NASA Contractor Report 4639

TEXCAD—Textile Composite Analysis for Design

Version 1.0 User's Manual

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Prepared for Langley Research Center
under Contract NAS1-19708

December 1994

This publication is available from the following sources:

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Introduction

The Textile Composite Analysis for Design (TEXCAD) code provides the materials/ design engineer with a user-friendly, desktop computer (IBM PC compatible or Apple Macintosh™) tool for the analysis of a wide variety of fabric reinforced woven and braided composites. It can be used to calculate overall thermal and mechanical properties along with engineering estimates of damage progression and strength. TEXCAD also calculates laminate properties for stacked, oriented fabric constructions. It discretely models the yarn centerline paths within the textile repeating unit cell (RUC) by assuming sinusoidal undulations at yarn cross-over points and uses a yarn discretization scheme (which subdivides each yarn into smaller, piecewise straight yarn slices) together with a 3-D stress averaging procedure to compute overall stiffness properties [1, 2]. In the calculations for strength [2], it uses a curved beam-on-elastic foundation model for yarn undulating regions together with an incremental approach in which stiffness properties for the failed yarn slices are reduced based on the predicted yarn slice failure mode. Nonlinear shear effects and nonlinear geometric effects can be simulated. Input to TEXCAD consists of: (i) material parameters like impregnated yarn and resin properties such as moduli, Poisson's ratios, coefficients of thermal expansion, nonlinear shear parameters, axial failure strains and in-plane failure stresses; and (ii) fabric parameters like yarn sizes, braid angle, yarn packing density, filament diameter and overall fiber volume fraction. Output consists of overall thermoelastic constants, yarn slice strains/ stresses, yarn slice failure history, in-plane stress-strain response and ultimate failure strength. Strength can be computed under the combined action of thermal and mechanical loading (tension, compression and shear). For the IBM PC compatible, both MS DOS™ and MS Windows™ versions of the TEXCAD program are available. The MS Windows version takes advantage of the Microsoft Windows graphical user interface which provides multitasking and easy access to available computer memory.

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Installation Instructions

TEXCAD can be installed on an IBM PC or compatible (PC) or an Apple Macintosh (MAC) computer. Except for the installation, the execution, input/output file formats, etc., for both the PC and the MAC versions are very similar. The PC version is available for the MS DOS and MS Windows environments.

MAC Installation

For the MAC version, all the files on the distribution diskette can be copied to a folder on the hard drive using the drag-and-drop MAC interface. The MAC executable file is called **TEXCAD** and the program can be launched by simply double-clicking on the **TEXCAD** icon. The MAC MPW Fortran compiler (version 3.2) was used to compile the TEXCAD program. The **README.TXT** file may contain changes to the program that were made after this manual was printed. **Please read the README.TXT file using the MAC TeachText or SimpleText editors before proceeding.** As metioned earlier, the instructions for analysis options, execution, input/ouput, sample problems, etc., are equally applicable for both the MAC and the PC versions.

After a successful installation, the following files should be in the TEXCAD directory/folder:

TEXCAD	TEXCAD executable*
MATERIAL.DAT	sample material data input file*
README.TXT	readme text file*
3A.DAT	plain weave yarn architecture file*
3B.DAT	5-harness satin weave yarn architecture file*
3C.DAT	8-harness satin weave yarn architecture file*
4A.DAT	plain 2-D braid yarn architecture file*
4B.DAT	5-harness satin 2-D braid yarn architecture file*
4C.DAT	8-harness satin 2-D braid yarn architecture file*
5.DAT	2x2, 2-D triaxial braid yarn architecture file*
6A.DAT	1x1, 2-D triaxial braid (alternate axials) yarn architecture file*
6B.DAT	1x1, 2-D triaxial braid (axial at each cross-over) yarn architecture file*
7.DAT	3-D multi-interlock, braid yarn architecture file*
PLAINWVE.PCX	plain weave yarn architecture graphics file*
PLAINWVE.IN	plain weave yarn architecture input file*
5HSATWVE.PCX	5-harness satin weave yarn architecture graphics file*

8HSATWVE.PCX	**8-harness satin weave yarn architecture graphics file***
2DBRAID.PCX	**2-D braid yarn architecture graphics file***
2X2TRBRD.PCX	**2x2, 2-D triaxial braid yarn architecture graphics file***
1X1EABRD.PCX	**1x1, 2-D triaxial braid (alternate axials) yarn architecture graphics file***
1X1AABRD.PCX	**1x1, 2-D triaxial braid (axial at each cross-over) yarn architecture graphics file***
3DIBRAID.PCX	**3-D multi-interlock, braid yarn architecture graphics file***
2DLAM.PCX	**2-D laminate graphics file***
2DLAM.IN	**2-D laminate sample input file***
3DCOMP.PCX	**3-D spatially oriented composite graphics file***
ICOSAHED.IN	**sample yarn architecture input file for the classical icosahedron problem***
SAMPLE5.RUN	**execution transcript of the sample problem no. 5 for analysis option no. 5***
SAMPLE5.OUT	**output file of the sample problem no. 5 for analysis option no. 5***
UNITCEL.DAT	**sample unitcel.dat file which is updated at every execution of TEXCAD**

Note: All the files marked with an * should not be tampered with since they are either crucial for the proper functioning of the TEXCAD program or they contain important information for future reference.

PC Installation

The distribution diskette contains the **INSTALL.BAT** file which is used for the installation of TEXCAD onto the hard drive for the MS DOS and MS Windows versions. The DOS requirements are MS DOS version 3.0 or later with 640 KBytes of memory while Windows requires MS Windows version 3.0 or later with 4 MBytes of memory. Before starting it is important to check the available space on the hard drive. TEXCAD files need **1 Mega Byte** of disk space (PC version). If TEXCAD output is saved to a file, more space will be required.

The INSTALL.BAT file contains commands that will automatically copy all required files from the distribution diskette to the hard drive. The installation of TEXCAD for the PC (MS DOS and MS Windows) is performed as follows:

1. Insert the distribution diskette into a floppy drive on your system. If you are currently running Windows move to a DOS prompt by **exiting** 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 TEXCAD. Be sure to include the colon ":" following the disk drive letter in your command. The installation program will automatically copy all TEXCAD files to a directory named **TEXCAD** on the drive you specify.

After a successful installation, all the files (except the first file) listed in the "MAC Installation" section should be present in the TEXCAD directory with the following additions:

TEXCADD.EXE	TEXCAD executable file for MS DOS
TEXCAD.EXE	TEXCAD executable file for MS Windows
TEXCAD.ICO	TEXCAD icon file used for MS Windows desktop
QWIN.HLP	contains online help for the drop-down menu items in MS Windows
README.WRI	readme file in the MS Windows Write editor format.

The README.TXT (or .WRI) file may contain changes to the program that were made after this manual was printed. It can be read using any text editor (e.g. MS DOS Editor (edit.com), MS Windows Notepad). **Please read the README.TXT (or .WRI) file before proceeding.**

The **MS DOS version of TEXCAD** can now be launched simply by entering **TEXCADD** from within the TEXCAD directory.

TEXCAD MS Windows Setup

The MS Windows TEXCAD version requires MS Windows 3.0 running in either standard or 386 enhanced mode. TEXCAD also runs under MS Windows 3.1 running in 386 enhanced mode. The following steps may be used to create a program item for TEXCAD under Program Manager in Windows:

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 TEXCAD 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 **TEXCAD**. Click in the **Command Line edit box** and enter **C:\TEXCAD\TEXCAD.EXE** where **C:** is the disk drive that you chose to install TEXCAD 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:\TEXCAD\TEXCAD.ICO** and then click on the "**View Next**" button. The TEXCAD 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:\TEXCAD\TEXCAD.ICO** in the **Filename edit box**. Next click on the "OK" button or press enter and the TEXCAD Icon  will be displayed in the Box.

5. Click on "**OK**" and you should be back in the earlier Box. Click on "**OK**" and the **TEXCAD** icon will appear in the program group that you selected earlier. If you cannot see the **TEXCAD** 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 **TEXCAD**. Just double-click on the **TEXCAD** Icon and the program will be launched.

7. **Full Screen TEXCAD Display:** - In the default mode, **TEXCAD** 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 (▲) button on the right hand top corner to increase the window size. If you wish to force **TEXCAD** to occupy the full screen every time it comes up (highly recommended) then use a **text editor** such as **Windows Notepad** to edit the **WIN.INI** file in your Windows directory and add the following two lines to it:

   [TEXCAD]
   QWINMaximized = 1

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

A sample material data file called **MATERIAL.DAT** was copied to the TEXCAD directory during Step I of the installation. This file may be viewed using a text editor to preview the format of the material input data. This file may be used as the material data file when you first run TEXCAD to see how the program works. The **SAMPLE5.RUN** and **SAMPLE5.OUT** text files may be used as a guide in getting started with TEXCAD.

TEXCAD User Interface (MS Windows)

The DOS version can be launched by simply entering TEXCADD from within the TEXCAD directory. The MS Windows version of TEXCAD can be launched simply by double-clicking on the TEXCAD icon. It may also be launched by choosing **"Run"** from Program Managers **"File"** menu, typing the full path for the program (e.g. **C:\TEXCAD\TEXCAD.EXE**) and then hitting **Enter** or clicking on the **"OK"** button. The program starts by displaying the eight different choices for analysis (see Figure 1). This is an indication that TEXCAD was properly installed on your computer.

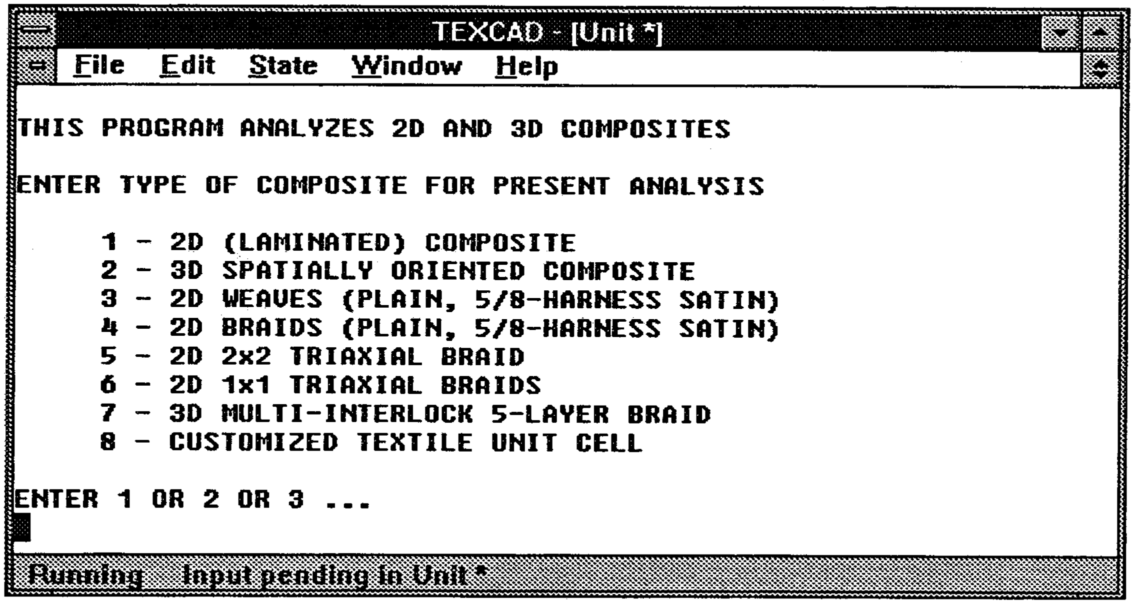


Figure 1. - The TEXCAD user interface showing the eight different analysis options.

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 TEXCAD files (.exe and .ico) are in the TEXCAD 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 TEXCAD diskette.

TEXCAD Window and Menu Bar

All the program requests and user responses will appear in the **TEXCAD window** (see Figure 1) on the screen. The contents of this window may be marked and copied using the **Edit** menu in the **Top Menu Bar** of the **TEXCAD window** (see Figure 1). 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 text, scroll bars will appear on the side of the **TEXCAD window**. These may be used to scroll through all the text that appears in the **TEXCAD window.** Note that, a maximum of 500 lines may be entered in the **TEXCAD window** at any time. Any excess output leads to a truncation of the text in the window which displays only the most recent 500 lines entered in the window. Thus, <u>it is highly recommended that the output be saved in a file</u>.

Program Control

The TEXCAD program 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. 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 ?**" <u>If you respond by clicking **Yes** then the **TEXCAD window** will be closed and all ouput in the **Output window** will be lost</u>. 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 **TEXCAD window** open and the output in that 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 TEXCAD version number and about the author of the TEXCAD program.

TEXCAD Analysis Options

The current version of TEXCAD offers 8 different analysis options (see Figure 1). Options 1-7 require a minimum amount of input data to define the textile architecture. Option No. 8 provides the flexibility of defining and analyzing new textile architectures that are not included in Options 1-7. However, Option No. 8 requires input regarding yarn orientations, yarn cross-over points, yarn projected and undulating lengths, yarn vertical shifts and yarn cross-sectional areas for each yarn within the textile repeating unit cell (RUC).

Analysis Option No. 1 - 2D Laminated Composite

This option provides a classical lamination theory analysis for modeling two dimensional, stacked, oriented yarns (or plies). TEXCAD requires ply thickness (all plies are assumed to be the same thickness), the fiber volume fraction in the plies, and the stacking sequence. The ply orientations are measured with respect to the X-axis (see Figure 2). The ply longitudinal and transverse directions are indicated by 1 and 2, respectively, in Figure 2.

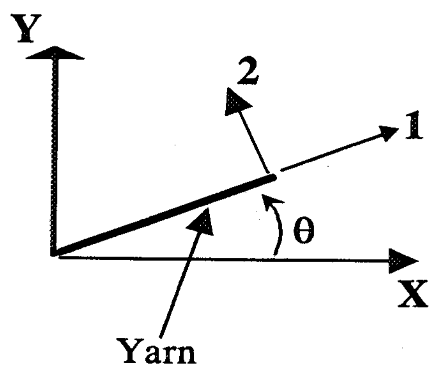


Figure 2. - Reference coordinate system for the 2-D laminated composite analysis option.

The material properties input during program execution are assumed to be for a unidirectional lamina with its longitudinal direction along the 1-axis (Figure 2). This option can also be used to conduct a progressive failure analysis for a unidirectional (0 degree) ply. Progressive failure analysis for a laminated composite with multi-directional ply orientations can be performed using Option No. 2. A sample problem is included in the Appendix.

Analysis Option No. 2 - 3D Spatially Oriented Composite

This analysis option allows the user to model a 3-dimensional, spatially oriented composite which is made up of straight yarns oriented along different directions. Examples of composites that can be modeled using this option are: whisker reinforced composites, chopped fiber composites, X-Y-Z weaves, etc. A 2-D laminated composite may also be modeled using this option, especially, for modeling progressive failure.

The RUC for this analysis option can be a prismatic solid with a cross-sectional shape which is either a square, a rectangle, or a diamond with equal or unequal sides. TEXCAD requires the length of two adjacent sides of the cross-section and the included angle between them along with the RUC thickness. The orientation of each yarn in the RUC is specified by two orientation angles θ and β (see Figure 3), which the yarn makes with the X-axis and the XY plane, respectively. The yarn longitudinal and transverse directions are indicated by 1 and 2, respectively, in Figure 3. The yarn thickness direction is indicated by 3.

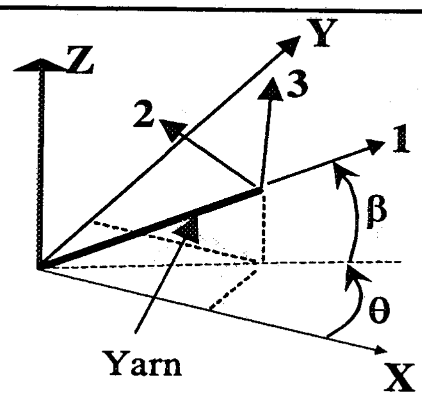


Figure 3. - Reference coordinate system for the 3-D spatially oriented composite.

The material properties input during program execution are assumed to be for a straight yarn with its longitudinal direction along the 1-axis (Figure 3). A sample problem is included in the Appendix.

Analysis Option No. 3 - 2D Weaves

This analysis option allows the user to model 2-dimensional weaves such as plain weaves, 5-harness satin weaves, and 8-harness satin weaves. TEXCAD requires the input of weave parameters such as yarn spacing, yarn filament count, yarn packing density (or fiber volume fraction), fiber diameter, and composite fiber volume fraction. A generic graphical representation of the RUC architecture and analysis model is included for each different textile architecture. The graphics files **PLAINWVE.PCX** (Figure 4), **5HSATWVE.PCX** (Figure 5),

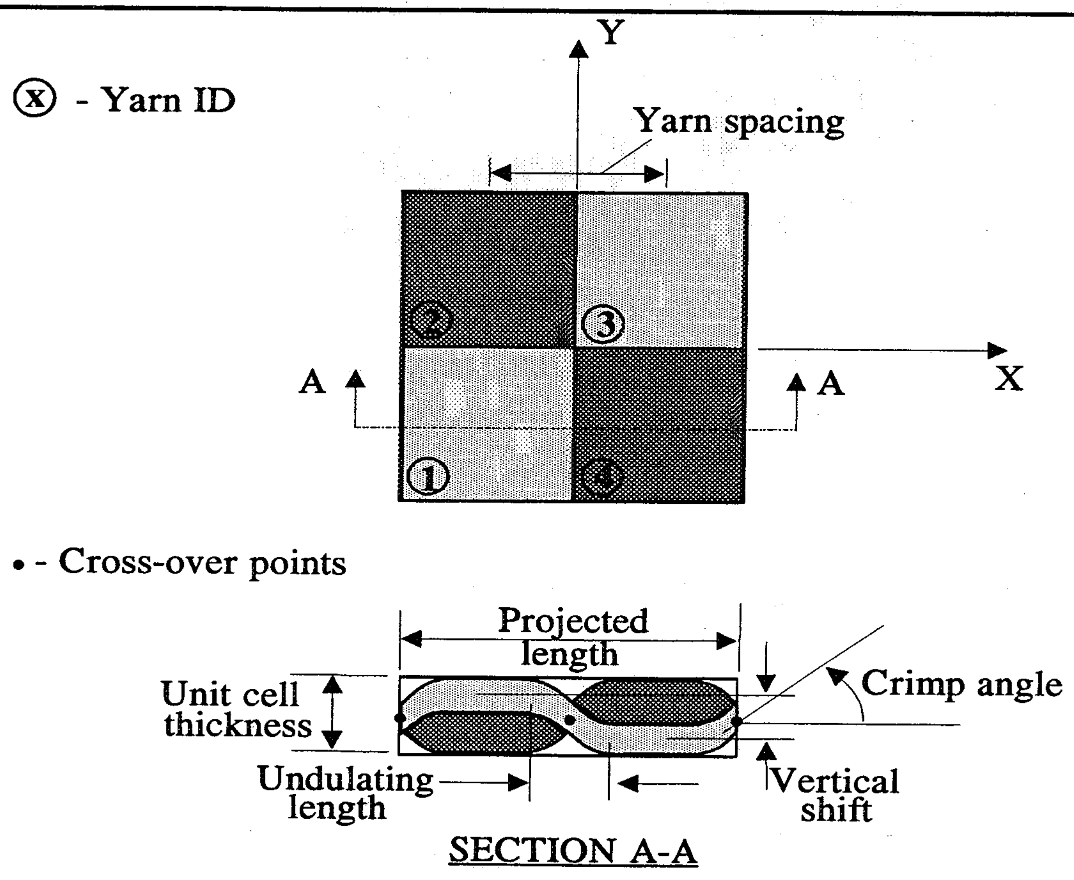


Figure 4. - RUC for the plain weave composite available in the PLAINWVE.PCX file.

and **8HSATWVE.PCX** (Figure 6) contain the model definition and yarn numbering used by TEXCAD for the plain weave, 5-harness satin weave, and 8-harness satin weave, respectively. These files may be viewed/printed using the Windows Paintbrush/MAC SimpleText programs.

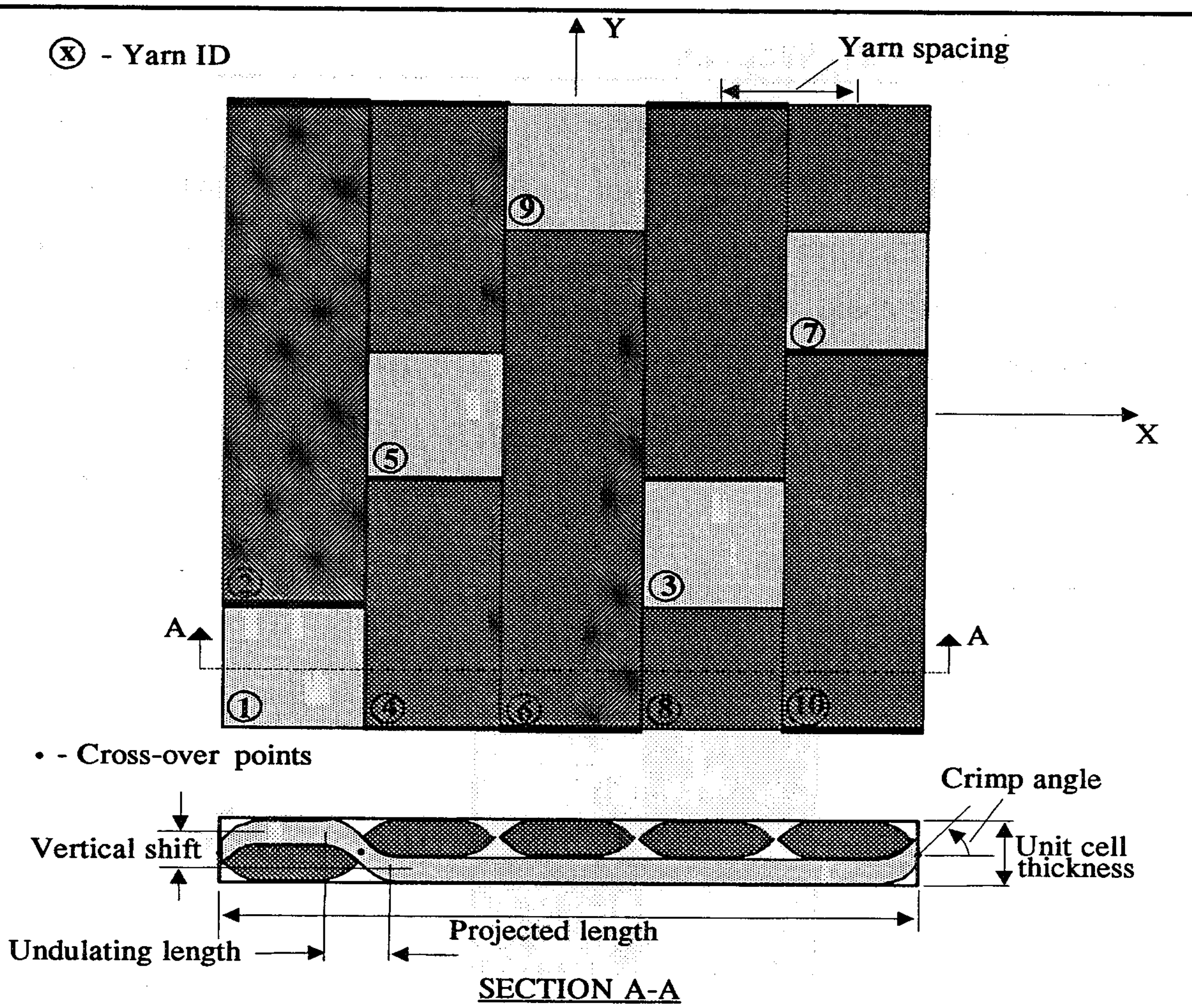


Figure 5. - RUC for the 5-harness satin weave composite available in the 5HSATWVE.PCX file.

The overall composite stiffness is computed by discretizing the yarn undulating path into smaller yarn slices. TEXCAD provides the user with the option of choosing the number of yarn slices in the yarn undulating region. Usually 12 slices are sufficient to achieve a converged solution. The yarn numbering shown in Figures 4-6 is also used for the output of stresses/strains. Calculated values for the yarn projected length, vertical shift, crimp angle, and RUC thickness are also included in the TEXCAD output. A sample problem for the plain weave composite is included in the Appendix.

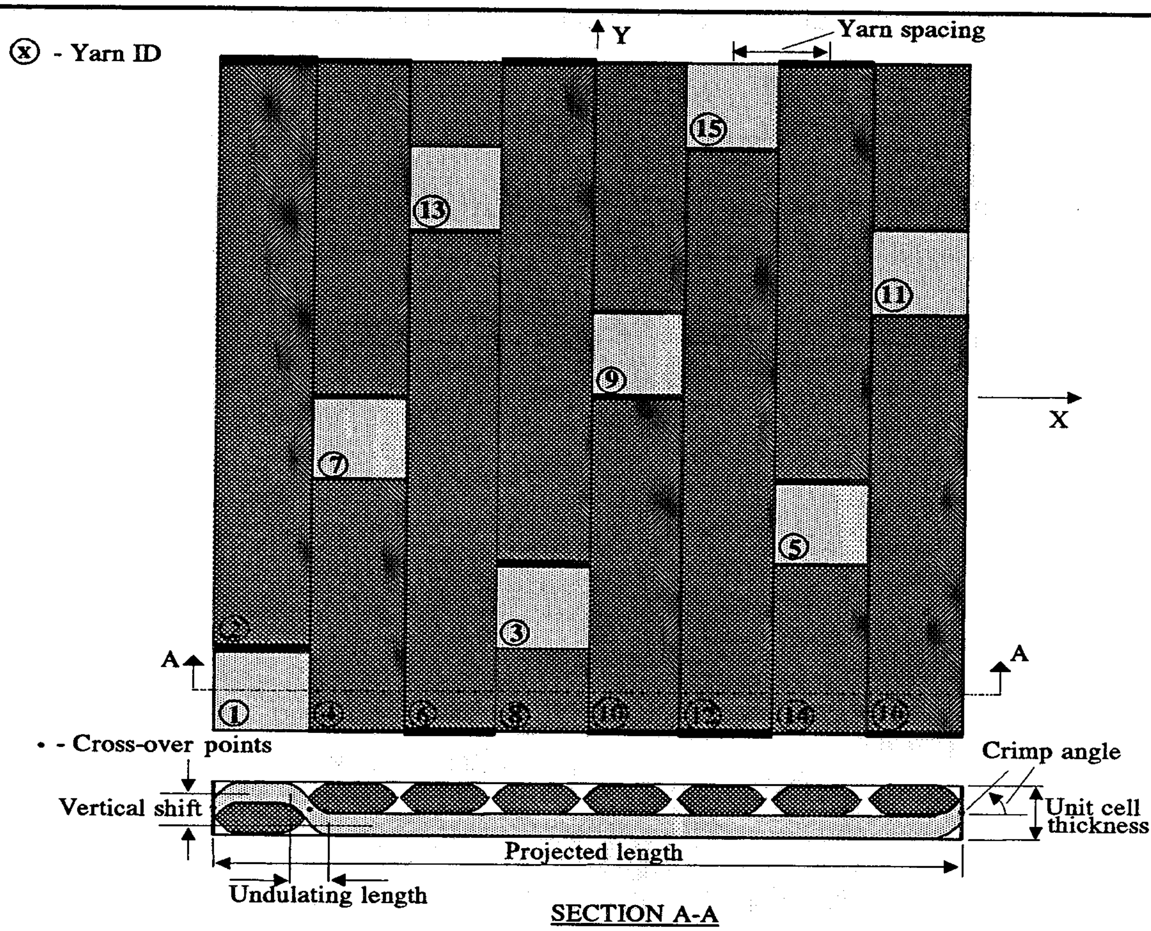


Figure 6. - RUC for the 8-harness satin weave composite available in the 8HSATWVE.PCX file.

Analysis Option No. 4 - 2D Braids

This analysis option allows the user to model 2-dimensional braids. TEXCAD requires the input of braid parameters such as braid angle, yarn spacing, yarn filament count, yarn packing density (or fiber volume fraction), fiber diameter, and composite fiber volume fraction. A generic graphical representation of the 2-D braid RUC architecture and analysis model is included in a graphics file (in Windows Paintbrush/MAC SimpleText format) called **2DBRAID.PCX**

(Figure 7) which contains the model definition and yarn numbering used by TEXCAD for the output of yarn slice stresses/strains.

The analysis option No. 4 also allows the user to model 2-D braids with architectures similar to the 5-harness satin and 8-harness satin weave composites. This capability may be used to analyze the satin weave composites loaded at an angle of 45 degrees to the fill or warp yarn directions. A sample problem for the 2D braid is included in the Appendix.

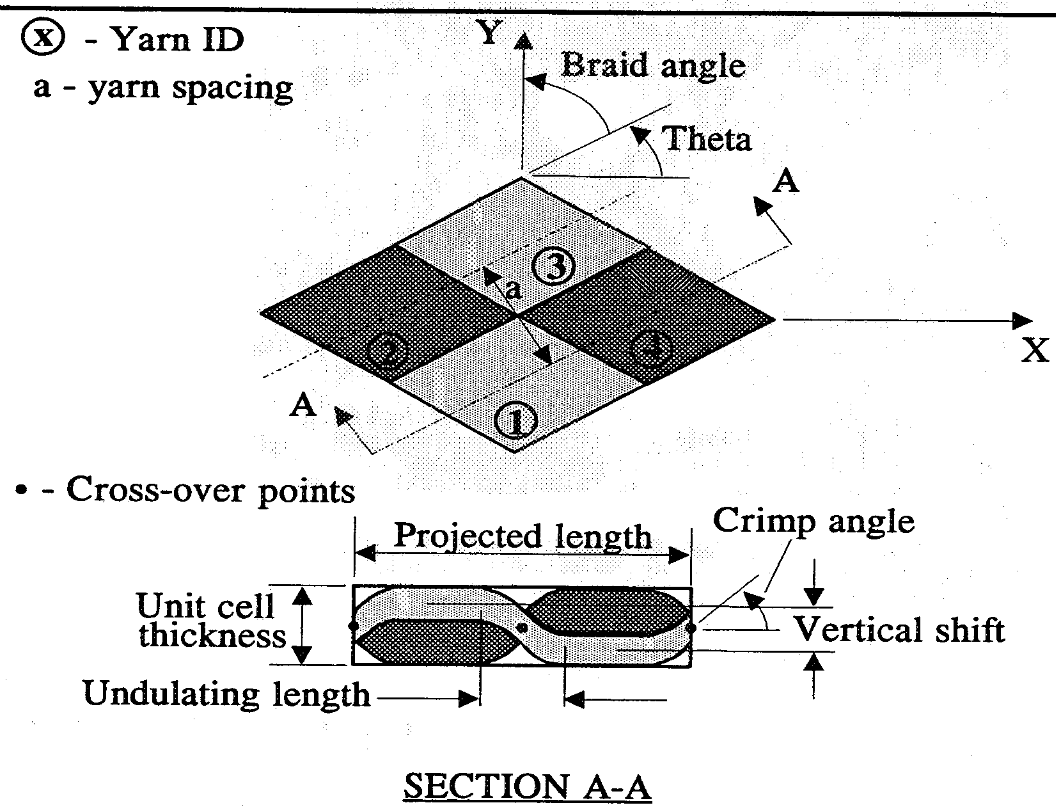
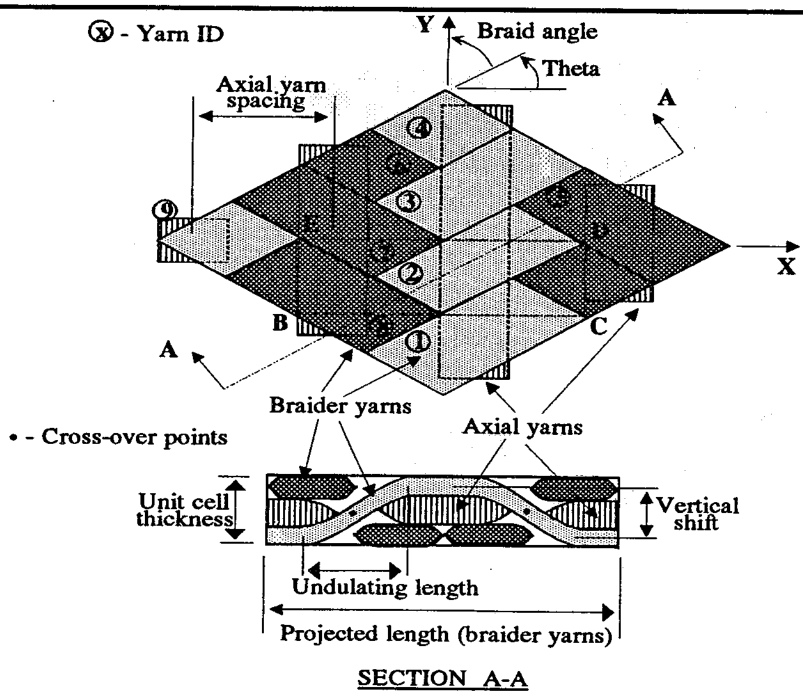


Figure 7. - RUC for the 2-D braided composite available in the 2DBRAID.PCX file.

Analysis Option No. 5 - 2D 2x2 Triaxial Braid

This analysis option allows the user to model 2-dimensional, 2x2 triaxial braids. TEXCAD requires the input of braid parameters such as braid angle, axial yarn spacing, filament counts for the axial and braider yarns, yarn packing density (or fiber volume fraction), fiber diameter, and composite fiber volume fraction. A generic graphical representation of the 2-D, 2x2 triaxial braid RUC architecture and analysis model is included in a graphics file (in Windows Paintbrush/MAC SimpleText format) called **2X2TRBRD.PCX** (Figure 8) which also contains the model definition and yarn numbering used by TEXCAD for the output of yarn slice stresses/ strains. Note that the four axial yarns in the RUC have the same yarn number. A sample execution run for the 2x2, 2-D triaxial braided composite is included in the section entitled 'TEXCAD Sample Execution.' The corresponding sample problem is described in the Appendix.



- Smallest unit cell = BCDE, where, BC = 2 x Axial yarn spacing, and CD = 0.5 x BC x TAN(Theta).

Figure 8. - RUC for the 2x2, 2-D triaxial braided composite available in the 2X2TRBRD.PCX file.

Analysis Option No. 6 - 2D 1x1 Triaxial Braids

This analysis option allows the user to model two different kinds of 2-dimensional, 1x1 triaxial braids: (i) triaxial braids with axials at every other braider yarn cross-over (Figure 9), and (ii) triaxial braids with axials at each braider yarn cross-over (Figure 10). TEXCAD requires the input of braid parameters such as braid angle, axial yarn spacing, filament counts for the axial and braider yarns, yarn packing density (or fiber volume fraction), fiber diameter, and composite fiber volume fraction. A generic graphical representation of the two types of 2-D, 1x1 triaxial

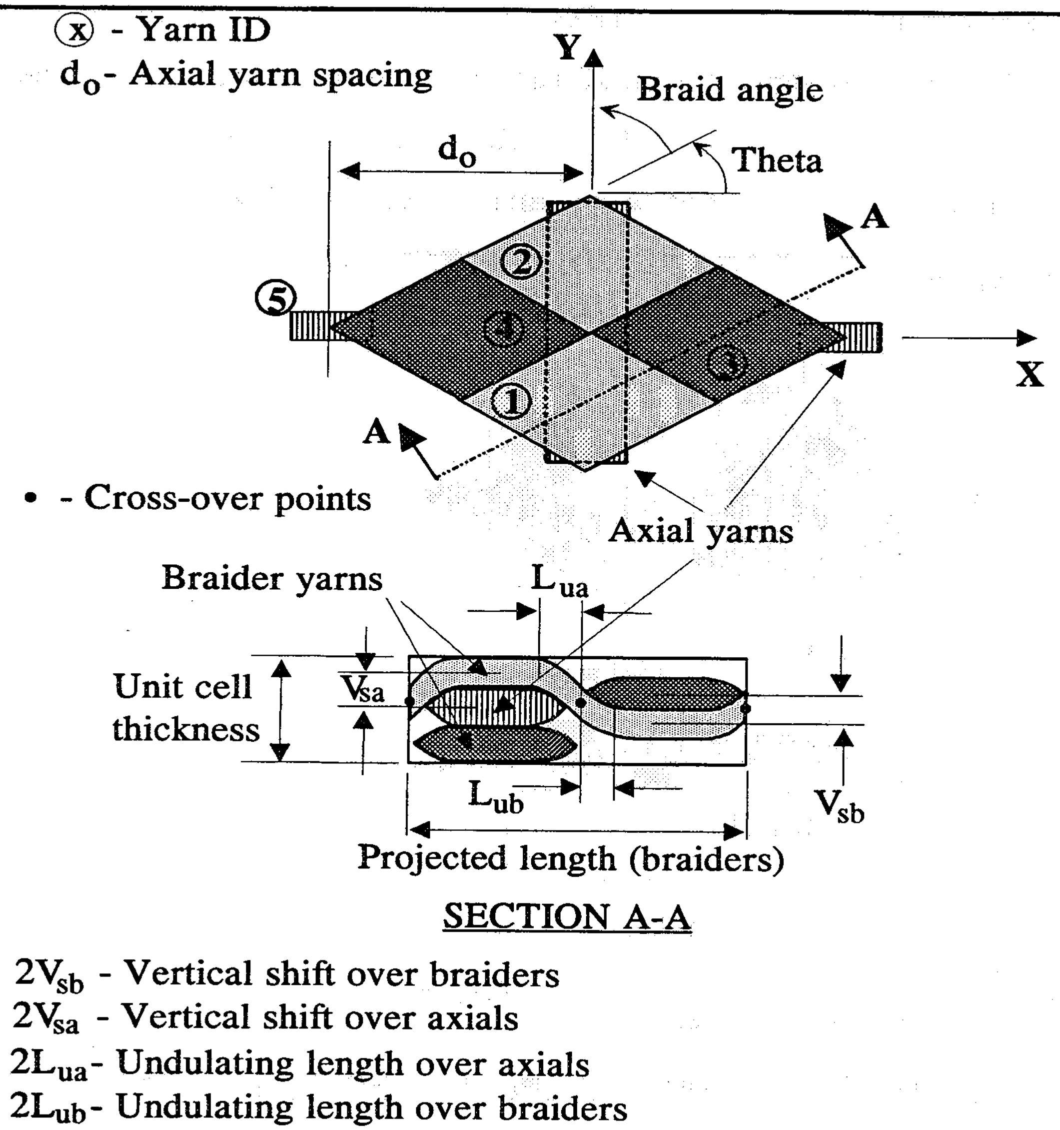


Figure 9. - RUC for the 1x1, 2-D triaxial braided composite available in the 1X1AABRD.PCX file.

braid RUC architectures and analysis models are included in graphics files (in Windows Paintbrush/MAC SimpleText format) called **1X1AABRD.PCX** and **1X1EABRD.PCX** which also contain the model definition and yarn numbering used by TEXCAD for the output of yarn slice stresses/ strains. As before, all the axial yarns have the same yarn number.

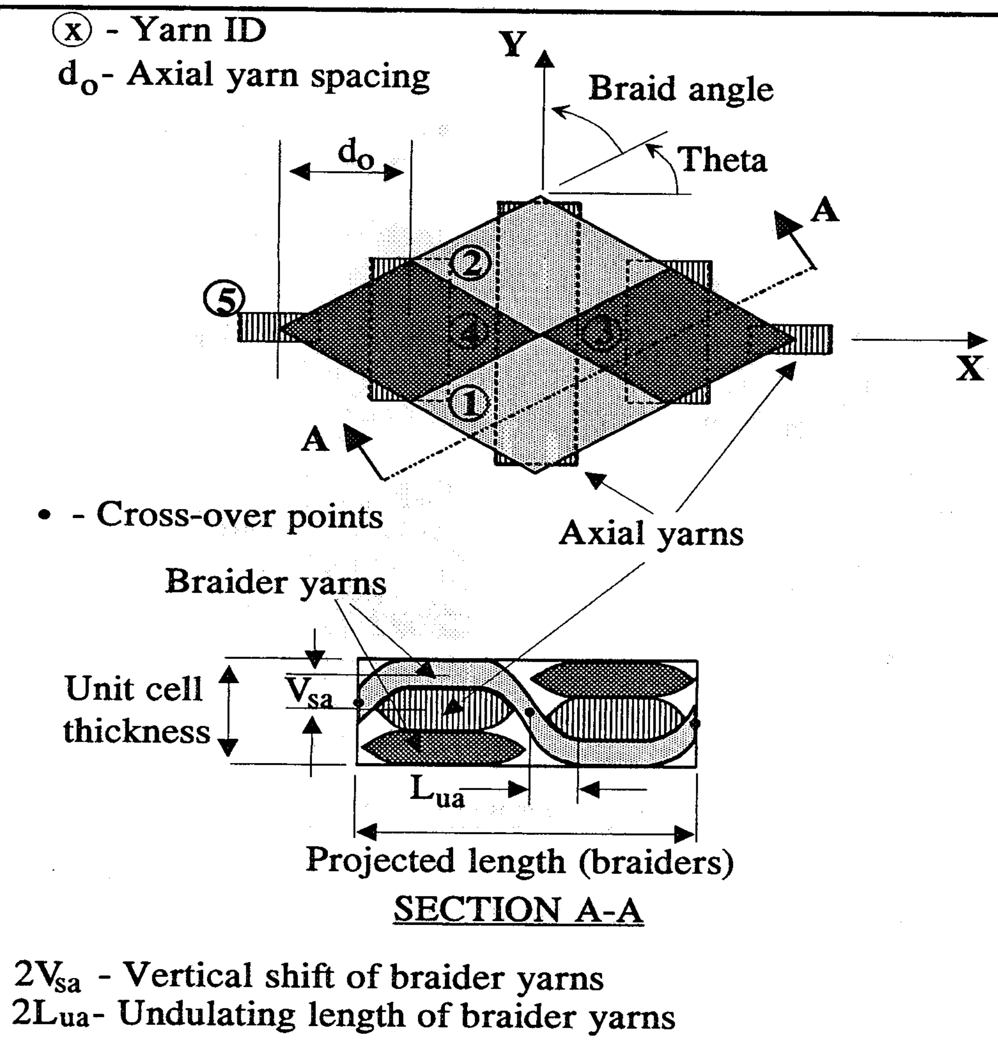


Figure 10. - RUC for the 1x1, 2-D triaxial braided composite available in the 1X1EABRD.PCX file.

Analysis Option No. 7 - 3D Multi-Interlock 5-Layer Braid

This analysis option allows the user to model a 3-dimensional, multi-interlock, 5-layer braid (Figure 11). TEXCAD requires the input of braid parameters such as braid angle, axial yarn spacing, filament counts for the axial and braider yarns, yarn packing density (or fiber volume fraction), fiber diameter, and composite fiber volume fraction. A generic graphical representation of the 3-D, multi-interlock braid RUC architecture and analysis model is included in a graphics file (in Windows Paintbrush/MAC SimpleText format) called **3DIBRAID.PCX**

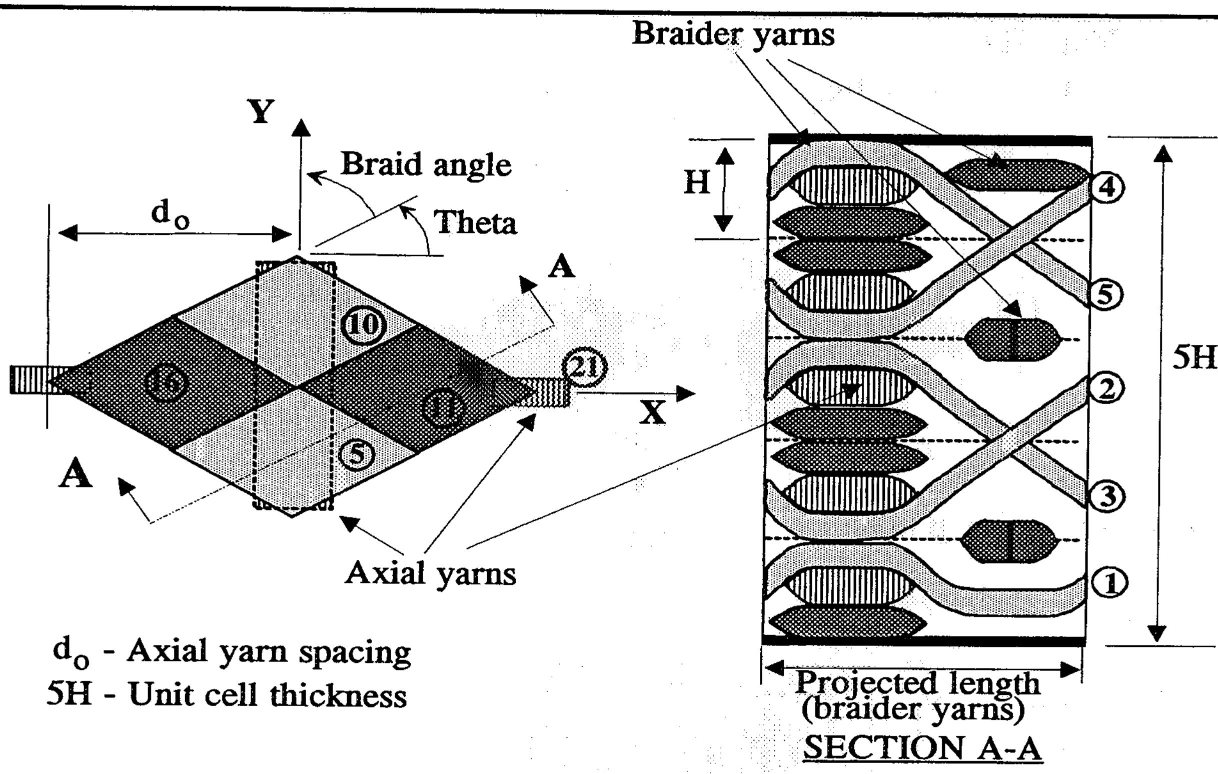


Figure 11. - RUC for the 3D multi-interlock braided composite available in the 3DIBRAID.PCX file.

which also contains the model definition and yarn numbering used by TEXCAD for the output of yarn slice stresses/strains. As before, all the axial yarns have the same yarn number.

Analysis Option No. 8 - Customized Textile Unit Cell

This analysis option allows the user to model a custom textile architecture which is not available in the first seven analysis options. Thus, it is possible to model 2D basket weaves, oxford weaves, 3D XYZ weaves, 3D braids, 3D interlock weaves, etc. with this option. However, the input required for this option is not as simple as the other options. TEXCAD requires the dimensions of the RUC, which may be a prismatic solid with either a rectangular or diamond cross-section. It also requires the input of orientation angle (θ, see Fig. 3), cross-sectional area, projected length, and number of cross-over points for each yarn within the RUC. At each cross-over point, TEXCAD requires the input of yarn undulating length, yarn vertical shift, whether yarn is going over or under another yarn, and whether the full undulation or only half the undulation is included in the RUC.

The RUC input may be entered interactively or through a previously prepared input file. It is advantageous to use an input file if multiple analyses are required. Whether the input is entered interactively or through a file, TEXCAD will save the RUC architecture in a file called **UNITCEL.DAT** at each execution. This file may be used (with a different filename) as an input file for future analyses of the same textile architecture either as is or with any desired modifications of the textile architecture parameters.

A sample **UNITCEL.DAT** file is included here, for the plain weave architecture, in order to demonstrate the process of yarn architecture specification for any arbitrary textile architecture. As a first step, the RUC (and its dimensions) for the textile architecture needs to be defined. Then the yarn paths, for each yarn within the RUC, need to be described using sectional views along the centerline of each yarn. For the plaine weave architecture, Fig. 4 shows one such sectional view (section A-A) which traces the path for the yarn number ①. As shown in Fig. 4, the yarn number ① has three cross-over points (COP) at which it either crosses over or under another yarn. In the following **UNITCEL.DAT** file, the COP are assumed to be numbered as 1, 2, and 3 starting from the left end of the section. At each COP, a 1 or 2 is used to indicate whether the yarn is going up or down, respectively. Also, at each COP, a 1, 2, or 3 is used to specify whether the first half, second half, or, both halves of the sine wave, respectively, are inside the RUC.

The **UNITCEL.DAT** file for a plain weave architecture is included here:

```
* TOTAL NO OF YARNS/PLIES IN UNIT CELL
  4
* YARN ID, MAT ID, THETA, YARN AREA, PROJECTED LENGTH, NO. OF C/O POINTS
  1   1   .000000   .153938   4.440000   3
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  1   1   2 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  2   2   3 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  3   1   1 1.058946  .083881
* YARN ID, MAT ID, THETA, YARN AREA, PROJECTED LENGTH, NO. OF C/O POINTS
```

```
  2  1  90.000000   .153938  4.440000  3
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  1  1  2 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  2  2  3 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  3  1  1 1.058946  .083881
* YARN ID, MAT ID, THETA, YARN AREA, PROJECTED LENGTH, NO. OF C/O POINTS
  3  1   .000000   .153938  4.440000  3
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  1  2  2 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  2  1  3 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  3  2  1 1.058946  .083881
* YARN ID, MAT ID, THETA, YARN AREA, PROJECTED LENGTH, NO. OF C/O POINTS
  4  1  90.000000   .153938  4.440000  3
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  1  2  2 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  2  1  3 1.058946  .083881
* C/O PT. ID, UP/DOWN, 1ST/2ND/BOTH HALF, UND. LGTH., VERT. SHIFT
  3  2  1 1.058946  .083881
*
* END OF INPUT DATA
```

TEXCAD Input

TEXCAD can be executed by entering all the required material and architecture parameters interactively. However, for the sake of convinience, some of the required parameters may be saved in a file. For example, all the material data for the impregnated yarns and the resin may be saved in a file and TEXCAD can be directed to read the data from that file. A sample material data file **MATERIAL.DAT** is included on the distribution diskette and was copied to the **TEXCAD** directory during installation.

Material Data Format

Following the choice of the analysis option, TEXCAD asks whether material 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. Material data may also be entered manually (not recommended). In this case the user will be prompted to enter material ID numbers and the impregnated yarn and resin properties.

The **MATERIAL.DAT** file is used as a sample input material data file. It contains six lines of input for each material in the model:

```
* MATERIAL ID NO.      (as4/3501-6, vf = 0.75) SI units
  1
* E11, E22, NU12, G12, NU23, ALFA11, ALFA22, SE(nonlinear shear exponent)
 .1448E+12 .1173E+11 .2300E+00 .5516E+10 .3000E+00 -.324E-06 .14E-04 2.78
* EPSTEN11, EPSCOMP11, SIGTEN22, SIGCOMP22, SIG12, SIG23
 0.014, 0.01, 26.E6, 206.E6, 87.5E6, 102.4E6

* MATERIAL ID NO.      (3501-6 resin) SI units
  2
* E11, E22, NU12, G12, NU23, ALFA11, ALFA22, SE
 .3448E+10 .3448E+10 .3500E+00 .1276E+10 .3500E+00 .40E-04 .40E-04 2.34
* SIGTEN11, SIGCOMP11, SIGTEN22, SIGCOMP22, SIG12, SIG23
 84.85E6, 84.85E6, 84.85E6, 84.85E6, 98.3E6, 98.3E6
```

The first, third and fifth lines consist of descriptive text up to 80 characters long. The second line contains the identification number for the material. The fourth line contains material (transversely isotropic) properties in the following order: E_{11}, E_{22}, ν_{12}, G_{12}, ν_{23}, α_{11}, α_{22}, SE where, 1 is the axial fiber direction and **E** is the Young's modulus, ν is Poisson's ratio, **G** is the shear modulus, α is the coefficient of thermal expansion (CTE) and **SE** is the nonlinear shear exponent which describes the inplane shear stress-strain response for the material using equation (1) [2]. **SE** = 1000 (a large number) simulates linear response.

$$\tau_{12} = G_{12}\,\gamma_{12} \Big/ \left[1 + \left(G_{12}\,\gamma_{12} / \tau_{12}^{ult}\right)^{SE}\right]^{\frac{1}{SE}} \qquad (1)$$

The sixth line contains material strength properties in the following order: EPSTEN11 (axial tension ultimate strain), EPSCOMP11 (axial compression ultimate strain), SIGTEN22 (transverse tension strength), SIGCOMP22 (transverse compression strength), SIG12 (longitudinal shear strength), and SIG23 (transverse shear strength). Data is input in free format and can be separated by a comma or a space. The first set of material properties (material ID No. 1) in the **MATERIAL.DAT** file are for the impregnated yarn which is assumed to be a unidirectional lamina with a 75% fiber volume fraction. The second set of properties (material ID No. 2) are for the resin which is assumed to be isotropic. <u>Note that, unlike the yarn properties, the first two strength entries for the resin are ultimate tension and compression strengths, respectively, and not ultimate strains to failure.</u> <u>The material properties for the resin must be specified last</u>.

Units Used in Input and Output Data

It is necessary to use **consistent units** for all the properties used in the input data. Thus, if SI units are used for the moduli **(Pa)** then the CTE's should also be in SI units **(m/m/°C)** for both the impregnated yarn and resin properties. <u>TEXCAD 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 **MATERIAL.DAT** file uses SI units for all the data.

Applied Stresses and Temperature Change

The applied stresses and temperature change **(DELTA-T)** are entered interactively during program execution. <u>Once again the **units** used for the applied stresses and temperature change should be consistent with those used for the material properties in the **MATERIAL.DAT** file</u>. The reference X-Y-Z coordinate system used for the applied stresses and output quantities for each textile architecture is defined in the appropriate **.PCX** graphics file which is supplied on the distribution diskette. The name of the appropriate **.PCX** file is supplied to the user by TEXCAD during execution. TEXCAD has been verified only for in-plane loading cases.

TEXCAD Sample Execution

The present section provides a sample TEXCAD run for the analysis of a 2x2, 2-D triaxial braided composite. This sample problem is described in the Appendix and the sample run is also available in the **SAMPLE5.RUN** file on the distribution diskette. A general overview of the TEXCAD run is presented first followed by a transcript of the actual execution.

TEXCAD starts by providing a choice of architectures that it can analyze. Having picked the architecture type, TEXCAD then provides the option of saving the output to a file (highly recommended). In the present case, the output was saved to a file called **SAMPLE5.OUT** which is discussed in the following section. Material data contained in the **MATERIAL.DAT** file was used in this run. For the 2x2, 2-D triaxial braided architecture, TEXCAD requires the interactive input of parameters such as: braid angle, axial yarn spacing, material IDs for the axial and braider yarns, fiber diameter and overall fiber volume fraction.

Using the input provided, TEXCAD creates a detailed architecture file called **UNITCEL.DAT** which contains RUC geometry information regarding the yarn undulating paths, yarn thicknesses, yarn cross-sectional areas, and yarn crimp angle. **UNITCEL.DAT** is updated at every execution. TEXCAD also informs the user that for the present architecture, a graphical representation of the textile RUC is available in a graphics file called **2x2TRBRD.PCX** which can be viewed/printed using the **Windows Paintbrush/MAC SimpleText** programs. In order to perform the stiffness and strength calculations, TEXCAD requires the number of yarn slices that the user wishes to use in the yarn undulating portions. Usually, 12 yarn slices are sufficient for reasonable accuracy. The number of slices must be an even number. TEXCAD will also calculate [A], [B], and [D] matrices for stacked oriented layers of the textile composite. This capability is not fully verified at this time. These matrices are not calculated for a single textile layer. The overall stiffness and compliance matrices for the RUC are printed to the output file **SAMPLE5.OUT**.

Following the stiffness computations, TEXCAD will proceed to the calculation of strength. The effects of thermal residual stresses can be included in the analysis of strength. TEXCAD includes a curved beam on elastic foundation model to account for yarn bending effects which may be used in the calculation of strength. This model can also be used to account for large deformations of the yarns under both tension and compression loadings. If more than one applied stress component is specified then the internal stresses/strains and strength under the combined action of all applied stresses (and temperature change) are output by TEXCAD.

A progressive failure model [2] is used by TEXCAD to compute yarn slice failure modes and appropriately reduce yarn slice stiffnesses. The history of the yarn slice failure modes and failure sequence can be stored in a **FAILURE.LOG** file. The inplane stress-strain response is output to the **TEXCAD Window** as the program increments the applied stresses. This stress strain response along with the yarn failure events at each increment are also printed to the output file **SAMPLE5.OUT**.

The actual TEXCAD run for the 2x2, 2-D triaxial braided composite follows:

```
THIS PROGRAM ANALYZES 2D AND 3D COMPOSITES

ENTER TYPE OF COMPOSITE FOR PRESENT ANALYSIS

   1 - 2D (LAMINATED) COMPOSITE
   2 - 3D SPATIALLY ORIENTED COMPOSITE
   3 - 2D WEAVES (PLAIN, 5/8-HARNESS SATIN)
   4 - 2D BRAIDS (PLAIN, 5/8-HARNESS SATIN)
   5 - 2D 2x2 TRIAXIAL BRAID
   6 - 2D 1x1 TRIAXIAL BRAIDS
   7 - 3D MULTI-INTERLOCK 5-LAYER BRAID
   8 - CUSTOMIZED TEXTILE UNIT CELL

ENTER 1 OR 2 OR 3 ...
5

STORE OUTPUT TO A FILE ? 1 - YES, 2 - NO
1

ENTER OUTPUT FILE NAME
sample5.out

ENTER DESCRIPTIVE TITLE FOR PRESENT ANALYSIS/MODEL
```

2x2, 2D Triaxial Braided Composite, Sample Problem No. 5

```
ENTER TOTAL NO. OF MATERIALS IN PRESENT COMPOSITE
THIS INCLUDES YARNS AND INTERSTITIAL MATRIX
2

IS MATERIAL DATA STORED IN A FILE? 1 - YES, 2 - NO
ENTER 1 OR 2
1

ENTER MATERIAL DATA INPUT FILE NAME
material.dat

************************* NOTE *************************
 THE UNITS USED FOR ALL THE MATERIAL AND GEOMETRIC
 INPUT QUANTITIES MUST BE THE SAME THROUGHOUT !
 THE USER MAY USE EITHER ENGLISH OR SI UNITS, BUT
 THE SAME UNITS MUST BE USED CONSISTENTLY THROUGHOUT !
 THE TEXCAD OUTPUT WILL BE IN THE SAME UNITS THAT WERE
 USED FOR THE INPUT. TEXCAD DOES NOT CONVERT ANY UNITS.
**********************************************************


Enter Positive Braid Angle w.r.t. Axial Yarns (deg)
62.3
!!!!! USE CONSISTENT UNITS FOR ALL INPUT DATA !!!!!
Enter Axial Yarn spacing (actual distance between two yarns)
6.1
Enter Fractional Volume of Fibers in Yarns (eg: 0.75)
NOTE: This should be consistent with volume fraction
    used for impregnated yarn material properties
0.75
Enter Fiber Count of Braider Yarns (in thousands, K)
12
Enter Fiber Count of Axial Yarns (in thousands, K)
24
Enter MATERIAL ID for Braider Yarns
1
Enter MATERIAL ID for Axial Yarns
1
Enter Fiber Diameter for single Yarn Filament
0.007
Enter Desired Composite Fiber Volume Fraction (%)
54

**************************************************
 UNIT CELL GEOMETRY (UCG) AND YARN ARCHITECTURE
 DATA IS STORED IN A TEXT FILE - UNITCEL.DAT
!!!!!!!!!!!!
!! CAUTION !! - UNITCEL.DAT IS UPDATED AT EVERY
!!!!!!!!!!!!   NEW EXECUTION RUN OF THIS CODE

A GENERIC GRAPHICAL REPRESENTATION OF THE UCG AND
YARN ARCHITECTURE IS STORED IN A WINDOWS PAINTBRUSH
```

FILE CALLED
2X2TRBRD.PCX
USE WINDOWS PAINTBRUSH TO VIEW/PRINT THIS FILE
****

ENTER NO. OF EQUAL SLICES FOR UNDULATING PORTION OF YARN
*** NOTE: 12 SLICES ARE USUALLY ENOUGH FOR CONVERGENCE
*** NOTE: USE EVEN NUMBER OF SLICES
12

*********************** NOTE ************************
TEXCAD WILL CALCULATE [A], [B], AND [D] MATRICES FOR
MULTIPLE STACKED LAYERS OF THE TEXTILE UNIT CELL (UC).
IF A SINGLE LAYER IS CHOSEN THEN [A][B][D] MATRICES
FOR THE UC ARCHITECTURE ARE NOT CALCULATED.
NOTE: [A][B][D] MATRIX CALCULATIONS HAVE NOT BEEN
EXPERIMENTALLY VERIFIED
****

DO YOU WISH TO ANALYZE:
1 - A SINGLE LAYER OF THE UNIT CELL (UC) ARCHITECTURE
2 - STACKED UNIDIRECTIONAL OR MULTI-DIRECTIONAL LAYERS
ENTER 1 OR 2
1

FINISHED OVERALL STIFFNESS CALCULATIONS ...
*********************** NOTE ************************
TEXCAD CURRENTLY CALCULATES STRESSES/FAILURE
EITHER FOR A SINGLE LAYER OF THE TEXTILE UNIT CELL
OR FOR STACKED LAYERS WITH THE SAME ORIENTATION
****
PROCEED TO CALCULATE TEXTILE UNIT CELL STRESSES/FAILURE
1 - YES, 2 - NO
1

THE EFFECT OF CURING STRESSES CAN BE INCLUDED IN THE
ANALYSES FOR INTERNAL STRESSES AND STRENGTH
INCLUDE THERMAL RESIDUAL STRESSES IN PRESENT ANALYSIS ?
1 - YES, 2 - NO
1

PRINT THERMAL STRESSES/STRAINS IN YARNS ? 1 - YES, 2 - NO
2

ENTER APPLIED DELTA-T
-150.

THE EFFECT OF YARN BENDING ON AXIAL YARN STRAINS/STRESSES
IS ACCOUNTED FOR BY USING A BEAM ON ELASTIC FOUNDATION MODEL
ACCOUNT FOR YARN BENDING EFFECTS ? 1 - YES, 2 - NO
1

FOR A GIVEN APPLIED STRESS STATE USE A LINEAR ELASTIC

(NON-INCREMENTAL) ANALYSIS TO COMPUTE STRESSES/STRAINS
IN YARN SLICES ?   1 - YES, 2 - NO
2

FOR AN APPLIED STRESS STATE USE INCREMENTAL APPROACH TO
COMPUTE STRENGTH, FAILURE MODE, STRESS-STRAIN RESPONSE?
1 - YES, 2 - NO
1

ENTER APPLIED SIG-XX,SIG-YY,SIG-ZZ,TAU-XY,TAU-YZ,TAU-ZX
ONLY INPLANE LOADING CASES HAVE BEEN CURRENTLY VERIFIED

FOR UNIAXIAL LOADING
ENTER MAXIMUM EXPECTED STRENGTH IN LOADING DIRECTION AND
FOR APPLIED STRESSES IN OTHER DIRECTIONS ENTER 0.0
FOR COMBINED LOADING
ENTER MAXIMUM EXPECTED STRENGTH FOR THE STRESS DIRECTION
WHICH HAS THE LARGEST EXPECTED STRENGTH. SCALE THE OTHER
APPLIED STRESSES TO REFLECT THE REQUIRED LOAD RATIOS.

---

*Note: XYZ axes shown in the architecture graphics file
0.,600.e6,0.,0.,0.,0.

ENTER No. OF STRESS INCREMENTS FOR INCREMENTAL ANALYSIS
EACH INCREMENT TAKES 2 SEC PER YARN ON A 486-25 MHz PC
IN MOST CASES 100 INCREMENTS SHOULD BE SUFFICIENT
50
ACCOUNT FOR LARGE DEFORMATIONS ? 1 - YES, 2 - NO
1
STORE YARN SLICE FAILURE HISTORY IN "FAILURE.LOG" FILE ?
1- YES, 2 - NO
1
UNIT CELL STRESS-STRAIN RESPONSE MAY BE REQUESTED FOR :
(1) IN-PLANE STRESSES AND STRAINS
(2) OUT-OF-PLANE STRESSES AND STRAINS
ENTER 1 OR 2
1

STRESS-STRAIN RESPONSE

	XX		YY		XY	
INC	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
1	.00000E+00	-.77487E-04	.12000E+08	.29922E-03	.00000E+00	-.25026E-19
2	.00000E+00	-.15497E-03	.24000E+08	.59845E-03	.00000E+00	-.43509E-19
3	.00000E+00	-.23246E-03	.36000E+08	.89767E-03	.00000E+00	-.43312E-19
4	.00000E+00	-.30996E-03	.48000E+08	.11969E-02	.00000E+00	-.84050E-19
5	.00000E+00	-.38746E-03	.60000E+08	.14961E-02	.00000E+00	-.11338E-18
6	.00000E+00	-.47825E-03	.72000E+08	.18418E-02	.00000E+00	-.18202E-18
7	.00000E+00	-.56904E-03	.84000E+08	.21875E-02	.00000E+00	-.21706E-18
8	.00000E+00	-.65985E-03	.96000E+08	.25332E-02	.00000E+00	-.25777E-18
9	.00000E+00	-.75067E-03	.10800E+09	.28789E-02	.00000E+00	-.33423E-18
10	.00000E+00	-.84150E-03	.12000E+09	.32246E-02	.00000E+00	-.37340E-18
11	.00000E+00	-.93236E-03	.13200E+09	.35704E-02	.00000E+00	-.42081E-18

12	.00000E+00	-.10232E-02	.14400E+09	.39161E-02	.00000E+00	-.43722E-18
13	.00000E+00	-.11142E-02	.15600E+09	.42620E-02	.00000E+00	-.49144E-18
14	.00000E+00	-.12051E-02	.16800E+09	.46078E-02	.00000E+00	-.57111E-18
15	.00000E+00	-.12961E-02	.18000E+09	.49537E-02	.00000E+00	-.62845E-18
16	.00000E+00	-.13871E-02	.19200E+09	.52997E-02	.00000E+00	-.63175E-18
17	.00000E+00	-.14782E-02	.20400E+09	.56457E-02	.00000E+00	-.67017E-18
18	.00000E+00	-.15694E-02	.21600E+09	.59918E-02	.00000E+00	-.72748E-18
19	.00000E+00	-.16606E-02	.22800E+09	.63379E-02	.00000E+00	-.78488E-18
20	.00000E+00	-.17519E-02	.24000E+09	.66842E-02	.00000E+00	-.87370E-18
21	.00000E+00	-.18432E-02	.25200E+09	.70305E-02	.00000E+00	-.93642E-18
22	.00000E+00	-.19346E-02	.26400E+09	.73769E-02	.00000E+00	-.96183E-18
23	.00000E+00	-.20261E-02	.27600E+09	.77234E-02	.00000E+00	-.99448E-18
24	.00000E+00	-.21197E-02	.28800E+09	.80803E-02	.00000E+00	-.10418E-17
25	.00000E+00	-.22134E-02	.30000E+09	.84374E-02	.00000E+00	-.10819E-17
26	.00000E+00	-.23071E-02	.31200E+09	.87945E-02	.00000E+00	-.11215E-17
27	.00000E+00	-.24010E-02	.32400E+09	.91517E-02	.00000E+00	-.11787E-17
28	.00000E+00	-.24950E-02	.33600E+09	.95091E-02	.00000E+00	-.11929E-17
29	.00000E+00	-.25891E-02	.34800E+09	.98666E-02	.00000E+00	-.12831E-17
30	.00000E+00	-.26833E-02	.36000E+09	.10224E-01	.00000E+00	-.13312E-17
31	.00000E+00	-.27776E-02	.37200E+09	.10582E-01	.00000E+00	-.13896E-17
32	.00000E+00	-.28721E-02	.38400E+09	.10940E-01	.00000E+00	-.14563E-17
33	.00000E+00	-.29666E-02	.39600E+09	.11298E-01	.00000E+00	-.15014E-17
34	.00000E+00	-.30613E-02	.40800E+09	.11656E-01	.00000E+00	-.15388E-17
35	.00000E+00	-.31561E-02	.42000E+09	.12015E-01	.00000E+00	-.16044E-17
36	.00000E+00	-.32510E-02	.43200E+09	.12373E-01	.00000E+00	-.16533E-17
37	.00000E+00	-.33460E-02	.44400E+09	.12732E-01	.00000E+00	-.17329E-17
38	.00000E+00	-.34412E-02	.45600E+09	.13090E-01	.00000E+00	-.17552E-17
39	.00000E+00	-.35364E-02	.46800E+09	.13449E-01	.00000E+00	-.18192E-17
40	.00000E+00	-.36318E-02	.48000E+09	.13808E-01	.00000E+00	-.18947E-17
41	.00000E+00	-.37272E-02	.49200E+09	.14167E-01	.00000E+00	-.19298E-17
42	.00000E+00	-.38228E-02	.50400E+09	.14527E-01	.00000E+00	-.19864E-17

PRINT FINAL STRESSES/STRAINS IN YARNS ? 1 - YES, 2 - NO
2
Stop - Program terminated.

TEXCAD Output

The output that was created by the above TEXCAD execution was stored in three different files. The primary output was saved in the **SAMPLE5.OUT** file. Auxiliary output is also stored in the **UNITCEL.DAT** and the **FAILURE.LOG** files. The **UNITCEL.DAT** file is created by default at each TEXCAD execution and contains textile architecture information that may be used in a subsequent TEXCAD run. The **FAILURE.LOG** file is created upon request during the incremental loading analysis and contains a log of the failure modes and failure sequence for every yarn slice that failed during loading. Note that, the **UNITCEL.DAT** and **FAILURE.LOG** files are updated at every TEXCAD execution. A sample **UNITCEL.DAT** file is included in the section called 'Analysis Option No. 8 - Customized Textile Unit Cell' (see page 18).

The SAMPLE5.OUT File

The **SAMPLE5.OUT** file contains, first, the title that was supplied during TEXCAD execution followed by an echo of the material properties in the **MATERIAL.DAT** file. The textile architecture input parameters are then included together with other architecture parameters that were calculated by TEXCAD. These include yarn/fiber content, resin content, layer thickness, yarn crimp, yarn undulation lengths, yarn thicknesses, cross-sectional areas, and projected lengths. Next, the overall textile composite stiffness and compliance matrices, 3-dimensional moduli and Poisson's ratios, and CTE's are printed to the output file.

Stress (and/or strain) results for the thermal and mechanical loading are then printed to the output file. If the effects of yarn bending and/or large deformations were included in the analysis, then TEXCAD confirms the inclusion of these effects in the analysis. The inplane stress-strain response also includes information regarding failure events in the yarn slices along with the number of failed yarn slices in a particular failure mode in a particular yarn.

The **SAMPLE5.OUT** file is included here:

```
2x2, 2D Triaxial Braided Composite, Sample Problem No. 5

* MATERIAL ID NO.
   1
* E11, E22, NU12, G12, NU23, ALFA11, ALFA22, SE
 .1448E+12 .1173E+11 .2300E+00 .5516E+10 .3000E+00-.3240E-06 .1400E-04 .2788E+01
* STEN11, SCOMP11, STEN22, SCOMP22, SHEAR12, SHEAR23
  .1400E-01  .1000E-01  .2600E+08  .2060E+09  .8750E+08  .1024E+09
* MATERIAL ID NO.
   2
* E11, E22, NU12, G12, NU23, ALFA11, ALFA22, SE
 .3448E+10 .3448E+10 .3500E+00 .1276E+10 .3500E+00 .4000E-04 .4000E-04 .2340E+01
* STEN11, SCOMP11, STEN22, SCOMP22, SHEAR12, SHEAR23
  .8485E+08  .8485E+08  .8485E+08  .8485E+08  .9830E+08  .9830E+08
```

2x2 TRIAXIAL BRAID PARAMETERS - INPUT

BRAID ANGLE = 62.30
BRAIDER YARN SIZE (k) = 12
YARN PACKING DENSITY = .750

AXIAL YARN SPACING = 6.100
AXIAL YARN SIZE (k) = 24
COMPOSITE Vf (%) = 54.000

2x2 TRIAXIAL BRAID PARAMETERS - CALCULATED

FRACTIONAL VOLUME OF Yarns IN UNIT CELL = .71989
FRACTIONAL VOLUME OF Interstitial Matrix IN UNIT CELL = .28011
FRACTIONAL VOLUME OF Fibers IN UNIT CELL = .53992
LAYER THICKNESS = .884

Braider Yarn Undulation Parameters

Crimp Angle = 11.269
Sinusoidal Undulation Length = 4.762
Vertical Shift at Cross Over Point = .604

Yarn Characteristics

	Braider Yarns	Axial Yarns
Thickness	.280	.325
C/S Area	.616	1.231
Proj. Length	13.779	25.621
% Yarns	68.267	31.733

OVERALL STIFFNESS MATRIX FOR UNIT CELL
COMPONENTS ARE IN FOLLOWING ORDER - XX,YY,ZZ,XY,YZ,ZX

.50533E+11	.14161E+11	.43100E+10	-.30229E-05	-.85199E-08	-.18363E-06
.14161E+11	.44730E+11	.38472E+10	.18675E-05	-.42984E-08	-.10485E-06
.43100E+10	.38472E+10	.10954E+11	.66796E-08	-.63622E-09	-.22557E-07
-.30229E-05	.20229E-05	.24043E-07	.14838E+11	-.43560E-07	.70818E-08
.22339E-08	-.51243E-08	-.24537E-09	-.88264E-07	.41241E+10	-.23351E-07
-.21716E-06	-.11649E-06	-.35046E-08	.34443E-08	-.46600E-08	.46370E+10

OVERALL COMPLIANCE MATRIX FOR UNIT CELL
COMPONENTS ARE IN FOLLOWING ORDER - XX,YY,ZZ,XY,YZ,ZX

.22148E-10	-.64573E-11	-.64469E-11	.53278E-26	.38031E-28	.69974E-27
-.64573E-11	.24935E-10	-.62170E-11	-.44510E-26	.11690E-28	.27786E-27
-.64469E-11	-.62170E-11	.96013E-10	-.57414E-27	-.49864E-29	.71186E-28
.54030E-26	-.47049E-26	-.62139E-27	.67393E-10	.71183E-27	-.10292E-27
-.20404E-28	.34110E-28	.14799E-29	.14423E-26	.24248E-09	.12211E-26
.87016E-27	.31932E-27	-.38554E-27	-.50058E-28	.24368E-27	.21566E-09

UNIT CELL OVERALL PROPERTIES

EXX = .45150E+11   EYY = .40104E+11   EZZ = .10415E+11

NuXY = .29154   NuYX = .25896

NuXZ = .29108 NuYZ = .24933

GXY = .14838E+11 GYZ = .41241E+10 GXZ = .46370E+10

UNIT CELL OVERALL THERMAL COEFFICIENTS

ALPHAXX	ALPHAYY	ALPHAZZ	ALPHAXY	ALPHAYZ	ALPHAZX
.16763E-05	.26497E-05	.25589E-04	-.23107E-21	.37567E-23	.34367E-21

THERMAL STRESS/STRAIN RESULTS

APPLIED DELTA-T: -150.00000

THERMAL STRAINS IN UC: EPS-XX,EPS-YY,EPS-ZZ,GAM-XY,GAM-YZ,GAM-ZX

-.25144E-03 -.39745E-03 -.38383E-02 .34661E-19 -.56351E-21 -.51550E-19

AVERAGE STRESSES IN UC DUE TO THERMAL LOADING (EQUILIBRIUM CHECK)

SIG-XX	SIG-YY	SIG-ZZ	SIG-XY	SIG-YZ	SIG-ZX
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00

INCREMENTAL ANALYSIS RESULTS

APPLIED STRESSES TO UC: SIG-XX,SIG-YY,SIG-ZZ,TAU-XY,TAU-YZ,TAU-ZX

.00000E+00 .60000E+09 .00000E+00 .00000E+00 .00000E+00 .00000E+00

*** YARN BENDING EFFECTS INCLUDED ***

*** LARGE DEFORMATION EFFECTS INCLUDED ***

STRESS-STRAIN RESPONSE

	XX		YY		XY	
INC	STRESS	STRAIN	STRESS	STRAIN	STRESS	STRAIN
1	.00000E+00	-.77487E-04	.12000E+08	.29922E-03	.00000E+00	-.25026E-19
2	.00000E+00	-.15497E-03	.24000E+08	.59845E-03	.00000E+00	-.43509E-19
3	.00000E+00	-.23246E-03	.36000E+08	.89767E-03	.00000E+00	-.43312E-19
4	.00000E+00	-.30996E-03	.48000E+08	.11969E-02	.00000E+00	-.84050E-19
5	.00000E+00	-.38746E-03	.60000E+08	.14961E-02	.00000E+00	-.11338E-18

25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 1
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 2
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 3
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 4
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 5
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 6
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 7
25 YARN SLICES FAILED IN TRANSVERSE (22) MODE IN YARN ID. 8

6	.00000E+00	-.47825E-03	.72000E+08	.18418E-02	.00000E+00	-.18202E-18
7	.00000E+00	-.56904E-03	.84000E+08	.21875E-02	.00000E+00	-.21706E-18
8	.00000E+00	-.65985E-03	.96000E+08	.25332E-02	.00000E+00	-.25777E-18
9	.00000E+00	-.75067E-03	.10800E+09	.28789E-02	.00000E+00	-.33423E-18
10	.00000E+00	-.84150E-03	.12000E+09	.32246E-02	.00000E+00	-.37340E-18
11	.00000E+00	-.93236E-03	.13200E+09	.35704E-02	.00000E+00	-.42081E-18
12	.00000E+00	-.10232E-02	.14400E+09	.39161E-02	.00000E+00	-.43722E-18
13	.00000E+00	-.11142E-02	.15600E+09	.42620E-02	.00000E+00	-.49144E-18
14	.00000E+00	-.12051E-02	.16800E+09	.46078E-02	.00000E+00	-.57111E-18
15	.00000E+00	-.12961E-02	.18000E+09	.49537E-02	.00000E+00	-.62845E-18
16	.00000E+00	-.13871E-02	.19200E+09	.52997E-02	.00000E+00	-.63175E-18
17	.00000E+00	-.14782E-02	.20400E+09	.56457E-02	.00000E+00	-.67017E-18
18	.00000E+00	-.15694E-02	.21600E+09	.59918E-02	.00000E+00	-.72748E-18
19	.00000E+00	-.16606E-02	.22800E+09	.63379E-02	.00000E+00	-.78488E-18
20	.00000E+00	-.17519E-02	.24000E+09	.66842E-02	.00000E+00	-.87370E-18
21	.00000E+00	-.18432E-02	.25200E+09	.70305E-02	.00000E+00	-.93642E-18
22	.00000E+00	-.19346E-02	.26400E+09	.73769E-02	.00000E+00	-.96183E-18
23	.00000E+00	-.20261E-02	.27600E+09	.77234E-02	.00000E+00	-.99448E-18
INTERSTITIAL MATRIX FAILURE						
24	.00000E+00	-.21197E-02	.28800E+09	.80803E-02	.00000E+00	-.10418E-17
25	.00000E+00	-.22134E-02	.30000E+09	.84374E-02	.00000E+00	-.10819E-17
26	.00000E+00	-.23071E-02	.31200E+09	.87945E-02	.00000E+00	-.11215E-17
27	.00000E+00	-.24010E-02	.32400E+09	.91517E-02	.00000E+00	-.11787E-17
28	.00000E+00	-.24950E-02	.33600E+09	.95091E-02	.00000E+00	-.11929E-17
29	.00000E+00	-.25891E-02	.34800E+09	.98666E-02	.00000E+00	-.12831E-17
30	.00000E+00	-.26833E-02	.36000E+09	.10224E-01	.00000E+00	-.13312E-17
31	.00000E+00	-.27776E-02	.37200E+09	.10582E-01	.00000E+00	-.13896E-17
32	.00000E+00	-.28721E-02	.38400E+09	.10940E-01	.00000E+00	-.14563E-17
33	.00000E+00	-.29666E-02	.39600E+09	.11298E-01	.00000E+00	-.15014E-17
34	.00000E+00	-.30613E-02	.40800E+09	.11656E-01	.00000E+00	-.15388E-17
35	.00000E+00	-.31561E-02	.42000E+09	.12015E-01	.00000E+00	-.16044E-17
36	.00000E+00	-.32510E-02	.43200E+09	.12373E-01	.00000E+00	-.16533E-17
37	.00000E+00	-.33460E-02	.44400E+09	.12732E-01	.00000E+00	-.17329E-17
38	.00000E+00	-.34412E-02	.45600E+09	.13090E-01	.00000E+00	-.17552E-17
39	.00000E+00	-.35364E-02	.46800E+09	.13449E-01	.00000E+00	-.18192E-17
40	.00000E+00	-.36318E-02	.48000E+09	.13808E-01	.00000E+00	-.18947E-17
41	.00000E+00	-.37272E-02	.49200E+09	.14167E-01	.00000E+00	-.19298E-17
42	.00000E+00	-.38228E-02	.50400E+09	.14527E-01	.00000E+00	-.19864E-17

LONGITUDINAL FAILURE IN YARN ID. 9

COMPOSITE FAILED BY LONGITUDINAL YARN FAILURE

The FAILURE.LOG File

The **FAILURE.LOG** file contains a log of the failure sequence of the yarn slices with increasing load. For each yarn slice that has failed, information regarding the yarn ID, cross-over point ID, yarn slice ID, inplane orientation angle (θ) of the yarn slice (see Fig. 3), out-of-plane orientation angle (β) of the yarn slice, inplane stresses at yarn slice failure, and the yarn slice failure mode is included on two lines of output. The failure mode designation has the format **Rij** where **ij** **(i = 1-3, j = 1-3)** indicates the type of failure. Thus, **R11** indicates longitudinal, **R22** indicates transverse, **R31** and **R12** indicate longitudinal shear failure, etc. Resin failure is indicated by **RVM.**

The **FAILURE.LOG** file can be quite large as it contains failure information for each yarn slice in the model. Only a small portion of a sample **FAILURE.LOG** file is included here:

FAILURE LOG

OVERALL STRESS-STRAIN/ YARN SLICE INFO, FAILURE MODE

XX		YY		XY	
STRESS YARN ID	STRAIN C/O PT. ID	STRESS SLICE NO.	STRAIN THETA	STRESS BETA	STRAIN FAILURE MODE
.000000E+00	-.387460E-03	.600000E+08	.149614E-02	.000000E+00	-.113380E-18
1	1	1	27.70000	11.14385	R22
.000000E+00	-.387460E-03	.600000E+08	.149614E-02	.000000E+00	-.113380E-18
1	1	2	27.70000	10.40157	R22
.000000E+00	-.387460E-03	.600000E+08	.149614E-02	.000000E+00	-.113380E-18
1	1	3	27.70000	8.95776	R22

References

1. Naik, R. A.: "Analysis of Woven and Braided Fabric Reinforced Composites," NASA CR-194930, June 1994, National Aeronautics and Space Administration, Hampton, Virginia. Presented at the ASTM 12th Symposium on Composite Materials: Testing and Design, Montreal, Canada, May 16-17, 1994.

2. Naik, R. A.: "Failure Analysis of Woven and Braided Fabric Reinforced Composites," NASA CR-194981, September 1994, National Aeronautics and Space Administration, Hampton, Virginia. Also available in Proceedings of the Fifth NASA/DoD Advanced Composites Technology (ACT) Conference, Seattle, Washington, August 22-26, 1994, National Aeronautics and Space Administration, Hampton, Virginia.

Appendix - Sample Problems

Several sample problems are included here to demonstrate the input required by TEXCAD to analyze the different textile architectures.

Sample Problem No. 1 - 2D Laminated Composite

Consider a $[0/\pm 60]_s$ laminate with a ply thickness of **0.13 mm** and a fiber volume fraction of **60%** having the material properties given in the **MATERIAL.DAT** file (page 21). After entering the analysis option number (1 for this case, see page 9), the analysis title, the output and material data file names, TEXCAD requires interactive input of

(i) the ply thickness: **0.13**

(ii) the fiber volume fraction in the ply: **0.60**

(iii) the total number of plies: **6**

(iv) the laminate stacking sequence: **0., 60., -60., -60., 60., 0.**

Based on this input TEXCAD will calculate the [A], [B], and [D] matrices and overall laminate moduli, Poisson's ratio, coefficients of thermal expansion, etc.

Sample Problem No. 2 - 3D XYZ Woven Composite

Consider a **XYZ weave** made of three sets of mutually orthogonal straight yarns oriented in the X, Y and Z directions, respectively (Fig. A1). Each yarn is made up of **6 k** (n = 6000) AS4 (graphite) filaments and has a packing density, p_d, (fiber volume fraction) of **0.75**. The diameter, d_f, of the AS4 fibers is **0.007 mm**. As shown in Fig. A1 the **unit cell** dimensions are **1 mm X 1 mm X 1 mm**. The material properties, for the impregnated yarns and the resin, given in the **MATERIAL.DAT** file (page 21) can be used for this example.The yarn cross-sectional area (A_y) is calculated using the formula:

$$A_y = \frac{\pi \, d_f^2 \, n}{4 \, p_d} \tag{A1}$$

After entering the analysis option number (2 for this case, see page 9), the analysis title, the output and material data file names, TEXCAD requires the following input:

(i) unit cell cross-sectional parameters and thickness;
lenght1, length2, included angle, thickness: **1., 1., 90., 1.**

(ii) the fiber volume fraction within the yarns: **0.75**

(iii) the total number of yarns in the unit cell: **3**

(iv) for each yarn:
(a) the yarn orientation angles θ (in-plane) and β (out-of-plane) (see Fig. 3)
(b) the yarn cross-sectional area: **0.3079**
(c) the yarn centerline length: **1.0**

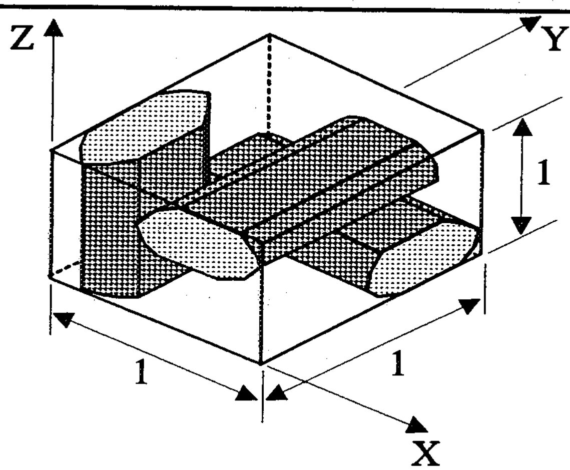


Figure A1. - Repeating unit cell showing yarn orientations for the XYZ woven composite.

Based on this input TEXCAD will calculate the volume fraction of the yarns and the interstitial matrix in the unit cell, overall fiber volume fraction, overall 3D XYZ weave moduli, Poisson's ratios, coefficients of thermal expansion, etc.

Sample Problem No. 3 - Plain Weave Composite

Consider a **plain weave** composite (Fig. 4) made of graphite AS4 yarns and 3501-6 epoxy resin. Both the fill and warp yarns are made up of **3 k** filaments and have a packing density (fiber volume fraction) of **0.75**. The yarn spacing is specified as **4.5 yarns/cm**, i.e. the actual spacing between two yarns is **2.22 mm**. The diameter of the AS4 fibers is **0.007 mm**. The material properties, for the impregnated yarns and the resin, given in the **MATERIAL.DAT** file (page 21) can be used for this example. The overall composite fiber volume fraction is specified as **60%**. After entering the analysis option number (3 for this case, see page 9), the analysis title, the output and material data file names, type of 2D weave (i.e. plain, 5-harness satin, or, 8-harness satin), TEXCAD requires the following input:

(i) yarn spacing, i. e. actual distance between yarns: **2.22**

(ii) the fiber volume fraction within the yarns: **0.75**

(iii) yarn filament count (in thousands, k): **3**

(iv) filament diameter (in consistent units): **0.007**

(v) overall composite fiber volume fraction (in percent, %): **60.**

(vi) number of equal yarn slices for undulating regions: **12**

Based on this input TEXCAD will calculate the volume fraction of the yarns and the interstitial matrix in the unit cell, layer thickness, yarn crimp angle, yarn cross-sectional area, yarn projected length, yarn thickness, overall plain weave moduli, Poisson's ratios, coefficients of thermal expansion, etc.

Sample Problem No. 4 - 2D Braided Composite

Consider a **2D braided** composite (Fig. 7) which is very similar in construction to the above plain weave composite (Sample Problem No. 3). However, this 2D braid is obtained by rotating the plain weave by 45 degrees. As before, the yarns are made of AS4 graphite **3 k** filaments and impregnated with 3501-6 epoxy resin. The impregnated yarns have a packing density (fiber volume fraction) of **0.75**. The yarn spacing is specified as **4.5 yarns/cm**, i.e. the *perpendicular* spacing between two yarns is **2.22 mm**. Note that, unlike the present example, in which the fill and warp yarns are orthogonal, the 2D braided composite, in general, has non-orthogonal yarns. **TEXCAD requires the *perpendicular* spacing between adjacent yarns as input and so one must be careful in making the input for yarn spacing for 2D braided**

composites. The diameter of the AS4 fibers is **0.007 mm**. The material properties, for the impregnated yarns and the resin, given in the **MATERIAL.DAT** file (page 21) can be used for this example. The overall composite fiber volume fraction is specified as **60%**. After entering the analysis option number (4 for this case, see page 9), the analysis title, the output and material data file names, type of 2D braid (i.e. plain, 5-harness satin, or, 8-harness satin), TEXCAD requires the following input:

(i) braid angle (in degrees): **45.**

(ii) yarn spacing, i. e. actual distance between yarns: **2.22**

(iii) the fiber volume fraction within the yarns: **0.75**

(iv) yarn filament count (in thousands, k): **3**

(v) filament diameter (in consistent units): **0.007**

(vi) overall composite fiber volume fraction (in percent, %): **60.**

(vii) number of equal yarn slices for undulating regions: **12**

Based on this input TEXCAD will calculate the volume fraction of the yarns and the interstitial matrix in the unit cell, layer thickness, yarn crimp angle, yarn cross-sectional area, yarn projected length, yarn thickness, overall 2D braided composite moduli, Poisson's ratios, coefficients of thermal expansion, etc. The computed elastic constants for this particular 2D braid, which was obtained by a 45 degree rotation of the plain weave composite, can be verified by taking the elastic constants computed for the plain weave composite of Sample Problem No. 3 and transforming them by a 45 degree rotation using standard tensor transformation laws.

Sample Problem No. 5 - 2D 2x2 Triaxial Braided Composite

Consider a **2D 2x2 triaxial braided** composite (Fig. 8) which has a braid angle of **62.3** degrees with **12 k** braider yarns and **24 k** axial yarns. The yarns are made of AS4 graphite filaments and impregnated with 3501-6 epoxy resin. The impregnated yarns have a packing density (fiber volume fraction) of **0.75**. TEXCAD requires the actual spacing between two axial yarns which is **6.1 mm** (data sheets sometimes use the reciprocal of the actual yarn spacing, e. g.

1.64 yarns/cm). The diameter of the AS4 fibers is **0.007 mm**. The material properties, for the impregnated yarns and the resin, given in the **MATERIAL.DAT** file (page 21) can be used for this example. The overall composite fiber volume fraction is specified as **54%**. After entering the analysis option number (5 for this case, see page 9), the analysis title, the output and material data file names, TEXCAD requires the following input:

(i) braid angle (in degrees): **62.3**

(ii) axial yarn spacing, i. e. actual distance between yarns: **6.1**

(iii) the fiber volume fraction within the yarns: **0.75**

(iv) braider yarn filament count (in thousands, k): **12**

(v) axial yarn filament count (in thousands, k): **24**

(vi) filament diameter (in consistent units): **0.007**

(vii) overall composite fiber volume fraction (in percent, %): **54.**

(viii) number of equal yarn slices for undulating regions: **12**

Based on this input TEXCAD will calculate the volume fraction of the yarns and the interstitial matrix in the unit cell, layer thickness, yarn crimp angle, yarn cross-sectional areas, yarn projected lengths, yarn thicknesses, overall 2D 2x2 triaxial braided composite moduli, Poisson's ratios, coefficients of thermal expansion, etc. The sample execution run and the corresponding output for the above sample problem have been included in the **SAMPLE5.RUN** and **SAMPLE5.OUT** files, respectively, which have been included on the distribution diskette and have been discussed and reproduced in the **TEXCAD Sample Execution** (page 23) and **TEXCAD Output** (page 28) sections, respectively.

Acknowledgments

This work was performed as part of the NASA Advanced Composites Technology (ACT) Program under NASA Contract No. NAS1-19708. The author wishes to sincerely thank Dr. C. E. Harris and Mr. C. C. Poe, Jr. of the Mechanics of Materials branch (MEMB) at the NASA Langley Research Center for their support and valuable suggestions throughout this project. Finally, the author gratefully acknowledges the contributions of Mr. James R. Reeder (MEMB, NASA) and Mr. Wade C. Jackson (MEMB, U.S. Army) in the preparation of the Apple Macintosh version of the program.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1994	Contractor Report

4. TITLE AND SUBTITLE

TEXCAD - Textile Composite Analysis for Design
Version 1.0 User's Manual

5. FUNDING NUMBERS

NAS1-19708

WU 510-02-11-07

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Analytical Services and Materials, Inc.
Hampton, VA 23666

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR-4639

11. SUPPLEMENTARY NOTES

Langley Technical Monitor: Charles E. Harris
Final Report

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited

Subject Category - 24

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Textile Composite Analysis for Design (TEXCAD) code provides the materials/design engineer with a user-friendly, desktop computer (IBM PC compatible or Apple Macintosh) tool for the analysis of a wide variety of fabric reinforced woven and braided composites. It can be used to calculate overall thermal and mechanical properties along with engineering estimates of damage progression and strength. TEXCAD also calculates laminate properties for stacked, oriented fabric constructions. It discretely models the yarn centerline paths within the textile repeating unit cell (RUC) by assuming sinusoidal undulations at yarn cross-over points an users a yarn discretization scheme (which subdivides each yarn not smaller, piecewise straight yarn slices) together with a 3-D stress averaging procedure to compute overall stiffness properties. In the calculations for strength, it uses a curved beam-on-elastic foundation model for yarn undulating regions together with an incremental approach in which stiffness properties for the failed yarn slices are reduced based on the predicted yarn slice failure mode. Nonlinear shear effects and nonlinear geometric effects can be simulated. Input to TEXCAD consists of: (i) materials parameters like impregnated yarn and resin properties such as moduli, Poisson's ratios, coefficients of thermal expansion, nonlinear shear parameters, axial failure strains and in-plane failure stresses; and (ii) fabric parameters like yarn sizes, braid angle, yarn packing density, filament diameter and overall fiber volume fraction. Output consists of overall thermoelastic constants, yarn slice strains/stresses, yarn slice failure history, in-plane stress-strain response and ultimate failure strength. Strength can be computed under the combined action of thermal and mechanical loading (tension, compression and shear).

14. SUBJECT TERMS

Weaves; Braids; Composites; Textiles; Stiffness; Strength; Damage progression; Software; Fabric

15. NUMBER OF PAGES

40

16. PRICE CODE

A03

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