7/22/92
E 6944

NASA Technical Memorandum 105607

METCAN Demonstration Manual
Version 1.0

H.-J. Lee and P.L.N. Murthy
Lewis Research Center
Cleveland, Ohio

April 1992

NASA

METCAN DEMONSTRATION MANUAL

VERSION 1.0

JANUARY 1992

Prepared by:

H.-J. Lee and P.L.N. Murthy

NASA Lewis Research Center

Cleveland, Ohio 44135

Table of Contents

1.0 Introduction

METCAN (Metal Matrix Composite Analyzer) is a computer program developed at NASA Lewis Research Center (References 1-3) to simulate the high temperature nonlinear behavior of continuous fiber reinforced metal matrix composites. METCAN incorporates constituent material models along with composite micromechanical and macromechanical models to allow a comprehensive point analysis of the composite thermal and mechanical behavior.

The following sections contain problems demonstrating the various features and capabilities of METCAN. Each demonstration problem is complete and independent of the other problems. The general format for each problem contains brief descriptions of the problem, model, loading history, and a complete listing of the corresponding input file. Section 1.0 will begin with an overview of METCAN, followed by a brief review of the input file and the micromechanical unit cell model. Section 2.0 will contain static problems using the linear and discrete loading history options, while section 3.0 will feature problems demonstrating the cyclic analysis. Section 4.0 will show a complete output file, while section 5.0 will list the constituent databank used for the problems in this manual.

For more detailed discussions regarding the methodologies implemented in METCAN, the reader is referred to the METCAN User's Manual (Reference 4) and the upcoming METCAN Theoretical Manual. The Demonstration Manual is not intended to be a stand alone manual and should be used in conjunction with the other manuals. Additional information regarding METCAN and the efforts to validate and verify the code can be found in References 5-9.

1.1 METCAN Overview

High temperature metal matrix composites offer great potential for use in advanced aerospace structural applications. The realization of this goal however, requires concurrent developments in (1) a technology base for fabricating high temperature metal matrix composite structural components, (2) experimental techniques for measuring thermal and mechanical characteristics, and (3) computational methods to predict their behavior. In the development of high temperature metal matrix composites, it proves beneficial to initially simulate their behavior through computational methods. In addition to providing an initial assessment of the metal matrix composite, this method helps to minimize the costly and time consuming experimental effort that would otherwise be required.

Recent research into computational methods for simulating the nonlinear behavior of high temperature metal matrix composites at NASA Lewis Research Center has led to the development of the METCAN (Metal Matrix Composite Analyzer) computer code. METCAN treats material nonlinearity at the constituent (fiber, matrix, and interphase) level, where the behavior of each constituent is modelled using a time-temperature-stress dependence. The composite properties are synthesized from the constituent instantaneous properties by making use of composite micromechanics and composite macromechanics models. Factors which affect the behavior of the composite properties include the fabrication process variables, the in-situ fiber and matrix properties, the bonding between the fiber and matrix, and/or the properties of the interphase between the fiber and matrix. The METCAN simulation is performed as a point-wise analysis and produces composite properties which can be incorporated into a finite element code to perform a global structural analysis. After the global structural analysis is performed, METCAN decomposes the composite properties back into the localized response at the various levels of the simulation. At this point the constituent properties are updated and the next iteration in the analysis is initiated. This cyclic procedure is referred to as the integrated approach to metal matrix composite analysis and is depicted in figure 1.1-1.

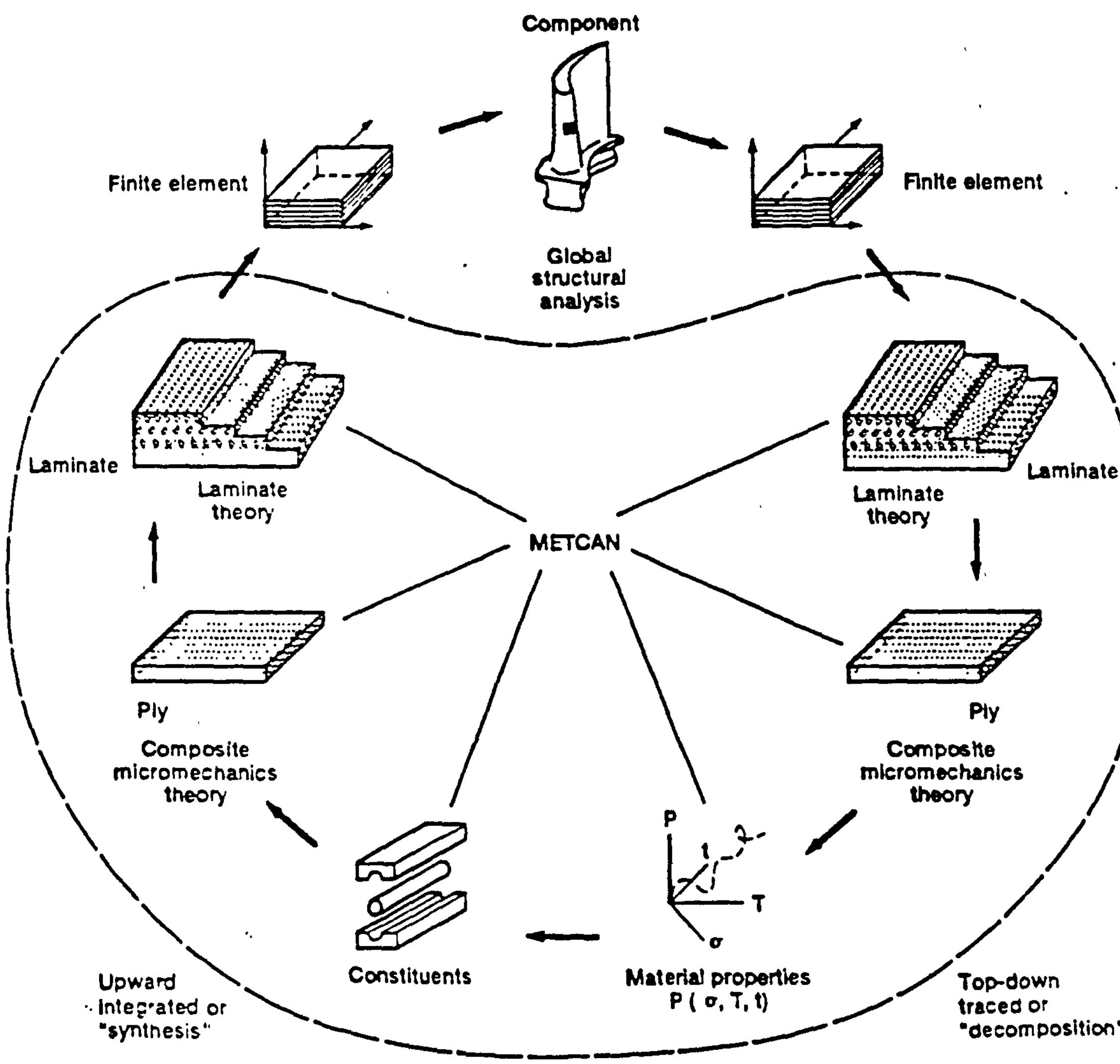


Figure 1.1-1—Integrated approach to metal-matrix composite analysis.

Figure 1.1-2 shows the modular structure of METCAN. In the development of METCAN, emphasis has been placed on maintaining a modular software structure and in providing a user friendly interface. The code features (1) a dynamic storage allocation scheme for efficient use of computer resources, (2) a resident databank of constituent material properties, (3) user selected control of the printed output, (4) generation of postprocessing files for convenient graphical representation, (5) an input file structure which provides a straightforward user interface, and (6) separate modules containing the failure criteria, the material model, the composite micromechanics analysis, and the laminate analysis which are incorporated into METCAN.

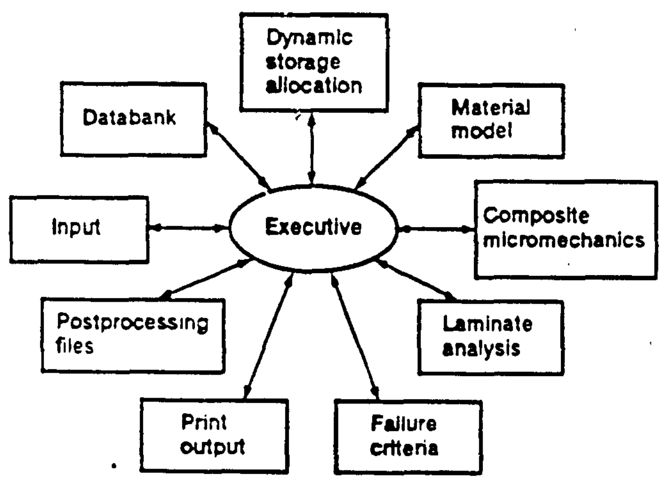


Figure 1.1-2—Modular structure of METCAN.

1.2 Input Data Records

The METCAN input file structure provides a straightforward user interface. The input file is organized into different records in a specific order. Each record in the input file must be ordered as they are defined in figure 1.2-1, where each record can be composed of one or several physical lines of data. Each line of data has a fixed format of ten eight-column fields (except for the title and comment records). The usual convention is that each record is identified by a character mnemonic in the first field of the data. The character mnemonics and other alphanumeric data are entered with character format (A8), while integer data are entered in integer format (I8). Real data can be entered in either floating point (F8) or exponential (E8) formats. Alphanumeric, integer, and exponential formats must be right justified, while the floating point format can be entered anywhere in the appropriate field. Figure 1.2-1 describes the individual records required in the input file, the mnemonic which identifies the record, the number of lines of data which comprise each record, and the order in which each record is read by METCAN. Detailed information regarding each record can be found in the METCAN User's Manual (Reference 4), which should be read prior to the Demonstration Manual in order to benefit most from the various demonstration problems.

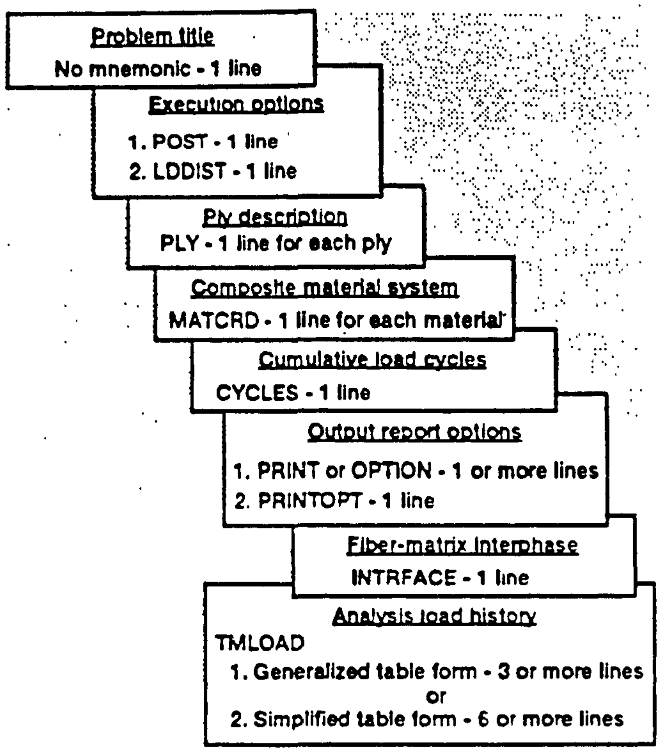
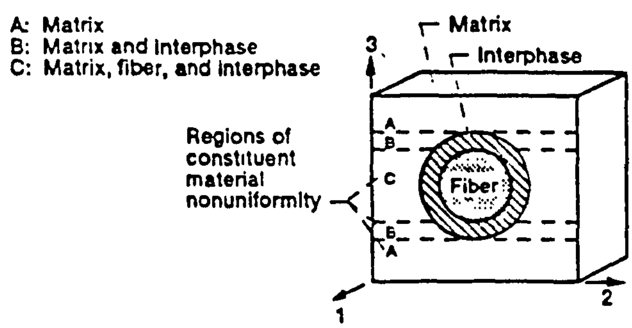


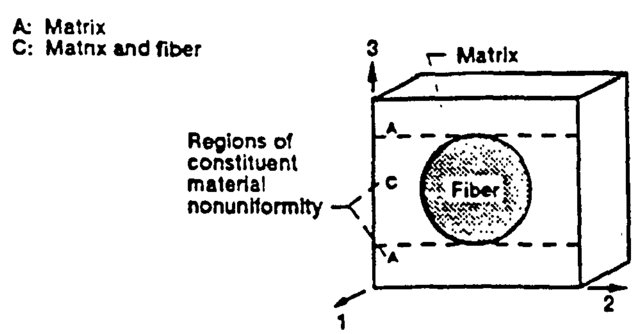
Figure 1.2-1.—Composition of the primary input data file.

1.3 Micromechanical Unit Cell and Subregions

There are two alternative versions of the generic unit cell model used in METCAN, as shown in figure 1.3-1. A typical unit cell consists of a fiber and a matrix with or without an interphase. The unit cell is further subdivided into two or three subregions depending on the presence of an interphase. If an interphase is present, subregion A consists entirely of matrix material, subregion B consists of matrix and interphase, and subregion C consists of fiber, matrix, and interphase. If there is no interphase, only two subregions exist. Subregion A consists entirely of matrix material, while subregion C consists of fiber and matrix, and subregion B does not exist. The user is expected to be familiar with the unit cell terminology described here in order to interpret the printed output.



(a) Unit cell with an interphase.



(b) Unit cell without an interphase.

Figure 1.3-1.—METCAN generic unit cells.

2.0 Static Analysis

Four problems highlighting various features of METCAN for static analysis are presented. Three of the problems involve a linear loading history, while the fourth problem utilizes a nonlinear loading history. All problems begin with a fabrication process simulation to account for any residual effects. The first demonstration problem simulates the longitudinal stress-strain behavior of a cross ply laminate subjected to a longitudinal tensile load at room temperature. The second problem tracks the variation of longitudinal fiber modulus in an angle plied laminate under a pressure load containing a temperature gradient through the thickness. The third demonstration problem shows the matrix shear strengths at different points in the loading history for an angle plied laminate under a combination of moment and shear loads at an elevated temperature. The fourth problem shows the development of transverse matrix stresses at different points in the loading history for an angle plied laminate subjected to a nonlinear transverse compressive load with increasing temperature.

2.1 Demonstration Problem 1

Description: Longitudinal Stress-Strain Behavior of a Cross-Ply Laminate Subjected to Longitudinal Tensile Load at Room Temperature

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A cross-ply laminate

(2) An interphase between the fiber and matrix

(3) Laminate stress-strain behavior

(4) A linear loading history

(5) A monotonic longitudinal tensile loading

(6) Residual effects arising from processing

Model Description:

A cross-ply $[0/90]_S$ laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-15V-3Cr-3Al-3Sn) matrix is modelled. An interphase with a thickness of 5% of the fiber diameter is used. The interphase moduli and strengths are taken as 25% of the respective matrix values. All other interphase properties are assumed to be equal to their corresponding matrix values. Each ply has a fiber volume ratio (FVR) of 35%, a void volume ratio (VVR) of 0%, and a thickness of 0.005 inches. The laminate configuration is shown in table 2.1-1.

Table 2.1-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.35	0.0	SiC/ Ti-15-3
2	90°	0.005"	0.35	0.0	SiC/ Ti-15-3
3	90°	0.005"	0.35	0.0	SiC/ Ti-15-3
4	0°	0.005"	0.35	0.0	SiC/ Ti-15-3

Loading History:

The loading history for this problem is divided into two linear segments as shown in figure 2.1-1. The first segment simulates the processing of the laminate as a cool down

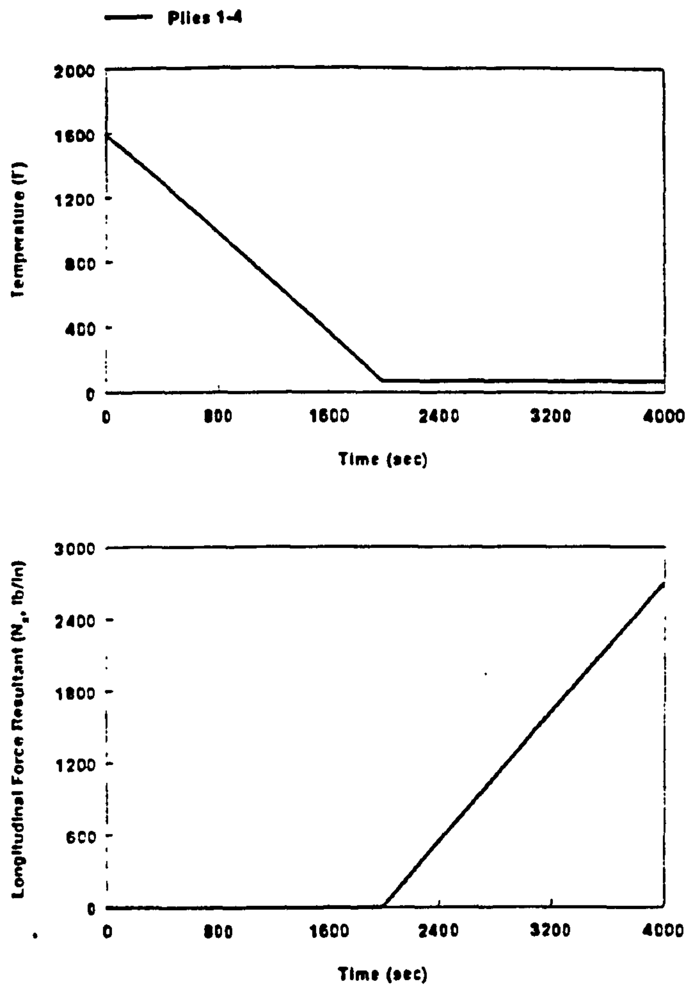


Figure 2.1-1.—Demonstration problem 1: Loading history.

from the processing temperature (1600°F) to room temperature (70°F) in the absence of mechanical loads. The second segment models the application of a 2700 lb/in longitudinal tensile load (N_x) at room temperature. The first segment is divided into 45 load steps and the second segment into 25 load steps for a total of 70 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 2.1-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The room temperature stress-strain behavior of the SiC/Ti-15-3 laminate subjected to a longitudinal tensile load is shown in figure 2.1-3. The nonlinear stress-strain behavior depicted in the figure demonstrates the ability of METCAN to capture the nonlinear behavior of metal matrix composites.

```
METCAN DEMONSTRATION PROBLEM 1
$ No postprocessing files requested.
   POST      T
$ No load redistribution option.
  LDOIST     F
$ Ply details: ply no, matcrd no, orientation and thickness.
     PLY      1       1     0.    .005
     PLY      2       1    90.    .005
     PLY      3       1 .  90.    .005
     PLY      4       1     0.    .005
$ Material details: matcrd no, fvr, vvr and fiber/matrix.
  MATCRD      1     .35     0.SICATI15
$ Number of mechanical and thermal cycles requested.
  CYCLES      1       1
$ Output requests.
   PPINT    ALL
$ Print output at all load steps.
PRINTOPT    LAST
$ Interphase details.
INTFACE       1     .05
$ Simplified table input.
  TMLOAD     -2
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing
     0.   2000.     45
$ Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.
    70.     70.     70.     70.
$ Mechanical loads at the beginning and end of the processing.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: application of longitudinal load.
$ Start time, end time ,and number of increments for loading.
   2000.   4000.    25
$ Temperature in each ply at the beginning and end of loading.
    70.     70.     70.     70.
    70.     70.     70.     70.
$ Mechanical loads at the beginning and end of loading.
     0.      0.      0.      0.      0.     .0.      0.      0.      0.      0.
   2700.     0.      0.      0.      0.      0.      0.      0.      0.      0.
$ End data.
```

Figure 2.1-2.—Demonstration problem 1: Input data file.

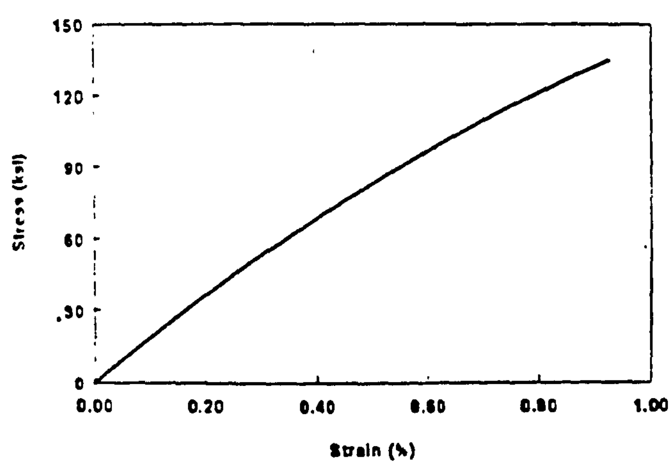


Figure 2.1-3.—Demonstration problem 1: Longitudinal stress-strain behavior of $[0/90]_s$ SiC/Ti-15 at 70 °F.

2.2 Demonstration Problem 2

Description: Longitudinal Fiber Modulus Variation of a Unidirectional Laminate Containing Temperature Gradients Through-the-Thickness and Subjected to a Pressure Loading

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A linear loading history

(2) A monotonic pressure loading

(3) A perfect bond between the fiber and matrix

(4) Residual effects arising from processing

(5) Temperature gradients within a laminate

(6) Track the development of fiber modulus

(7) A unidirectional laminate

Model Description:

A four ply unidirectional $[0]_4$ laminate composed of tungsten (W) fibers and a copper (Cu) matrix is modelled. A perfect bond between the fiber and matrix is modelled.

Each ply has a fiber volume ratio (FVR) of 40%, a void volume ratio (VVR) of 0%, and a thickness of 0.010 inches. The laminate configuration is shown in table 2.2-1.

Table 2.2-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.010"	0.40	0.0	W/Cu
2	0°	0.010"	0.40	0.0	W/Cu
3	0°	0.010"	0.40	0.0	W/Cu
4	0°	0.010"	0.40	0.0	W/Cu

Loading History:

The loading history for this problem is divided into three linear segments as shown in figure 2.2-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1400°F) to room temperature (70°F) in the absence of mechanical loads. The second segment involves heating up the individual plies of the laminate to different use temperatures (800°F for ply 1, 700°F for ply 2, 600°F for ply 3, and 500°F for ply 4), again in the absence of mechanical loads. The third segment models the application of a 1000 psi lower surface pressure (P_l) psi on the laminate with

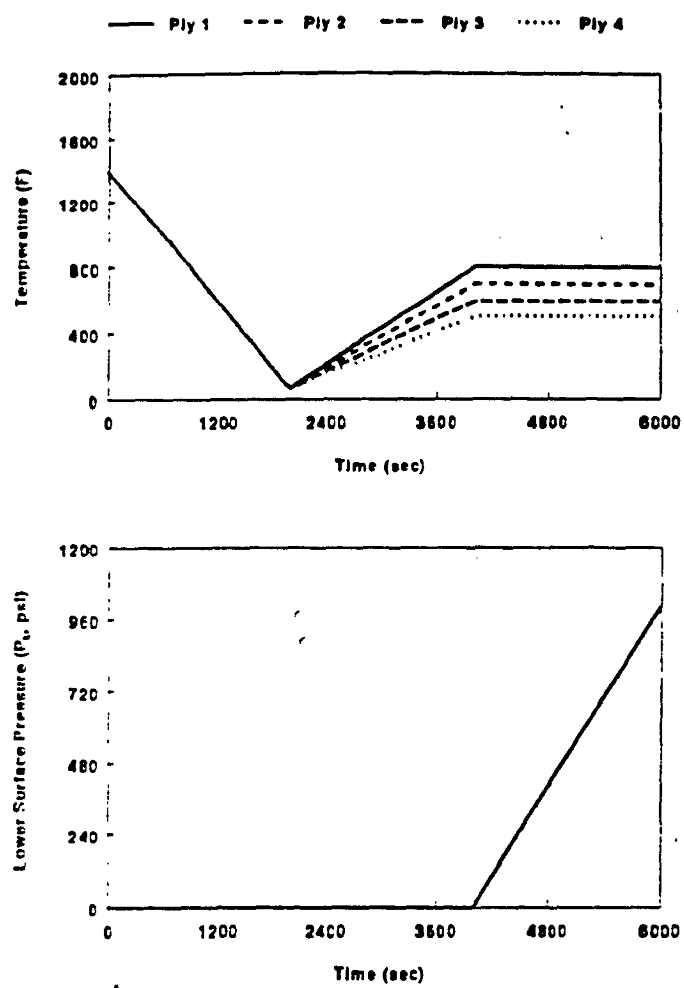


Figure 2.2-1.—Demonstration problem 2: Loading history.

the temperature of the individual plies held constant at their respective use temperatures. The first segment is divided into 40 load steps, the second segment into 25 load steps, and the third segment into 25, for a total of 90 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 2.2-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The variation in longitudinal fiber modulus (E_{f11}) for each ply of the laminate throughout the loading history is shown in figure 2.2-3. The fiber modulus increases during processing (0-2000 sec) due to the build up of residual stresses. As each ply of the the laminate is heated up to different use temperatures (2000 - 4000 sec), some of the residual stress is relieved. However, since each ply is heated up to different temperatures, the resulting fiber modulus degradation for each ply differs. The application of the pressure load (4000 - 6000 sec) has little effect on the fiber modulus, which remains almost constant during this segment.

```
METCAN DEMONSTRATION PROBLEM 2
$ No postprocessing files requested.
    POST       T
$ No load redistribution option.
  LDDIST       F
$ Ply details: ply no, matcrd no, orientation and thickness .
     PLY       1        1       0.   0.010
     PLY       2        1       0.   0.010
     PLY       3        1       0.   0.010
     PLY       4        1       0.   0.010
$ Material details: matcrd no, fvr, vvr and fiber/matrix.
  MATCRD       1     .40      0.TUNGCOPR
$ Number of mechanical and thermal cycles requested.
  CYCLES       1        1
$ Output requests.
   PRINT  LDSTEP
   PRINT   MICRO
   PRINT PROPDUP
$ Print output for every tenth load step.
PRINTOPT     LAST
$ Interphase details.
INTERFACE        0     .05
$ Simplified table input.
  TMLOAD       -3
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing.
     0.   2000.     40
$ Temperature in each ply at the beginning and end of processing.
   1400.   1400.   1400.   1400.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: heat-up to use temperatures.
$ Start time, end time ,and number of increments for the heat up.
   2000.   4000.     25
$ Temperature in each ply at the beginning and end of heat up.
     70.     70.     70.     70.
    800.    700.    600.    500.
$ Mechanical loads at the beginning and end of heat up.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0       0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Third loading segment: application of pressure load.
$ Start time, end time ,and number of increments for loading.
   4000.   6000.     25
$ Temperature in each ply at the beginning and end of loading.
    800.    700.    600.    500.
    800.    700.    600.    500.
$ Mechanical loads at the beginning and end of loading.
      0.      0.      0.      0.      0       0.      0.      0.      0       0.
      0.      0.      0.      0.      0.      0.      0       0.  1000.      0.
$ End data
```

Figure 2.2-2.—Demonstration problem 2: Input data file.

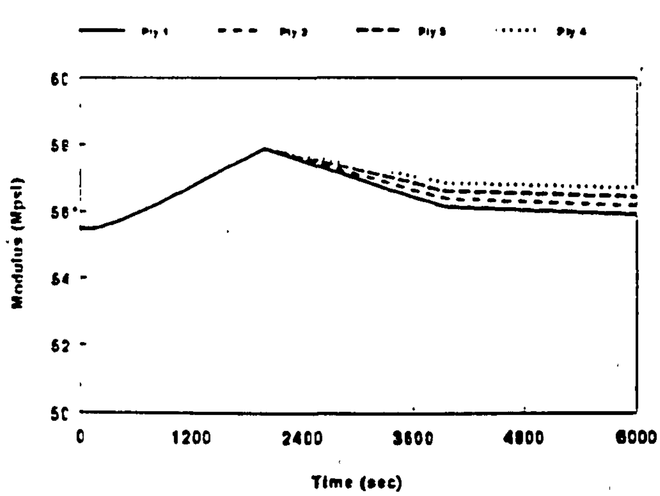


Figure 2.2-3 —Demonstration problem 2: Variation in longitudinal fiber modulus of $[0]_4$ W/Cu.

2.3 Demonstration Problem 3

Description: Matrix Shear Strengths in an Angle-Plied Laminate with Ply Thickness Variations Under Combined Moment and Shear Loads at an Elevated Temperature

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) An angle-plied laminate

(2) A carbon coating between the fiber and matrix

(3) Combined moment and shear loads

(4) A linear loading history

(5) Residual effects arising from processing

(6) Track the development of matrix shear strengths

(7) Variations in ply thickness

Model Description:

An angle-plied [0/30/90/-30/0] laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-6Al-4V) matrix is modelled. A carbon coating with a thickness of 1% of the fiber diameter is modelled between the fiber and matrix. Each ply has a fiber volume ratio (FVR) of 32%, a void volume ratio (VVR) of 0%, and variations in thickness. The laminate configuration is shown in table 2.3-1.

Table 2.3-1: Laminate Configuration					
Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.32	0.0	SiC/Ti-6-4
2	30°	0.0075"	0.32	0.0	SiC/Ti-6-4
3	90°	0.010"	0.32	0.0	SiC/Ti-6-4
4	-30°	0.0075"	0.32	0.0	SiC/Ti-6-4
5	0°	0.005"	0.32	0.0	SiC/Ti-6-4

Loading History:

The loading history for this problem is divided into three linear segments as shown in figure 2.3-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1600°F) to room temperature (70°F) in the absence of mechanical loads. The second segment involves heating up the laminate to the use

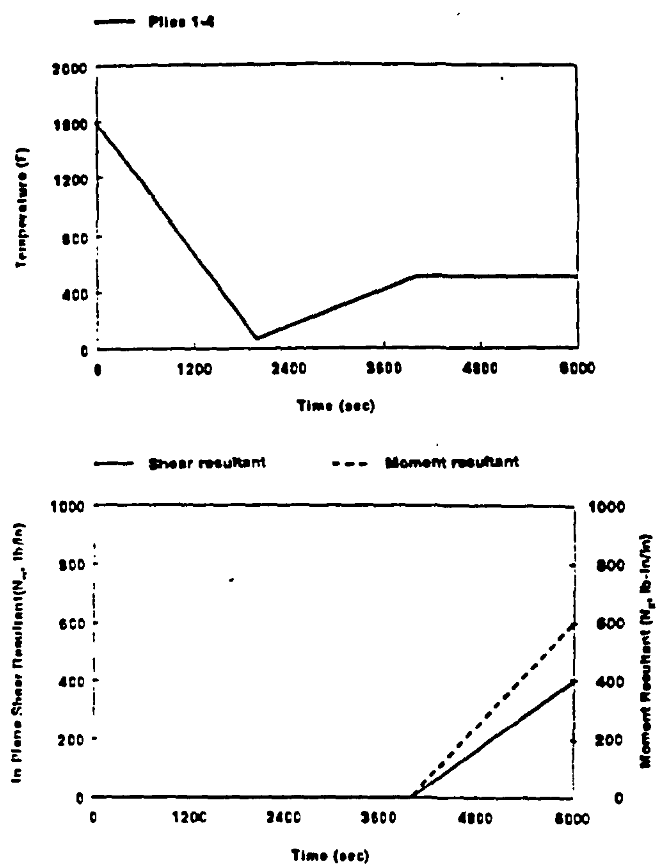


Figure 2.3-1.—Demonstration problem 3: Loading history.

temperature (500°F), again in the absence of mechanical loads. The third segment models the application of a combination of a 400 lb-in/in moment (M_x) and a 600 lb-in shear (N_{xy}) on the laminate with the temperature held constant at the use temperature. The first segment is divided into 40 load steps, the second segment into 25 load steps, and the third segment into 25, for a total of 90 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 2.3-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The matrix shear strengths (S_{m12}, S_{m13}, and S_{m23}) at three different points (before processing, after processing, and after heat-up) in the loading history are shown in figure 2.3-3. All three matrix shear strengths turn out to be equivalent. Before processing, the shear strength is 62 ksi. The shear strength increases during processing as residual stresses build up to a value of 88 ksi at the completion of processing. As some of the residual stresses are relieved during the heat-up, the matrix shear strengths decrease accordingly to 80 ksi.

```
METCAN DEMONSTRATION PROBLEM 3
$ No postprocessing files requested.
   POST        F
$ No load redistribution option.
  LDDIST       F
$ Ply details: ply no, matcrd no, orientation and thickness .
     PLY       1       1      0.  0.005
     PLY       2       1     30.  0.0075
     PLY       3       1     90.  0.010
     PLY       4       1    -30.  0.0075
     PLY       5       1      0.  0.005
$ Material details: matcrd no, fvr, vvr and fiber/matrix.
  MATCRD       1     .32     0.SICATI64
$ Number of mechanical and thermal cycles requested.
  CYCLES       1       1
$ Output requests.
   PRINT PROPCUF
$ Print output for every tenth load step.
PRINTOPT    LAST
$ Interphase details.
INTRFACE       1     .01
$ Simplified table input.
  TMLOAD      -3
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing.
     0.   2000.      40
$ Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.   1600.
     70.     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: heat-up to use temperatures.
$ Start time, end time ,and number of increments for the heat up.
   2000.   4000.     25
$ Temperature in each ply at the beginning and end of heat up.
    70.     70.     70.     70.     70.
   500.    500.    500.    500.    500.
$ Mechanical loads at the beginning and end of heat up.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Third loading segment: application of moment and shear loads.
$ Start time, end time ,and number of increments for loading.
   4000.   6000.     25
$ Temperature in each ply at the beginning and end of loading.
   500.    500.    500.    500.    500.
   500.    500.    500.    500.    500.
$ Mechanical loads at the beginning and end of loading.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.    400.    600.      0.      0.      0.      0.      0.      0.
$ End data.
```

Figure 2.3-2.—Demonstration problem 3: Input data file.

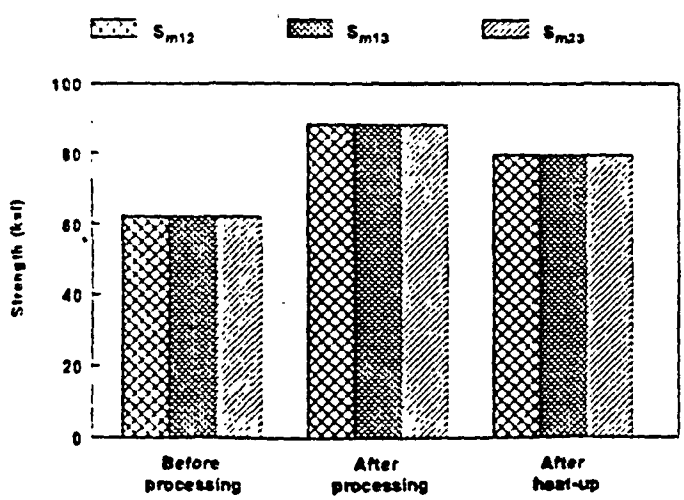


Figure 2.3-3.—Demonstration problem 3: Matrix shear strengths of [0/30/90/-30/0] SiC/Ti-6.

2.4 Demonstration Problem 4

Description: Transverse Matrix Stresses in an Angle-Plied Laminate Subjected to a Nonlinear Transverse Compressive Loading with Increasing Temperature

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) An angle-plied laminate

(2) A compliant layer between the fiber and matrix

(3) A monotonic transverse compressive loading

(4) A nonlinear loading history

(5) Residual effects arising from processing

(6) Track the development of constituent stresses

Model Description:

An angle-plied [0/45/-45/0] laminate composed of high modulus graphite (P100) fibers and a copper (Cu) matrix is modelled. A gadolinium (Gd) compliant layer with a thickness of 2% of the fiber diameter is specified. Each ply has a fiber volume ratio (FVR) of 50%, a void volume ratio (VVR) of 0%, and a thickness of 0.020 inches. The

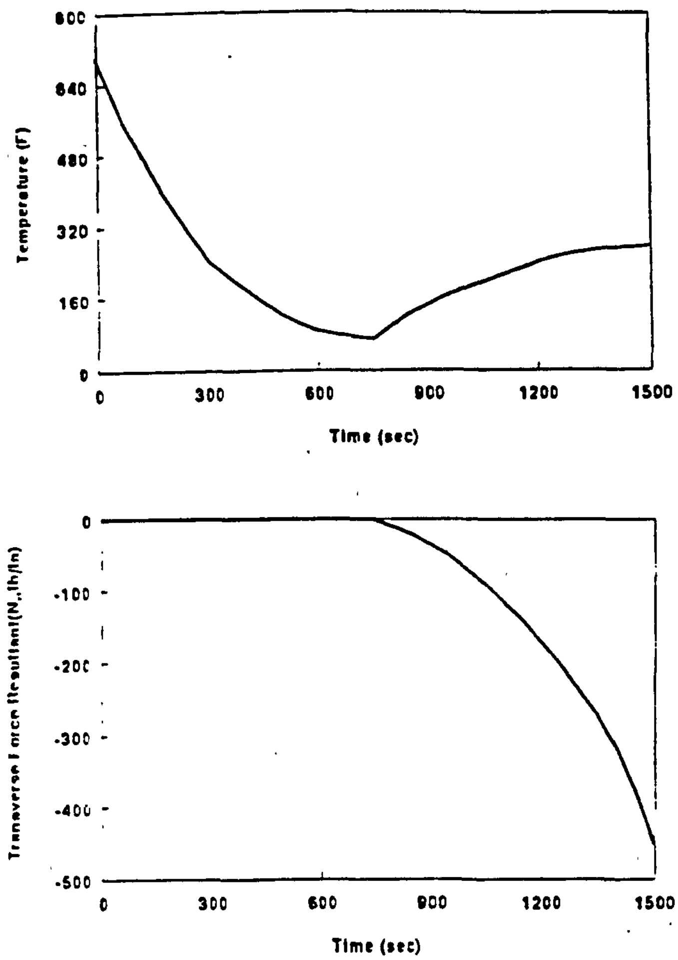


Figure 2.4-1.—Demonstration problem 4: Loading history.

laminate configuration is shown in table 2.4-1.

Table 2.4-1: Laminate Configuration					
Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.020"	0.50	0.0	P100/Cu
2	45°	0.020"	0.50	0.0	P100/Cu
3	-45°	0.020"	0.50	0.0	P100/Cu
4	0°	0.020"	0.50	0.0	P100/Cu

Loading History:

The loading history for this problem differs from the previous cases in that the loading history cannot be approximated into a few linear segments. Instead, the loading history must be discretized sufficiently to capture the nonlinear behavior, with each discretized point provided in the input data file. The loading history is divided into two segments as shown in figure 2.4-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (700°F) to room temperature (70°F) in the absence of mechanical loads and is composed of 20 discrete points. The second segment involves a combination of heating up the laminate to 275°F and the application of a 450 lb/in transverse compressive load (N_y) and contains 17 discrete points, for a total of 37 discrete points in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 2.4-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The variations in the transverse matrix stresses (σ_{m22A}, σ_{m22B}, and σ_{m22C}) throughout the loading history are shown in figure 2.4-3. The stresses increase during processing (0-750 sec) as residual stresses build up. The different stress levels occur in the three transverse matrix stresses due to the presence of the other constituents in regions 22B and 22C of the unit cell. The application of the compressive transverse load (750-1500 sec) results in a corresponding decrease in transverse matrix stress as the load increases.

```
METCAN DEMONSTRATION PROBLEM 4
$ No postprocessing files requested.
    POST        F
$ No load redistribution option.
  LDDIST        F
$ Ply details: ply no, matcrd no, orientation and thickness.
     PLY        1         1      0.   0.020
     PLY        2         1     45.   0.020
     PLY        3         1    -45.   0.020
     PLY        4         1      0.   0.020
$ Material details: matcrd no, fvr, vvr and fiber/matrix.
  MATCRD        1     .50      0.P100COPR
$ Number of mechanical and thermal cycles requested.
  CYCLES        1         1
$ Output requests.
   PRINT  CONSTI
   PRINT DISPFOR
   PRINT FEMDATA
$ Print output for the last load step.
PRINTOFF      10
$ Compliant layer details.
COMPLAYR        1     .02
$ Discrete points input.
  TM,DAT      37
$ First loading segment: processing.
$ Time and temperature in each ply.
      0.    700.    700.    700.    700.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
     25.    650.    650.    650.    650.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
     50.    600.    600.    600.    600.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
     75.    550.    550.    550.    550.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
    100.   512.5   512.5   512.5   512.5
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
    125.    475.    475.    475.    475.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
    150.   437.5   437.5   437.5   437.5
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
    175.    400.    400.    400.    400.
$ Mechanical loads.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Time and temperature in each ply.
    200.    365.    365.    365.    365.
$ Mechanical loads.
```

Figure 2.4-2 —Demonstration problem 4: Input data file.

```
$ Mechanical loads.
     0.   -20.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
   900.   145.   145.   145.   145.
$ Mechanical loads.
     0.   -35.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
   950.   165.   165.   165.   165.
$ Mechanical loads.
     0.   -50.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1000.   180.   180.   180.   180.
$ Mechanical loads.
     0.   -70.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1050.   195.   195.   195.   195.
$ Mechanical loads.
     0.   -90.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1100.   210.   210.   210.   210.
$ Mechanical loads.
     0.  -115.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1150.   225.   225.   225.   225.
$ Mechanical loads.
     0.  -140.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1200.   240.   240.   240.   240.
$ Mechanical loads.
     0.  -170.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1250.   250.   250.   250.   250.
$ Mechanical loads.
     0.  -200.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1300.   260.   260.   260.   260.
$ Mechanical loads.
     0.  -235.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1350.   265.   265.   265.   265.
$ Mechanical loads.
     0.  -270.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1400.   270.   270.   270.   270.
$ Mechanical loads.
     0.  -315.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1450.   273.   273.   273.   273.
$ Mechanical loads.
     0.  -375.     0.     0.     0.     0.     0.     0.     0.     0.
$ Time and temperature in each ply.
  1500.   275.   275.   275.   275.
$ Mechanical loads.
     0.  -450.     0.     0.     0.     0.     0.     0.     0.     0.
$ End data.
```

Figure 2.4-2.—Concluded.

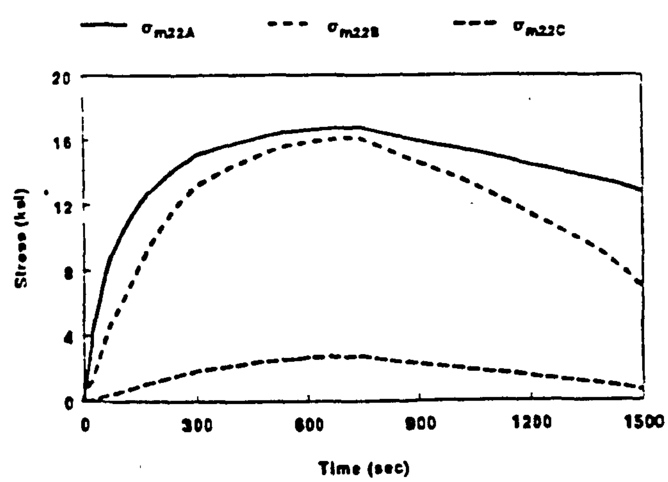


Figure 2.4-3.—Demonstration problem 4: Variation in transverse matrix stresses of [0/45/-45/0] P100/Cu.

3.0 Cyclic Analysis

Four problems demonstrating different features of METCAN for cyclic analysis are presented. All problems in this section make use of the same cross ply laminate used in Demonstration Problem 1 and examine the effects of various cyclic loads on the stress-strain behavior of the laminate. Each problem begins with the fabrication process to account for any residual effects, followed by the cyclic loads, and ends with the application of a longitudinal tensile load at room temperature. The cyclic loads examined include thermal cycling, tension-tension mechanical cycling, tension-compression mechanical cycling, and combined thermal and mechanical cycling. METCAN simulates the various types of cycling by accounting for the cumulative damage in the laminate due to cycling. Typically, the required input consists of the number of thermal and/or mechanical cycles desired and the loading history for a single cycle. Since cycling is modelled through cumulative damage, output for cycling is produced for only the last cycle.

3.1 Demonstration Problem 5

Description: Longitudinal Stress-Strain Behavior of a Cross-Ply Laminate Subjected to Thermal Cycling

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A cross-ply laminate

(2) An interphase between the fiber and matrix

(3) Laminate stress-strain behavior

(4) A linear loading history

(5) Residual effects arising from processing

(6) Thermal cycling

Model Description:

A cross-ply $[0/90]_S$ laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-15V-3Cr-3Al-3Sn) matrix is modelled. An interphase with a thickness of 5% of the fiber diameter is used. The interphase moduli and strengths are taken as 25% of the respective matrix values. All other interphase properties are assumed equal to their corre-

sponding matrix values. Each ply has a fiber volume ratio (FVR) of 35%, a void volume ratio (VVR) of 0%, and a thickness of 0.005 inches. The laminate configuration is shown in table 3.1-1.

Table 3.1-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.35	0.0	SiC/Ti-15-3
2	90°	0.005"	0.35	0.0	SiC/Ti-15-3
3	90°	0.005"	0.35	0.0	SiC/Ti-15-3
4	0°	0.005"	0.35	0.0	SiC/Ti-15-3

Loading History:

The loading history for this problem is divided into four linear loading segments as shown in figure 3.1-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1600°F) to room temperature (70°F). The second and third segments model the thermal cycling of the laminate. A total of 400 thermal cycles is simulated, with the second segment defining one half of a single thermal cycle

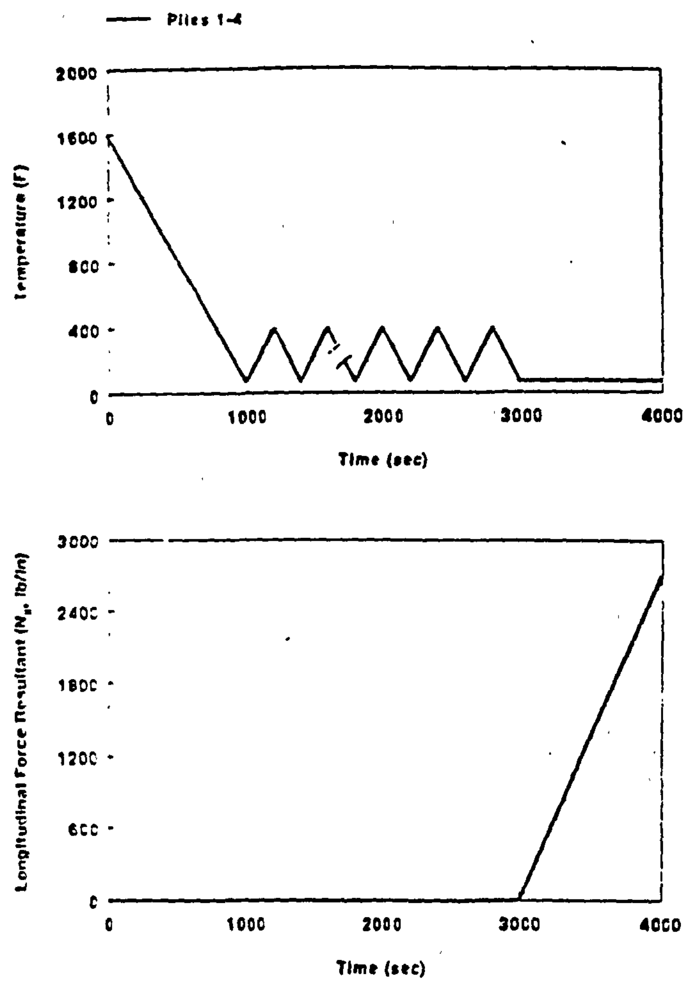


Figure 3.1-1.—Demonstration problem 5: Loading history.

(from 70° to 400°F), while the third segment defines the remaining portion of the cycle (from 400° to 70°F). The fourth segment involves application of a 2700 lb/in longitudinal tensile load (N_x) at room temperature. The first segment is composed of 45 load steps while the second, third, and fourth segments each contain 25 load steps for a total of 120 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 3.1-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The stress-strain behavior of the SiC/Ti-15-3 laminate after undergoing thermal cycling is shown in figure 3.1-3. Also included in the figure is the stress-strain behavior of the uncycled laminate for comparison. For this case, the thermal cycling results in the degradation of the laminate stress-strain behavior, causing a 40% reduction in ultimate tensile strength (from 135 to 81 ksi).

```
METCAN DEMONSTRATION PROBLEM 5
$ No postprocessing files requested.
   POST       T
$ No load redistribution option.
  LDCIST      F
$ Ply details: ply no, matcrd no, orientation, and thickness.
    PLY       1       1      0.   0.005
    PLY       2       1     90.   0.005
    PLY       3       1     90.   0.005
    PLY       4       1      0.   0.005
$ Material details: matcrd no, fvr, vvr, and fiber/matrix.
  MATCRD      1     .35     0.SICATI15
$ Number of mechanical and thermal cycles requested.
  CYCLES      1    200.
$ Output requests.
   PRINT FLINDEX
   PRINT PROPCOM
$ Print output for the last load step.
PRINTOPT     LAST
$ Interphase details.
INTRFACE      1     .05
$ Simplified table input.
  TMLOAD     -4          PROCESS
$ First loading segment: processing
$ Start time, end time , and number of increments for processing.
    0.   1000.       45         BEGPROCESS
$ Temperature in each ply at the beginning and end of processing.
  1600.   1600.   1600.   1600.
    70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: upper portion of thermal cycling.
$ Start time  end time ,and number of increments for heat up.
  1000.  2000.       25         BEGCYCL UPPER
$ Temperature in each ply at the beginning and end of upper cycle.
    70.     70.     70.     70.
   400.    400.    400.    400.
$ Mechanical loads at the beginning and end of upper cycle.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Third loading segment: lower portion of thermal cycling.
$ Start time, end time ,and number of increments for lower cycle.
  2000.  3000.       25         ENDCYCL LOWER
$ Temperature in each ply at the beginning and end of lower cycle.
   400.    400.    400.    400.
    70.     70.     70.     70.
$ Mechanical loads at the beginning and end of lower cycle.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Fourth loading segment: application of longitudinal load
$ Start time, end time ,and number of increments for loading.
  [illegible]  4000.  [illegible]
$ Temperature in each ply at the beginning and end of loading.
    70.     70.     70.     70.
    70.     70.     70.     70.
$ Mechanical loads at the beginning and end of loading.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  [illegible]    0.      0.      0.      0.      0.      0.      0.      0.      0.
$ End data.
```

Figure 3.1-2.—Demonstration problem 5: Input data file.

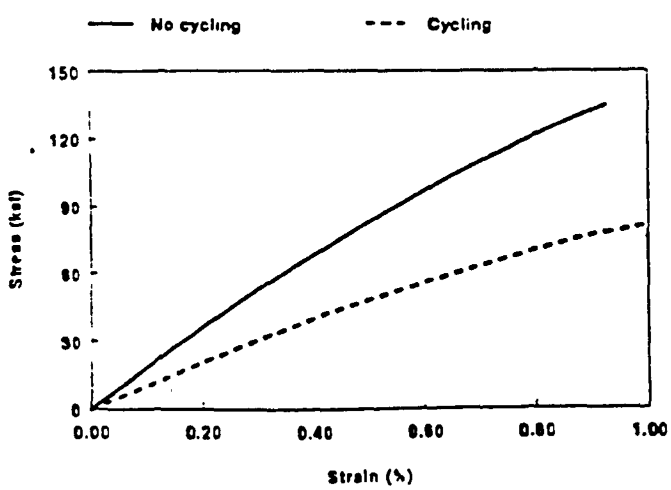


Figure 3.1-3.—Demonstration problem 5: Effect of thermal cycling on stress-strain behavior of $[0/90]_s$ SiC/Ti-15.

3.2 Demonstration Problem 6

Description: Longitudinal Stress-Strain Behavior of a Cross-Ply Laminate Subjected to Tension-Tension Mechanical Cycling

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A cross-ply laminate

(2) An interphase between the fiber and matrix

(3) Laminate stress-strain behavior

(4) A linear loading history

(5) Residual effects arising from processing

(6) Tension-tension mechanical cycling

Model Description:

A cross-ply $[0/90]_S$ laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-15V-3Cr-3Al-3Sn) matrix is modelled. An interphase with a thickness of 5% of the fiber diameter is used. The interphase moduli and strengths are taken as 25% of the respective matrix values. All other interphase properties are assumed equal to their corre-

sponding matrix values. Each ply has a fiber volume ratio (FVR) of 35%, a void volume ratio (VVR) of 0%, and a thickness of 0.005 inches. The laminate configuration is shown in table 3.2-1.

Table 3.2-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.35	0.0	SiC/Ti-15-3
2	90°	0.005"	0.35	0.0	SiC/Ti-15-3
3	90°	0.005"	0.35	0.0	SiC/Ti-15-3
4	0°	0.005"	0.35	0.0	SiC/Ti-15-3

Loading History:

The loading history for this problem is divided into four linear loading segments as shown in figure 3.2-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1600°F) to room temperature (70°F). The second and third segments model the mechanical cycling of the laminate. A total of 20000 mechanical cycles is simulated, with the second segment defines one half of a single

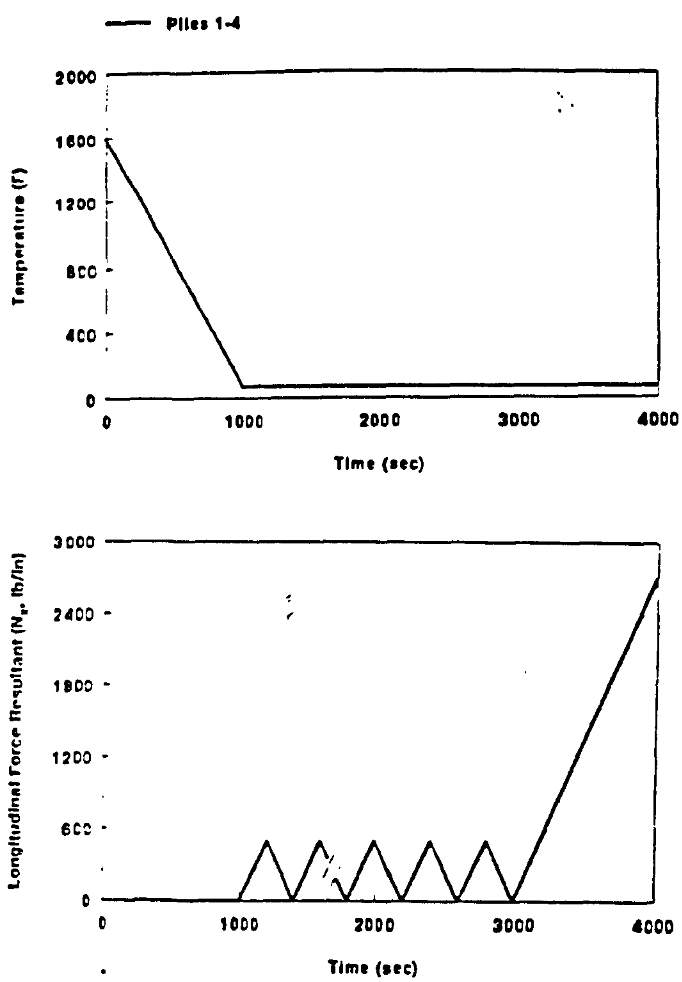


Figure 3.2-1.—Demonstration problem 6: Loading history.

mechanical cycle (from 0 to 500 lb/in), while the third segment defines the remaining portion of the cycle (from 500 to 0 lb/in). The fourth segment involves application of a 2700 lb/in longitudinal tensile load (N_x) at room temperature. The first segment is composed of 45 load steps while the second, third, and fourth segments each contain 25 load steps for a total of 120 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 3.2-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The stress-strain behavior of the SiC/Ti-15-3 laminate after undergoing tension-tension mechanical cycling is shown in figure 3.2-3. Also included in the figure is the stress-strain behavior of the uncycled laminate for comparison. For this case, the mechanical cycling results in the degradation of the laminate stress-strain behavior, causing a 12% reduction in ultimate tensile strength (from 135 to 119 ksi).

```
METCAN DEMONSTRATION PROBLEM 6
$ No postprocessing files requested.
   POST        T
$ No load redistribution option.
  LODIST       F
$ Ply details: ply no, matcrd no, orientation, and thickness.
     PLY       1       1       0.    0.005
     PLY       2       1      90.    0.005
     PLY       3       1      90.    0.005
     PLY       4       1       0.    0.005
$ Material details: matcrd no, fvr, vvr, and fiber/matrix.
  MATCRD       1     .35      0.SICATI15
$ Number of mechanical and thermal cycles requested.
  CYCLES  2.E+04        1
$ Output requests.
   PRINT PLYRESP
   PRINT PLYSTRS
$ Print output for the last load step.
PRINTOPT      ALL
$ Interphase details.
INTRFACE        1    .05
$ Simplified table input.
  TMLOAD       -4           PROCESS
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing.
     0.   1000.      45          BEGPROCESS
$ Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: upper portion of mechanical cycle.
$ Start time, end time ,and number of increments for upper cycle.
  1000.   2000.      25          BEGCYCL UPPER
$ Temperature in each ply at the beginning and end of upper cycle.
     70.     70.     70.     70.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of upper cycle.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   500.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Third loading segment: lower portion of mechanical cycle.
$ Start time, end time ,and number of increments for lower cycle.
  2000.   3000.      25          ENDCYCL LOWER
$ Temperature in each ply at the beginning and end of lower cycle.
     70.     70.     70.     70.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of lower cycle.
   500.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Fourth loading segment: application of longitudinal load
$ Start time, end time ,and number of increments for loading
  3000.   4000.      25
$ Temperature in each ply at the beginning and end loading.
     70.     70.     70.     70.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of loading.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
[illegible]  0.      0.      0.      0.      0.      0.      0.      0.      0.
$ End data.
```

Figure 3.2-2.—Demonstration problem 6: Input data file.

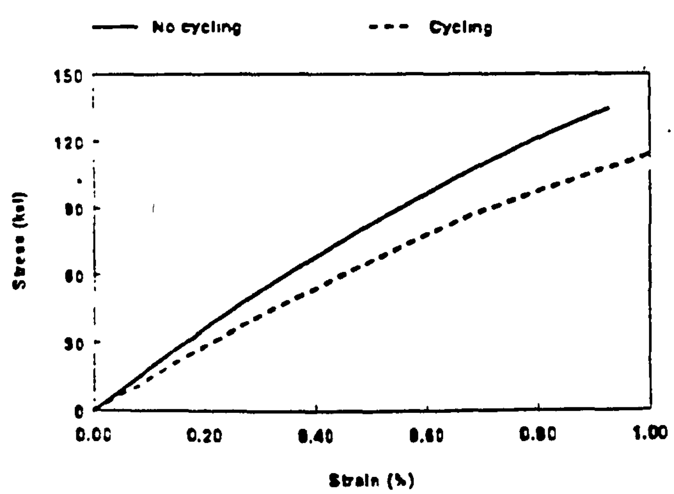


Figure 3.2-3.—Demonstration problem 6: Effect of mechanical cycling on stress-strain behavior of $[0/90]_s$ SiC/Ti -15.

3.3 Demonstration Problem 7

Description: Longitudinal Stress-Strain Behavior of a Cross-Ply Laminate Subjected to Tension-Compression Mechanical Cycling

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A cross-ply laminate

(2) A interphase between the fiber and matrix

(3) Laminate stress-strain behavior

(4) A linear loading history

(5) Residual effects arising from processing

(6) Tension-compression mechanical cycling

Model Description:

A cross-ply $[0/90]_S$ laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-15V-3Cr-3Al-3Sn) matrix is modelled. An interphase with a thickness of 5% of the fiber diameter is used. The interphase moduli and strengths are taken as 25% of the respective matrix values. All other interphase properties are assumed equal to their corre-

sponding matrix values. Each ply has a fiber volume ratio (FVR) of 35%, a void volume ratio (VVR) of 0%, and a thickness of 0.005 inches. The laminate configuration is shown in table 3.3-1.

Table 3.3-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.35	0.0	SiC/Ti-15-3
2	90°	0.005"	0.35	0.0	SiC/Ti-15-3
3	90°	0.005"	0.35	0.0	SiC/Ti-15-3
4	0°	0.005"	0.35	0.0	SiC/Ti-15-3

Loading History:

The loading history for this problem is divided into five linear loading segments as shown in figure 3.3-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1600°F) to room temperature (70°F). In the second segment a compressive longitudinal load is applied. The third and fourth segments model the mechanical cycling of the laminate. A total of 15000 mechanical cycles is

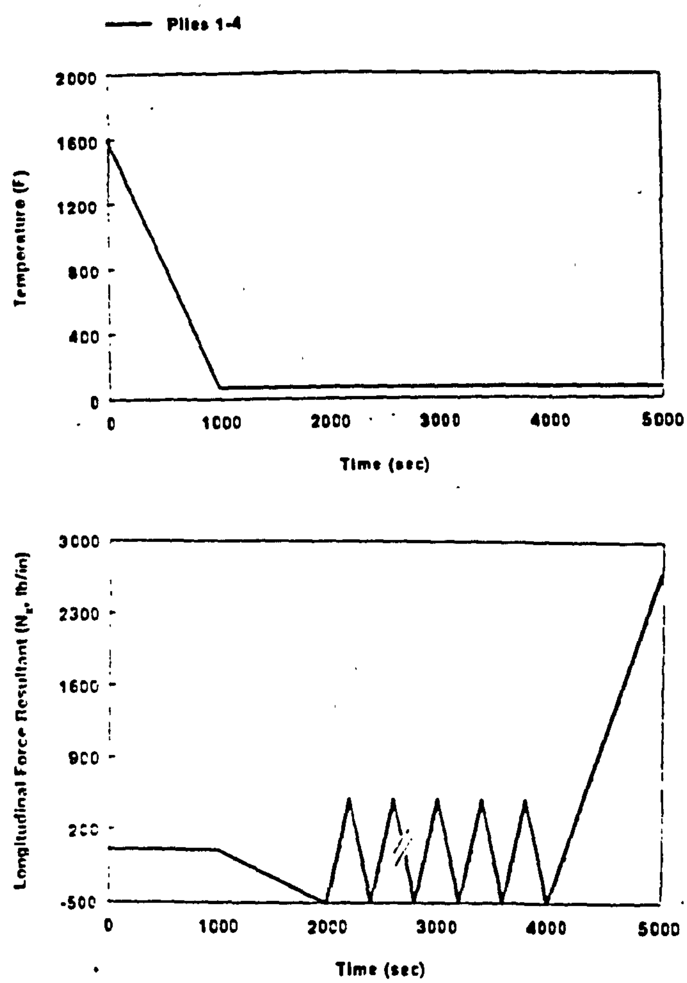


Figure 3.3-1.—Demonstration problem 7: Loading history.

simulated, with the third segment defining one half of a single mechanical cycle (from -500 to 500 lb/in), while the fourth segment defines the remaining portion of the cycle (from 500 to -500 lb/in). The fifth segment involves the application of a 2700 lb/in longitudinal tensile load (N_x) at room temperature. The first segment is composed of 45 load steps while the second through fifth segments each contain 25 load steps for a total of 145 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 3.3-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The stress-strain behavior of the SiC/Ti-15-3 laminate after undergoing tension-compression mechanical cycling is shown in figure 3.3-3. Also included in the figure is the stress-strain behavior of the uncycled laminate for comparison. For this case, the mechanical cycling results in the degradation of the laminate stress-strain behavior, causing a 10% reduction in ultimate tensile strength (from 135 to 122 ksi).

```
METCAN DEMONSTRATION PROBLEM 7
$ No postprocessing files requested.
    POST       T
$ No load redistribution option.
  LDDIST       F
$ Ply details: ply no, matcrd no, orientation, and thickness.
     PLY       1       1      0.   0.005
     PLY       2       1     90.   0.005
     PLY       3       1     90.   0.005
     PLY       4       1      0.   0.005
$ Material details: matcrd no, fvr, vvr, and fiber/matrix.
  MATCRD       1     .35      0.SICATI15
$ Number of mechanical and thermal cycles requested.
  CYCLES 1.5E-04         1
$ Output requests.
   PRINT PROPREF
   PRINT REDSTIF
$ Print output for the last load step.
PRINTOPT    LAST
$ Interphase details.
INTRFACE       1     .05
$ Simplified table input.
  TMLOAD       -5          PROCESS
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing.
      0.   1000.      45           BEGPROCESS
$ Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
      0.       0.      0.       0.       0.       0.       0.      0       0.       0.
      0.       0.      0.       0.       0.       0.       0.      0.      0.       0.
$ Second loading segment: application of compressive load.
$ Start time, end time ,and number of increments for compressive loading
   1000.   2000.      25
$ Temperature in each ply at the beginning and end of compressive load.
     70.      70.     70.     70.
     70.      70.     70.     70.
$ Mechanical loads at the beginning and end of compressive load.
      0.       0.      0.       0.       0.       0.       0.      0.      0.       0.
   -500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
$ Third loading segment: upper portion of mechanical cycle.
$ Start time, end time ,and number of increments for upper cycle.
   2000.   3000.      25           BEGCYCL UPPER
$ Temperature in each ply at the beginning and end of upper cycle.
     70.      70.     70.     70.
     70.      70.     70.     70.
$ Mechanical loads at the beginning and end of upper cycle.
   -500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
    500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
$ Fourth loading segment: lower portion of mechanical cycle.
$ Start time, end time ,and number of increments for lower cycle.
   3000.   4000.      25           ENDCYCL LOWER
$ Temperature in each ply at the beginning and end of lower cycle.
     70.      70.     70.     70.
     70.      70.     70.     70.
$ Mechanical loads at the beginning and end of lower cycle.
    500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
   -500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
$ Fifth loading segment: application of longitudinal load.
$ Start time, end time ,and number of increments for loading.
   4000.   5000.      25
$ Temperature in each ply at the beginning and end of loading.
     70.      70.     70.     70.
     70.      70.     70.     70.
$ Mechanical loads at the beginning and end of cool down.
   -500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
    500.       0.      0.       0.       0.       0.       0.      0.      0.       0.
$ End data.
```

Figure 3.3-2.—Demonstration problem 7: Input data file.

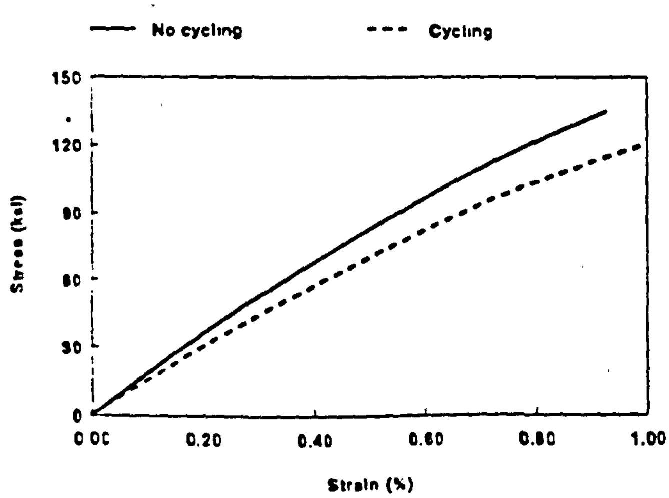


Figure 3.3-3—Demonstration problem 7: Effect of mechanical cycling on stress-strain behavior of $[0/90]_s$ SiC/Ti-15.

3.4 Demonstration Problem 8

Description: Longitudinal Stress-Strain Behavior of a Cross-Ply Laminate Subjected to Thermo-Mechanical Cycling

Problem Description:

This problem demonstrates the use of METCAN to model:

(1) A cross-ply laminate

(2) An interphase between the fiber and matrix

(3) Laminate stress-strain behavior

(4) A linear loading history

(5) Residual effects arising from processing

(6) Thermo-mechanical cycling

Model Description:

A cross-ply $[0/90]_S$ laminate composed of silicon carbide (SiC) fibers and a titanium (Ti-15V-3Cr-3Al-3Sn) matrix is modelled. An interphase with a thickness of 5% of the fiber diameter is used. The interphase moduli and strengths are taken as 25% of the respective matrix values. All other interphase properties are assumed equal to their corre-

sponding matrix values. Each ply has a fiber volume ratio (FVR) of 35%, a void volume ratio (VVR) of 0%, and a thickness of 0.005 inches. The laminate configuration is shown in table 3.4-1.

Table 3.4-1: Laminate Configuration

Ply Number	Angle	Thickness	FVR	VVR	Fiber/ Matrix
1	0°	0.005"	0.35	0.0	SiC/Ti-15-3
2	90°	0.005"	0.35	0.0	SiC/Ti-15-3
3	90°	0.005"	0.35	0.0	SiC/Ti-15-3
4	0°	0.005"	0.35	0.0	SiC/Ti-15-3

Loading History:

The loading history for this problem is divided into four linear loading segments as shown in figure 3.4-1. The first segment simulates the processing of the laminate as a cool down from the processing temperature (1600°F) to room temperature (70°F). A total of 200 thermal cycles and 20000 mechanical cycles are simulated with the second and third segments modelling the thermo-mechanical cycling of the laminate. The second segment

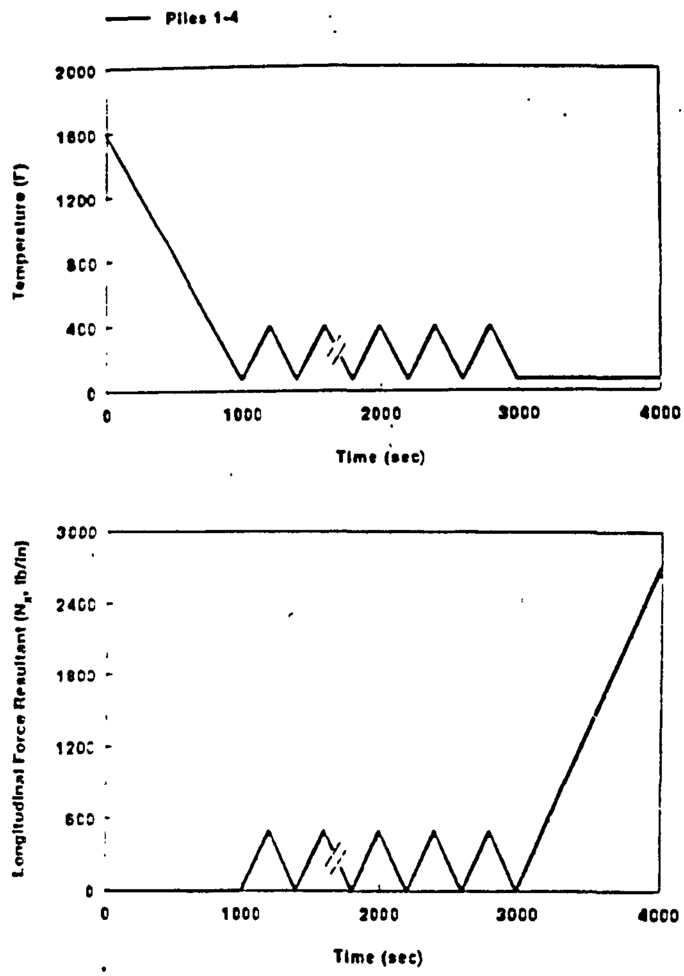


Figure 3.4-1.—Demonstration problem 8: Loading history.

defines one half of a single thermo-mechanical cycle (from 70° to 400°F and 0 to 500 lb/in), while the third segment defines the remaining portion of the cycle (from 400° to 70°F and 500 to 0 lb/in). The fourth segment involves the application of a 2700 lb/in longitudinal tensile load (N_x) at room temperature. The first segment is composed of 45 load steps while the second, third, and fourth segments each contain 25 load steps for a total of 120 load steps in the simulation.

Input Data File:

The input file for this demonstration problem is shown in figure 3.4-2. Comment records, denoted by a '$' in the first column, are inserted throughout the file to briefly describe each record.

Demonstration Problem Results:

The stress-strain behavior of the SiC/Ti-15-3 laminate after undergoing combined thermal and mechanical cycling is shown in figure 3.4-3. Also included in the figure is the stress-strain behavior of the uncycled laminate for comparison. For this case, the mechanical cycling results in the degradation of the laminate stress-strain behavior, causing a 44% reduction in ultimate tensile strength (from 135 to 76 ksi).

```
METCAN DEMONSTRATION PROBLEM 8
$ No postprocessing files requested.
     POST       T
$ No load redistribution option.
  LDDIST        F
$ Ply details: ply no, matcrd no, orientation, and thickness.
      PLY       1       1       0.   0.005
      PLY       2       1      90.   0.005
      PLY       3       1      90.   0.005
      PLY       4       1       0.   0.005
$ Material details: matcrd no, fvr, vvr, and fiber/matrix.
  MATCRD        1     .35       0.SICATI15
$ Number of mechanical and thermal cycles requested.
  CYCLES  2.E+04    200.
$ Output requests.
   PRINT  STRCON
   PRINT STRSTRN
$ Print output for the last load step.
PRINTOPT     LAST
$ Interphase details.
INTRFACE        1     .05
$ Simplified table input.
  TMLOAD       -4          PROCESS
$ First loading segment: processing.
$ Start time, end time , and number of increments for processing.
     0.   1000.       45          BEGPROCESS
$ Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of processing.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Second loading segment: upper portion of thermo-mechanical cycle.
$ Start time, end time ,and number of increments for upper cycle.
   1000.   2000.       25         BEGCYCL UPPER
$ Temperature in each ply at the beginning and end of upper cycle.
     70.     70.     70.     70.
    400.    400.    400.    400.
$ Mechanical loads at the beginning and end of upper cycle.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   500.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Third loading segment: lower portion of thermo-mechanical cycle.
$ Start time, end time ,and number of increments for lower cycle.
   2000.   3000.       25         ENDCYCL LOWER
$ Temperature in each ply at the beginning and end of lower cycle.
    400.    400.    400.    400.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of lower cycle.
   500.      0.      0.      0.      0.      0.      0.      0.      0.      0.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ Fourth loading segment: application of longitudinal load.
$ Start time, end time ,and number of increments for loading
   3000.   4000.       25
$ Temperature in each ply at the beginning and end of loading.
     70.     70.     70.     70.
     70.     70.     70.     70.
$ Mechanical loads at the beginning and end of loading.
     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   200.      0.      0.      0.      0.      0.      0.      0.      0.      0.
$ End data.
```

Figure 3.4-2.—Demonstration problem 8: Input data file.

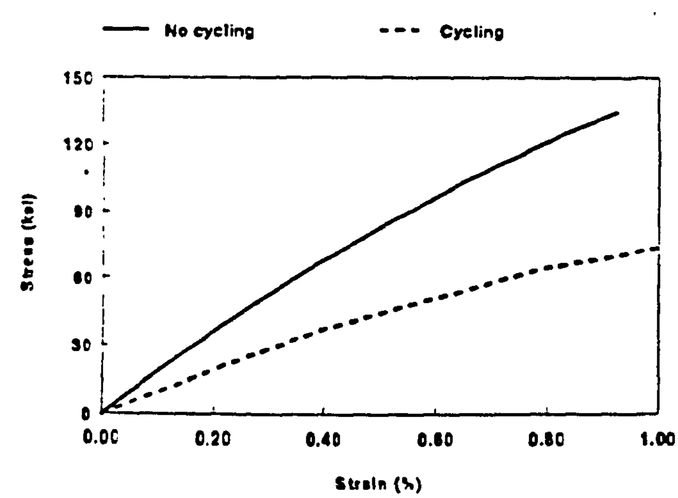


Figure 3.4-3.—Demonstration problem 8: Effect of thermo-mechanical cycling on stress-strain behavior of $[0/90]_s$ SiC/Ti-15.

4.0 Complete Output File

A typical METCAN output file containing all output request options is presented for the first demonstration problem. For clarity of description, the output file is divided into fifteen different sections (one for the default output along with one for each output request option). A brief description is provided in each section before the actual output. These descriptions are not part of the actual output file, but are included to guide the reader. The ordering of the sections corresponds to the order in which the various output request options are actually generated. A list of notation and units is also included at the end to help interpret the output.

A total of fourteen different output request options are available. The output file can be tailored by the user (as defined in the PRINT data record in the input file) by choosing various combinations of the fourteen available output requests options. These fourteen request options are listed in table 4.0-1. The following sections demonstrate all the different output request options, allowing the user to effectively tailor the output file.

Table 4.0-1: Output Requests	
Option	Type of Output
PRINT CONSTI	Laminate consititutive relationships
PRINT DISPFOR	Displacement-force relationships
PRINT FEMDATA	Information for finite element analysis
PRINT FLINDEX	Report of failure index
PRINT LDSTEP	Information about the load step
PRINT MICRO	Stresses and strains in the constituents
PRINT PLYRESP	Ply properties and response variables
PRINT PLYSTRS	Stresses and strains in the plies
PRINT PROPCOM	2-D and 3-D laminate properties
PRINT PROPCUR	Current constituent properties
PRINT PROPREF	Reference constituent properties
PRINT REDSTIF	Laminate reduced membrane and bending stiffnesses
PRINT STRCON	Stress concentration factors around a circular hole in an infinite plate

PRINT STRSTRN	Laminate stress-strain relationship and MSC/NASTRAN MAT9 record

4.1 Default Output

The following output is produced regardless of the PRINT records chosen in the input file. This default output contains:

(1) The METCAN logo

(2) The structural and material axes

(3) A list of the properties used in METCAN

(4) An echo of the constituent databank

(5) An echo of the input file

(6) A summary of the input data

Each of the default outputs are described and shown in this section.

Description: METCAN Logo

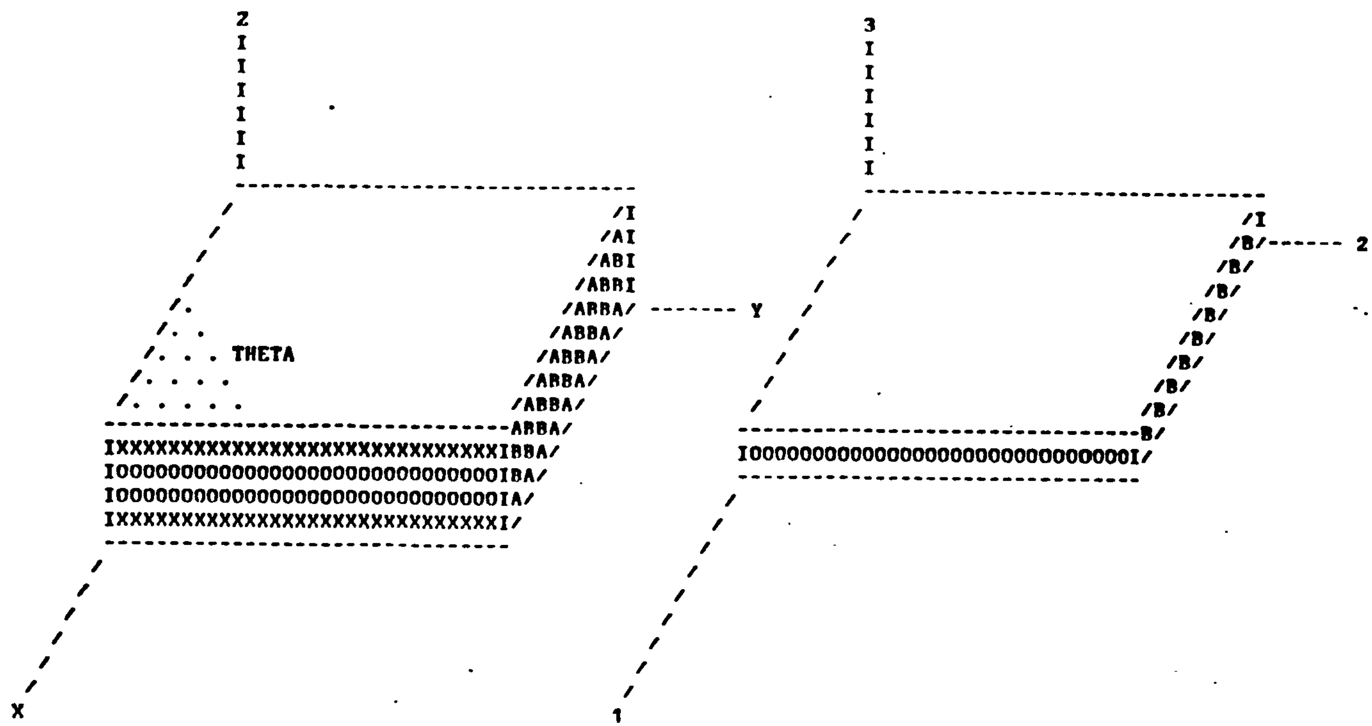
This part of the default output contains a logo of METCAN, along with version and author information.

```
============================================================
============================================================
============================================================

MMM   MMM UUUUUUUUU RRRRRRRRR  TTTTTTT    HHHHH   YYY   YYY
MMMM MMMM UUUUUUUUU RRRRRRRRR TTTTTTTTT  HHHHHHH  YYYY  YYY
MMMMMMMMM UUU          RRR    TTT   TTT HHH   HHH YYYYY YYY
MMMMMMMMM UUUUUUUU     RRR    TTT       HHHHHHHHH YYYYYYYYY
MMM M MMM UUUUUUUU     RRR    TTT       HHHHHHHHH YYYYYYYYY
MMM   MMM UUU          RRR    TTT   TTT HHH   HHH YYY YYYYY
MMM   MMM UUUUUUUUU    RRR    TTTTTTTTT HHH   HHH YYY  YYYY
MMM   MMM UUUUUUUUU    RRR     TTTTTTT  HHH   HHH YYY   YYY

============================================================
============================================================
============================================================
    Version 3.0 Sept. 1989
           by
    Pappu L. N. Murthy
    NASA/LeRC, Cleveland,OHIO
    Ph. (216) 433 3332
```

Description: METCAN Coordinate Axes

This part of the default output depicts the two different coordinate systems used in METCAN: (1) a structural or laminate axes and (2) a material or ply axes.

M E T C A N: COORDINATE SYSTEMS



LAMINATE STRUCTURAL AXES

PLY MATERIAL AXES

Description: List of Properties

This part of the default output lists various properties used in METCAN along with their corresponding symbols and units.

METCAN UNITS FOR CONSTITUENT,
PLY AND LAMINATE PROPERTIES

Property	Symbol	Unit
ELASTIC MODULUS	E	psi
SHEAR MODULUS	G	psi
POISSONS RATIO	NU	non-dim
THERM. EXP. COEFF.	CTE	in/in/F
DENSITY	RHO	lb/in**3
FIBER DIAMETER	Df	in
HEAT CAPACITY	C	BTU/lb/F
HEAT CONDUCTIVITY	K	BTU-in/HR/in**2/F
STRENGTH	S	psi
MOISTURE EXP. COEFF.	BTA	in/in/1% mositure
MOISTURE DIFFUSIVITY	DP	in**2/sec
THICKNESS	T	in
DISTANCE TO MIDPLANE	Z	in
ANGLE TO AXES	TH	degrees
TEMPERATURE	TEMP	F
STRAIN	EPS	in/in
STRESS	SIG	psi
MEMBRANE LOADS	N	lb/in
BENDING LOADS	M	lb-in/in
MOISTURE	MPC	% by wt
FIBER VOLUME RATIO	Kf	non-dim
FIBER VOID RATIO	Kv	non-dim
PLY RELATIVE ROTATION	DELFI	radians

Description: Constituent Databank Echo

This part of the default output reproduces, in tabular form, the constituent material properties found in the constituent databank. The table begins with fiber properties, followed by matrix properties, and ends with interphase properties.

TABLE OF FIBER PROPERTIES FROM METCAN DATABASE

PROP.	UNITS	FIBER CODE NAMES		
		P100	SICA	TUNG
Df	mils	0.390	5.600	10.000
Rhof	lb/in**3	0.078	0.110	0.683
Tempmf	Deg. F	6600.000	4870.000	6170.000
Ef11	Mpsi	105.000	62.000	59.000
Ef22	Mpsi	0.900	62.000	59.000
Nuf12	in/in	0.200	0.300	0.290
Nuf23	in/in	0.250	0.300	0.290
Gf12	Mpsi	1.100	23.800	22.700
Gf23	Mpsi	0.700	23.800	22.700
Alfaf11	Ppm/F	-0.900	2.720	2.500
Alfaf22	Ppm/F	5.600	2.720	2.500
Kf11	BTU/hr/in/F	25.000	0.750	8.280
Kf22	BTU/hr/in/F	1.740	0.750	8.280
Cf	BTU/lb	0.170	0.290	0.024
Sf11T	Ksi	325.000	500.000	390.000
Sf11C	Ksi	200.000	650.000	390.000
Sf22T	Ksi	25.000	500.000	390.000
Sf22C	Ksi	25.000	650.000	390.000
Sf12S	Ksi	25.000	300.000	236.000
Sf23S	Ksi	12.500	300.000	236.000

P100 HIGH MODULUS GRAPHITE FIBER
SICA SILICON CARBIDE FIBER
TUNG TUNGSTEN FIBER

TABLE OF MATRIX PROPERTIES FROM METCAN DATABASE

PROP.	UNITS	MATRIX CODE NAMES		
		COPR	TI15	TI64
Rhom	Lb/in**3	0.320	0.172	0.170
Em	Mpsi	17.700	12.300	16.500
Num	in/in	0.300	0.320	0.300
Alfam	Ppm/F	9.800	4.500	5.240
Km	BTU/hr/in/F	19.300	0.390	0.390
Cm	BTU/lb	0.090	0.120	0.120
SmT	Ksi	32.000	130.000	144.000
SmC	Ksi	32.000	130.000	144.000
SmS	Ksi	19.000	78.000	90.000
EpsmT	%	35.000	12.000	2.000
EpsmC	%	35.000	12.000	2.000
EpsmS	%	35.000	12.000	2.000
EpsmTOR	%	35.000	12.000	2.000
Kvoid	BTU/hr/in/F	0.019	0.019	0.019
Tempmm	Deg. F	1980.000	1800.000	3000.000

COPR COPPER MATRIX
TI15 TI-15V-3CR-3AL-3SN MATRIX
TI64 Ti-6Al-4V MATRIX

TABLE OF INTERFACE PROPS. FROM METCAN DATABASE

PROP.	UNITS	0.01	0.02	0.05
		INTERFACE THICKNESS IN %		
Rhod	Lb/in**3	0.172	0.285	0.172
Ed	Mpsi	2.500	7.900	3.000
Nud	in/in	0.220	0.260	0.320
Alfad	Ppm/F	2.120	5.550	4.500
Kd	BTU/hr/in/F	0.390	0.506	0.390
Cd	BTU/lb	0.120	0.120	0.120
SdT	Ksi	10.000	57.000	32.500
SdC	Ksi	10.000	57.000	32.500
SdS	Ksi	10.000	28.000	19.500
EpsdT	%	12.000	12.000	12.000
EpsdC	%	12.000	12.000	12.000
EpsdS	%	12.000	12.000	12.000
EpsdTOR	%	12.000	12.000	12.000
Kvoid	BTU/hr/in/F	0.019	0.019	0.019
Tempmd	Deg. F	1800.000	2390.000	1800.000

INTERFACE CARBON COATING FOR SIC FIBERS
INTERFACE COMPLIANT LAYER GD
INTERFACE FOR TI-15-3 WITH 25% OF MATRIX PROPERTIES

Description: Input File Echo

This part of the default output echoes the input file.

M E T C A N
I N P U T   D A T A   E C H O

```
METCAN DEMONSTRATION PROBLEM 1
* No postprocessing files requested.
    POST        F
* No load redistribution option.
  LDDIST        F
* Ply details: ply no, matcrd no, orientation and thickness.
     PLY         1        1      0.     .005
     PLY         2        1     90.     .005
     PLY         3        1     90.     .005
     PLY         4        1      0.     .005
* Material details: matcrd no, fvr, vvr and fiber/matrix.
  MATCRD        1      .35      0.SICATI15
* Number of mechanical and thermal cycles requested.
  CYCLES        1        1
* Output requests.
   PRINT     ALL
* Print output at all load steps.
PRINTOPT     ALL
* Interface details.
INTRFACE        1      .05
* Simplified table input.
  TMLOAD       -2          PROCESS
* First loading segment: processing.
* Start time, end time , and number of increments for processing.
      0.    2000.      45          BEGPROCESS
* Temperature in each ply at the beginning and end of processing.
   1600.   1600.   1600.   1600.
     70.     70.     70.     70.
* Mechanical loads at the beginning and end of the processing.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
* Second loading segment: application of longitudinal load.
* Start time, end time ,and number of increments for loading.
   2000.   4000.      25
* Temperature in each ply at the beginning and end of loading.
     70.     70.     70.     70.
     70.     70.     70.     70.
* Mechanical loads at the beginning and end of loading.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   2700.      0.      0.      0.      0.      0.      0.      0.      0.      0.
* End data.
```

Description: Input Data Summary

This part of the default output provides a summary of pertinent data from the input file. The summary contains:

(1) The amount of words required in the analysis

(2) A case control deck summary

(3) Details about the laminate configuration

(4) A list of the material systems

(5) Information about thermal and mechanical cycling

(6) A summary of the output options chosen

```
S U M M A R Y   O F   I N P U T   D A T A

METCAN DEMONSTRATION PROBLEM 1
   TOTAL AMOUNT OF WORDS NEEDED FOR THE ANALYSIS     2824


- - -      CASE    CONTROL    DECK          - - -
NUMBER OF LAYERS                NL  =     4
NUMBER OF LOADING CONDITIONS NLC =     1
NUMBER OF MATERIAL SYSTEMS    NMS =     1


- - --    LAMINATE    CONFIGURATION     - - -

----------------------------------------
    PLY   NO       MID      THETA   T-NESS
----------------------------------------
    PLY    1        1        0.0     0.005
    PLY    2        1       90.0     0.005
    PLY    3        1       90.0     0.005
    PLY    4        1        0.0     0.005
----------------------------------------


- - -    COMPOSITE MATERIAL SYSTEMS    - - -

----------------------------------------
 MATCRD    MID  FIB    MAT   VFP     VVP

 MATCRD      1 SICA/TI15  0.35    0.00
----------------------------------------
NUMBER OF MECHANICAL CYCLES                    0.0
NUMBER OF THERMAL    CYCLES                    0.0
MECHANICAL CYCLES LIMIT FOR FIBER      1000000.0
THERMAL CYLES LIMIT     FOR FIBER          400.0
MECHANICAL CYCLES LIMIT FOR MATRIX     1000000.0
THERMAL CYLES LIMIT     FOR MATRIX         400.0
MECHANICAL CYCLES LIMIT FOR INTERPHASE 1000000.0
THERMAL CYLES LIMIT     FOR INTERPHASE     400.0


----->  OUTPUT OPTIONS SELECTED  <------


 OPTION  0 --> COMPLETE OUTPUT IS REQUESTED <---
```

4.2 Reference Constituent Properties (PROPREF) Output

Description:

This part of the output file echos the material properties and the exponents for the constituents selected for the analysis from the constituent databank. This is the same output found in the constituent databank echo from the default output section (sect. 4.1) in a different format for the user's convenience.

ECHO OF CONSTITUENT PROPERTIES FROM DATABANK AT THE REFERENCE TEMPERATURE

THE FOLLOWING PROPERTIES ARE FOR SICA FIBER , TI15 MATRIX AND THE CORRESPONDING INTERFACE

NO.	PROPERTY	FIBER	PROPERTY	MATRIX	PROPERTY	INTERFACE
1	DF	0.5600E-02	NUMMPO	0.2200E+02	TD %	0.5000E-01
2	TEMPFO	0.7000E+02	TEMPMO	0.7000E+02	TEMPDO	0.7000E+02
3	TEMPMF	0.4870E+04	TEMPMM	0.1800E+04	TEMPDM	0.1800E+04
4	DOTHF	0.4667E+04	DOTHM	0.1662E+06	DOTHD	0.8209E+05
5	RHOFO	0.1100E+00	RHOMO	0.1720E+00	RHODO	0.1720E+00
6	EF110	0.6200E+08	EM110	0.1230E+08	ED110	0.3000E+07
7	EF220	0.6200E+08	EM220	0.1230E+08	ED220	0.3000E+07
8	GF120	0.2380E+08	GM120	0.4659E+07	GD120	0.1136E+07
9	GF230	0.2380E+08	GM230	0.4659E+07	GD230	0.1136E+07
10	NUF120	0.3000E+00	NUM120	0.3200E+00	NUD120	0.3200E+00
11	NUF230	0.3000E+00	NUM230	0.3200E+00	NUD230	0.3200E+00
12	CPFO	0.2900E+00	CPMO	0.1200E+00	CPDO	0.1200E+00
13	KF110	0.7500E+00	KM110	0.3900E+00	KD110	0.3900E+00
14	KF220	0.7500E+00	KM220	0.3900E+00	KD220	0.3900E+00
15	ALF110	0.2720E-05	ALM110	0.4500E-05	ALD110	0.4500E-05
16	ALF220	0.2720E-05	ALM220	0.4500E-05	ALD220	0.4500E-05
17	SF11TO	0.5000E+06	SM11TO	0.1300E+06	SD11TO	0.3250E+05
18	SF11CO	0.6500E+06	SM11CO	0.1300E+06	SD11CO	0.3250E+05
19	SF22TO	0.5000E+06	SM22TO	0.1300E+06	SD22TO	0.3250E+05
20	SF22CO	0.6500E+06	SM22CO	0.1300E+06	SD22CO	0.3250E+05
21	SF12SO	0.3000E+06	SM12SO	0.7800E+05	SD12SO	0.1950E+05
22	SF23SO	0.3000E+06	SM23SO	0.7800E+05	SD23SO	0.1950E+05

NOTE:---
E YOUNGS MODULUS
G SHEAR MODULUS
NU POISSON''S RATIO
AL THERMAL EXP. COEFF.
S STRENGTH
TEMP 0 REF. TEMPERATURE
TEMPM MELTING TEMPERATURE
DOTH STRESS RATE
F FOR FIBER, M FOR MATRIX, D FOR INTERFACE

USER SELECTED EXPONENTS IN THE CONSTITUTIVE RELATIONSHIP

Property	Temp	Stress	Str.Rate	T-Cycles	M-Cycles	Time

EXPONENTS N , M , AND L ETC FOR FIBER

	n	m	l	p	q	r
MODULI	0.25	0.25	0.25	0.50	0.50	0.50
NU"S	0.25	0.25	0.25	0.50	0.50	0.50
STRENGTHS	0.25	0.00	0.25	0.50	0.50	0.50
ALFA"S	0.25	0.00	0.25	0.50	0.50	0.50
HEAT COND.	0.25	0.00	0.25	0.50	0.50	0.50

EXPONENTS N , M , AND L ETC FOR MATRIX

	n	m	l	p	q	r
MODULI	0.50	0.50	0.50	0.50	0.50	0.50
NU"S	0.50	0.50	0.50	0.50	0.50	0.50
STRENGTHS	0.50	0.00	0.50	0.50	0.50	0.50
ALFA"S	0.50	0.00	0.50	0.50	0.50	0.50
HEAT COND.	0.50	0.00	0.50	0.50	0.50	0.50

EXPONENTS N , M , AND L ETC FOR INTERFACE

Property	n	m	l	p	q	r
MODULI	0.50	0.50	0.50	0.50	0.50	0.50
NU"S	0.50	0.50	0.50	0.50	0.50	0.50
STRENGTHS	0.50	0.00	0.50	0.50	0.50	0.50
ALFA"S	0.50	0.00	0.50	0.50	0.50	0.50
HEAT COND.	0.50	0.00	0.50	0.50	0.50	0.50

4.3 Load Step Details (LDSTEP) Output

Description:

This part of the output file contains information for each load step of the analysis. The load step information includes:

(1) The load step number

(2) The total and incremental time corresponding to the current load step

(3) The current exponents for the mechanical cycling, thermal cycling, and time terms of the multifactor interaction relationship

(4) The incremental mechanical loads for the current load step

(5) The total and incremental thermal loads for the current load step

```
LOAD STEP NO.    15
Time     622.2  sec. (  10.37 mts.)  Dtime      44.4 sec.
EXPONENT FOR MECHANICAL CYCLES  0.50
EXPONENT FOR THERMAL    CYCLES  0.50
EXPONENT FOR TIME       CYCLES  0.50
------  MECHANICAL LOADS ------
MEMBRANE   LOADS Nx,Ny,Nxy  ...    0.0      0.0      0.0
BENDING    LOADS Mx,My,Mxy  ...    0.0      0.0      0.0
TRANSVERSE LOADS Qx,Qy,Pu,Pl...    0.0      0.0      0.0      0.0
------  THERMAL    LOADS ------
THERMAL LOADS TEMP...
1124.0    1124.0    1124.0    1124.0
THERMAL LOADS DELTA T
 -34.0     -34.0     -34.0     -34.0
```

4.4 Constituent Failure Index (FLINDEX) Output

Description:

This part of the output file provides failure information at both the ply and constituent levels for each load step. Failure is indicated by a "1", while "0" represents no failure. This failure index pinpoints failure for each ply in the laminate to the different subregions defined in the micromechanical unit cell.

As well as providing a failure index for each load step, a failure modes history is also provided at the end of the output file. The failure modes history combines the failure index from each load step into one location for convenience. For the failure modes history, failure is indicated by "y" and no failure by "n".

C O N S T I T U E N T   F A I L U R E   I N D E X

PLY NO.	Fiber Normal	Fiber Shear	Matrix Normal	Matrix Shear	Interface Normal	Interface Shear
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0

4.5 Finite Element Analysis Data (FEMDATA) Output

Description:

This part of the output file is produced for each load step and contains information which can be incorporated into a material property card for a finite element analysis. The data includes:

(1) The composite thickness

(2) Equivalent ply moduli (E_{11}, E_{12}, E_{13}, E_{22}, E_{23}, and E_{33})

(3) Equivalent composite bending properties:

Poisson's ratios (ν_{xy} and ν_{yx}) and moduli (E_{xx}, E_{yy} and G_{xy})

(4) Equivalent membrane elastic coefficients for MSC/NASTRAN (G_{11}, G_{12}, G_{13}, G_{22}, G_{23}, and G_{33})

(5) Equivalent bending elastic coefficients for MSC/NASTRAN (G_{11}, G_{12}, G_{13}, G_{22}, G_{23}, and G_{33})

(6) Equivalent membrane/bending coupling data for use with MSC/NASTRAN (G_{11}, G_{12}, G_{13}, G_{22}, G_{23}, and G_{33})

(7) Equivalent properties for a MSC/NASTRAN MAT9 card for solid elements and 3-D anisotropic properties for MARC

(8) MAT9 property card for MSC/NASTRAN in single and double field formats

(9) MAT2 property card for MSC/NASTRAN

Values for items (1) through (5) are provided for each iteration that occurs in the load step.

```
U S E F U L   D A T A   F O R   "MSC/NASTRAN  PSHELL CARD"
USE THIS DATA FOR "MID4" ON PSHELL TO INCLUDE MEMBRANE/BENDING  COUPLING ON A MAT2 CARD
G11,G12,G13,G22,G23,G33

 0.00000E+00  -0.11444E+00   0.39790E-08  -0.12207E+01  -0.90950E-06   0.00000E+00


S O M E   U S E F U L   D A T A   F O R  F.E.  A N A L Y S I S

COMPOSITE THICKNESS FOR F.E. ANALYSIS  =  0.20000E-01

PROPERTIES FOR F.E. ANALYSIS E11,E12,E13,E22,E23,E33  PROPERTIES SCALED BY 10**-6
 0.66863E-01 -0.85777E-02 -0.21490E-07  0.66863E-01  0.16195E-06  0.29560E+00

BENDING EQUIVALENT PROPERTIES  NUCXY, NCYX, ECXX, ECYY, GCXY
 0.18789E+00  0.97392E-01  0.19663E+08  0.10193E+08  0.33830E+07

NASTRAN MEMBRANE EQUIVALENT ELASTIC COEFFICIENTS G11,G12,G13,G22,G23,G33
 0.15206E+08  0.19507E+07 -0.36741E-01  0.15206E+08  0.81891E+01  0.33830E+07

NASTRAN BENDING EQUIVALENT ELASTIC COEFFICIENTS  G11,G12,G13,G22,G23,G33
 0.20030E+08  0.19507E+07 -0.91852E-02  0.10383E+08  0.20473E+01  0.33830E+07
```

F I N I T E   E L E M E N T   A N A L Y S I S   M A T E R I A L   C A R D S.   (MAT9 IN N A S T R A N)

MAT9 CARD FOR MSC/NASTRAN SOLID ELEMENTS AND 3-D ANISOTROPIC PROPERTIES FOR MARC
G11,G12,G13,G14,G15,G16,G22,G23,G24,G25,G26,G33,G34,G35,G36,G44,G45,G46,G55,G56,G66

```
 0.16072287E+08 0.28154880E+07 0.28915280E+07-0.68969190E-01 0.00000000E+00 0.00000000E+00 0.16072287E+08 0.28915280E+07
 0.81586952E+01 0.00000000E+00 0.00000000E+00 0.96608400E+07-0.10469383E+00 0.00000000E+00 0.00000000E+00 0.33830060E+07
 0.00000000E+00 0.00000000E+00 0.33688150E+07-0.17984848E 01 0.33688150E+07
```

NOTE: MAT9 CARD FOR SINGLE FIELD FORMAT

```
MAT9     MID          0.1607E+08  0.2815E+07  0.2892E+07 -0.6897E-01  0.0000E+00  0.0000E+00  0.1607E+08+MAT1
+MAT1     0.2892E+07  0.8159E+01  0.0000E+00  0.0000E+00  0.9661E+07 -0.1047E+00  0.0000E+00  0.0000E+00+MAT2
+MAT2     0.3383E+07  0.0000E+00  0.0000E+00  0.3369E+07 -0.1798E-01  0.3369E+07  0.1503E+00  0.5263E-05+MAT3
+MAT3     0.5263E-05  0.5896E-05
```

NOTE: THIS MATERIAL CARD IS FOR DOUBLE FIELD FORMAT

```
MAT9*   MID. NO.            0.1607E+08      0.2815E+07      0.2892E+07*MAT1
*MAT1       -0.6897E-01     0.0000E+00      0.0000E+00      0.1607E+08*MAT2
*MAT2        0.2892E+07     0.8159E+01      0.0000E+00      0.0000E+00*MAT3
*MAT3        0.9661E+07    -0.1047E+00      0.0000E+00      0.0000E+00*MAT4
*MAT4        0.3383E+07     0.0000E+00      0.0000E+00      0.3369E+07*MAT5
*MAT5       -0.1798E-01     0.3369E+07      0.1503E+00      0.5263E-05*MAT6
*MAT6        0.5263E-05     0.5896E-05
```

MAT2 CARD FOR MSC/NASTRAN PLATE ELEMENTS FOR TRANSVERSE SHEAR (MID3 ON "PSHELL")
G11,G12,G22

```
 0.33688150E+07-0.17984848E-01 0.33688150E+07
```

4.6 Ply Stresses and Strains (PLYSTRS) Output

Description:

This part of the output file is produced for each load step and contains stresses and strains in each ply of the laminate for the current load step.

PLY STRESSES (IN KSI. UNITS) AND PLY STRAINS (in %)

NO.	SIG11	SIG22	SIG33	SIG12	SIG13	SIG23	EPS11	EPS22	EPS12	EPS13	EPS23
1	-2.51	2.51	0.00	0.00	0.00	0.00	-0.29	-0.29	0.00	0.00	0.00
2	-2.51	2.51	0.00	0.00	0.00	0.00	-0.29	-0.29	0.00	0.00	0.00
3	-2.51	2.51	0.00	0.00	0.00	0.00	-0.29	-0.29	0.00	0.00	0.00
4	-2.51	2.51	0.00	0.00	0.00	0.00	-0.29	-0.29	0.00	0.00	0.00

4.7 Laminate Stress-Strain Relationship (STRSTRN) Output

Description:

This part of the output file is produced for each load step and contains:

(1) 3-D composite strain-stress relationships with thermal effects around a plane of symmetry at z=0:

$$\begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & S_{16} \\ S_{12} & S_{22} & S_{23} & 0 & 0 & S_{26} \\ S_{13} & S_{23} & S_{33} & 0 & 0 & S_{36} \\ 0 & 0 & 0 & S_{44} & S_{45} & 0 \\ 0 & 0 & 0 & S_{45} & S_{55} & 0 \\ S_{16} & S_{26} & S_{36} & 0 & 0 & S_{66} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix} + \alpha_i \Delta T$$

(2) 3-D composite stress-strain relationships around a plane of symmetry at z=0:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & C_{16} \\ C_{12} & C_{22} & C_{23} & 0 & 0 & C_{26} \\ C_{13} & C_{23} & C_{33} & 0 & 0 & C_{36} \\ 0 & 0 & 0 & C_{44} & C_{45} & 0 \\ 0 & 0 & 0 & C_{45} & C_{55} & 0 \\ C_{16} & C_{26} & C_{36} & 0 & 0 & C_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix}$$

3-D COMPOSITE STRAIN STRESS TEMPERATURE MOISTURE RELATIONS - STRUCTURAL AXES

	-1-	-2-	-3-	-4-	-5-	-6-	-DT-	-DM-
1	0.6686E-07	-0.8574E-08	-0.1745E-07	0.0000E+00	0.0000E+00	0.2150E-13	0.5263E-05	0.0000E+00
2	-0.8574E-08	0.6686E-07	-0.1745E-07	0.0000E+00	0.0000E+00	-0.1620E-12	0.5263E-05	0.0000E+00
3	-0.1745E-07	-0.1745E-07	0.1140E-06	0.0000E+00	0.0000E+00	0.4524E-13	0.5896E-05	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00	0.2968E-06	0.1585E-14	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00	0.1585E-14	0.2968E-06	0.0000E+00	0.0000E+00	0.0000E+00
6	0.2150E-13	-0.1620E-12	0.4524E-13	0.0000E+00	0.0000E+00	0.2956E-06	-0.1500E-11	0.0000E+00

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

	-1-	-2-	-3-	-4-	-5-	-6-
1	0.1607E+08	0.2815E+07	0.2892E+07	0.0000E+00	0.0000E+00	-0.6897E-01
2	0.2815E+07	0.1607E+08	0.2892E+07	0.0000E+00	0.0000E+00	0.8159E+01
3	0.2892E+07	0.2892E+07	0.9661E+07	0.0000E+00	0.0000E+00	-0.1047E+00
4	0.0000E+00	0.0000E+00	0.0000E+00	0.3369E+07	-0.1798E-01	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00	-0.1798E-01	0.3369E+07	0.0000E+00
6	-0.6897E-01	0.8159E+01	-0.1047E+00	0.0000E+00	0.0000E+00	0.3383E+07

4.8 Force-Displacement Relations (CONSTI) Output

Description:

This part of the output file is produced for each load step and contains the force displacement relations with thermal effects:

$$\left\{\frac{N}{M}\right\} = \left[\begin{array}{c|c} A & B \\ \hline B & D \end{array}\right]\left\{\frac{\epsilon^0}{\kappa}\right\} - \left\{\frac{N^T}{M^T}\right\}$$

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^0 \\ \epsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} - \begin{Bmatrix} N_x^T \\ N_y^T \\ N_{xy}^T \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^0 \\ \epsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} - \begin{Bmatrix} M_x^T \\ M_y^T \\ M_{xy}^T \end{Bmatrix}$$

FORCE DISPLACEMENT RELATIONS

FORCES							DISPL	T-FORCES
NX	0.3041E+06	0.3901E+05	-0.7348E-03	0.0000E+00	-0.4578E-04	0.1592E-11	UX	-0.6141E+02
NY	0.3901E+05	0.3041E+06	0.1638E+00	-0.4578E-04	-0.4883E-03	-0.3638E-09	VY	-0.6141E+02
NXY	-0.7348E-03	0.1638E+00	0.6766E+05	0.1592E-11	-0.3638E-09	-0.7629E-04	VXPUY	-0.2573E-04
MX	0.0000E+00	-0.4578E-04	0.1592E-11	0.1335E+02	0.1300E+01	-0.6123E-08	WXX	0.0000E+00
MY	-0.4578E-04	-0.4883E-03	-0.3638E-09	0.1300E+01	0.6922E+01	0.1365E-05	WYY	0.5960E-07
MXY	0.1592E-11	-0.3638E-09	-0.7629E-04	-0.6124E-08	0.1365E-05	0.2255E+01	WXY	0.7105E-13

4.9 Reduced Stiffness Matrix (REDSTIF) Output

Description:

This part of the output file is produced for each load step and contains the reduced stiffness and bending matrices:

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{12} & A_{22} & 0 \\ 0 & 0 & A_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^0 \\ \epsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^0 \\ \epsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & 0 \\ D_{12} & D_{22} & 0 \\ 0 & 0 & D_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$

REDUCED STIFFNESS MATRIX

0.30412E+06	0.39015E+05	-0.73481E-03
0.39015E+05	0.30412E+06	0.16378E+00
-0.73484E-03	0.16378E+00	0.67660E+05

REDUCED BENDING RIGIDITIES

0.13353E+02	0.13005E+01	-0.61234E-08
0.13005E+01	0.69217E+01	0.13649E-05
-0.61237E-08	0.13649E-05	0.22553E+01

4.10 Displacement Force Relations (DISPFOR) Output

Description:

This part of the output file is produced for each load step and contains the displacement force relations:

$$\left\{\begin{array}{c}\epsilon^0\\ \hline \kappa\end{array}\right\} = \left[\begin{array}{c|c}A' & B'\\ \hline H' & D'\end{array}\right]\left\{\begin{array}{c}N\\ \hline M\end{array}\right\}$$

	DISP.	DISPLACEMENT FORCE RELATIONS						COMBINED FORCES
		-1-	-2-	-3-	-4-	-5-	-6-	
1	-0.1790E-03	0.3343E-05	-0.4289E-06	0.1074E-11	-0.6896E-12	-0.8016E-11	-0.3034E-16	-0.6141E+02
2	-0.1790E-03	-0.4289E-06	0.3343E-05	-0.8097E-11	-0.1144E-10	0.2352E-09	0.1233E-15	-0.6141E+02
3	0.5100E-10	0.1074E-11	-0.8097E-11	0.1478E-04	-0.4116E-16	0.1218E-15	0.5000E-09	-0.2573E-04
4	-0.1094E-09	-0.6896E-12	-0.1144E-10	-0.4116E-16	0.7628E-01	-0.1433E-01	0.8881E-08	0.0000E+00
5	-0.5176E-08	-0.8016E-11	0.2352E-09	0.1218E-15	-0.1433E-01	0.1472E+00	-0.8910E-07	0.5960E-07
6	0.7622E-14	-0.3034E-16	0.1233E-15	0.5000E-09	0.8881E-08	-0.8910E-07	0.4434E+00	0.7105E-13

NOTE: THE DISPLACEMENTS ARE REFERENCE PLANE MEMBRANE STRAINS (UX , VY , VXPUY) AND CURVATURES (WXX , WYY , WXY)

4.11 2-D and 3-D Laminate Properties (PROPCOM) Output

Description:

This part of the output file is produced for each load step and contains the 2-D and 3-D composite properties.

COMPOSITE PROPERTIES

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS
LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES
LINES 33 TO 62 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.1503E+00	32	B2DEC	0.0000E+00
2	TC	0.2000E-01	33	CC11	0.1521E+08
3	CC11	0.1607E+08	34	CC12	0.1951E+07
4	CC12	0.2815E+07	35	CC13	-0.3674E-01
5	CC13	0.2892E+07	36	CC22	0.1521E+08
6	CC22	0.1607E+08	37	CC23	0.8189E+01
7	CC23	0.2892E+07	38	CC33	0.3383E+07
8	CC33	0.9661E+07	39	EC11	0.1496E+08
9	CC44	0.3369E+07	40	EC22	0.1496E+08
10	CC55	0.3369E+07	41	EC12	0.3383E+07
11	CC66	0.3383E+07	42	NUC12	0.1283E+00
12	CTE11	0.5263E-05	43	NUC21	0.1283E+00
13	CTE22	0.5263E-05	44	CSN13	-0.3214E-06
14	CTE33	0.5896E-05	45	CSN31	-0.7270E-07
15	HK11	0.6864E+00	46	CSN23	0.2422E-05
16	HK22	0.6864E+00	47	CSN32	0.5479E-06
17	HK33	0.6966E+00	48	CTE11	0.5263E-05
18	HHC	0.1586E+00	49	CTE22	0.5263E-05
19	EC11	0.1496E+08	50	CTE12	-0.1500E-11
20	EC22	0.1496E+08	51	HK11	0.6864E+00
21	EC33	0.8776E+07	52	HK22	0.6864E+00
22	EC23	0.3369E+07	53	HK12	0.1297E-07
23	EC31	0.3369E+07	54	HHC	0.1586E+00
24	EC12	0.3383E+07			
25	NUC12	0.1282E+00			
26	NUC21	0.1282E+00			
27	NUC13	0.2609E+00			
28	NUC31	0.1531E+00			
29	NUC23	0.2609E+00			
30	NUC32	0.1531E+00			
31	ZCGC	0.1000E-01			

4.12 Current Constituent Properties (PROPCUR) Output

Description:

This part of the output file is produced for each load step and contains the current constituent and ply properties for each ply of the laminate at the current load step.

CURRENT CONSTITUENT PROPERTIES AT USE TEMPERATURE FOR PLY NO. 1 PLY ANGLE 0

THE FOLLOWING PROPERTIES ARE FOR SICA FIBER , TI15 MATRIX AND THE CORRESPONDING INTERFACE AND THE PLY

NO.	PROPERTY	FIBER	PROPERTY	MATRIX	PROPERTY	INTERFACE	PROPERTY	PLY
1	NUMFPN	0.2700E+02	NUMMPN	0.5900E+02	NUMDPN	0.4800E+02	NUMPPN	0.2700E+02
2	RHOFN	0.1100E+00	RHOM	0.1720E+00	RHOD	0.1720E+00	RHOL	0.1503E+00
3	EF11	0.5753E+08	EM11	0.7344E+07	ED11	0.1811E+07	EL11	0.2120E+08
4	EF22	0.5815E+08	EM22A	0.7322E+07	ED22B	0.1754E+07	EL22	0.8599E+07
5	GF12	0.2236E+08	EM22B	0.7531E+07	ED22C	0.1751E+07	EL33	0.8573E+07
6	GF23	0.2236E+08	EM22C	0.7528E+07	ED22	0.1752E+07	GL12	0.3383E+07
7	NUF12	0.2818E+00	EM22	0.7399E+07	GD12B	0.7059E+06	GL23	0.3355E+07
8	NUF23	0.2818E+00	GM12A	0.2894E+07	GD12C	0.7059E+06	GL13	0.3383E+07
9	CPF	0.2900E+00	GM12B	0.2894E+07	GD12	0.7059E+06	NUL12	0.2223E+00
10	KF11	0.7984E+00	GM12C	0.2894E+07	GD23B	0.7059E+06	NUL23	0.2816E+00
11	KF22	0.7985E+00	GM12	0.2894E+07	GD23C	0.7059E+06	NUL13	0.2223E+00
12	ALF11	0.2896E-05	GM23A	0.2894E+07	GD23	0.7059E+06	CPL	0.1586E+00
13	ALF22	0.2896E-05	GM23B	0.2894E+07	NUD12	0.1988E+00	KL11	0.6762E+00
14	SF11T	0.4697E+06	GM23C	0.2894E+07	NUD23	0.1988E+00	KL22	0.6966E+00
15	SF11C	0.6106E+06	GM23	0.2894E+07	CPD	0.1200E+00	KL33	0.6966E+00
16	SF22T	0.4697E+06	NUM12	0.1988E+00	KD11	0.6278E+00	AL11	0.5033E-05
17	SF22C	0.6105E+06	NUM23	0.1988E+00	KD22	0.6278E+00	AL22	0.5771E-05
18	SF12	0.2818E+06	CPM	0.1200E+00	ALD11	0.7244E-05	AL33	0.5807E-05
19	SF23	0.2818E+06	KM11	0.6278E+00	ALD22B	0.7244E-05	SL11T	0.1731E+06
20	SF13	0.2818E+06	KM22	0.6648E+00	ALD22C	0.7244E-05	SL11C	0.9687E+05
21	NUF13	0.2818E+00	ALM11	0.7244E-05	ALD22	0.7244E-05	SL22T	0.2685E+05
22	GF13	0.2236E+08	ALM22A	0.7244E-05	SD11T	0.2019E+05	SL22C	0.7297E+05
23	EF33	0.5809E+08	ALM22B	0.7244E-05	SD11C	0.2019E+05	SL33T	0.2685E+05
24	ALF33	0.2896E-05	ALM22C	0.7244E-05	SD22T	0.2019E+05	SL33C	0.7297E+05
25	NUF13	0.2818E+00	ALM22	0.7430E-05	SD22C	0.2019E+05	SL12	0.1611E+05
26	SF33T	0.4697E+06	SM11T	0.8076E+05	SD12	0.1211E+05	SL23	0.1611E+05
27	SF33C	0.6105E+06	SM11C	0.8076E+05	SD23	0.1211E+05	SL13	0.1611E+05
28			SM22T	0.8076E+05	SD13	0.1211E+05		
29			SM22C	0.8076E+05	GD13B	0.7059E+06		
30			SM12	0.4845E+05	GD13C	0.7059E+06		
31			SM23	0.4845E+05	GD13	0.7059E+06		
32			SM13	0.4845E+05	NUD13	0.1988E+00		
33			GM13A	0.2894E+07	NUD12B	0.1988E+00		
34			GM13B	0.2894E+07	NUD12C	0.1988E+00		
35			GM13C	0.2894E+07	NUD23B	0.1988E+00		
36			GM13	0.2894E+07	NUD23C	0.1988E+00		
37			NUM13	0.1988E+00	NUD13B	0.1988E+00		
38			NUM12A	0.1988E+00	NUD13C	0.1988E+00		
39			NUM12B	0.1988E+00	ED33B	0.1774E+07		
40			NUM12C	0.1988E+00	ED33C	0.1661E+07		
41			NUM23A	0.1988E+00	ED33	0.1720E+07		
42			NUM23B	0.1988E+00	ALD33B	0.7244E-05		
43			NUM23C	0.1988E+00	ALD33C	0.7244E-05		

44	NUM13A	0.1988E+00	ALD33	0.7244E-05
45	NUM13B	0.1988E+00	ED11B	0.1811E+07
46	NUM13C	0.1988E+00	ED11C	0.1811E+07
47	EM33A	0.7390E+07	SD33T	0.2019E+05
48	EM33B	0.7551E+07	SD33C	0.2019E+05
49	EM33C	0.7442E+07		
50	EM33	0.7413E+07		
51	ALM33A	0.7244E-05		
52	ALM33B	0.7244E-05		
53	ALM33C	0.7244E-05		
54	ALM33	0.7430E-05		
55	EM11A	0.7344E+07		
56	EM11B	0.7344E+07		
57	EM11C	0.7344E+07		
58	SM33T	0.8076E+05		
59	SM33C	0.8076E+05		

NOTE:--- E YOUNGS MODULUS
G SHEAR MODULUS
NU POISSON"S RATIO
AL THERMAL EXP. COEFF.
S STRENGTH
A,B AND C ARE REGIONS
F FOR FIBER, M FOR MATRIX, D FOR INTERFACE AND L FOR PLY

CURRENT CONSTITUENT PROPERTIES AT USE TEMPERATURE FOR PLY NO. 2 PLY ANGLE 90

THE FOLLOWING PROPERTIES ARE FOR SICA FIBER , TI15 MATRIX AND THE CORRESPONDING INTERFACE AND THE PLY

NO.	PROPERTY	FIBER	PROPERTY	MATRIX	PROPERTY	INTERFACE	PROPERTY	PLY
1	NUMFPN	0.2700E+02	NUMMPN	0.5900E+02	NUMDPN	0.4800E+02	NUMPPN	0.2700E+02
2	RHOFN	0.1100E+00	RHOM	0.1720E+00	RHOD	0.1720E+00	RHOL	0.1503E+00
3	EF11	0.5753E+08	EM11	0.7344E+07	ED11	0.1811E+07	EL11	0.2120E+08
4	EF22	0.5815E+08	EM22A	0.7322E+07	ED22B	0.1754E+07	EL22	0.8599E+07
5	GF12	0.2236E+08	EM22B	0.7531E+07	ED22C	0.1751E+07	EL33	0.8573E+07
6	GF23	0.2236E+08	EM22C	0.7528E+07	ED22	0.1752E+07	GL12	0.3383E+07
7	NUF12	0.2818E+00	EM22	0.7399E+07	GD12B	0.7059E+06	GL23	0.3355E+07
8	NUF23	0.2818E+00	GM12A	0.2894E+07	GD12C	0.7059E+06	GL13	0.3383E+07
9	CPF	0.2900E+00	GM12B	0.2894E+07	GD12	0.7059E+06	NUL12	0.2223E+00
10	KF11	0.7984E+00	GM12C	0.2894E+07	GD23B	0.7059E+06	NUL23	0.2816E+00
11	KF22	0.7985E+00	GM12	0.2894E+07	GD23C	0.7059E+06	NUL13	0.2223E+00
12	ALF11	0.2896E-05	GM23A	0.2894E+07	GD23	0.7059E+06	CPL	0.1586E+00
13	ALF22	0.2896E-05	GM23B	0.2894E+07	NUD12	0.1988E+00	KL11	0.6762E+00
14	SF11T	0.4697E+06	GM23C	0.2894E+07	NUD23	0.1988E+00	KL22	0.6966E+00
15	SF11C	0.6106E+06	GM23	0.2894E+07	CPD	0.1200E+00	KL33	0.6966E+00
16	SF22T	0.4697E+06	NUM12	0.1988E+00	KD11	0.6278E+00	AL11	0.5033E-05
17	SF22C	0.6105E+06	NUM23	0.1988E+00	KD22	0.6278E+00	AL22	0.5771E-05
18	SF12	0.2818E+06	CPM	0.1200E+00	ALD11	0.7244E-05	AL33	0.5807E-05
19	SF23	0.2818E+06	KM11	0.6278E+00	ALD22B	0.7244E-05	SL11T	0.1731E+06
20	SF13	0.2818E+06	KM22	0.6648E+00	ALD22C	0.7244E-05	SL11C	0.9687E+05
21	NUF13	0.2818E+00	ALM11	0.7244E-05	ALD22	0.7244E-05	SL22T	0.2685E+05
22	GF13	0.2236E+08	ALM22A	0.7244E-05	SD11T	0.2019E+05	SL22C	0.7297E+05
23	EF33	0.5809E+08	ALM22B	0.7244E-05	SD11C	0.2019E+05	SL33T	0.2685E+05
24	ALF33	0.2896E-05	ALM22C	0.7244E-05	SD22T	0.2019E+05	SL33C	0.7297E+05
25	NUF13	0.2818E+00	ALM22	0.7430E-05	SD22C	0.2019E+05	SL12	0.1611E+05
26	SF33T	0.4697E+06	SM11T	0.8076E+05	SD12	0.1211E+05	SL23	0.1611E+05
27	SF33C	0.6105E+06	SM11C	0.8076E+05	SD23	0.1211E+05	SL13	0.1611E+05
28			SM22T	0.8076E+05	SD13	0.1211E+05		
29			SM22C	0.8076E+05	GD13B	0.7059E+06		
30			SM12	0.4845E+05	GD13C	0.7059E+06		
31			SM23	0.4845E+05	GD13	0.7059E+06		
32			SM13	0.4845E+05	NUD13	0.1988E+00		
33			GM13A	0.2894E+07	NUD12B	0.1988E+00		
34			GM13B	0.2894E+07	NUD12C	0.1988E+00		
35			GM13C	0.2894E+07	NUD23B	0.1988E+00		
36			GM13	0.2894E+07	NUD23C	0.1988E+00		
37			NUM13	0.1988E+00	NUD13B	0.1988E+00		
38			NUM12A	0.1988E+00	NUD13C	0.1988E+00		
39			NUM12B	0.1988E+00	ED33B	0.1774E+07		
40			NUM12C	0.1988E+00	ED33C	0.1661E+07		
41			NUM23A	0.1988E+00	ED33	0.1720E+07		
42			NUM23B	0.1988E+00	ALD33B	0.7244E-05		
43			NUM23C	0.1988E+00	ALD33C	0.7244E-05		

44	NUM13A	0.1988E+00	ALD33	0.7244E-05
45	NUM13B	0.1988E+00	ED11B	0.1811E+07
46	NUM13C	0.1988E+00	ED11C	0.1811E+07
47	EM33A	0.7390E+07	SD33T	0.2019E+05
48	EM33B	0.7551E+07	SD33C	0.2019E+05
49	EM33C	0.7442E+07		
50	EM33	0.7413E+07		
51	ALM33A	0.7244E-05		
52	ALM33B	0.7244E-05		
53	ALM33C	0.7244E-05		
54	ALM33	0.7430E-05		
55	EM11A	0.7344E+07		
56	EM11B	0.7344E+07		
57	EM11C	0.7344E+07		
58	SM33T	0.8076E+05		
59	SM33C	0.8076E+05		

NOTE:--- E YOUNGS MODULUS
G SHEAR MODULUS
NU POISSON"S RATIO
AL THERMAL EXP. COEFF.
S STRENGTH
A,B AND C ARE REGIONS
F FOR FIBER, M FOR MATRIX, D FOR INTERFACE AND L FOR PLY

CURRENT CONSTITUENT PROPERTIES AT USE TEMPERATURE FOR PLY NO. 3 PLY ANGLE 90

THE FOLLOWING PROPERTIES ARE FOR SICA FIBER , TI15 MATRIX AND THE CORRESPONDING INTERFACE AND THE PLY

NO.	PROPERTY	FIBER	PROPERTY	MATRIX	PROPERTY	INTERFACE	PROPERTY	PLY
1	NUMFPN	0.2700E+02	NUMMPN	0.5900E+02	NUMDPN	0.4800E+02	NUMPPN	0.2700E+02
2	RHOFN	0.1100E+00	RHOM	0.1720E+00	RHOD	0.1720E+00	RHOL	0.1503E+00
3	EF11	0.5753E+08	EM11	0.7344E+07	ED11	0.1811E+07	EL11	0.2120E+08
4	EF22	0.5815E+08	EM22A	0.7322E+07	ED22B	0.1754E+07	EL22	0.8599E+07
5	GF12	0.2236E+08	EM22B	0.7531E+07	ED22C	0.1751E+07	EL33	0.8573E+07
6	GF23	0.2236E+08	EM22C	0.7528E+07	ED22	0.1752E+07	GL12	0.3383E+07
7	NUF12	0.2818E+00	EM22	0.7399E+07	GD12B	0.7059E+06	GL23	0.3355E+07
8	NUF23	0.2818E+00	GM12A	0.2894E+07	GD12C	0.7059E+06	GL13	0.3383E+07
9	CPF	0.2900E+00	GM12B	0.2894E+07	GD12	0.7059E+06	NUL12	0.2223E+00
10	KF11	0.7984E+00	GM12C	0.2894E+07	GD23B	0.7059E+06	NUL23	0.2816E+00
11	KF22	0.7985E+00	GM12	0.2894E+07	GD23C	0.7059E+06	NUL13	0.2223E+00
12	ALF11	0.2896E-05	GM23A	0.2894E+07	GD23	0.7059E+06	CPL	0.1586E+00
13	ALF22	0.2896E-05	GM23B	0.2894E+07	NUD12	0.1988E+00	KL11	0.6762E+00
14	SF11T	0.4697E+06	GM23C	0.2894E+07	NUD23	0.1988E+00	KL22	0.6966E+00
15	SF11C	0.6106E+06	GM23	0.2894E+07	CPD	0.1200E+00	KL33	0.6966E+00
16	SF22T	0.4697E+06	NUM12	0.1988E+00	KD11	0.6278E+00	AL11	0.5033E-05
17	SF22C	0.6105E+06	NUM23	0.1988E+00	KD22	0.6278E+00	AL22	0.5771E-05
18	SF12	0.2818E+06	CPM	0.1200E+00	ALD11	0.7244E-05	AL33	0.5807E-05
19	SF23	0.2818E+06	KM11	0.6278E+00	ALD22B	0.7244E-05	SL11T	0.1731E+06
20	SF13	0.2818E+06	KM22	0.6648E+00	ALD22C	0.7244E-05	SL11C	0.9687E+05
21	NUF13	0.2818E+00	ALM11	0.7244E-05	ALD22	0.7244E-05	SL22T	0.2685E+05
22	GF13	0.2236E+08	ALM22A	0.7244E-05	SD11T	0.2019E+05	SL22C	0.7297E+05
23	EF33	0.5809E+08	ALM22B	0.7244E-05	SD11C	0.2019E+05	SL33T	0.2685E+05
24	ALF33	0.2896E-05	ALM22C	0.7244E-05	SD22T	0.2019E+05	SL33C	0.7297E+05
25	NUF13	0.2818E+00	ALM22	0.7430E-05	SD22C	0.2019E+05	SL12	0.1611E+05
26	SF33T	0.4697E+06	SM11T	0.8076E+05	SD12	0.1211E+05	SL23	0.1611E+05
27	SF33C	0.6105E+06	SM11C	0.8076E+05	SD23	0.1211E+05	SL13	0.1611E+05
28			SM22T	0.8076E+05	SD13	0.1211E+05		
29			SM22C	0.8076E+05	GD13B	0.7059E+06		
30			SM12	0.4845E+05	GD13C	0.7059E+06		
31			SM23	0.4845E+05	GD13	0.7059E+06		
32			SM13	0.4845E+05	NUD13	0.1988E+00		
33			GM13A	0.2894E+07	NUD12B	0.1988E+00		
34			GM13B	0.2894E+07	NUD12C	0.1988E+00		
35			GM13C	0.2894E+07	NUD23B	0.1988E+00		
36			GM13	0.2894E+07	NUD23C	0.1988E+00		
37			NUM13	0.1988E+00	NUD13B	0.1988E+00		
38			NUM12A	0.1988E+00	NUD13C	0.1988E+00		
39			NUM12B	0.1988E+00	ED33B	0.1774E+07		
40			NUM12C	0.1988E+00	ED33C	0.1661E+07		
41			NUM23A	0.1988E+00	ED33	0.1720E+07		
42			NUM23B	0.1988E+00	ALD33B	0.7244E-05		
43			NUM23C	0.1988E+00	ALD33C	0.7244E-05		

44	NUM13A	0.1988E+00	ALD33	0.7244E-05
45	NUM13B	0.1988E+00	ED11B	0.1811E+07
46	NUM13C	0.1988E+00	ED11C	0.1811E+07
47	EM33A	0.7390E+07	SD33T	0.2019E+05
48	EM33B	0.7551E+07	SD33C	0.2019E+05
49	EM33C	0.7442E+07		
50	EM33	0.7413E+07		
51	ALM33A	0.7244E-05		
52	ALM33B	0.7244E-05		
53	ALM33C	0.7244E-05		
54	ALM33	0.7430E-05		
55	EM11A	0.7344E+07		
56	EM11B	0.7344E+07		
57	EM11C	0.7344E+07		
58	SM33T	0.8076E+05		
59	SM33C	0.8076E+05		

NOTE:--- E YOUNGS MODULUS
G SHEAR MODULUS
NU POISSON"S RATIO
AL THERMAL EXP. COEFF.
S STRENGTH
A,B AND C ARE REGIONS
F FOR FIBER, M FOR MATRIX, D FOR INTERFACE AND L FOR PLY

CURRENT CONSTITUENT PROPERTIES AT USE TEMPERATURE FOR PLY NO. 4 PLY ANGLE 0

THE FOLLOWING PROPERTIES ARE FOR SICA FIBER , TI15 MATRIX AND THE CORRESPONDING INTERFACE AND THE PLY

NO.	PROPERTY	FIBER	PROPERTY	MATRIX	PROPERTY	INTERFACE	PROPERTY	PLY
1	NUMFPN	0.2700E+02	NUMMPN	0.5900E+02	NUMDPN	0.4800E+02	NUMPPN	0.2700E+02
2	RHOFN	0.1100E+00	RHOM	0.1720E+00	RHOD	0.1720E+00	RHOL	0.1503E+00
3	EF11	0.5753E+08	EM11	0.7344E+07	ED11	0.1811E+07	EL11	0.2120E+08
4	EF22	0.5815E+08	EM22A	0.7322E+07	ED22B	0.1754E+07	EL22	0.8599E+07
5	GF12	0.2236E+08	EM22B	0.7531E+07	ED22C	0.1751E+07	EL33	0.8573E+07
6	GF23	0.2236E+08	EM22C	0.7528E+07	ED22	0.1752E+07	GL12	0.3383E+07
7	NUF12	0.2818E+00	EM22	0.7399E+07	GD12B	0.7059E+06	GL23	0.3355E+07
8	NUF23	0.2818E+00	GM12A	0.2894E+07	GD12C	0.7059E+06	GL13	0.3383E+07
9	CPF	0.2900E+00	GM12B	0.2894E+07	GD12	0.7059E+06	NUL12	0.2223E+00
10	KF11	0.7984E+00	GM12C	0.2894E+07	GD23B	0.7059E+06	NUL23	0.2816E+00
11	KF22	0.7985E+00	GM12	0.2894E+07	GD23C	0.7059E+06	NUL13	0.2223E+00
12	ALF11	0.2896E-05	GM23A	0.2894E+07	GD23	0.7059E+06	CPL	0.1586E+00
13	ALF22	0.2896E-05	GM23B	0.2894E+07	NUD12	0.1988E+00	KL11	0.6762E+00
14	SF11T	0.4697E+06	GM23C	0.2894E+07	NUD23	0.1988E+00	KL22	0.6966E+00
15	SF11C	0.6106E+06	GM23	0.2894E+07	CPD	0.1200E+00	KL33	0.6966E+00
16	SF22T	0.4697E+06	NUM12	0.1988E+00	KD11	0.6278E+00	AL11	0.5033E-05
17	SF22C	0.6105E+06	NUM23	0.1988E+00	KD22	0.6278E+00	AL22	0.5771E-05
18	SF12	0.2818E+06	CPM	0.1200E+00	ALD11	0.7244E-05	AL33	0.5807E-05
19	SF23	0.2818E+06	KM11	0.6278E+00	ALD22B	0.7244E-05	SL11T	0.1731E+06
20	SF13	0.2818E+06	KM22	0.6648E+00	ALD22C	0.7244E-05	SL11C	0.9687E+05
21	NUF13	0.2818E+00	ALM11	0.7244E-05	ALD22	0.7244E-05	SL22T	0.2685E+05
22	GF13	0.2236E+08	ALM22A	0.7244E-05	SD11T	0.2019E+05	SL22C	0.7297E+05
23	EF33	0.5809E+08	ALM22B	0.7244E-05	SD11C	0.2019E+05	SL33T	0.2685E+05
24	ALF33	0.2896E-05	ALM22C	0.7244E-05	SD22T	0.2019E+05	SL33C	0.7297E+05
25	NUF13	0.2818E+00	ALM22	0.7430E-05	SD22C	0.2019E+05	SL12	0.1611E+05
26	SF33T	0.4697E+06	SM11T	0.8076E+05	SD12	0.1211E+05	SL23	0.1611E+05
27	SF33C	0.6105E+06	SM11C	0.8076E+05	SD23	0.1211E+05	SL13	0.1611E+05
28			SM22T	0.8076E+05	SD13	0.1211E+05		
29			SM22C	0.8076E+05	GD13B	0.7059E+06		
30			SM12	0.4845E+05	GD13C	0.7059E+06		
31			SM23	0.4845E+05	GD13	0.7059E+06		
32			SM13	0.4845E+05	NUD13	0.1988E+00		
33			GM13A	0.2894E+07	NUD12B	0.1988E+00		
34			GM13B	0.2894E+07	NUD12C	0.1988E+00		
35			GM13C	0.2894E+07	NUD23B	0.1988E+00		
36			GM13	0.2894E+07	NUD23C	0.1988E+00		
37			NUM13	0.1988E+00	NUD13B	0.1988E+00		
38			NUM12A	0.1988E+00	NUD13C	0.1988E+00		
39			NUM12B	0.1988E+00	ED33B	0.1774E+07		
40			NUM12C	0.1988E+00	ED33C	0.1661E+07		
41			NUM23A	0.1988E+00	ED33	0.1720E+07		
42			NUM23B	0.1988E+00	ALD33B	0.7244E-05		
43			NUM23C	0.1988E+00	ALD33C	0.7244E-05		

44	NUM13A	0.1988E+00	ALD33	0.7244E-05
45	NUM13B	0.1988E+00	ED11B	0.1811E+07
46	NUM13C	0.1988E+00	ED11C	0.1811E+07
47	EM33A	0.7390E+07	SD33T	0.2019E+05
48	EM33B	0.7551E+07	SD33C	0.2019E+05
49	EM33C	0.7442E+07		
50	EM33	0.7413E+07		
51	ALM33A	0.7244E-05		
52	ALM33B	0.7244E-05		
53	ALM33C	0.7244E-05		
54	ALM33	0.7430E-05		
55	EM11A	0.7344E+07		
56	EM11B	0.7344E+07		
57	EM11C	0.7344E+07		
58	SM33T	0.8076E+05		
59	SM33C	0.8076E+05		

NOTE:--- E YOUNGS MODULUS
G SHEAR MODULUS
NU POISSON"S RATIO
AL THERMAL EXP. COEFF.
S STRENGTH
A,B AND C ARE REGIONS
F FOR FIBER, M FOR MATRIX, D FOR INTERFACE AND L FOR PLY

4.13 Constituent Stresses and Strains (MICRO) Output

Description:

This part of the output file is produced for each load step and contains the current stresses and strains in the individual constituents and plies for each ply of the laminate for the current load step.

M I C R O S T R E S S E S

MICRO STRESSES (in ksi. units) IN PLY NO. 1 PLY ANGLE 0

NO.	STRESS	FIBER	STRESS	MATRIX	STRESS	INTERFACE	STRESS	PLY INC.	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000	7.000
2	SIGF11	-30.986	SIGM11A	9.918	SIGD11B	1.810	SIGL11	-0.136	-2.510
3	SIGF22	-3.820	SIGM22A	10.620	SIGD22B	3.722	SIGL22	0.136	2.510
4	SIGF12	0.000	SIGM22B	3.722	SIGD22C	-3.820	SIGL33	0.000	0.000
5	SIGF23	0.000	SIGM22C	-3.820	SIGD12B	0.000	SIGL12	0.000	0.000
6	SIGF13	0.000	SIGM12A	0.000	SIGD12C	0.000	SIGL23	0.000	0.000
7	SIGF33	-6.691	SIGM12B	0.000	SIGD23B	0.000	SIGL33	0.000	0.000
8			SIGM12C	0.000	SIGD23C	0.000			
9			SIGM23A	0.000	SIGD13B	0.000			
10			SIGM23B	0.000	SIGD13C	0.000			
11			SIGM23C	0.000	SIGD33B	3.052			
12			SIGM13A	0.000	SIGD33C	-6.691			
13			SIGM13B	0.000	SIGD11C	1.810			
14			SIGM13C	0.000					
15			SIGM33A	8.409					
16			SIGM33B	3.052					
17			SIGM33C	-6.691					
18			SIGM11B	9.918					
19			SIGM11C	9.918					

MICRO STRESSES (in ksi. units) IN PLY NO. 2 PLY ANGLE 90

NO.	STRESS	FIBER	STRESS	MATRIX	STRESS	INTERFACE	STRESS	PLY INC.	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000	7.000
2	SIGF11	-30.986	SIGM11A	9.918	SIGD11B	1.810	SIGL11	-0.136	-2.510
3	SIGF22	-3.820	SIGM22A	10.620	SIGD22B	3.722	SIGL22	0.136	2.510
4	SIGF12	0.000	SIGM22B	3.722	SIGD22C	-3.820	SIGL33	0.000	0.000
5	SIGF23	0.000	SIGM22C	-3.820	SIGD12B	0.000	SIGL12	0.000	0.000
6	SIGF13	0.000	SIGM12A	0.000	SIGD12C	0.000	SIGL23	0.000	0.000
7	SIGF33	-6.691	SIGM12B	0.000	SIGD23B	0.000	SIGL33	0.000	0.000
8			SIGM12C	0.000	SIGD23C	0.000			
9			SIGM23A	0.000	SIGD13B	0.000			
10			SIGM23B	0.000	SIGD13C	0.000			
11			SIGM23C	0.000	SIGD33B	3.052			
12			SIGM13A	0.000	SIGD33C	-6.691			
13			SIGM13B	0.000	SIGD11C	1.810			
14			SIGM13C	0.000					
15			SIGM33A	8.409					
16			SIGM33B	3.052					
17			SIGM33C	-6.691					

18	SIGM11B	9.918
19	SIGM11C	9.918

M I C R O S T R E S S E S

MICRO STRESSES (in ksi. units) IN PLY NO. 3 PLY ANGLE 90

NO.	STRESS	FIBER	STRESS	MATRIX	STRESS	INTERFACE	STRESS	PLY INC.	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000	7.000
2	SIGF11	-30.986	SIGM11A	9.918	SIGD11B	1.810	SIGL11	-0.136	-2.510
3	SIGF22	-3.820	SIGM22A	10.620	SIGD22B	3.722	SIGL22	0.136	2.510
4	SIGF12	0.000	SIGM22B	3.722	SIGD22C	-3.820	SIGL33	0.000	0.000
5	SIGF23	0.000	SIGM22C	-3.820	SIGD12B	0.000	SIGL12	0.000	0.000
6	SIGF13	0.000	SIGM12A	0.000	SIGD12C	0.000	SIGL23	0.000	0.000
7	SIGF33	-6.691	SIGM12B	0.000	SIGD23B	0.000	SIGL33	0.000	0.000
8			SIGM12C	0.000	SIGD23C	0.000			
9			SIGM23A	0.000	SIGD13B	0.000			
10			SIGM23B	0.000	SIGD13C	0.000			
11			SIGM23C	0.000	SIGD33B	3.052			
12			SIGM13A	0.000	SIGD33C	-6.691			
13			SIGM13B	0.000	SIGD11C	1.810			
14			SIGM13C	0.000					
15			SIGM33A	8.409					
16			SIGM33B	3.052					
17			SIGM33C	-6.691					
18			SIGM11B	9.918					
19			SIGM11C	9.918					

MICRO STRESSES (in ksi. units) IN PLY NO. 4 PLY ANGLE 0

NO.	STRESS	FIBER	STRESS	MATRIX	STRESS	INTERFACE	STRESS	PLY INC.	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000	7.000
2	SIGF11	-30.986	SIGM11A	9.918	SIGD11B	1.810	SIGL11	-0.136	-2.510
3	SIGF22	-3.820	SIGM22A	10.620	SIGD22B	3.722	SIGL22	0.136	2.510
4	SIGF12	0.000	SIGM22B	3.722	SIGD22C	-3.820	SIGL33	0.000	0.000
5	SIGF23	0.000	SIGM22C	-3.820	SIGD12B	0.000	SIGL12	0.000	0.000
6	SIGF13	0.000	SIGM12A	0.000	SIGD12C	0.000	SIGL23	0.000	0.000
7	SIGF33	-6.691	SIGM12B	0.000	SIGD23B	0.000	SIGL33	0.000	0.000
8			SIGM12C	0.000	SIGD23C	0.000			
9			SIGM23A	0.000	SIGD13B	0.000			
10			SIGM23B	0.000	SIGD13C	0.000			
11			SIGM23C	0.000	SIGD33B	3.052			
12			SIGM13A	0.000	SIGD33C	-6.691			
13			SIGM13B	0.000	SIGD11C	1.810			
14			SIGM13C	0.000					
15			SIGM33A	8.409					
16			SIGM33B	3.052					
17			SIGM33C	-6.691					

18	SIGM11B	9.918
19	SIGM11C	9.918

M I C R O S T R A I N S

MICRO STRAINS (in % units) IN PLY NO. 1 PLY ANGLE 0

NO.	STRAIN	FIBER	STRAIN	MATRIX	STRAIN	INTERFACE	STRAIN	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000
2	EPSF11	-0.054	EPSM11A	0.172	EPSD11B	0.127	EPSL11	-0.292
3	EPSF22	-0.007	EPSM22A	0.182	EPSD22B	0.263	EPSL22	-0.292
4	EPSF12	0.000	EPSM22B	0.063	EPSD22C	-0.265	EPSL33	0.000
5	EPSF23	0.000	EPSM22C	-0.063	EPSD12B	0.000	EPSL12	0.000
6	EPSF13	0.000	EPSM12A	0.000	EPSD12C	0.000	EPSL23	0.000
7	EPSF33	0.000	EPSM12B	0.000	EPSD23B	0.000		
8			EPSM12C	0.000	EPSD23C	0.000		
9			EPSM23A	0.000	EPSD13B	0.000		
10			EPSM23B	0.000	EPSD13C	0.000		
11			EPSM23C	0.000	EPSD33B	0.214		
12			EPSM13A	0.000	EPSD33C	-0.484		
13			EPSM13B	0.000	EPSD11C	0.127		
14			EPSM13C	0.000				
15			EPSM33A	0.143				
16			EPSM33B	0.051				
17			EPSM33C	-0.113				
18			EPSM11B	0.172				
19			EPSM11C	0.172				

MICRO STRAINS (in % units) IN PLY NO. 2 PLY ANGLE 90

NO.	STRAIN	FIBER	STRAIN	MATRIX	STRAIN	INTERFACE	STRAIN	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000
2	EPSF11	-0.054	EPSM11A	0.172	EPSD11B	0.127	EPSL11	-0.292
3	EPSF22	-0.007	EPSM22A	0.182	EPSD22B	0.263	EPSL22	-0.292
4	EPSF12	0.000	EPSM22B	0.063	EPSD22C	-0.265	EPSL33	0.000
5	EPSF23	0.000	EPSM22C	-0.063	EPSD12B	0.000	EPSL12	0.000
6	EPSF13	0.000	EPSM12A	0.000	EPSD12C	0.000	EPSL23	0.000
7	EPSF33	0.000	EPSM12B	0.000	EPSD23B	0.000		
8			EPSM12C	0.000	EPSD23C	0.000		
9			EPSM23A	0.000	EPSD13B	0.000		
10			EPSM23B	0.000	EPSD13C	0.000		
11			EPSM23C	0.000	EPSD33B	0.214		
12			EPSM13A	0.000	EPSD33C	-0.484		
13			EPSM13B	0.000	EPSD11C	0.127		
14			EPSM13C	0.000				
15			EPSM33A	0.143				
16			EPSM33B	0.051				
17			EPSM33C	-0.113				

18	EPSM11B	0.172
19	EPSM11C	0.172

M I C R O S T R A I N S

MICRO STRAINS (in % units) IN PLY NO. 3 PLY ANGLE 90

NO.	STRAIN	FIBER	STRAIN	MATRIX	STRAIN	INTERFACE	STRAIN	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000
2	EPSF11	-0.054	EPSM11A	0.172	EPSD11B	0.127	EPSL11	-0.292
3	EPSF22	-0.007	EPSM22A	0.182	EPSD22B	0.263	EPSL22	-0.292
4	EPSF12	0.000	EPSM22B	0.063	EPSD22C	-0.265	EPSL33	0.000
5	EPSF23	0.000	EPSM22C	-0.063	EPSD12B	0.000	EPSL12	0.000
6	EPSF13	0.000	EPSM12A	0.000	EPSD12C	0.000	EPSL23	0.000
7	EPSF33	0.000	EPSM12B	0.000	EPSD23B	0.000		
8			EPSM12C	0.000	EPSD23C	0.000		
9			EPSM23A	0.000	EPSD13B	0.000		
10			EPSM23B	0.000	EPSD13C	0.000		
11			EPSM23C	0.000	EPSD33B	0.214		
12			EPSM13A	0.000	EPSD33C	-0.484		
13			EPSM13B	0.000	EPSD11C	0.127		
14			EPSM13C	0.000				
15			EPSM33A	0.143				
16			EPSM33B	0.051				
17			EPSM33C	-0.113				
18			EPSM11B	0.172				
19			EPSM11C	0.172				

MICRO STRAINS (in % units) IN PLY NO. 4 PLY ANGLE 0

NO.	STRAIN	FIBER	STRAIN	MATRIX	STRAIN	INTERFACE	STRAIN	PLY TOTAL.
1	NOFS	7.000	NOMS	19.000	NODS	13.000	NOLS	7.000
2	EPSF11	-0.054	EPSM11A	0.172	EPSD11B	0.127	EPSL11	-0.292
3	EPSF22	-0.007	EPSM22A	0.182	EPSD22B	0.263	EPSL22	-0.292
4	EPSF12	0.000	EPSM22B	0.063	EPSD22C	-0.265	EPSL33	0.000
5	EPSF23	0.000	EPSM22C	-0.063	EPSD12B	0.000	EPSL12	0.000
6	EPSF13	0.000	EPSM12A	0.000	EPSD12C	0.000	EPSL23	0.000
7	EPSF33	0.000	EPSM12B	0.000	EPSD23B	0.000		
8			EPSM12C	0.000	EPSD23C	0.000		
9			EPSM23A	0.000	EPSD13B	0.000		
10			EPSM23B	0.000	EPSD13C	0.000		
11			EPSM23C	0.000	EPSD33B	0.214		
12			EPSM13A	0.000	EPSD33C	-0.484		
13			EPSM13B	0.000	EPSD11C	0.127		
14			EPSM13C	0.000				
15			EPSM33A	0.143				
16			EPSM33B	0.051				
17			EPSM33C	-0.113				

18	EPSM11B	0.172
19	EPSM11C	0.172

4.14 Ply Thermomechanical Properties and Response (PLYRESP) Output

Description:

This part of the output file is produced for each load step and contains the current load conditions and the corresponding thermomechanical properties and response for each ply.

P L Y   T H E R M O M E C H A N I C A L   P R O P E R T I E S / R E S P O N S E

```
FOR LOAD CONDITIONS .
MEMBRANE LOADS NBS(X,Y,XY-M)   ARE    0.000    0.000    0.000
BENDING  LOADS MBS(X,Y,XY-M)   ARE    0.000    0.000    0.000
QXZ,QYZ AND APPLIED PRESSURES  ARE    0.000    0.000    0.000    0.000
Note : No Moisture or Temperature
```

LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

	PLY NUMBER	1	2	3	4
	MATERIAL SYSTEM	SICA/TI15 /	SICA/TI15 /	SICA/TI15 /	SICA/TI15 /
	ORIENTATION	0.0	90.0	90.0	0.0
1	KV	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	KF	0.3500E+00	0.3500E+00	0.3500E+00	0.3500E+00
3	KFB	0.3500E+00	0.3500E+00	0.3500E+00	0.3500E+00
4	KM	0.6500E+00	0.6500E+00	0.6500E+00	0.6500E+00
5	KMB	0.6500E+00	0.6500E+00	0.6500E+00	0.6500E+00
6	RHOL	0.1503E+00	0.1503E+00	0.1503E+00	0.1503E+00
7	TL	0.5000E-02	0.5000E-02	0.5000E-02	0.5000E-02
8	DELTA	0.2789E-02	0.2789E-02	0.2789E-02	0.2789E-02
9	ILDC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	ZB	0.2500E-02	0.7500E-02	0.1250E-01	0.1750E-01
11	ZGC	-0.7500E-02	-0.2500E-02	0.2500E-02	0.7500E-02
12	THCS	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	THLC	0.0000E+00	0.1571E+01	0.1571E+01	0.0000E+00
14	THLS	0.0000E+00	0.1571E+01	0.1571E+01	0.0000E+00
15	SC11	0.2245E+08	0.2245E+08	0.2245E+08	0.2245E+08
16	SC12	0.2815E+07	0.2815E+07	0.2815E+07	0.2815E+07
17	SC13	0.2809E+07	0.2809E+07	0.2809E+07	0.2809E+07
18	SC22	0.9690E+07	0.9690E+07	0.9690E+07	0.9690E+07
19	SC23	0.2974E+07	0.2974E+07	0.2974E+07	0.2974E+07
20	SC33	0.9661E+07	0.9661E+07	0.9661E+07	0.9661E+07
21	SC44	0.3355E+07	0.3355E+07	0.3355E+07	0.3355E+07
22	SC55	0.3383E+07	0.3383E+07	0.3383E+07	0.3383E+07
23	SC66	0.3383E+07	0.3383E+07	0.3383E+07	0.3383E+07
24	CTE11	0.5033E-05	0.5033E-05	0.5033E-05	0.5033E-05
25	CTE22	0.5771E-05	0.5771E-05	0.5771E-05	0.5771E-05
26	CTE33	0.5807E-05	0.5807E-05	0.5807E-05	0.5807E-05
27	HK11	0.6762E+00	0.6762E+00	0.6762E+00	0.6762E+00
28	HK22	0.6966E+00	0.6966E+00	0.6966E+00	0.6966E+00
29	HK33	0.6966E+00	0.6966E+00	0.6966E+00	0.6966E+00
30	HCL	0.1586E+00	0.1586E+00	0.1586E+00	0.1586E+00
31	EL11	0.2120E+08	0.2120E+08	0.2120E+08	0.2120E+08
32	EL22	0.8599E+07	0.8599E+07	0.8599E+07	0.8599E+07
33	EL33	0.8573E+07	0.8573E+07	0.8573E+07	0.8573E+07

34	GL23	0.3355E+07	0.3355E+07	0.3355E+07	0.3355E+07
35	GL13	0.3383E+07	0.3383E+07	0.3383E+07	0.3383E+07
36	GL12	0.3383E+07	0.3383E+07	0.3383E+07	0.3383E+07
37	NUL12	0.2223E+00	0.2223E+00	0.2223E+00	0.2223E+00
38	NUL21	0.9016E-01	0.9016E-01	0.9016E-01	0.9016E-01
39	NUL13	0.2223E+00	0.2223E+00	0.2223E+00	0.2223E+00
40	NUL31	0.8989E-01	0.8989E-01	0.8989E-01	0.8989E-01
41	NUL23	0.2816E+00	0.2816E+00	0.2816E+00	0.2816E+00
42	NUL32	0.2808E+00	0.2808E+00	0.2808E+00	0.2808E+00
43	DPL1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	DPL2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	DPL3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
46	BTAL1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
47	BTAL2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
48	BTAL3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
49	ILMFC	0.0000E+00	0.1667E+01	0.1667E+01	0.1667E+01
50	TEMPD	-0.3400E+02	-0.3400E+02	-0.3400E+02	-0.3400E+02
51	SL11T	0.1731E+06	0.1731E+06	0.1731E+06	0.1731E+06
52	SL11C	0.9687E+05	0.9687E+05	0.9687E+05	0.9687E+05
53	SL22T	0.2685E+05	0.2685E+05	0.2685E+05	0.2685E+05
54	SL22C	0.7297E+05	0.7297E+05	0.7297E+05	0.7297E+05
55	SL33T	0.2685E+05	0.2685E+05	0.2685E+05	0.2685E+05
56	SL33C	0.7297E+05	0.7297E+05	0.7297E+05	0.7297E+05
57	SL12S	0.1611E+05	0.1611E+05	0.1611E+05	0.1611E+05
58	SL23S	0.1611E+05	0.1611E+05	0.1611E+05	0.1611E+05
59	SL13S	0.1611E+05	0.1611E+05	0.1611E+05	0.1611E+05
60	LSCDF	0.0000E+00	0.2099E-01	0.2099E-01	0.2099E-01
61	KL12AB	0.9093E+00	0.9093E+00	0.9093E+00	0.9093E+00
62	MDEIE	0.1000E+01	0.1000E+01	0.1000E+01	0.1000E+01
63	RELROT	0.0000E+00	0.1000E+01	0.1000E+01	0.1000E+01
64	EPS11	-0.1790E-03	-0.1790E-03	-0.1790E-03	-0.1790E-03
65	EPS22	-0.1790E-03	-0.1790E-03	-0.1790E-03	-0.1790E-03
66	EPS12	0.5100E-10	-0.5100E-10	-0.5100E-10	0.5100E-10
67	SIG11	-0.1361E+03	-0.1361E+03	-0.1361E+03	-0.1361E+03
68	SIG22	0.1361E+03	0.1361E+03	0.1361E+03	0.1361E+03
69	SIG12	0.1725E-03	-0.1725E-03	-0.1725E-03	0.1725E-03
70	DELFI	0.0000E+00	-0.5100E-10	0.0000E+00	0.5100E-10
71	HFC	0.9989E+00	0.9989E+00	0.9989E+00	0.9989E+00
72	MFCTGE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
73	SIG13	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
74	SIG23	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
75	SIG33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

4.15 Stress Concentration Factors (STRCON) Output

Description:

This part of the output file is produced for each load step and contains the stress concentration factors at various positions around a circular hole in an infinite plate arising from stresses, σ_{xx}, σ_{yy}, and σ_{xy}.

STRESS CONCENTRATION FACTORS
(AROUND A CIRCULAR HOLE)

NOTE: K1XX --> STRESS CONCENTRATION FACTOR DUE TO SIGMA XX
K1YY --> STRESS CONCENTRATION FACTOR DUE TO SIGMA YY
K1XY --> STRESS CONCENTRATION FACTOR DUE TO SIGMA XY
LAYUP --> 0 90 90 0

THETA	K1XX	K1YY	K1XY	THETA	K1XX	K1YY	K1XY
0.0	-1.0000	3.4828	0.0000	180.0	-1.0000	3.4828	0.0001
5.0	-0.9504	3.3934	-0.9508	185.0	-0.9505	3.3934	-0.9507
10.0	-0.8133	3.1484	-1.7900	190.0	-0.8134	3.1484	-1.7899
15.0	-0.6163	2.8034	-2.4509	195.0	-0.6164	2.8033	-2.4509
20.0	-0.3887	2.4180	-2.9235	200.0	-0.3887	2.4179	-2.9234
25.0	-0.1513	2.0359	-3.2356	205.0	-0.1513	2.0358	-3.2356
30.0	0.0859	1.6803	-3.4282	210.0	0.0858	1.6803	-3.4282
35.0	0.3213	1.3589	-3.5386	215.0	0.3212	1.3588	-3.5386
40.0	0.5589	1.0695	-3.5943	220.0	0.5589	1.0694	-3.5943
45.0	0.8055	0.8056	-3.6111	225.0	0.8055	0.8056	-3.6111
50.0	1.0694	0.5590	-3.5943	230.0	1.0694	0.5589	-3.5943
55.0	1.3588	0.3214	-3.5386	235.0	1.3587	0.3213	-3.5387
60.0	1.6802	0.0859	-3.4282	240.0	1.6802	0.0859	-3.4282
65.0	2.0358	-0.1512	-3.2356	245.0	2.0357	-0.1513	-3.2357
70.0	2.4179	-0.3886	-2.9235	250.0	2.4178	-0.3887	-2.9236
75.0	2.8033	-0.6163	-2.4510	255.0	2.8032	-0.6163	-2.4511
80.0	3.1484	-0.8133	-1.7901	260.0	3.1483	-0.8133	-1.7902
85.0	3.3934	-0.9504	-0.9509	265.0	3.3933	-0.9504	-0.9510
90.0	3.4828	-1.0000	0.0000	270.0	3.4828	-1.0000	-0.0002
95.0	3.3934	-0.9504	0.9508	275.0	3.3934	-0.9505	0.9506
100.0	3.1484	-0.8133	1.7900	280.0	3.1484	-0.8134	1.7898
105.0	2.8033	-0.6163	2.4509	285.0	2.8034	-0.6164	2.4508
110.0	2.4179	-0.3887	2.9235	290.0	2.4180	-0.3887	2.9234
115.0	2.0358	-0.1513	3.2356	295.0	2.0359	-0.1513	3.2356
120.0	1.6803	0.0859	3.4282	300.0	1.6803	0.0858	3.4282
125.0	1.3588	0.3213	3.5386	305.0	1.3589	0.3212	3.5386
130.0	1.0694	0.5589	3.5943	310.0	1.0695	0.5589	3.5943
135.0	0.8056	0.8055	3.6111	315.0	0.8056	0.8055	3.6111
140.0	0.5589	1.0694	3.5943	320.0	0.5590	1.0694	3.5943
145.0	0.3213	1.3588	3.5387	325.0	0.3214	1.3587	3.5387
150.0	0.0859	1.6802	3.4282	330.0	0.0859	1.6802	3.4282
155.0	-0.1513	2.0358	3.2357	335.0	-0.1512	2.0357	3.2357
160.0	-0.3887	2.4179	2.9236	340.0	-0.3886	2.4178	2.9236
165.0	-0.6163	2.8033	2.4510	345.0	-0.6163	2.8032	2.4511
170.0	-0.8133	3.1484	1.7901	350.0	-0.8133	3.1483	1.7903
175.0	-0.9504	3.3934	0.9510	355.0	-0.9504	3.3933	0.9511

4.16 Notation and Units

The notation used in the output file along with their corresponding units are presented below.

Symbol	Units	Description
AL, ALFA, or CTE	ppm/°F	coefficient of thermal expansion
C	psi	stress-strain relations
CP or HH	Btu/lb	heat capacity
CSN or NU	in/in	Poisson's ratio
D	mils	fiber diameter
DOTH	psi/sec	stress rate
E	psi	modulus
EPS	%	strain
G	psi	shear modulus
HK or K	Btu/hr/in/°F	thermal conductivity
KF	--	fiber volume ratio

KFB	--	apparent fiber volume ratio
KM	--	matrix volume ratio
KMB	--	apparent matrix volume ratio
KV or KVOID	--	void volume ratio
RHO	lb/in^3	weight density
S	psi	strength
SC	in^2/psi	strain-stress relations
SIG	psi	stress
T	in	thickness
TEMP	°F	temperature
TEMPM	°F	melting temperature
THCS	° (degrees)	angle from structural axes to composite material axes

THLC	° (degrees)	angle from ply material axes to composite material axes
THLS	° (degrees)	angle from ply material axes to composite structural axes
ZB	in	distance from bottom of composite to reference plane
ZCG	in	distance from reference plane to ply centroid

Extensions	Description
A, B, C	subregions of the unit cell
F, M, D, L, C	fiber, matrix, interface, ply or composite related quantities
T, C, S, TOR	tensile, compressive, shear or torsion related quantities
0	reference temperature related quantity
11	direction along the fiber
22, 33	directions transverse to the fiber
12, 13, 23	shear directions

5.0 Constituent Databank for Demonstration Problems

The constituent databank contains the room temperature material properties of the constituents (fiber, matrix, and interface). The databank used for the demonstration problems is presented in this section. An echo of this databank is also generated by default in the output file (Sect 4.1) in a more convenient format.

```
P100  HIGH MODULUS GRAPHITE FIBER
FP   10000 0.390E-03 0.780E-01 0.660E+04
FE   0.105E 09 0.900E 06 0.200E 00 0.250E 00 0.110E 07 0.700E 06
FT  -0.900E-06 0.560E-05 0.250E 02 0.174E 01 0.170E 00
FS   0.325E 06 0.200E 06 0.250E 05 0.250E 05 0.250E 05 0.125E 05
SIGFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
DOTFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.00 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25
SICA  SILICON CARBIDE FIBER
FP       1 0.560E-02 0.110E+00 0.487E+04
FE   0.620E+08 0.620E+08 0.300E+00 0.300E+00 0.238E+08 0.238E+08
FT   0.272E-05 0.272E-05 0.750E+00 0.750E+00 0.290E+00
FS   0.500E+06 0.650E+06 0.500E+06 0.650E+06 0.300E+06 0.300E+06
SIGFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
DOTFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.00 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25
TUNG  TUNGSTEN FIBER
FP       1 0.100E-01 0.683E 00 0.617E+04
FE   0.590E 08 0.590E 08 0.290E 00 0.290E 00 0.227E 08 0.227E 08
FT   0.250E-05 0.250E-05 0.828E 01 0.828E 01 0.240E-01
FS   0.390E 06 0.390E 06 0.390E 06 0.390E 06 0.236E 06 0.236E 06
SIGFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
DOTFO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.00 +0.25 +0.25 +0.00 +0.25 +0.25
EXPONENTS +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25 +0.25
EXPONENTS +0.25
OVER END OF FIBER PROPERTIES
COPR  COPPER MATRIX
MP   0.320E+00
ME   0.177E+08 0.300E 00 0.980E-05
MT   0.193E 02 0.090E 00
MS   0.320E 05 0.320E 05 0.190E 05 0.350E 00 0.350E 00 0.350E 00 0.350E 00
MV   0.019E 00 0.198E 04
SIGMO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
SIGMO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
SIGMO      0.0        0.0       0.0        0.0       0.0
DOTMO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
DOTMO      0.0        0.0       0.0        0.0       0.0       0.0      0.0
DOTMO      0.0        0.0       0.0        0.0       0.0
EXPONENTS +0.50 +0.50 +4.00 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
TI15  TI-15V-3CR-3AL-3SN MATRIX
```

```
MP   0.172E 00
ME   0.123E 08 0.320E 00 0.450E-05
MT   0.390E 00 0.120E 00
MS   0.130E 06 0.130E 06 0.780E 05 0.120E 00 0.120E 00 0.120E 00 0.120E 00
MV   0.019E 00 0.180E 04
SIGMO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
SIGMO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
SIGMO       0.0         0.0        0.0         0.0        0.0
DOTMO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
DOTMO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
DOTMO       0.0         0.0        0.0         0.0        0.0
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
TI64  Ti-6Al-4V MATRIX
MP   0.170E+00
ME   0.165E+08 0.300E+00 0.524E-05
MT   0.390E+00 0.120E+00
MS   0.144E+06 0.144E+06 0.900E+05 0.020E+00 0.020E+00 0.020E+00 0.020E+00
MV   0.019E+00 0.300E+04
SIGMO      0.0        0.0        0.0        0.0        0.0        0.0        0.0
SIGMO      0.0        0.0        0.0        0.0        0.0        0.0        0.0
SIGMO      0.0        0.0        0.0        0.0        0.0
DOTMO      0.0        0.0        0.0        0.0        0.0        0.0        0.0
DOTMO      0.0        0.0        0.0        0.0        0.0        0.0        0.0
DOTMO      0.0        0.0        0.0        0.0        0.0
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.00
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
OVER   END OF MATRIX PROPERTIES.
INTERFACE  CARBON COATING FOR SIC FIBERS
DP   0.172E+00 0.010E+00
DE   0.250E+07 0.220E+00 2.120E-06
DT   0.390E+00 0.120E+00
DS   0.010E+06 0.010E+06 0.010E+06 0.120E 00 0.120E 00 0.120E 00 0.120E 00
DV   0.019E 00 0.180E 04
SIGDO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
SIGDO       0.0         0.0        0.0         0.0        0.0        0.0
DOTDO       0.0         0.0        0.0         0.0        0.0        0.0      0.0
DOTDO       0.0         0.0        0.0         0.0        0.0        0.0
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
INTERFACE  COMPLIANT LAYER CD
DP   0.285E 00 0.020E 00
DE   0.790E 07 0.260E 00 0.555E-05
DT   0.506E 00 0.120E 00
DS   0.570E 05 0.570E 05 0.280E 05 0.120E 00 0.120E 00 0.120E 00 0.120E 00
DV   0.019E 00 0.239E 04
```

```
SIGDO       0.0         0.0       0.0        0.0       0.0       0.0      0.0
SIGDO       0.0         0.0       0.0        0.0       0.0       0.0
DOTDO       0.0         0.0       0.0        0.0       0.0       0.0      0.0
DOTDO       0.0         0.0       0.0        0.0       0.0       0.0
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
INTERFACE  FOR TI-15-3 WITH 25% OF MATRIX PROPERTIES
DP  0.172E+00 0.050E 00
DE  0.300E 07 0.320E 00 0.450E-05
DT  0.390E 00 0.120E 00
DS  0.325E 05 0.325E 05 0.195E 05 0.120E 00 0.120E 00 0.120E 00 0.120E 00
DV  0.019E 00 0.180E 04
SIGDO       0.0         0.0       0.0        0.0       0.0       0.0      0.0
SIGDO       0.0         0.0       0.0        0.0       0.0       0.0
DOTDO       0.0         0.0       0.0        0.0       0.0       0.0      0.0
DOTDO       0.0         0.0       0.0        0.0       0.0       0.0
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.00 +0.50 +0.50 +0.00 +0.50 +0.50
EXPONENTS +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50 +0.50
EXPONENTS +0.50
```

6.0 References

1 D.A. Hopkins and C.C. Chamis, "A Unique Set of Micromechanics Equations for High Temperature Metal Matrix Composites". NASA TM-87154, 1985.

2 C.C. Chamis and D.A. Hopkins, "Thermoviscoplastic Nonlinear Constitutive Relation ships for Structural Analysis of High Temperature Metal Matrix Composites". NASA TM-87291, 1985.

3 C.C. Chamis, P.L.N. Murthy, and D.A. Hopkins, "Computational Simulation of High Temperature Metal Matrix Composite Cyclic Behavior". NASA TM-102115, 1988.

4 H.-J. Lee, P.K. Gotsis, P.L.N. Murthy, and D.A. Hopkins, "METCAN User's Manual". NASA TM-

5 P.L.N. Murthy, D.A. Hopkins, and C.C. Chamis, "Metal Matrix Composite Micromechanics: In-Situ Behavior Influence on Composite Behavior". NASA TM-102302, 1989.

6 C.C. Chamis, J.J. Caruso, H.-J. Lee, and P.L.N. Murthy, "METCAN Verification Status". NASA TM-103119, 1990.

7 H.-J. Lee, "METCAN Simulation of Candidate Metal Matrix Composites for High Temperature Applications". NASA TM-103636, 1990.

8 H.-J. Lee, P.L.N. Murthy, and C.C. Chamis, "METCAN Updates for High Temperature Composite Behavior: Simulation/Verification". NASA TM-103682, 1991.

9 P.K. Gotsis, "Combined Thermal and Bending Fatigue of High Temperature Metal Matrix Composites: Computational Simulation". NASA TM-104354, 1991.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1992

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
METCAN Demonstration Manual
Version 1.0

5. FUNDING NUMBERS
WU-510-01-50

6. AUTHOR(S)
H.-J. Lee and P.L.N. Murthy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-6944

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-105607

11. SUPPLEMENTARY NOTES
Responsible person, H.-J. Lee, (216) 433-3316.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

LIMITED DISTRIBUTION DOCUMENT

Because of its significant technological potential, this information which has been developed under a U.S. Government program is being given a limited distribution whereby advanced access is provided for use by domestic interests. This legend shall be marked on any reproduction of this information in whole or in part.
Date for general release ______April 1994______

Subject Category 24

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This manual demonstrates the various features of the METCAN (Metal Matrix Composite Analyzer) computer program to simulate the high temperature nonlinear behavior of continuous fiber reinforced metal matrix composites. Different problems are used to demonstrate various capabilities of METCAN for both static and cyclic analyses. A complete description of the METCAN output file is also included to help interpret results.

14. SUBJECT TERMS
Constituent databank; Demonstration; Dynamic analysis; Input file; Metal matrix composite; Output file; Static analysis

15. NUMBER OF PAGES
126

16. PRICE CODE
A07

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

Official Business
Penalty for Private Use $300

FOURTH CLASS MAIL

ADDRESS CORRECTION REQUESTED

U.S.MAIL

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA 451

NASA