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MICROMECHANICAL COMBINED STRESS ANALYSIS - MICSTRAN, A USER MANUAL

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National Aeronautics and
Space Administration

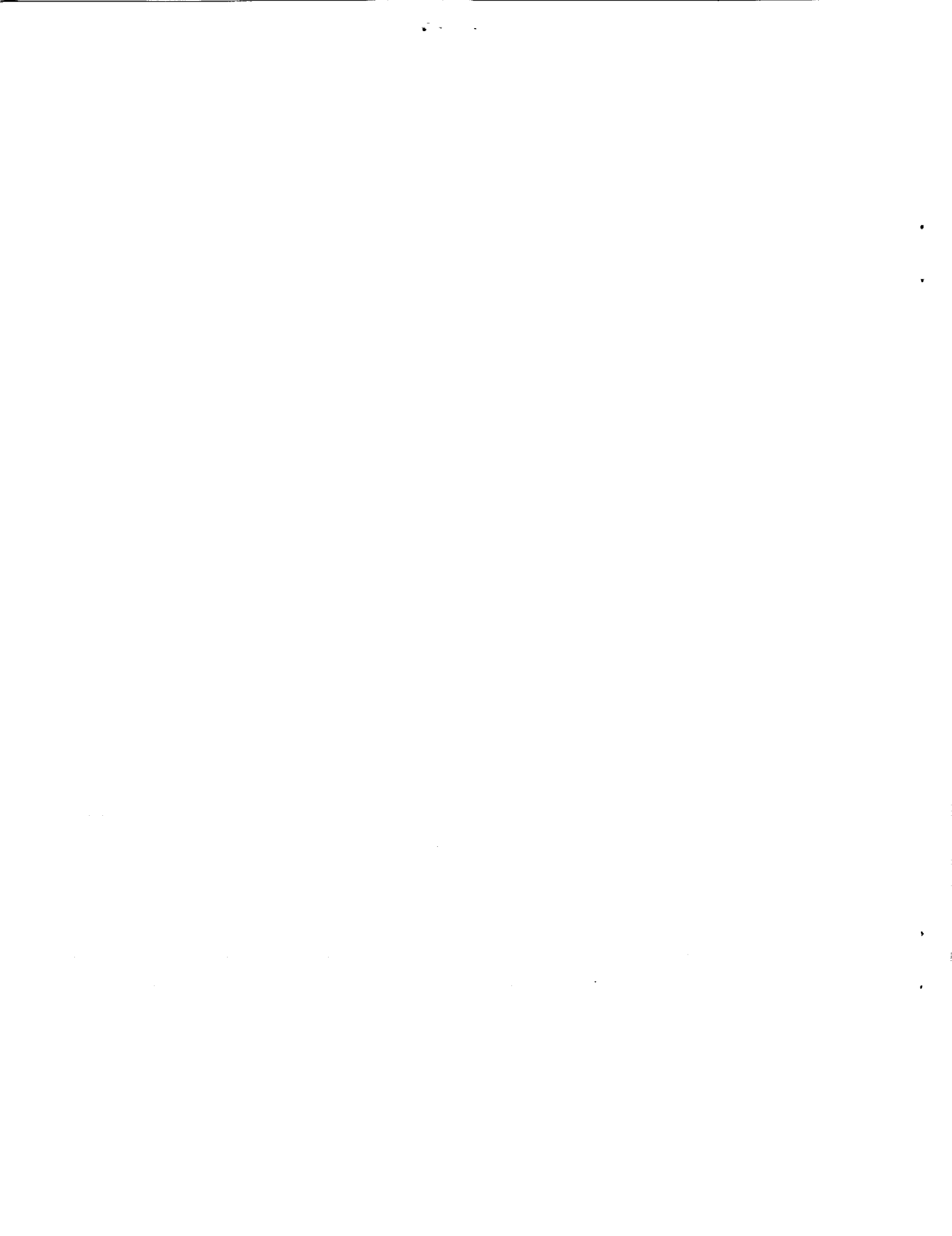**Langley Research Center**
Hampton, Virginia 23665-5225

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NATURE OF THE PROBLEM AND METHOD OF SOLUTION

The Micromechanical Combined Stress Analysis (MICSTRAN) code is a user-friendly micromechanics program that runs in the MS Windows™[1] environment on a IBM®[2] personal computer (PC) or compatible with a 80286 or higher microprocessor. A math coprocessor and a 80386 or higher processor are highly recommended. MICSTRAN calculates overall thermoelastic constants and fiber-matrix stresses for a unidirectional composite or for a single ply within a composite laminate.

Within a composite ply, fibers are arranged randomly and may resemble a square array in some regions, a diamond array in some regions and a hexagonal array in other regions. Micromechanics analyses usually assume that, within a ply, the fibers are arranged in a regular repeating array. The square, diamond, and hexagonal arrays are often used to calculate overall elastic constants and internal stresses in a composite ply. It has been shown [1] that the overall elastic constants (except the longitudinal shear modulus) calculated using the square and diamond array models can be averaged to obtain values that are close to those calculated using the hexagonal array model. Under combined loading, the square and diamond array models have been shown [2] to produce higher stress concentrations than the hexagonal array model. MICSTRAN uses the square and diamond array models to calculate the overall thermoelastic constants and internal stresses.

The micromechanics analysis developed in Ref. [3] for the square and diamond array models is implemented in MICSTRAN. This analysis is based on a classical elasticity approach. Figure 1 shows the reference cylindrical and Cartesian coordinate systems used in MICSTRAN. The origin for both systems is located at the center of the fiber and the Z-direction for both systems is along the fiber axis. The X-axis is constructed by joining the centerlines of two adjacent fibers and the angle θ is measured from the X-axis. The analysis uses the repeating unit

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[1]MS Windows is a trademark of Microsoft Corporation.
[2]IBM is a registered trademark of International Business Machines Corporation.
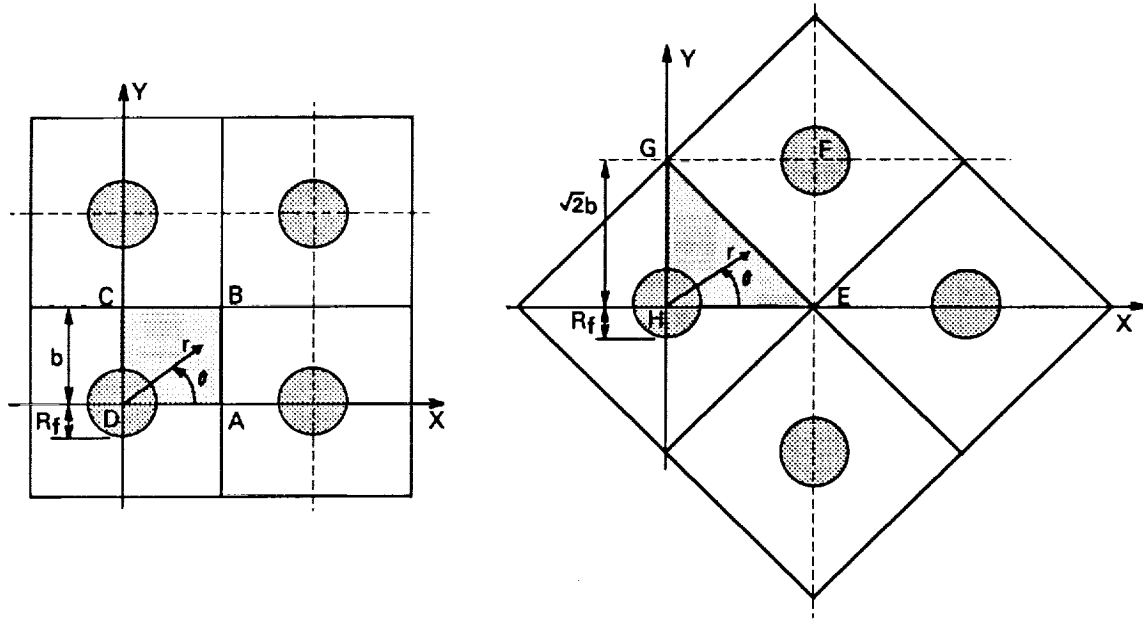
Fig. 1 - Configurations for the square and diamond array analysis.

cell ABCD for the square array and EGH for the diamond array as indicated by the shaded areas in Fig. 1.

The fibers are assumed to be circular in cross section, homogeneous, and orthotropic with transverse isotropy in the X-Y plane. The matrix is homogeneous and isotropic. The fiber and matrix are perfectly bonded. A state of generalized plane strain is assumed (ε_Z = constant) for all loading cases except the longitudinal shear loading case. The loading is input with reference to the Cartesian X-Y-Z coordinates. Stresses can be output in either the cylindrical or the Cartesian systems. All radial coordinates are normalized by the fiber radius (R_f) in the input and output of data. Details of the analysis procedure and comparison of stress results with finite element results are given in Ref. [3], which is included with this user guide.

INSTALLATION INSTRUCTIONS

MICSTRAN can be installed on a IBM PC or compatible. It requires MS Windows 3.0 running in either standard or 386 enhanced mode. It also runs under MS Windows 3.1 running in 386 enhanced mode. The distribution diskette should have the following files in order to insure proper installation of MICSTRAN:

INSTALL.BAT

MICSTRAN.FOR

MICSTRAN.EXE

MICSTRAN.ICO

MICSTRAN.IN

MICSTRAN.OUT

QWIN.HLP

README.WRI

README.TXT

The INSTALL.BAT file contains commands that will automatically copy all required files from the distribution diskette to your hard drive. MICSTRAN.FOR and MICSTRAN.EXE are the FORTRAN source code and executable files, respectively. MICSTRAN.ICO is an icon file that creates a color icon in the Windows environment. MICSTRAN.IN and MICSTRAN.OUT are sample input and output files, respectively. The QWIN.HLP file contains online help for the drop-down menu items. The README files contain installation instructions and important information about MICSTRAN that was updated after this User's Manual was printed. The README.WRI file can be read and printed by using the Windows Write program. The README.TXT file can be read using any text editor (e.g. Windows Notepad). **Please read the README.TXT (or .WRI) file before proceeding.** The installation is performed in two major steps. Step I involves copying required files to your hard drive. Step II involves setting up MICSTRAN as a program item in Windows.

Available Hard Disk Space

Before you start it is important to check the available space on the hard drive. MICSTRAN files need **270 Kbytes** of disk space. If you save MICSTRAN output to a file, you will need more space.

Step-By-Step Installation of MICSTRAN

Step I   **Instructions for Copying all MICSTRAN files on to your Hard Drive**

Note: The first 3 instructions are for copying files from the floppy disk to a directory called MICSTRAN on the hard disk. If you are familiar with the Windows File Manager, or an equivalent file manager, then you can bypass these instructions by creating a directory called MICSTRAN and copying all the MICSTRAN files (.exe, .ico, .in, .out) and the file QWIN.HLP into it. You may then proceed to **Step II** of the instructions (starting with Instruction No. 2) for setting up MICSTRAN as a program item in Windows. If you prefer to use the installation program, the required files will be automatically copied by following the next three instructions.

1. Insert the distribution diskette into a floppy drive on your system. If you are currently running Windows move to a DOS prompt by <u>exiting</u> Windows.

2. Make the floppy drive your current directory by entering either **A:** or **B:** depending on which floppy drive the distribution diskette is in.

3. Enter **INSTALL C:** where **C:** is the hard disk drive that you would like to install MICSTRAN to (e.g., **INSTALL C:**). Be sure to include the colon ":" following the disk drive letter in your command. The installation program will automatically copy all MICSTRAN files to a directory named **MICSTRAN** on the drive you specify.

Step II   Instructions to Setup MICSTRAN as Program Item in Windows 3.0 or 3.1

You should create a program item for MICSTRAN under the Program Manager in Windows. This part of the installation will guide you in setting up the MICSTRAN icon in the program group of your choice.

1.   After the INSTALL program has finished copying all files, change back to your hard disk drive (usually by entering **C:**) and then re-start Windows (usually by entering **WIN**).

2.   Highlight the group (e.g., **Accessories**) that you would like to place MICSTRAN in by clicking on it with the mouse. Select "**New...**" from Program Manager's "**File**" menu, make sure the "**Program Item**" radio button is selected, and click on "**OK**". Click in the **Description box** and enter **MICSTRAN**. Click in the **Command Line edit box** and enter **C:\MICSTRAN\MICSTRAN.EXE** where **C:** is the disk drive that you chose to install MICSTRAN on in **Step I**, Instruction No. **3**.

3.   If you have **Windows 3.1** go to Instruction No. **4**. For **Windows 3.0**, click on "**Change Icon**" to get to the next menu. Now click in the **Filename edit box** and enter **C:\MICSTRAN\MICSTRAN.ICO** and then click on the "**View Next**" button. The MICSTARN icon will be displayed in the Box. Proceed to Instruction No. **5**.

4.   For **Windows 3.1**, click on "**Change Icon**". A message saying "**There are no icons available in the specified file ....**" will be displayed. Click on the "**OK**" button to get the next menu. Use the backspace key to remove the highlighted text (C:\WINDOWS\PROGMAN.EXE) in the **Filename edit box** and enter **C:\MICSTRAN\MICSTRAN.ICO** in the **Filename edit box**. Next click on the "**OK**" button or press enter and the MICSTRAN Icon will be displayed in the Box.

5. Click on "OK" and you should be back in the earlier Box. Click on "OK" and you should see the MICSTRAN icon [image] appear in your program group. If you cannot see the MICSTRAN icon it may be because all of the icons cannot be displayed at once; try using the "**Arrange Icons**" command from Program Manager's "**Window**" menu as well as the group's scroll bar controls.

6. You are now ready to run **MICSTRAN**. Just double-click on the **MICSTRAN** Icon and the program will be launched.

7. <u>Full Screen MICSTRAN Display:</u> - In the default mode, MICSTRAN runs in a window that could sometimes be as large as your Program Manager window or sometimes be quite small. You may use the maximize ($\blacktriangle$) button on the right hand top corner to increase the window size. If you wish to force MICSTRAN to occupy the full screen every time it comes up (<u>highly recommended</u>) then use a <u>text editor</u> such as **Windows Notepad** to edit the **WIN.INI** file in your Windows directory and add the following two lines to it:

[MICSTRAN]

QWINMaximized = 1

<u>Caution:</u> It is a good idea to make a backup of the **WIN.INI** file <u>before</u> editing it. <u>Do not use the Windows Write program or your wordprocessor to edit the WIN.INI file</u> as it may corrupt the file and cause problems with the operation of Windows.

The installation of MICSTRAN is now complete and you are now ready to run the MICSTRAN program. A sample input file called **MICSTRAN.IN** was copied to the MICSTRAN directory during Step I of the installation. This file may be edited using a text editor such as Windows Notepad to view the format of the input data. This file will be used to demonstrate various aspects of the MICSTRAN program in the following section.

USER INSTRUCTIONS

MICSTRAN can be launched simply by double-clicking on the MICSTRAN icon. It may also be launched by choosing "**Run**" from Program Managers "**File**" menu, typing the full path for the program (e.g. **C:\MICSTRAN\MICSTRAN.EXE**) and then hitting **Enter** or clicking on the "**OK**" button. The program starts by displaying an introductory message (see Fig. 2). This is an indication that MICSTRAN was properly installed on your computer.
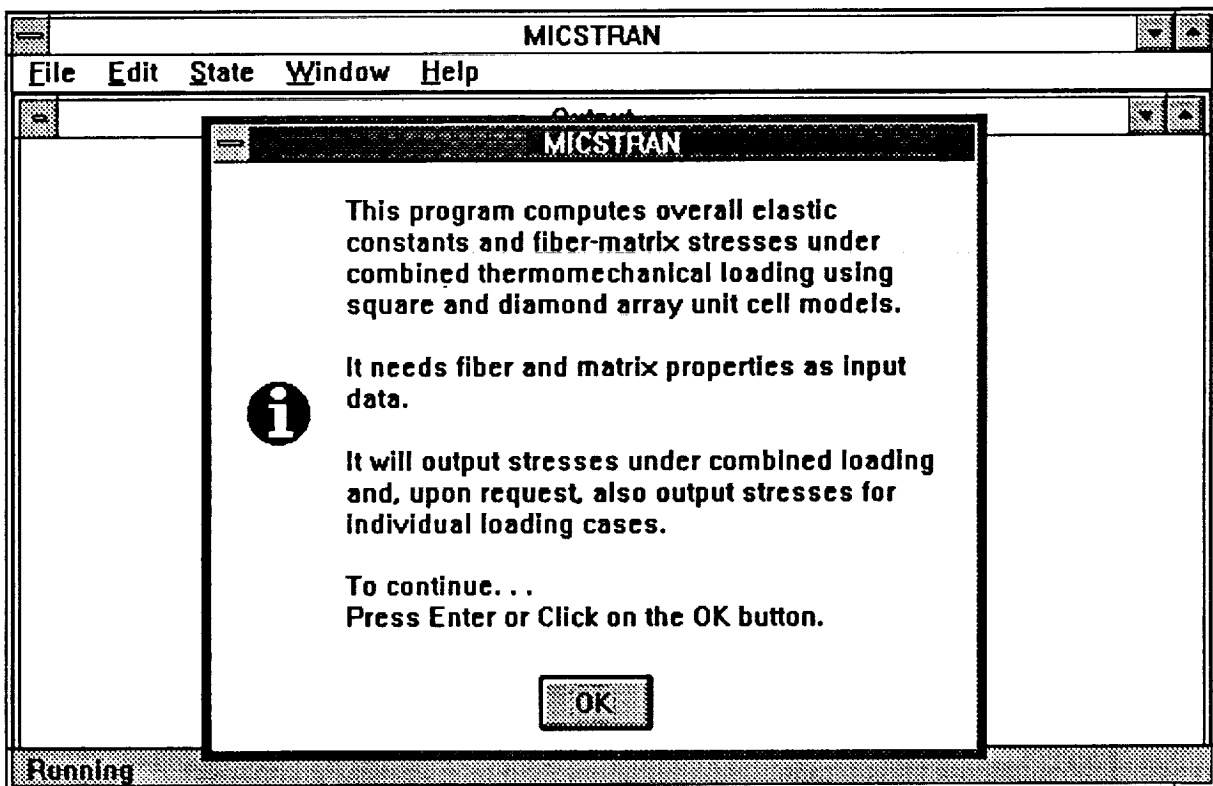
Fig. 2 - Introductory MICSTRAN message at program startup.

If you get an error, make sure that Windows 3.0 is running in standard or 386 enhanced mode. For Windows 3.1, make sure that it is running in 386 enhanced mode. If you still have problems, check to see if all the MICSTRAN files (.exe, .ico, .in) are in the MICSTRAN directory. If you still have problems, the files that you received on the distribution diskette may be corrupt and you may need to get a new MICSTRAN diskette.

Input Data Format

After the message in Fig. 2, MICSTRAN asks whether input data is saved in a file. If the response to this question is "Yes" then the user is asked to enter the input file name. Remember that **DOS** allows only eight characters for the file name and three characters for the extension. MICSTRAN can also be run with keyboard input. In this case the user will be prompted to enter a descriptive title and the fiber and matrix properties.

Figure 3 shows the **Input window** for entering input data. The **MICSTRAN.IN** file is used as a sample input file. It contains the following three lines:

```
MICROMECHANICS ANALYSIS OF AS4/3501-6 UNIDIRECTIONAL COMPOSITE
220.e9, 13.8e9, .20, .25, 34.e9, -.36E-6, 18.E-6, .625
4.3609e9, .34, 41.8135E-6
```

The first line is a descriptive title up to 80 characters long. The second line contains fiber properties in the following order: E_Z, E_r, v_{Zr}, v_{rr}, G_{rZ} α_Z, α_r, V_f where, E is the
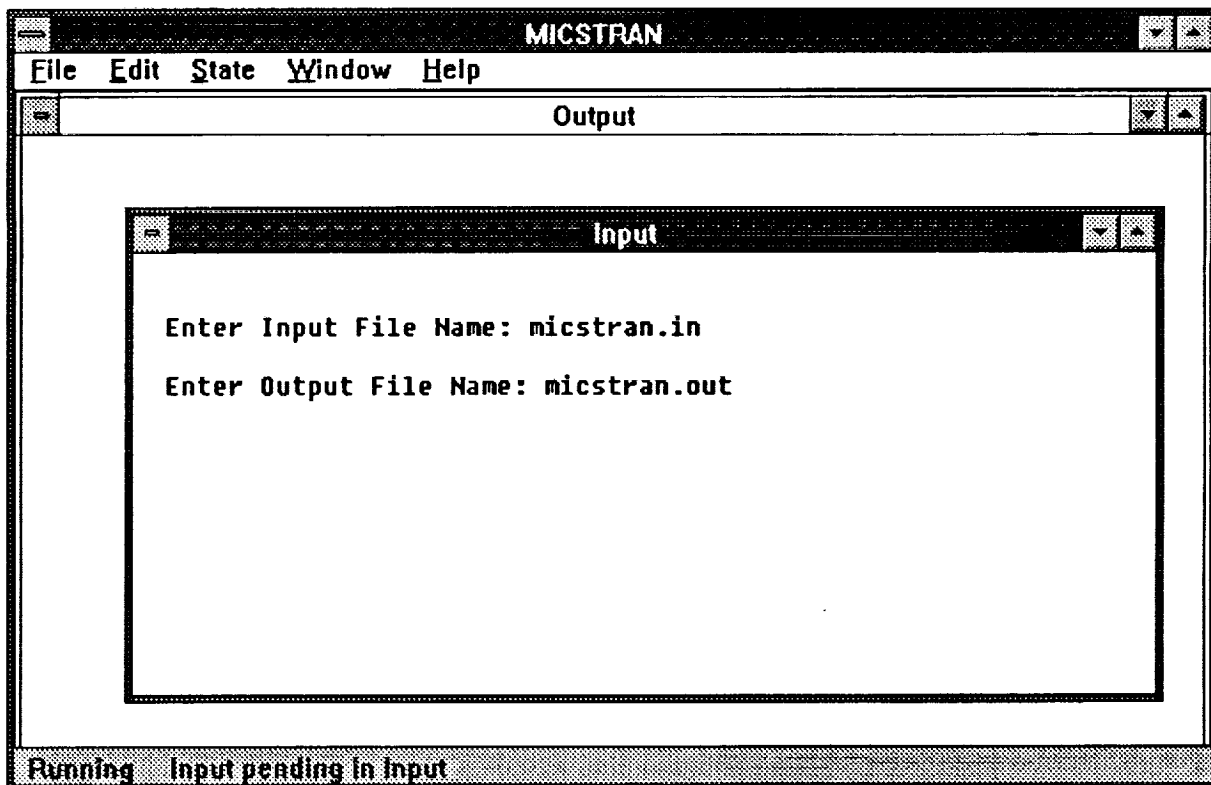
Fig. 3 - The Input window for entering input data.

Young's modulus, ν is Poisson's ratio, α is the coefficient of thermal expansion and V_f is the fiber volume fraction (expressed as a fraction and not as a percentage). The subscripts Z and r refer to the r-θ-Z coordinate system. The third line contains isotropic matrix properties E, ν, and α. Data is input in free format and can be separated by a comma or a space.

Units Used in Input and Output Data

It is necessary to use **consistent units** for all the properties used in the input data file. Thus, if SI units are used for the moduli (**Pa**) then the coefficients of thermal expansion should also be in SI units (**m/m/°C**) for both the fiber and matrix properties. <u>MICSTRAN does not check for consistency of the units</u>. It will output elastic constants and stresses in the same units that were used for the input data. Thus if the moduli were input in **Pa** then the output stresses will also be in **Pa**. The above MICSTRAN.IN file uses SI units for all the data.

Output Window and Menu Bar

After reading the input either from a file or from the keyboard, MICSTRAN will ask if you want to save output to a file and, if you say yes, it will ask you to enter an output filename (see Fig. 3). Output will also appear in the **Output window** on the screen. This ouput may be marked and copied using the **Edit** menu in the **Top Menu Bar** of the **MICSTRAN window** (see Fig. 3). For help on using the menus in the **Top Menu Bar**, use the **Help** menu that appears in the bar. When the screen gets full with output, scroll bars will appear on the side of the **Output window**. These may be used to scroll through all the output that appears in the **Output window**.

Analysis Model

The next two requests for input deal with the type of analysis that the user wishes to perform. Either the square unit cell (Fig. 1), the diamond unit cell, or both may be requested for calculating the overall composite properties and stresses. If both unit cells are chosen then the square array analysis will be performed first.

The next request deals with the computation of stresses under applied thermal and mechanical loads. If only overall elastic properties are required, the response to this question should be **No**. If your response is **Yes** then you will be asked to enter the applied loads to the model. If you have requested both square and diamond array analysis, the same loads will be used for both analyses.

Applied Stresses and Temperature Change

The applied stresses and temperature change (DELTA-T) are entered in the **Input Window** which reappears on the screen (see Fig. 4). Once again the units used for the applied stresses and temperature change should be consistent with those used for the fiber and matrix

```
┌─────────────────────────────────────────────────────────────────┐
│ ─                          MICSTRAN                          ▼ ▲ │
├─────────────────────────────────────────────────────────────────┤
│  File   Edit   State   Window   Help                             │
├─────────────────────────────────────────────────────────────────┤
│ ─                          Output                           ▼ ▲ │
├─────────────────────────────────────────────────────────────────┤
│ MICROMECHANICS ANALYSIS OF AS4/3501-6 UNIDIRECTIONAL COMPOSITE   │
│      ┌────────────────────── Input ──────────────────────▼ ─┐   │
│ EFZ  │                                                      │   │
│ NuZR │   Enter Input File Name: micstran.in                 │   │
│ GFRZ │                                                      │   │
│ ALFAZ│   Enter Output File Name: micstran.out               │   │
│ Vf   │                                                      │   │
│      │   Enter DELTA-T: -150.0                              │   │
│      │                                                      │   │
│      │   Enter Applied SIGMA-X: 92.5e6                      │   │
│ EM  ■│                                                      │   │
│ ALFA ■│  Enter Applied SIGMA-YZ: 24.8e6█                   │   │
│      │                                                      │   │
│      └──────────────────────────────────────────────────────┘   │
├─────────────────────────────────────────────────────────────────┤
│ Running   Input pending in Input                                 │
└─────────────────────────────────────────────────────────────────┘
```
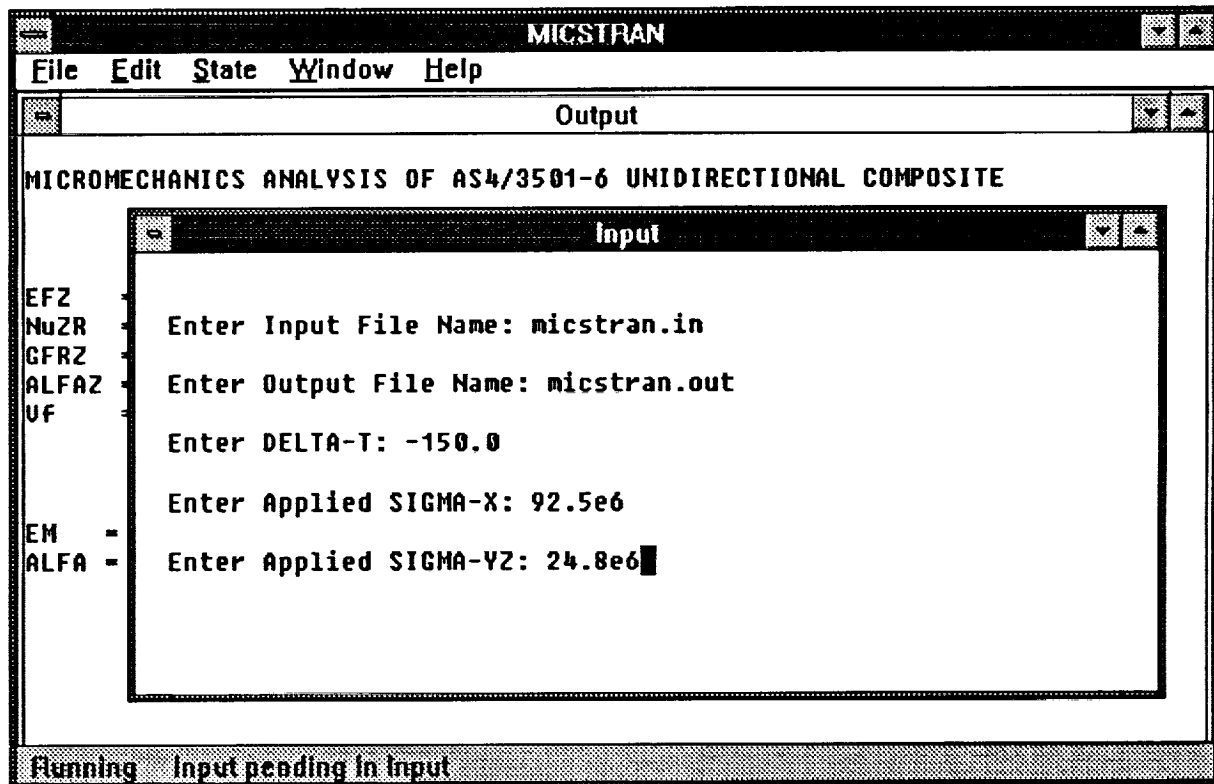
Fig. 4 - Applied stresses and temperature change being entered in the Input window.

properties in the input data. For example, the units for **DELTA-T** in Fig. 4 are °C to match the units for α in the input file **MICSTRAN.IN**. The X-Y-Z coordinate system (see Fig. 1) is used

to enter the applied stresses to both the models. If more than one applied stress is specified then the internal stresses under the combined action of all applied stresses are output by default. Stress output for each individual applied stress can also be requested.

Status Boxes and the Status Bar

MICSTRAN will display a **Status Box** as it proceeds with the calculations. Each **Status Box** indicates the specific calculation that is in progress at a specific time. Sometimes there may be a small pause between the time a **Status Box** disappears and the time when output is printed to the **Output Window**. At such times the **Status Bar** at the bottom of the **MICSTRAN Window** may be useful. Throughout the operation of the program the **Status Bar** indicates whether the program is "**Running**" (see Fig. 2), whether "**Input is Pending in the Input window**" (see Figs. 3 and 4), or whether the program has "**Finished**".

Stress Output Location

As shown in Fig. 5, there are three choices for selecting the location where stress output is desired. Using these three choices, the user is able to recover stresses at all possible locations in both the square and diamond array models.

Stress output in the interior of the two models can be requested either along a circular arc or at a set of user-selected points which extend from 0 - 90 degrees. In either case the stress output location is specified in terms of the normalized radial coordinate R_n

$$R_n = (r / R_f) \tag{1}$$

where r is the desired radial coordinate and R_f is the fiber radius. For example, the fiber-matrix interface is defined by a circular arc with $R_n = 1$. Locations in the fiber region will be specified by $R_n < 1$ and locations in the matrix region will have $R_n > 1$. The specified R_n cannot be outside the model boundary. MICSTRAN automatically calculates the R_n values

```
┌─────────────────────────────────────────────────────────────────────────────┐
│ ▣                              MICSTRAN                                  ▼ ▲ │
├─────────────────────────────────────────────────────────────────────────────┤
│  File   Edit   State   Window   Help                                        │
├─────────────────────────────────────────────────────────────────────────────┤
│ ▣                              Output                                    ▼ ▲ │
│  ┌──────────────────────────────────────────────────────────────────┐    ▣ │
│  OVERALL YC│ ▣            Stress Output Location              │          ▒ │
│  ├──────────────────────────────────────────────────────────┤          ▒ │
│  EXX   - .9│   Stress output may be requested either along a          ▒ │
│  NuXY  -   │   circular arc or at user-specified points extending     ▒ │
│            │   from 0 - 90 degrees.                                   ▒ │
│            │   (i.e. in the first quadrant between the positive X-    ▒ │
│  LONGITUDI │   and Y-axes)                                            ▒ │
│            │                                                          ▒ │
│  GYZ, GXZ =│    ┌──┐  The following choices are available:           ▒ │
│            │    │i │  (1) Stresses at the fiber-matrix interface      ▒ │
│  TRANSVERS │    └──┘  (2) Stresses along model boundary              ▒ │
│            │          (3) Stresses in the interior of the model.      ▒ │
│  GXY - .30 │                                                          ▒ │
│            │   Do you wish to output stresses at the fiber-matrix    ▒ │
│  OVERALL C │   interface ?                                            ▒ │
│            │                                                          ▒ │
│  ALPHA-XX =│             ┌─────────┐    ┌─────────┐                   ▒ │
│  ALPHA-YY =│             │   Yes   │    │   No    │                   ▒ │
│  ALPHA-ZZ =│             └─────────┘    └─────────┘                   ▒ │
│  └──────────────────────────────────────────────────────────────────┘  ▒ │
│ Running                                                                     │
└─────────────────────────────────────────────────────────────────────────────┘
```
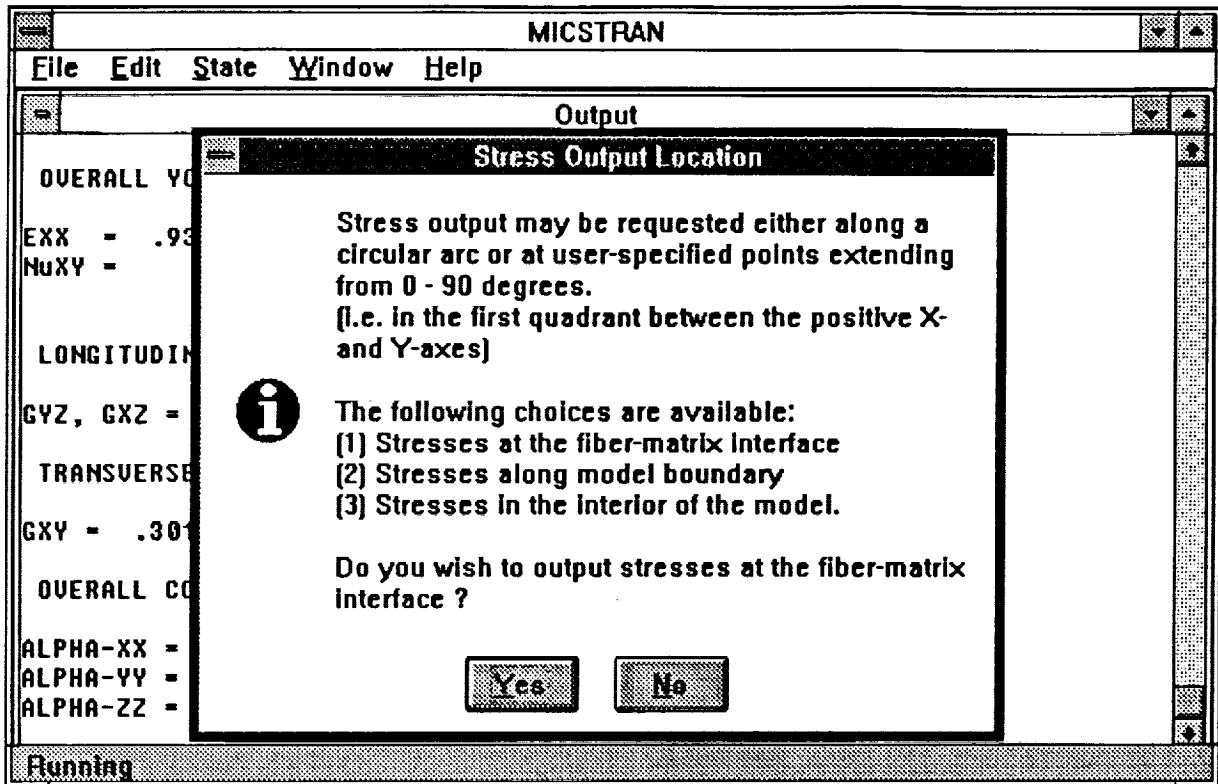
Fig. 5 - Choices for stress output locations.

for the boundary points for each model and displays them in the **Input Window** as **Max. R_n**.

Specified R_n values cannot exceed the **Max. R_n** value.

For the set of user-specified points, R_n values are specified at 5 degree increments for

THETA varying from 0 - 45 degrees. The points are assumed to be reflected about the 45 degree

diagonal line for both models. MICSTRAN displays the **Max. R_n** values for each angle in this

case (see Fig. 6). Additionally, the points specified cannot cross the fiber-matrix interface at any

point.

Output Coordinate System

The stress output locations are always specified in terms of **THETA** and **R_n**. The stresses

at each location, however, may be output in either the cylindrical or Cartesian coordinate system

(see Fig. 1). The user selects this option following the specification of the stress output location.
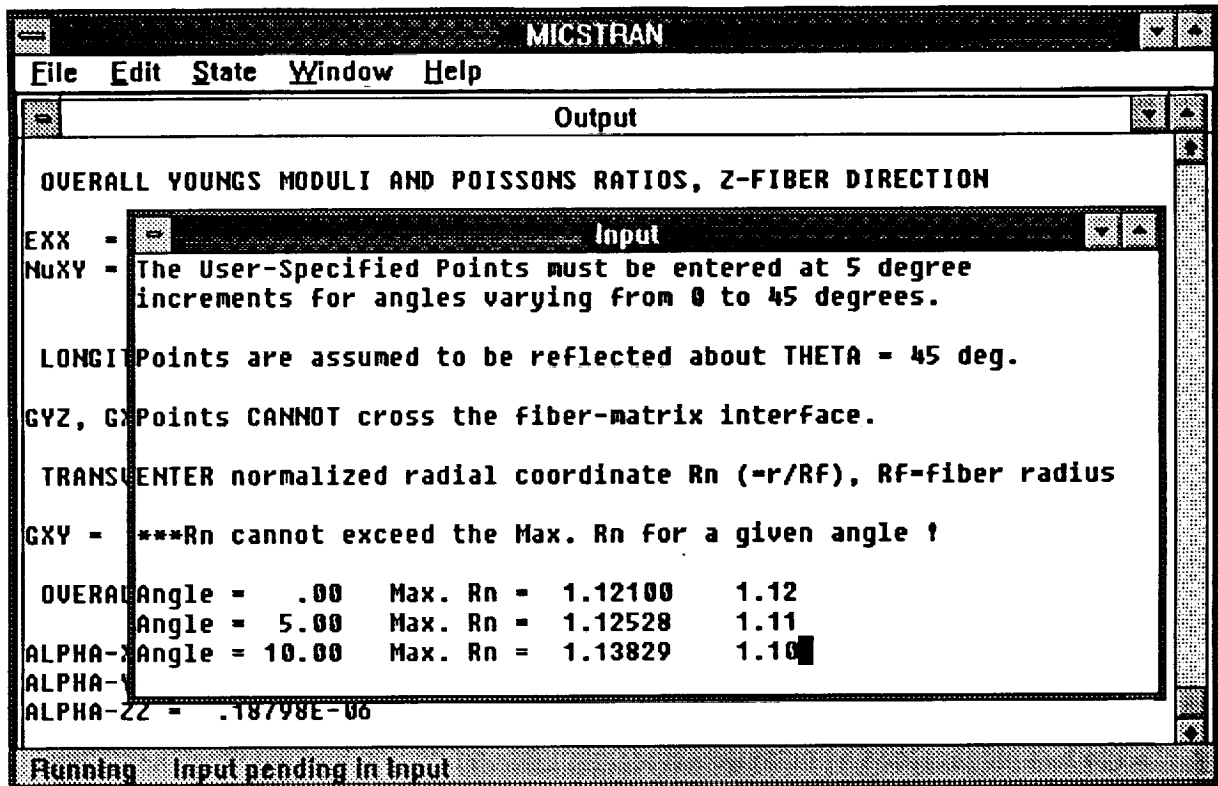
12

```
─                              MICSTRAN                          ▼▲
 File  Edit  State  Window  Help
 ─                              Output                            ▼▲
                                                                  ▲
  OVERALL YOUNGS MODULI AND POISSONS RATIOS, Z-FIBER DIRECTION

 EXX  = ─                         Input                      ▼▲
 NuXY = The User-Specified Points must be entered at 5 degree
         increments for angles varying from 0 to 45 degrees.

 LONGI  Points are assumed to be reflected about THETA = 45 deg.

 GYZ, G  Points CANNOT cross the fiber-matrix interface.

 TRANS  ENTER normalized radial coordinate Rn (=r/Rf), Rf=fiber radius

 GXY  =  ***Rn cannot exceed the Max. Rn for a given angle !

 OVERAL  Angle =    .00   Max. Rn =  1.12100    1.12
         Angle =   5.00   Max. Rn =  1.12528    1.11
 ALPHA-X Angle =  10.00   Max. Rn =  1.13829    1.10█
 ALPHA-Y
 ALPHA-ZZ =   .18798E-06

 Running  Input pending in Input
```

Fig. 6 - Specification of R_n values for stress output at user-specified points.

The next request for input asks whether stress output is desired at other locations. If the response is Yes then the menu for selecting the location (see Fig. 5) is displayed once again.

Square and Diamond Array Analyses in Sequence

If both the square and the diamond array models are selected for the analysis, the square array analysis is performed first. Thus, all the stresses at the requested locations are first calculated for the square array. When these are completed, MICSTRAN alerts the user to this fact and asks to proceed with the diamond array analysis. The stress output locations for the diamond array analysis are requested by MICSTRAN at this point. The same applied loading that was specified initially is used for the diamond array analysis.

Stress Output Format

When stresses for the inidividual loading cases are requested, only the non-zero stresses are output. Thus, for the cases of applied DELTA-T, SIGMA-Z, SIGMA-X, SIGMA-Y or SIGMA-XY, the longitudinal shear stresses are zero and are not included in the output. Similarly, for the cases of applied SIGMA-YZ or SIGMA-XZ only the longitudinal shear stresses are output since all the other stresses are zero. All six stress components are output for the combined loading case. Since the **Output Window** can display a maximum of 80 columns, stress output for the combined loading case is not fully visible on the screen. The right and left arrow keys on the keyboard may be used to scroll the text horizontally. Alternatively, the **Horizontal Scroll Bar** at the bottom of the **Output Window** can be used to scroll to the left or right extremes of the output. If the **Horizontal Scroll Bar** is not fully visible, you may remove the **Status Bar** at the bottom of the MICSTRAN **Window** by deselecting the **Status Bar** in the **Window** menu in the **Top Menu Bar**.

Program Control

The MICSTRAN program runs in a fully multitasking mode. Thus, it can run in its window (either maximized or minimized) while the user chooses to run other programs in other windows. The **File** menu in the **Top Menu Bar** allows the user to terminate the program and close its window at any time during its operation except when it is waiting for a response to a question in a dialogue box. The **State** menu in the **Top Menu Bar** allows the user to temporarily suspend program execution using the **Pause** command and resume execution with the **Resume** command.

When the program terminates normally after completing the requested analysis it displays a message that says "**Program Terminated with exit code 0 - Exit Window ?**" If you respond by clicking Yes then the MICSTRAN window will be closed and all ouput in the Output window will be lost. If an output file was specified earlier, all output is written to and automatically saved in that file, which can be read and edited with any text editor. The default

response to this question is No which then leaves the **MICSTRAN window** open and the output in the **Output window** can then be manipulated as desired using the **Edit** menu in the **Top Menu Bar**.

About Box

The **About Box** can be accessed from the **Help** menu in the **Top Menu Bar**. This box contains information about the MICSTRAN version number and about the author of the MICSTRAN program.

SAMPLE INPUT/OUTPUT

The **MICSTRAN.IN** file (supplied on the distribution diskette) is used as a sample input file in this manual. It contains the following three lines:

```
MICROMECHANICS ANALYSIS OF AS4/3501-6 UNIDIRECTIONAL COMPOSITE
220.e9,  13.8e9,  .20,  .25,  34.e9,  -.36E-6,  18.E-6,  .625
4.3609e9,  .34,  41.8135E-6
```

The format and description of each of the entries in the above three lines was explained in the **Input Data Format** section earlier. Besides the data contained in the input file, MICSTRAN also relies on **Interactive Data** entered during program execution. The following data was entered interactively for the present sample problem.:

Ouput file name: **MICSTRAN.OUT**

Analysis Model : **Square** *and* **Diamond Array Models**

Loading: **DELTA-T = -150.0 (°C)**

   SIGMA-X =   92.5E6 (Pa)

   SIGMA-YZ =   24.8E6 (Pa)

Stress Ouput: **Each individual loading case and combined loading.**

Square Array:

Stress Ouput Location: **Along fiber-matrix interface (for Square Array).**

Fiber or Matrix stresses: **Matrix stresses at fiber-matrix interface.**

Coordinate System for stresses: **r-θ-Z Cylindrical system (see Fig. 1).**

Stresses at another location ? - **No.**

Diamond Array:

Stress Ouput Location: **Along model boundary (for Diamond Array).**

Coordinate System for stresses: **X-Y-Z Cartesian system (see Fig. 1).**

Stresses at another location ? - **No.**

The ouput is displayed in the **Output Window** on the screen and also stored in the **MICSTRAN.OUT** file. A printout of the output is shown below:

MICROMECHANICS ANALYSIS OF AS4/3501-6 UNIDIRECTIONAL COMPOSITE

FIBER PROPERTIES

EFZ   =   .22000E+12   EFR   =   .13800E+11
NuZR   =   .20000E+00   NuRR   =   .25000E+00
GFRZ   =   .34000E+11
ALFAZ =   -.36000E-06   ALFAR =   .18000E-04
Vf   =   .62500

MATRIX PROPERTIES

EM   =   .43609E+10   NuM   =   .34000
ALFA   =   .41814E-04

RESULTS USING SQUARE ARRAY ANALYSIS

OVERALL YOUNGS MODULI AND POISSONS RATIOS, Z-FIBER DIRECTION

EXX   =   .93788E+10   EYY   =   .93788E+10   EZZ   =   .13916E+12
NuXY =   .34201   NuZX =   .24826   NuZY =   .24826

LONGITUDINAL SHEAR MODULI

GYZ, GXZ   =   .63418E+10

TRANSVERSE SHEAR MODULUS

GXY   =   .30126E+10

OVERALL COEFFICIENTS OF THERMAL EXPANSION

ALPHA-XX   =   .31017E-04
ALPHA-YY   =   .31017E-04
ALPHA-ZZ   =   .18798E-06

MATRIX STRESSES ALONG F/M INTERFACE FOR DELTA-T = -.15000E+03

ANGLE	Rn (=r/Rf)	SIG-RR	SIG-TT	SIG-RT	SIG-ZZ
.000	1.000	-.201819E+08	.203489E+08	.000000E+00	.272855E+08

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5.000	1.000	-.188561E+08	.206481E+08	.439776E+07	.278380E+08
10.000	1.000	-.153423E+08	.214248E+08	.776592E+07	.292968E+08
15.000	1.000	-.107387E+08	.224085E+08	.951362E+07	.311965E+08
20.000	1.000	-.617422E+07	.233488E+08	.963496E+07	.330681E+08
25.000	1.000	-.237893E+07	.241075E+08	.852675E+07	.346164E+08
30.000	1.000	.385080E+06	.246502E+08	.669158E+07	.357407E+08
35.000	1.000	.216788E+07	.249983E+08	.452960E+07	.364652E+08
40.000	1.000	.313794E+07	.251883E+08	.227029E+07	.368596E+08
45.000	1.000	.344273E+07	.252483E+08	.150842E-05	.369836E+08
50.000	1.000	.313794E+07	.251883E+08	-.227029E+07	.368596E+08
55.000	1.000	.216788E+07	.249983E+08	-.452960E+07	.364652E+08
60.000	1.000	.385080E+06	.246502E+08	-.669158E+07	.357407E+08
65.000	1.000	-.237893E+07	.241075E+08	-.852675E+07	.346164E+08
70.000	1.000	-.617422E+07	.233488E+08	-.963496E+07	.330681E+08
75.000	1.000	-.107387E+08	.224085E+08	-.951362E+07	.311965E+08
80.000	1.000	-.153423E+08	.214248E+08	-.776592E+07	.292968E+08
85.000	1.000	-.188561E+08	.206481E+08	-.439776E+07	.278380E+08
90.000	1.000	-.201819E+08	.203489E+08	-.382289E-07	.272855E+08

APPLIED AVERAGE STRESSES AND STRAINS FOR SIG-X = .92500E+08

AVG SX = .92500E+08	STRAIN EX = .98627E-02
AVG SY = .22335E-05	STRAIN EY = -.33731E-02
AVG SZ = .58100E-06	STRAIN EZ = -.16502E-03

MATRIX STRESSES ALONG F/M INTERFACE FOR SIG-X = .92500E+08

ANGLE	Rn (=r/Rf)	SIG-RR	SIG-TT	SIG-RT	SIG-ZZ
.000	1.000	.124616E+09	.590267E+08	.000000E+00	.617190E+08
5.000	1.000	.122445E+09	.582757E+08	-.109772E+08	.607254E+08
10.000	1.000	.116231E+09	.562083E+08	-.212190E+08	.579097E+08
15.000	1.000	.106871E+09	.532843E+08	-.299388E+08	.537333E+08
20.000	1.000	.956904E+08	.500248E+08	-.365362E+08	.488235E+08
25.000	1.000	.840304E+08	.468341E+08	-.408546E+08	.437743E+08
30.000	1.000	.728778E+08	.439350E+08	-.431808E+08	.389967E+08
35.000	1.000	.627070E+08	.413887E+08	-.440454E+08	.346729E+08
40.000	1.000	.535201E+08	.391430E+08	-.439874E+08	.307858E+08
45.000	1.000	.449998E+08	.370814E+08	-.433768E+08	.271880E+08
50.000	1.000	.367009E+08	.350633E+08	-.423385E+08	.236802E+08
55.000	1.000	.282185E+08	.329556E+08	-.407557E+08	.200796E+08
60.000	1.000	.193425E+08	.306621E+08	-.383208E+08	.162819E+08
65.000	1.000	.101974E+08	.281571E+08	-.346619E+08	.123209E+08
70.000	1.000	.129382E+07	.255174E+08	-.295386E+08	.839620E+07
75.000	1.000	-.657211E+07	.229409E+08	-.230292E+08	.484575E+07
80.000	1.000	-.125881E+08	.207314E+08	-.155787E+08	.204909E+07
85.000	1.000	-.162503E+08	.192281E+08	-.778317E+07	.292828E+06
90.000	1.000	-.174586E+08	.186944E+08	-.647044E-07	-.299457E+06

APPLIED AVERAGE LONGITUDINAL SHEAR STRESS AND STRAIN

AVG SIGMA-YZ = .24800E+08   STRAIN GAMMA-YZ = .39105E-02

MATRIX STRESSES ALONG F/M INTERFACE FOR SIGMA-YZ = .24800E+08

ANGLE	Rn (=r/Rf)	SIG-RZ	SIG-TZ
.000	1.000	.00000000000E+00	.10228072508E+07
5.000	1.000	.28226362113E+06	.10323325440E+07
10.000	1.000	.71445346967E+06	.10600868422E+07
15.000	1.000	.14504681247E+07	.11027353640E+07
20.000	1.000	.26108699960E+07	.11535552145E+07
25.000	1.000	.42333695774E+07	.12038632261E+07
30.000	1.000	.62649081762E+07	.12460633357E+07
35.000	1.000	.86023853414E+07	.12759275776E+07
40.000	1.000	.11149899912E+08	.12928968742E+07
45.000	1.000	.13863012063E+08	.12987342464E+07
50.000	1.000	.16768249712E+08	.12953434869E+07
55.000	1.000	.19956489795E+08	.12824097217E+07
60.000	1.000	.23552836646E+08	.12553034949E+07
65.000	1.000	.27663563114E+08	.12034495013E+07
70.000	1.000	.32291399748E+08	.11096252290E+07
75.000	1.000	.37213092058E+08	.95182230209E+06
80.000	1.000	.41854492703E+08	.71062598867E+06
85.000	1.000	.45294443959E+08	.38368305519E+06
90.000	1.000	.46580897925E+08	.32866674575E-08

COMBINED LOADING APPLIED TO THE MODEL

DELTA-T   = -.15000E+03
SIGMA-X   = .92500E+08
SIGMA-YZ = .24800E+08

MATRIX STRESSES ALONG F/M INTERFACE UNDER COMBINED LOADING

ANGLE	Rn (=r/Rf)	SIG-RR	SIG-TT	SIG-RT	SIG-ZZ	SIG-RZ	SIG-TZ
.0	1.000	.10443E+09	.79376E+08	.00000E+00	.89004E+08	.00000E+00	.10228E+07
5.0	1.000	.10359E+09	.78924E+08	-.65794E+07	.88563E+08	.28226E+06	.10323E+07
10.0	1.000	.10089E+09	.77633E+08	-.13453E+08	.87206E+08	.71445E+06	.10601E+07
15.0	1.000	.96133E+08	.75693E+08	-.20425E+08	.84930E+08	.14505E+07	.11027E+07
20.0	1.000	.89516E+08	.73374E+08	-.26901E+08	.81892E+08	.26109E+07	.11536E+07
25.0	1.000	.81651E+08	.70942E+08	-.32328E+08	.78391E+08	.42334E+07	.12039E+07
30.0	1.000	.73263E+08	.68585E+08	-.36489E+08	.74737E+08	.62649E+07	.12461E+07
35.0	1.000	.64875E+08	.66387E+08	-.39516E+08	.71138E+08	.86024E+07	.12759E+07
40.0	1.000	.56658E+08	.64331E+08	-.41717E+08	.67645E+08	.11150E+08	.12929E+07
45.0	1.000	.48443E+08	.62330E+08	-.43377E+08	.64172E+08	.13863E+08	.12987E+07
50.0	1.000	.39839E+08	.60252E+08	-.44609E+08	.60540E+08	.16768E+08	.12953E+07
55.0	1.000	.30386E+08	.57954E+08	-.45285E+08	.56545E+08	.19956E+08	.12824E+07
60.0	1.000	.19728E+08	.55312E+08	-.45012E+08	.52023E+08	.23553E+08	.12553E+07
65.0	1.000	.78185E+07	.52265E+08	-.43189E+08	.46937E+08	.27664E+08	.12034E+07
70.0	1.000	-.48804E+07	.48866E+08	-.39174E+08	.41464E+08	.32291E+08	.11096E+07
75.0	1.000	-.17311E+08	.45349E+08	-.32543E+08	.36042E+08	.37213E+08	.95182E+06
80.0	1.000	-.27930E+08	.42156E+08	-.23345E+08	.31346E+08	.41854E+08	.71063E+06
85.0	1.000	-.35106E+08	.39876E+08	-.12181E+08	.28131E+08	.45294E+08	.38368E+06

| 90.0 | 1.000 | -.37640E+08 | .39043E+08 | -.10293E-06 | .26986E+08 | .46581E+08 | .32867E-08 |

RESULTS USING DIAMOND ARRAY ANALYSIS

OVERALL YOUNGS MODULI AND POISSONS RATIOS, Z-FIBER DIRECTION

EXX =	.84712E+10	EYY =	.84712E+10	EZZ =	.13916E+12
NuXY =	.40597	NuZX =	.24814	NuZY =	.24814

LONGITUDINAL SHEAR MODULI

GYZ, GXZ   =   .63418E+10

TRANSVERSE SHEAR MODULUS

GXY   =   .34943E+10

OVERALL COEFFICIENTS OF THERMAL EXPANSION

ALPHA-XX	=	.31002E-04
ALPHA-YY	=	.31002E-04
ALPHA-ZZ	=	.18873E-06

MATRIX STRESSES ALONG MODEL BOUNDARY FOR DELTA-T = -.15000E+03

ANGLE	Rn (=r/Rf)	SIG-XX	SIG-YY	SIG-XY	SIG-ZZ
.000	1.585	.122132E+08	.122132E+08	.147715E-02	.355332E+08
5.000	1.463	.126557E+08	.126557E+08	-.676088E+06	.358341E+08
10.000	1.368	.124511E+08	.124511E+08	-.229611E+07	.356950E+08
15.000	1.294	.119110E+08	.119110E+08	-.504603E+07	.353277E+08
20.000	1.237	.107990E+08	.107990E+08	-.858134E+07	.345716E+08
25.000	1.193	.903463E+07	.903463E+07	-.125037E+08	.333718E+08
30.000	1.161	.670557E+07	.670557E+07	-.162785E+08	.317880E+08
35.000	1.138	.419912E+07	.419912E+07	-.193641E+08	.300836E+08
40.000	1.125	.219935E+07	.219935E+07	-.213436E+08	.287238E+08
45.000	1.121	.142733E+07	.142733E+07	-.220179E+08	.281988E+08
50.000	1.125	.219935E+07	.219935E+07	-.213436E+08	.287238E+08
55.000	1.138	.419912E+07	.419912E+07	-.193641E+08	.300836E+08
60.000	1.161	.670557E+07	.670557E+07	-.162785E+08	.317880E+08
65.000	1.193	.903463E+07	.903463E+07	-.125037E+08	.333718E+08
70.000	1.237	.107990E+08	.107990E+08	-.858134E+07	.345716E+08
75.000	1.294	.119110E+08	.119110E+08	-.504603E+07	.353277E+08
80.000	1.368	.124511E+08	.124511E+08	-.229611E+07	.356950E+08
85.000	1.463	.126557E+08	.126557E+08	-.676088E+06	.358341E+08
90.000	1.585	.122132E+08	.122132E+08	.147715E-02	.355332E+08

APPLIED AVERAGE STRESSES AND STRAINS FOR SIG-X = .92500E+08

AVG	SX	=	.92500E+08	STRAIN	EX	=	.10916E-01
AVG	SY	=	.24930E+05	STRAIN	EY	=	-.44317E-02
AVG	SZ	=	-.44455E+03	STRAIN	EZ	=	-.16489E-03

MATRIX STRESSES ALONG MODEL BOUNDARY FOR SIG-X = .92500E+08

ANGLE	Rn (=r/Rf)	SIG-XX	SIG-YY	SIG-XY	SIG-ZZ
.000	1.585	.944388E+08	-.831897E+07	.000000E+00	.285617E+08
5.000	1.463	.911057E+08	-.813475E+07	.493064E+06	.274910E+08
10.000	1.368	.878704E+08	-.440643E+07	.811417E+06	.276587E+08
15.000	1.294	.845570E+08	-.768783E+06	.184165E+07	.277689E+08
20.000	1.237	.831242E+08	.148630E+07	.311647E+07	.280485E+08
25.000	1.193	.843883E+08	.150028E+07	.454171E+07	.284830E+08
30.000	1.161	.879588E+08	-.376161E+06	.591056E+07	.290590E+08
35.000	1.138	.923952E+08	-.299306E+07	.703072E+07	.296777E+08
40.000	1.125	.959664E+08	-.511086E+07	.774832E+07	.301718E+08
45.000	1.121	.973252E+08	-.590840E+07	.799336E+07	.303626E+08
50.000	1.125	.959657E+08	-.511151E+07	.774897E+07	.301714E+08
55.000	1.138	.923956E+08	-.299264E+07	.703030E+07	.296779E+08
60.000	1.161	.879583E+08	-.376594E+06	.591100E+07	.290587E+08
65.000	1.193	.843889E+08	.150090E+07	.454108E+07	.284835E+08
70.000	1.237	.831230E+08	.148509E+07	.311768E+07	.280477E+08
75.000	1.294	.845602E+08	-.765601E+06	.183846E+07	.277711E+08
80.000	1.368	.878594E+08	-.441742E+07	.822411E+06	.276512E+08
85.000	1.463	.911486E+08	-.809176E+07	.450076E+06	.275203E+08
90.000	1.585	.944388E+08	-.831897E+07	-.504786E-07	.285617E+08

APPLIED AVERAGE LONGITUDINAL SHEAR STRESS AND STRAIN

AVG SIGMA-YZ = .24800E+08   STRAIN GAMMA-YZ = .39105E-02

MATRIX STRESSES ALONG MODEL BOUNDARY FOR SIGMA-YZ = .24800E+08

ANGLE	Rn (=r/Rf)	SIG-XZ	SIG-YZ
.000	1.585	.00000000000E+00	.11159769701E+08
5.000	1.463	.69510590009E+06	.12460078116E+08
10.000	1.368	.28373238642E+07	.12627020663E+08
15.000	1.294	.56312716181E+07	.13153168219E+08
20.000	1.237	.88679031200E+07	.14215915618E+08
25.000	1.193	.12299839941E+08	.15867327499E+08
30.000	1.161	.15671060337E+08	.17994084407E+08
35.000	1.138	.18639280940E+08	.20232129660E+08
40.000	1.125	.20741866860E+08	.21989660307E+08
45.000	1.121	.21511665985E+08	.22663086525E+08
50.000	1.125	.20741878393E+08	.21989648775E+08
55.000	1.138	.18639250181E+08	.20232160419E+08
60.000	1.161	.15671136075E+08	.17994008669E+08
65.000	1.193	.12299632143E+08	.15867535297E+08
70.000	1.237	.88685849767E+07	.14215233762E+08
75.000	1.294	.56284994264E+07	.13155940411E+08
80.000	1.368	.28513435838E+07	.12613000944E+08

| 85.000 | 1.463 | .61511744426E+06 | .12540066572E+08 |
| 90.000 | 1.585 | .89859564694E-08 | .11159769701E+08 |

COMBINED LOADING APPLIED TO THE MODEL

DELTA-T = -.15000E+03
SIGMA-X = .92500E+08
SIGMA-YZ = .24800E+08

MATRIX STRESSES ALONG MODEL BOUNDARY UNDER COMBINED LOADING

ANGLE	Rn (=r/Rf)	SIG-XX	SIG-YY	SIG-XY	SIG-ZZ	SIG-XZ	SIG-YZ
.0	1.585	.10665E+09	.38942E+07	.14771E-02	.64095E+08	.00000E+00	.11160E+08
5.0	1.463	.10376E+09	.45209E+07	-.18302E+06	.63325E+08	.69511E+06	.12460E+08
10.0	1.368	.10032E+09	.80447E+07	-.14847E+07	.63354E+08	.28373E+07	.12627E+08
15.0	1.294	.96468E+08	.11142E+08	-.32044E+07	.63097E+08	.56313E+07	.13153E+08
20.0	1.237	.93923E+08	.12285E+08	-.54649E+07	.62620E+08	.88679E+07	.14216E+08
25.0	1.193	.93423E+08	.10535E+08	-.79620E+07	.61855E+08	.12300E+08	.15867E+08
30.0	1.161	.94664E+08	.63294E+07	-.10368E+08	.60847E+08	.15671E+08	.17994E+08
35.0	1.138	.96594E+08	.12061E+07	-.12333E+08	.59761E+08	.18639E+08	.20232E+08
40.0	1.125	.98166E+08	-.29115E+07	-.13595E+08	.58896E+08	.20742E+08	.21990E+08
45.0	1.121	.98752E+08	-.44811E+07	-.14025E+08	.58561E+08	.21512E+08	.22663E+08
50.0	1.125	.98165E+08	-.29122E+07	-.13595E+08	.58895E+08	.20742E+08	.21990E+08
55.0	1.138	.96595E+08	.12065E+07	-.12334E+08	.59762E+08	.18639E+08	.20232E+08
60.0	1.161	.94664E+08	.63290E+07	-.10367E+08	.60847E+08	.15671E+08	.17994E+08
65.0	1.193	.93424E+08	.10536E+08	-.79626E+07	.61855E+08	.12300E+08	.15868E+08
70.0	1.237	.93922E+08	.12284E+08	-.54637E+07	.62619E+08	.88686E+07	.14215E+08
75.0	1.294	.96471E+08	.11145E+08	-.32076E+07	.63099E+08	.56285E+07	.13156E+08
80.0	1.368	.10031E+09	.80337E+07	-.14737E+07	.63346E+08	.28513E+07	.12613E+08
85.0	1.463	.10380E+09	.45639E+07	-.22601E+06	.63354E+08	.61512E+06	.12540E+08
90.0	1.585	.10665E+09	.38942E+07	.14771E-02	.64095E+08	.89860E-08	.11160E+08

DESCRIPTION OF OPERATING ENVIRONMENT

The MICSTRAN program runs under the Microsoft (MS) Windows environment on a IBM PC or compatible with a 80286 or higher microprocessor. It requires Windows 3.0 running in standard or 386 enhanced mode or Windows 3.1 running in 386 enhanced mode. The Windows standard mode requires at least **1 Megabyte** of memory, and the 386 enhanced mode requires a 80386 (or better) processor with at least **2 Megabytes** of memory. MS Windows provides a graphical user interface, facilitates multitasking, and extends memory access far beyond the 640 Kilobyte limit imposed by the DOS operating system. A DOS version 3.1 or later operating system is required to run MS Windows.

The source code MICSTRAN.FOR is written in Microsoft FORTRAN (version 5.1). It contains calls to the Microsoft QuickWin libraries that are available with MS FORTRAN version 5.1. The MICSTRAN.EXE executable was created on an IBM PC with a 80486 processor and 4 Megabytes of memory using the following compilation command line:

FL /MW /G2 /Gt /Ot /Ol /Fs MICSTRAN.FOR

The large memory model available with MS FORTRAN version 5.1 was used for the compilation.

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3. Naik, R. A. and Crews, J. H., Jr.: "Closed-Form Analysis of Fiber-Matrix Interface Stresses Under Thermo-Mechanical Loadings," NASA TM-107575, March 1992. National Aeronautics and Space Administration, Hampton, Virginia.

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13. ABSTRACT (Maximum 200 words)

Composite materials are currently being used in aerospace and other applications. The ability to tailor the composite properties by the appropriate selection of its constituents, the fiber and matrix, is a major advantage of composite materials. The Micromechanical Combined Stress Analysis (MICSTRAN) code provides the materials engineer with a user-friendly, personal computer (PC) based tool to calculate overall composite properties given the constituent fiber and matrix properties. To assess the ability of the composite to carry structural loads, the materials engineer also needs to calculate the internal stresses in the composite material. MICSTRAN is a simple tool to calculate such internal stresses within a composite ply under combined thermomechanical loading. It assumes that the fibers have a circular cross-section and are arranged either in a repeating square or diamond array pattern within a ply. It uses a classical elasticity solution technique that has been demonstrated to calculate accurate stress results. Input to the program consists of transversely isotropic fiber properties and isotropic matrix properties such as moduli, Poisson's ratios, coefficients of thermal expansion, and volume fraction. Output consists of overall thermoelastic constants and stresses. Stresses can be computed under the combined action of thermal, transverse, longitudinal, transverse shear, and longitudinal shear loadings. Stress output can be requested along the fiber-matrix interface, the model boundaries, circular arcs, or at user-specified points located anywhere in the model. The MICSTRAN program is Windows compatible and takes advantage of the Microsoft Windows graphical user interface which facilitates mulitasking and extends memory access far beyond the limits imposed by the DOS operating system.

14. SUBJECT TERMS
MICSTRAN; Internal stresses; Thermomechanical loading; Composite materials

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