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VOLUME 3

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# EFFECT OF VARIANCES AND MANUFACTURING TOLERANCES ON THE DESIGN STRENGTH AND LIFE OF MECHANICALLY FASTENED COMPOSITE JOINTS

## VOLUME 3 - BOLTED JOINT STRESS FIELD MODEL (BJSFM) COMPUTER PROGRAM USER'S MANUAL

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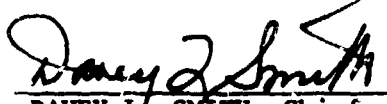
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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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

  
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The subject of this program was structural evaluation of mechanically fastened composite joints. Program objectives were threefold: (1) development and verification by test of improved static strength methodology, (2) experimental evaluation of the effects of manufacturing anomalies on joint static strength, and (3) experimental evaluation of joint fatigue life.			

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Program activities to accomplish these objectives were organized under five tasks. Under Task 1 - Literature Survey, a survey was performed to determine the state-of-the-art in design and analysis of bolted composite joints. Experimental evaluations of joint static strength were performed under Tasks 2 and 3. In Task 2 - Evaluation of Joint Design Variables, strength data were obtained through an experimental program to evaluate the effects of twelve joint design variables. In Task 3 - Evaluation of Manufacturing and Service Anomalies, effects of seven anomalies on joint strength were evaluated experimentally and compared with Task 2 strength data. Bolted composite joint durability was evaluated under Task 4 - Evaluation of Critical Joint Design Variables on Fatigue Life. Seven critical design variables or manufacturing anomalies were identified based on Task 2 and 3 strength data. Under Task 5 - Final Analyses and Correlation, required data reduction, methodology development and correlation, and necessary documentation were performed.

This report documents all program activities performed under Tasks 2, 3, 4 and 5. Activities performed under Task 1 - Literature Survey, were previously reported on AFFDL-TR-78-179. Static strength methodology and evaluations of joint static and fatigue test data are reported. Analytic studies complement methodology development and illustrate: the need for detailed stress analysis, the utility of the developed "Bolted Joint Stress Field Model" (BJSFM) procedure, and define model limitations. For static strength data, correlations with analytic predictions are included. Data trends in all cases are discussed relative to joint strength and failure mode. For joint fatigue studies, data trends are discussed relative to life, hole elongation, and failure mode behavior. *Z*

This final report is organized in the following three volumes:

- Volume 1 - Methodology Development and Data Evaluation
- Volume 2 - Test Data, Equipment and Procedures
- Volume 3 - Bolted Joint Stress Field Model (BJSFM) Computer Program User's Manual

FOREWORD

The work reported herein was performed by the McDonnell Aircraft Company (MCAIR) of the McDonnell Douglas Corporation (MDC), St. Louis, Missouri, under Air Force Contract F33615-77-C-3140, for the Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. This effort was conducted under Project No. 2401 "Structural Mechanics", Task 240101 "Structural Integrity for Military Aerospace Vehicles", Work Unit 24010110 "Effect of Variances and Manufacturing Tolerances on the Design Strength and Life of Mechanically Fastened Composite Joints". The Air Force Project Engineer at contract go-ahead was Mr. Roger J. Aschenbrenner (AFWAL/FIBEC); in December 1979, Capt. Robert L. Gallo (AFWAL/FIBEC) assumed this assignment. The work described was conducted during the period 15 February 1978 through 15 April 1981.

Program Manager was Mr. Ramon A. Garrett, Branch Chief Technology, MCAIR Structural Research Department. Principal Investigator was Mr. Samuel P. Garbo, MCAIR Structural Research Department.

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## SECTION I

### INTRODUCTION

One objective of this program was to develop a static strength methodology for mechanically-fastened composite joints. This volume documents user-options and instructions for a computer program to analyze the effects of stress concentrations on laminate strength. Entitled "Bolted Joint Stress Field Model" (BJSFM), it computes stress distributions on a lamina or laminate basis for unloaded or loaded (bolt bearing) holes in isotropic or anisotropic materials. Failure predictions based on lamina properties and one of several failure criteria are possible. This volume describes the formulation and input data requirements and output options. Sample problems and a computer program listing are also included.



## SECTION II

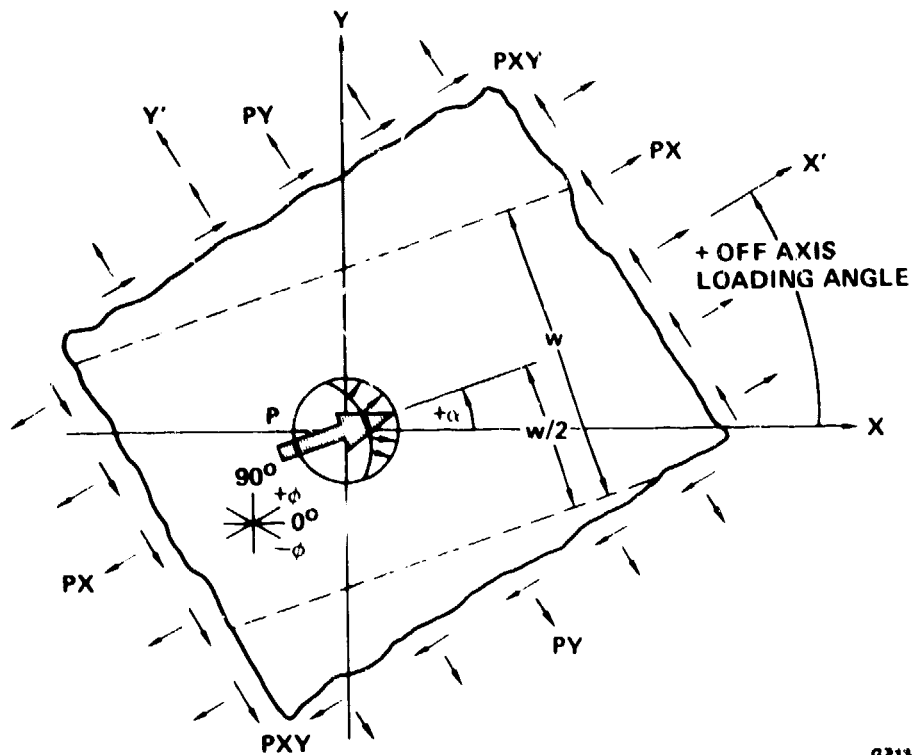
### PROGRAM DESCRIPTION

The Bolted Joint Stress Field Model has been developed to facilitate strength analysis of isotropic or anisotropic materials at individual fastener holes. Static strength of an anisotropic laminate with a fastener hole is predicted using a closed-form analytic approach based on (1) elastic anisotropic theory of elasticity, (2) lamination plate theory and (3) one of several optional failure hypotheses. The program has capability to handle strength and stiffness anisotropy, general in-plane loadings, as shown in Figure 1, multi-material (hybrid) laminates and arbitrary hole (bolt) sizes. BJSFM modular substructuring is illustrated in Figure 2. Input data required are: lamina mechanical properties, in-plane loadings, hole geometry, and hole loading. Options are available which provide computation results after each program block.

The stress field calculations are based on two-dimensional anisotropic theory of elasticity solutions for a homogeneous, anisotropic infinite plate. Laminate stress distributions around an unloaded or loaded (bolt bearing) hole are calculated using plane stress assumptions. Laminate stress and strain distributions for combined bearing and bypass loads are obtained using the principle of superposition (Figure 3). Fastener bearing is idealized as a cosine radial stress distribution (Figure 4). Finite width corrections for loaded holes are based on superposition of infinite plate results as shown in Figure 5. Infinite plate solutions are exact while corrections for finite width joints are approximate and most accurate for width-to-diameter ratios greater than four.

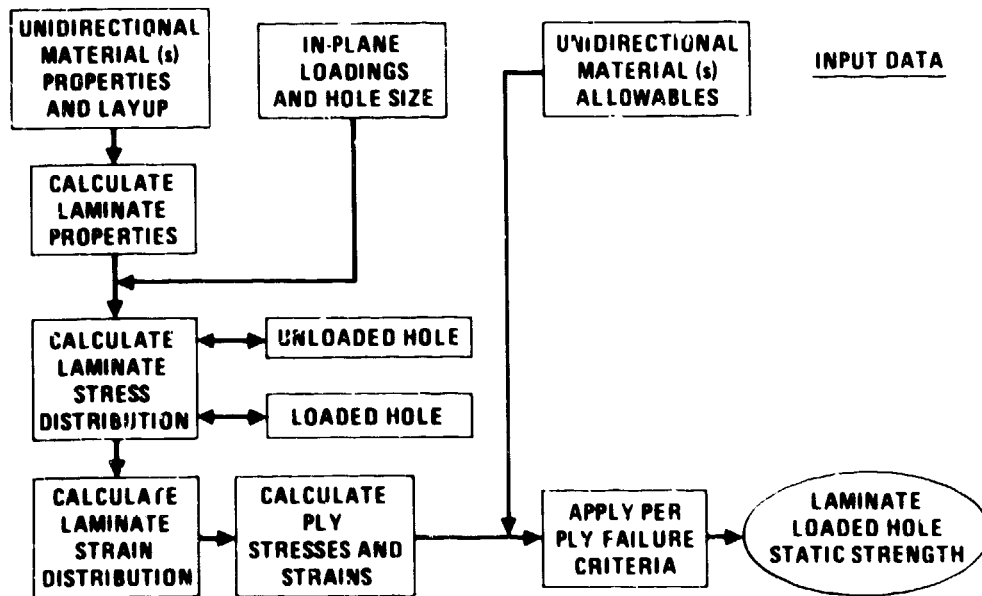
Laminate strains are calculated using material compliance relations. Laminate compliance coefficients are determined using lamination plate theory with unidirectional (lamina) elastic constants, lamina orientations and thicknesses. Strains for individual plies along lamina principal material axes are calculated using coordinate transformations. The solution is strictly valid only for homogeneous media; however, it has been assumed valid for mid-plane symmetric laminates.

Laminate failure is predicted by comparing elastic stress distributions with any of five material failure criteria on a ply-by-ply basis. Failure can be assessed at any location in the field of the plate.



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Figure 1. General Load Conditions Analyzed Using BJSFM



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Figure 2. Bolted Joint Stress Field Model - BJSFM Computer Program Flow Chart

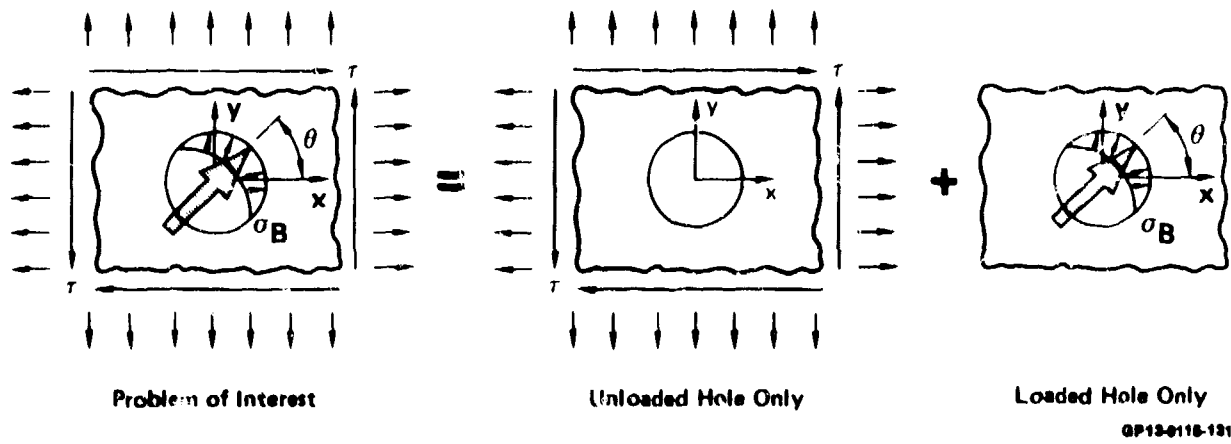


Figure 3. Superposition of Linear-Elastic Stress Solutions

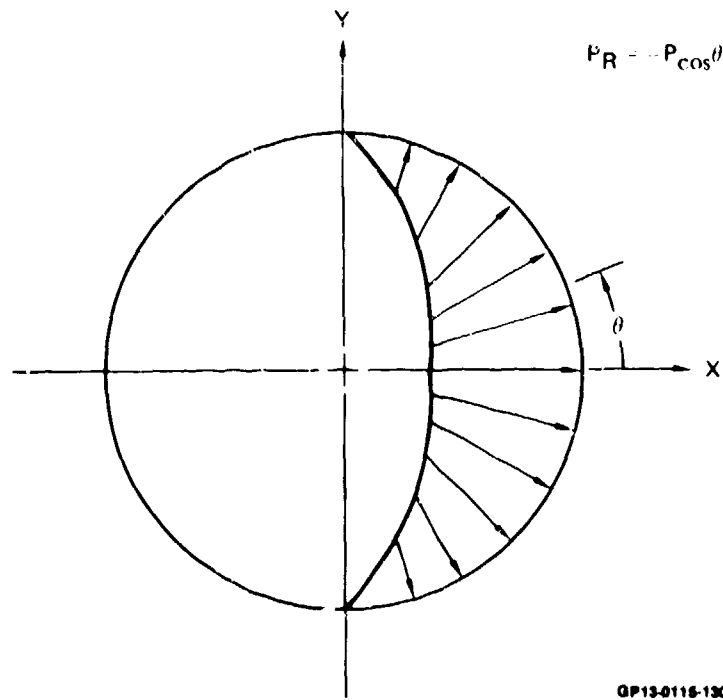
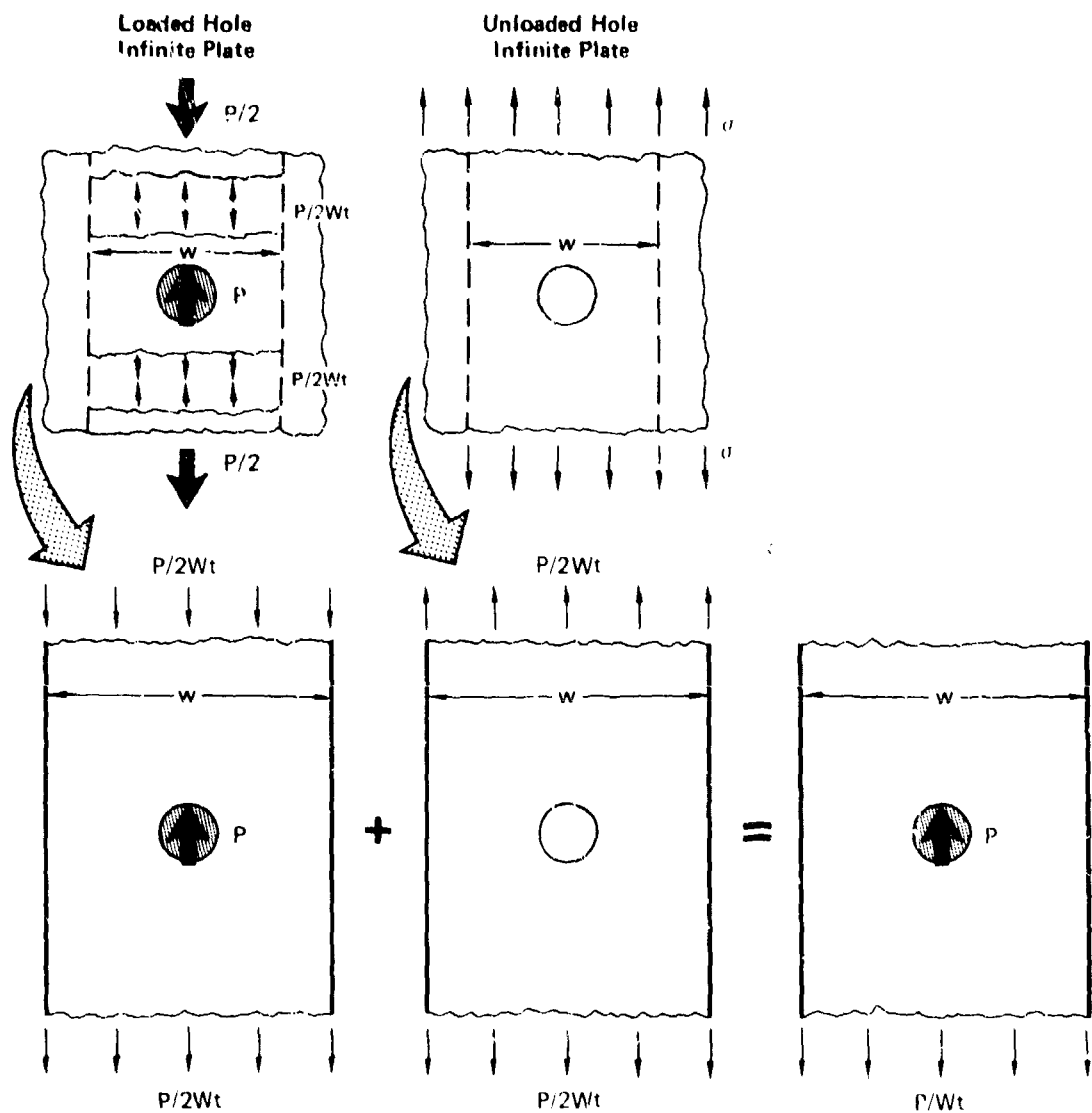


Figure 4. Assumed Cosine Bolt-Load Distribution



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Figure 5. Superposition of Infinite Plate Results Approximates a Finite Width Joint

### SECTION III

#### USER'S INSTRUCTIONS

Conversational interactive procedures are used for specifying input data for operation of the BJSFM program which is programmed to accept free formatted input data. A user may, after becoming familiar with the input procedures, elect to delete input instructions and receive only question marks, identifying all required input data. Using the various output options, users may receive as much or as little data as desired. The nature of required input data is dependent on user-selected output data options; the BJSFM program automatically adjusts its input data requirements to accommodate each output data option.

Up to eight different ply orientations and three different materials may be input. For each ply orientation, a corresponding thickness must be specified as well as material for hybrid laminates. Ply thickness may be either actual or a normalized thickness. A mid-plane symmetric stacking sequence is assumed. Zero degree plies are oriented parallel to the X-axis. Nomenclature applicable to the BJSFM is summarized in Figure 6. Positive angles are measured counterclockwise from the X-axis. All input data units must be consistent.

Unidirectional lamina material stiffness properties are required input data for each different material specified. Unidirectional lamina strength allowables for each material are required only if failure analysis is to be performed. If the maximum strain material failure criterion is used, lamina strain allowables must be input; otherwise, input lamina allowables are in terms of stress.

Any set of in-plane far-field stresses may be applied to an infinite anisotropic or isotropic plate (Figure 1). Bearing stress direction is independent of far-field stress directions.

The BJSFM is only capable of handling finite widths for bolt bearing problems; the width,  $W$ , is defined as perpendicular to the bolt load direction (Figure 1). The stresses calculated in a finite-width bolt bearing problem are approximate and most accurate for width-to-diameter ratios greater than four. In combined loading conditions, the finite width routine applies to only the loaded hole portion of the problem. To obtain infinite plate results for a loaded hole, input specimen width as  $\phi.\phi$ .

The user must specify the "range" (between low and high) of angular interval between locations around the hole for which data will be calculated. This range must also be subdivided by user-selected "degrees between output" to specify points at which calculations are to be made. "Step increments" are used to obtain data at increasing distances away from the hole boundary.

### Coordinate Systems

- X - Y Laminate Axis System Originating at the Center of the Hole. Zero Degree Plies are Parallel to the X-Axis.
- X' - Y' Rotation of the X-Y Axis System for Application of Far-Field Stresses
- 1 - 2 Lamina Axis System; Fibers are Parallel to the 1 Axis and Transverse to the 2 Axis.

### Variable Description (Units)\*\*

- E1 Lamina Modulus of Elasticity in Fiber (1) Direction ( $F/L^2$ )
- E2 Lamina Modulus of Elasticity in Transverse (2) Direction ( $F/L^2$ )
- G12 Lamina Shear Modulus ( $F/L^2$ )
- V12 Lamina Poisson's Ratio
- EX Laminate Modulus of Elasticity in X Direction ( $F/L^2$ )
- EY Laminate Modulus of Elasticity in Y Direction ( $F/L^2$ )
- GXY Laminate Shear Modulus ( $F/L^2$ )
- VXY Laminate Poisson's Ratio
- T1 Lamina Allowable Tensile Strength in Fiber (1) Direction ( $F/L^2$  or L/L)
- C1 Lamina Allowable Compressive Strength in Fiber (1) Direction ( $F/L^2$  or L/L)
- T2 Lamina Allowable Tensile Strength in Transverse (2) Direction ( $F/L^2$  or L/L)
- C2 Lamina Allowable Compressive Strength in Transverse (2) Direction ( $F/L^2$  or L/L)
- S Lamina Allowable Shear Strength ( $F/L^2$  or L/L)
- PX Stress in X' Direction ( $F/L^2$ ) - Independent of Input Thickness
- PY Stress in Y' Direction ( $F/L^2$ ) - Independent of Input Thickness
- PXY Shear Stress ( $F/L^2$ ) - Independent of Input Thickness
- P Applied Bearing Stress ( $F/L^2$ ) -  $P = \text{Bolt Load}/(\text{Dia} \times \text{Actual Thickness})$
- U Displacement in X Direction (L)
- V Displacement in Y Direction (L)
- W Specimen Width (L) - Bolt Loading Only
- DIST Radial Distance from Hole Boundary (L)
- $\alpha$  Angle of Applied Bolt Load with X Axis (i.e., Bolt Loading Angle)
- $\beta$  Rotation Angle of X' - Y' Axes from X - Y Axis System (i.e., Off Axis Loading Angle)
- $\theta$  Angle from X Axis to a Point Around Fastener Hole
- $\phi$  Rotation Angle of 1 - 2 Axes from X - Y Axis System (i.e., Ply Orientation Angle)

All angular measurements are positive counterclockwise from the X axis.

\* See also Figure 1.

\*\* Any consistent set of units may be used:

F = Force

L = Length

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Figure 6. Program Nomenclature\*

The maximum input step increment is seven evenly spaced concentric circles; the first step is always at the hole boundary.

The option to use any one of five different failure criteria has been programmed into the BJSFM. Failure analysis is applied on a ply-by-ply basis; therefore, only unidirectional (lamina) allowables are required input data. Only the maximum strain criterion requires the allowables to be input as strains; all others use stress allowables. Equations for each of the programmed failure criteria are given below. When the right hand side of any of the equations exceeds unity, failure has been predicted for the ply. Tension or compression stress/strain allowables used in each criteria are selected automatically, depending on the sign of individual stress field components being evaluated.

#### Maximum Strain

$$\frac{\epsilon_1}{F_1} = 1 \quad \frac{\epsilon_2}{F_2} = 1 \quad \frac{\gamma_{12}}{F_{12}} = 1$$

#### Maximum Stress

$$\frac{\sigma_1}{F_1} = 1 \quad \frac{\sigma_2}{F_2} = 1 \quad \frac{\tau_{12}}{F_{12}} = 1$$

#### Tsai-Hill

$$\left(\frac{\sigma_1}{F_1}\right)^2 + \left(\frac{\sigma_2}{F_2}\right)^2 + \left(\frac{\tau_{12}}{F_{12}}\right)^2 - \frac{\sigma_1 \sigma_2}{F_1^2} = 1$$

#### Modified Tsai-Wu

$$\frac{\sigma_1^2}{F_1^t F_1^c} + \frac{\sigma_2^2}{F_2^t F_2^c} + \left(\frac{1}{F_1^t} - \frac{1}{F_1^c}\right) \sigma_1 + \left(\frac{1}{F_2^t} - \frac{1}{F_2^c}\right) \sigma_2 + \frac{\tau_{12}^2}{F_{12}^2} = 1$$

Hoffman

$$\frac{\sigma_1^2}{F_1^t F_1^c} + \frac{\sigma_2^2}{F_2^t F_2^c} - \frac{\sigma_1 \sigma_2}{F_1^t F_1^c} + \frac{F_1^c - F_1^t}{F_1^t F_1^c} \sigma_1 + \frac{F_2^c - F_2^t}{F_2^t F_2^c} \sigma_2$$
$$+ \frac{\tau_{12}^2}{F_{12}^2} = 1$$

An example printout of the "conversational" language used to request input data is shown in Figure 7.



RNH  
 1 DO YOU WANT INSTRUCTIONS?  
 ?YES  
 SELECT DESIRED OUTPUT FROM THE FOLLOWING CASES.  
 1 CARPET PLOT DATA  
 2 LAMINATE PROPERTIES  
 3 LAMINATE STRESSES  
 4 LAMINATE STRAINS  
 5 CIRCUMFERENTIAL & RADIAL STRESSES/STRAINS  
 6 DISPLACEMENTS  
 7 STRAINS PER PLY  
 8 STRESSES PER PLY  
 9 FAILURE CRITERIA PER PLY  
 10 AUTOMATIC SEARCH FOR FAILURE  
 ?2,3,4,5,6,7,8,9,10  
 INPUT NUMBER OF DIFFERENT PLYS TO BE INPUT (8 MAX) AND  
 NUMBER OF DIFFERENT MATERIALS (3 MAX)  
 ?4,1  
 INPUT THE UNIDIRECTIONAL MATERIAL PROPERTIES FOR EACH MATERIAL.  
 IN THE FOLLOWING ORDER: E1, E2, G12, POISSONS RATIO  
 ?18.85E6,1.9E6,.85E6,.3  
 INPUT THE UNIDIRECTIONAL ALLOWABLES FOR EACH MATERIAL  
 IN THE FOLLOWING ORDER: T1, C1, T2, C2, SHEAR  
 ?230000,320000,28200,32300,17300  
 INPUT THE ANGULAR ORIENTATION OF EACH PLY  
 ?0.,45.,-45.,90.  
 INPUT THE THICKNESS OF EACH PLY  
 ?.5,.2,.2,.1  
 INPUT: FAR FIELD STRESSES PX, PY, PXY, OFF AXIS ANGLE, BEARING STRESS  
 AND BOLT LOADING ANGLE.  
 ?10000.,0.,2500.,45.,50000.,10.  
 INPUT WIDTH (0.0 FOR INFINITE PLATE)  
 ?1.5  
 INPUT BOLT DIAMETER, DEGREES BETWEEN OUTPUT, LOW RANGE, HIGH RANGE,  
 STEP INCREMENT AND NUMBER OF STEPS DESIRED (7 MAX)  
 ?.25,30.,0.,360.,.02,2  
 INPUT THE NUMBER WHICH CORRESPONDS TO THE FAILURE CRITERIA  
 YOU WISH TO USE  
 1 MAXIMUM STRAIN  
 2 MAXIMUM STRESS  
 3 TSAI-HILL  
 4 MODIFIED TSAI-WU  
 5 HOFFMAN  
 ?3

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Figure 7. Example Input Instructions

## SECTION IV

### OUTPUT OPTIONS

Various output options are available for user selection. The user may select any or all of the following options by inputting the appropriate number(s):

1. Carpet Plot Data
2. Laminate Properties
3. Laminate Stresses
4. Laminate Strains
5. Circumferential and Radial Stresses/Strains
6. Laminate Displacements
7. Strains per Ply
8. Stresses per Ply
9. Failure Criteria per Ply
10. Automatic Search for Failure

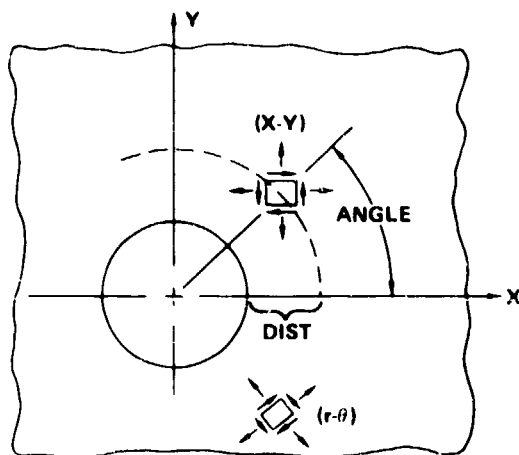
A brief description of each output option follows.

Option #1 - Carpet Plot Data - The carpet plot data routine will automatically vary the layup of a user input  $0^\circ/\pm\phi/90^\circ$  laminate family and calculate any one or all of the other output options (2 through 10) for each layup. Sixty-six different layups are automatically calculated in this routine; therefore, large amounts of data will be generated when using this output option.

Option #2 - Laminate Properties - Laminate stiffness properties are calculated using the unidirectional material elastic constants, ply angular orientations and ply thicknesses. These properties are calculated with respect to the X-Y axes and are the same as would be obtained using conventional lamination theory approaches.

Options #3 and #4 - Laminate Stresses/Strains - Laminate stress and strain distributions are available as output at points around the perimeter of the hole and at other user-specified concentric circles about the hole boundary. Principal stresses and strains are also calculated. All output is referenced to the X-Y axes. Points are located by the radial distance away from the hole boundary and the angular orientation from the X-axis (Figure 8).

Option #5 - Circumferential and Radial Stresses/Strains - Circumferential and radial laminate stresses and strains are calculated by a coordinate transformation. Output is in polar coordinates.



**EXAMPLE BJSFM OUTPUT:**

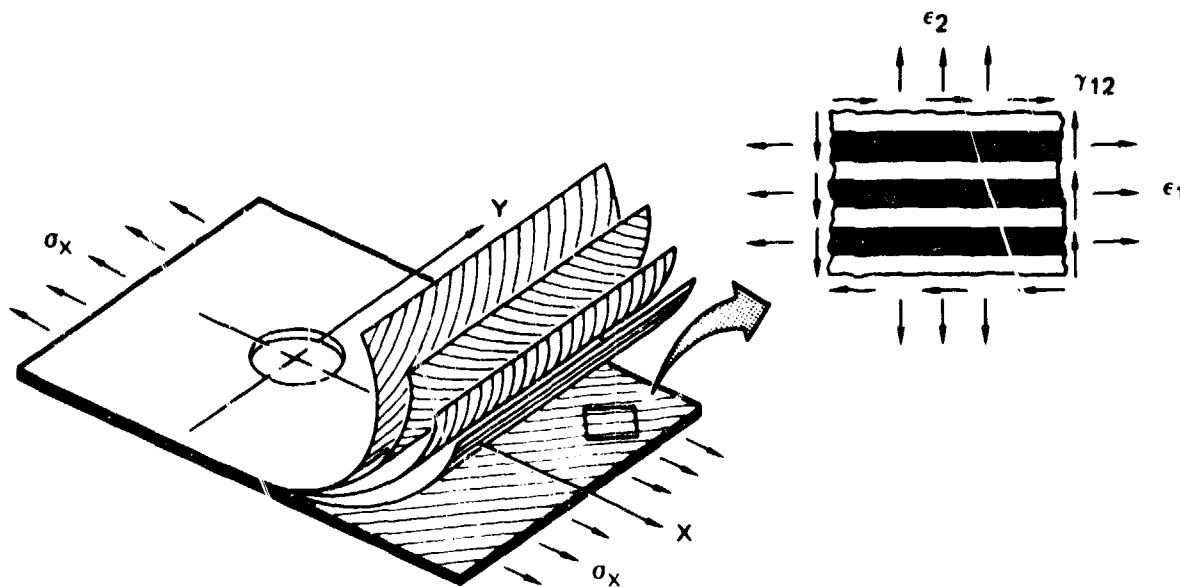
LAMINATE STRESSES							
DIST	ANGLE	X STRESS	Y STRESS	SHIAR STRESS	MAX. PRINCIPAL	MIN. PRINCIPAL	DIRECTION
0.000	0.00	-62693.22	44412.49	-9.44	44412.50	-62693.23	.01
0.000	30.00	-40151.99	-813.39	-34070.37	18954.04	-59924.32	10
0.000	60.00	-6819.86	-29542.53	-19699.77	4552.17	-60	
0.000	90.00	53351.08	-11093.21	-9.44	53351		
0.000	120.00	48122.47	16033.31	27733.47			
0.000	150.00	9612.46	29347.34	166			

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**Figure 8. Laminate Stress Distribution Output Data Option**

Option #6 - Laminate Displacements - Displacements for each point are output as U and V, which are displacements in the X and Y directions respectively. Due to limitations in the derivation, displacements for the loaded hole case shall be considered accurate only within approximately three times the diameter of the fastener. Unloaded hole displacements are exact throughout the plate.

Options #7 and 8 - Strains/Stresses per Ply - Strains and stresses per ply are calculated and output in the lamina (1-2) coordinate system. Each ply is identified along with the location of the point around the hole for which stresses/strains are calculated (Figure 9).



EXAMPLE BJSFM OUTPUT:

STRAINS PER PLY					
DIST	ANGLE	PLY	STRAIN 1	STRAIN 2	SHEAR STRAIN
0.000	0.00	0.00	-.007128	.011127	-.000004
0.000	0.00	45.00	.001998	.002001	.018254
0.000	0.00	-45.00	.002001	.001998	-.018254
0.000	0.00	90.00	.011127	-.007128	0.000000
0.000	30.00	0.00	-.003509		

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Figure 9. Ply-by-Ply Strain Distribution Output Data Option

Option #9 - Failure Criteria per Ply - Failure criteria per ply option applies the user-selected material failure criterion (max. stress, Tsai-Hill, etc.) to each ply using the input material allowables. The "failure number" obtained as output data indicates the value calculated by the failure criterion using the stress or strain components at a point. A failure number equal to or greater than one predicts ply failure. The program automatically selects tension or compression allowables depending on the sign of individual stress/strain components being evaluated. "Failure ratios" are output which indicate the relative magnitude of contributing stress components to the overall failure number. Therefore, failure can be assessed as to which stress component is most significant. These failure ratios are in terms of the lamina (1-2) coordinate system.

Option #10 - Automatic Search for Failure - The automatic search for failure routine will search over a user-specified range at each angular increment for the most critical single point as calculated by the material failure criterion. Search for failure is only done at the first step increment away from the hole boundary. Therefore, if a search for failure is to be performed at the boundary of the hole, the step increment must be input as  $\emptyset.\emptyset$ . The program will automatically ratio the input stress field until first ply failure is predicted. Output is the in-plane stresses at which failure is predicted along with the angular orientation of the predicted failure location. Failure numbers are also given for all other plies at the critical ply failure initiation angle. Failure ratios are also output.

## SECTION V

### PROGRAM LIMITATIONS

The following are the limitations of the BJSFM program.

- o Strictly valid for homogeneous anisotropic flat plates and assumed valid for mid-plane symmetric laminates.
- o Displacements inaccurate at points more than three times the hole diameter away from the hole boundary for loaded hole cases.
- o Stress fields inaccurate for width-to-diameter ratios less than four.
- o Maximum of eight different ply angular orientations (input).
- o Maximum of three different materials for hybrid laminates (input).
- o Maximum of seven steps away from the hole (output).

The following equation must be satisfied to obtain valid output.

$$[(\text{High Range}) - (\text{Low Range})] / (\text{Degrees Between Output}) \leq 72$$

The following data must be input as integers:

Output Option Numbers  
Number of Different Plies  
Number of Different Materials  
Material Number  
Number of Steps  
Failure Criteria Number

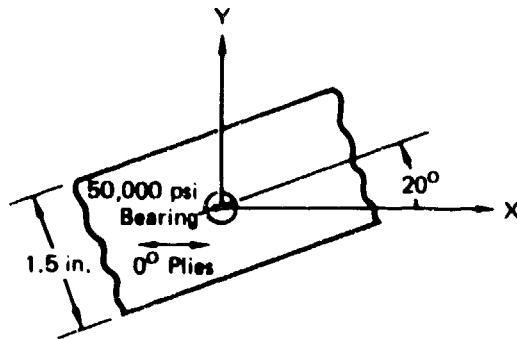
SECTION VI  
EXAMPLE PROBLEMS

1DO YOU WANT INSTRUCTIONS?

7YES

SELECT DESIRED OUTPUT FROM THE FOLLOWING CASES.

- 1 CARPET PLOT DATA
- 2 LAMINATE PROPERTIES
- 3 LAMINATE STRESSES
- 4 LAMINATE STRAINS
- 5 CIRCUMFERENTIAL & RADIAL STRESSES/STRAINS
- 6 DISPLACEMENTS
- 7 STRAINS PER PLY
- 8 STRESSES PER PLY
- 9 FAILURE CRITERIA PER PLY
- 10 AUTOMATIC SEARCH FOR FAILURE



74.6

INPUT NUMBER OF DIFFERENT PLYS TO BE INPUT (8 MAX) AND NUMBER OF DIFFERENT MATERIALS (3 MAX)

74.1

INPUT THE UNIDIRECTIONAL MATERIAL PROPERTIES FOR EACH MATERIAL IN THE FOLLOWING ORDER: E1, E2, G12, POISSONS RATIO

710.4526,1.9E6,.85E6,.3

INPUT THE ANGULAR ORIENTATION OF EACH PLY

70.45,-45,90

INPUT THE THICKNESS OF EACH PLY

7.42,.25,.25,.00

42% - 0° Plies, 50% ±45°, 8% - 90°

INPUT: FAR FIELD STRESSES PX,PY,PXY, OFF AXIS ANGLE, BEARING STRESS AND BOLT LOADING ANGLE.

70,0,0,0,50000,.20

INPUT WIDTH (0.0 FOR INFINITE PLATE)

71.5

INPUT BOLT DIAMETER, DEGREES BETWEEN OUTPUT, LOW RANGE, HIGH RANGE, STEP INCREMENT AND NUMBER OF STEPS DESIRED (7 MAX)

7.25,30,.0,.90,.02,3

LAMINATE STRAINS (Output Option No. 4)

DIST	ANGLE	X STRAIN	Y STRAIN	SHEAR STRAIN	MAX. PRINCIPAL	MIN. PRINCIPAL	DIRECTION
0.000	0.00	-.006927	.007109	.000001	.007109	-.006927	-0.00
0.000	30.00	-.004137	.001938	-.012340	.005705	-.008005	38.20
0.000	60.00	.001704	-.006583	-.010110	.004099	-.008979	-33.87
0.000	90.00	.005512	-.006573	.000001	.005512	-.006573	.01
.020	0.00	-.005642	.005766	.000253	.005767	-.005643	-1.27
.020	30.00	-.003419	.001412	-.009993	.004546	-.006554	38.21
.020	60.00	.001920	-.005302	-.009304	.003762	-.007443	-32.92
.020	90.00	.003843	-.004336	.001880	.003949	-.004442	12.34
.040	0.00	-.004698	.004788	.000437	.004793	-.004703	-2.63
.040	30.00	-.002855	.001130	-.000420	.003795	-.005520	38.34
.040	60.00	.001898	-.004792	-.006542	.003231	-.005125	-31.46
.040	90.00	.002845	-.003118	.001857	.002986	-.003259	15.96

DISPLACEMENTS (Output Option No. 6)

DIST	ANGLE	U	V
0.000	0.00	.000794	-.000080
0.000	30.00	.000943	.000342
0.000	60.00	.000691	.000535
0.000	90.00	.000215	.000294
.020	0.00	.000655	-.000093
.020	30.00	.000794	.000300
.020	60.00	.000519	.000471
.020	90.00	.000058	.000234
.040	0.00	.000538	-.000104
.040	30.00	.000668	.000268
.040	60.00	.000378	.000419
.040	90.00	-.000045	.000192

DO YOU WISH TO CONTINUE?

7NO

STOP

Figure 10. Loaded Hole Case

GP13-0116-220

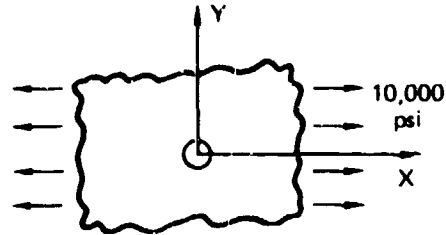


1 DO YOU WANT INSTRUCTIONS?

?YES

SELECT DESIRED OUTPUT FROM THE FOLLOWING CASES.

- 1 CARPET PLOT DATA
- 2 LAMINATE PROPERTIES
- 3 LAMINATE STRESSES
- 4 LAMINATE STRAINS
- 5 CIRCUMFERENTIAL & RADIAL STRESSES/STRAINS
- 6 DISPLACEMENTS
- 7 STRAINS PER PLY
- 8 STRESSES PER PLY
- 9 FAILURE CRITERIA PER PLY
- 10 AUTOMATIC SEARCH FOR FAILURE



?3.5

INPUT NUMBER OF DIFFERENT PLYS TO BE INPUT (8 MAX) AND NUMBER OF DIFFERENT MATERIALS (3 MAX)

?1.1

INPUT THE UNIDIRECTIONAL MATERIAL PROPERTIES FOR EACH MATERIAL IN THE FOLLOWING ORDER: E1, E2, G12, POISSONS RATIO

?10.E6,10.E6,3.85E6,.3

INPUT THE ANGULAR ORIENTATION OF EACH PLY

?70.

INPUT THE THICKNESS OF EACH PLY

?71.

INPUT: FAR FIELD STRESSES PX, PY, PXY, OFF AXIS ANGLE, BEARING STRESS AND BOLT LOADING ANGLE.

?10000.,0.,0.,0.,0.,0.

INPUT BOLT DIAMETER, DEGREES BETWEEN OUTPUT, LOW RANGE, HIGH RANGE, STEP INCREMENT AND NUMBER OF STEPS DESIRED (7 MAX)

?.25,15.,0.,90.,0.,1

Isotropic Properties  

$$\left( E1 = E2, G = \frac{E1}{2(1 + \nu)} \right)$$

LAMINATE STRESSES (Output Option No. 3)

DIST	ANGLE	X STRESS	Y STRESS	SHEAR STRESS	MAX. MIN.		DIRECTION
					PRINCIPAL	PRINCIPAL	
0.000	0.00	-.00	-10000.00	0.00	-.00	-10000.00	0.00
0.000	15.00	-490.49	-6831.64	180.53	-.00	-7322.13	15.00
0.000	30.00	-.41	-1.22	.70	-.00	-1.62	30.00
0.000	45.00	5001.62	5001.62	-5001.62	10003.25	-.00	45.00
0.000	60.00	15003.65	5001.22	-8602.36	20004.87	.00	-30.00
0.000	75.00	25488.87	1830.02	-6819.72	27318.88	.00	-15.00
0.000	90.00	29993.51	-.00	-.00	29993.51	-.00	-.00

CIRCUMFERENTIAL AND RADIAL STRESSES & STRAINS (Output Option No. 5)

DIST	ANGLE	THETA STRESS	RADIAL STRESS	SHEAR STRESS	THETA RADIAL		SHEAR STRAIN
					STRAIN	STRAIN	
0.000	0.00	-10000.00	-.00	0.00	-.001000	.000300	0.000000
0.000	15.00	-7322.13	-.00	-.00	-.000732	.000220	.000206
0.000	30.00	-1.62	-.00	.00	-.000000	.000000	.000000
0.000	45.00	10003.25	-.00	.00	.001000	-.000299	-.000000
0.000	60.00	20004.87	.00	.00	.002000	-.000599	.000562
0.000	75.00	27318.88	.00	.00	.002731	-.000819	.000767
0.000	90.00	29993.51	-.00	-.00	.002999	-.000900	.000000

DO YOU WISH TO CONTINUE?

?NO

STOP

QP13-0115-221

Figure 11. Isotropic Unloaded Hole

DO YOU WANT INSTRUCTIONS?

YES

SELECT DESIRED OUTPUT FROM THE FOLLOWING CASES.

- 1 CARPET PLOT DATA
- 2 LAMINATE PROPERTIES
- 3 LAMINATE STRESSES
- 4 LAMINATE STRAINS
- 5 CIRCUMFERENTIAL & RADIAL STRESSES/STRAINS
- 6 DISPLACEMENTS
- 7 STRAINS PER PLY
- 8 STRESSES PER PLY
- 9 FAILURE CRITERIA PER PLY
- 10 AUTOMATIC SEARCH FOR FAILURE

710

INPUT NUMBER OF DIFFERENT PLYS TO BE INPUT (8 MAX)  
AND NUMBER OF DIFFERENT MATERIALS (3 MAX)

74,1

INPUT THE UNIDIRECTIONAL MATERIAL PROPERTIES FOR EACH  
MATERIAL IN THE FOLLOWING ORDER: E1, E2, G12, POISSONS RATIO

718.85E6,1.9E6,.85E6,.3

INPUT THE UNIDIRECTIONAL ALLOWABLES FOR EACH MATERIAL  
IN THE FOLLOWING ORDER: T1, C1, T2, C2, SHEAR

72.3E5,3.2E5,2.82E4,.23E4,1.73E4

INPUT THE ANGULAR ORIENTATION OF EACH PLY

70.,45.,-45.,90.

INPUT THE THICKNESS OF EACH PLY

7.5.,2.,2.,.1

INPUT: FAR FIELD STRESSES PX, PY, FXY, OFF AXIS ANGLE, BEARING STRESS  
AND BOLT LOADING ANGLE.

710000.,500.,2500.,30.,35000.,10.

INPUT WIDTH (0.0 FOR INFINITE PLATE)

70.0

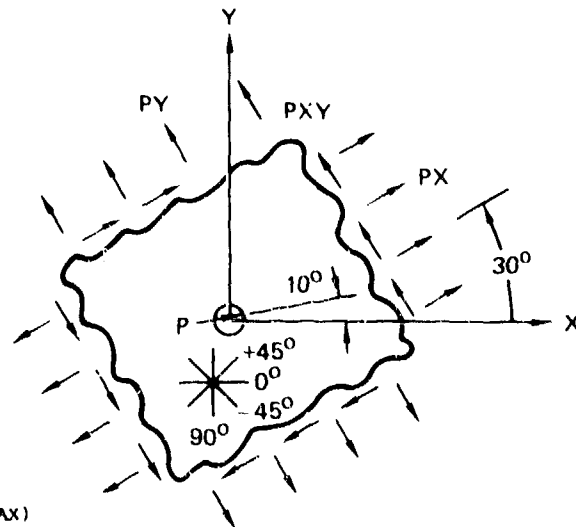
INPUT BOLT DIAMETER, DEGREES BETWEEN OUTPUT, LOW RANGE, HIGH RANGE,  
STEP INCREMENT AND NUMBER OF STEPS DESIRED (7 MAX)

7.25,5.,0.,360.,.02,2

INPUT THE NUMBER WHICH CORRESPONDS TO THE FAILURE CRITERIA  
YOU WISH TO USE

- 1 MAXIMUM STRAIN
- 2 MAXIMUM STRESS
- 3 TSAI-HILL
- 4 MODIFIED TSAI-WU
- 5 HOFFMAN

73



AUTOMATIC SEARCH FOR FAILURE (Output Option No. 10)

FAILURE STRESSES						
	PX	PY	PXY	P	FAILURE RATIOS	
	17243.40	862.17	4310.85	60351.88	2	SHEAR
DIST	ANGLE	PLY	FAILURE NUMBER	FAILURE RATIOS		
.020	335.00	0.00	.355	-.210	.469	.953
.020	335.00	45.00	.999	.811	-.181	.537
.020	335.00	-45.00	.730	-.400	.650	-.628
.020	335.00	90.00	1.000	.606	-.075	-.788

Input Stresses are Ratioed Uniformly Until First Ply Failure is Predicted

Indicates Ply Failure

Depicts Relative Magnitude of Stress Components to Failure Number

Failure Initiation Location Angle

User Specified Distance Away from Hole at Which Failure is Predicted

Note: The "search" is only done within the user specified "range" with an accuracy of 1/2 the "degrees between output" in locating failure initiation.

GP13-0115-219

Figure 12. General Loading Condition

SECTION VII  
PROGRAM LISTING



```

C      IF(ANS.EQ.YES.AND.PUTOUT(IOUT,9).GE.1.) WRITE(6,70)
70  FORMAT(' INPUT THE UNIDIRECTIONAL ALLOWABLES FOR EACH ',
1 'MATERIAL'/' IN THE FOLLOWING ORDER: T1, C1, T2, C2, SHEAR')
      IF(PUTOUT(IOUT,9).GE.1.) READ(5,  )(FXT(J),FXC(J),FYT(J),
1 FYC(J),FXV(J),J=1,NUMMAT)
C
C      INPUT ANGULAR ORIENTATION, THICKNESS AND MATERIAL
C      IDENTIFICATION PER PLY
C
      IF(ANS.EQ.YES) WRITE(6,80)
80  FORMAT(' INPUT THE ANGULAR ORIENTATION OF EACH PLY')
      READ(5,  )(ANG(L),L=1,NUMPLY)
C
      IF(ANS.EQ.YES) WRITE(6,90)
90  FORMAT(' INPUT THE THICKNESS OF EACH PLY')
      READ(5,  )(PLYTHK(J),J=1,NUMPLY)
100 CONTINUE
C
      IF(NUMMAT.NE.1) GO TO 120
      DO 110 L=1,NUMPLY
      MATID(L)=1
110 CONTINUE
      GO TO 140
120 CONTINUE
C
      IF(ANS.EQ.YES) WRITE(6,130)
130 FORMAT(' INPUT THE MATERIAL NUMBER FOR EACH PLY')
      READ(5,  )(MATID(L),L=1,NUMPLY)
140 CONTINUE
      IF(PUTOUT(IOUT,3).EQ.0.0) GO TO 200
C
      IF(ANS.EQ.YES.AND.PUTOUT(IOUT,3).GE.1.) WRITE(6,150)
150 FORMAT(' INPUT: FAR FIELD STRESSES PX,PY,PXY, OFF AXIS ANGLE,',
1 ' BEARING STRESS'/' AND BOLT LOADING ANGLE.')
      IF(PUTOUT(IOUT,3).GE.1.) READ(5,  ) PX,PY,PXY,BETA,P,ALPHA
C
      IF(ANS.EQ.YES.AND.P.NE.0.0) WRITE(6,160)
160 FORMAT(' INPUT WIDTH (0.0 FOR INFINITE PLATE)')
      IF(PUTOUT(IOUT,3).GE.1..AND.P.NE.0.0) READ(5,  ) W
C
170 CONTINUE
      IF(ANS.EQ.YES.AND.PUTOUT(IOUT,3).GE.1.) WRITE(6,190)
180 FORMAT(' INPUT BOLT DIAMETER, DEGREES BETWEEN OUTPUT, LOW ',
1 'RANGE, HIGH RANGE,'/' STEP INCREMENT AND NUMBER OF STEPS',
2 ' DESIRED (7 MAX)')
C
      IF(PUTOUT(IOUT,3).GE.1.) READ(5,  ) DIA,IANG,ILOW,IHIGH,
1STPINK,NUMSTP
C
      IF(NUMSTP.GT.7) NUMSTP=7
      RANGE=(IHIGH-ILOW)/IANG
      IF(RANGE.GT.72) OUTPUT(6)' DEGREES BETWEEN OUTPUT TO SMALL; ',
1 ' TRY AGAIN'
      IF(RANGE.GT.72) GO TO 170
C
      BL=P*DIA
      PW=0.0
      IF(P.NE.0.0.AND.W.NE.0.0) PW=BL/(2.0*W)
      WD=W/DIA
      IF(WD.LT.4.0.AND.W.NE.0.0) OUTPUT(6)' CAUTION: WIDTH-TO-DIAMETER'
1 ' RATIOS LESS THAN 4 GIVE ERRONEOUS RESULTS'

```

```

C      IF(ANS.EQ.YES.AND.PUTOUT(IOUT,9).GE.1.) WRITE(6,190)
190  FORMAT(' INPUT THE NUMBER WHICH CORRESPONDS TO THE ',
1     ' FAILURE CRITERIA '/' YOU WISH TO USE '/' 1 MAXIMUM STRAIN'/',
2     ' 2 MAXIMUM STRESS'/' 3 TSAI-HILL'/' 4 MODIFIED ',
3     ' TSAI-WU'/' 5 HOFFMAN')
      IF(PUTOUT(IOUT,9).GE.1.) READ(5, )IFAIL
C
C      IF(PUTOUT(IOUT,10).EQ.2.) NUMSTP=2
200  CONTINUE
C
C      CARPET PLOT ROUTINE
C
      IF(PUTOUT(IOUT,1).NE.2.) GO TO 240
      ANG1=ANG(1)
      ANG2=ANG(2)
      ANG3=ANG(3)
      ANG4=ANG(4)
      PLYT1=PLYTHK(1)
      PLYT2=PLYTHK(2)
      PLYT3=PLYTHK(3)
      PLYT4=PLYTHK(4)
      DO 280 JKI=1,11
      FORFIV=-.1
      DO 270 IJK=1,11
      ANG(1)=ANG1
      ANG(2)=ANG2
      ANG(3)=ANG3
      ANG(4)=ANG4
      PLYTHK(1)=PLYT1
      PLYTHK(2)=PLYT2
      PLYTHK(3)=PLYT3
      PLYTHK(4)=PLYT4
      NUMPLY=4
      PLYTHK(1)=1.1-JKI*.1
      FORFIV=FORFIV+.1
      CHECK=FORFIV+PLYTHK(1)
      IF(CHECK.GT.1.0) GO TO 280
      PLYTHK(2)=FORFIV/2.
      PLYTHK(3)=FORFIV/2.
      PLYTHK(4)=1.0-PLYTHK(1)-FORFIV
      IO=PLYTHK(1)*100.4
      I45=PLYTHK(2)*200.4
      I90=PLYTHK(4)*100.4
      IF(IO.NE.0) GO TO 210
      NUMPLY=NUMPLY-1
      PLYTHK(1)=PLYTHK(2)
      PLYTHK(2)=PLYTHK(3)
      PLYTHK(3)=PLYTHK(4)
      ANG(1)=ANG(2)
      ANG(2)=ANG(3)
      ANG(3)=ANG(4)
210  CONTINUE
      IF(I45.NE.0) GO TO 220
      NUMPLY=NUMPLY-2
      IF(NUMPLY.EQ.1) PLYTHK(1)=PLYTHK(4)
      IF(NUMPLY.EQ.1) ANG(1)=ANG(4)
      PLYTHK(2)=PLYTHK(4)
      ANG(2)=ANG(4)
220  CONTINUE
      IF(I90.EQ.0) NUMPLY=NUMPLY-1
      IF(PUTOUT(IOUT,1).EQ.2.) WRITE(6,230) IO,I45,I90
230  FORMAT('//25X,'LAYUP: ',I3,'/',I3,'/',I3)

```

```

C
C   BRANCHES TO OTHER SUBROUTINES
C
240 IF(PUTOUT(IOUT,2).EQ.0.) GO TO 260
    ALPH=ALPHA
    CALL ABD(ALPH)
C
    CORRECT=1.0
    DUMMY=PUTOUT(IOUT,98)
250 CONTINUE
    IF(PUTOUT(IOUT,3).EQ.0.) GO TO 260
    CALL LAMSTR
C
    IF(PUTOUT(IOUT,7).EQ.0.) GO TO 260
    CALL PLYSTR(IFAIL)
C
    IF(PUTOUT(IOUT,9).EQ.0.) GO TO 260
    CALL FAILURE
C
    IF(PUTOUT(IOUT,10).EQ.2.) DUMMY=PUTOUT(IOUT,99)
    IF(CORRECT.LT..999.OR.CORRECT.GT.1.001) GO TO 250
C
C
260 CONTINUE
    DUMMY=PUTOUT(IOUT,98)
    IF(PUTOUT(IOUT,1).NE.2.) GO TO 290
C
270 CONTINUE
280 CONTINUE
290 CONTINUE
C
    OUTPUT(6)' DO YOU WISH TO CONTINUE?'
    READ(5,300) ANS2
300 FORMAT(A3)
    IF(ANS2.NE.NO) GO TO 10
C
C
C
    STOP
    END
C
C
C *****
C
FUNCTION PUTOUT(IOUT,IN)
DIMENSION IOUT(15)
PUTOUT=0.
DO 10 J=1,15
IF(IOUT(J).GE.IN) PUTOUT=1.
10 CONTINUE
DO 20 J=1,15
IF(IOUT(J).EQ.IN) PUTOUT=2.
20 CONTINUE
IF(IN.EQ.98) DATA=0.0
IF(IN.EQ.99) DATA=1.0
IF(DATA.EQ.1.0.AND.IN.LT.10) PUTOUT=0.5
RETURN
END

```

```

C
C *****
C
C SUBROUTINE ABD (ALPHA)
C
C CALCULATES LAMINATE PROPERTIES FROM LAMINA INPUT
C
C COMMON/ONE/E1(3),E2(3),G12(3),V12(3)
C COMMON/TWO/IOUT(15),NUMPLY,NUMMAT,ANG(8),PLYTHK(8),MATID(8)
C COMMON/SIX,AI(3,3)
C COMMON/SEVEN/S(3,3)
C
C DIMENSION V21(3),DIV(3),Q11(3),Q22(3),Q12(3),Q66(3),U1(3),
C U2(3),U3(3),U4(3),U5(3),QBAR(8,3,3),ZZ(16),Z(16),Q(3,3),
C 2AA(3,3),A(3,3)
C
C C
C C REDUCED STIFFNESSES FOR EACH MATERIAL
C
C DO 10 M=1,NUMMAT
C V21(M)=E2(M)*V12(M)/E1(M)
C DIV(M)=1.-V12(M)*V21(M)
C Q11(M)=E1(M)/DIV(M)
C Q22(M)=E2(M)/DIV(M)
C Q12(M)=V12(M)*E2(M)/DIV(M)
C Q66(M)=G12(M)
10 CONTINUE
C
C C
C C INVARIANT PROPERTIES
C
C DO 20 M=1,NUMMAT
C U1(M)=(3.*Q11(M)+3.*Q22(M)+2.*Q12(M)+4.*Q66(M))/8.
C U2(M)=(Q11(M)-Q22(M))/2.
C U3(M)=(Q11(M)+Q22(M)-2.*Q12(M)-4.*Q66(M))/8.
C U4(M)=(Q11(M)+Q22(M)+6.*Q12(M)-4.*Q66(M))/8.
C U5(M)=(Q11(M)+Q22(M)-2.*Q12(M)+4.*Q66(M))/8.
20 CONTINUE
C
C DO 30 I=1,3
C DO 30 J=1,3
C A(I,J)=0.
C AA(I,J)=0.
30 CONTINUE
C
C C
C C TRANSFORMED REDUCED STIFFNESSES PER PLY
C
C THICK=0.
C DO 40 L=1,NUMPLY
C DEG=ANG(L)*3.1415926535/180.0
C M=MATID(L)
C QBAR(L,1,1)=U1(M)+U2(M)*COS(2.*DEG)+U3(M)*COS(4.*DEG)
C QBAR(L,1,2)=U4(M)-U3(M)*COS(4.*DEG)
C QBAR(L,2,2)=U1(M)-U2(M)*COS(2.*DEG)+U3(M)*COS(4.*DEG)
C QBAR(L,1,3)=.5*U2(M)*SIN(2.*DEG)+U3(M)*SIN(4.*DEG)
C QBAR(L,2,3)=.5*U2(M)*SIN(2.*DEG)-U3(M)*SIN(4.*DEG)
C QBAR(L,3,3)=U5(M)-U3(M)*COS(4.*DEG)
C QBAR(L,2,1)=QBAR(L,1,2)
C QBAR(L,3,1)=QBAR(L,1,3)
C QBAR(L,3,2)=QBAR(L,2,3)
C
C THICK=PLYTHK(L)+THICK
C ZZ(L+1)=THICK
40 CONTINUE
C Z(1)=-1.*THICK/2.0

```



```

C
C C
C   CALCULATE A MATRIX
C
C   DO 70 I=1,3
C   DO 60 J=1,3
C   DO 50 L=1,NUMPLY
C   Z(L+1)=Z(1)+ZZ(L+1)
C   ZA=Z(L+1)-Z(L)
C
C   A(I,J)=A(I,J)+QBAR(L,I,J)*ZA
C
C 50 CONTINUE
C
C   MATRIX Q AND QQ ARE DUMMY MATRICIES USED IN CALCULATIONS INVOLVING
C   THE MANIPULATION OF OTHER MATRICIES
C
C   Q(I,J)=A(I,J)/THICK
C 60 CONTINUE
C 70 CONTINUE
C
C   COMPUTE A/THICK INVERSE MATRIX
C
C   ISTEP=1
C   CALL INVERSE(Q,AI)
C
C   LAMINATE MID-PLANE PROPERTIES
C
C   EX1=1.0/AI(1,1)
C   EY1=1.0/AI(2,2)
C   VXY1=-EX1*AI(1,2)
C   GXY1=1.0/AI(3,3)
C
C   IF(PUTOUT(IOUT,2).EQ.2.) WRITE(6,90) EX1,EY1,GXY1,VXY1
C 80 FORMAT(/25X,'LAMINATE PROPERTIES'/' EX = ',E9.3,2X,' EY = ',
C 1E9.3,2X,' GXY = ',E9.3,2X,' VXY = ',F5.3)
C
C   CALCULATE MATERIAL PROPERTIES FOR OFF-AXIS BOLT LOAD
C
C   TRANSFORMED REDUCED STIFFNESSES PER PLY
C
C   THICK=0.
C   ALPHA=ALPHA*3.1415926535/180.0
C   DO 90 L=1,NUMPLY
C   DEG=ANG(L)*3.1415926535/180.0
C   DEG=DEG-ALPHA
C   M=MATID(L)
C   QBAR(L,1,1)=U1(M)+U2(M)*COS(2.*DEG)+U3(M)*COS(4.*DEG)
C   QBAR(L,1,2)=U4(M)-U3(M)*COS(4.*DEG)
C   QBAR(L,2,2)=U1(M)-U2(M)*COS(2.*DEG)+U3(M)*COS(4.*DEG)
C   QBAR(L,1,3)=.5*U2(M)*SIN(2.*DEG)+U3(M)*SIN(4.*DEG)
C   QBAR(L,2,3)=.5*U2(M)*SIN(2.*DEG)-U3(M)*SIN(4.*DEG)
C   QBAR(L,3,3)=U5(M)-U3(M)*COS(4.*DEG)
C   QBAR(L,2,1)=QBAR(L,1,2)
C   QBAR(L,3,1)=QBAR(L,1,3)
C   QBAR(L,3,2)=QBAR(L,2,3)
C
C   THICK=PLYTHK(L)+THICK
C   ZZ(L+1)=THICK
C 90 CONTINUE
C   Z(1)=-1.*THICK/2.0

```

```

C
C
C      CALCULATE AA MATRIX
C
C      DO 120 I=1,3
C      DO 110 J=1,3
C      DO 100 L=1,NUMPLY
C      Z(L+1)=Z(L)+ZZ(L+1)
C      ZA=Z(L+1)-Z(L)
C
C      AA(I,J)=AA(I,J)+QBAR(L,I,J)*ZA
C
100 CONTINUE
   Q(I,J)=AA(I,J)/THICK
110 CONTINUE
120 CONTINUE
C
C      COMPUTE AA/THICK INVERSE MATRIX
C
C      ISTEP=4
C      CALL INVERSE(Q,S)
C
C      OFF-AXIS LAMINATE PROPERTIES
C
C      EX2=1.0/S(1,1)
C      EY2=1.0/S(2,2)
C      VXY2=-EX2*S(1,2)
C      GXY2=1.0/S(3,3)
C
C
C      RETURN
C      END
C
C      *****
C
C      SUBROUTINE INVERSE (X,XI)
C
C      CALCULATES THE INVERSE OF A 3X3 MATRIX
C
C      DIMENSION X(3,3), XI(3,3)
C      COMMON ISTEP
C
C      DET=(X(1,1)*X(2,2)*X(3,3))+(X(1,2)*X(2,3)*X(3,1))+
1      (X(1,3)*X(2,1)*X(3,2))-(X(1,3)*X(2,2)*X(3,1))-
2      (X(1,1)*X(2,3)*X(3,2))-(X(1,2)*X(2,1)*X(3,3))
C
C      IF(DET.EQ.0.0) GO TO 10
C
C      XI(1,1)=(X(2,2)*X(3,3)-X(2,3)*X(3,2))/DET
C      XI(1,2)=(X(2,3)*X(3,1)-X(2,1)*X(3,3))/DET
C      XI(1,3)=(X(2,1)*X(3,2)-X(2,2)*X(3,1))/DET
C      XI(2,2)=(X(1,1)*X(3,3)-X(1,3)*X(3,1))/DET
C      XI(2,3)=(X(1,2)*X(3,1)-X(1,1)*X(3,2))/DET
C      XI(3,3)=(X(1,1)*X(2,2)-X(1,2)*X(2,1))/DET
C      XI(2,1)=(X(3,2)*X(1,3)-X(1,2)*X(3,3))/DET
C      XI(3,1)=(X(1,2)*X(2,3)-X(2,2)*X(1,3))/DET
C      XI(3,2)=(X(2,1)*X(1,3)-X(1,1)*X(2,3))/DET
C      GO TO 30
10 PRINT 20,ISTEP
20 FORMAT(' SUBROUTINE INVERSE CALCULATES A SINGULAR MATRIX ',
1' AT STEP' I3)
30 CONTINUE
   RETURN
   END

```

```

C
C *****
C
C SUBROUTINE LAMSTR
C
C CALCULATES THE LAMINATE STRESSES AND STRAINS DUE TO A
C GENERAL INPLANE LOADING WITH A BOLT LOAD
C
C COMMON/TWO/IOUT(15),NUMPLY,NUMMAT,ANG(8),PLYTHK(9),MATID(9)
C COMMON/THREE/IANG,ILOW,IHIGH,STPINK,NUMSTP
C COMMON/FOUR/PX,PY,PXY,P,PW,ALPHA,BETA,DIA,CORRECT
C COMMON/SIX/AI(3,3)
C COMMON/SEVEN/S(3,3)
C COMMON/EIGHT/STRESS(3,7,73),STRAIN(3,7,73)
C
C REAL IANG,ILOW,IHIGH
C DIMENSION STR(3,7,73),U(7,73),V(7,73),UX(7,73),VY(7,73)
C
C PX=CORRECT*PX
C PY=CORRECT*PY
C PXY=CORRECT*PXY
C P=CORRECT*P
C PW=CORRECT*PW
C
C
C
C
C PI=3.1415926535
C NUMPT=((IHIGH-ILOW)/IANG)+1
C DO 10 J=1,NUMSTP
C DO 10 K=1,NUMPT
C U(J,K)=0.0
C V(J,K)=0.0
C DO 10 I=1,3
C STRESS(I,J,K)=0.0
C STRAIN(I,J,K)=0.0
10 CONTINUE
C
C
C CALCULATE UNLOADED HOLE STRESSES
C
C IF(PX.EQ.0.0) GO TO 20
C BETA0=BETA
C CALL UNLODED(PX,DIA,AI,BETA0,STRESS,U,V)
20 CONTINUE
C
C IF(PY.EQ.0.0) GO TO 40
C BETA90=BETA+90.0
C CALL UNLODED(PY,DIA,AI,BETA90,STR,UX,VY)
C DO 30 J=1,NUMSTP
C DO 30 K=1,NUMPT
C U(J,K)=U(J,K)+UX(J,K)
C V(J,K)=V(J,K)+VY(J,K)
C DO 30 I=1,3
C STRESS(I,J,K)=STRESS(I,J,K)+STR(I,J,K)
30 CONTINUE
C
C 40 CONTINUE
C IF(PXY.EQ.0.0) GO TO 70
C BETA45=BETA+45.0
C CALL UNLODED(PXY,DIA,AI,BETA45,STR,UX,VY)
C DO 50 J=1,NUMSTP
C DO 50 K=1,NUMPT
C U(J,K)=U(J,K)+UX(J,K)
C V(J,K)=V(J,K)+VY(J,K)
C DO 50 I=1,3
C STRESS(I,J,K)=STRESS(I,J,K)+STR(I,J,K)
50 CONTINUE

```

```

C
  BETA45=BETA-45.0
  PXYI=-PXY
  CALL UNLODED(PXYN, DIA, AI, BETA45, STR, UX, VY)
  DO 60 J=1, NUMSTP
  DO 60 K=1, NUMPT
  U(J,K)=U(J,K)+UX(J,K)
  V(J,K)=V(J,K)+VY(J,K)
  DO 60 I=1, 3
  STRESS(I, J, K)=STRESS(I, J, K)+STR(I, J, K)
60 CONTINUE
C
70 CONTINUE
C
C
C
  CALCULATE LOADED HOLE STRESSES
C
  IF(P.EQ.0.0) GO TO 100
  ALPHA0=ALPHA
  PB=P
  CALL LOADED(PB, DIA, S, ALPHA0, STR, UX, VY)
  DO 80 J=1, NUMSTP
  DO 80 K=1, NUMPT
  U(J,K)=U(J,K)+UX(J,K)
  V(J,K)=V(J,K)+VY(J,K)
  DO 80 I=1, 3
  STRESS(I, J, K)=STRESS(I, J, K)+STR(I, J, K)
80 CONTINUE
C
  ALPHA0=ALPHA
  CALL UNLODED(PW, DIA, AI, ALPHA0, STR, UX, VY)
  DO 90 J=1, NUMSTP
  DO 90 K=1, NUMPT
  U(J,K)=U(J,K)+UX(J,K)
  V(J,K)=V(J,K)+VY(J,K)
  DO 90 I=1, 3
  STRESS(I, J, K)=STRESS(I, J, K)+STR(I, J, K)
90 CONTINUE
100 CONTINUE
C
  IF(PUTOUT(IOUT, 3).EQ.2.) WRITE(5, 110)
110 FORMAT(///29X, 'LAMINATE STRESSES'//
1' Y STRESS SHEAR MAX. MIN. ANGLE X STRESS',
29X, 'STRESS PRINCIPAL PRINCIPAL')
  DIST
  MIN.
  DIRECTION'//

```

```

C
C
C
CALCULATE PRINCIPAL STRESSES

IF(PUTOUT(IOUT,3).NE.2.) GO TO 140
DO 130 JJ=1,NUMSTP
DO 130 NN=1,NUMPT
PRINA=(STRESS(1,JJ,NN)-STRESS(2,JJ,NN))*(STRESS(1,JJ,NN)-
1 STRESS(2,JJ,NN))/4.
PRINA=SQRT(PRINA+STRESS(3,JJ,NN)*STRESS(3,JJ,NN))
PRIN1=(STRESS(1,JJ,NN)+STRESS(2,JJ,NN))/2.+PRINA
PRIN2=(STRESS(1,JJ,NN)+STRESS(2,JJ,NN))/2.-PRINA
TSTS=STRESS(1,JJ,NN)-STRESS(2,JJ,NN)
DIRCT=0.
IF(TSTS.NE.0.) DIRCT=.5*ATAN(2.*STRESS(3,JJ,NN)/TSTS)
DIRCT=180.*DIRCT/3.1415926535

C
IF(PUTOUT(IOUT,3).NE.2.) GO TO 140
ANGLE=(NN-1)*IANG+ILOW
DIST=(JJ-1)*STPINK
WRITE(6,120) DIST,ANGLE,STRESS(1,JJ,NN),STRESS(2,JJ,NN),
1 STKENS(3,JJ,NN),PRIN1,PRIN2,DIRCT
120 FORMAT(F6.3,F8.2,5F11.2,F8.2)
130 CONTINUE
140 CONTINUE

C
IF(PUTOUT(IOUT,4).EQ.2.) WRITE(6,150)
150 FORMAT(///28X,'LAMINATE STRAINS'//' DIST ANGLE X STRAIN',
1' Y STRAIN SHEAR MAX. MIN. DIRECTION'/,
239X,'STRAIN PRINCIPAL PRINCIPAL')

C
C
C
CALCULATE LAMINATE STRAINS

DO 160 JJ=1,NUMSTP
DO 160 NN=1,NUMPT
DO 160 KK=1,3
DO 160 MM=1,3
STRAIN(KK,JJ,NN)=AI(KK,MM)*STRESS(MM,JJ,NN)+STRAIN(KK,JJ,NN)
160 CONTINUE

C
C
C
CALCULATE PRINCIPAL STRAINS

IF(PUTOUT(IOUT,4).NE.2.) GO TO 130
DO 180 JJ=1,NUMSTP
DO 180 NN=1,NUMPT
PRINA=(STRAIN(1,JJ,NN)-STRAIN(2,JJ,NN))*(STRAIN(1,JJ,NN)-
1 STRAIN(2,JJ,NN))/4.
PRINA=SQRT(PRINA+STRAIN(3,JJ,NN)*.25*STRAIN(3,JJ,NN))
PRIN1=(STRAIN(1,JJ,NN)+STRAIN(2,JJ,NN))/2.+PRINA
PRIN2=(STRAIN(1,JJ,NN)+STRAIN(2,JJ,NN))/2.-PRINA
TSTS=STRAIN(1,JJ,NN)-STRAIN(2,JJ,NN)
DIRCT=0.
IF(TSTS.NE.0.) DIRCT=.5*ATAN(2.*STRAIN(3,JJ,NN)/TSTS)
DIRCT=180.*DIRCT/3.1415926535
DIST=(JJ-1)*STPINK

C
ANGLE=(NN-1)*IANG+ILOW
WRITE(6,170) DIST,ANGLE,STRAIN(1,JJ,NN),STRAIN(2,JJ,NN),
1 STRAIN(3,JJ,NN),PRIN1,PRIN2,DIRCT
170 FORMAT(F6.3,F8.2,5F11.6,F8.2)
180 CONTINUE
190 CONTINUE

```

```

C
C
C
      CALCULATE CIRCUMFERENTIAL AND RADIAL STRESSES & STRAINS
      IF(PUTOUT(IOUT,5).EQ.2.) WRITE(6,200)
200  FORMAT(///15X,'CIRCUMFERENTIAL AND RADIAL STRESSES & STRAINS',
1//  '  DIST   -ANGLE   THETA   RADIAL   SHEAR   THETA',
2'    RADIAL   SHEAR'/21X,'STRESS   STRESS   ',
3'STRESS   STRAIN   STRAIN   STRAIN')
      IF(PUTOUT(IOUT,5).NE.2.) GO TO 230
      DO 220 J=1,NUMSTP
      DO 220 N=1,NUMPT
      ENERGY=.5*(STRESS(1,J,N)*STRAIN(1,J,N)+STRESS(2,J,N)*
1      STRAIN(2,J,N)+STRESS(3,J,N)*STRAIN(3,J,N))
      ANGLE=(N-1)*IANG+ILOW
      D=ANGLE*PI/180
      DIST=(J-1)*STPINK
      RADSTS=STRESS(1,J,N)*COS(D)*COS(D)+STRESS(2,J,N)*SIN(D)*
1      SIN(D)+2.*STRESS(3,J,N)*SIN(D)*COS(D)
      CIRSTS=STRESS(1,J,N)*SIN(D)*SIN(D)+STRESS(2,J,N)*COS(D)*
1      COS(D)-2.*STRESS(3,J,N)*SIN(D)*COS(D)
      SHRSTS=-1.*STRESS(1,J,N)*SIN(D)*COS(D)+STRESS(2,J,N)*SIN(D)*
1      COS(D)+STRESS(3,J,N)*(COS(D)*COS(D)-SIN(D)*SIN(D))
      RADSTN=STRAIN(1,J,N)*COS(D)*COS(D)+STRAIN(2,J,N)*SIN(D)*
1      SIN(D)+STRAIN(3,J,N)*SIN(D)*COS(D)
      CIRSTN=STRAIN(1,J,N)*SIN(D)*SIN(D)+STRAIN(2,J,N)*COS(D)*
1      COS(D)-STRAIN(3,J,N)*SIN(D)*COS(D)
      SHRSTN=-1.*STRAIN(1,J,N)*SIN(D)*COS(D)+STRAIN(2,J,N)*SIN(D)*
1      COS(D)+STRAIN(3,J,N)*(COS(D)*COS(D)-SIN(D)*SIN(D))
      WRITE(6,210) DIST,ANGLE,CIRSTS,RADSTS,SHRSTS,CIRSTN,RADSTN,
1      SHRSTN
210  FORMAT(F6.3,F10.2,F12.2,2F11.2,3F9.6)
220  CONTINUE
230  CONTINUE
C
C
C
      OUTPUT DISPLACEMENTS
      D3=3.0*DIA
      DISP=DIA/2.0+NUMSTP*STPINK
      IF(PUTOUT(IOUT,6).EQ.2.0.AND.P.NE.0.0.AND.DISP.GT.D3) OUTPUT(6)
1' CAUTION:  DISPLACEMENTS AT POINTS GREATER THAN 3D AWAY ',
2' FROM THE HOLE MAY BE IN ERROR'
      IF(PUTOUT(IOUT,6).EQ.2.) WRITE(6,240)
240  FORMAT(///20X,'DISPLACEMENTS'//  '  DIST   ANGLE'10X,'U'10X,'V')
      IF(PUTOUT(IOUT,6).NE.2.) GO TO 270
      DO 260 J=1,NUMSTP
      DO 260 K=1,NUMPT
      ANGLE=(K-1)*IANG+ILOW
      DIST=(J-1)*STPINK
      WRITE(6,250) DIST,ANGLE,U(J,K),V(J,K)
250  FORMAT(F7.3,F10.2,F13.6,F12.6)
260  CONTINUE
270  CONTINUE
      RETURN
      END

```

```

C
C *****
C
C SUBROUTINE UNLODED(P,DIA,AI,BETA,STRESS,U,V)
C
C CALCULATE STRESS DISTRIBUTION AROUND AN UNLOADED HOLE
C
COMMON/THREE/IANG,ILOW,IHIGH,STPINK,NUMSTP
REAL IANG,ILOW,IHIGH
DIMENSION STRESS(3,7,73),U(7,73),V(7,73),AI(3,3)
DIMENSION WORK(5),COEF(5),RTR(4),RTI(4)
COMPLEX R1,R2,COMPLX,XI1,XI2,COM1,COM2,DEN1,DEN2,PHI1,PHI2
COMPLEX Z,Z1,Z2,P1,P2,Q1,Q2

C
C CALCULATE COMPLEX PARAMETERS
C
C INITIALIZE COMPLEX NUMBER:  SQRT(-1.)
C
COMPLX=(0.,1.)
NUMCO=4
COEF(1)=AI(2,2)*1000000
COEF(2)=-2.*AI(2,3)*1000000
COEF(3)=(2.*AI(1,2)+AI(3,3))*1000000
COEF(4)=-2.*AI(1,3)*1000000
COEF(5)=AI(1,1)*1000000
CALL ROOTS(COEF,WORK,NUMCO,RTR,RTI,IE)
R1=RTR(1)+COMPLX*RTI(1)
IF(RTI(2).GT.0.0) R1=RTR(2)+COMPLX*RTI(2)
R2=RTR(3)+COMPLX*RTI(3)
IF(RTI(4).GT.0.0) R2=RTR(4)+COMPLX*RTI(4)
P1=AI(1,1)*R1*R1+AI(1,2)-AI(1,3)*R1
P2=AI(1,1)*R2*R2+AI(1,2)-AI(1,3)*R2
Q1=AI(1,2)*R1+AI(2,2)/R1-AI(2,3)
Q2=AI(1,2)*R2+AI(2,2)/R2-AI(2,3)

C
C
C PI=3.1415926535
C BETA=BETA*PI/180.0
C
C NUMPT=((IHIGH-ILOW)/IANG)+1
C
C DC 20 JJ=1,NUMSTP
C DO 10 NN=1,NUMPT
C
C U(JJ,NN)=0.0
C V(JJ,NN)=0.0
C NNN=NN-1
C JJJ=JJ-1
C
C THETA=(JJ*NUMPT+ILOW)*PI/180.0
C RADIUS=JJJ*STPINK+DIA/2.0
C
C CALCULATE X & Y COORDINATES OF POINTS AROUND UNLOADED HOLE
C
C X=RADIUS*COS(THETA)
C Y=RADIUS*SIN(THETA)
C
C CALCULATE LOCATION PARAMETERS FOR UNLOADED HOLE EQUATIONS
C
C Z1=X+R1*Y
C Z2=X+R2*Y
C Z=X+COMPLX*Y
C

```

```

C     MAPPING FUNCTION
C
X11=CSQRT(Z1*Z1-DIA*DIA/4.-R1*R1*DIA*DIA/4.)
X12=CSQRT(Z2*Z2-DIA*DIA/4.-R2*R2*DIA*DIA/4.)
C
C     CHOOSE CORRECT SIGN OF CSQRT
C
X11=Z1/X11
X12=Z2/X12
C
IF(REAL(X11).LT.-.00001) X11=-1.*X11
IF(REAL(X12).LT.-.00001) X12=-1.*X12
C
X11=1.-X11
X12=1.-X12
C
C     CALCULATE PHI PRIME
C
COM1=R2*SIN(2.*BETA)+2.*COS(BETA)*COS(BETA)+COMPLX*(2.*R2*
1 SIN(BETA)*SIN(BETA)+SIN(2.*BETA))
COM2=R1*SIN(2.*BETA)+2.*COS(BETA)*COS(BETA)+COMPLX*(2.*R1*
1 SIN(BETA)*SIN(BETA)+SIN(2.*BETA))
C
DEN1=2.*DIA*(R1-R2)*(1.+COMPLX*R1)
DEN2=2.*DIA*(R1-R2)*(1.+COMPLX*R2)
C
PHI1=-COMPLX*P*DIA*COM1*X11/(2.*DEN1)
PHI2=COMPLX*P*DIA*COM2*X12/(2.*DEN2)
C
C     CALCULATE STRESSES AROUND HOLE
C
STRESS(1,JJ,NN)=P*COS(BETA)*COS(BETA)+2.*REAL(R1*R1*PHI1+
1 R2*R2*PHI2)
STRESS(2,JJ,NN)=P*SIN(BETA)*SIN(BETA)+2.*REAL(PHI1+PHI2)
STRESS(3,JJ,NN)=P*SIN(BETA)*COS(BETA)-2.*REAL(R1*PHI1+
1 R2*PHI2)
C
C     CALCULATE DISPLACEMENTS
C
X11=1.-X11
X12=1.-X12
C
X11=Z1/X11
X12=Z2/X12
C
DEN1=16.*(R1-R2)*(Z1+X11)
DEN2=16.*(R1-R2)*(Z2+X12)
C
PHI1=-P*DIA*DIA*(COMPLX+R1)*COM1/DEN1
PHI2=P*DIA*DIA*(COMPLX+R2)*COM2/DEN2
C
U(JJ,NN)=2.*REAL(P1*PHI1+P2*PHI2)
V(JJ,NN)=2.*REAL(Q1*PHI1+Q2*PHI2)
C
10 CONTINUE
20 CONTINUE
C
C     RETURN
C     END

```





```

C
C   A COSINE LOAD DISTRIBUTION OVER HALF OF HOLE AT AN ANGLE
C   ALPHA TO X AXIS
C
C   CALCULATE COMPLEX CONSTANTS
C
      PI2=PI/2.0
      M=-1
20  CONTINUE
      M=M+1
      IF(M.EQ.1) GO TO 40
30  CONTINUE
      C1=SIN((M-1)*PI2)/(2*(M-1))
      C2=SIN((M+1)*PI2)/(2*(M+1))
      C3=SIN((M-1)*(-PI2))/(2*(M-1))
      C4=SIN((M+1)*(-PI2))/(2*(M+1))
      C5=COS((M-1)*PI2)/(2*(M-1))
      C6=COS((M+1)*PI2)/(2*(M+1))
      C7=COS((M-1)*(-PI2))/(2*(M-1))
      C8=COS((M+1)*(-PI2))/(2*(M+1))
      CM=P*((C1+C2-C3-C4)-COMPLX*(-C5-C6+C7+C8))/(2.0*PI)
      IF(M.EQ.0) CZERO=CM
      IF(M.GT.1) CPOS(M)=CM
      IF(M.LT.-1) MN=-1*M
      IF(M.LT.-1) CNEG(MN)=CM
      IF(M.LE.0) GO TO 50
      M=-1*M
      GO TO 30
40  CONTINUE
      C1=PI2
      C2=SIN(2.*(PI2))/4.
      C3=SIN(2.*(-PI2))/4.
      C4=SIN(PI2)*SIN(PI2)/2.
      C5=SIN(-PI2)*SIN(-PI2)/2.
      CM=P*((C1+C2-C3)-M*COMPLX*(C4-C5))/(2.*PI)
      IF(M.EQ.1) CPOS(1)=CM
      IF(M.EQ.-1) CNEG(1)=CM
      IF(M.EQ.-1) GO TO 50
      M=-1*M
      GO TO 40
50  CONTINUE
      M=IABS(M)
      IF(M.LT.49) GO TO 20
C
C   TRANSFORM COMPLEX PARAMETERS INTO REAL AND IMAGINARY PARTS
C
      S1=REAL(R1)
      S2=REAL(R2)
      T1=AIMAG(R1)
      T2=AIMAG(R2)

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```

C      EQUATING COEFFICIENTS AND SOLVING FOR CONSTANTS
C
DO 80 M=1,45
MN=M-1
IF(MN.NE.0) GO TO 60
BMATRIX(1)=REAL(-CZERO*DIA/2.)
BMATRIX(2)=AIMAG(-CZERO*DIA/2.)
GO TO 70
60 CONTINUE
BMATRIX(1)=REAL(-CPOS(MN)*DIA/(2.*(MN+1)))
BMATRIX(2)=AIMAG(-CPOS(MN)*DIA/(2.*(MN+1)))
70 CONTINUE
MN=M+1
MNEG=-1*MN
BMATRIX(3)=REAL(-CNEG(MN)*DIA/(2.*(MNEG+1)))
BMATRIX(4)=AIMAG(-CNEG(MN)*DIA/(2.*(MNEG+1)))
AMATRIX(1,1)=T1+1.
AMATRIX(1,2)=S1
AMATRIX(1,3)=T2+1.
AMATRIX(1,4)=S2
AMATRIX(2,1)=S1
AMATRIX(2,2)=-T1-1.
AMATRIX(2,3)=S2
AMATRIX(2,4)=-T2-1.
AMATRIX(3,1)=1.-T1
AMATRIX(3,2)=-S1
AMATRIX(3,3)=1.-T2
AMATRIX(3,4)=-S2
AMATRIX(4,1)=S1
AMATRIX(4,2)=1.-T1
AMATRIX(4,3)=S2
AMATRIX(4,4)=1.-T2
CALL SIMULT(AMATRIX,BMATRIX,4,J)
IF(J.EQ.1)OUTPUT(6)' SIMULT CALCULATES A SINGULAR SET OF EQS.'
A1(M)=BMATRIX(1)+COMPLX*BMATRIX(2)
A2(M)=BMATRIX(3)+COMPLX*BMATRIX(4)
80 CONTINUE
C
PX=2.*PI*AIMAG(COMPLX*DIA*CNEG(1)/2.)
PY=2.*PI*REAL(COMPLX*DIA*CNEG(1)/2.)
C
AMATRIX(1,1)=T1
AMATRIX(1,2)=S1
AMATRIX(1,3)=T2
AMATRIX(1,4)=S2
AMATRIX(2,1)=0.0
AMATRIX(2,2)=1.0
AMATRIX(2,3)=0.0
AMATRIX(2,4)=1.0
AMATRIX(3,1)=2.*S1*T1
AMATRIX(3,2)=S1*S1-T1*T1
AMATRIX(3,3)=2.*S2*T2
AMATRIX(3,4)=S2*S2-T2*T2
AMATRIX(4,1)=-T1/(S1*S1+T1*T1)
AMATRIX(4,2)=S1/(S1*S1+T1*T1)
AMATRIX(4,3)=-T2/(S2*S2+T2*T2)
AMATRIX(4,4)=S2/(S2*S2+T2*T2)
BMATRIX(1)=PX/(4.*PI)
BMATRIX(2)=-PY/(4.*PI)
BMATRIX(3)=(S(1,2)*PY+S(1,3)*PX)/(4.*PI*S(1,1))
BMATRIX(4)=-S(1,2)*PX+S(2,3)*PY/(4.*PI*S(2,2))
CALL SIMULT(AMATRIX,BMATRIX,4,J)
IF(J.EQ.1)OUTPUT(6)' SIMULT CALCULATES A SINGULAR SET OF EQS.'
C
AK1=BMATRIX(1)+COMPLX*BMATRIX(2)
AK2=BMATRIX(3)+COMPLX*BMATRIX(4)

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```

C
NUMPT=(( IHIGH-ILOW)/IANG)+1
ALPHA=-ALPHA*PI/180.0
ALPH=-ALPHA
DO 150 JJ=1, NUMSTP
DO 140 NN=1, NUMPT

C
U(JJ, NN)=0.0
V(JJ, NN)=0.0
NNN=NN-1
JJJ=JJ-1
THETA=(NNN*IANG+ILOW)*PI/180.0
RADIUS=JJJ*STPINK+DIA/2.0

C
C
CALCULATE X AND Y COORDINATES OF POINTS AROUND LOADED HOLE
C
X=RADIUS*COS(THETA+ALPHA)
Y=RADIUS*SIN(THETA+ALPHA)

C
C
CALCULATE PARAMETERS FOR LOADED HOLE EQUATIONS
C
Z1=X+R1*Y
Z2=X+R2*Y
Z=X+COMPLX*Y

C
C
MAPPING FUNCTION
C
C
XXI1=CSQRT(Z1*Z1-DIA*DIA/4.-R1*R1*DIA*DIA/4.)
XXI2=CSQRT(Z2*Z2-DIA*DIA/4.-R2*R2*DIA*DIA/4.)

C
C
CHOOSE CORRECT SIGN OF CSQRT
C
90 CONTINUE
XI1=Z1+XXI1
XI2=Z2+XXI2
XI1=2.*XI1/(DIA*(1.-COMPLX*R1))
XI2=2.*XI2/(DIA*(1.-COMPLX*R2))
COX1=REAL(XI1)*REAL(XI1)+AIMAG(XI1)*AIMAG(XI1)
COX2=REAL(XI2)*REAL(XI2)+AIMAG(XI2)*AIMAG(XI2)
IF(COX1.GE..99999) GO TO 100
XXI1=-XXI1
GO TO 90
100 CONTINUE
IF(COX2.GE..99999) GO TO 110
XXI2=-XXI2
GO TO 90
110 CONTINUE
XXI1=XI1
XXI2=XI2

C
C
CALCULATE PHI PRIME
C
COM1=(0.,0.)
COM2=(0.,0.)
DO 120 M=1,45
COM1=COM1+M*A1(M)*XI1**(-1*M)
COM2=COM2+M*A2(M)*XI2**(-1*M)
120 CONTINUE

```

```

C
C
C
CHECK SIGN OF CSQRT
X11=CSQRT(Z1*Z1-DIA*DIA/4.-DIA*DIA*R1*R1/4.)
X12=CSQRT(Z2*Z2-DIA*DIA/4.-DIA*DIA*R2*R2/4.)
CHECK1=Z1/X11
CHECK2=Z2/X12
IF (REAL(CHECK1).LT.-.00001) X11=-1.*X11
IF (REAL(CHECK2).LT.-.00001) X12=-1.*X12
PHI1=(AK1-COM1)/X11
PHI2=(AK2-COM2)/X12

C
C
C
CALCULATE STRESS COMPONENTS IN LAMINATE AT COORDINATES X,Y
STRX=2.*REAL(R1*R1*PHI1+R2*R2*PHI2)
STRY=2.*REAL(PHI1+PHI2)
STRXY=-2.*REAL(R1*PHI1+R2*PHI2)
STRESS(1,JJ,NN)=STRX*COS(ALPH)*COS(ALPH)+STRY*SIN(ALPH)*
1 SIN(ALPH)-2.*STRXY*SIN(ALPH)*COS(ALPH)
STRESS(2,JJ,NN)=STRX*SIN(ALPH)*SIN(ALPH)+STRY*COS(ALPH)*
1 COS(ALPH)+2.*STRXY*SIN(ALPH)*COS(ALPH)
STRESS(3,JJ,NN)=STRX*SIN(ALPH)*COS(ALPH)-STRY*SIN(ALPH)*
1 COS(ALPH)+STRXY*(COS(ALPH)*COS(ALPH)-
2 SIN(ALPH)*SIN(ALPH))

C
C
C
CALCULATE DISPLACEMENTS
X11=XXI1
X12=XXI2
COM1=(0.,0.)
COM2=(0.,0.)
DO 130 M=1,45
COM1=COM1+A1(M)*X11**(-1*M)
COM2=COM2+A2(M)*X12**(-1*M)
130 CONTINUE
XXI1=CLOG(X11)
XXI2=CLOG(X12)
PHI1=AK1*XXI1+COM1
PHI2=AK2*XXI2+COM2
U(JJ,NN)=2.*REAL(P1*PHI1+P2*PHI2)
V(JJ,NN)=2.*REAL(Q1*PHI1+Q2*PHI2)

C
140 CONTINUE
150 CONTINUE

C
RETURN
END

```

```

C
C *****
C
SUBROUTINE PLYSTR(IFAIL)
C
C TRANSFORMS LAMINATE STRAINS TO PLY STRESSES/STRAINS BY ASSUMING
C CONSTANT STRAIN THROUGH THE THICKNESS
C
COMMON/ONE/E1(3),E2(3),G12(3),V12(3)
COMMON/TWO/IOUT(15),NUMPLY,NUMMAT,ANG(8),PLYTHK(8),MATID(8)
COMMON/THREE/IANG,ILOW,IHIGH,STPINK,NUMSTP
COMMON/EIGHT/STRESS(3,7,73),STRAIN(3,7,73)
COMMON/NINE/STR1(8,7,73),STR2(8,7,73),STR12(8,7,73)
REAL IANG,ILOW,IHIGH
C
C STRAINS PER PLY
C
MOVE=0
NUMPT=((IHIGH-ILOW)/IANG)+1
IF(PUTOUT(IOUT,7).EQ.2.) WRITE(6,10)
10 FORMAT(///20X,'STRAINS PER PLY',///' DIST ANGLE PLY',
1' STRAIN 1 STRAIN 2 SHEAR STRAIN'/)
20 CONTINUE
DO 40 JJ=1,NUMSTP
DO 40 NN=1,NUMPT
DO 40 L=1,NUMPLY
D=ANG(L)*3.1415926535/180.0
STRANX=STRAIN(1,JJ,NN)
STRANY=STRAIN(2,JJ,NN)
GAMA=STRAIN(3,JJ,NN)
C
STRAN1=STRANX*COS(D)*COS(D)
STRAN2=STRANY*SIN(D)*SIN(D)
GAMA12=GAMA*SIN(D)*COS(D)
STR1(L,JJ,NN)=STRAN1+STRAN2+GAMA12
STRAN1=STRANX*SIN(D)*SIN(D)
STRAN2=STRANY*COS(D)*COS(D)
GAMA12=-1.*GAMA*SIN(D)*COS(D)
STR2(L,JJ,NN)=STRAN1+STRAN2+GAMA12
STRAN1=-2.*STRANX*SIN(D)*COS(D)
STRAN2=2.*STRANY*SIN(D)*COS(D)
GAMA12=GAMA*COS(D)*COS(D)-GAMA*SIN(D)*SIN(D)
STR12(L,JJ,NN)=STRAN1+STRAN2+GAMA12
C
ANGLE=(NN-1)*IANG+ILOW
DIST=(JJ-1)*STPINK
IF(PUTOUT(IOUT,7).EQ.2.) WRITE(6,30)DIST,ANGLE,ANG(L),
1STR1(L,JJ,NN),STR2(L,JJ,NN),STR12(L,JJ,NN)
30 FORMAT(F6.3,2F8.2,3F12.6)
C
C
C
C
40 CONTINUE
IF(MOVE.EQ.1) GO TO 80

```

```

C
C
C
      STRESSES PER PLY
      IF(PUTOUT(IOUT,8).EQ.2.) WRITE(6,50)
50  FORMAT(///20X,'STRESSES PER PLY',//'  DIST    ANGLE    PLY',
1'   STRESS 1    STRESS 2    SHEAR STRESS'/)
      DO 70 JJ=1,NUMSTP
      DO 70 NN=1,NUMPT
      DO 70 L=1,NUMPLY
      M=MATID(L)
      V21=V12(M)*E2(M)/E1(M)
      DEN=1.-V12(M)*V21
      ABC=STR2(L,JJ,NN)/DEN
      BCA=STR1(L,JJ,NN)
C
      STR1(L,JJ,NN)=E1(M)*STR1(L,JJ,NN)/DEN+V12(M)*E2(M)*ABC
      STR2(L,JJ,NN)=V12(M)*E2(M)*BCA/DEN+E2(M)*ABC
      STR12(L,JJ,NN)=STR12(L,JJ,NN)*G12(M)
C
      ANGLE=(NN-1)*IANG+ILOW
      DIST=(JJ-1)*STPINK
      IF(PUTOUT(IOUT,8).EQ.2.) WRITE(6,60)DIST,ANGLE,ANG(L),
1STR1(L,JJ,NN),STR2(L,JJ,NN),STR12(L,JJ,NN)
60  FORMAT(F6.3,2F8.2,3F12.2)
C
      70 CONTINUE
      MOVE=1
      IF(IFAIL.EQ.1) GO TO 20
      80 CONTINUE
C
      RETURN
      END
C
C
C
*****
C
      SUBROUTINE FAILURE
C
      POINT STRESS/STRAIN ANALYSIS FOR FAILURE USING UNIDIRECTIONAL
      MATERIAL ALLOWABLES
C
      COMMON/TWO/IOUT(15),NUMPLY,NUMMAT,ANG(8),PLYTHK(8),MATID(8)
      COMMON/THREE/IANG,ILOW,IHIGH,STPINK,NUMSTP
      COMMON/FOUR/PX,PY,PXY,P,PW,ALPHA,BETA,DIA,CORRECT
      COMMON/FIVE/FXT(3),FXC(3),FYT(3),FYC(3),FXY(3),IFAIL
      COMMON/NINE/STR1(8,7,73),STR2(8,7,73),STR12(8,7,73)
      REAL IANG,ILOW,IHIGH
      DIMENSION PLYFAIL(3,8),FAILS(3,8),RATIO(3,8),PLYRATO(3,8)
C
      IF(PUTOUT(IOUT,9).NE.2.) GO TO 40
      IF(IFAIL.GT.2) GO TO 20
      WRITE(6,10)
10  FORMAT(///20X,'FAILURE CRITERIA PER PLY',//'  DIST    ANGLE ',
1'   PLY',12X,'FAILURE NUMBERS'/35X,'1    2    SHEAR')
      GO TO 40
20  CONTINUE
      WRITE(6,30)
30  FORMAT(///20X,'FAILURE CRITERIA PER PLY',//'  DIST    ANGLE ',
1'   PLY    FAILURE    FAILURE RATIOS'/32X'NUMBER    ',
2'   1    2    SHEAR')
40  CONTINUE

```

```

CHECK=0.
KKK=1
F2=0.0
F3=0.0
NUMPT=(( IHIGH-ILOW)/IAN )+1
DO 170 JJ=1, NUMSTP
DO 170 KK=1, NUMPT
SIG=1.0
DO 160 II=1, NUMPLY
C
X=STR1(II, JJ, KK)
Y=STR2(II, JJ, KK)
XY=STR12(II, JJ, KK)
MATII=MATID(II)
C
C
GO TO (50,50,60,70,80) IFAIL
C
50 CONTINUE
C
C
MAXIMUM STRESS/STRAIN
C
FX=FXT(MATII)
IF(X.LT.0.0) FX=FXC(MATII)
FY=FYT(MATII)
IF(Y.LT.0.0) FY=FYC(MATII)
F1=X/FX
F2=Y/FY
F3=XY/FXY(MATII)
GO TO 90
C
C
60 CONTINUE
C
C
TSAI-HILL CRITERIA
C
FX=FXT(MATII)
IF(X.LT.0.0) FX=FXC(MATII)
FY=FYT(MATII)
IF(Y.LT.0.0) FY=FYC(MATII)
F1=X*X/(FX*FX)+Y*Y/(FY*FY)-X*Y/(FX*FX)+
1 XY*XY/(FXY(MATII)*FXY(MATII))
RATIOX=(X/FX)/SQRT(F1)
RATIOY=(Y/FY)/SQRT(F1)
RATIOXY=(XY/FXY(MATII))/SQRT(F1)
GO TO 90
C
C
70 CONTINUE
C
C
MODIFIED TSAI-WU CRITERIA
C
F1=1./FXT(MATII)-1./FXC(MATII)
F2=1./FYT(MATII)-1./FYC(MATII)
F11=1./(FXT(MATII)*FXC(MATII))
F22=1./(FYT(MATII)*FYC(MATII))
F66=1./(FXY(MATII)*FXY(MATII))
F1=F1*X+F2*Y+F11*X*X+F22*Y*Y+F66*XY*XY
FX=FXT(MATII)
IF(X.LT.0.0) FX=FXC(MATII)
FY=FYT(MATII)
IF(Y.LT.0.0) FY=FYC(MATII)
F1=ABS(F1)
RATIOX=(X/FX)/SQRT(F1)
RATIOY=(Y/FY)/SQRT(F1)
RATIOXY=(XY/FXY(MATII))/SQRT(F1)
GO TO 90

```



80 CONTINUE

C  
C  
C

HOFFMAN FAILURE CRITERIA

```
F1=1./FXT(MATII)-1./FXC(MATII)
F2=1./FYT(MATII)-1./FYC(MATII)
F11=1./(FXT(MATII)*FXC(MATII))
F22=1./(FYT(MATII)*FYC(MATII))
F66=1./(FXY(MATII)*FXC(MATII))
F12=-1./(FXT(MATII)*FXC(MATII))
F1=F1*X+F2*Y+F11*X*X+F22*Y*Y+F12*X*Y+F66*XY*XY
FX=FXT(MATII)
IF(X.LT.0.0) FX=FXC(MATII)
FY=FYT(MATII)
IF(Y.LT.0.0) FY=FYC(MATII)
F1=ABS(F1)
RATIOX=(X/FX)/SQRT(F1)
RATIOY=(Y/FY)/SQRT(F1)
RATIOXY=(XY/FXY(MATII))/SQRT(F1)
GO TO 90
```

C  
C  
C

90 CONTINUE

```
ANGLE=(KK-1)*IANG+ILOW
DIST=(JJ-1)*STPINK
IF(IFAIL.GT.2) GO TO 110
IF(PUTOUT(IOUT,9).EQ.2.) WRITE(6,100) DIST,ANGLE,ANG(II),
1F1,F2,F3
100 FORMAT(F7.3,2F10.2,3F10.3)
GO TO 130
110 CONTINUE
IF(PUTOUT(IOUT,9).EQ.2.) WRITE(6,120) DIST,ANGLE,ANG(II),
1F1,RATIOX,RATIOY,RATIOXY
120 FORMAT(F7.3,2F10.2,4F10.3)
130 CONTINUE
```

C  
C  
C

AUTOMATIC SEARCH FOR FAILURE ROUTINE

```
IF(SIG.EQ.2.) FAILS(1,II)=F1
IF(SIG.EQ.2.) FAILS(2,II)=F2
IF(SIG.EQ.2.) FAILS(3,II)=F3
IF(SIG.EQ.2.) RATIO(1,II)=RATIOX
IF(SIG.EQ.2.) RATIO(2,II)=RATIOY
IF(SIG.EQ.2.) RATIO(3,II)=RATIOXY
IF(JJ.NE.2) GO TO 150
PLYFAIL(1,II)=F1
PLYFAIL(2,II)=F2
PLYFAIL(3,II)=F3
PLYRATO(1,II)=RATIOX
PLYRATO(2,II)=RATIOY
PLYRATO(3,II)=RATIOXY
CHK=CHECK
IF(ABS(CHECK).LT.ABS(F1)) CHECK=F1
IF(ABS(CHECK).LT.ABS(F2)) CHECK=F2
IF(ABS(CHECK).LT.ABS(F3)) CHECK=F3
IF(CHECK.EQ.CHK) GO TO 150
KKK=KK
III=II
SIG=2.0
DO 140 M=1,III
DO 140 N=1,3
FAILS(N,M)=PLYFAIL(N,M)
RATIO(N,M)=PLYRATO(N,M)
140 CONTINUE
150 CONTINUE
```

```

C
C
160 CONTINUE
170 CONTINUE
C
C
IF(CHECK.EQ.0.0) GO TO 260
IF(IFAIL.EQ.1) CORRECT=1.0/ABS(CHECK)
IF(IFAIL.EQ.2) CORRECT=1.0/ABS(CHECK)
IF(IFAIL.EQ.3) CORRECT=1.0/SQRT(CHECK)
IF(IFAIL.EQ.4) CORRECT=1.0/SQRT(CHECK)
IF(IFAIL.EQ.5) CORRECT=1.0/SQRT(CHECK)
C
IF(PUTOUT(IOUT,10).NE.2.) GO TO 250
IF(CORRECT.LT..999.OR.CORRECT.GT.1.001) GO TO 250
ANGLE=(KKK-1)*IANG+ILOW
C
IF(IFAIL.GT.2) GO TO 210
WRITE(6,190) PX,PY,PXY,P
180 FORMAT(///20X,'AUTOMATIC SEARCH FOR FAILURE'//25X,
1'FAILURE STRESSES'/19X,'PX',10X,'PY',10X,'PXY',10X,'P'//,
211X,4F12.2//9X,'DIST ANGLE PLY FAILURE NUMBERS'//,
336X,'1 2 SHEAR')
C
DO 200 I=1,NUMPLY
WRITE(6,190) STPINK,ANGLE,ANG(I),FAILS(1,I),FAILS(2,I),FAILS(3,I)
190 FORMAT(F11.3,F9.2,F10.2,3F8.3)
200 CONTINUE
GO TO 260
C
210 CONTINUE
WRITE(6,220) PX,PY,PXY,P
220 FORMAT(///20X,'AUTOMATIC SEARCH FOR FAILURE'//25X,
1'FAILURE STRESSES'/19X,'PX',10X,'PY',10X,'PXY',10X,'P'//,
211X,4F12.2//5X,' DIST ANGLE PLY FAILURE ',
39X,'FAILURE RATIOS'/35X,'NUMBER',7X,'1',9X,'2',7X,'SHEAR')
DO 240 I=1,NUMPLY
WRITE(6,230) STPINK,ANGLE,ANG(I),FAILS(1,I),RATIO(1,I),
1 RATIO(2,I),RATIO(3,I)
230 FORMAT(F11.3,F9.2,F10.2,4F10.3)
240 CONTINUE
250 CONTINUE
C
C
260 CONTINUE
IF(PUTOUT(IOUT,10).NE.2.) CORRECT=1.0
C
RETURN
END

```

```

C *****
C SUBROUTINE SIMULT(A,B,N,KS)
C TEST FOR ALGORITHMIC SINGULARITY ADDED 01/10/79
C DIMENSION A(1),B(1)
C MACHINE EPSILON FOR CYBER SINGLE PRECISION
DATA EPS/7.11E-15/
TOL=3.16*EPS*(N-1)
BETA=0.0
KS=0
JJ=-N
DO 65 J=1,N
JY=J+1
JJ=JJ+N+1
BIGA=0.0
IT=JJ-J
DO 30 I=J,N
IJ=IT+I
IF(ABS(BIGA)-ABS(A(IJ))) 20,30,30
20 BIGA=A(IJ)
IMAX=I
30 CONTINUE
IF(ABS(BIGA).GT.BETA)BETA=ABS(BIGA)
IF(ABS(BIGA)-TOL*BETA) 35,35,40
35 KS=1
RETURN
40 I1=J+N*(J-2)
IT=IMAX-J
DO 50 K=J,N
I1=I1+N
I2=I1+IT
SAVE=A(I1)
A(I1)=A(I2)
A(I2)=SAVE
50 A(I1)=A(I1)/BIGA
SAVE=B(IMAX)
B(IMAX)=B(J)
B(J)=SAVE/BIGA
IF(J=N) 55,70,55
55 IQS=N*(J-1)
DO 65 IX=JY,N
IXJ=IQS+IX
IT=J-IX
DO 60 JX=JY,N
IXJX=N*(JX-1)+IX
JJK=IXJX+IT
60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJK))
65 B(IX)=B(IX)-(B(J)*A(IXJ))
70 NY=N-1
IT=N*N
DO 80 J=1,NY
IA=IT-J
IB=N-J
IC=N
DO 80 K=1,J
B(IB)=B(IB)-A(IA)*B(IC)
IA=IA-N
80 IC=IC-1
RETURN
END

```

```

C *****
SUBROUTINE ROOTS(XCOF,COF,M,ROOTR,ROOTI,IER)
DIMENSION XCOF(M),COF(M),ROOTR(M),ROOTI(M)
DOUBLE PRECISION XO,YO,X,Y,XPR,YPR,UX,UY,V,YT,XT,U
1           ,YT2,YT2,SUMSQ,DX,DY,TEMP,ALPHA,FI
2           ,RMPREC,TOL
C RELATIVE MACHINE PRECISION (TEST FOR 'ALMOST ZERO')
DATA RMPREC/1.0D-14/ ,TOL/1.0D-4/
IFIT=0
N=M
IER=0
IF(XCOF(N+1)) 10,30,10
10 IF(N) 20,20,50
20 IER=1
GO TO 360
30 IER=4
GO TO 360
40 IER=2
GO TO 360
50 IF(N-36) 60,60,40
60 NX=N
NXX=N+1
N2=1
KJ1 = N+1
DO 70 L=1,KJ1
MT=KJ1-L+1
70 COF(MT)=XCOF(L)
80 XO=.00500101D0
YO=0.01000101D0
IN=0
90 X=XO
XO=-10.D0*YO
YO=-10.D0*X
X=XO
Y=YO
IN=I+1
GO TO 110
100 IFIT=1
XPR=X
YPR=Y
110 ICT=0
120 UX=0.D0
UY=0.D0
V =0.D0
YT=0.D0
XT=1.D0
U=COF(N+1)
IF(DABS(U).LE.RMPREC)GO TO 280
130 DO 140 I=1,N
L =N-I+1
TEMP=COF(L)
XT2=X*XT-Y*YT
YT2=X*YT+Y*XT
U=U+TEMP*XT2
V=V+TEMP*YT2
FI=I
UX=UX+FI*XT*TEMP
UY=UY-FI*YT*TEMP
XT=XT2
140 YT=YT2
SUMSQ=UX*UX+UY*UY
IF(SUMSQ.LE.RMPREC)GO TO 230
150 DX=(V*UY-U*UX)/SUMSQ

```

```

X=X+DX
DY=-(U*UY+V*UX)/SUMSQ
Y=Y+DY
160 IF( DABS(DY)+ DABS(DX).LE.TOL) GO TO 210
170 ICT=ICT+1
    IF(ICT-500) 120,180,180
180 IF(IFIT) 210,190,210
190 IF(IN-5) 90,200,200
200 IER=3
    GO TO 360
210 DO 220 L=1,NXX
    IPT=KJ1-L+1
    RTEMP=XCOF(MT)
    XCOF(MT)=COF(L)
220 COF(L)=RTEMP
    ITEMP=N
    N=NX
    NX=ITEMP
    IF(IFIT) 250,100,250
230 IF(IFIT) 240,90,240
240 X=XPR
    Y=YPR
    GO TO 210
250 IFIT=0
260 IF(DABS(Y)-1.0D-4*DABS(X)) 290,270,270
270 ALPHA=X+X
    SUMSQ=X*X+Y*Y
    N=N-2
    GO TO 300
280 X=0.DO
    NX=NX-1
    NXX=NXX-1
290 Y=0.DO
    SUMSQ=0.DO
    ALPHA=X
    N=N-1
300 COF(2)=COF(2)+ALPHA*COF(1)
310 DO 320 L=2,N
320 COF(L+1)=COF(L+1)+ALPHA*COF(L)-SUMSQ*COF(L-1)
330 ROOTI(N2)=Y
    ROOTR(N2)=X
    N2=N2+1
    IF(SUMSQ.IE.RMPREC) GO TO 350
340 Y=-Y
    SUMSQ=0.DO
    GO TO 330
350 IF(N.GT.0)GO TO 80
360 RETURN
    END

```