 1$	$\sigma^T F \sigma + \bar{F}^T \sigma = 1$	$\sigma^T F \sigma = 1$
F_{xx}	$\frac{1}{XX'}$	$\frac{1}{X^2}, (\frac{1}{X'^2})^\dagger$	$\frac{1}{XX'}$	$\frac{1}{X^2}$
F_{yy}	$\frac{1}{YY'}$	$\frac{1}{Y^2}, (\frac{1}{Y'^2})^\dagger$	$\frac{1}{YY'}$	$\frac{1}{Y^2}$
F_{xy}	$F_{xy}^* \sqrt{F_{xx} F_{yy}}$	$F_{xy}^* \sqrt{F_{xx} F_{yy}}$	$F_{xy}^* \sqrt{F_{xx} F_{yy}}$	$F_{xy}^* \sqrt{F_{xx} F_{yy}}$
F_{xy}^*	$-1 < F_{xy}^* < 1^{++}$	Material Property $^{+++}$	$-\frac{1}{2} \sqrt{\frac{YY'}{XX'}}$	$-\frac{1}{2} \frac{Y}{X}$
F_{ss}	$\frac{1}{S^2}$	$\frac{1}{S^2}$	$\frac{1}{S^2}$	$\frac{1}{S^2}$
F_x	$\frac{1}{X} - \frac{1}{X'}$		$\frac{1}{X} - \frac{1}{X'}$	
F_y	$\frac{1}{Y} - \frac{1}{Y'}$		$\frac{1}{Y} - \frac{1}{Y'}$	

⁺The values within the parenthesis are used when the corresponding stress component is compressive.

⁺⁺In the Tsai-Wu criterion F_{xy}^* is taken to be $-1/2$.

⁺⁺⁺In Chamis criterion F_{xy}^* varies from material to material. For T300/5208 $F_{xy}^* = -.7$.

X = Longitudinal tensile strength

X' = Longitudinal compressive strength

Y = Transverse tensile strength

Y' = Transverse compressive strength

S = Longitudinal shear strength

$$F = \begin{bmatrix} F_{xx} & F_{xy} & 0 \\ F_{xy} & F_{yy} & 0 \\ 0 & 0 & F_{ss} \end{bmatrix}, \quad \bar{F} = \begin{bmatrix} F_x \\ F_y \\ 0 \end{bmatrix}, \quad \sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{bmatrix}$$

A superscript T denotes transpose of the matrix and the subscripts x, y and s denote, respectively, longitudinal, transverse and shear directions, E denotes the Young's modulus of the ply. The quadratic polynomial failure criterion, through the use of the stress strain relations, can be expressed in strain space as follows:

$$\epsilon^T G \epsilon + \bar{G}^T \epsilon = 1 \quad (13a)$$

where the elements of matrix G and vector $\bar{G}^T$ are dependent upon the ply modulus matrix Q_{ij} , and F_{ij} and $\bar{F}_i$ of Table 8 and

$$\epsilon = \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_s \end{bmatrix}$$

For the computation of the failure envelopes in the $\sigma\tau$ space the following definitions are used:

$$p_\epsilon = (\epsilon_1 + \epsilon_2)/2$$

$$p_\sigma = (\sigma_1 + \sigma_2)/2$$

$$q_\epsilon = (\epsilon_1 - \epsilon_2)/2$$

$$q_\sigma = (\sigma_1 - \sigma_2)/2$$

$$r_\epsilon = \epsilon_6/2$$

$$r_\sigma = \sigma_6$$

where ϵ_i and σ_i are stress and strain components in the laminate axes.

Chamis, Hoffman and Hill criteria can be deduced from Tsai-Wu failure criterion by using different values of F_{xy}^* and appropriate X, X', Y and Y' as given in Table 8.

According to the quadratic polynomial failure criterion the failure surface in strain space, equation 13a, is represented by the following quadratic equation:

$$G_{ij}\epsilon_i\epsilon_j + G_i\epsilon_i = 1 \quad (i,j = x,y,s) \quad (13)$$

where nonzero coefficients G_{ij} in the foregoing equation are given by

$$\begin{aligned}
G_{xx} &= F_{xx} Q_{xx}^2 + 2F_{xy} Q_{xx} Q_{xy} + F_{yy} Q_{xy}^2 \\
G_{yy} &= F_{xx} Q_{xy}^2 + 2F_{xy} Q_{xy} Q_{yy} + F_{yy} Q_{yy}^2 \\
G_{xy} &= F_{xx} Q_{xx} Q_{xy} + F_{xy} [Q_{xx} Q_{yy} + Q_{xy}^2] + F_{yy} Q_{xy} Q_{yy} \\
G_{ss} &= F_{ss} Q_{ss}^2 = (Q_{ss}/s)^2 \\
G_x &= F_x Q_{xx} + F_y Q_{xy} \\
G_y &= F_x Q_{xy} + F_y Q_{yy}
\end{aligned} \tag{14}$$

Subroutine FAILCO computes the coefficients G_{ij} and G_i in Equation 13.

Equation 13 can be written in the following expanded form:

$$\begin{aligned}
&G_{xx} \epsilon_x^2 + 2G_{xy} \epsilon_x \epsilon_y + G_{yy} \epsilon_y^2 + G_{ss} \epsilon_s^2 \\
&+ G_x \epsilon_x + G_y \epsilon_y = 1
\end{aligned} \tag{15}$$

With the knowledge of applied stress or strain, the above relation will enable the designer to predict if the structure is going to survive or fail. This relation becomes easier to use if we introduce a strength ratio parameter R defined by:

$$\epsilon_{\text{allowed}}^M = R \epsilon_{\text{imposed}}^M \tag{16}$$

Here, the superscript M denotes the mechanical strain. The strains that must satisfy the failure criterion are:

$$\begin{aligned}
\epsilon_{ij}^{\text{allowed}} &= \epsilon_{ij}^M \text{ allowed} + \epsilon_i^N - e_i \\
&= \begin{aligned} &\epsilon_x^M + \epsilon_x^N - e_x \\ &\epsilon_y^M + \epsilon_y^N - e_y \\ &\epsilon_s^M + \epsilon_s^N \end{aligned}
\end{aligned} \tag{17}$$

The superscript N denotes nonmechanical strain, e_x and e_y are longitudinal and transverse strain components in the ply axis. Using Equations 16 and 17, Equation 15 is given in the following form:

$$G_{ij} (R \epsilon_i^M + \epsilon_i^N - e_i) (R \epsilon_j^M + \epsilon_j^N - e_j) + G_i (R \epsilon_i^M + \epsilon_i^N - e_i) = 1 \quad (18)$$

With algebraic rearrangements this equation reduces to:

$$aR^2 + bR + c = 0 \quad (19)$$

where a , b and c are coefficients of R^2 , R and 1 in Equation 18 and are dependent upon the material properties of the laminate and applied loadings. The roots of this equation give the strength ratios R and R^* , where R^* denotes the reversed load strength ratio.

Subroutine FSFTY computes the strength ratios R and R^* . However, in the print output only R has been given. A parameter R/h that corresponds to the strength of the ply (in case of a unit applied stress resultant N_i , $i=1,2,6$) has also been given in the print output. Since on variation of ply number or orientation in a laminate the total laminate thickness may vary, thus the introduction of R/h will be helpful in understanding the strength of different laminates.

For Chamis' criterion, when nonmechanical loads are included, the signs of mechanical stress components govern the choice of F_{xx} and F_{yy} of table 8. This can be changed to incorporate the resultant ply strains in subroutines FSFTY and STRNG.

REFERENCES

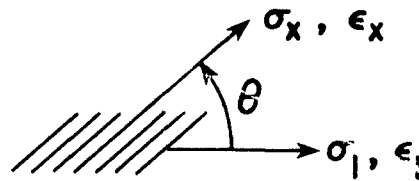
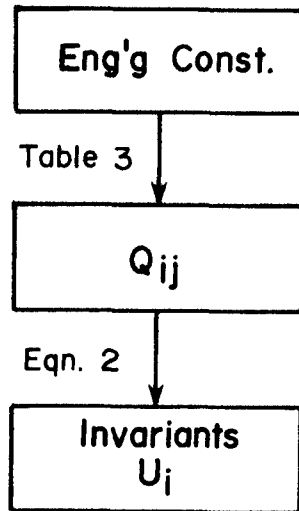
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6. O. Hoffman, "The Brittle Strength of Orthotropic Materials", *J. Composite Materials*, Vol. 1, 1967, p. 200.
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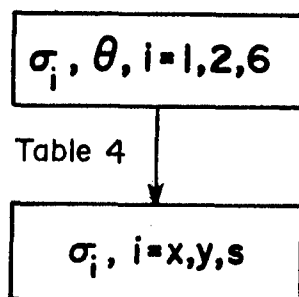
9.

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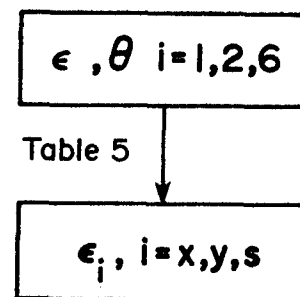
Subroutine MODULS: Calculates ply on axis modulus



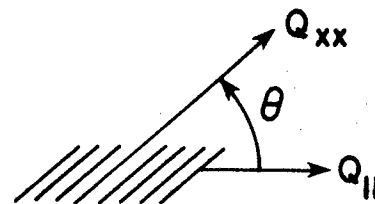
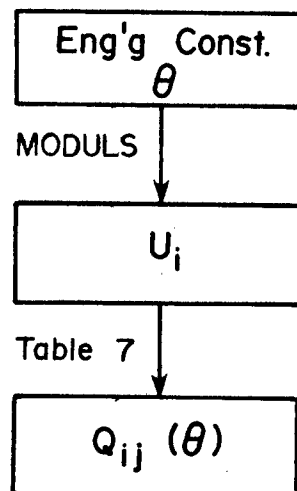
Subroutine TRS:
Stress transformation



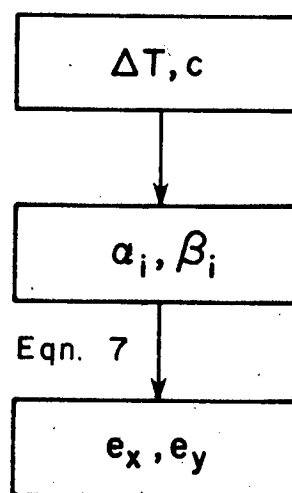
Subroutine TRE:
Strain transformation



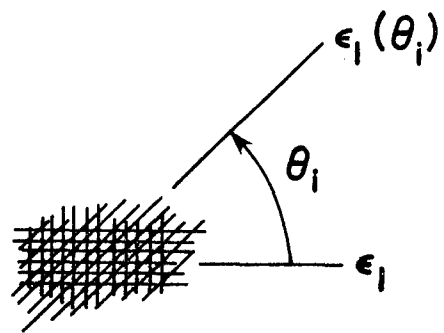
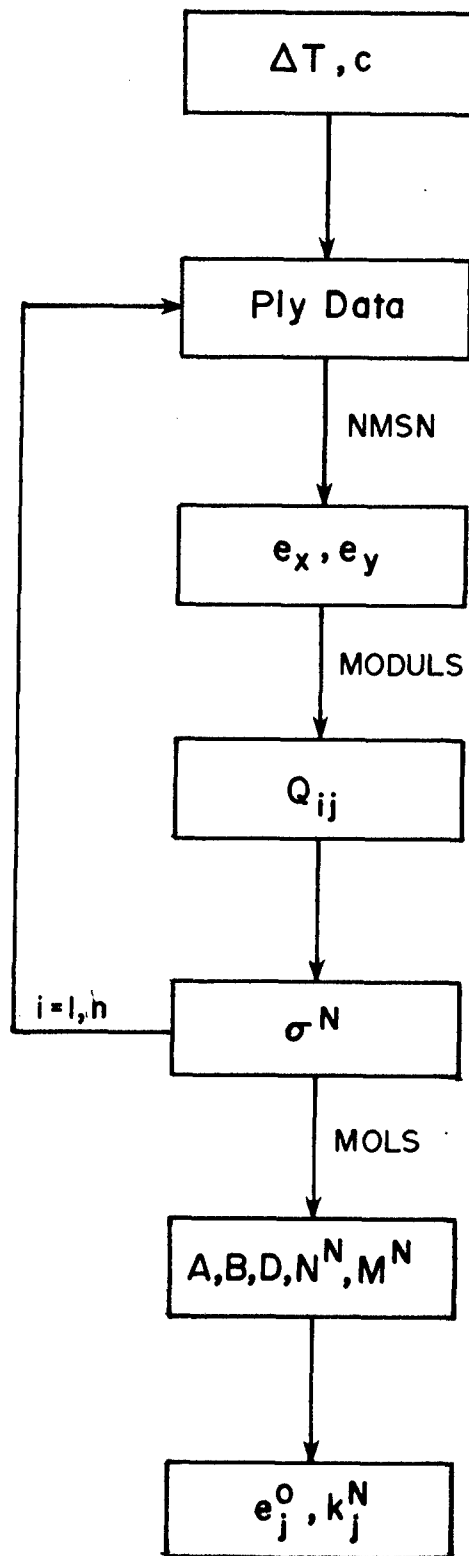
Subroutine MODCM: Ply off axis modulus



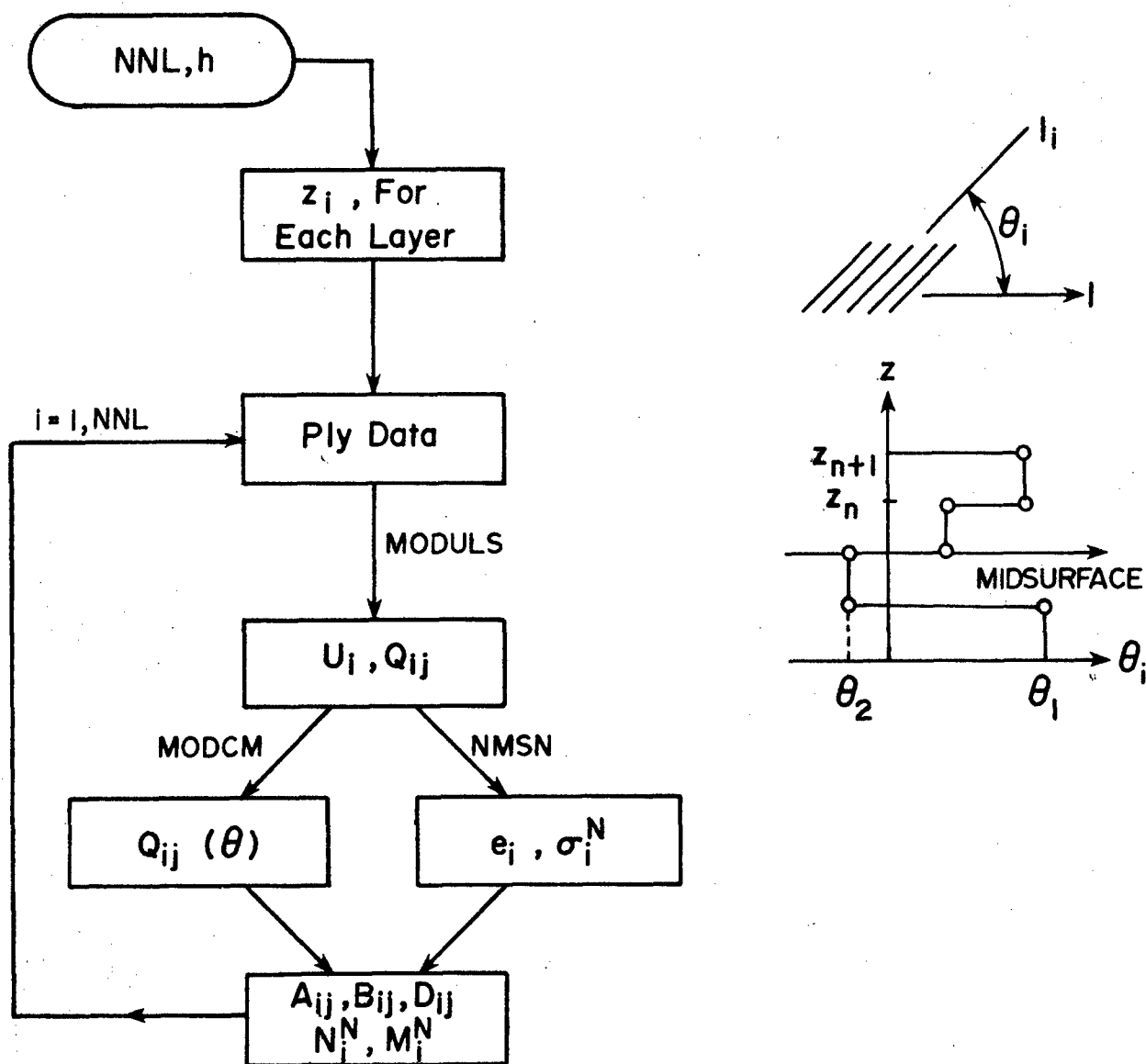
Subroutine NMSN: Ply nonmechanical strain



Flow Chart for inplane nonmechanical strain



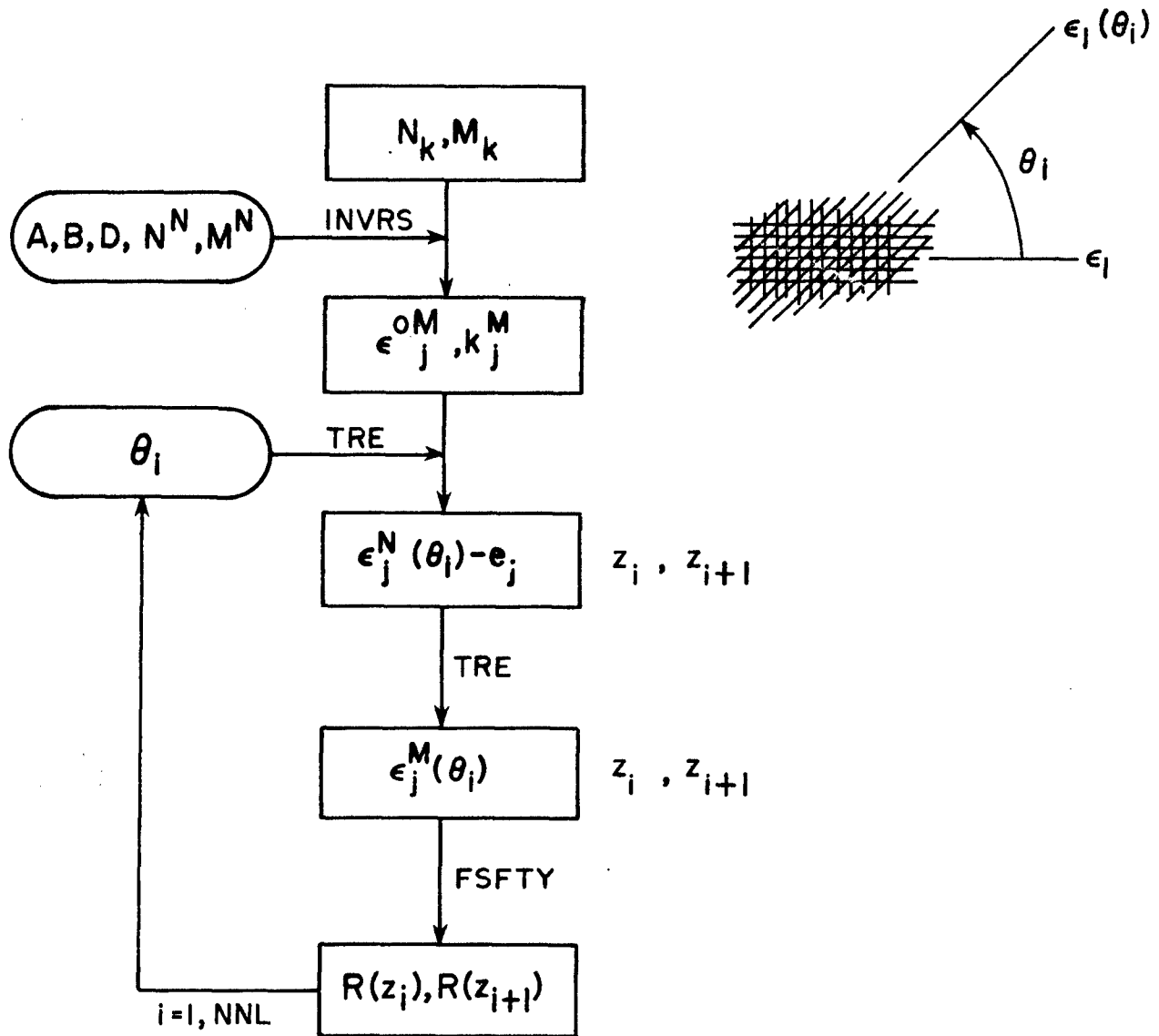
Subroutine MOLS: Effective modulus and nonmechanical loads



NNL = Number of layers in the laminate.

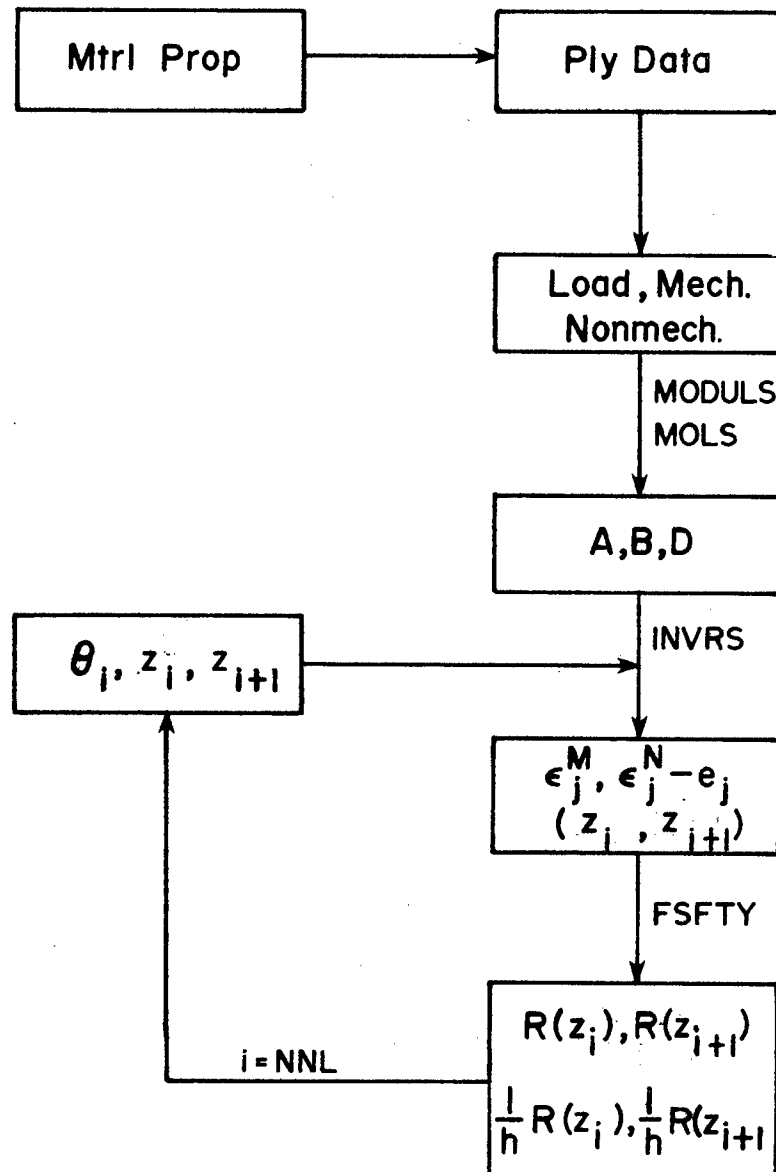
= n

Flow chart for each ply strength in general laminates.



NNL = n

Program Main



APPENDIX A

```

INTEGER TITL(4),CASE,PARAM,PARAM1,PARAM2,PARAM3,MATRIAL,UNITS
DIMENSION PLNM(40),T(3)
DIMENSION ZERO(3,3),DUM(3,3),DUM1(3,3)
DIMENSION U(5),DU7(3,3),HS(41),AN(3),AM(3)
DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),DU5(3,3)
DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
DIMENSION SB3(3,3),HLC(40),HT(40),TL(40),TT(40),P(3),SH(8)
DIMENSION EX(8),EY(8),VX(8),ES(8),ALFX(8),ALFY(8),BTAX(8)
DIMENSION BTAY(8),X(8),XD(8),Y(8),YD(8),S(8),LMPI(40)
DIMENSION Q(3,3),A(3,3),HL(40),TH(40),SFL(40),QQ(3)
DIMENSION NAMES(17)
DIMENSION NEWN(3)
COMMON /SF/SFL,COUNT
COMMON /BLH/ H,HI
COMMON /BLM/ PARAM2,PARAM3
COMMON/BLK/HLC,HT,TL,TT
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON /UNIT/ IUNIT
COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
COMMON /TIT/ TITL
COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
COMMON /MPIL/ LMPI
COMMON /BLDU/ DU2,DU4,DU5,DU7
NAMELIST /LAMDATA/NNM,EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,
*SH
NAMELIST/LAYERS/NNL,LMPI,TH,PLNM,IUNIT,DT,C,NLDCN
NAMELIST/LAYER/NNL,TH,PLNM,DT,C,NLDCN
NAMELIST /STRESS/ AN,AM
DATA NAMES/7HINITIAL,6HTHEEND,9HTRANSFORM,6HSTRESS,6HSTRAIN,
*7HMODULUS,10HCOMPLIANCE,6HMODCOM,8HLAMINATE,7HINPLANE,4HPURE,
*6HHYBRID,7HGENERAL,8HSTRENGTH,4H,10HSTRNGTHPLT,7HENGCLPT/
DATA NEWN/8HNEWMTRLS,2HSI,7HENGLISH/

```

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*****

```

A COMPOSITE LAMINATE ANALYSIS PROGRAM

DEVELOPED BY

SOM R. SONI
UNIVERSITY OF DAYTON
RESEARCH INSTITUTE
300 COLLEGE PK.
DAYTON OHIO 45469
TEL. # (513) 255- 6809

```

*****

```

```

13  FORMAT(5X,*-----)

```

```

*-----*)

```

```

WRITE 13
WRITE 1001
WRITE 13

```

```

WRITE 1003
WRITE 13
1001  FORMAT(5X,*A COMPOSITE LAMINATE ANALYSIS PROGRAM*)
      CALL LMDT
1002  FORMAT(5X,*DEVELOPED BY*,/,
15X,*SOM R. SONI*,/,
25X,*UNIVERSITY OF DAYTON RESEARCH INSTITUTE*,/,
35X,*DAYTON OHIO 45469*,/,
45X,*FOR QUESTIONS CALL 513-255-6809*,/)
1003  FORMAT(5X,*MATERIAL PROPERTY DATA*)
      WRITE 13
      DO 303 I=1,3
      DO 303 J=1,3
      ZERO(I,J)=0.
303   CONTINUE
706   FORMAT(7F10.3)
799   CONTINUE
      IUNIT=2
      WRITE 711
711   FORMAT(1H1)
      READ 700,(TITL(I),I=1,4)
      IF(TITL(1) .EQ. NAMES(2)) STOP
      IF(TITL(1) .EQ. NEWN(1)) READ LAMDATA
      IF(TITL(1) .EQ. NEWN(1)) GO TO 799
      PRINT LAMDATA
700   FORMAT(6A10)
      IF(TITL(1) .EQ. NAMES(2)) GO TO 902
      IF(TITL(1) .EQ. NAMES(9) .AND. TITL(2) .EQ. NAMES(10)) GO TO 722
      IF(TITL(1) .EQ. NAMES(9) .AND. TITL(2) .EQ. NAMES(13)) GO TO 723
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(4)) GO TO 724
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(5)) GO TO 725
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(6)) GO TO 726
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(7)) GO TO 726
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(8)) GO TO 726
724   CONTINUE
      READ 701,(AN(I),I=1,3), THETA
701   FORMAT(4F10.3)
      WRITE 702,THETA
702   FORMAT(5X,*STRESS TRANSFORMATION THRU *,F7.2,2X,*DEGREES*,/,10X,
.*          SIGMA1    SIGMA2    SIGMA6*)
      WRITE 13
      WRITE 703,(AN(I),I=1,3)
703   FORMAT(5X,*GIVEN          *,3F10.3)
      CALL TRS(AN,T,THETA)
      WRITE 704,(T(I),I=1,3)
704   FORMAT(5X,*TRANSFORMED    *,3F10.3)
      WRITE 13
      GO TO 799
725   CONTINUE
      READ 701,(AN(I),I=1,3), THETA
      WRITE 705,THETA
705   FORMAT(5X,*STRAIN TRANSFORMATION THRU *,F7.2,2X,*DEGREES*,/,10X,
.*          EPSLN1    EPSLN2    EPSLN6*)
      WRITE 13
      WRITE 703,(AN(I),I=1,3)
      CALL TRE(AN,T,THETA)
      WRITE 704,(T(I),I=1,3)
      WRITE 13

```

```

GO TO 799
726 CONTINUE
READ 700,MATRIAL,UNITS
IF(UNITS .NE. NEWN(3)) IUNIT=1
CALL MINP(MATRIAL,LI)
IF(LI .EQ. 8) READ 706,EX(LI),EY(LI),VX(LI),ES(LI),TH(1)
IF(LI .LT. 8) READ 706,TH(1)
NNL=1
LMPI(1)=LI
PLNM(1)=1.
CALL MTDM(PLNM,PM,GM,PMI,TPI)
CALL MODULS(ES11(1),ES22(1),VS12(1),GS12(1),Q,U)
CALL MODCM(TH(1),U,SB1)
CALL MTAD(ZERO, SB1,SB2,PMI)
CALL MTAD(ZERO,Q,SB3,PMI)
IF(TITL(2) .EQ. NAMES(7)) GO TO 727
WRITE 707,TH(1)
707 FORMAT(5X,*MODULUS TRANSFORMATION THRU *,F7.2,* DEGREE ANGLE*)
IF(IUNIT .NE. 1) WRITE 713
IF(IUNIT .EQ. 1) WRITE 712
712 FORMAT(30X,*(GPA)*)
713 FORMAT(30X,*(1.E+06 PSI)*)
WRITE 13
WRITE 709
709 FORMAT(5X,*MODULUS OF THE MATERIAL*,10X,*TRANSFORMED MODULUS*)
WRITE 13
CALL WITE1(SB3,SB2)
WRITE 13
IF(TITL(2) .EQ. NAMES(6)) GO TO 799
727 CONTINUE
CALL INVRS(SB3,DUM)
CALL INVRS(SB2,DUM1)
CALL MTAD(ZERO,DUM,DU1,1000.)
CALL MTAD(ZERO,DUM1,DU2,1000.)
WRITE 708, TH(1)
708 FORMAT(5X,*COMPLIANCE TRANSFORMATION THRU *,F7.2,* DEGREE ANGLE*
.)
IF(IUNIT .EQ. 1) WRITE 714
IF(IUNIT .NE. 1) WRITE 715
714 FORMAT(30X,*(1/TPA)*)
715 FORMAT(30X,*(1.0E-09/PSI)*)
WRITE 13
WRITE 710
710 FORMAT(5X,*COMPLIANCE OF MATERIAL*,13X,*TRANSFORMED COMPLIANCE*)
WRITE 13
CALL WITE1(DU1,DU2)
WRITE 13
GO TO 799
722 READ 700,CASE,PARAM,PARAM1,PARAM2,PARAM3
TITL(4)=CASE
IF(CASE .EQ. NAMES(12)) GO TO 731
IF(CASE .NE. NAMES(11)) STOP "ERROR IN MIND"
CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
CALL MTDM(PLNM,PM,GM,PMI,TPI)
CALL MOLS(TH,HL,HS)
CALL INVRS(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
CALL MTAD(ZERO,SB1,DUM1,HI)
CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
CALL NORM1(TPI,A,PARAM1)

```

```

IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
GO TO 799
731 CONTINUE
CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
CALL MTDM(PLNM,PM,GM,PMI,TPI)
CALL MOLS(TH,HL,HS)
CALL INVRS(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
CALL MTAD(ZERO,SB1,DUM1,HI)
CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
CALL NORM1(TPI,A,PARAM1)
IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
GO TO 799
723 READ 700,CASE,PARAM,PARAM1,PARAM2
TITL(4)=CASE
IF(CASE .EQ. NAMES(12)) GO TO 732
IF(CASE .NE. NAMES(11)) STOP "ERROR IN MIND"
CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
CALL MTDM(PLNM,PM,GM,PMI,TPI)
CALL MOLS(TH,HL,HS)
CALL INVRS(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
CALL MTAD(ZERO,SB1,DUM1,HI)
CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
CALL NORM1(TPI,A,PARAM1)
IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
GO TO 799
732 CONTINUE
CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
CALL MTDM(PLNM,PM,GM,PMI,TPI)
CALL MOLS(TH,HL,HS)
CALL INVRS(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
CALL MTAD(ZERO,SB1,DUM1,HI)
CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
CALL NORM1(TPI,A,PARAM1)
IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
GO TO 799
902 CONTINUE
WRITE 13
STOP
END

```

```

SUBROUTINE ADJUST(ICND,SFLN,SPLC,AN)
INTEGER CRITRIA,SPACE,PLANE
DIMENSION STX1(200),STY1(200),SCX1(200),SCY1(200)
DIMENSION STX2(200),STY2(200),SCX2(200),SCY2(200)
DIMENSION STX3(200),STY3(200),SCX3(200),SCY3(200)
DIMENSION SFLN(40),SPLC(40),AN(3),NAME(2)
COMMON /ST1/ STX1,STY1,SCX1,SCY1,NSF1
COMMON /ST2/ STX2,STY2,SCX2,SCY2,NSF2
COMMON /ST3/ STX3,STY3,SCX3,SCY3,NSF3
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
DATA NAME/2HQR,6HSTRESS/
IF(PLANE .EQ. NAME(1)) GO TO 1
STX1(ICND)=SFLN(NSF1)*AN(1)
STY1(ICND)=SFLN(NSF1)*AN(2)
SCX1(ICND)=SPLC(NSF1)*AN(1)
SCY1(ICND)=SPLC(NSF1)*AN(2)
STX2(ICND)=SFLN(NSF2)*AN(1)
STY2(ICND)=SFLN(NSF2)*AN(2)
SCX2(ICND)=SPLC(NSF2)*AN(1)
SCY2(ICND)=SPLC(NSF2)*AN(2)
STX3(ICND)=SFLN(NSF3)*AN(1)
STY3(ICND)=SFLN(NSF3)*AN(2)
SCX3(ICND)=SPLC(NSF3)*AN(1)
SCY3(ICND)=SPLC(NSF3)*AN(2)
RETURN
1 CONTINUE
SQ2=SQRT(2.0)
SQ3=SQ2
IF(SPACE .EQ. NAME(2)) SQ3=1./SQ2
STX1(ICND)=SQ2*SFLN(NSF1)*AN(1)
STX2(ICND)=SQ2*SFLN(NSF2)*AN(1)
STX3(ICND)=SQ2*SFLN(NSF3)*AN(1)
SCX1(ICND)=SQ2*SPLC(NSF1)*AN(1)
SCX2(ICND)=SQ2*SPLC(NSF2)*AN(1)
SCX3(ICND)=SQ2*SPLC(NSF3)*AN(1)
STY1(ICND)=SFLN(NSF1)*AN(3)/SQ3
STY2(ICND)=SFLN(NSF2)*AN(3)/SQ3
STY3(ICND)=SFLN(NSF3)*AN(3)/SQ3
SCY1(ICND)=SPLC(NSF1)*AN(3)/SQ3
SCY2(ICND)=SPLC(NSF2)*AN(3)/SQ3
SCY3(ICND)=SPLC(NSF3)*AN(3)/SQ3
RETURN
END

```

```

SUBROUTINE AMAX(XX,NN,AMX)
DIMENSION XX(10)
AMX=XX(1)
DO 1 I=1,NN
IF(XX(I) .GE. AMX) AMX=XX(I)
1 CONTINUE
RETURN
END

```

```

SUBROUTINE AMIN(XX,NN,AMN,IK)
DIMENSION XX(20)
AMN=XX(1)
DO 1 I=1,NN
IF(XX(I) .LE. AMN) GO TO 2
GO TO 1
2 AMN=XX(I)
IK=I
1 CONTINUE
RETURN
END

```

```

SUBROUTINE COEF(G,GB,GS,GSB,THET)
DIMENSION G(3,3),GB(3),GS(3,3),GSB(3),U(5)
CALL US(G,U)
CALL MODCM(THET,U,GS)
H1=(GB(1)+GB(2))/2.
H2=(GB(1)-GB(2))/2.
TH2=2.*THET
C=COSM(TH2)
S=SINM(TH2)
GSB(1)=H1+H2*C
GSB(2)=H1-H2*C
GSB(3)=H2*S
RETURN
END

```

```

SUBROUTINE FAILCO(E,Q,X,XD,Y,YD,XLT,G,GB)
INTEGER CRITRIA,SPACE,PLANE
DIMENSION E(3),E1(3)
DIMENSION Q(3,3),G(3,3),F(3,3),GB(3),FB(3),C(3,3)
DIMENSION NAME(6)
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
DATA NAME /7HTSAI WU,7HHOFFMAN,4HHILL,6HCHAMIS,6HSTRAIN,6HSTRESS/
XL=X
XC=XD
YL=Y
YC=YD
IF(CRITRIA .EQ. NAME(1) .OR. CRITRIA .EQ. NAME(2)) GO TO 1
IF(CRITRIA .EQ. NAME(4)) GO TO 2
XC=X
YC=Y
GO TO 1
2 CALL MVM(Q,E,E1)
IF(E1(1) .LT.0.) XL=XD
IF(E1(1) .GT.0.) XC=X
IF(E1(2) .LT.0.) YL=YD
IF(E1(2) .GT.0.) YC=Y
1 CONTINUE
F(1,1)=1.0/(XL*XC)
F(2,2)=1.0/(YL*YC)
C F(1,2)=0.
COE=SQRT(F(1,1)*F(2,2))
F(1,2)=FS12*COE
IF(CRITRIA.EQ. NAME(2) .OR. CRITRIA .EQ. NAME(3)) F(1,2)=-.5*F(1,1)
IF(CRITRIA .EQ. NAME(4)) F(1,2)=FS12*COE
F(3,3)=1.0/(XLT*XLT)
FB(1)=(XC-XL)*F(1,1)
FB(2)=(YC-YL)*F(2,2)
FB(3)=0.0
F(2,1)=F(1,2)
F(3,1)=0.0
F(3,2)=0.0
F(1,3)=0.0
F(2,3)=0.0
CALL MATM(Q,F,C)
CALL MATM(C,Q,G)
CALL MVM(Q,FB,GB)
RETURN
END

```

```

SUBROUTINE FSFTY(ET,EN,G,GB,SM,SMN)
DIMENSION ET(3),EN(3),G(3,3),GB(3),TS(3),T(3)
CALL MVM(G,ET,T)
CALL MVM(G,EN,TS)
AC=VVM(T,ET)
BC= VVM(T,EN)+VVM(TS,ET)+VVM(ET,GB)
CC=VVM(EN,TS)+VVM(GB,EN)-1.0
CALL ROOTS(AC,BC,CC,SM,SMN)
RETURN
END

```

```

SUBROUTINE INVR(S,Q,A)
  DIMENSION Q(3,3),A(3,3)
  DET=Q(1,1)*Q(2,2)*Q(3,3)+2.0*Q(1,2)*Q(1,3)*Q(2,3)-Q(2,2)*Q(1,3)**2
  *-Q(1,1)*Q(2,3)**2-Q(3,3)*Q(1,2)**2
  A(1,1)=(Q(2,2)*Q(3,3)-Q(2,3)**2)/DET
  A(3,3)=(Q(1,1)*Q(2,2)-Q(1,2)**2)/DET
  A(2,2)=(Q(1,1)*Q(3,3)-Q(1,3)**2)/DET
  A(1,3)=(Q(1,2)*Q(2,3)-Q(2,2)*Q(1,3))/DET
  A(1,2)=(Q(1,3)*Q(2,3)-Q(1,2)*Q(3,3))/DET
  A(2,3)=(Q(1,2)*Q(1,3)-Q(1,1)*Q(2,3))/DET
  DO 1 I=1,3
  DO 1 J=1,3
  A(J,I)=A(I,J)
1 CONTINUE
  RETURN
  END

```

```

SUBROUTINE LMDT
  DIMENSION EX(8),EY(8),VX(8),ES(8) ,ALFX(8),ALFY(8),BTAX(8)
  DIMENSION BTAY(8),X(8), XD(8),Y(8), YD(8),S(8),SH(8)
  COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
C DATA EX/145.,204.,138.,38.6,76.,0.,69.,0./
C DATA EX/181.,204.,138.,38.6,76.,0.,69.,0./
C DATA EY/11.0,18.5,8.96,8.27,5.5,0.,69.,0./
C DATA EY/10.3,18.5,8.96,8.27,5.5,0.,69.,0./
C DATA VX/.25,.23,.3,.26,.34,0.,.3,0./
C DATA VX/.28,.23,.3,.26,.34,0.,.3,0./
C DATA ES/5.50,5.59,7.1,4.14,2.3,0.,26.5,0./
C DATA ES/7.17,5.59,7.1,4.14,2.3,0.,26.5,0./
C DATA ALFX/.02,6.1,-.3,8.6,-4.0,.0,0.,0./
C DATA ALFY/22.5,30.3,28.1,22.1,79.0,.0,12.5,0./
C DATA BTAX/0.,0.,0.,0.,0.,0.,0.,0./
C DATA BTAY/0.6,0.6,.44,.6,.6,.0,0.,0./
C DATA X/1448.,1260.,1447.,1062.,1400.,.0,400.,0./
C DATA X/1500.,1260.,1447.,1062.,1400.,.0,400.,0./
C DATA XD/1448.,2500.,1447.,610.,235.,.0,400.,0./
C DATA XD/1500.,2500.,1447.,610.,235.,.0,400.,0./
C DATA Y/52.,61.,51.7,31.,12.,0.,400.,0./
C DATA Y/40.,61.,51.7,31.,12.,0.,400.,0./
C DATA YD/207.,202.,206.,118.,53.,0.,400.,0./
C DATA YD/246.,202.,206.,118.,53.,0.,400.,0./
C DATA S/93.0,67.,93.,72.,34.,0.,230.,0./
C DATA S/68.0,67.,93.,72.,34.,0.,230.,0./
C DATA SH/.125E-03,.125E-03,.125E-03,.125E-03,.125E-03,.001,1.,0./
C DATA NNM/7/
  RETURN
  END

```

```

SUBROUTINE LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
INTEGER TITL(4),MATRIAL,UNITS
DIMENSION TH(40),NAMES(4),PLNM(40),LMPI(40),DESCRP(8)
COMMON /UNIT/ IUNIT
COMMON /TIT/ TITL
NAMelist/LAYERS/NNL,LMPI,TH,PLNM,IUNIT,DT,C,NLDCN
NAMelist/LAYER/NNL,TH,PLNM,DT,C,NLDCN
DATA NAMES /4HPURE,6HHYBRID,2HSI,7HENGLISH/
444  FORMAT(8A10)
    WRITE 13
445  FORMAT(1H0,8A10)
    WRITE 13
    READ 444,DESCRP
    PRINT445,DESCRP
    WRITE 13
    IF (TITL(4) .EQ. NAMES(1)) GO TO 609
    READ LAYERS
    GO TO 610
609  READ 700,MATRIAL,UNITS
    IF(UNITS .NE. NAMES(4)) IUNIT=1
    READ LAYER
700  FORMAT(2A10)
    CALL MINP(MATRIAL,LI)
    DO 711 IM=1,NNL
        LMPI(IM)=LI
711  CONTINUE
610  CONTINUE
    WRITE 604,NNL
604  FORMAT(6X,*NUMBER OF PLYS =*,I3)
    WRITE 605
605  FORMAT(6X,*ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1*)
    WRITE 6051,(TH(I),I=1,NNL)
6051 FORMAT(6X,12F5.1)
    WRITE 665
665  FORMAT(6X,*NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION*)
    WRITE 6051,(PLNM(I),I=1,NNL)
    WRITE 607
607  FORMAT(6X,*MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY*)
    WRITE 6071,(LMPI(I),I=1,NNL)
6071 FORMAT(6X,12I5)
    WRITE 608,DT,C
608  FORMAT(6X,*TEMPERATURE DT=*,F10.4,*      MOISTURE=*,F10.4)
13   FORMAT(5X,*-----*)
*-----*)
    RETURN
    END

```

```

SUBROUTINE MATM(A,B,C)
DIMENSION A(3,3),B(3,3),C(3,3)
DO 2 I=1,3
DO 2 J=1,3
SUM=0.0
DO 1 K=1,3
SUM=SUM+A(J,K)*B(K,I)
1 CONTINUE
C(J,I)=SUM
2 CONTINUE
RETURN
END

```

```

SUBROUTINE MINP(MAT,LI)
DIMENSION NAMES(8)
DATA NAMES/9HT300/5208,7HB4/5505,7HAS/3501,9HSCOTCHPLY,8HKEVLAR49,
*4HCORE,8HALUMINUM,3HNEW/
DO 1 I=1,8
1 IF(MAT .EQ. NAMES(I)) GO TO 2
STOP "ERROR IN MIND"
2 LI=I
RETURN
END

```

```

SUBROUTINE MODCM(TH,U,Q)
DIMENSION U(5)
DIMENSION Q(3,3)
TH2=2.*TH
C2=COSM(TH2)
S2=SINM(TH2)
TH4=4.*TH
C4=COSM(TH4)
S4=SINM(TH4)
Q(1,1)=U(1)+U(2)*C2+U(3)*C4
Q(2,2)=U(1)-U(2)*C2+U(3)*C4
Q(1,2)=U(4)-U(3)*C4
Q(3,3)=U(5)-U(3)*C4
Q(1,3)=U(2)*S2/2.+U(3)*S4
Q(2,3)=U(2)*S2/2.-U(3)*S4
CALL SYM(Q)
RETURN
END

```

```

SUBROUTINE MODULS(EL,ET,VLT,GLT,Q,U)
DIMENSION U(5)
DIMENSION Q(3,3)
DO 1 I=1,3
DO 1 J=1,3
Q(I,J)=0.
1 CONTINUE
IF (EL.EQ. 0.) GO TO 2
AM=1./(1.0-VLT*VLT*ET/EL)
Q(1,1)=EL*AM
Q(1,2)=AM*ET*VLT
Q(2,1)=Q(1,2)
Q(2,2)=AM*ET
Q(3,3)=GLT
2 CONTINUE
CALL US(Q,U)
RETURN
END

```

```

SUBROUTINE MOLS(THETA,HL,HN)
DIMENSION E(3),E1(3),P(3),QQ(3),F(3),ES11(40),ES22(40),GS12(40)
DIMENSION VS12(40),SB1(3,3),SB2(3,3),SB3(3,3),HL(40),HN(41),Q(3,3)
DIMENSION THETA(40),HLC(40),HT(40),TL(40),TT(40)
DIMENSION U(5),QX(3,3)
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON/BLK/HLC,HT,TL,TT
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON /BLH/ H,HI
TH1=0.
DO 1 I=1,NNL
  TH1=TH1+HL(I)
1 CONTINUE
  HTT=TH1/2.
  HH=TH1*TH1
  NN=NNL+1
  HN(1)=-HTT
  DO 2 J=2,NN
    HN(J)=HN(J-1)+HL(J-1)
2 CONTINUE
  DO 66 I=1,3
    P(I)=0.
    QQ(I)=0.
    DO 66 J=1,3
      SB2(I,J)=0.
      SB3(I,J)=0.
66 CONTINUE
  DO 6 NL=1,NNL
    H1=HN(NL+1)-HN(NL)
    H2=H1*(HN(NL+1)+HN(NL))/2.
    G=HN(NL+1)*HN(NL)
    H3=H1*(H1*H1+3.*G)/3.
    THT=THETA(NL)
    CALL MODULS(ES11(NL),ES22(NL),VS12(NL),GS12(NL),QX,U)
    CALL MODCM(THT,U,Q)
    CALL NMSN(C,DT,E,HLC,HT,TL,TT,NL)
    CALL MVM(QX,E,E1)
    CALL TRS(E1,F,-THT)
    DO 4 I=1,3
      DO 3 J=I,3
        SB1(I,J)=SB1(I,J)+Q(I,J)*H1
        SB2(I,J)=SB2(I,J)+Q(I,J)*H2
        SB3(I,J)=SB3(I,J)+Q(I,J)*H3
3 CONTINUE
    P(I)=P(I)+F(I)*H1
    QQ(I)=QQ(I)+F(I)*H2
4 CONTINUE
    CALL SYM(SB1)
    CALL SYM(SB2)
    CALL SYM(SB3)
6 CONTINUE
  H=TH1
  HI=1./H
  RETURN
END

```

```

SUBROUTINE MTAD(A,B,C,CN)
DIMENSION A(3,3),B(3,3),C(3,3)
DO 1 I=1,3
DO 1 J=1,3
C(I,J)=A(I,J)+CN*B(I,J)
1 CONTINUE
RETURN
END

SUBROUTINE MTDH(PLNM,PM,GM,PHI,TPI)
DIMENSION PLNM(40),HL(40)
DIMENSION ES11(40),ES22(40),VS12(40),GS12(40)
DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
DIMENSION HLC(40),HT(40),TL(40),TT(40),SH(8)
DIMENSION EX(8),EY(8),VX(8),ES(8),ALFX(8),ALFY(8),BTAX(8)
DIMENSION BTAY(8),X(8),XD(8),Y(8),YD(8),S(8),LMPI(40)
COMMON /UNIT/ IUNIT
COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
COMMON /BLK2/ HLC,HT,TL,TT
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
COMMON /MPIL/ LMPI
CON1=1.0
CON2=1.0
PM=1.0E+06
IF(IUNIT.EQ. 1) GO TO 4455
PM=PM/6895.
CON1=5./9.
CON2=39.4
4455 CONTINUE
GM=1000.*PM
DO 1 I=1,NNL
II=LMPI(I)
ES11(I)=EX(II)*GM
ES22(I)=EY(II)*GM
VS12(I)=VX(II)
GS12(I)=ES(II)*GM
TL(I)=ALFX(II)*CON1*1.0E-06
TT(I)=ALFY(II)*CON1*1.0E-06
HLC(I)=BTAX(II)
HT(I)=BTAY(II)
SXL(I)=X(II)*PM
SXC(I)=XD(II)*PM
SYL(I)=Y(II)*PM
SYC(I)=YD(II)*PM
SXLT(I)=S(II)*PM
HL(I)=SH(II)*CON2*PLNM(I)
1 CONTINUE
IF(IUNIT.NE. 1) PM=1.0E+03
GM=1000.*PM
PHI=1./GM
TPI=1000.*GM
IF(IUNIT.EQ.1) WRITE 24
IF(IUNIT.NE.1) WRITE 25
24 FORMAT(20X,*SI UNITS*)
25 FORMAT(20X,*ENGLISH UNITS*)
RETURN
END

```

```

SUBROUTINE MVM(X,Y,Z)
DIMENSION X(3,3),Y(3),Z(3)
DO 1 I=1,3
SUM=0.0
DO 2 J=1,3
SUM=SUM+X(I,J)*Y(J)
2 CONTINUE
Z(I)=SUM
1 CONTINUE
RETURN
END

```

```

SUBROUTINE MXSTRN(K,EN,AAN,Q,PM)
DIMENSION EPST(3),EPSC(3),SIGR(3),SIGA(3),EN(3),AAN(3),AK(3)
DIMENSION SXL(40),SXC(40),SYL(40),SYC(40),SXLT(40),A(3,3),Q(3,3)
DIMENSION HL(40)
COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
COMMON /BLH/ H,HI
COMMON /UNIT/ IUNIT
COMMON /SF/SFL,COUNT
CALL INVRN(Q,A)
EPST(1)=SXL(K)*A(1,1)
EPSC(1)=-SXC(K)*A(1,1)
EPST(2)=SYL(K)*A(2,2)
EPSC(2)=-SYC(K)*A(2,2)
EPST(3)=SXLT(K)*A(3,3)
EPSC(3)=-SXLT(K)*A(3,3)
DO 1 I=1,3
DEN=EPST(I)
IF(EN(I) .LT. 0.) DEN=EPSC(I)
AK(I)=EN(I)/DEN
1 CONTINUE
CALL AMAX(AK,3,AMX)
DO 2 II=1,3
SIGR(II)=AAN(II)/AMX
SIGA(II)=SIGR(II)/H/PM
2 CONTINUE
SFL=1./(AMX*H*PM)
IF(COUNT.EQ.1.) RETURN
WRITE 6,(SIGR(I),I=1,3)
6 FORMAT(5X,*STRESS RESULTANTS*,9X,*N1=*,E8.2,4X,*N2=*,E8.2,4X,
U*N6=*,E8.2)
IF(IUNIT .EQ. 1) WRITE 7,(SIGA(I),I=1,3)
IF(IUNIT .NE. 1) WRITE 8,(SIGA(I),I=1,3)
7 FORMAT(5X,*AVERAGE STRESSES MPA *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
,F6.1,2X,*SIGMA6=*,F6.1)
8 FORMAT(5X,*AVERAGE STRESSES KSI *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
,F6.1,2X,*SIGMA6=*,F6.1)
RETURN
END

```

```

SUBROUTINE MXSTRS(K,AN,AAN,PM)
DIMENSION SIGT(3),SIGC(3),SIGR(3),SIGA(3),AN(3),AAN(3),AK(3)
DIMENSION SXL(40),SXC(40),SYL(40),SYC(40),SXLT(40)
DIMENSION HL(40)
COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
COMMON /BLH/ H,HI
COMMON /UNIT/ IUNIT
COMMON /SF/SFL,COUNT
SIGT(1)=SXL(K)
SIGT(2)=SYL(K)
SIGT(3)=SXLT(K)
SIGC(1)=-SXC(K)
SIGC(2)=-SYC(K)
SIGC(3)=-SXLT(K)
DO 1 I=1,3
DEN=SIGT(I)
IF(AN(I) .LT. 0.) DEN=SIGC(I)
AK(I)=AN(I)/DEN
1 CONTINUE
CALL AMAX(AK,3,AMX)
DO 2 II=1,3
SIGR(II)=AAN(II)/AMX
SIGA(II)=SIGR(II)/H/PM
2 CONTINUE
SFL=1./(AMX*H*PM)
IF(COUNT.EQ.1.) RETURN
WRITE 6,(SIGR(I),I=1,3)
6 FORMAT(5X,*STRESS RESULTANTS*,9X,*N1=*,E8.2,4X,*N2=*,E8.2,4X,
U*N6=*,E8.2)
IF(IUNIT .EQ. 1) WRITE 7,(SIGA(I),I=1,3)
IF(IUNIT .NE. 1) WRITE 8,(SIGA(I),I=1,3)
7 FORMAT(5X,*AVERAGE STRESSES MPA *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
,F6.1,2X,*SIGMA6=*,F6.1)
8 FORMAT(5X,*AVERAGE STRESSES KSI *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
,F6.1,2X,*SIGMA6=*,F6.1)
RETURN
END

```

```

SUBROUTINE NMSN(C,DT,EN1,HL,HT,TL,TT,K)
DIMENSION EN1(3),HL(40),HT(40),TL(40),TT(40)
EN1(1)=C*HL(K)+DT*TL(K)
EN1(2)=C*HT(K)+DT*TT(K)
EN1(3)=0.
RETURN
END

```

```

SUBROUTINE NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PAR)
INTEGER PAR
DIMENSION NAMES(6),A(3,3)
DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),ZERO(3,3)
DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),HLC(40),HT(40)
DIMENSION TL(40),TT(40),DUM(3,3),DUM1(3,3),ECON(4),ECONF(4)
COMMON /UNIT/ IUNIT
COMMON /BLH/ H,HI
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON/BLK/HLC,HT,TL,TT
DATA NAMES /10HDIMENSIONL,10HNORMALIZED,4HBOTH,8HENGCONST,3HALL,
*4H /
13  FORMAT(5X,*-----*)
*-----*)
HSQ=H*H
HIS=1./HSQ
PMN1=PMI/H
PMN2=2.*PMI/HSQ
PMN3=12.*PMN1/HSQ
CALL INVR(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
ECON(1)=PMI/DUM(1,1)
ECON(2)=PMI/DUM(2,2)
ECON(3)=-DUM(1,2)/DUM(1,1)
ECON(4)=PMI/DUM(3,3)
CALL INVR(SB3,DUM1)
HQTW=HSQ*H/12.
CALL MTAD(ZERO,DUM1,DUM,HQTW)
ECONF(1)=PMI/DUM(1,1)
ECONF(2)=PMI/DUM(2,2)
ECONF(3)=-DUM(1,2)/DUM(1,1)
ECONF(4)=PMI/DUM(3,3)
CALL MTAD(ZERO,SB1,DU1,PMN1)
CALL MTAD(ZERO,SB2,DU2,PMN2)
CALL MTAD(ZERO,DU2,DU3,3.)
CALL MTAD(ZERO,SB3,DU4,PMN3)
WRITE 13
IF(PAR .EQ. NAMES(6)) GO TO 725
IF(PAR .EQ. NAMES(4)) GO TO 724
IF(PAR .EQ. NAMES(2)) GO TO 723
WRITE 14
WRITE 15
14  FORMAT(35X,*A B*,//)
15  FORMAT(35X,*B D*)
WRITE 13
CALL WITE(SB1,SB2)
CALL WITE(SB2,SB3)
WRITE 13
IF(PAR .EQ. NAMES(1)) GO TO 725
723 CONTINUE
WRITE 42
42  FORMAT(35X,* A# B#*,//)
IF(IUNIT .EQ. 1) WRITE 43
IF(IUNIT .NE. 1) WRITE 443

```

```

43   FORMAT(35X,*3B#   D#       GPA*)
443  FORMAT(35X,*3B#   D#       1.E+06 PSI*)
      WRITE 13
      CALL WITE1(DU1,DU2)
      CALL WITE1(DU3,DU4)
      WRITE 13
      IF(PAR .NE. NAMES(5)) GO TO 725
724  CONTINUE
      IF(IUNIT.EQ.1) WRITE 446
446  FORMAT(6X,*SOME ENGINEERING CONSTANTS, ES IN GPA*)
      IF(IUNIT.NE.1) WRITE 4461
4461 FORMAT(6X,*SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI*)
      WRITE 447,(ECON(IE),IE=1,4)
447  FORMAT(6X,*INPLANE :, E1=*,F7.3,* E2=*,F7.3,* V21=*,F7.3,* E6=*
*,F7.3)
      WRITE 448,(ECONF(IE),IE=1,4)
448  FORMAT(6X,*FLEXURAL:,EF1=*,F7.3,* EF2=*,F7.3,* VF21=*,F7.3,* EF6=*
*,F7.3)
725  CONTINUE
      RETURN
      END

```

```

SUBROUTINE NORM1(TPI,A,PARAM)
INTEGER PARAM
DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),ZERO(3,3)
DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),HLC(40),HT(40)
DIMENSION TL(40),TT(40),DU5(3,3),DU6(3,3),DU7(3,3),DU8(3,3)
DIMENSION DU9(3,3),DU10(3,3),PNV(3),QNV(3),DUM(3,3),A(3,3)
DIMENSION NAMES(4),D7(3,3),DM(3,3)
COMMON /UNIT/ IUNIT
COMMON /BLH/ H,HI
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON/BLK/HLC,HT,TL,TT
COMMON /BLDU/ DU2,DU4,DU5,DU7
DATA NAMES /10HDIMENSIONL,10HNORMALIZED,4H BOTH,4H /
13   FORMAT(5X,*-----*)
*-----*)
      HSQ=H*H
      HI=1./H
      HIS=1./HSQ
      TPN1=TPI*H
      TPN2=HSQ*TPI/2.
      TPN3=TPN1*HSQ/12.
      TPNN=TPN2/3.
      DO 75 I=1,3
      DO 75 J=1,3
75   ZERO(I,J)=0.

```

```

CALL MATM(A,SB2,DU1)
CALL MATM(SB2,DU1,DU2)
CALL MTAD(SB3,DU2,DU3,-1.)
CALL INVRS(DU3,DU4)
CALL MATM(DU1,DU4,DU5)
CALL MATM(SB2,A,DU1)
CALL MATM(DU5,DU1,DU6)
CALL MATM(DU4,DU1,DU2)
CALL MTAD(A,DU6,DU7,1.)
CALL MTAD(ZERO,DU5,DUM,-1.)
CALL MTAD(ZERO,DU7,D7,1.)
CALL MTAD(ZERO,DUM,DM,1.)
CALL MTAD(ZERO,DU7,DU1,TPN1)
CALL MTAD(ZERO,DUM,DU8,TPNN)
CALL MTAD(ZERO,DU2,DUM,-1.)
CALL MTAD(ZERO,DUM,DU9,TPN2)
CALL MTAD(ZERO,DU4,DU10,TPN3)
IF(PARAM .EQ.NAMES(4)) GO TO 74
IF(PARAM .EQ.NAMES(1)) GO TO 71
IF(PARAM .EQ.NAMES(2)) GO TO 72
71 CONTINUE
WRITE 13
WRITE 16
WRITE 17
16 FORMAT(35X,*ALPHA      BETA *,//)
17 FORMAT(35X,*TRSBTA    DELTA*)
WRITE 13
CALL WITE(D7,DM)
CALL WITE(DUM,DU4)
WRITE 555
555 FORMAT(6X,*NONMECH. STRESS AND MOMENT RESULTANTS N,M*)
CALL WRT(P,5)
CALL WRT(QQ,5)
WRITE 13
IF(PARAM .NE.NAMES(3)) GO TO 74
72 CONTINUE
WRITE 44
44 FORMAT(35X,* ALPHA#      BETA#/3*,//)
IF( IUNIT .EQ. 1) WRITE 45
IF( IUNIT .NE. 1) WRITE 4451
45 FORMAT(35X,* TRSBTA#      DELTA#      (1./TPA) *)
4451 FORMAT(35X,* TRSBTA#      DELTA#      1.0E-09/PSI*)
WRITE 13
CALL WITE1(DU1,DU8)
CALL WITE1(DU9,DU10)
DO 557 IST=1,3
PNV(IST)=P(IST)*HI
QNV(IST)=6.*QQ(IST)*HIS
557 CONTINUE
WRITE 556
556 FORMAT(6X,*NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#*)
CALL WRT(PNV,5)
CALL WRT(QNV,5)
WRITE 13
74 CONTINUE
RETURN
END

```

```

SUBROUTINE PLT(X,X1,XX,X2,XXX,X3,XC,XC1,XXC,XC2,XXXC,XC3,N,TH,IC)
INTEGER SMBL,IMM,PLANE
DIMENSION X(200),X1(200),XX(200),X2(200),XXX(200),X3(200),XC(200),
*XC1(200),XXC(200),XC2(200),XXXC(200),XC3(200)
DIMENSION TH(40),NAME(2)
COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
COMMON /SMB/ SMBL,IMM
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
DATA NAME /9HSUPERPOSE,2HQR/
N2=N+1
N3=N+2
X(N2)=PXX
X(N3)=PXXI
X1(N2)=PYY
X1(N3)=PYYI
PYS=PYY/PYYI
PXS=PXX/PXXI
DDY=2.55
IF(PLANE .EQ. NAME(2)) DDY=3.55
DDY1=DDY-.3
DDY2=DDY-.6
IF(SMBL .EQ. NAME(1) .AND. IMM .GT. 1) GO TO 3
CALL SPAXIS(0.,PYS,1H ,1,YUL,90.,X1(N2),X1(N3),0.2,3.,.2,0.,2.,IT,
*.15)
CALL SPAXIS(PXS,0.,1H ,-1,7.0,0.,X(N2),X(N3),2.25,.1,.25,0.,2.,IT,
*.15)
3 CONTINUE
IF(IC .EQ. 1) GO TO 1
IF(IC .EQ. 2) GO TO 2
XC(N2)=0.
XC(N3)=PXXI
XC1(N2)=0.
XC1(N3)=PYYI
XXC(N2)=0.
XXC(N3)=PXXI
XC2(N2)=0.
XC2(N3)=PYYI
XXXC(N2)=0.
XXXC(N3)=PXXI
XC3(N2)=0.
XC3(N3)=PYYI
IF(SMBL .EQ. NAME(1)) GO TO 4
CALL NUMBER(1.0,DDY,.15,TH(1),0.,1)
CALL FLINE(XC,XC1,-N,1,10,5)
CALL NUMBER(1.0,DDY1,.15,TH(2),0.,1)
CALL FLINE(XXC,XC2,-N,1,10,6)
CALL NUMBER(1.0,DDY2,.15,TH(3),0.,1)
CALL FLINE(XXXC,XC3,-N,1,10,7)
GO TO 1
4 CONTINUE
CALL FLINE(XC,XC1,-N,1,0,5)
CALL FLINE(XXC,XC2,-N,1,0,6)
CALL FLINE(XXXC,XC3,-N,1,0,7)
1 CONTINUE

```

```

X3(N2)=0.
X3(N3)=PYYI
XXX(N2)=0.
XXX(N3)=PXXI
X2(N2)=0.
X2(N3)=PYYI
XX(N2)=0.
XX(N3)=PXXI
IF(SMBL .EQ. NAME(1)) GO TO 5
CALL SYMBOL(.5, DDY2,.15,7,0.,-1)
CALL FLINE(XXX,X3,-N,1,10,7)
CALL SYMBOL(.5, DDY1,.15,6,0.,-1)
CALL FLINE(XX,X2,-N,1,10,6)
GO TO 2
5 CONTINUE
CALL FLINE(XXX,X3,-N,1,0,7)
CALL FLINE(XX,X2,-N,1,0,6)
2 CONTINUE
X1(N2)=0.
X(N2)=0.
IF(SMBL .EQ. NAME(1)) GO TO 6
CALL SYMBOL(.5, DDY ,.15,5,0.,-1)
CALL FLINE(X,X1,-N,1,10,5)
CALL PLOT(13.,0.,3)
CALL PLOT(13.,0.,-2)
RETURN
6 CONTINUE
CALL FLINE(X,X1,-N,1,0,5)
RETURN
END

```

```

SUBROUTINE PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
INTEGER PARAM2,PARAM3
DIMENSION NAME(3),PLNM(20)
DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),DUM(3,3),X(200)
DIMENSION ZERO(3,3),ECON1(200),ECON2(200),ECON3(200),ECON4(200)
DIMENSION TH(40),HL(40),HLC(40),HT(40),TL(40),TT(40),HS(41)
DIMENSION ES11(40),ES22(40),GS12(40),VS12(40),A(3,3)
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON /BLH/ H,HI
COMMON /UNIT/ IUNIT
COMMON /SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON /BLK/HLC,HT,TL,TT
COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
COMMON /BLM/ PARAM2,PARAM3
DATA NAME/6HPLTEND,8HPLTSTART,6HPLTONE/
IF(PARAM2 .EQ. NAME(3)) GO TO 7
IF(PARAM2 .NE. NAME(2)) GO TO 6
7 CONTINUE
CALL PLOTS(DUM,DUM,99)
CALL PLOT(5.,2.,3)
CALL PLOT(5.,2.,-2)
6 CONTINUE
DO 1 II=1,91
X(II)=TH(3)
CALL MOLS(TH,HL,HS)
CALL INVR(SB1,A)
CALL MTAD(ZERO,A,DUM,H)
ECON1(II)=PMI/DUM(1,1)
ECON2(II)=PMI/DUM(2,2)
ECON4(II)=PMI/DUM(3,3)
ECON3(II)=-DUM(1,2)/DUM(1,1)
TH(3)=TH(3)+1.
TH(4)=-TH(3)
TH(5)=TH(4)
TH(6)=TH(3)
1 CONTINUE
YUL=6.0
PXX=0.
PXXI=15.0
PYY=0.
CONT=1.
IF(IUNIT .EQ. 1) CONT=10.0
PYYI=5.*CONT
IF(IUNIT .EQ. 1) CALL SYMBOL(.1,4.5,.15,3HGPA,0.,3)
IF(IUNIT .NE. 1) CALL SYMBOL(.1,4.5,.15,3HMSI,0.,3)
CALL SYMBL(3.,5.,TH,PLNM,NNL,0)
CALL SYMBOL(0.2,5.0,.2,1HE,0.,1)
CALL SYMBOL(6.2,0.2,.2,140,0.,-1)
CALL SYMBOL(1.00,2.55,.15,1HE,0.,1)
CALL SYMBOL(1.15,2.45,.15,2H11,0.,2)
CALL SYMBOL(1.00,2.25,.15,1HE,0.,1)
CALL SYMBOL(1.15,2.15,.15,2H22,0.,2)
CALL SYMBOL(1.00,1.95,.15,1HE,0.,1)
CALL SYMBOL(1.15,1.85,.15,2H6 ,0.,2)
CALL PLT(X,ECON1,X,ECON2,X,ECON4,X,ECON1,X,ECON2,X,ECON4,91,TH,1)
PYYI=0.2
CALL SYMBL(3.,5.,TH,PLNM,NNL,0)
CALL SYMBOL(6.2,0.2,.2,140,0.,-1)
CALL SYMBOL(0.2,5.0,.25,133,0.,-1)

```

```

CALL SYMBOL(0.35,4.9,.10,2H21,0.,2)
CALL SYMBOL(1.00,2.55,.15,133,0.,-1)
CALL SYMBOL(1.15,2.45,.15,2H21,0.,2)
IT=1
CALL PLT(X,ECON3,X,ECON2,X,ECON4,X,ECON1,X,ECON2,X,ECON4,91,TH,2)
IT=0
IF(PARAM2.EQ.NAME(3)) GO TO 8
IF(PARAM2.NE.NAME(1)) GO TO 5
8  CONTINUE
   CALL PLOTE(N)
5  CONTINUE
   WRITE 3
3  FORMAT(10X,*PLOTS FOR ENGINEERING CONSTANTS DRAWN*)
   RETURN
   END

```

```

SUBROUTINE ROOTS(A,B,C,SM,SMN)
A2=2.0*A
BS=B*B
DC=BS-2.0*A2*C
DS=SQRT(DC)
SM=(DS-B)/A2
SMN=-(B+DS)/A2
RETURN
END

```

```

SUBROUTINE SETAN(AN,DCN)
INTEGER PLANE,SPACE,CRITRIA
DIMENSION AN(3),NAME(2)
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
DATA NAME/2HQR,6HSTRAIN/
IF(PLANE .EQ. NAME(1)) GO TO 1
AN(1)=COSM(DCN)
AN(2)=SINM(DCN)
AN(3)=0.
RETURN
1 CONTINUE
SQ2=SQRT(2.)
AN(1)=SQ2*COSM(DCN)
AN(2)=-AN(1)
AN(3)=SQ2*SINM(DCN)
IF(SPACE .EQ. NAME(2)) AN(3)=AN(3)/2.
RETURN
END

```

```

SUBROUTINE STPLT(TH,HS,PM,PLNM)
INTEGER PARAM2,PARAM3,CRITRIA,SPACE,PLANE,SMBL,MULTI
DIMENSION VN(3),PLNM(40)
DIMENSION GS(3,3),GSB(3)
DIMENSION NAME(14)
DIMENSION Q(3,3),HL(40),TH(40),SFLN(40)
DIMENSION SPLC(40),STX1(200),STY1(200),SCX1(200),SCY1(200)
DIMENSION STX2(200),STY2(200),SCX2(200),SCY2(200)
DIMENSION STX3(200),STY3(200),SCX3(200),SCY3(200)
DIMENSION GB(3),G(3,3),SFL(40),SFU(40),EN1(3),END(3),QQ(3)
DIMENSION SB3(3,3),HT(40),TL(40),TT(40),P(3),HLC(40)
DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXL(40)
DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
DIMENSION DU2(3,3),DU4(3,3),DU5(3,3),E1(3),E2(3),E3(3),E4(3)
DIMENSION ETR(3),ENT(3),U(5),DU7(3,3),HS(21),AN(3),AM(3)
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON/BLK/HLC,HT,TL,TT
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
COMMON /BLK1/ SXL,SXC,SYL,SYC,SXL,HL
COMMON /UNIT/ IUNIT
COMMON /BLH/ H,HI
COMMON /BLDU/ DU2,DU4,DU5,DU7
COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
COMMON /SMB/ SMBL,IMM
COMMON /BLM/ PARAM2,PARAM3
COMMON /SF/SFL,COUNT
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
COMMON /ST1/ STX1,STY1,SCX1,SCY1,NSF1
COMMON /ST2/ STX2,STY2,SCX2,SCY2,NSF2
COMMON /ST3/ STX3,STY3,SCX3,SCY3,NSF3

```

DATA NAME/6HPLTEND,8HPLTSTART,7HTSAI WU,9HMAXSTRESS,
 *9HMAXSTRAIN,6HSTRAIN,6HSTRESS,6HCHAMIS,7HHOFFMAN,4HHILL,6HPLTONE,
 *2HQR,9HSUPERPOSE,9HMULTICURV/

COUNT=1.

FCTRS=1.

FCTRF=1.

705 READ 705,CRIITRIA,SPACE,PLANE,SMBL,FS12,MULTI,FCTRS,FCTRF
 FORMAT(4A10,F10.3,A10,2F10.3)

IF(PARAM3 .EQ. NAME(11)) GO TO 716

IF(PARAM3 .NE. NAME(2)) GO TO 701

716 CONTINUE

CALL PLOTS(DUM,DUM,99)

CALL PLOT(5.,5.,3)

CALL PLOT(5.,5.,-2)

IF(FCTRF .EQ. 0.) FCTRF=1.

CALL FACTOR(FCTRF)

701 CONTINUE

YUL=8.

IT=0

IF(FCTRS .EQ. 0.) FCTRS=1.

CONT=FCTRS*1.

IF(IUNIT .EQ. 1) CONT=FCTRS*10.0

PXX=-400.0*CONT

PXXI=100.0*CONT

PYY=-500.0*CONT

PYYI=PXXI

IF(PLANE .NE. NAME(12)) GO TO 726

PXX=-75.0*CONT

C PXX=-150.0*CONT

C PXXI=50.0*CONT

PXXI=25.0*CONT

C PYY=-200.0*CONT

PYY=-100.0*CONT

PYYI=PXXI

726 CONTINUE

NPT=91

MM>NNL/2

IF(SMBL .NE. NAME(13)) MM=1

DO 722 IMM=1,MM,3

725 CONTINUE

DO 601 ICND=1,NPT

DCN=180*(ICND-1)/(NPT-1)

CALL SETAN(AN,DCN)

AM(1)=0.

AM(2)=0.

AM(3)=0.

NSF1=1

NSF2=2

NSF3=3

DO 600 IK=NSF1,NSF3

K=IMM+IK-1

IF(K .GT.>NNL) K=1

IF(ES11(K) .EQ. 0.0) GO TO 600

DO 109 I=1,3

SUM1=0.

SUM2=0.

SUM3=0.

SUM4=0.

DO 209 J=1,3

SUM1=SUM1+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K)*(-DU2(I,J)*AN(J)+

```

*DU4(I,J)*AM(J))
SUM2=SUM2+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K+1)*(-DU2(I,J)*AN(J)+
*DU4(I,J)*AM(J))
SUM3=SUM3+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K)*(-DU2(I,J)* P(J)+
*DU4(I,J)*QQ(J))
SUM4=SUM4+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K+1)*(-DU2(I,J)* P(J)+
*DU4(I,J)*QQ(J))
209 CONTINUE
E1(I)=SUM1
E2(I)=SUM2
E3(I)=SUM3
E4(I)=SUM4
109 CONTINUE
C E1(J) =MECHANICAL STRAIN COMPONENTS LOWER SURFACE
C E2(J) =MECHANICAL STRAIN COMPONENTS UPPER SURFACE
C E4(J) =NONMECHANICAL STRAIN COMPONENTS UPPER SURFACE
C E3(J) =NONMECHANICAL STRAIN COMPONENTS LOWER SURFACE
THT=TH(K)
CALL TRE(E1,ETR,THT)
CALL TRE(E3,ENT,THT)
CALL NMSN(C,DT,EN1,HLC,HT,TL,TT,K)
CALL VDI(ENT,EN1,END)
CALL MODULS(ES11(K),ES22(K),VS12(K),GS12(K),Q,U)
IF(CRITRIA .EQ. NAME(4) .AND. SPACE .EQ. NAME(7)) GO TO 702
IF(CRITRIA .EQ. NAME(5) .AND. SPACE .EQ. NAME(7)) GO TO 703
IF(SPACE .EQ. NAME(6)) GO TO 708
IF(SPACE .EQ. NAME(7)) GO TO 709
708 CALL TRE(AN,ETR,THT)
IF(FCTRS EQ. 0.0) FCTRS=1.
PXX=-.04*FCTRS
PXXI=.01*FCTRS
PYY=-.05*FCTRS
PYYI=PXXI
IT=2
IF(CRITRIA .EQ. NAME(4)) GO TO 702
IF(CRITRIA .EQ. NAME(5)) GO TO 703
CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
CALL COEF(G,GB,GS,GSB,THT)
CALL FSFTY(AN,END,GS,GSB,SM,SMN)
SFLN(IK)=SM
CALL VNF(AN,VN)
CALL TRE(VN,ETR,THT)
CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
CALL COEF(G,GB,GS,GSB,THT)
CALL FSFTY(AN,END,GS,GSB,SM,SMN)
SPLC(IK)=SMN
GO TO 600
709 CONTINUE
CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
CALL FSFTY(ETR,END,G,GB,SM,SMN)
SFLN(IK)=SM/(H*PM)
IF(CRITRIA .NE. NAME(8)) GO TO 710
CALL VNF(ETR,VN)
CALL FAILCO(VN,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
CALL FSFTY(ETR,END,G,GB,SM,SMN)
710 CONTINUE
SFLL(IK)=SM
SPLC(IK)=SMN/(H*PM)
GO TO 600
702 CONTINUE

```

```

CALL MVM(Q,ETR,E1)
CALL MXSTRS(K,E1,AN,PM)
IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
SFLN(IK)=SFL
CALL VNF(E1,VN)
CALL MXSTRS(K,VN,AN,PM)
IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
SPLC(IK)=-SFL
GO TO 600
703 CONTINUE
CALL MXSTRN(K,ETR,AN,Q,PM)
IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
SFLN(IK)=SFL
CALL VNF(ETR,VN)
CALL MXSTRN(K,VN,AN,Q,PM)
IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
SPLC(IK)=-SFL
600 CONTINUE
CALL ADJUST(ICND,SFLN,SPLC,AN)
601 CONTINUE
IF(IMM .GT. 1) GO TO 721
IF(PLANE .EQ. NAME(12)) GO TO 718
IF(SMBL .NE. NAME(13)) CALL SYMBL(-3.0,2.75,TH,PLNM,NNL,1)
C CALL RECT(-4.,-5.,8.0,6.0,0.,3)
IF(SPACE .EQ. NAME(7)) GO TO 711
CALL SYMBOL(-.3,2.4,.25,129,0.,-1)
CALL SYMBOL(1.6,.35,.25,129,0.,-1)
GO TO 712
711 CONTINUE
CALL SYMBOL(-.3,2.4,.25,108,0.,-1)
CALL SYMBOL(1.6,.35,.25,108,0.,-1)
IF(IUNIT .EQ. 1) CALL SYMBOL(-.5,2.,.15,3HMPA,0.,3)
IF(IUNIT .NE. 1) CALL SYMBOL(-.5,2.,.15,3HKSI,0.,3)
712 CONTINUE
CALL SYMBOL(-.1,2.30,.10,1H2,0.,1)
CALL SYMBOL(-.1,2.55,.10,1H0,0.,1)
CALL SYMBOL(1.8,0.25,.10,1H1,0.,1)
CALL SYMBOL(1.8,0.50,.10,1H0,0.,1)
GO TO 719
718 CONTINUE
IF(SMBL .NE. NAME(13)) CALL SYMBL(-2.3,3.75,TH,PLNM,NNL,1)
C CALL RECT(-3.,-4.,8.0,6.0,0.,3)
CALL SYMBOL(-.5,3.4,.2,2H2R,0.,2)
CALL SYMBOL(-.7,3.4,.2,25,0.,-1)
CALL SYMBOL(2.4,.35,.2,2H2Q,0.,2)
CALL SYMBOL(2.2,.35,.2,25,0.,-1)
IF(SPACE .EQ. NAME(7)) GO TO 720
CALL SYMBOL(2.8,0.25,.15,129,0.,-1)
CALL SYMBOL(-.1,3.3,.15,129,0.,-1)
GO TO 719
720 CONTINUE
CALL SYMBOL(2.8,0.25,.15,108,0.,-1)
CALL SYMBOL(-.1,3.3,.15,108,0.,-1)
IF(IUNIT .EQ. 1) CALL SYMBOL(-.5,3.,.15,3HMPA,0.,3)
IF(IUNIT .NE. 1) CALL SYMBOL(-.5,3.,.15,3HKSI,0.,3)
719 CONTINUE
DDX=-2.85
DDY=-3.7
IF(CRITRIA .EQ. NAME(3) .OR. CRITRIA .EQ. NAME(8)) GO TO 900
GO TO 901

```

```

900  CALL SYMBOL(0.8,-3.5,0.15,4HF =,0.,4)
     CALL NUMBER(1.5,-3.5,0.15,FS12,0.,1)
     CALL SYMBOL(0.95,-3.6,0.12,2HXY,0.,2)
     CALL SYMBOL(1.05,-3.3,0.12,11,0.,-1)
901  CONTINUE
     IF(CRITRIA .EQ. NAME(3)) CALL SYMBOL(DDX,DDY,0.15,16HTSAI WU CRITE
*RIA,0.,16)
     IF(CRITRIA .EQ. NAME(4)) CALL SYMBOL(DDX,DDY,.15,10HMAX STRESS,0.,
*10)
     IF(CRITRIA .EQ. NAME(5)) CALL SYMBOL(DDX,DDY,.15,10HMAX STRAIN,0.,
*10)
     IF(CRITRIA .EQ. NAME(8)) CALL SYMBOL(DDX,DDY,0.15,15HCHAMIS CRITER
*IA,0.,15)
     IF(CRITRIA .EQ. NAME(9)) CALL SYMBOL(DDX,DDY,0.15,16HHOFFMAN CRITE
*RIA,0.,16)
     IF(CRITRIA .EQ. NAME(10)) CALL SYMBOL(DDX,DDY,0.15,16HHILL CRITERI
*A ,0.,16)
721  CONTINUE
     CALL PLT(STX1,STY1,STX2,STY2,STX3,STY3,SCX1,SCY1,SCX2,SCY2,SCX3,
*SCY3,NPT,TH,9)
722  CONTINUE
     IF(MULTI .EQ. NAME(14)) GO TO 729
     IF(SMBL .EQ. NAME(13)) GO TO 728
     GO TO 729
728  CALL PLOT(13.,0.,3)
     CALL PLOT(13.,0.,-2)
729  CONTINUE
     IF(PARAM3 .EQ. NAME(11)) GO TO 717
     IF(PARAM3.NE.NAME(1)) GO TO 6
717  CONTINUE
     CALL PLOTE(N)
6    CONTINUE
     WRITE 11
11   FORMAT(5X,*FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED*)
     RETURN
     END

```

```

SUBROUTINE STRNG(TH,HS,PM,NLDCN)
INTEGER CRITRIA,SPACE,PLANE
DIMENSION Q(3,3),HL(40),TH(40),SFLN(40),SFUN(40)
DIMENSION GB(3),G(3,3),SFLL(40),SFU(40),EN1(3),END(3),QQ(3)
DIMENSION SB3(3,3),HT(40),TL(40),TT(40),P(3),HLC(40)
DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXL(40)
DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
DIMENSION DU2(3,3),DU4(3,3),DU5(3,3),E1(3),E2(3),E3(3),E4(3)
DIMENSION ETR(3),ENT(3),U(5),DU7(3,3),HS(41),AN(3),AM(3)
DIMENSION NAMES(3),ETR2(3)
COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
COMMON/BLK/HLC,HT,TL,TT
COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C

```

```

COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
COMMON /UNIT/ IUNIT
COMMON /BLH/ H,HI
COMMON /BLDU/ DU2,DU4,DU5,DU7
COMMON /SF/SFL,COUNT
COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
NAMELIST /STRESS/ AN,AM
DATA NAMES/7HTSAI WU,9HMAXSTRAIN,9HMAXSTRESS/
COUNT=2.
READ 700,CRITRIA,SPACE,PLANE,SMBL,FS12
IF(NLDCN.EQ. 1) READ STRESS
700  FORMAT(4A10,F10.3)
DO 601 ICND=1,NLDCN
IF(NLDCN.EQ.1) GO TO 602
READ STRESS
602  CONTINUE
WRITE 13
WRITE 603
603  FORMAT(6X,*APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M*)
CALL WRT1(AN)
CALL WRT1(AM)
WRITE 13
DO 600 K=1,NNL
IF(ES11(K).EQ. 0.0) GO TO 600
DO 109 I=1,3
SUM1=0.
SUM2=0.
SUM3=0.
SUM4=0.
DO 209 J=1,3
SUM1=SUM1+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K)*(-DU2(I,J)*AN(J)+
*DU4(I,J)*AM(J))
SUM2=SUM2+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K+1)*(-DU2(I,J)*AN(J)+
*DU4(I,J)*AM(J))
SUM3=SUM3+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K)*(-DU2(I,J)* P(J)+
*DU4(I,J)*QQ(J))
SUM4=SUM4+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K+1)*(-DU2(I,J)* P(J)+
*DU4(I,J)*QQ(J))
209  CONTINUE
E1(I)=SUM1
E2(I)=SUM2
E3(I)=SUM3
E4(I)=SUM4
109  CONTINUE
C  E1(J)  =MECHANICAL STRAIN COMPONENTS LOWER SURFACE
C  E2(J)  =MECHANICAL STRAIN COMPONENTS UPPER SURFACE
C  E4(J)  =NONMECHANICAL STRAIN COMPONENTS UPPER SURFACE
C  E3(J)  =NONMECHANICAL STRAIN COMPONENTS LOWER SURFACE
WRITE 4494
4494  FORMAT(5X,*EFFECTIVE NONMECHANICAL STRAIN COMP. AT LOWER SURF.*)
CALL WRT(E3,5)
WRITE 13
WRITE 18,TH(K)
13  FORMAT(5X,*-----*)
*-----*)
18  FORMAT(5X,*ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =*,F5.1)
WRITE 19
19  FORMAT(5X,*MECH/NONMECH      LOWER SURF.      UPPER SURF. *)
WRITE 20
20  FORMAT(5X,*  MECH.              1              2      *)

```

```

21  WRITE 21
    FORMAT(5X,* NONMECH.          3          4 *)
    WRITE 13
    THT=TH(K)
    CALL TRE(E1,ETR,THT)
    CALL TRE(E3,ENT,THT)
    CALL NMSN(C,DT,EN1,HLC,HT,TL,TT,K)
    CALL VDI(ENT,EN1,END)
    CALL MODULS(ES11(K),ES22(K),VS12(K),GS12(K),Q,U)
    CALL FAILCO(E1,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
    CALL FSFTY(ETR,END,G,GB,SM,SMN)
    WRITE 701
    WRITE 13
    CALL WRT(ETR,1)
    CALL MVM(Q,ETR,E1)
    SFLL(K)=SM
    SFLN(K)=SM/(H*PM)
    CALL TRE(E2,ETR2,THT)
    CALL WRT(ETR2,2)
    CALL MVM(Q,ETR2,E2)
    CALL WRT(END,3)
    CALL MVM(Q,END,E3)
    CALL TRE(E4,ENT,THT)
    CALL VDI(ENT,EN1,END)
    CALL WRT(END,4)
    CALL MVM(Q,END,E4)
701  FORMAT (10X,*STRAIN COMPONENTS*)
    WRITE 13
703  FORMAT (10X,*STRESS COMPONENTS*)
    WRITE 703
    WRITE 13
    CALL WRT(E1,1)
    CALL WRT(E2,2)
    CALL WRT(E3,3)
    CALL WRT(E4,4)
    CALL FSFTY(ETR2,END,G,GB,SM,SMN)
    SFU(K)=SM
    SFUN(K)=SM/(H*PM)
    WRITE 13
    IF(CRITRIA .EQ. NAMES(2)) GO TO 502
    IF(CRITRIA .EQ. NAMES(3)) GO TO 503
501  WRITE 510,CRITRIA
510  FORMAT(5X,A10,*FAILURE CRITERIA*)
    WRITE 606,SFLL(K),SFU(K)
606  FORMAT(5X,*STRENGTH RATIO R: LOWER SURF.=*,E10.3,* UPPER SURF.=*,
    *E10.3)
    IF(IUNIT .EQ.1) GO TO 4492
    WRITE 4491,SFLN(K),SFUN(K)
    GO TO 4493
4492 WRITE 449,SFLN(K),SFUN(K)
4493 CONTINUE
449  FORMAT(5X,*STRENGTH R# MPA : LOWER SURF.=*,F10.3,* UPPER SURF.=*,
    *F10.3)
4491 FORMAT(5X,*STRENGTH R# KSI : LOWER SURF.=*,F10.3,* UPPER SURF.=*,
    *F10.3)
    WRITE 13
    GO TO 504
502  WRITE 505
505  FORMAT(5X,*MAXIMUM STRAIN FAILURE CRITERIA*)
    WRITE 506

```

```

506  FORMAT(5X,*MAX APPLIED STRESS RESULTANTS/ AVERAGE STRESSES*)
      WRITE 13
      WRITE 507
507  FORMAT(5X,*LOWER SURFACE*)
      CALL MXSTRN(K,ETR,AN,Q,PM)
      WRITE 508
508  FORMAT(5X,*UPPER SURFACE*)
      CALL MXSTRN(K,ETR2,AN,Q,PM)
      GO TO 504
503  WRITE 509
509  FORMAT(5X,*MAXIMUM STRESS FAILURE CRITERIA*)
      WRITE 506
      WRITE 507
      CALL MXSTRS(K,E1,AN,PM)
      WRITE 508
      CALL MXSTRS(K,E2,AN,PM)
504  CONTINUE
      WRITE 702
702  FORMAT(1H0//)
600  CONTINUE
601  CONTINUE
      RETURN
      END

```

```

SUBROUTINE SYM(X)
  DIMENSION X(3,3)
  X(3,1)=X(1,3)
  X(3,2)=X(2,3)
  X(2,1)=X(1,2)
  RETURN
  END

```

```

SUBROUTINE SYMBL(X,Y,TH,PLNM,N,I)
  DIMENSION TH(20),PLNM(20)
  CALL SYMBOL(X,Y,.15,4HNNL=,0.,4)
  X1=X+.6
  HNL=N
  CALL NUMBER(X1,Y,.15,HNL,0.,-1)
  X2=X-.25
  Y1=Y-.25
  CALL SYMBOL(X2,Y1,.15,144,0.,-1)
  CALL SYMBOL(X1,Y1,.15,5HPLIES,0.,5)
  XS1=X-.25
  XS2=X+.8
  YS1=Y-.55
  NHL=N/2
  DO 1 INL=1,NHL
    IF(I .EQ. 0 .AND. INL. GT. 2) GO TO 2
    IF(TH(INL) .GE. 0.) CALL NUMBER(XS1,YS1,.15,TH(INL),0.,1)
    XS3=XS1-.15
    IF(TH(INL) .LT. 0.) CALL NUMBER(XS3,YS1,.15,TH(INL),0.,1)
  CONTINUE

```

```

IF(I .EQ. 0 .AND. INL. GT. 2) CALL SYMBOL(XS1,YS1,.15,140,0.,-1)
IF(I .EQ. 0 .AND. INL .EQ. 4) CALL SYMBOL(XS3,YS1,.15,1H-,0.,1)
CALL NUMBER(XS2,YS1,.15,PLNM(INL),0.,-1)
YS1=YS1-.3
1 CONTINUE
RETURN
END

```

```

SUBROUTINE TRE(Z,T,THE)
DIMENSION Z(3),T(3)
TH2=2.*THE
C=COSM(TH2)
S=SINM(TH2)
P=0.5*(Z(1)+Z(2))
Q=0.5*(Z(1)-Z(2))
R=0.5*Z(3)
T(1)=P+Q*C+R*S
T(2)=P-Q*C-R*S
T(3)=-2.*(Q*S-R*C)
RETURN
END

```

```

SUBROUTINE TRS(Z,T,THE)
DIMENSION Z(3),T(3)
TH2=2.*THE
C=COSM(TH2)
S=SINM(TH2)
P=0.5*(Z(1)+Z(2))
Q=0.5*(Z(1)-Z(2))
R=Z(3)
T(1)=P+Q*C+R*S
T(2)=P-Q*C-R*S
T(3)=-Q*S+R*C
RETURN
END

```

```

SUBROUTINE US(Q,U)
DIMENSION Q(3,3),U(5)
SQ12=Q(1,1)+Q(2,2)
SQ24=2.*Q(1,2)+4.*Q(3,3)
U(1)=(3.*SQ12+SQ24)/8.
U(2)=(Q(1,1)-Q(2,2))/2.
U(3)=(SQ12-SQ24)/8.
U(4)=(SQ12+6.*Q(1,2)-4.*Q(3,3))/8.
U(5)=(SQ12-2.*Q(1,2)+4.*Q(3,3))/8.
RETURN
END

```

```

SUBROUTINE VDI(A,B,C)
DIMENSION A(3),B(3),C(3)
DO 1 I=1,3
C(I)=A(I)-B(I)
1 CONTINUE
RETURN
END

```

```

SUBROUTINE VNF(V,VN)
DIMENSION V(3),VN(3)
DO 1 I=1,3
VN(I)=-V(I)
1 CONTINUE
RETURN
END

```

```

SUBROUTINE WITE(Q,A)
DIMENSION Q(3,3),A(3,3)
DO 1 I=1,3
WRITE 2,(Q(I,J),J=1,3),(A(I,J),J=1,3)
2 FORMAT(2X,3E11.3,1X,3E11.3)
1 CONTINUE
RETURN
END

```

```

SUBROUTINE WITE1(X,Y)
DIMENSION X(3,3),Y(3,3)
DO 1 I=1,3
WRITE2,(X(I,J),J=1,3),(Y(I,K),K=1,3)
1 CONTINUE
2 FORMAT(2X,6F10.1)
RETURN
END

```

```

SUBROUTINE WRITE(Q)
DIMENSION Q(3,3)
DO 1 I=1,3
WRITE2,(Q(I,J),J=1,3)
2 FORMAT(10X,3(10X,E16.3))
1 CONTINUE
RETURN
END

```

```

SUBROUTINE WRT(X,INDX)
DIMENSION X(3)
IF(INDX.GT.4) GO TO 1
WRITE2,INDX,(X(I),I=1,3)
2  FORMAT(10X,I4,3E16.3)
RETURN
1  WRITE3,(X(I),I=1,3)
3  FORMAT(10X,3E16.3)
RETURN
END

```

```

SUBROUTINE WRT1(X)
DIMENSION X(3)
WRITE2,(X(I),I=1,3)
2  FORMAT(10X,3F16.3)
RETURN
END

```

```

FUNCTION COSM(ALPHA)
DATA CONV/.017453292519943/
IF(ALPHA .EQ. 90.0 .OR. ALPHA .EQ. 270.) GO TO 10
IF(ALPHA .EQ. -90.0 .OR. ALPHA .EQ. -270.) GO TO 10
COSM=COS(CONV*ALPHA)
RETURN
10 COSM=0.
RETURN
END

```

```

FUNCTION SINM(ALPHA)
DATA CONV/.017453292519943/
IF(ALPHA .EQ. 180. .OR. ALPHA .EQ. 360.) GO TO 10
IF(ALPHA .EQ. -180. .OR. ALPHA .EQ. -360.) GO TO 10
SINM=SIN(CONV*ALPHA)
RETURN
10 SINM=0.
RETURN
END

```

```

FUNCTION VVM(X,Y)
DIMENSION X(3),Y(3)
SUM=0.0
DO 1 I=1,3
SUM=SUM+X(I)*Y(I)
1  CONTINUE
VVM=SUM
RETURN
END

```

USER'S INSTRUCTIONS

TRANSFORMATIONS

<u>Objective</u>	<u>Card #</u>	<u>Input Data</u>	<u>Format</u>
Stress Trans.	1	TRANSFORMb STRESS	(2A10)
	2	$\sigma_1, \sigma_2, \sigma_6, \theta^\circ$	(4F10.3)
Strain Trans.	1	TRANSFORMb STRAIN	(2A10)
	2	$\epsilon_1, \epsilon_2, \epsilon_6, \theta^\circ$	(4F10.3)
Modulus Trans.	1	TRANSFORMb MODULUS	(2A10)
	2	Material ⁺ Units*	(2A10)
	3	θ°	(5F10.3)
Compliance Trans.	1	TRANSFORMb COMPLIANCE	(2A10)
	2	Material ⁺ Units*	(2A10)
	3	θ°	(5F10.3)
Modulus & Compliance Trans.	1	TRANSFORMb MODCOM	(2A10)
	2	Material ⁺ Units*	(2A10)
	3	θ°	(5F10.3)

*Units - either SI or English

⁺If the name of the material being used is not given in Table 1, give NEW and replace the card #3 by $E_x, E_y, \nu_x, E_s, \theta^\circ$. E_x, E_y and E_s are in GPa.

b denotes a blank column between two commands.

Input commands are punched strictly according to the format. The first letter starting from the first column of the assigned columns.

Material Properties

The material properties of seven commonly used materials, given in Table 1, are included in the program. These properties can be used by providing the corresponding material name for pure laminates and the material property identification number for hybrid laminates. If the problem under investigation requires material properties different from those given in Table 1, the existing values can be replaced through appropriate input data. The following data cards are used:

(1) NEWMTRLS Format (A10)

(2) b\$LAMDATAb NNM= , EX= , EY= ... etc. such that

NNM = Number of materials being read in

EX = E_x for each material

EY = E_y -do-

VX = ν_x -do-

ES = E_s -do-

ALFX = α_x -do-

ALFY = α_y -do-

BTAX = β_x -do-

BTAY = β_y -do-

X = X -do-

XD = X' -do-

Y = Y -do-

YD = Y' -do-

S = S -do-

SH = h_o -do-

For the use of these properties in the mechanics problems, the corresponding names or material property identification numbers given in Table 1 are used. The units of these input quantities are the same as those of Table 1, i.e. SI units. The output results can be obtained either in SI units or in English units, by providing suitable instructions.

PARAM2 (Strength)	STRENGTH
	STRNGTHPLT
	PLTSTART
	PLTEND
	PLTONE
	Blank for none

PARAM3 (Engg. Constants)	ENGCP LT
	PLTSTART
	PLTEND
	PLTONE
	Blank for none

(3) Title of the problem

Format (8A10)

(4) If the CASE is pure then:

(a) MATERIAL* UNITS⁺ (2A10)

*name of the material from Table 1

⁺SI or English

(b) b\$LAYERbNNL= , TH= , PLNM= ,
DT= , C= , NLDCN= \$

NNL = Total number of layers

TH = $\theta_1, \theta_2, \dots, \theta_{NNL}$, bottom ply is the first ply

PLNM = Number of plies corresponding to each ply orientation

DT = Temperature difference, ΔT

C = Moisture content

NLDLN = Number of loading conditions considered

In all cases when PARAM2 is not STRENGTH, NLDCN is not active and is given equal to 1. When PARAM2 is STRENGTH, NLDCN is active and will require like number of STRESS input cards following card #(5).

If the case is HYBRID then:

(c) b\$LAYERSbNNL= , LMPI= , TH= , PLNM= , IUNIT= ,
DT= , C= , NLDCN= bb\$

NNL = Total number of layers
LMPI = Layer material property identification number (Table 1)
TH = $\theta_1, \theta_2, \theta_3 \dots \theta_{NNL}$ starting from bottom
IUNIT = 1 for SI and 2 for ENGLISH units
PLNM = Number of plies corresponding to each orientation
DT = Temperature difference
C = Moisture content
NLDCN = Number of loading conditions considered

(5) CRITERIA SPACE PLANE SMBL FS12 MULTICURV FCTRS FCTRF⁺
(IF APPLICABLE) (4A10, F10.3, A10, 2F10.3)

CRITERIA	TSAI WU
	CHAMIS
	HOFFMAN
	HILL
	MAXSTRAIN
	MAXSTRESS

SPACE	STRESS
	STRAIN

PLANE	QR
	PRINCIPAL

*b denotes a blank column.

⁺FCTRF remains the same for all cases in a computer run.

SMBL	SUPERPOSE YES
------	------------------

FS12: Quadratic polynomial failure criteria interaction term.

MULTICURV: If the failure surfaces following the failure surfaces being generated are going to be drawn in the same figure, use this command. Otherwise, leave blank.

FCTRS: Factor by which the scale for strength plot to be altered.

FCTRF: Factor by which the figure size in the strength plot to be altered.

(6) b\$STRESSb AN = N₁, N₂, N₆, AM = M₁, M₂, M₆bb\$

where AN(I), I = 1, 2, 3 = Mechanical stress resultants

AM(I), I = 1, 2, 3 = Mechanical moment resultants

(7) THEEND Format(A10)

This card denotes the end of input instructions.

Description of Each Command

TYPE: What type of laminate is being considered, INPLANE or GENERAL? If only inplane analysis is conducted, one can still use general option, but some of the outputs may not be of interest. Also because in the inplane case stacking sequence does not matter, the input instructions become a bit simpler.

CASE: Which case of the laminate material system is under consideration, PURE or HYBRID? For a pure laminate the data card stating the name of the material is sufficient, whereas in hybrid laminates the layer material property identification number (LMPI) for each ply orientation is required. This parameter (LMPI) is given in \$LAYERS card. The description of LAYERS card is given in #(4)c, page 69.

PARAM: What quantities in the effective modulus of the laminate are required?

DIMENSIONL: Dimensional effective modulus matrices A, B, and D.

NORMALIZED: Normalized effective modulus matrices A*, B*, and D*.

BOTH: Both dimensional and normalized modulus matrices A, B, D and A*, B*, D*.

ENGCONST: Effective inplane engineering constants of the laminate E_1^o , E_2^o , ν_{21}^o , E_6^o and effective flexural engineering constants E_1^f , E_2^f , ν_{21}^f , E_6^f .

ALL: All the aforementioned quantities.

Blank: If you don't want any of these quantities leave this column blank.

PARAM1: What quantities in the effective compliance of the composite laminate are required?

DIMENSIONL: Dimensional effective compliance matrices α , β , δ .

NORMALIZED: Normalized effective compliance matrices α^* , β^* , δ^* .

BOTH: Both dimensional and normalized compliance matrices α , β , δ and α^* , β^* , δ^* .

PARAM2: This command controls the strength predictions and plotting the failure surface.

STRENGTH: Computes the strength ratio R for each ply orientation and corresponding parameter R/h

for a given loading condition. These parameters are calculated on the basis of six different failure criteria viz. Tsai Wu, Chamis, Hoffman, Hill, maximum stress (MAXSTRESS) and maximum strain (MAXSTRAIN) failure criteria. The criteria to be used has to be assigned at an appropriate place in the input data.

- STRNGTHPLT: This command generates failure surfaces for each ply orientation of the laminate. The program is set such that it will give failure surfaces for the first three ply orientations, or all the ply orientations. For obtaining failure envelopes for all the plies in the laminate if the number of plies is more than 6, the SMBL parameter in card number 5 is SUPER-IMPOSE, otherwise blank. There is a choice of failure criteria space, plane and the failure criteria interaction term F_{xy}^* , as given in card 5.
- PLTSTART: If the plot assigned by this card is the first, strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTSTART.
- PLTEND: If the plot assigned by this card is the last strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTEND.
- PLTONE: If there is only one strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTONE.
- Blank: If no strength/effective engineering constants plot is required leave these columns blank.

PARAM3: This command controls the plots of effective engineering constants versus the angle ply ϕ in the laminate $(\theta_n/\bar{\theta}_p/\pm\phi_q)_s$.

ENGCPLOT: This command will give the plot of the effective engineering constants E_1^o , E_2^o , E_6^o and ν_{21}^o .

PLTSTART }
PLTEND } : As mentioned in PARAM2.
PLTONE }

Blank: If no effective engineering constants/strength plot is required.

CRITERIA: There is a choice of failure theories that can be used for finding the successive ply strengths of the laminate. Six failure theories [9] have been included in the program. In the quadratic polynomial failure criteria, the hygrothermal effects are included whereas in the Max. stress and the Max. strain failure theories these effects are not included.

SPACE: The failure surfaces can be obtained either in stress space or in strain space.

PLANE: Stress space and strain spaces can be represented either in principal stress or strain loadings or in qr plane loading in which:

$$p_\epsilon = (\epsilon_1 + \epsilon_2)/2 = 0$$

$$q_\epsilon = (\epsilon_1 - \epsilon_2)/2, \quad r_\epsilon = \epsilon_6/2$$

$$p_\sigma = (\sigma_1 + \sigma_2)/2 = 0$$

$$q_\sigma = (\sigma_1 - \sigma_2)/2$$

$$r_\sigma = \sigma_6$$

By assigning the PLANE parameter as QR a strength plot in qr space can be obtained. Otherwise the strength plot will be in principal strain or stress space as the case may be.

SMBL: This input parameter controls the plotting of failure surfaces w.r.t. the number of plies for which the failure surfaces are plotted. SUPERPOSE will plot the failure envelopes of all the plies if the number of plies is up to 50. If the corresponding columns are left blank, failure envelopes for the first three layers will be plotted. The laminate layer data should be given such that the first three orientations are of prime interest.[†]

FS12: The failure criteria interaction term (F_{xy}^*) in the case of Tsai Wu and Chamis failure criteria.

MULTICURV: In case the failure envelopes generated by the current data input is going to be plotted on the same figure as those generated by the following data set provide the command MULTICURV in the corresponding columns, otherwise leave these columns blank.

FCTRS: For changing the scale of the strength plot, i.e. for reducing the scale to 1/2, FCTRS is given as 0.5.

FCTRF: For changing the figure size in the strength plot, i.e. for increasing the figure size by 25%, FCTRF is given as 1.25. $FCTRF < 1.4$.

[†]For laminates with a number of ply orientations less than 3, laminate data should be arranged such that $NNL \geq 3$. This precaution is taken to avoid the use of unspecified values of θ_i , ($i=2,3$) in case $NNL=1$, stored in the available spaces.

ILLUSTRATIONS

I. Transformation of in-plane stress ($\sigma_1, \sigma_2, \sigma_6$) through an angle θ .

$$\sigma_1 = 10, \text{ MPa}, \sigma_2 = 15. \text{ MPa}, \sigma_6 = 12. \text{ MPa}, \theta = 27.5^\circ$$

Input data:

```

TRANSFORM STRESS
  10.      15.      12.      27.5
THEEND

```

Output:

```

STRESS TRANSFORMATION THRU      27.5 DEGREES
              SIGMA1      SIGMA2      SIGMA6
-----
GIVEN              10.000      15.000      12.000
TRANSFORMED        20.896      4.104      8.931
-----

```

II. Transformation of in-plane strain ($\epsilon_1, \epsilon_2, \epsilon_6$) through an angle θ .

$$\epsilon_1 = 2.0, \epsilon_2 = .05, \epsilon_6 = 1.0, \theta = 15.0$$

Input data:

```

TRANSFORM STRAIN
  2.0      .05      1.0      15.0
THEEND

```

Output:

```

STRAIN TRANSFORMATION THRU      15. DEGREES
              EPSLN1      EPSLN2      EPSLN6
-----
GIVEN              2.000      .050      1.000
TRANSFORMED        2.119      -.069      -.109
-----

```

III. Modulus/Compliance Transformation

1. Transformation of modulus matrix of T300/5208 material stored in the program through 30° angle.
2. Transformation of compliance matrix of AS/3501 material stored in the program through 30° angle.
3. Transformation of modulus matrix and compliance matrix of a new material through 30° angle.

$$E_x = 190. \text{ GPa}, \quad E_y = 12.0 \text{ GPa}, \quad \nu_x = 0.3, \quad E_s = 8.1 \text{ GPa}.$$

Input:

```

TRANSFORM MODULUS
T300/5208 ENGLISH
30.0
TRANSFORM COMPLIANCE
AS/3501 SI
30.0
TRANSFORM MODCOM
NEW ENGLISH
190. 12.0 0.3 8.1 30.0
THEEND

```

Output :

ENGLISH UNITS
MODULUS TRANSFORMATION THRU 30. DEGREE ANGLE
(1.E+06 PSI)

Case

MODULUS OF THE MATERIAL			TRANSFORMED MODULUS		
26.4	.4	0.0	15.9	4.7	7.9
.4	1.5	0.0	4.7	3.4	2.9
0.0	0.0	1.0	7.9	2.9	5.3

1

SI UNITS
COMPLIANCE TRANSFORMATION THRU 30. DEGREE ANGLE
(1/TPA)

COMPLIANCE OF MATERIAL			TRANSFORMED COMPLIANCE		
7.2	-2.2	0.0	36.6	-5.5	-49.0
-2.2	111.6	0.0	-5.5	88.8	-41.4
0.0	0.0	140.8	-49.0	-41.4	127.6

2

ENGLISH UNITS
MODULUS TRANSFORMATION THRU 30. DEGREE ANGLE
(1.E+06 PSI)

MODULUS OF THE MATERIAL			TRANSFORMED MODULUS		
27.7	.5	0.0	16.8	5.0	8.2
.5	1.8	0.0	5.0	3.8	3.1
0.0	0.0	1.2	8.2	3.1	5.6

3

COMPLIANCE TRANSFORMATION THRU 30. DEGREE ANGLE
(1.0E-09/PSI)

COMPLIANCE OF MATERIAL			TRANSFORMED COMPLIANCE		
36.3	-10.9	0.0	211.8	-51.9	-280.4
-10.9	574.6	0.0	-51.9	481.0	-185.8
0.0	0.0	851.2	-280.4	-185.8	687.3

IV. Effective material properties of laminates and strength of sandwich laminates:

1. Modulus matrix A for a $(0/90)_s$ laminate - dimensional.
2. Modulus matrix A^* for a $(0/90)_s$ laminate - normalized.
3. Compliance matrix a for a $(0/90)_s$ laminate - dimensional.
4. Compliance matrix a^* for a $(0/90)_s$ laminate - normalized.
5. Engineering constants for a $(0/90)_s$ laminate.
6. Strength of a sandwich laminate. One layer thickness of sandwich core is equal to the thickness of eight plies.

Input:

```

① LAMINATE INPLANE
   PURE DIMENSIONL
   MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE
   T300/5208 SI
   $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
   C=0.,NLDCN=1 $

② LAMINATE INPLANE
   PURE NORMALIZED
   MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE
   T300/5208 SI
   $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
   C=0.,NLDCN=1 $

③ LAMINATE INPLANE
   PURE DIMENSIONL
   COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE
   T300/5208 SI
   $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
   C=0.,NLDCN=1 $

④ LAMINATE INPLANE
   PURE NORMALIZED
   COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE
   T300/5208 SI
   $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
   C=0.,NLDCN=1 $

⑤ LAMINATE INPLANE
   PURE ENGCONST
   ENGINEERING CONSTANTS FOR (0/90)-SYM. LAMINATE
   T300/5208 SI
   $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
   C=0.,NLDCN=1 $

⑥ LAMINATE INPLANE
   HYBRID STRENGTH
   STRENGTH OF (0/0/90/90/4CORE)-SYMM. LAMI. TSAI-WU FXYS=-.5
   $LAYERS NNL=5,LMPI=2*1,6,2*1,TH=0.,90.,0.,90.,0.,
   PLNM=2*2.,1.,2*2.,IUNIT=1,DT=0.,C=0.,NLDCN=1 $
   TSAI WU STRESS -0.5
   $STRESS AN=1.,0.,0.,AM=3*0. $
THEEND

```

Output:

MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE

1

NUMBER OF PLYS = 4
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 0.0 90.0 90.0 0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1
 TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
 SI UNITS

A B

B D

.480E+08	.145E+07	0.	.291E-10	0.	0.
.145E+07	.480E+08	0.	0.	.637E-11	0.
0.	0.	.358E+07	0.	0.	.909E-12
.291E-10	0.	0.	.167E+01	.302E-01	0.
0.	.637E-11	0.	.302E-01	.331E+00	0.
0.	0.	.909E-12	0.	0.	.747E-01

MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE

2

NUMBER OF PLYS = 4
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 0.0 90.0 90.0 0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1
 TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
 SI UNITS

A# B#

3B# D# GPA

96.1	2.9	0.0	.0	0.0	0.0
2.9	96.1	0.0	0.0	.0	0.0
0.0	0.0	7.2	0.0	0.0	.0
.0	0.0	0.0	160.4	2.9	0.0
0.0	.0	0.0	2.9	31.8	0.0
0.0	0.0	.0	0.0	0.0	7.2

COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE

3

NUMBER OF PLYS = 4
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 0.0 90.0 90.0 0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1
 TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
 SI UNITS

ALPHA BETA

TRSBTA DELTA

.208E-07	-.628E-09	0.	-.364E-18	.452E-19	0.
-.628E-09	.208E-07	0.	.182E-19	-.402E-18	0.
0.	0.	.279E-06	0.	0.	-.340E-17
-.364E-18	.182E-19	0.	.600E+00	-.547E-01	0.
.452E-19	-.402E-18	0.	-.547E-01	.303E+01	0.
0.	0.	-.340E-17	0.	0.	.134E+02

NONMECH. STRESS AND MOMENT RESULTANTS N,M

0.	0.	0.
0.	0.	0.

COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE

4

NUMBER OF PLYS = 4
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 0.0 90.0 90.0 0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1
 TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
 SI UNITS

ALPHA# BETA#/3

TRSBTA# DELTA# (1./TPA)

10.4	-.3	0.0	-.0	.0	0.0
-.3	10.4	0.0	.0	-.0	0.0
0.0	0.0	139.5	0.0	0.0	-.0
-.0	.0	0.0	6.2	-.6	0.0
.0	-.0	0.0	-.6	31.5	0.0
0.0	0.0	-.0	0.0	0.0	139.5

NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#

0.	0.	0.
0.	0.	0.

ENGINEERING CONSTANTS FOR (0/90)-SYM. LAMINATE

5

NUMBER OF PLYS = 4
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
0.0 90.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 1 1
TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
SI UNITS

SOME ENGINEERING CONSTANTS, ES IN GPA
INPLANE :, E1= 95.991 E2= 95.991 V21= .030 E6= 7.170
FLEXURAL:, EF1=160.114 EF2= 31.727 VF21= .091 EF6= 7.170

STRENGTH OF (0/0/90/90/4CORE)-SYMM. LAMI. TSAI-WU FXYS=-.5

6

NUMBER OF PLYS = 5
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
0.0 90.0 0.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
2.0 2.0 1.0 2.0 2.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 6 1 1
TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
SI UNITS

APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M
1.000 0.000 0.000
0.000 0.000 0.000

EFFECTIVE NONMECHANICAL STRAIN COMP.

0. 0. 0.

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 0.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH. 1 2
NONMECH. 3 4

STRAIN COMPONENTS

1 .104E-07 -.314E-09 0.
2 .104E-07 -.314E-09 0.
3 0. 0. 0.
4 0. 0. 0.

STRESS COMPONENTS

1 .189E+04 .269E+02 0.
2 .189E+04 .269E+02 0.
3 0. 0. 0.
4 0. 0. 0.

TSAI-WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .682E+06 UPPER SURF.= .682E+06
STRENGTH R# MPA : LOWER SURF.= 340.941 UPPER SURF.= 340.941

EFFECTIVE NONMECHANICAL STRAIN COMP.

0. 0. 0.

```

-----
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIENT. = 90.0
MECH/NONMECH   LOWER SURF.   UPPER SURF.
MECH.           1             2
NONMECH.        3             4
-----

```

STRAIN COMPONENTS

```

-----
1      -.314E-09      .104E-07      0.
2      -.314E-09      .104E-07      0.
3       0.             0.             0.
4       0.             0.             0.
-----

```

STRESS COMPONENTS

```

-----
1      -.269E+02      .107E+03      0.
2      -.269E+02      .107E+03      0.
3       0.             0.             0.
4       0.             0.             0.
-----

```

```

-----
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.= .373E+06  UPPER SURF.= .373E+06
STRENGTH R# MPA : LOWER SURF.= 186.698  UPPER SURF.= 186.698
-----

```

EFFECTIVE NONMECHANICAL STRAIN COMP.

0. 0. 0.

```

-----
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIENT. = 90.0
MECH/NONMECH   LOWER SURF.   UPPER SURF.
MECH.           1             2
NONMECH.        3             4
-----

```

STRAIN COMPONENTS

```

-----
1      -.314E-09      .104E-07      0.
2      -.314E-09      .104E-07      0.
3       0.             0.             0.
4       0.             0.             0.
-----

```

STRESS COMPONENTS

```

-----
1      -.269E+02      .107E+03      0.
2      -.269E+02      .107E+03      0.
3       0.             0.             0.
4       0.             0.             0.
-----

```

```

-----
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.= .373E+06  UPPER SURF.= .373E+06
STRENGTH R# MPA : LOWER SURF.= 186.698  UPPER SURF.= 186.698
-----

```

EFFECTIVE NONMECHANICAL STRAIN COMP.

0.

0.

0.

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 0.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	.104E-07	-.314E-09	0.
2	.104E-07	-.314E-09	0.
3	0.	0.	0.
4	0.	0.	0.

STRESS COMPONENTS

1	.189E+04	.269E+02	0.
2	.189E+04	.269E+02	0.
3	0.	0.	0.
4	0.	0.	0.

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .682E+06 UPPER SURF.= .682E+06

STRENGTH R# MPA : LOWER SURF.= 340.941 UPPER SURF.= 340.941

V. Unsymmetric Laminates:

Replace the properties of first two materials by new material properties, calculate the effective modulus matrices and engineering constants and conduct the strength analysis of two unsymmetric laminates in the presence of curing stress

1. Laminate (30/-30/30/-30/90/90) total.
2. Laminate (0/90/45/-45) total.

Input data:

```
NEUMTRLS SI
$LAMDATA NNM=2,EX=113.08,137.9,EY=9.24,11.03,VX=2*.3,
ES=2*5.86,ALFX=2*-.9,ALFY=2*23.04,BTAX=2*0.,BTAY=2*0.,
X=2*1448.,XD=1448.,Y=2*51.7,YD=2*207,S=2*93,SH=.000125 $
① LAMINATE GENERAL
PURE ALL BOTH STRENGTH
(30/-30/30/-30/90/90)-TOTAL LAMINATE
T300/5208 ENGLISH
$SLAYER NNL=6,TH=2*90.,-30.,30.,-30.,30.,PLNM=6*1.,DT=-175.,
C=0.,NLDCN=1 $
TSAI WU -0.5
$STRESS AN=1.,2*0.,AM=3*0. $
② LAMINATE GENERAL
PURE ALL BOTH STRENGTH
(0/90/45/-45)-TOTAL LAMINATE
T300/5208 ENGLISH
$SLAYER NNL=4,TH=-45.,45.,90.,0.,PLNM=4*1.,DT=-175.,
C=0.,NLDCN=1 $
TSAI WU -0.5
$STRESS AN=1.,2*0.,AM=3*0. $
THEEND
```

Note: The stacking sequence is such that the bottom ply corresponds to TH(1) in the input data card "\$SLAYER", where as in customary notation symbols (0/90/+45)_T, 0 denotes top ply angle and -45 denotes bottom ply.

Output:

(30/-30/30/-30/90/90)-TOTAL LAMINATE

1

NUMBER OF PLYS = 6
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 90.0 90.0-30.0 30.0-30.0 30.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1 1 1
 TEMPERATURE DT= -175.0000 MOISTURE= 0.0000
 ENGLISH UNITS

A B

B D

.214E+06	.624E+05	0.	.855E+03	.249E+03	.231E+03
.624E+05	.214E+06	0.	.249E+03	-.135E+04	.876E+02
0.	0.	.756E+05	.231E+03	.876E+02	.249E+03
.855E+03	.249E+03	.231E+03	.127E+02	.373E+01	.228E+01
.249E+03	-.135E+04	.876E+02	.373E+01	.200E+02	.863E+00
.231E+03	.876E+02	.249E+03	.228E+01	.863E+00	.468E+01

A# B#

3B# D# 1.E+06 PSI

7.2	2.1	0.0	2.0	.6	.5
2.1	7.2	0.0	.6	-3.1	.2
0.0	0.0	2.6	.5	.2	.6
5.9	1.7	1.6	5.9	1.7	1.1
1.7	-9.3	.6	1.7	9.3	.4
1.6	.6	1.7	1.1	.4	2.2

SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI
 INPLANE :, E1= 6.611 E2= 6.611 V21= .292 E6= 2.558
 FLEXURAL:, EF1= 5.151 EF2= 8.782 VF21= .167 EF6= 1.988

ALPHA BETA

TRSBTA DELTA

.767E-05	-.328E-05	.210E-05	-.382E-03	-.247E-03	-.198E-03
-.328E-05	.114E-04	.493E-07	-.238E-03	.862E-03	-.973E-04
.210E-05	.493E-07	.170E-04	-.295E-03	-.505E-05	-.861E-03
-.382E-03	-.238E-03	-.295E-03	.127E+00	-.330E-01	-.166E-01
-.247E-03	.862E-03	-.505E-05	-.330E-01	.118E+00	-.937E-02
-.198E-03	-.973E-04	-.861E-03	-.166E-01	-.937E-02	.281E+00

NONMECH. STRESS AND MOMENT RESULTANTS N,M

-.362E+02	-.362E+02	.119E-11
.257E+00	-.257E+00	.741E-01

ALPHA#		BETA#/3			
TRSBTA#		DELTA#		1.0E-09/PSI	
226.7	-96.9	62.2	-55.6	-35.9	-28.8
-96.9	337.3	1.5	-34.7	125.4	-14.2
62.2	1.5	501.5	-42.9	-.7	-125.3
-166.8	-104.0	-128.8	272.7	-71.0	-35.7
-107.8	376.3	-2.2	-71.0	253.8	-20.1
-86.3	-42.5	-375.9	-35.7	-20.1	603.3
NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#					
-.123E+04		-.123E+04		.404E-10	
.176E+04		-.176E+04		.509E+03	
APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M					
1.000		0.000		0.000	
0.000		0.000		0.000	
EFFECTIVE NONMECHANICAL STRAIN COMP.					
-.113E-02		.328E-03		-.654E-03	
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0					
MECH/NONMECH	LOWER SURF.		UPPER SURF.		
MECH.	1		2		
NONMECH.	3		4		
STRAIN COMPONENTS					
1	.367E-06		.133E-04		-.503E-05
2	-.848E-06		.114E-04		-.405E-05
3	.240E-03		.111E-02		.654E-03
4	-.636E-04		.142E-02		.508E-03
STRESS COMPONENTS					
1	.115E+02		.181E+02		-.427E+01
2	-.939E+01		.151E+02		-.344E+01
3	.442E+04		.160E+04		.556E+03
4	-.476E+03		.189E+04		.432E+03
TSAI WU FAILURE CRITERIA					
STRENGTH RATIO R: LOWER SURF.=		.330E+03		UPPER SURF.= .366E+03	
STRENGTH R# KSI : LOWER SURF.=		11.174		UPPER SURF.= 12.396	

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.821E-03

.239E-04

-.508E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	-.848E-06	.114E-04	-.405E-05
2	-.206E-05	.955E-05	-.308E-05
3	-.636E-04	.142E-02	.508E-03
4	-.368E-03	.173E-02	.362E-03

STRESS COMPONENTS

1	-.939E+01	.151E+02	-.344E+01
2	-.302E+02	.121E+02	-.262E+01
3	-.476E+03	.189E+04	.432E+03
4	-.537E+04	.218E+04	.308E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .366E+03 UPPER SURF.= .415E+03

STRENGTH R# KSI : LOWER SURF.= 12.396 UPPER SURF.= 14.048

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.515E-03

-.280E-03

-.362E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = -30.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	.532E-05	.217E-05	.116E-04
2	.402E-05	.369E-06	.105E-04
3	-.387E-03	.174E-02	-.384E-03
4	-.296E-03	.166E-02	.217E-03

STRESS COMPONENTS

1	.887E+02	.509E+01	.986E+01
2	.666E+02	.213E+01	.896E+01
3	-.569E+04	.220E+04	-.327E+03
4	-.422E+04	.212E+04	.185E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .747E+03 UPPER SURF.= .103E+04

STRENGTH R# KSI : LOWER SURF.= 25.278 UPPER SURF.= 34.700

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.208E-03

-.584E-03

-.216E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 30.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH. 1 2

NONMECH. 3 4

STRAIN COMPONENTS

1	.584E-05	-.145E-05	-.843E-05
2	.371E-05	-.241E-05	-.834E-05
3	-.483E-03	.184E-02	-.433E-03
4	-.266E-03	.163E-02	-.889E-03

STRESS COMPONENTS

1	.960E+02	.405E+00	-.717E+01
2	.603E+02	-.176E+01	-.709E+01
3	-.724E+04	.229E+04	-.368E+03
4	-.374E+04	.209E+04	-.756E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .127E+04 UPPER SURF.= .164E+04

STRENGTH R# KSI : LOWER SURF.= 42.843 UPPER SURF.= 55.621

EFFECTIVE NONMECHANICAL STRAIN COMP.

.983E-04

-.888E-03

-.703E-04

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = -30.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH. 1 2

NONMECH. 3 4

STRAIN COMPONENTS

1	.273E-05	-.144E-05	.947E-05
2	.144E-05	-.324E-05	.841E-05
3	-.205E-03	.157E-02	.819E-03
4	-.115E-03	.148E-02	.142E-02

STRESS COMPONENTS

1	.445E+02	-.832E+00	.805E+01
2	.224E+02	-.379E+01	.715E+01
3	-.276E+04	.203E+04	.696E+03
4	-.129E+04	.195E+04	.121E+04

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .145E+04 UPPER SURF.= .198E+04

STRENGTH R# KSI : LOWER SURF.= 49.147 UPPER SURF.= 67.112

EFFECTIVE NONMECHANICAL STRAIN COMP.

.405E-03

-.119E-02

.755E-04

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 30.0

MECH/NONMECH

LOWER SURF.

UPPER SURF.

MECH.

1

2

NONMECH.

3

4

STRAIN COMPONENTS

1	.157E-05	-.337E-05	-.825E-05
2	-.565E-06	-.434E-05	-.817E-05
3	-.492E-04	.141E-02	-.135E-02
4	.168E-03	.120E-02	-.180E-02

STRESS COMPONENTS

1	.246E+02	-.392E+01	-.702E+01
2	-.111E+02	-.608E+01	-.694E+01
3	-.240E+03	.189E+04	-.114E+04
4	.326E+04	.169E+04	-.153E+04

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .202E+04 UPPER SURF.= .226E+04

STRENGTH R# KSI : LOWER SURF.= 68.433 UPPER SURF.= 76.599

 (0/90/45/-45)-TOTAL LAMINATE

NUMBER OF PLYS = 4
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
 -45.0 45.0 90.0 0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
 1.0 1.0 1.0 1.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
 1 1 1 1
 TEMPERATURE DT= -175.0000 MOISTURE= 0.0000
 ENGLISH UNITS

A B

B D

.142E+06	.416E+05	-.582E-09	.350E+03	-.166E+03	.920E+02
.416E+05	.142E+06	.582E-09	-.166E+03	-.183E+02	.920E+02
-.582E-09	.582E-09	.504E+05	.920E+02	.920E+02	-.166E+03
.350E+03	-.166E+03	.920E+02	.642E+01	.135E+01	-.906E+00
-.166E+03	-.183E+02	.920E+02	.135E+01	.279E+01	-.906E+00
.920E+02	.920E+02	-.166E+03	-.906E+00	-.906E+00	.135E+01

A# B#

3B# D# 1.E+06 PSI

7.2	2.1	-.0	1.8	-.9	.5
2.1	7.2	.0	-.9	-.1	.5
-.0	.0	2.6	.5	.5	-.9
5.4	-2.6	1.4	10.1	2.1	-1.4
-2.6	-.3	1.4	2.1	4.4	-1.4
1.4	1.4	-2.6	-1.4	-1.4	2.6

SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI

INPLANE :, E1= 6.611 E2= 6.611 V21= .292 E6= 2.558
 FLEXURAL: EF1= 8.796 EF2= 3.404 VF21= .368 EF6= 2.036

ALPHA BETA

TRSBTA DELTA

.128E-04	-.444E-05	-.233E-05	-.111E-02	.111E-02	-.709E-03
-.444E-05	.916E-05	-.132E-05	.558E-03	-.559E-03	-.401E-03
-.233E-05	-.132E-05	.308E-04	.155E-03	-.153E-03	.334E-02
-.111E-02	.558E-03	.155E-03	.279E+00	-.166E+00	.110E+00
.111E-02	-.559E-03	-.153E-03	-.166E+00	.562E+00	.173E+00
-.709E-03	-.401E-03	.334E-02	.110E+00	.173E+00	.117E+01

NONMECH. STRESS AND MOMENT RESULTANTS N,M

-.241E+02	-.241E+02	.587E-12
.428E-01	-.428E-01	.428E-01

			ALPHA#	BETA#/3	

			TRSBTA#	DELTA#	1.0E-09/PSI

252.3	-87.4	-46.0	-72.0	72.0	-45.9
-87.4	180.4	-25.9	36.1	-36.1	-25.9
-46.0	-25.9	607.5	10.0	-9.9	216.2
-215.9	108.2	30.1	177.8	-106.0	70.0
216.1	-108.4	-29.7	-106.0	358.0	110.2
-137.6	-77.8	648.6	70.0	110.2	747.7
NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#					
	-.123E+04		-.123E+04		.298E-10
	.661E+03		-.661E+03		.661E+03

APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M					
	1.000		0.000		0.000
	0.000		0.000		0.000

EFFECTIVE NONMECHANICAL STRAIN COMP.					
	-.693E-03		.283E-03		-.487E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =-45.0					
MECH/NONMECH	LOWER SURF.		UPPER SURF.		
MECH.	1		2		
NONMECH.	3		4		

STRAIN COMPONENTS					

1	.185E-05		.651E-05		.392E-04
2	.360E-05		.476E-05		.282E-04
3	-.492E-04		.179E-02		-.976E-03
4	-.232E-03		.197E-02		-.610E-03

STRESS COMPONENTS					

1	.333E+02		.953E+01		.333E+02
2	.615E+02		.789E+01		.240E+02
3	-.878E+02		.240E+04		-.830E+03
4	-.304E+04		.257E+04		-.519E+03

TSAI WU FAILURE CRITERIA					
STRENGTH RATIO R:		LOWER SURF.=	.279E+03	UPPER SURF.=	.357E+03
STRENGTH R# KSI :		LOWER SURF.=	14.160	UPPER SURF.=	18.138

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.511E-03

.996E-04

-.122E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 45.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	.476E-05	.360E-05	-.282E-04
2	.302E-05	.535E-05	-.172E-04
3	-.354E-03	.210E-02	.610E-03
4	-.171E-03	.191E-02	.244E-03

STRESS COMPONENTS

1	.801E+02	.679E+01	-.240E+02
2	.520E+02	.845E+01	-.147E+02
3	-.500E+04	.269E+04	.519E+03
4	-.205E+04	.251E+04	.208E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .371E+03 UPPER SURF.= .450E+03

STRENGTH R# KSI : LOWER SURF.= 18.835 UPPER SURF.= 22.828

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.328E-03

-.833E-04

.244E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	-.444E-05	.128E-04	.233E-05
2	.105E-05	.733E-05	.583E-05
3	-.171E-03	.191E-02	-.244E-03
4	-.354E-03	.210E-02	-.610E-03

STRESS COMPONENTS

1	-.681E+02	.155E+02	.198E+01
2	.203E+02	.103E+02	.495E+01
3	-.205E+04	.251E+04	-.208E+03
4	-.500E+04	.269E+04	-.519E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .297E+03 UPPER SURF.= .462E+03

STRENGTH R# KSI : LOWER SURF.= 15.095 UPPER SURF.= 23.466

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.145E-03

-.266E-03

.610E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 0.0

MECH/NONMECH LOWER SURF. UPPER SURF.

MECH.

1

2

NONMECH.

3

4

STRAIN COMPONENTS

1	.733E-05	.105E-05	-.583E-05
2	.185E-05	.653E-05	-.932E-05
3	-.232E-03	.197E-02	.610E-03
4	-.492E-04	.179E-02	.976E-03

STRESS COMPONENTS

1	.121E+03	.438E+01	-.495E+01
2	.332E+02	.957E+01	-.792E+01
3	-.304E+04	.257E+04	.519E+03
4	-.878E+02	.240E+04	.830E+03

TSAI WU FAILURE CPITERIA

STRENGTH RATIO R: LOWER SURF.= .934E+03 UPPER SURF.= .517E+03

STRENGTH R# KSI : LOWER SURF.= 47.422 UPPER SURF.= 26.242

VI. Engineering constants plot:

To replace material properties of the first two materials in the program and use the first material to compute effective modulus matrices for $(0/90/0_4)_s$ laminate, and plot engineering constants for $(0/90/\pm \phi_2)_s$ laminates, ϕ varies from 0° to 90° .

Input data:

```

NEWMTRLS
$LAMDATA NNM=2,EX=185.,220.,EY=11.2,10.5,VX=0.29,0.31,
ALFX=12.5,11.,ALFY=-.5,-.3,BTAX=2*0.,BTAY=2*0.,X=1400.,
1300.,XD=1400.,1300.,Y=35.,32,YD=230.,210.,S=2*75.,SH=2*.125E-3 $
LAMINATE INPLANE
PURE DIMENSIONL PLTONE ENGCPIT
PLOT FOR ENGINEERING CONSTANTS OF  $(0/90/F_2/-F_2)_s$  -
T300/5208 SI
$LAYER>NNL=8,TH=0.,90.,0.,0.,0.,0.,90.,0.,PLNM=2*1.,4*2.,
2*1.,DT=0.,C=0.,NLDCN=1 $
THEEND
    
```

Output:

PLOT FOR ENGINEERING CONSTANTS OF $(0/90/F_2/-F_2)_s$ -LAMINATE

```

NUMBER OF PLYS = 8
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
0.0 90.0 0.0 0.0 0.0 0.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 2.0 2.0 2.0 2.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 1 1 1 1 1 1
TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
SI UNITS
    
```

A B

B D

.235E+09	.490E+07	0.	.407E-09	.546E-11	0.
.490E+07	.606E+08	0.	.546E-11	.116E-09	0.
0.	0.	.108E+08	0.	0.	.182E-10
.407E-09	.546E-11	0.	.384E+02	.918E+00	0.
.546E-11	.116E-09	0.	.918E+00	.170E+02	0.
0.	0.	.182E-10	0.	0.	.202E+01

PLOTS FOR ENGINEERING CONSTANTS DRAWN

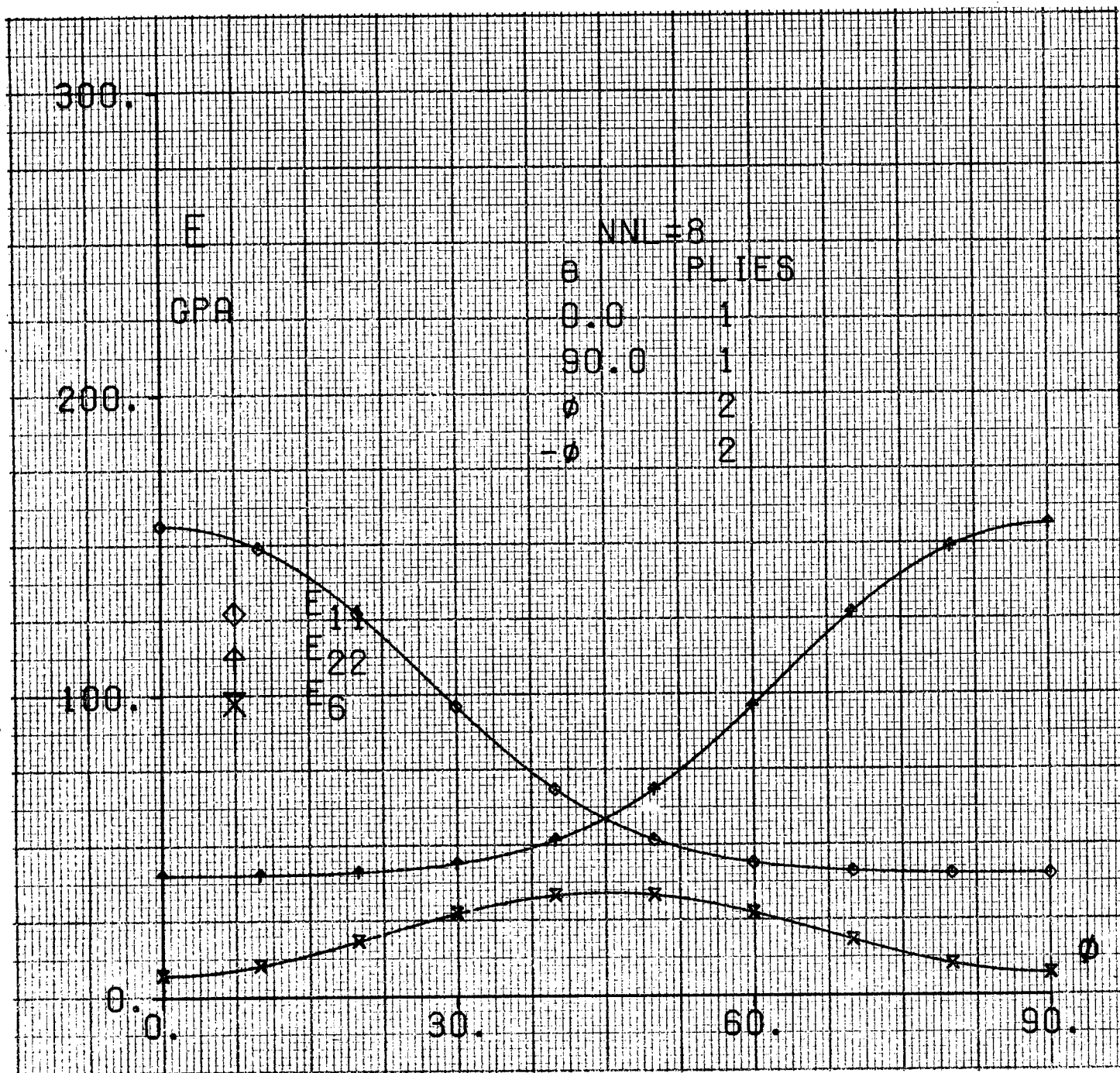


Figure A-1: Effective Engineering Constants for $(0/90/\pm\phi_2)_s$ - Laminates, ϕ Varies from 0° to 90° .

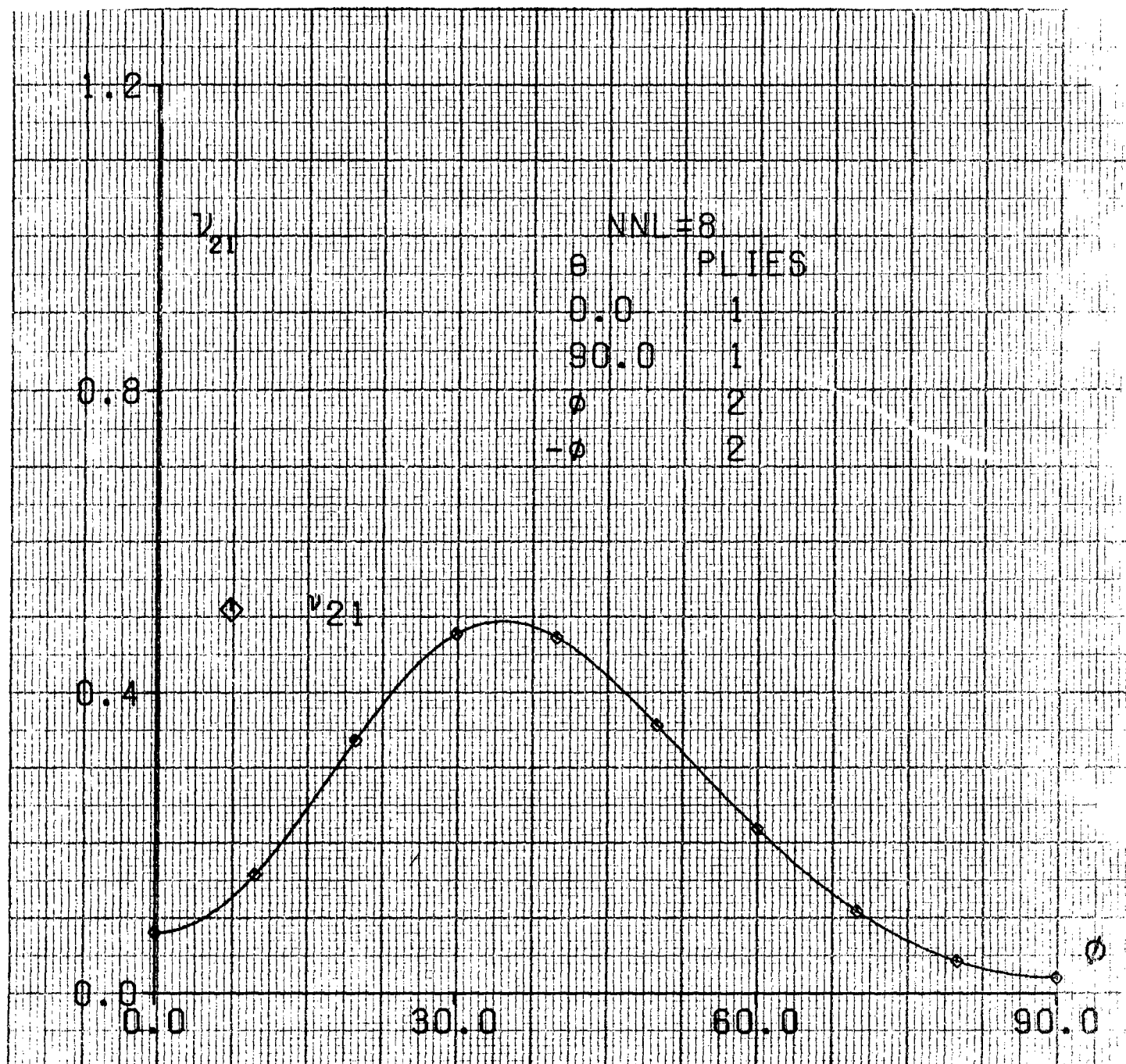


Figure A-2: Effective Poisson's Ratio v_{21} for $(0/90/+ \phi)_S$ Laminates, ϕ Varies from 0° to 90° .

VII. Failure envelopes for a pure or hybrid symmetric laminate on the basis of Tsai Wu failure criteria in strain space, $F_{xy}^* = -.5$.

1. $(0/90/+30)_s$ pure T300/5208 laminate.
2. $(0/90/+30)_s$ hybrid laminate 0° and 90° plies T300/5208 and $+30^\circ$ plies KEVLAR 49.

Input data:

```

LAMINATE INPLANE
PURE STRNGTHPLTPLTSTART
(0/90/30/-30) SYMMETRIC LAMINATE FAILURE SURFACE TSAI WU FSXY=-1./2.
T300/5208
1 $LAYER>NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,PLNM=8*1.,
DT=0.,C=0.,NLDCN=1 $
TSAI WU STRAIN -0.5
LAMINATE INPLANE
HYBRID STRNGTHPLTPLTEND
2 (0/90/30/-30) SYM. LAMINATE FAIL. ENVELOPES TSAI WU FSXY=-1./2. HYBRID.
$LAYERS>NNL=8,LMPI=2*1,4*5,2*1,TH=0.,90.,30.,2*-30.,30.,90.,0.,
PLNM=8*1., IUNIT=1, DT=0., C=0, NLDCN=1 $
TSAI WU STRAIN -0.5
THEEND

```

Output:

```

-----
(0/90/30/-30) SYMMETRIC LAMINATE FAILURE SURFACE TSAI WU FSXY=-1./2.
-----
NUMBER OF PLYS = 8
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
0.0 90.0 30.0-30.0-30.0 30.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 1 1 1 1 1 1
TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
SI UNITS
-----
FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED

```

Note: LMPI in input data card number 11 represents the material property identification number of each layer in the laminate.

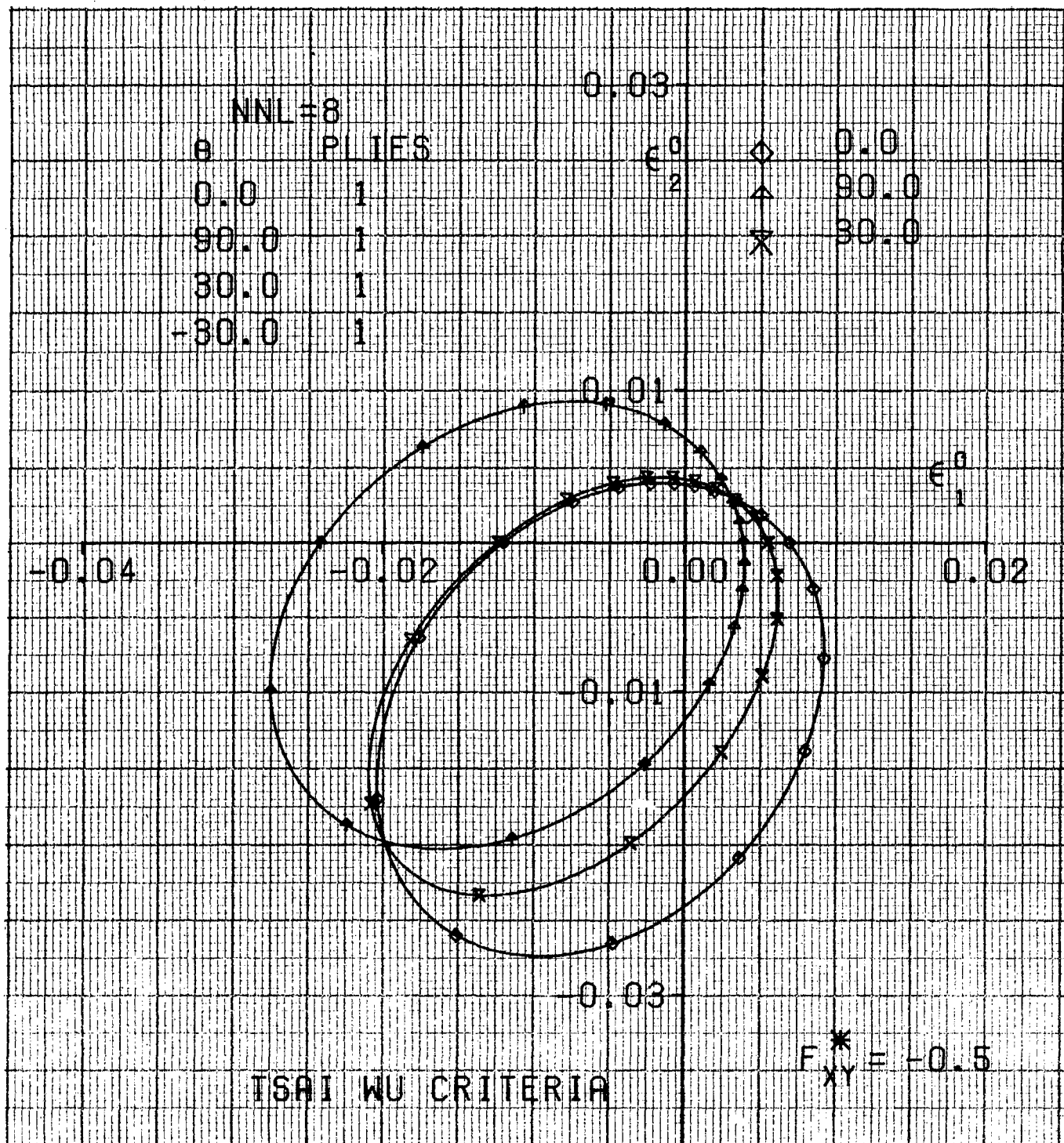


Figure A-3: Failure Envelopes for $(0/90/+30)_s$ - Laminate of T300/5208 Graphite Epoxy.

(0/90/30/-30) SYM. LAMINATE FAIL. ENVELOPES TSAI WU FSXY=-1/2. HYBRID.

NUMBER OF PLYS = 8
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
0.0 90.0 30.0-30.0-30.0 30.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 5 5 5 5 1 1
TEMPERATURE DT= 0.0000 MOISTURE= 0.0000
SI UNITS

FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED

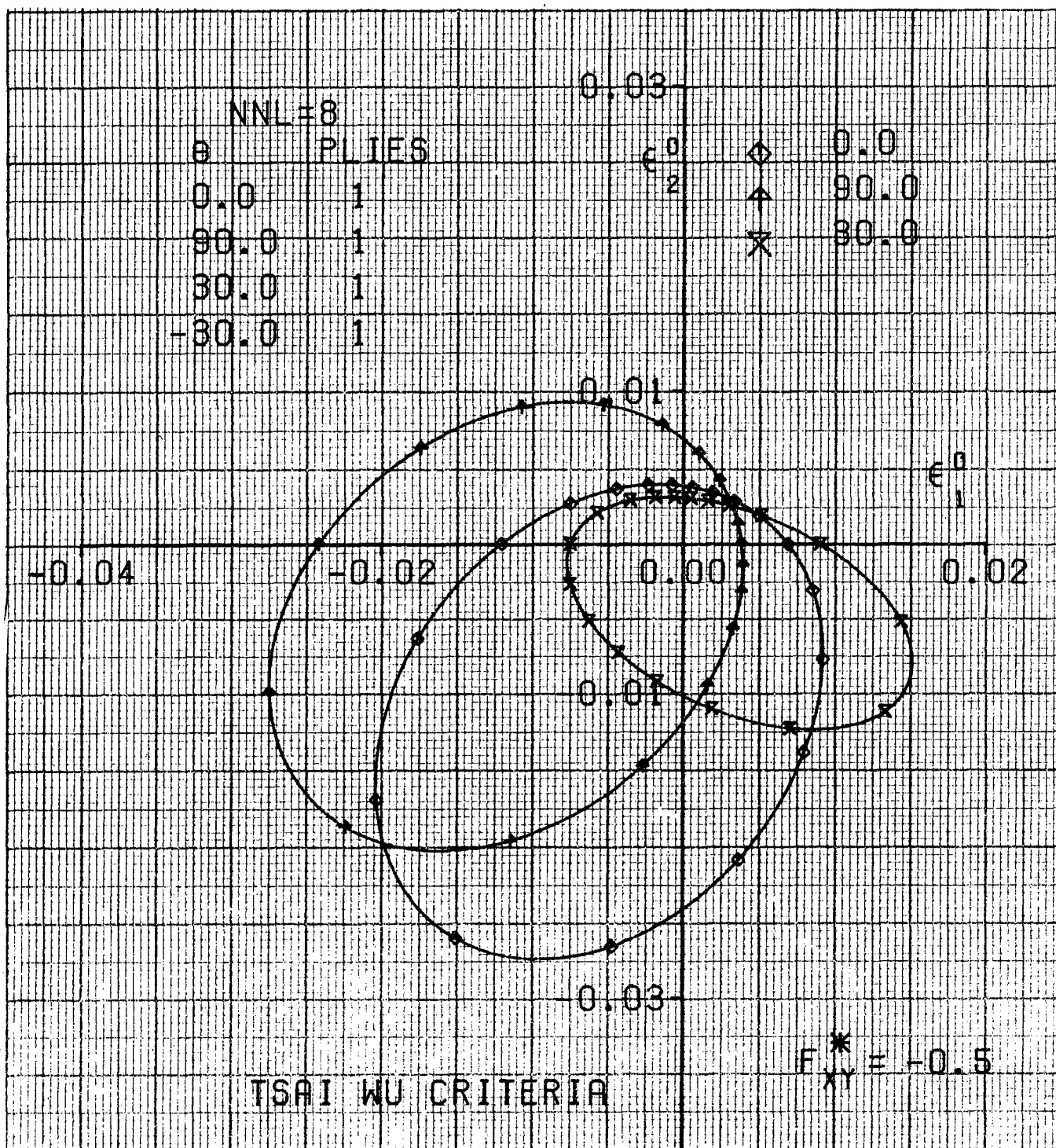


Figure A-4: Failure Envelopes for $(0/90/+30)_s$ - Hybrid Laminates
 0° and 90° Plies T300/5208 Material and $+30^\circ$ Layers
 Kevlar 49 Material.

VIII. Failure surfaces for different laminates in one figure:
 In this illustration the failure envelopes of 0° laminate on the basis of six failure theories are given for T300/5208 material, using the option of SUPERPOSE and MULTICURV.

Input data

```

LAMINATE INPLANE
PURE STRNGTHPLTPLTSTART
0 DEGREE LAMINATE T300/5208 MATERIAL TSAI WU FSXY=-.5
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
TSAI WU STRAIN SUPERPOSE -.5 MULTICURV
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
0 DEGREE LAMINATE T300/5208 MATERIAL CHAMIS
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
CHAMIS STRAIN SUPERPOSE -.7 MULTICURV
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
0 DEGREE LAMINATE T300/5208 MATERIAL HOFFMAN
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
HOFFMAN STRAIN SUPERPOSE MULTICURV
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
0 DEGREE LAMINATE T300/5208 MATERIAL HILL CRITERIA
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
HILL STRAIN SUPERPOSE MULTICURV
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
0 DEGREE LAMINATE T300/5208 MATERIAL MAXSTRAIN CRITERIA
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
MAXSTRAIN STRAIN SUPERPOSE MULTICURV
LAMINATE INPLANE
PURE STRNGTHPLTPLTEND
0 DEGREE LAMINATE T300/5208 MATERIAL MAXSTRESS CRITERIA
T300/5208
$ LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1 $
MAXSTRESS STRAIN SUPERPOSE MULTICURV
THEEND
  
```

Output: Figure A-5

IX. Failure envelopes for $(0/90/+30)_s$ laminate in different spaces on the basis of Tsai Wu failure criteria, $F_{xy}^* = -.5$.

1. qr - stress space
2. qr - strain space
3. principal stress space

Input Data:

```

1  LAMINATE INPLANE
    PURE STRNGTHPLTPLTSTART
    (0/90/30/-30) SYMMETRIC LAMINATE TSAI WU-STRESS QR.
    T300/5208
    $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
    PLNM=8*1.,DT=0.,C=0.,NLDCN=1 $
    TSAI WU STRESS QR -0.5

2  LAMINATE INPLANE
    PURE STRNGTHPLTPLTFOLLOW
    (0/90/30/-30) SYMMETRIC LAMINATE TSAI WU-STRAIN QR.
    T300/5208
    $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
    PLNM=8*1.,DT=0.,C=0.,NLDCN=1 $
    TSAI WU STRAIN QR -0.5

3  LAMINATE INPLANE
    PURE STRNGTHPLTPLTEND
    (0/90/30/-30) SYMM. LAMINATE TSAI WU- STRESS SPACE
    T300/5208
    $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
    PLNM=8*1.,DT=0.,C=0.,NLDCN=1 $
    TSAI WU STRESS -0.5
    THEEND

```

Output: Figures A-6 through A-8.

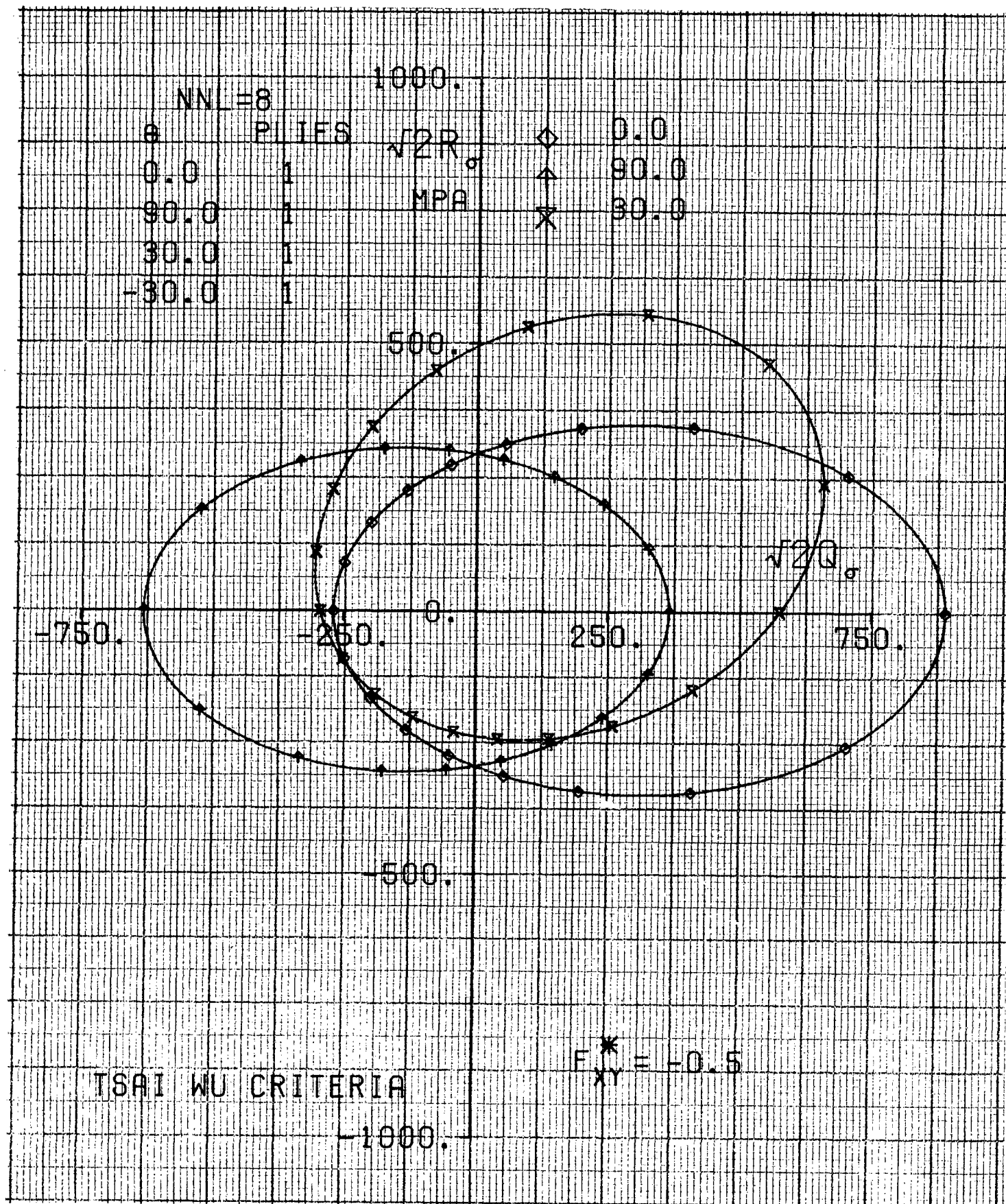


Figure A-6: Failure Envelopes for $(0/90/+30)_s$ Laminate in qr Plane of Stress Space.

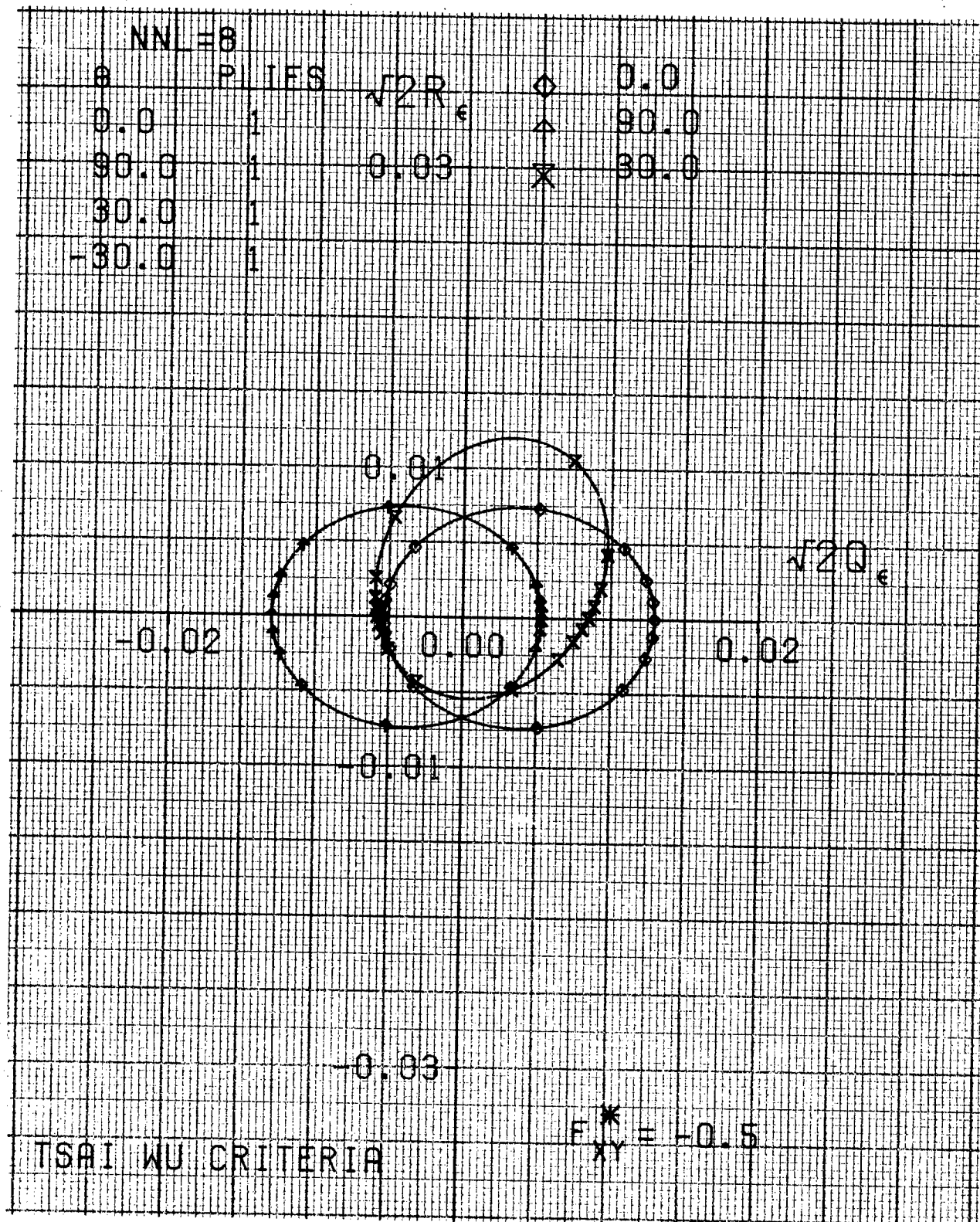


Figure A-7: Failure Envelopes for $(0/90/+30)_s$ Laminate in qr Plane of Strain Space.

X. Laminates consisting of more than three orientations:

1. Failure envelopes of 0°, 30° and 60° layers in a (0/+30/+45/+60/+75/90)_s laminate.
2. Failure Envelopes of 45°, 75° and 90° layers in a (0/+30/+45/+60/+75/90)_s laminate.
3. Failure envelopes of 0°, 30°, 45°, 60°, 75° and 90° layer of the aforementioned laminate.

Input data:

```

LAMINATE INPLANE
PURE                                STRNGTHPLTPLTSTART
(0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
$LAYER NNL=20,TH=0.,30.,60.,45.,75.,90.,-75.,-45.,-60.,-30.,
-30.,-60.,-45.,-75.,90.,75.,45.,60.,30.,0.,
PLNM=20*1.,DT=0.,C=0.,NLDCN=1 $
TSAI WU    STRAIN                    -.5
LAMINATE INPLANE
PURE                                STRNGTHPLTPLTFOLLOW
(0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
$LAYER NNL=20,TH=45.,75.,90.,0.,30.,60.,
-60.,-30.,-75.,-45.,-45.,-75.,-30.,-60.,60.,30.,0.,90.,75.,45.,
PLNM=20*1.,DT=0.,C=0.,NLDCN=1 $
TSAI WU    STRAIN                    -.5
LAMINATE INPLANE
PURE                                STRNGTHPLTPLTEND
(0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
$LAYER NNL=20,TH=0.,30.,60.,45.,75.,90.,-75.,-45.,-60.,-30.,
-30.,-60.,-45.,-75.,90.,75.,45.,60.,30.,0.,
PLNM=20*1.,DT=0.,C=0.,NLDCN=1 $
TSAI WU    STRAIN                    SUPERPOSE -.5
THEEND
```

Output: Figures A-9 through A-11.

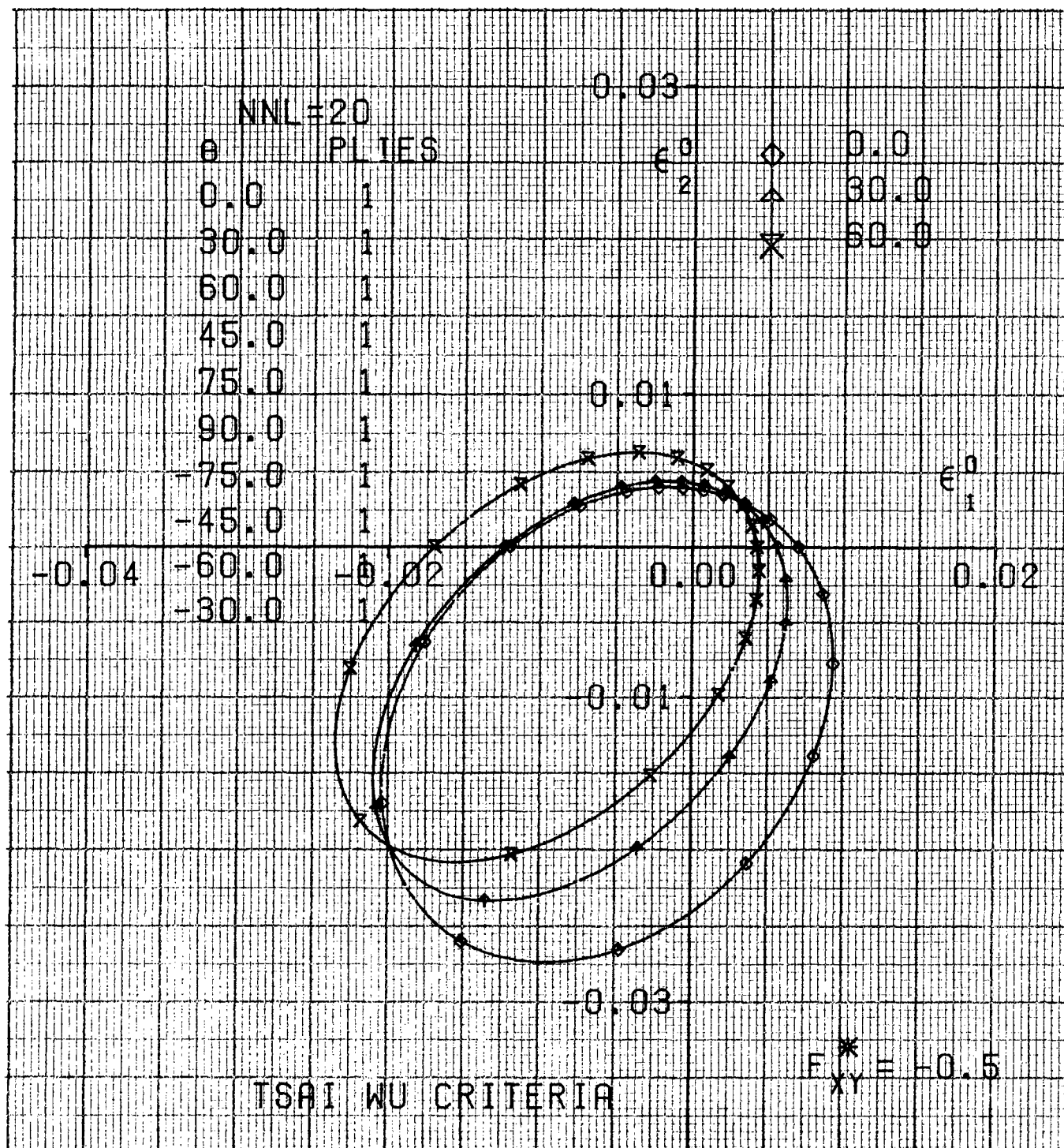


Figure A-9: Failure Envelopes of 0°, 30° and 60° Plies in (0/90/+30/+45/+60/+75)_s - Laminate in Principal Strain Space.

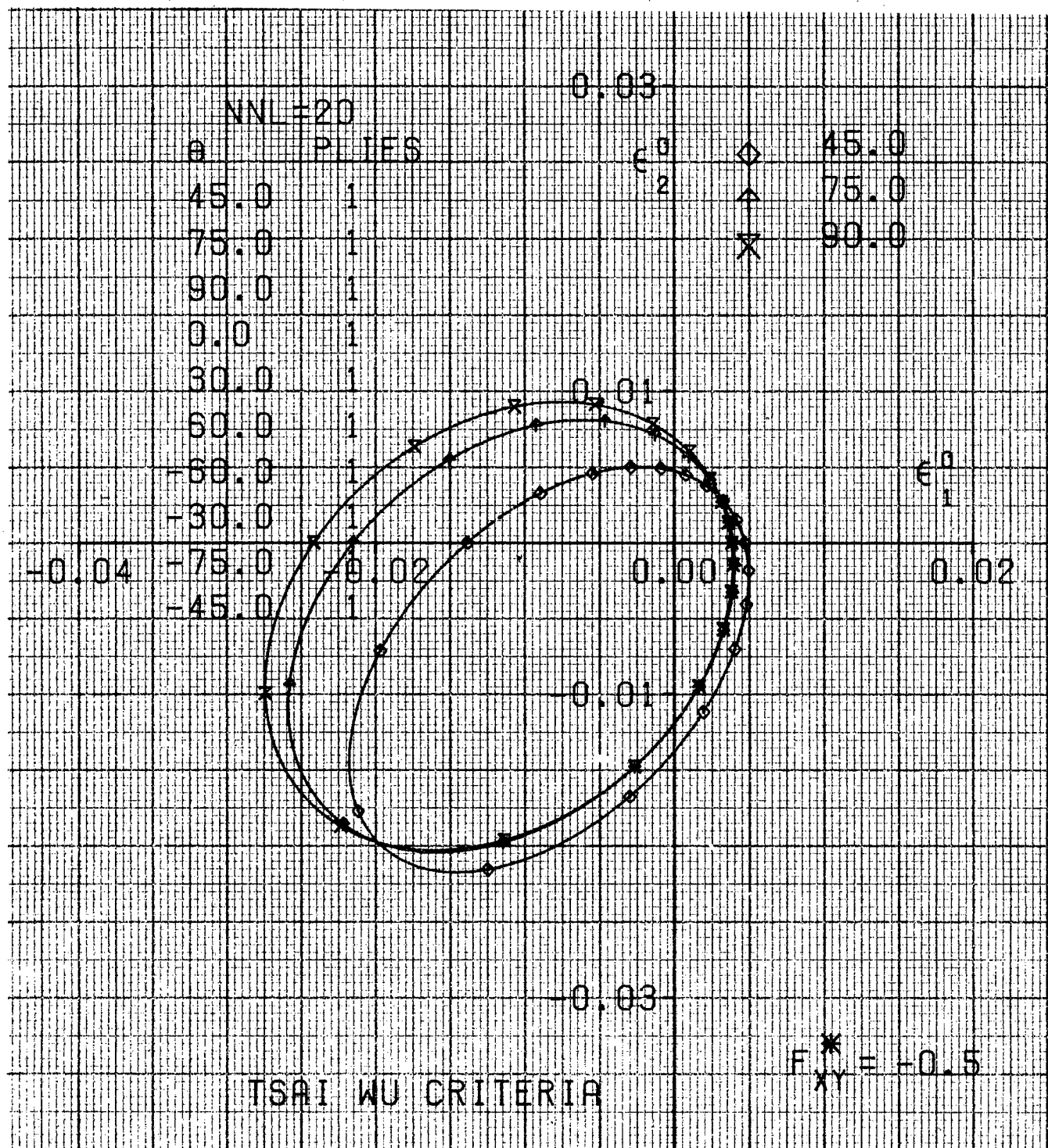


Figure A-10: Failure Envelopes of 45°, 75° and 90° Plies in (0/90/+30/+45/+60/+75)_s - Laminate in Principal Strain Space.

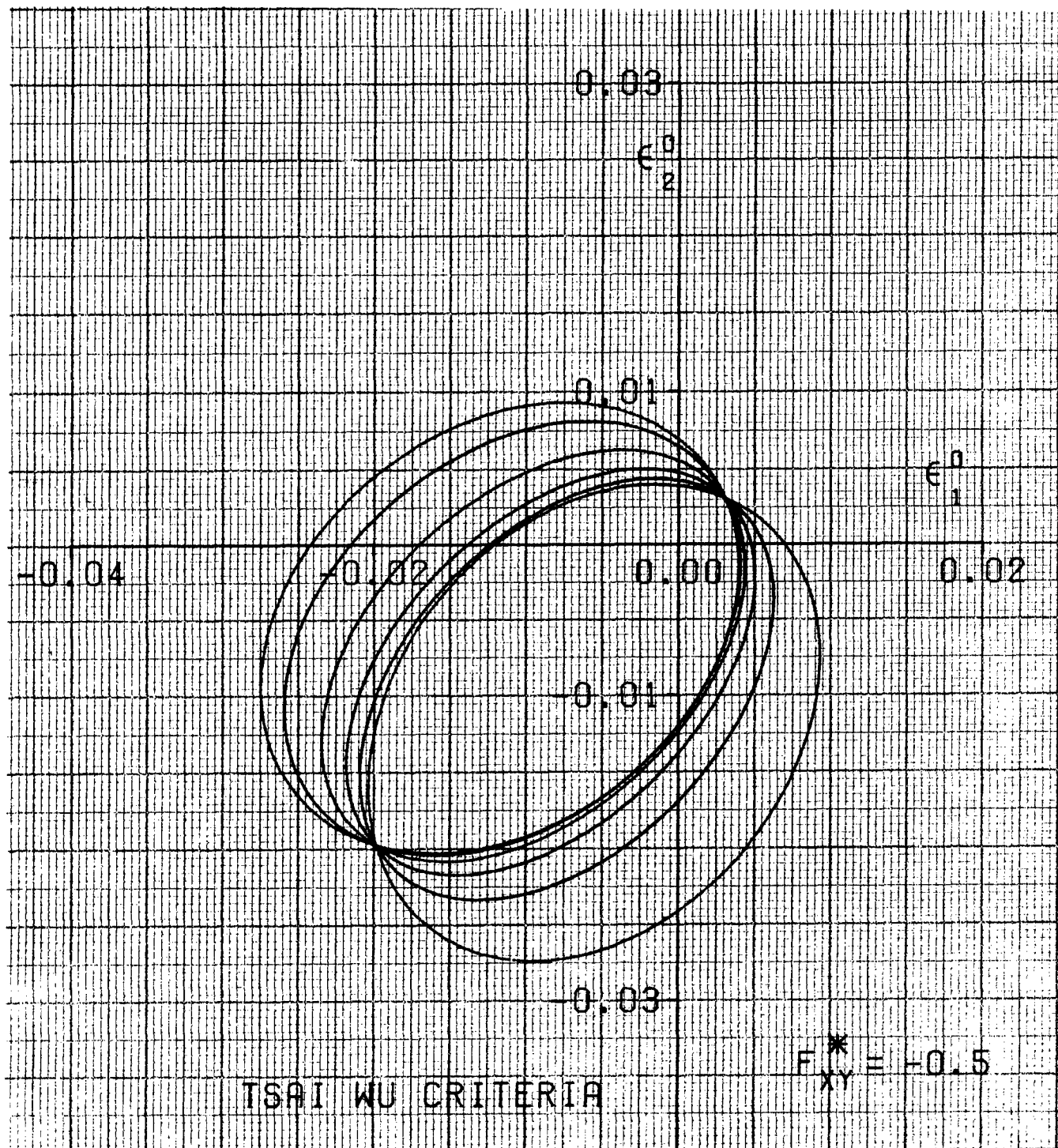


Figure A-11: Failure Envelopes of all the Ply Orientations for Laminate Considered in Figs. A-9, and A-10. Superposition of Figs. A-9 and A-10.

XI. Failure envelopes for $(0/90/+45)_s$ - laminate made of T300/5208 graphite epoxy material on the basis of six failure theories in principal stress and principal strain spaces.

Input data:

```

LAMINATE INPLANE
PURE STRNGTHPLTPLTSTART
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
TSAI WU STRESS -.5
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
TSAI WU STRAIN -.5
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
CHAMIS STRESS -.7
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
CHAMIS STRAIN -.7
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
HOFFMAN STRESS 0.
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
HOFFMAN STRAIN 0.
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208

```

```

$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
HILL STRESS
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
HILL STRAIN
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
MAXSTRAIN STRESS
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
MAXSTRAIN STRAIN
LAMINATE INPLANE
PURE STRNGTHPLTPLTFOLLOW
(0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
MAXSTRESS STRESS
LAMINATE INPLANE
PURE STRNGTHPLTPLTEND
(0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1 $
MAXSTRESS STRAIN
THEEND

```

Output: Figures A-12 through A-23.

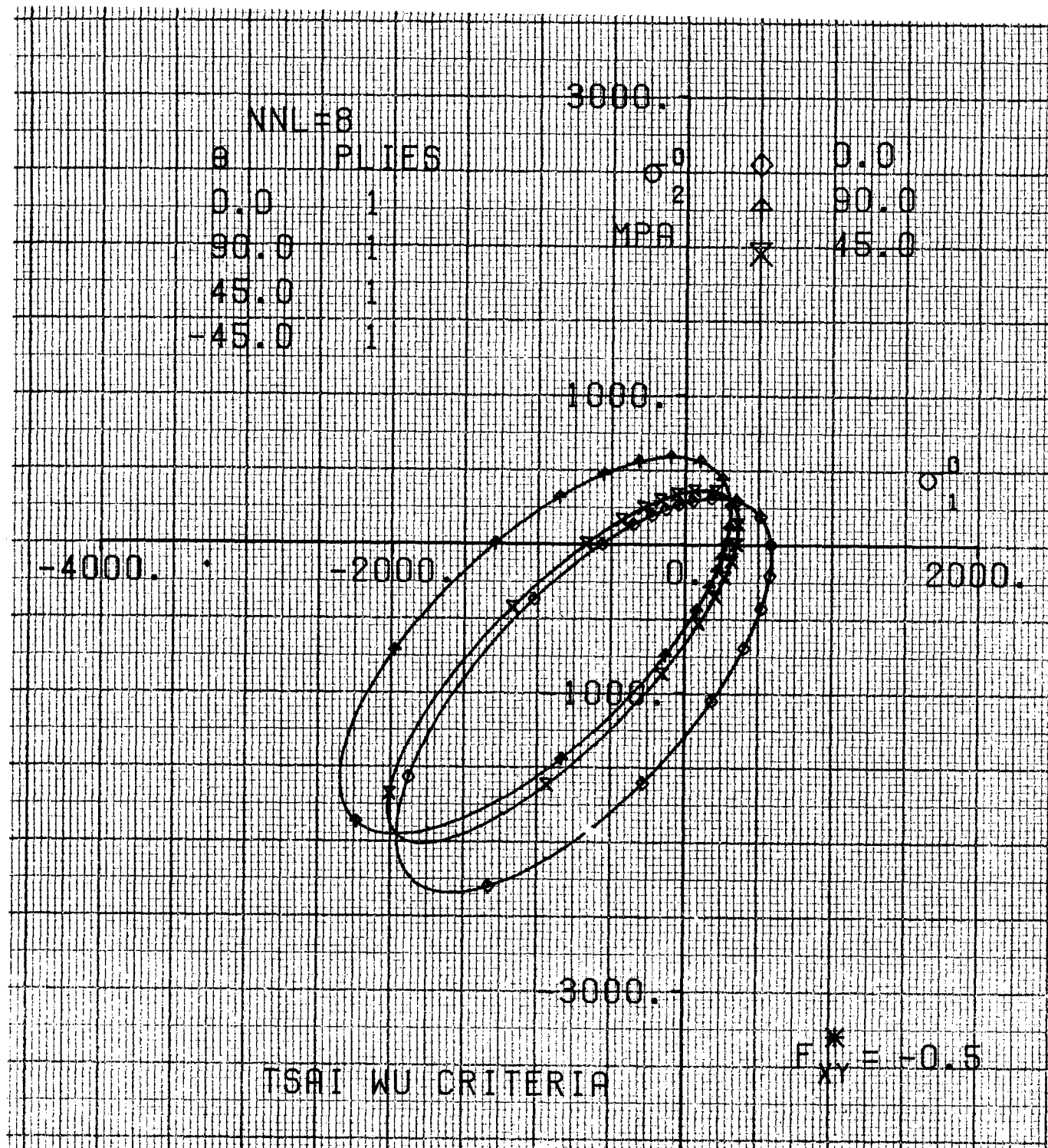


Figure A-12: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Tsai Wu Criterion.

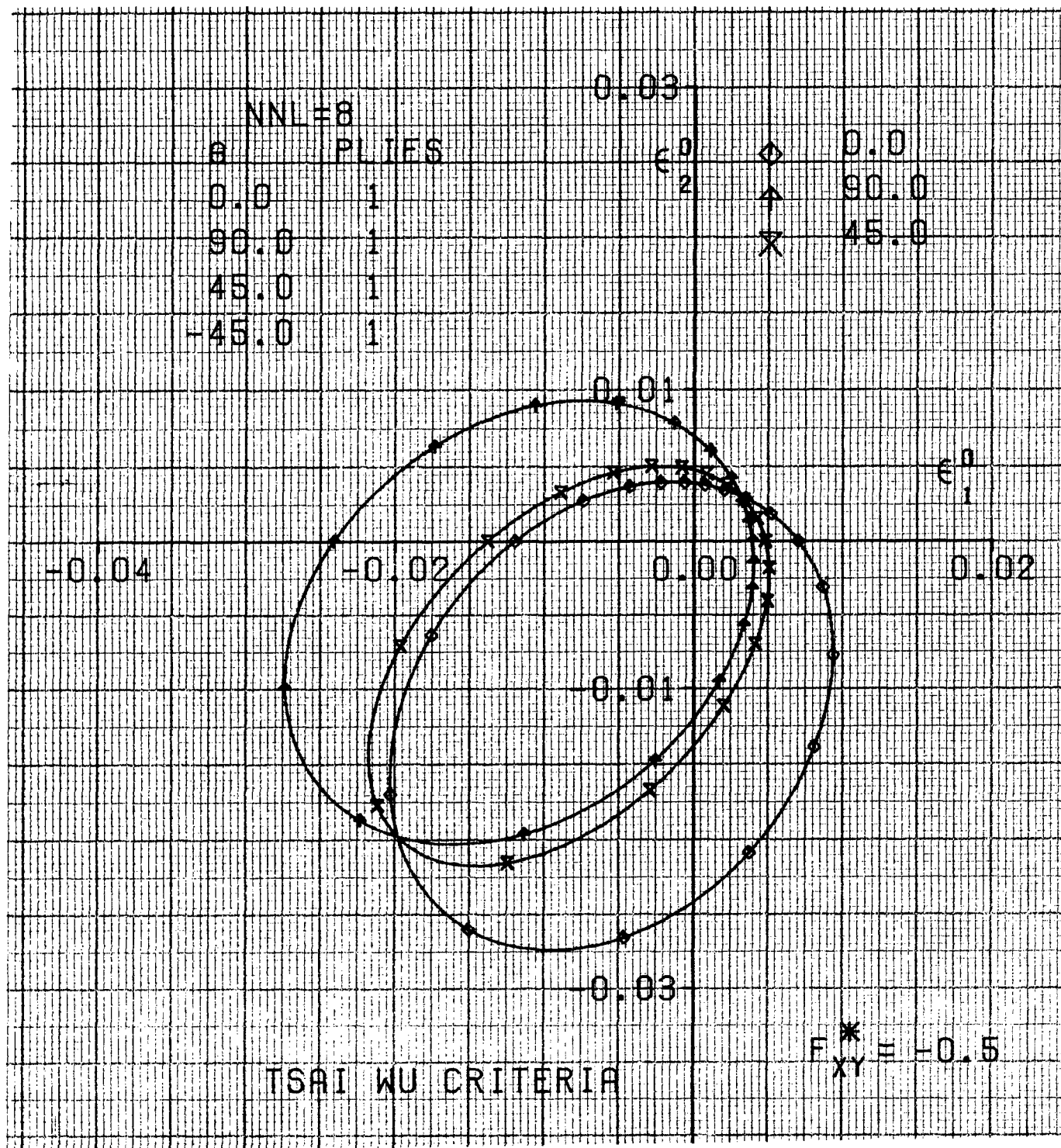


Figure A-13: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Tsai Wu Criterion.

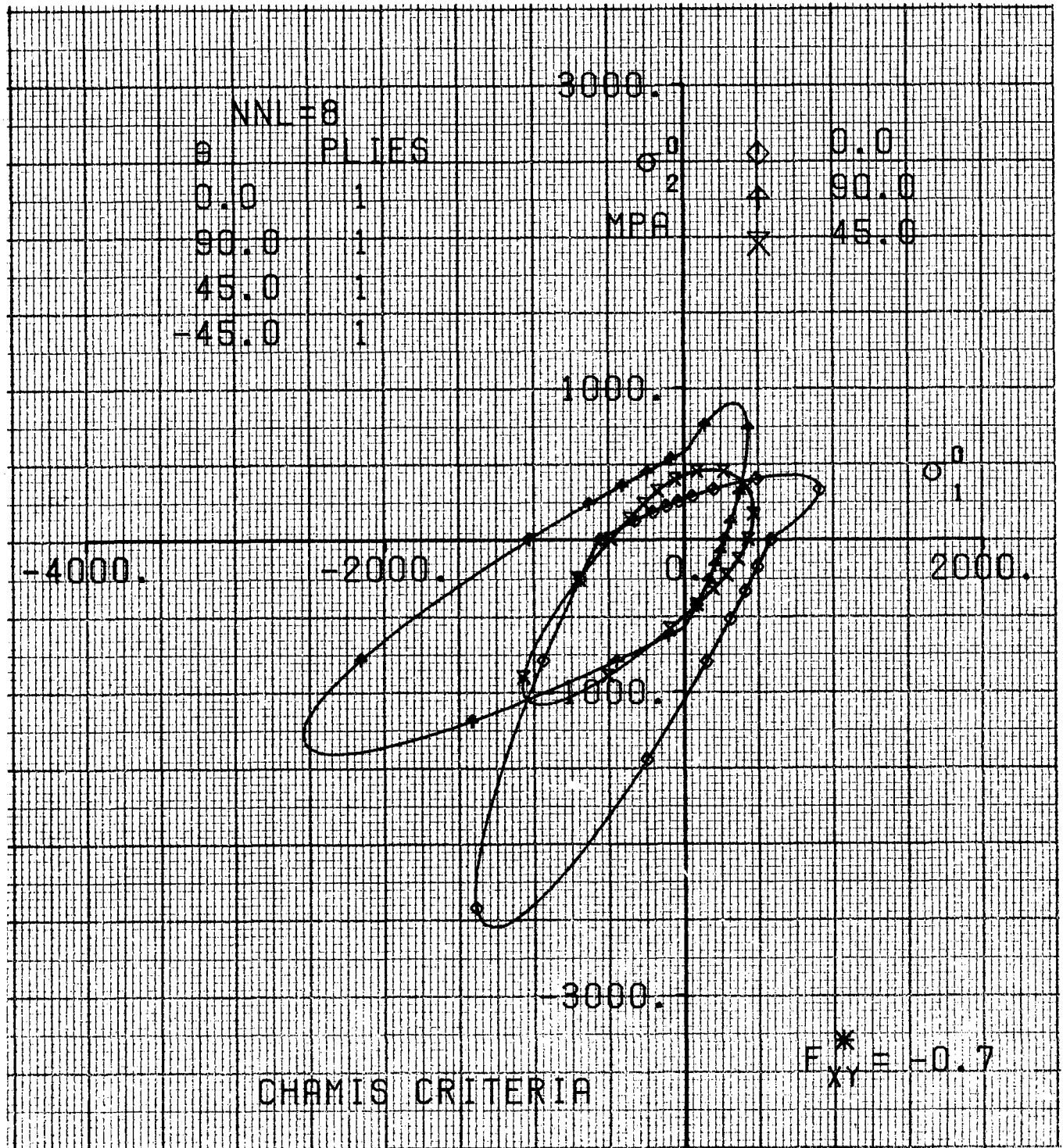


Figure A-14: Failure Envelopes for $(0/90/\pm 45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Chamis Criterion.

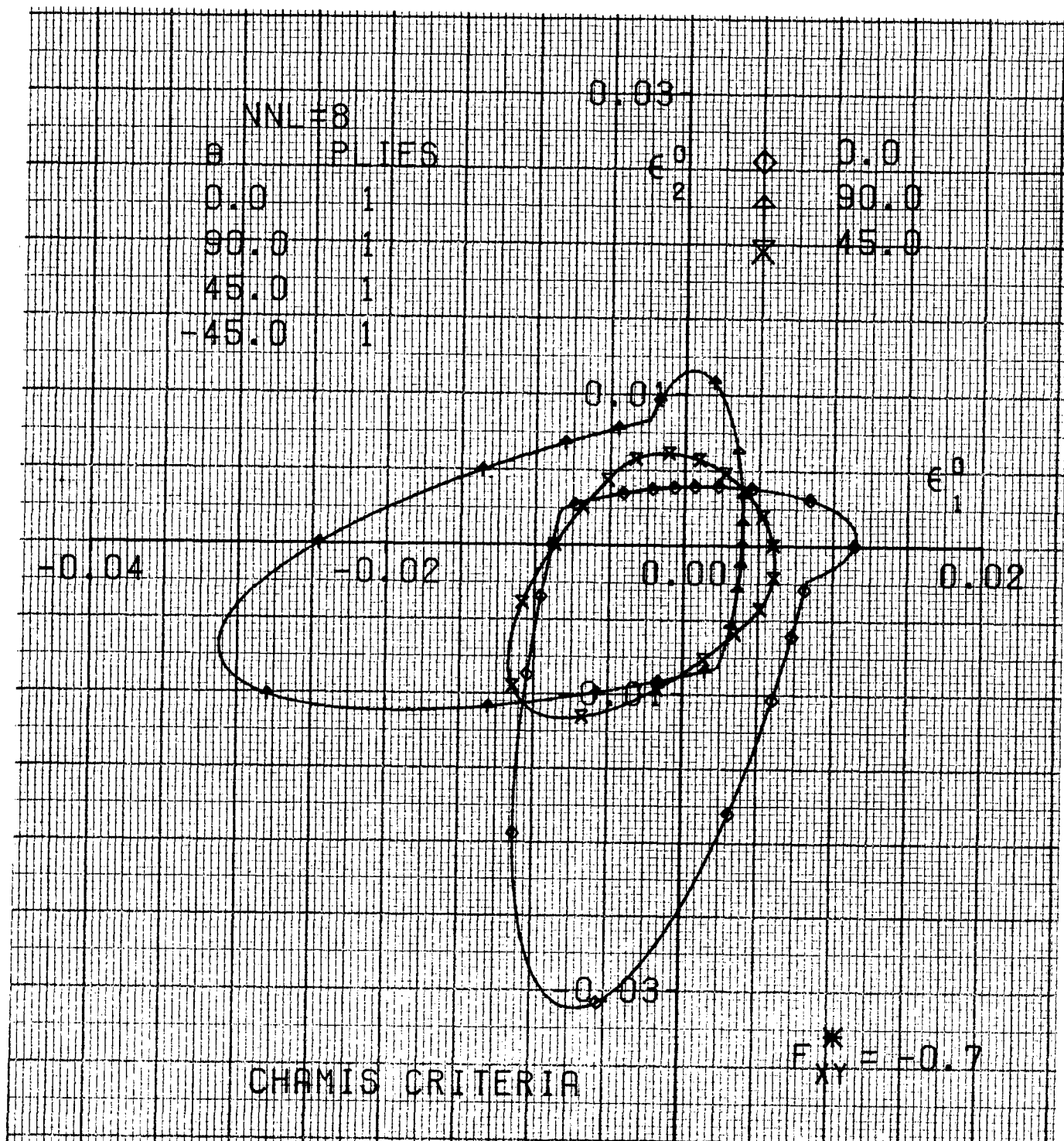


Figure A-15: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Chamis Criterion.

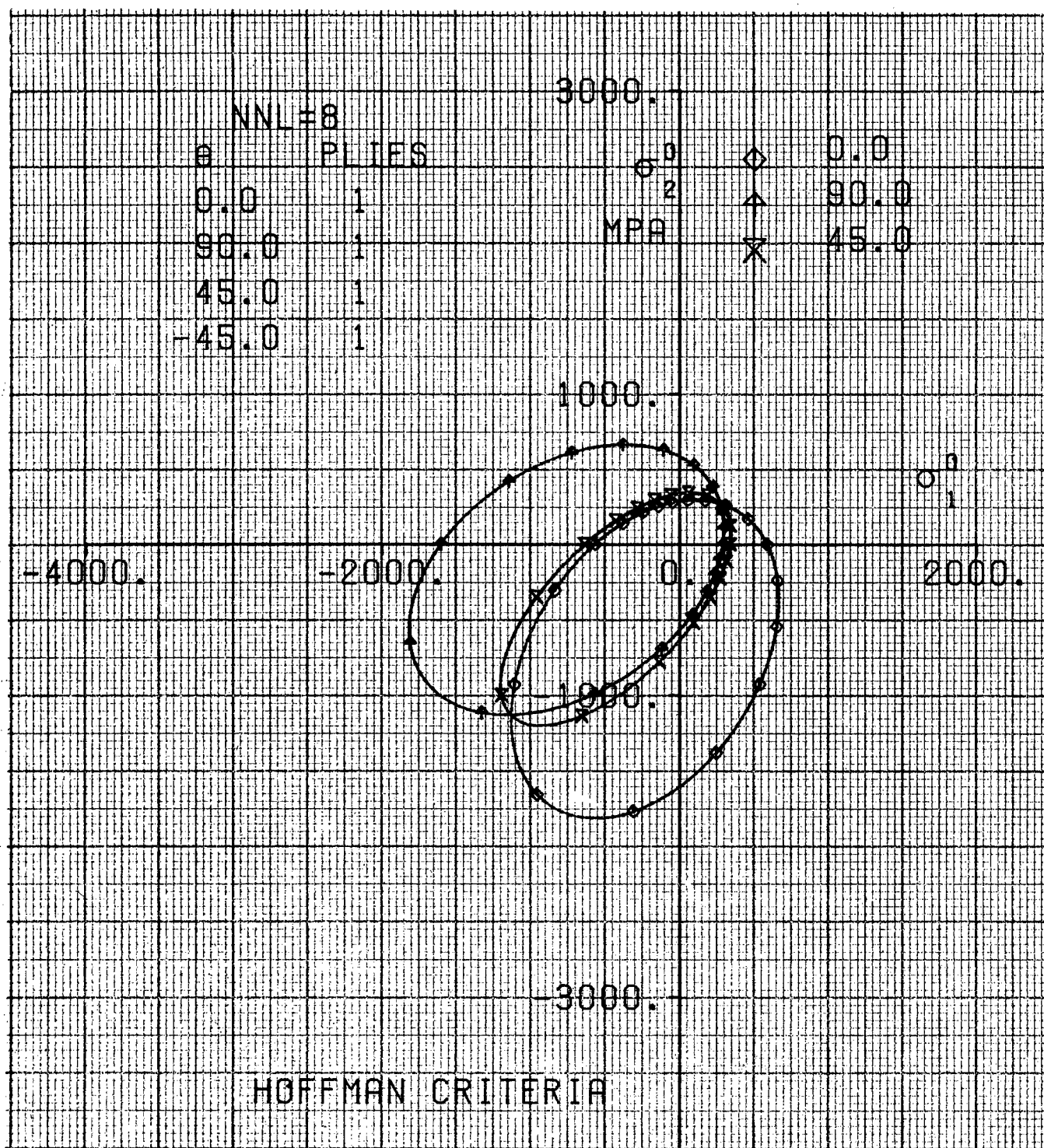


Figure A-16: Failure Envelopes for $(0/90/\pm 45)_8$ - Laminate of T300/5208 Material in Stress Space on the Basis of Hoffman Criterion.

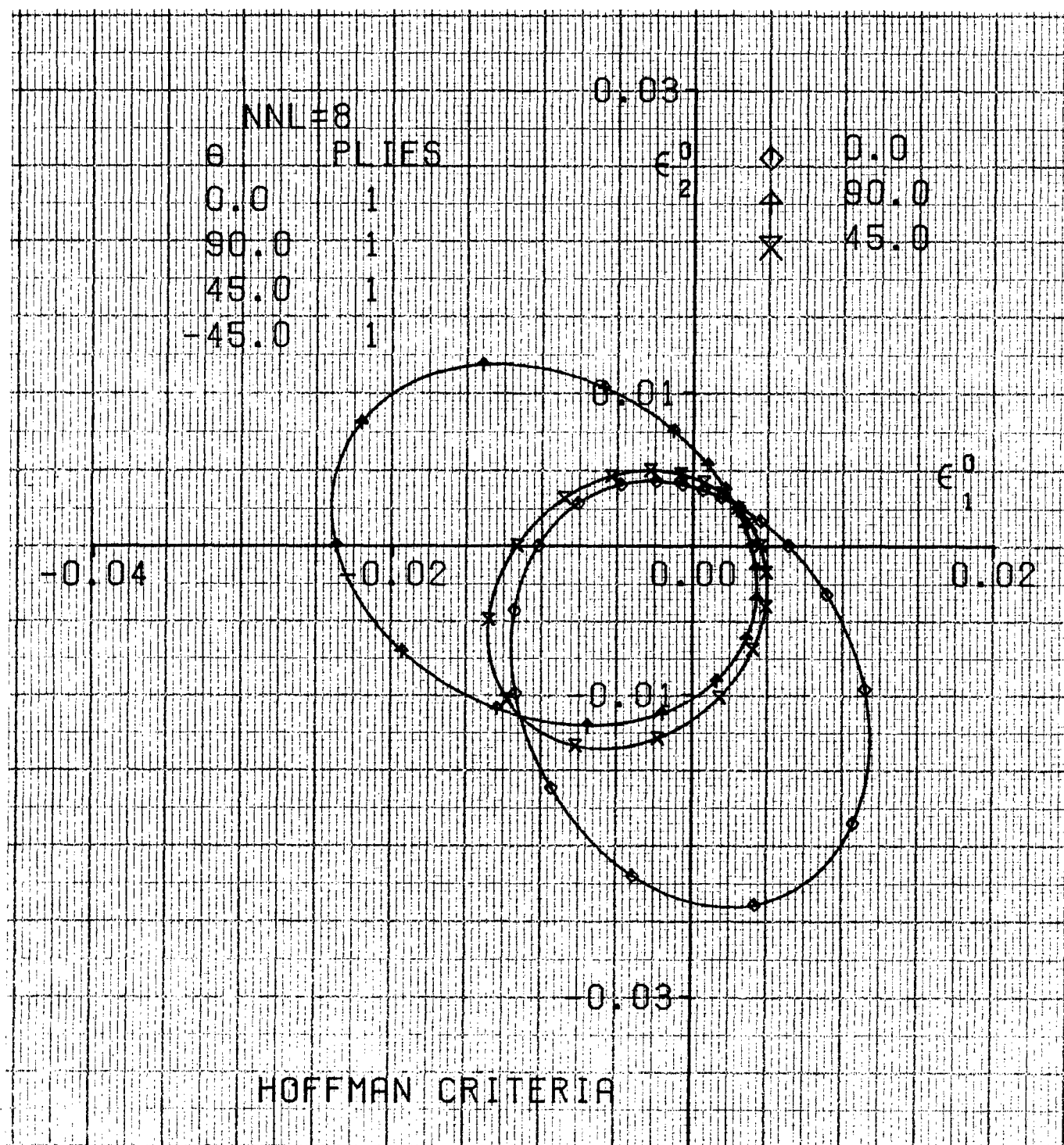


Figure A-17: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Hoffman Criterion.

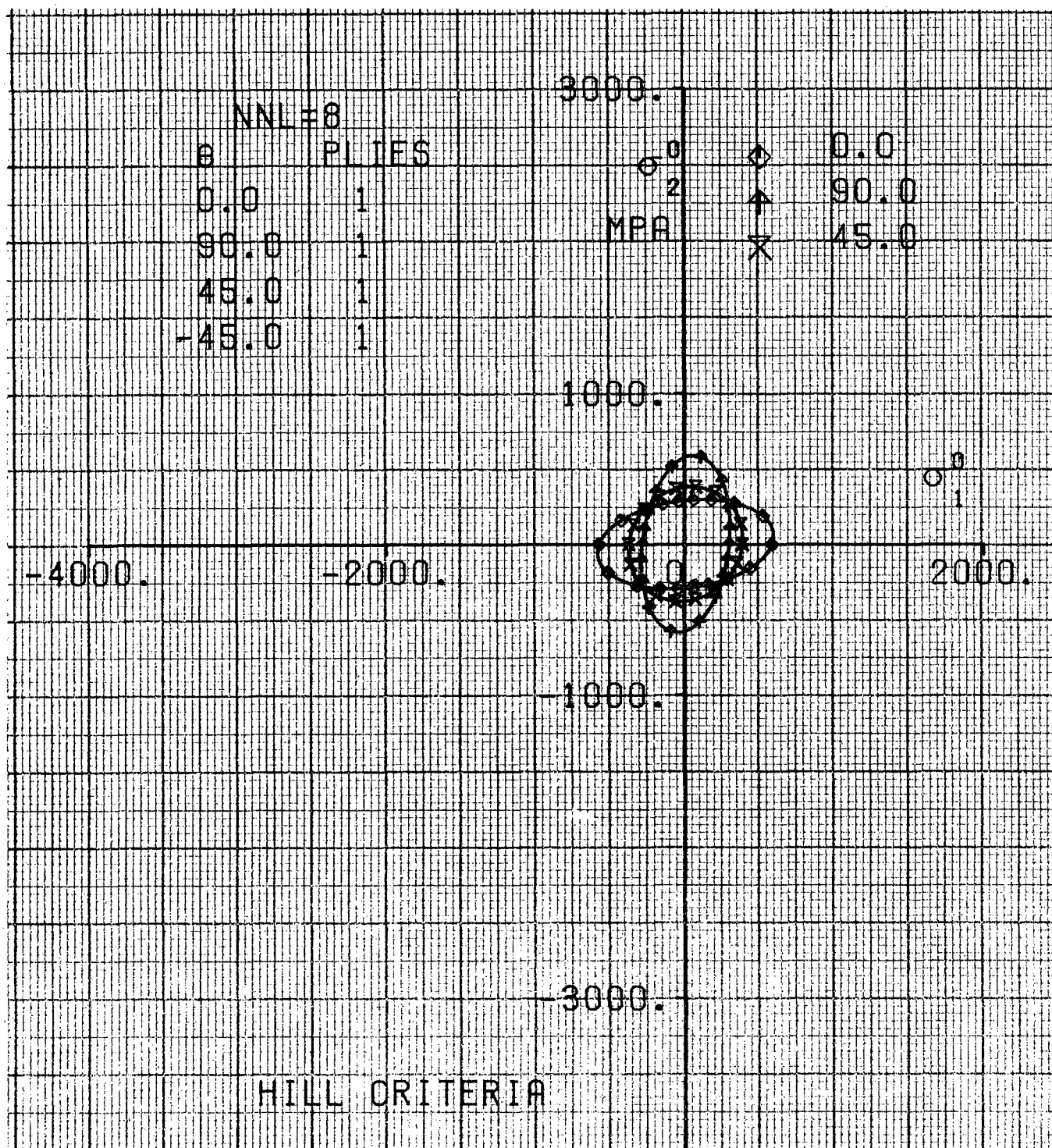


Figure A-18: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion.

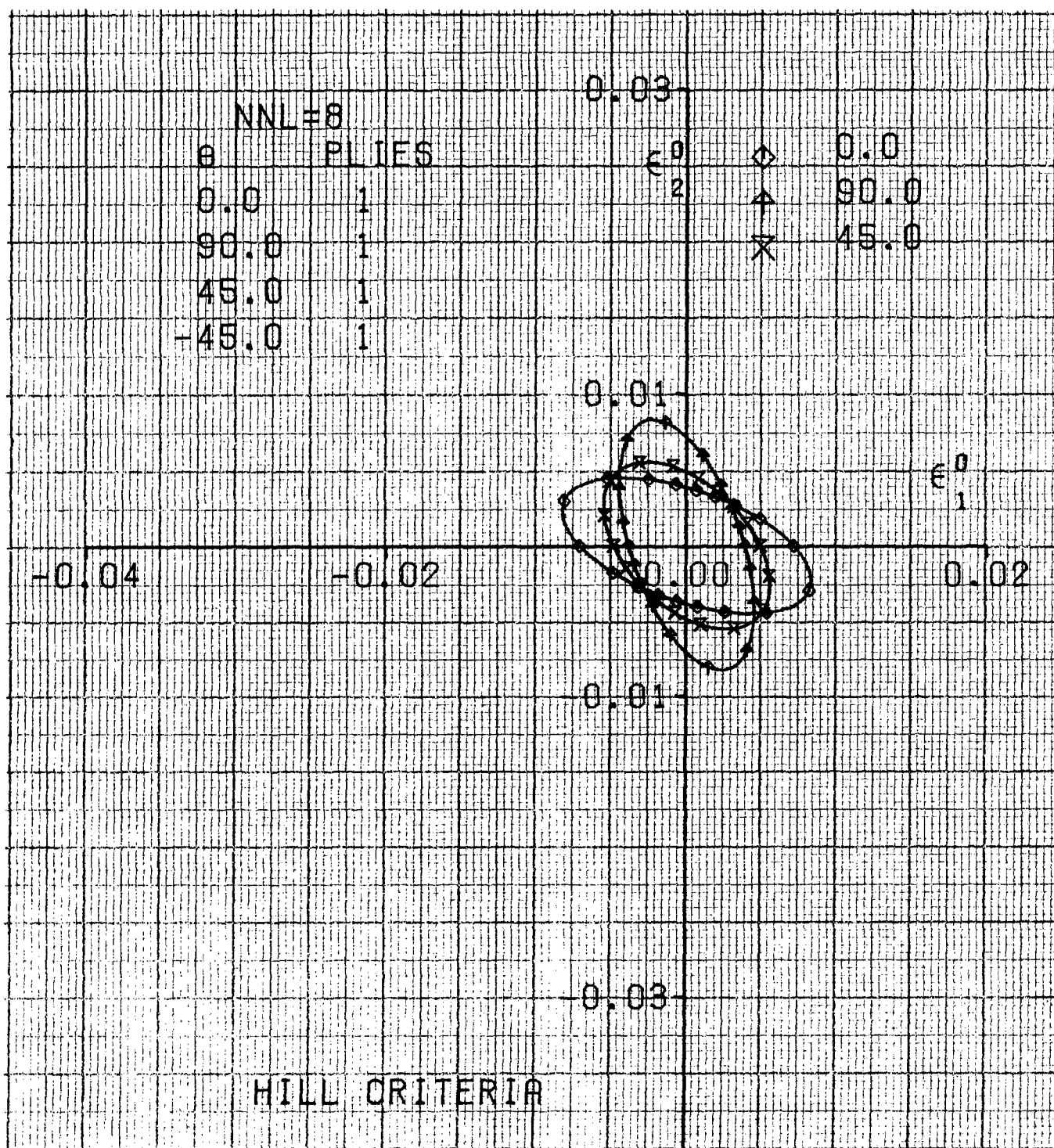


Figure A-19: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Hill Criterion.

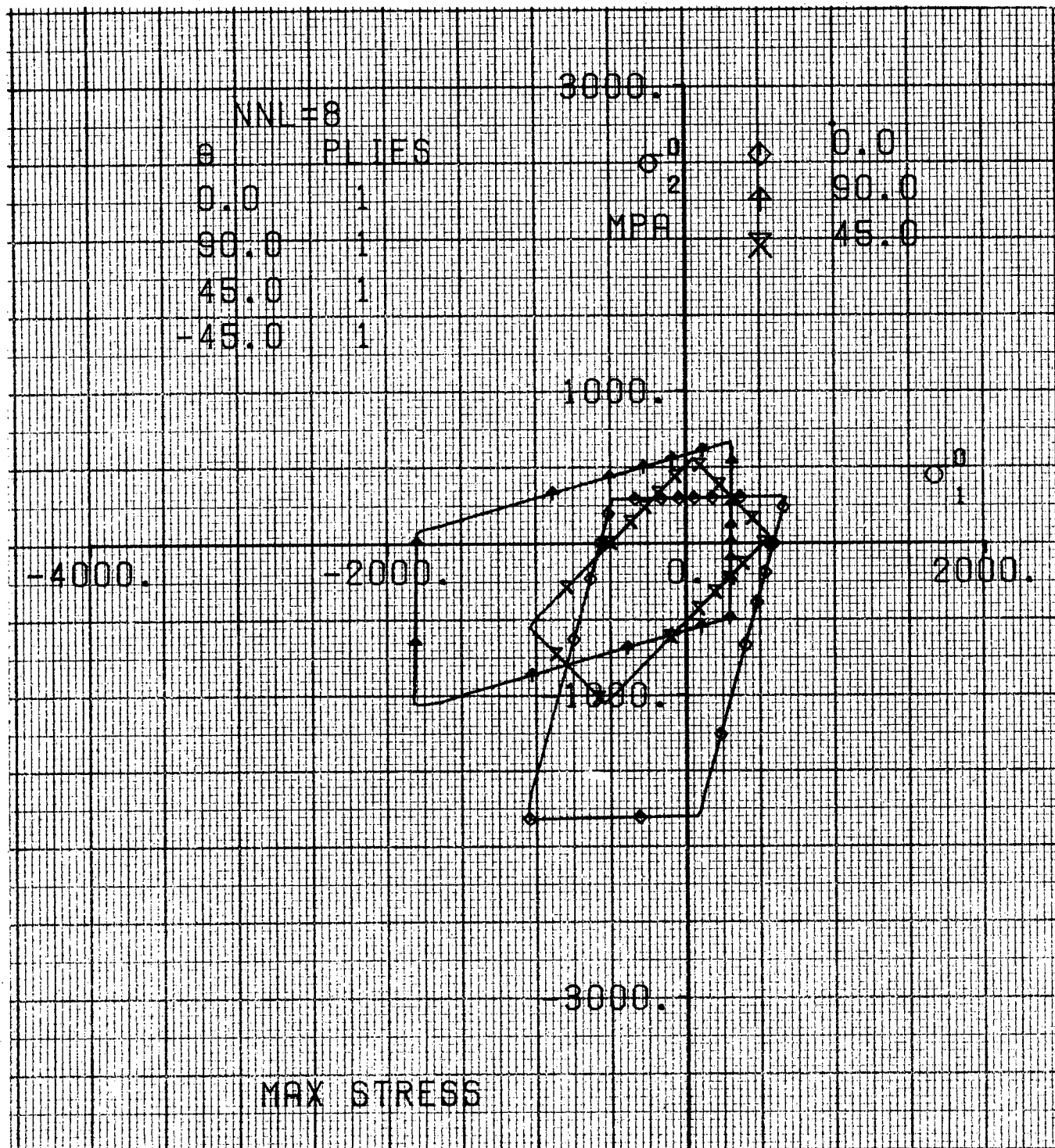


Figure A-20: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Max. Stress Criterion.

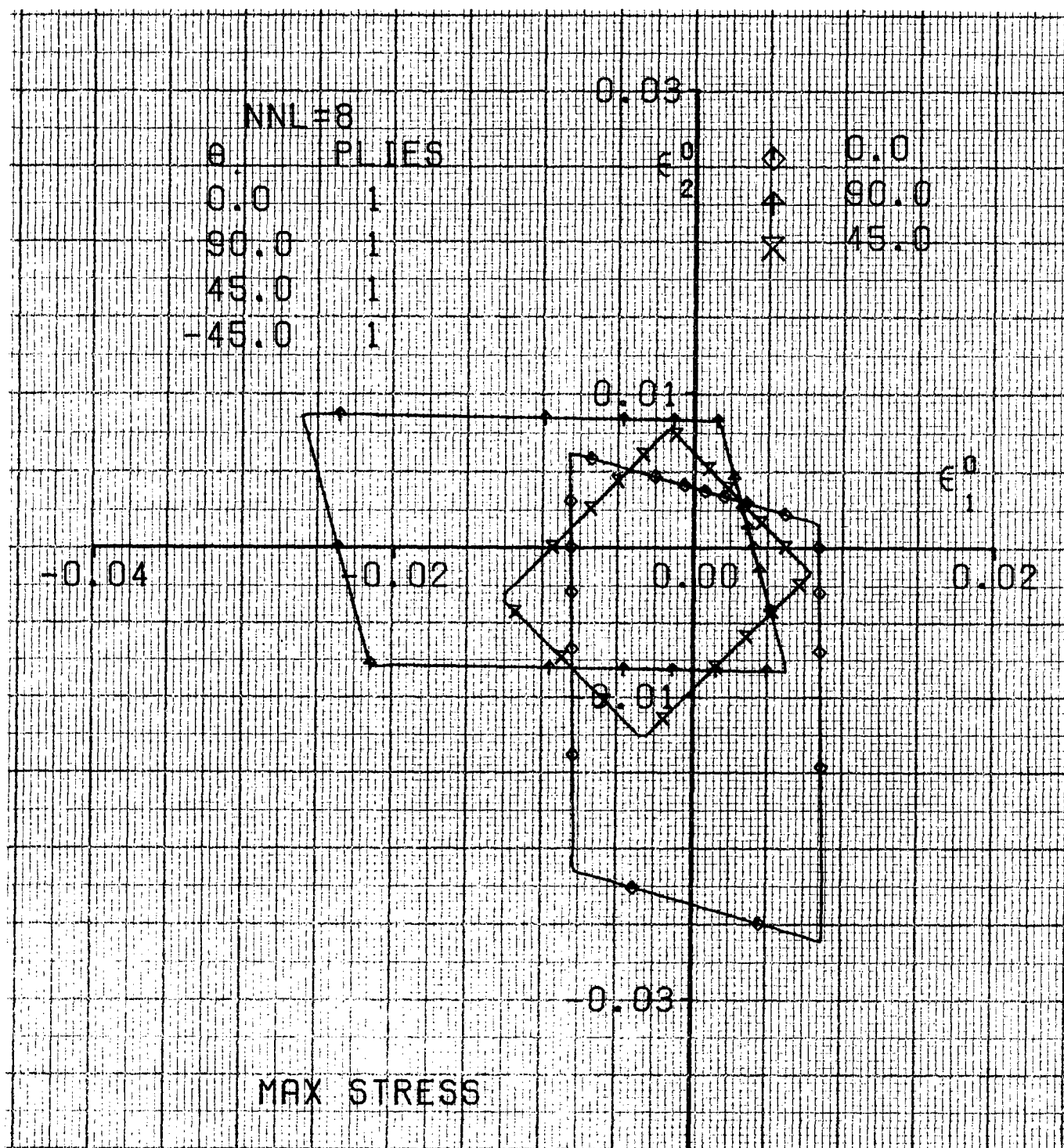


Figure A-21: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Max. Stress Criterion.

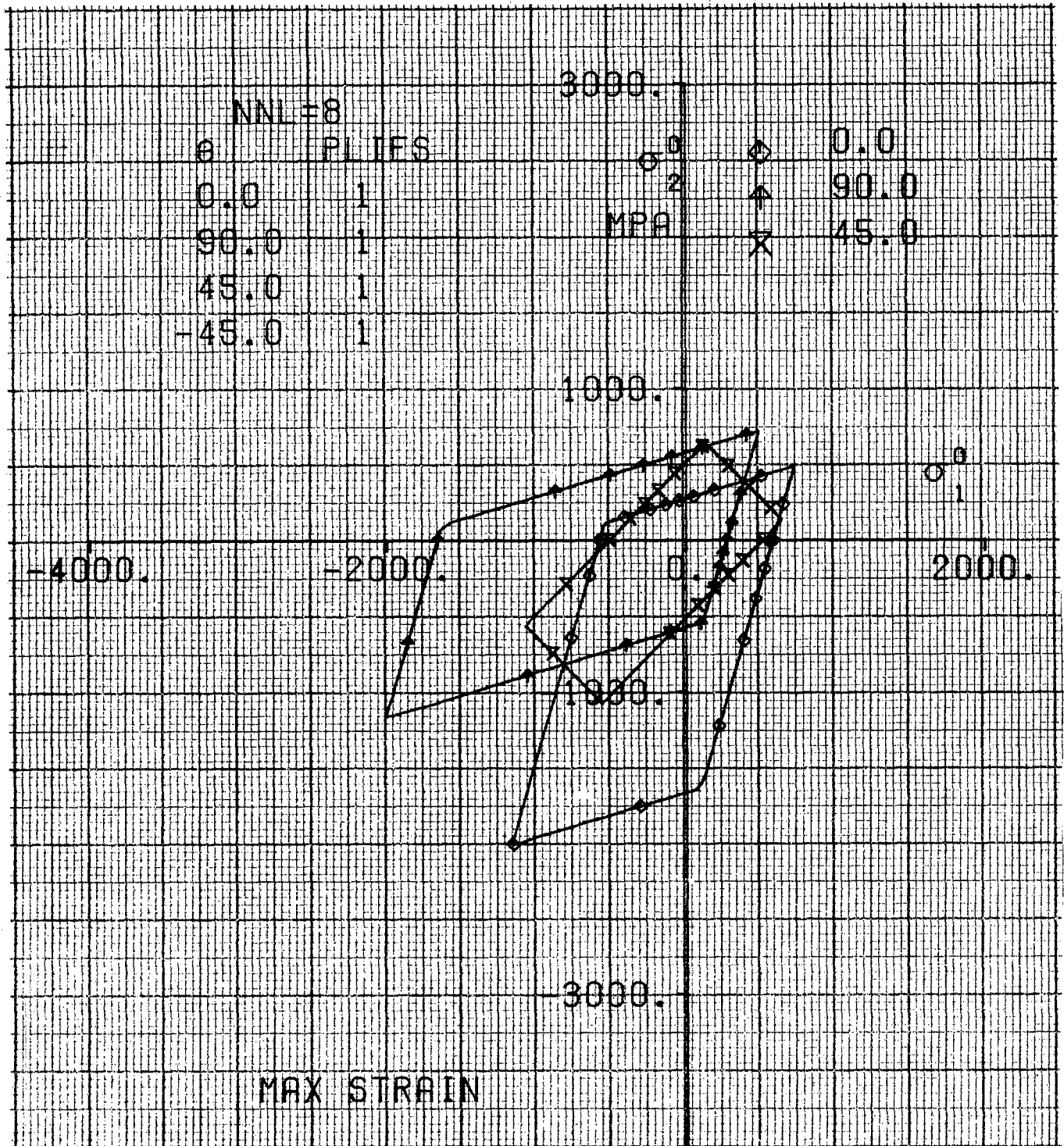


Figure A-22: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Max. Strain Criterion.

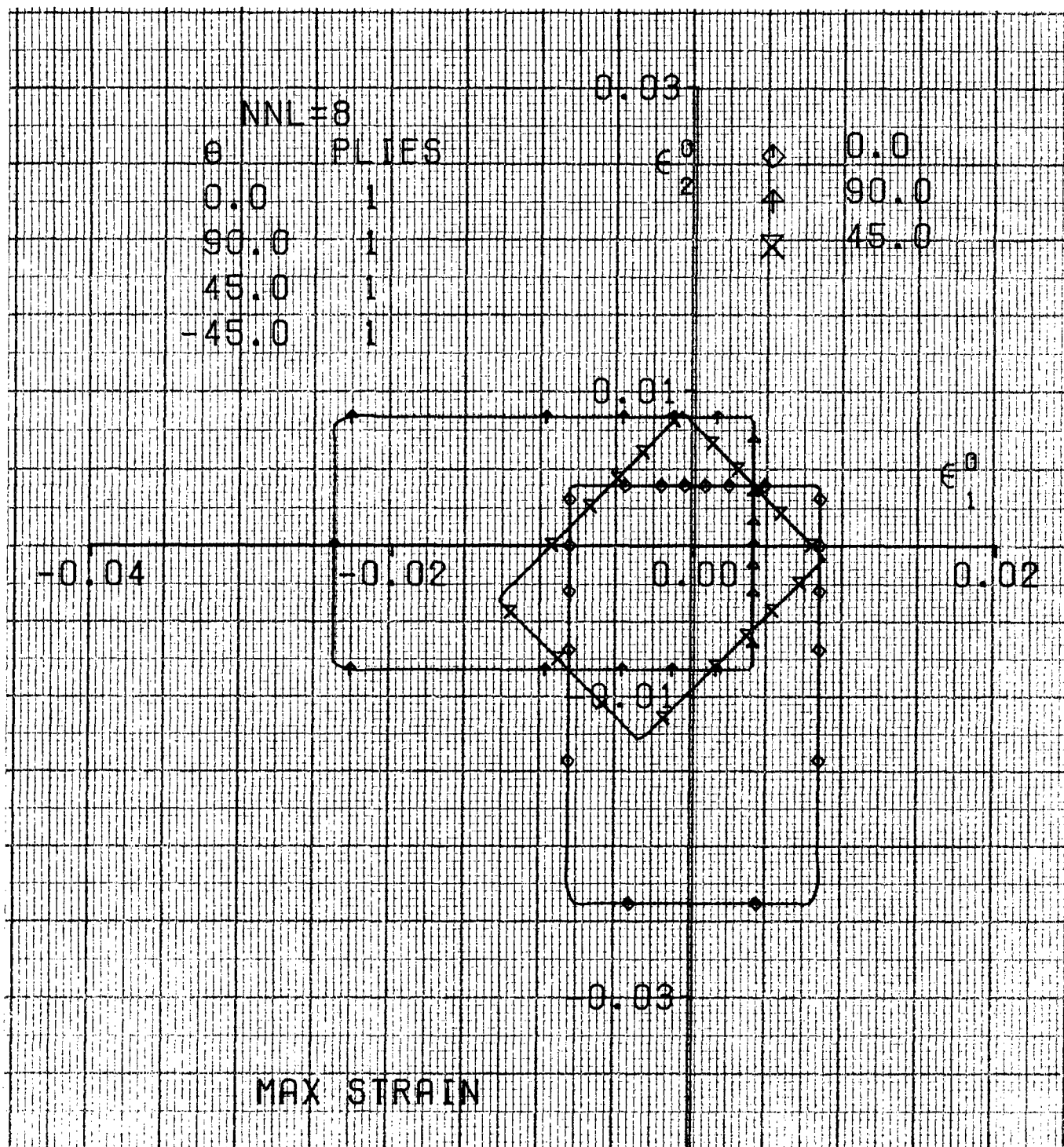


Figure A-23: Failure Envelopes for $(0/90/+45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Max. Strain Criterion.

XIII. Change of Scale:

The scale of the coordinate axis of Figure (A-18) has been reduced to 1/2 by the use of FCTRS.

Input data:

```

LAMINATE  INPLANE
PURE                               STRNGTHPLTPTONE
      (0/90/45/-45) LAMINATE
T300/5208
$LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
NLDCN=1  $
HILL      STRESS
THEEND
```

.5

Output: Figure A-24.

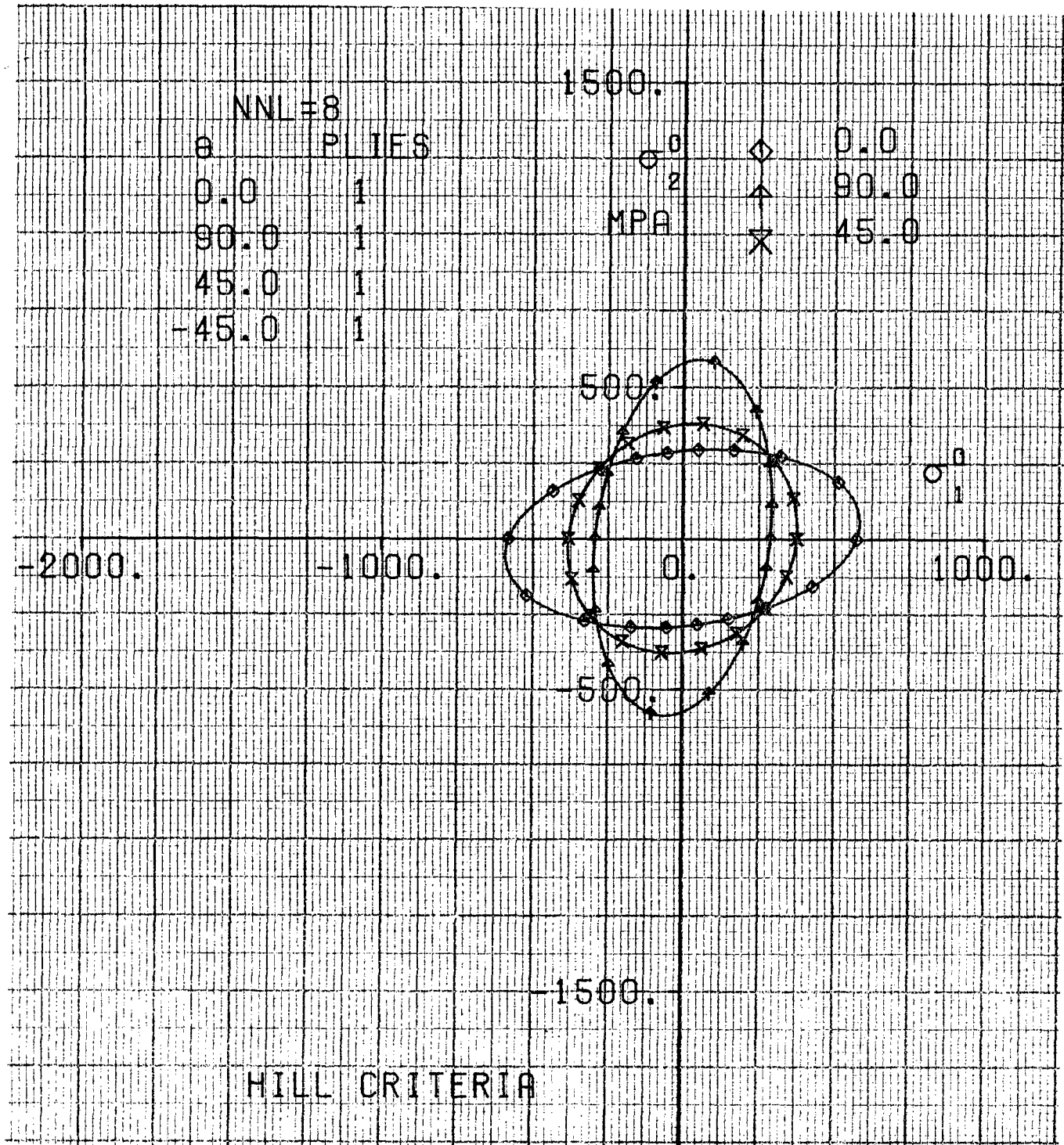


Figure A-24: Failure Envelopes for $(0/90/+45)_s$ Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion. Same Figure as A-18, with Scale Reduced to Half.

XIII. Reduce the size of the Figure A-23 to 75% using FCTRF command.

Input data:

LAMINATE INPLANE
PURE

STRNGTHPLTPTONE

(0/90/45/-45) LAMINATE

T300/5208

\$LAYER>NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNH=8*1.,DT=0.,C=0.,NLDCN=1 \$

HILL STRESS

.5

.75

Output:

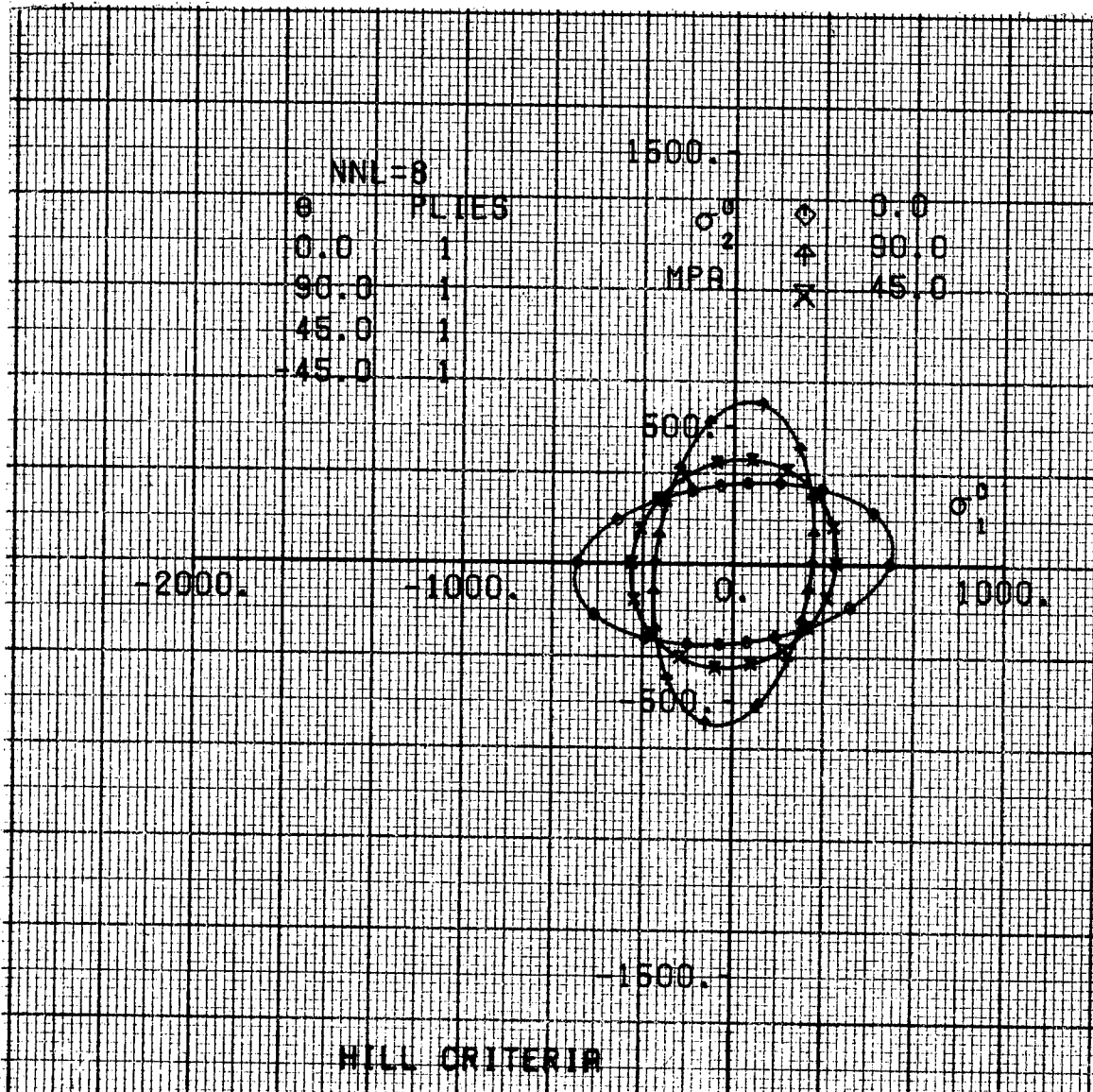


Figure A-25: Failure Envelopes for (0/90/+45)_s - Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion. Figure Size of A-23 Reduced to 75%.

XIV. Failure surfaces for isotropic materials:

1. Isotropic material with $\nu = .5$ and $X' = X$, $Y' = Y$, in principal strain space for $F_{xy}^* = -0.5$
2. Isotropic material with $\nu = 0$, (0.5) and $X' = X$, $Y' = Y$, in principal stress space for $F_{xy}^* = 0$, (-.5).
3. Isotropic material with $\nu = 0$ and $X' = X$, $Y' = Y$, in principal stress space, $F_{xy}^* = -.5$.
4. Isotropic material with $\nu = 0$, (.5) and $X' = 2X$, $Y' = 2Y$, in principal stress space for $F_{xy}^* = -.5$, (0).

Input data:

NEWMTRLS SI

\$LAMDATA NNM=4,EX=4*69.,EY=4*69.,VX=0.,.5,0.,.5,
ES=34.5,23.,34.5,23.,ALFX=4*0.,ALFY=4*0.,BTAX=4*0.,
BTAY=4*0.,X=4*400.,XD=2*400.,2*800.,Y=4*400.,
YD=2*400.,2*800.,S=4*230.,SH=.000125 \$

LAMINATE INPLANE

PURE

STRNGTHPLTPLTSTART

V=.5,X=XD

B4/5505

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRAIN

SUPERPOSE -.5

0.5

LAMINATE INPLANE

PURE

STRNGTHPLTPLTFOLLOW

V=0,X=XD,FSXY=-.5

T300/5208

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRESS

SUPERPOSE -.5

MULTICURV 0.25

LAMINATE INPLANE

PURE

STRNGTHPLTPLTFOLLOW

V=.5,X=XD,FSXY=.0

B4/5505

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRESS

SUPERPOSE 0.0

0.25

LAMINATE INPLANE

PURE

STRNGTHPLTPLTFOLLOW

V=0,X=XD,FSXY=-.5

T300/5208

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRESS

SUPERPOSE -.5

0.25

LAMINATE INPLANE

PURE

STRNGTHPLTPLTFOLLOW

V=0,XD=2X,FSXY=-.5

AS/3501

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRESS

SUPERPOSE -.5

MULTICURV 0.5

LAMINATE INPLANE

PURE

STRNGTHPLTPLTEND

V=.5,XD=2X,FSXY= 0.0

SCOTCHFLY

\$LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1 \$

TSAI WU STRESS

SUPERPOSE 0.0

0.5

THEEND

Output: Figures A-26 through A-29.

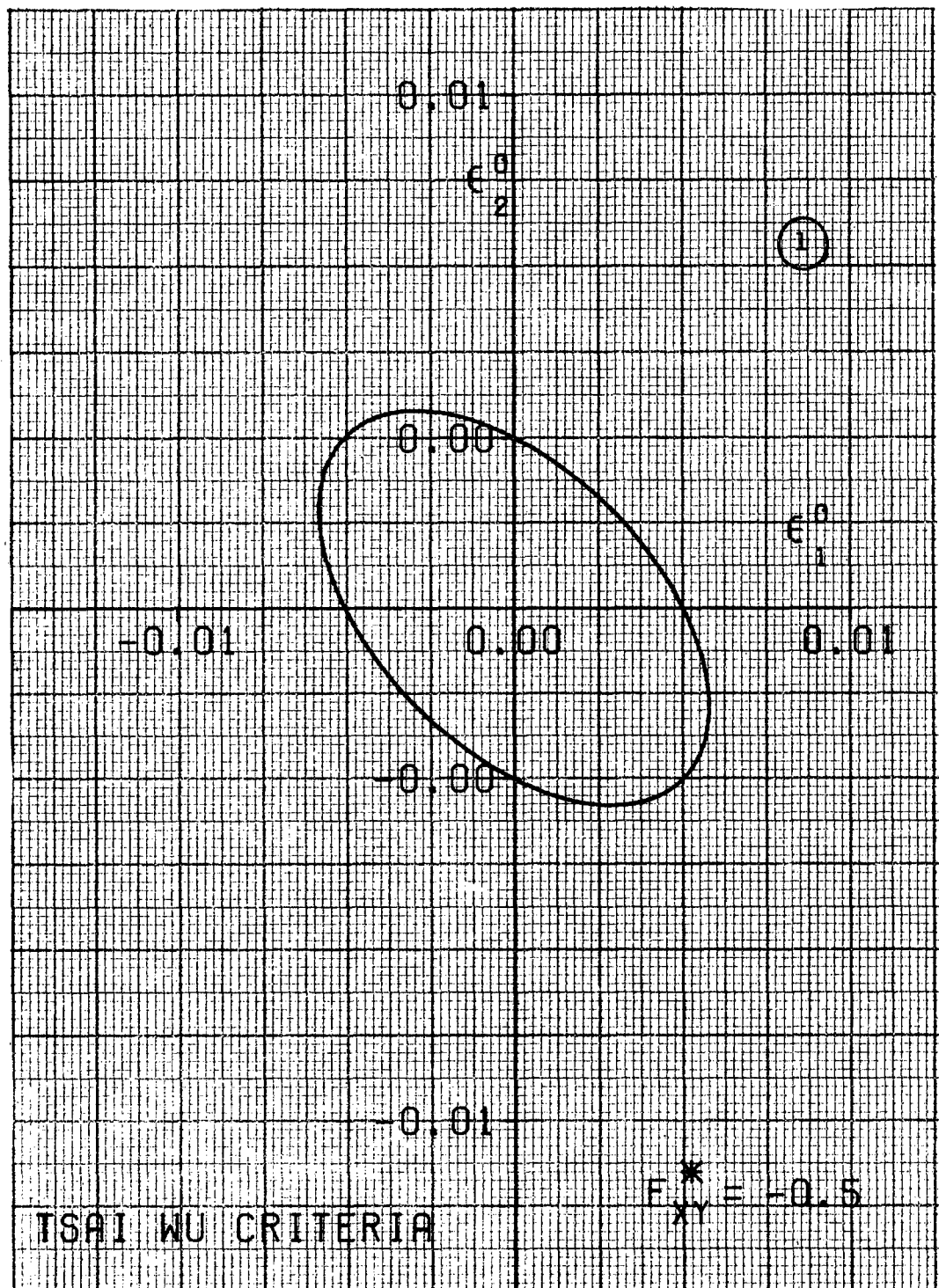


Figure A-26: Failure Surface for an Isotropic Material in Principal Strain Space, $\nu = 0.5$.

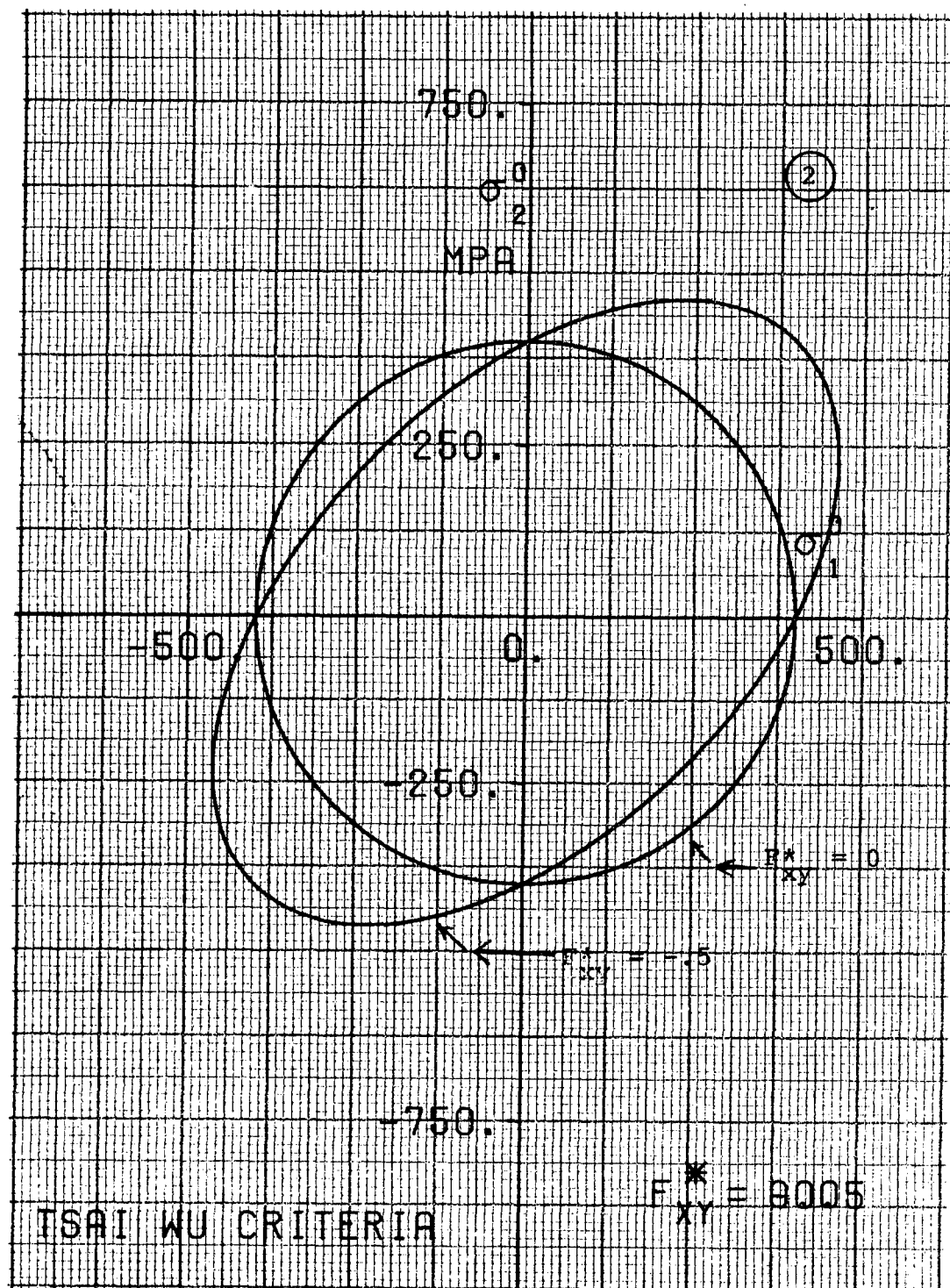


Figure A-27: Failure Surfaces for an Isotropic Material in Principal Stress Space $\nu = 0$ (-.5) and $F^*_{xy} = 0$, (-.5).

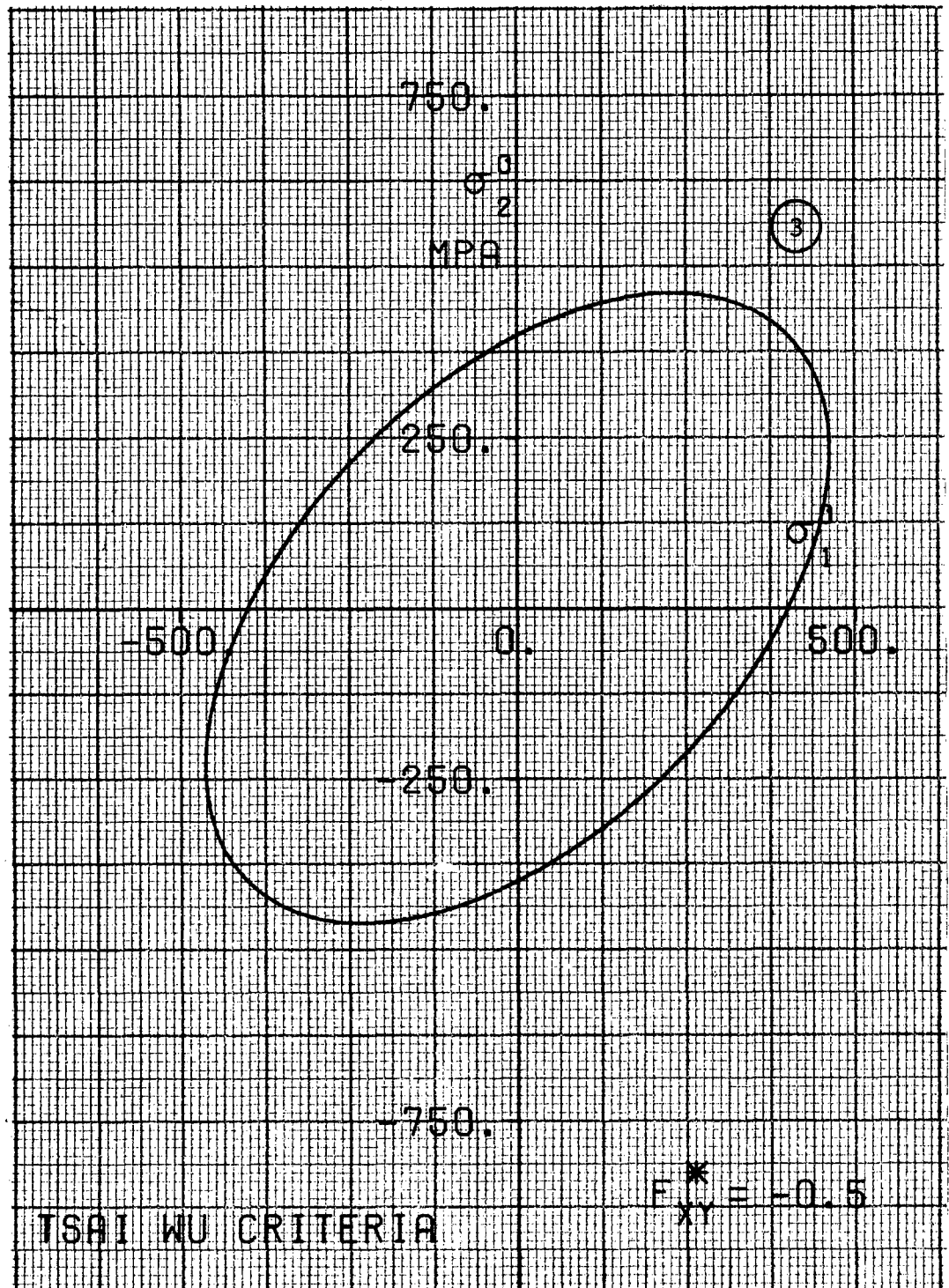


Figure A-28: Failure Surface for an Isotropic Material in Principal Stress Space, $\nu = 0$.

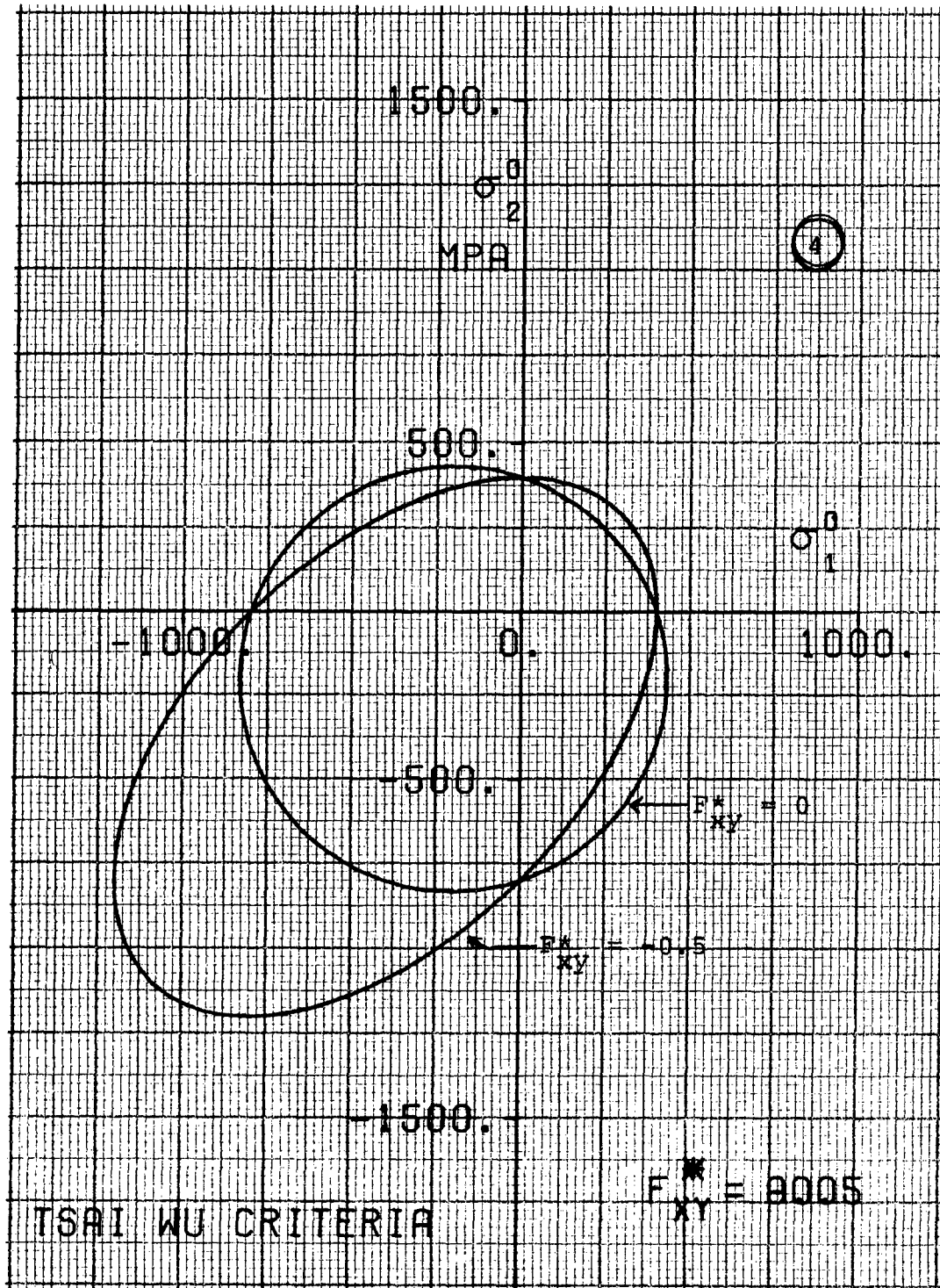


Figure A-29: Failure Surfaces for an Isotropic Material with $\nu = 0, (.5)$, $X' = 2X$, $Y' = 2Y$ in Principal Stress Space for $F^*_{xy} = 0, (-.5)$.

APPENDIX B

CURRENT AFWAL/MLBM LAMINATE PROGRAMS

MAY 1983

	SYMMETRIC ONLY	BALANCED ONLY	IN-PLANE STIFFNESS	FLEXURAL STIFFNESS	LAMINATE STRENGTH	THERMAL EFFECT	HYGROSCOPIC EFFECT	HARDCOPY MEDIUM	STORAGE MEDIUM	OPTIMIZATION (SIZING)	SANDWICH CORE	HYBRID MATERIALS
FORTRAN (CDC)			X	X	1,2	X	X	4	10		X	X
TI CC-40	X		16	16	16			16	16	14,15	16	
TI-59 W/ COMBO CARDS	X		X	X	1			5	11		X	14
APPLE II *			X	X	1,3	X	X	6	12		X	
TIMEX 1000 (+16K)	X							7	13	14		
TRS-80 PC-1	X		X	X	1			5	13		X	
SHARP PC-1500 (+8K)	X		X	X	1			5,8	13		X	
EPSON HX-20	X		X	X	1			8,9	13	14	X	
PANASONIC HHC (4K)	X		X	X	1			5			X	

- | | |
|---|--|
| <ol style="list-style-type: none"> 1. QUADRATIC (TSAI-WU) FAILURE CRITERION 2. REPORT IN PROGRESS INCLUDES ADDITIONAL FAILURE CRITERIA: <ol style="list-style-type: none"> a. CHAMIS b. HOFFMAN c. HILL d. MAX STRESS e. MAX STRAIN 3. MAX STRAIN FAILURE CRITERION 4. LINE PRINTER AND CALCOMP FAILURE SURFACE PLOTS 5. PRINTING CRADLE 6. 80 COLUMN PRINTER | <ol style="list-style-type: none"> 7. TIMEX/SINCLAIR COMPATIBLE PRINTERS 8. ALSO PLOTS FAILURE SURFACES 9. BUILT-IN PRINTER 10. PUNCHED CARDS/MAG. TAPE 11. REQUIRES CUSTOM AFWAL/MLBM ROM MODULE AND MAG. CARDS 12. 5 1/4" DISK 13. AUDIO CASSETTE TAPE 14. IN-PLANE LOADS ONLY 15. BALANCED LAMINATES ONLY 16. PROGRAMMING IN PROGRESS |
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* ALSO AVAILABLE ARE DISKS CONTAINING PROGRAMS TO ANALYZE BEAMS, SHAFTS, PRESSURE VESSELS, MOISTURE ABSORPTION AND DESORPTION, CURING OF EPOXY-MATRIX COMPOSITES, AND LIFE PREDICTION (COMING SOON).

CURRENT AFWAL/MLBM LAMINATE PROGRAMS DOCUMENTATION

<u>Machine</u>	<u>Title</u>	<u>Report No.</u>
Fortran (CDC)	"A Digital Algorithm for Composite Laminate Analysis - Fortran", S. Soni	AFWAL-TR-81-4073
TI CC-40	Report in Progress	
TI-59 w/Combo Cards	"Revised Instructions for TI-59 Combined Card/Module Calculations for In-Plane and Flexural Properties of Symmetric Laminates", S. Donaldson	AFWAL-TR-82-4081 AFWAL-TR-81-4183 (Hybrid)
Apple II	"An Apple Computer Program for the Analysis of Composite Laminates", H. Chai	AFWAL-TR-83-4041
Timex/Sinclair 1000	"Composite Laminate Weight Optimization on the Timex-Sinclair 1000 Microcomputer", G. Flanagan	AFWAL-TR-83-4017
TRS-80 PC-1	"Radio Shack TRS-80 Pocket Computer Solutions to Composite Materials Formulas", W. Park and T. Massard	AFWAL-TR-81-4074
Sharp PC-1500	"Sharp PC-1500 Pocket Computer Solutions to Composite Materials Formulas", W. Park and T. Massard	AFWAL-TR-83-4016
Epson HX-20	Report in Progress	
Panasonic HHC	Report in Progress	