

## PROMAL 1997 SOFTWARE PACKAGE: A USER' S GUIDE

- *Show how to set up PROMAL on a personal computer*
- *Show how to use PROMAL for*
  - *matrix algebra such as multiplication of matrices, solving a set of equations and finding inverse of a matrix,*
  - *developing and maintaining a database for properties of unidirectional laminas,*
  - *conducting macromechanics of a lamina,*
  - *conducting micromechanics of a lamina,*
  - *conducting macromechanics of a laminate*
- *Show by examples how to use each of the above programs*

### 1 INTRODUCTION

Studying mechanics of composites required lengthy and repetitive algebraic manipulations, such as, matrix multiplication, inversion of matrices, etc. If you want to fully understand the scope of the mechanics of composites, especially the design of laminated structures, you may need to write a computer program or use a mathematical package, such as MATHCAD and MATLAB. I highly recommend the student to develop some of their own programs but it is time consuming to build a program that is professional and efficient for all the principles taught in this book. The instructor and the student can therefore turn to the software package PROMAL which was developed using the VISUAL BASIC language<sup>1</sup>. PROMAL is designed for classroom instruction as well as for homework assignments.

The software has five different programs:

- Matrix Algebra - Appendix of Chapter 2,
- Lamina Properties Database - Chapter 2,
- Replacing Corrupted Lamina Properties Database - Chapter 2,
- Macromechanics Analysis of a Single Lamina - Chapter 2,
- Micromechanics Analysis of a Single Lamina - Chapter 3,
- Macromechanics Analysis of a Laminate - Chapters 4 and 5.

The software package makes you more productive by giving a tool for numerical experimentation. It provides instant and step-by-step graphical and tabular feedback. Other special features of the software include

- systems of units switchable between the SI and USCS by a single click
- clear input and output data units
- output choices such as viewing on monitor, printing on a printer or writing to a text file.
- home page at <http://www.eng.usf.edu/ME/people/promal.html>

### SYSTEM REQUIREMENTS

- Personal computer running Microsoft Windows,
- Microsoft Mouse,

- Printer Recommended.

### 3 SETTING UP PROMAL

1. Read all the eligibility requirements, licensing agreement and warranty information given in the ABOUT THE SOFTWARE section of this book.
2. Unzip the *promal\_1997.zip* file.
3. Click on the *setup.exe* file.
4. Follow the instructions given on the screen. The default directory is C:\PROMAL. You can change the directory to anything you want.

### 4. USING THE PROGRAM

After the PROMAL set up program has run, it will create a new program group and a new program item for PROMAL. Simply double click on the PROMAL icon. You will be presented with two introductory screens and then the Master Menu. Figure 1 shows the Master Menu with five separate applications from which to choose from. To use, click the mouse or press the ENTER key on one of the six choices. In a menu, you can also use the TAB or SHIFT+TAB key to move from one button to another.

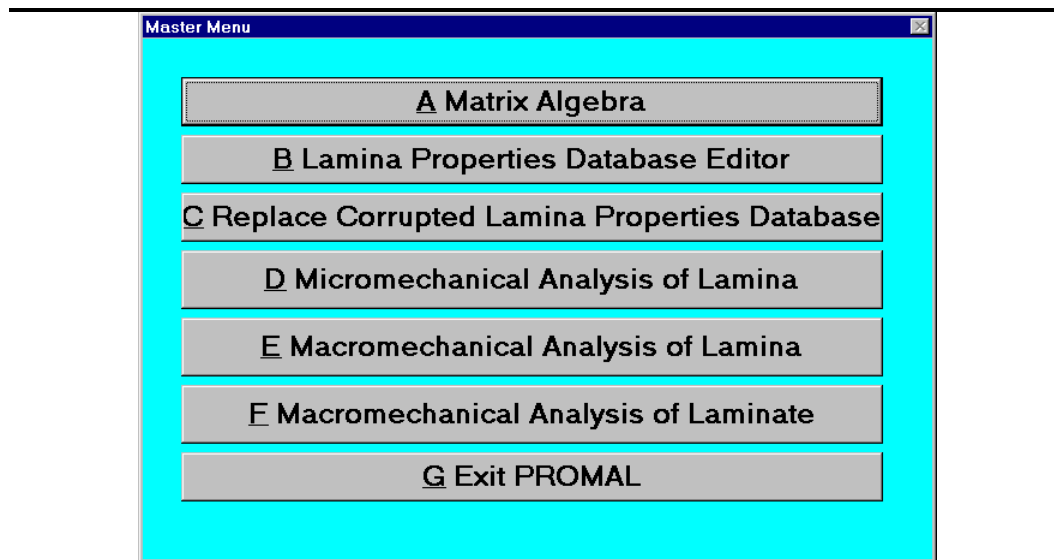


Figure 1. Master menu showing available programs in PROMAL.

#### 4.1. COMMON BUTTONS

Some buttons are common in all the five programs. These buttons are

Print: Click on this Button to print the output shown on the screen to the default printer. Each output starts on a new page. If this is not acceptable, use the Dump button, explained in the following.

Dump: Click on this Button to put the output shown on the screen to a text file called **PROMAL.TXT**.

This file resides in the directory where you installed PROMAL. If needed, rename the file when you exit the program, because the file gets erased when you start the program. You can view, edit or print this file using a wordprocessor or text editor. For proper formatting of the output, use Courier New font or any other scalable font and Pitch 10" size.

System of Units: Click on this option Button to select the units for input and output data. The default system of units is the SI (Systeme Internationale d Unites) system for all the programs. The other system of units is the USCS (United States Customary System) system.

Return to Master Menu: Click on this Button to return to the Master Menu.

Exit PROMAL: Click on this Button to exit the program.

#### *4.2 ACCESS KEYS*

Access keys allow you to navigate through the program by pressing the ALT key and typing the underlined letter in the buttons. For example, you can access Matrix Algebra program in the Master Menu by simultaneously pressing ALT and then the A key.

### **MATRIX ALGEBRA**

The first program conducts multiplication of matrices, solves a set of equations and finds the inverse of a matrix. Rather than spending time conducting lengthy matrix manipulations, this program allows you to concentrate on the fundamentals of this course while doing homework problems. Select from the menu of Matrix Algebra<sup>a</sup> shown in Figure 2 to do matrix calculations common to the macromechanical analysis of composite materials.

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<sup>a</sup>

Skip this program if you are comfortable with conducting matrix algebra using programmable calculators or mathematical packages such as MATHCAD and MATLAB.



Figure 2. Main menu for matrix algebra tools.

#### How do I enter a matrix?

1. Click on Matrix Algebra Button in the Master Menu.
2. Click on Create a Matrix Button.
3. Click on the option buttons for the number of rows and columns. *The maximum number of rows and columns is six.*
4. Click on the Option button if the matrix is symmetric. If the matrix is symmetric, enter only the upper triangular portion of the matrix. The program automatically enters the lower triangular portion.
5. Click on the Save Button to save the matrix and PROMAL will give it the next available name between A through O.
6. Click on Return to Previous Menu Button.

#### What happens if I use all the Matrices A through O?

1. In the Matrix Algebra menu, click on Erase All Input Matrices Button.
2. Leave the Matrix Algebra menu and start again. You will lose the value in all the matrices. That is why you should save only those matrices you need in a particular run.

#### How do I edit a matrix?

1. Click on Matrix Algebra Button in the Master Menu.
2. Click on Edit a Matrix Button.
3. Click on the matrix A through O you want to edit.
4. Click on Save Current Matrix Button to save the matrix.
5. Click on Return to Previous Menu Button.

**How do I multiply two matrices?**

1. Click on Matrix Algebra Button in the Master Menu.
2. Choose by clicking on the two matrices to be multiplied.
3. Click on Multiply Two Matrices Button.
4. You can then save the matrix in the next available name A through O.

**How do I solve a set of equations?**

1. Click on the Matrix Algebra Button in the Master Menu.
2. Click on Solve a Set of Equations Button.
3. Choose by clicking on the coefficient matrix and the right-hand side array.
4. Click on Solve A Set of Equations Button. The program displays the solution.
5. You can save the matrix in the next available name A through O.

**How do I find the inverse of a matrix?**

1. Click on Matrix Algebra Button in the Master Menu.
2. Click on Inverse of a Matrix Button.
3. Click on the matrix you want to invert. However, if the matrix is singular or non-square, you will get an appropriate message that PROMAL cannot calculate the inverse.
4. You can then save the matrix in the next available name A through O.

**Task 1**

Find the solution to the following set of equations.

$$\begin{bmatrix} 2 & 3 & 6 \\ 3 & 7 & 8 \\ 6 & 8 & 15 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 11 \\ 18 \\ 29 \end{bmatrix}$$

**Procedure**

1. Click on the Matrix Algebra Button in the Master Menu.
2. Click on Create a Matrix Button.
3. Click on the appropriate number of rows and columns. Here, both numbers are three.
4. Since the coefficient matrix is symmetric, check on the Yes option for matrix symmetry.
5. Enter only the upper triangular elements of the coefficient matrix and press Save.
6. Click on Yes Button when it asks you if you want to enter more matrices.
7. Repeat steps 3-5 for the right-hand side array.
8. Click on Return to Previous Menu Button .
9. Click on Solve a Set of Equations Button.
10. Click on the coefficient matrix and right-hand side array.
11. Click on Solve a Set of Equations Button. The text box displays the solution, which is  
[1      1      1].
12. You can now print or dump the solution. You can also save the solution under the next available matrix name for later use.

**LAMINA PROPERTIES DATABASE**

In the second program, you can enter the material properties of a composite lamina, update or correct the properties of an existing lamina, and simply review the properties. *You can enter properties for up to a maximum of 100 different lamina materials.* Properties of three typical composite systems - Graphite/Epoxy, Boron/Epoxy and Glass/Epoxy, and two typical isotropic metals - aluminum and steel are already entered for you in the database. You cannot change the values of the properties of these five materials.

Figure 3 shows the menu for entering and editing the lamina properties. This program enters fourteen properties - the four elastic moduli, lamina thickness, five strength parameters, two coefficients of thermal expansion, and two coefficients of moisture expansion of a specially orthotropic lamina.

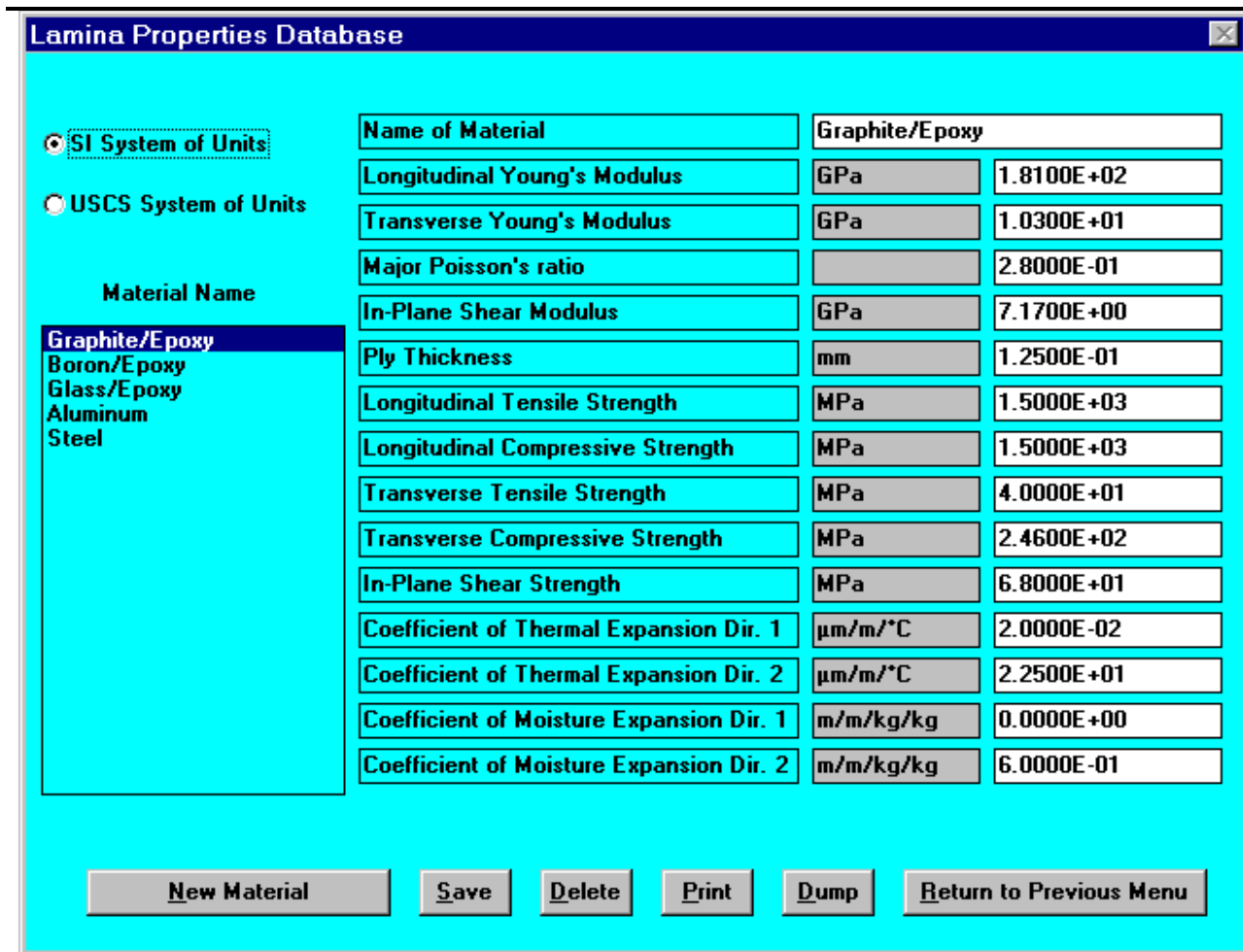


Figure 3. Menu for updating and adding lamina properties to material database.

**How do I enter the properties of a new material?**

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the proper system of units for the input.
3. Click on the New Material Button. *Note that PROMAL disables the Save Button.* The program will enable the Save Button when you enter the material name, and non-zero elastic moduli thickness and strength parameters of the lamina. This avoids errors such as division by zero in other programs of PROMAL. Put dummy non-zero numbers if a particular data is not available. *CAUTION: However, these dummy non-zero values will accordingly affect the results obtained in the other programs of PROMAL.* The material name can be up to 28 characters long; both letters and numbers are acceptable. To enter the data for the material, you can use either decimal or exponential notation.
4. Click on the Save Button to save the material properties.

**How do I delete a material?**

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the material you want to delete from the Material ListBox.
3. Click on the Delete Button. PROMAL will ask for confirmation if you really want to delete the material.

**Why can I not edit or delete the first five materials in the database?**

The first five materials are reserved. You cannot delete or edit these five materials. This is done so that the instructor can assign homework using these common material systems.

**How do I change some properties of materials I have already entered?**

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the material you want to edit from the Material ListBox.
3. Make changes to the properties.
4. Click on the Save Button to save the changes in the material properties. You need to save changes before editing another material.

**For a material system, I know some properties in the USCS system of units and some in the SI system of units? How do I enter the data without converting it into a single system of units?**

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the system of units of your choice for the input.
3. Click on the New Material Button.
4. Enter the properties of the material. Use dummy non-zero numbers for data given in another system of units.
5. Click on the Save Button to save the material properties.
6. Click now on the other system of units for the input.
7. Click on the material in the Material ListBox.
8. Edit the properties given in the other system of units.
9. Click on the Save Button to save the material properties.

**Task 2**

Create a material record for a typical Graphite/Epoxy-2 lamina with the following properties.

**Table 6 Properties of Graphite/Epoxy-2**

Property Name	Symbol	Value
Longitudinal Young's Modulus	$E_1$	30.00 Msi
Transverse Young's Modulus	$E_2$	0.750 Msi
Major Poisson's Ratio	$\nu_{12}$	0.250
In-Plane Shear Modulus	$G_{12}$	0.375 Msi
Ply Thickness		0.125 mm
Longitudinal Tensile Strength	$(\sigma_1^T)_{ult}$	150 Ksi
Longitudinal Compressive Strength	$(\sigma_1^C)_{ult}$	100 Ksi
Transverse Tensile Strength	$(\sigma_2^T)_{ult}$	6 Ksi
Transverse Compressive Strength	$(\sigma_2^C)_{ult}$	17 Ksi
In-Plane Shear Strength	$(\tau_{12})_{ult}$	10 Ksi
Longitudinal Coefficient of Thermal Expansion	$\alpha_1$	$1.8 \times 10^{-8}$ m/m/ $^{\circ}$ C
Transverse Coefficient of Thermal Expansion	$\alpha_2$	$1.8 \times 10^{-5}$ m/m/ $^{\circ}$ C
Longitudinal Coefficient of Moisture Expansion	$\beta_1$	0.0 m/m/kg/kg
Transverse Coefficient of Moisture Expansion	$\beta_1$	0.5 m/m/kg/kg

Note that you have different units for the input data. With **PROMAL**, you do not have to get all the data into the same system of units before data entry.

**Procedure**

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the USCS system of units for input.
3. Click on the New Material Button. Enter the name as Graphite/Epoxy -2, elastic moduli, strength properties.
4. Enter the name, elastic moduli, strength properties. Enter arbitrary non-zero value for the ply thickness since PROMAL will not enable the Save Button for a zero value for thickness.
5. Click on the Save Button.
6. Click on the Graphite/Epoxy-2 name in the Material List Box.
7. Click on the SI system of units for input.
8. Edit the ply thickness and enter the coefficients of thermal and moisture expansion in the SI

system.

9. Click on the Save Button. Note that you did not have to convert the units manually to enter the data.
10. Click on the Return to Previous Menu Button to return to the Master Menu.

## 7 REPLACING CORRUPTED LAMINA MATERIAL DATABASE

Sometimes, the material database for the lamina may get corrupted due to power shutdown, computer lockup, accidental rebooting or other reasons. This option allows you to replace the material database by either

- the database which you had the last time you exited out of the program, or
- the database which you received with the setup disk. Note that the database on the disk has properties for five common materials. *You do not need the setup disk to use this option.*

### How do I replace the corrupted database with the one which was on the setup disk?

1. In the Master Menu, click on Replace Corrupted Lamina Properties Database Button.
2. Click on Replace Corrupted Database with Database Which Came With the Setup Disk Button.
3. Click on the Yes Button, if you want to replace the corrupted database. Click on the No Button if you do not want to replace the corrupted database.

### How do I replace the corrupted database with the database which I saved the last time I used PROMAL?

1. In the Master Menu, click on Replace Corrupted Lamina Properties Database Button.
2. Click on Replace Corrupted Database with Previously Used Database Button.
3. Click on the Yes Button, if you want to replace the corrupted database. Click on the No Button if you do not want to replace the corrupted database.

## MACROMECHANICAL ANALYSIS OF A LAMINA

The fourth program conducts the macromechanical analysis of a lamina discussed in Chapter 2. The input mechanical properties of a lamina are chosen from the Lamina Properties Database. You can then calculate the stiffness and the compliance matrices, the engineering constants and the strength ratios for an angle ply and display the engineering constants and the strength ratios as a function of the ply angle in tabular or graphical form. Figure 4 gives the main menu of the macromechanical analysis of a lamina.

### How do I use this program?

1. Click on Select Lamina from Lamina Properties Database Button.
2. Select the lamina from the database by clicking on the material in the Material ListBox. Click on the Load Material Button or double click on the material in the Material List Box, and PROMAL returns you to the main menu.
3. Buttons with access keys B thru K allow you to

- i. review the loaded data for the selected lamina,
  - ii. view, print or/and dump the transformation matrices  $[T]$  and  $[T]^{-1}$ , reduced stiffness  $[Q]$  and compliance  $[S]$  matrices, transformed reduced stiffness  $[\bar{Q}]$  and transformed compliance  $[\bar{J}]$  matrices, engineering constants for an angle ply,
  - iii. tabulate and plot transformed stiffness  $[\bar{Q}]$  and transformed compliance  $[\bar{J}]$  matrices and engineering constants as a function of the angle of ply.
4. Click on Stresses/Strains and Strength Ratios Button to find the global and local strains and stresses, and the strength ratios for four major failure theories. Enter the components of the stress vector ( $\sigma_x$ ,  $\sigma_y$ , and  $\tau_{xy}$ ) and the angle of ply. At least one of the stresses should be non-zero and *the angle of the ply should be also be entered even if it is zero.*

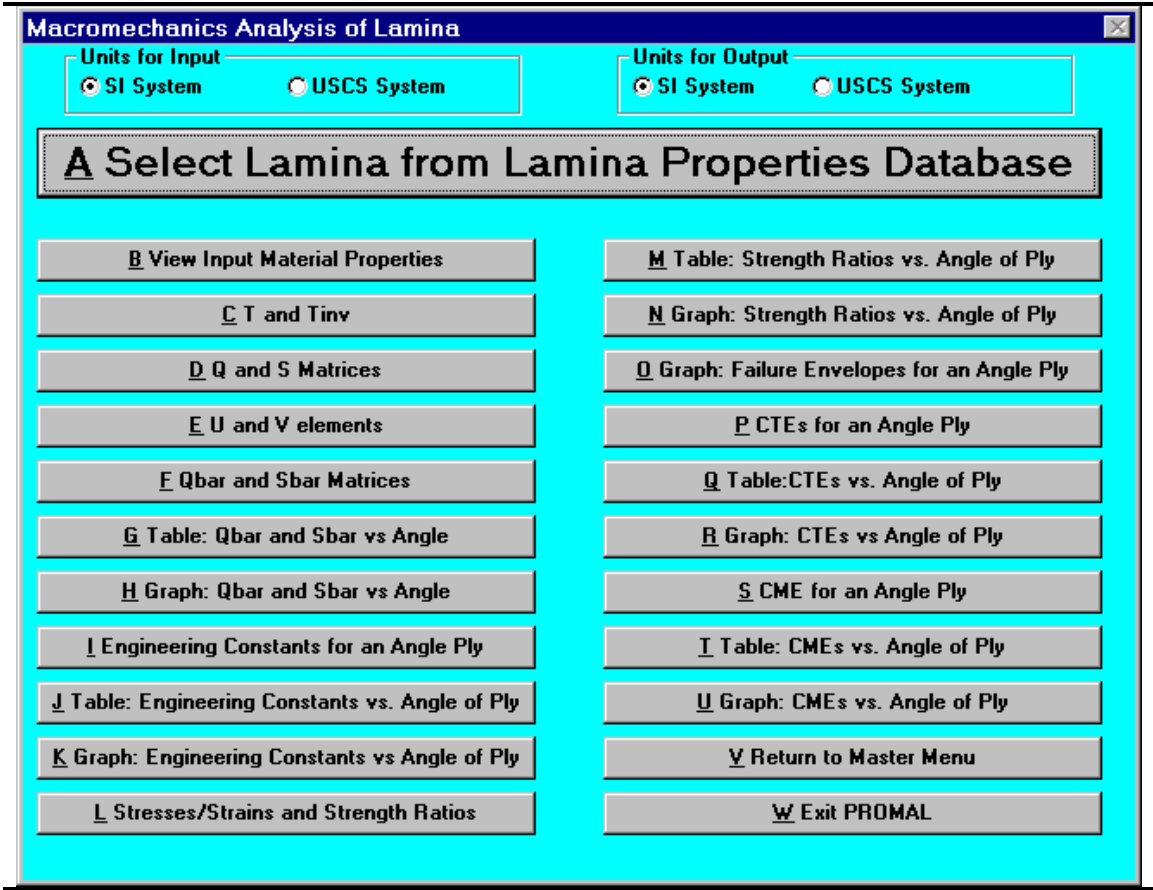


Figure 4. Main menu for macromechanical analysis of a lamina.

5. Click on Table: Strength Ratios vs. Angle of Ply or Graph Strength Ratios vs. Angle of Ply Button to tabulate or plot the strength ratios as a function of the angle of ply. Enter the components of the stress vector ( $\sigma_x$ ,  $\sigma_y$ , and  $\tau_{xy}$ ). *At least one of the stresses should be non-zero.* Then you can view the strength ratios as a function of the angle of ply. PROMAL also shows results from all the four failure theories in one graph to show the difference between the

- predictions using all the four failure theories.
6. Click on Graph: Failure Envelopes for an Angle Lamina Button. For a zero shear stress and angle of the ply as the input variable, this choice shows the failure envelopes ( $\sigma_x$  vs.  $\sigma_y$ ) for the four failure theories. You can see failure envelopes from all four theories on one graph.
  7. Buttons with access keys P through R show the coefficients of thermal expansion (CTE) for a particular angle of ply, and tabulate and plot the coefficients of thermal expansion as a function of the angle of ply.
  8. Buttons with access keys S through U show the coefficients of moisture expansion (CME) for a particular angle of ply, and tabulate and plot the coefficients of moisture expansion as a function of the angle of ply.

### Task 3

Consider a typical Graphite/Epoxy lamina with the mechanical properties given in Table 2.2. Find the optimum fiber angle which maximizes the safety factor for the following stress components .

Longitudinal Stress ( $\sigma_x$ ) = 4 Ksi,

Transverse Stress ( $\sigma_y$ ) = 2 Ksi,

Shear Stress ( $\tau_{xy}$ ) = 1 Ksi.

Use the Maximum Stress failure theory for your analysis and use the properties of unidirectional Graphite/Epoxy lamina from the Lamina Properties Database.

### Procedure

1. Click on the Macromechanics of a Lamina Button in the Master Menu.
2. Click on the proper system of units for the input and output.
3. Click on Select Lamina from Lamina Properties Database Button to select the material properties of the Graphite/Epoxy.
4. To analyze the lamina for the optimum fiber angle for the given load, select the Graph: Strength Ratios vs. Angle of Ply Button. Enter the components of the stress vector. Once you enter these values, you are presented with the first of four graphs showing the strength ratio as a function of the angle of ply. The second graph shows the results of using the Maximum Stress failure theory. From the graph (Figure 5), the lamina will not fail ( $SR > 1$ ) for fiber angles between  $10^\circ$  and  $30^\circ$ .
5. Further investigation using Stresses/Strains and Strength Ratios Button shows that  $22.5^\circ$  is the optimum fiber angle as it has a strength ratio of 3.784. So one can apply 3.784 times the stresses given above before the lamina fails.

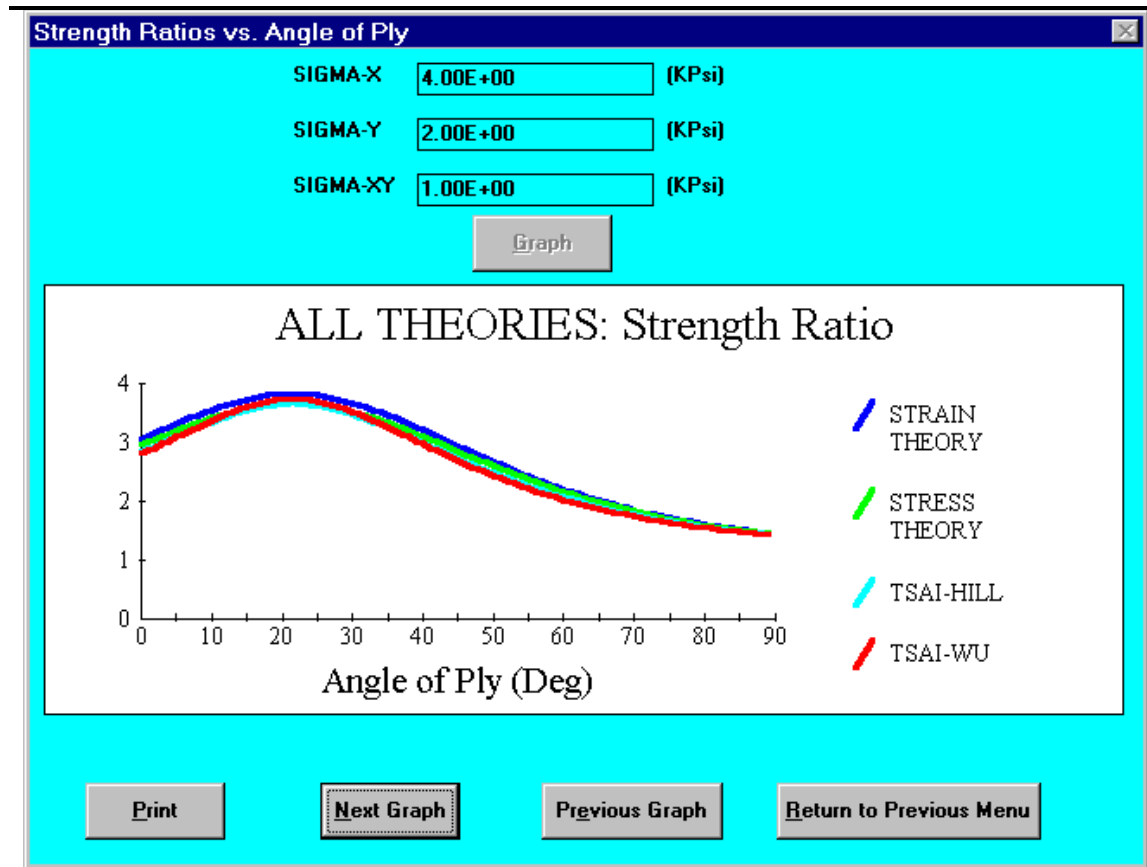


Figure 5. Strength ratio as a function of angle of ply for Task 6.3.

### 9. MICROMECHANICAL ANALYSIS OF A LAMINA

The fifth program conducts the micromechanical analysis of a lamina using formulas from the strength of materials approach. You enter the elastic moduli, coefficients of thermal and moisture expansion of the fiber and the matrix from the keyboard. You can then calculate the elastic moduli, thermal and moisture expansion coefficients of a unidirectional lamina for a particular fiber volume fraction. The program also displays these properties in a tabular/graphical form as a function of the fiber volume fraction. Figure 6 shows the main menu of the micromechanical analysis of a lamina.

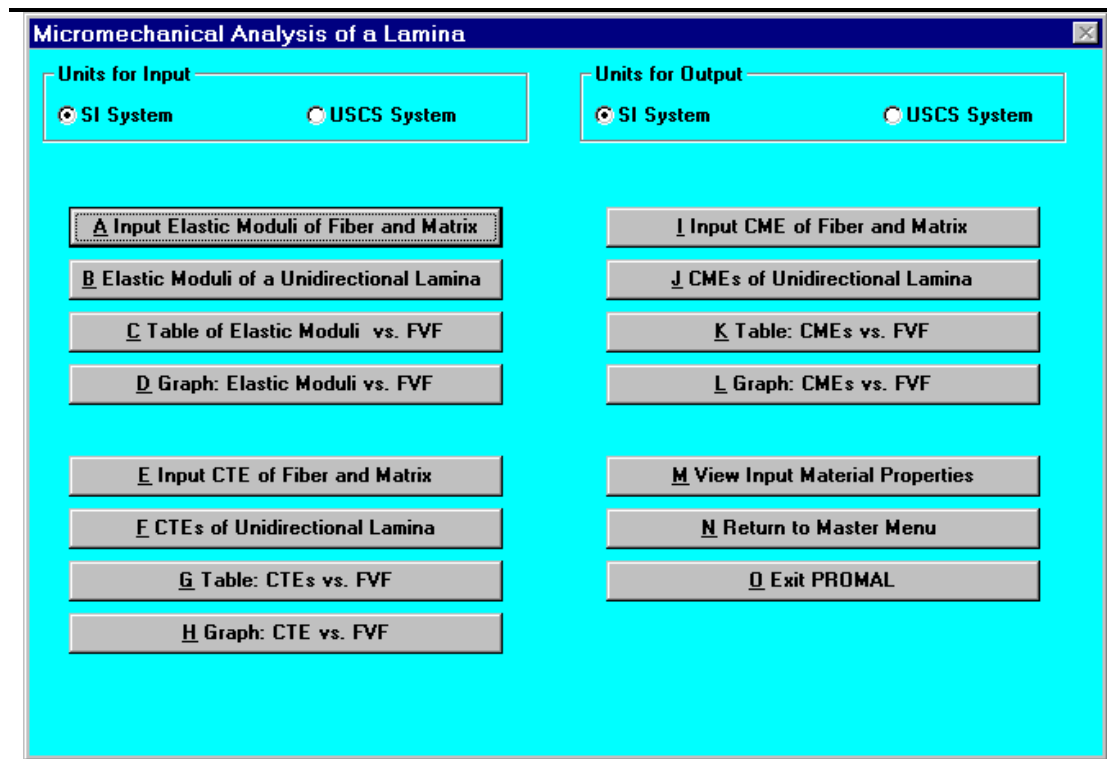


Figure 6. Main menu for the micromechanical analysis of a lamina.

#### How do I use this program?

1. Click on I Input Elastic Moduli of Fiber and Matrix Button to enter the isotropic elastic moduli of the fiber and the matrix. Direction 1 (longitudinal) is parallel to the fibers and Direction 2 (transverse) is perpendicular to the fibers. The program does not accept null input because of a possibility of division by zero.
2. The next three Buttons with access keys B through D display the elastic moduli and the ratio of the fiber load to the composite load of a unidirectional lamina for an input value of a fiber volume fraction; tabulate and plot these parameters as a function of the fiber volume fraction.
3. Click on E Input CTE of Fiber and Matrix Button to enter the coefficients of thermal expansion of the fiber and matrix. The next three buttons with access keys F through H display the longitudinal and transverse thermal expansion coefficients for an input value of a fiber volume fraction; tabulate and plot these parameters as a function of the fiber volume fraction.
4. Click on I Input CME of Fiber and Matrix Button to enter the coefficients of moisture expansion and specific gravities of the fiber and matrix. The next three buttons with access keys J through L display the longitudinal and transverse moisture expansion coefficients for an input value of a fiber volume fraction; tabulate and plot these parameters as a function of the fiber volume fraction.

#### Task 4

The following are the mechanical properties of the constituents of a typical Glass/Epoxy lamina:

Fiber Young's modulus ( $E_f$ ) = 70 GPa

Matrix Young's modulus ( $E_m$ ) = 3.5 GPa

Fiber Poisson's ratio ( $\nu_f$ ) = 0.2

Matrix Poisson's ratio ( $\nu_m$ ) = 0.35

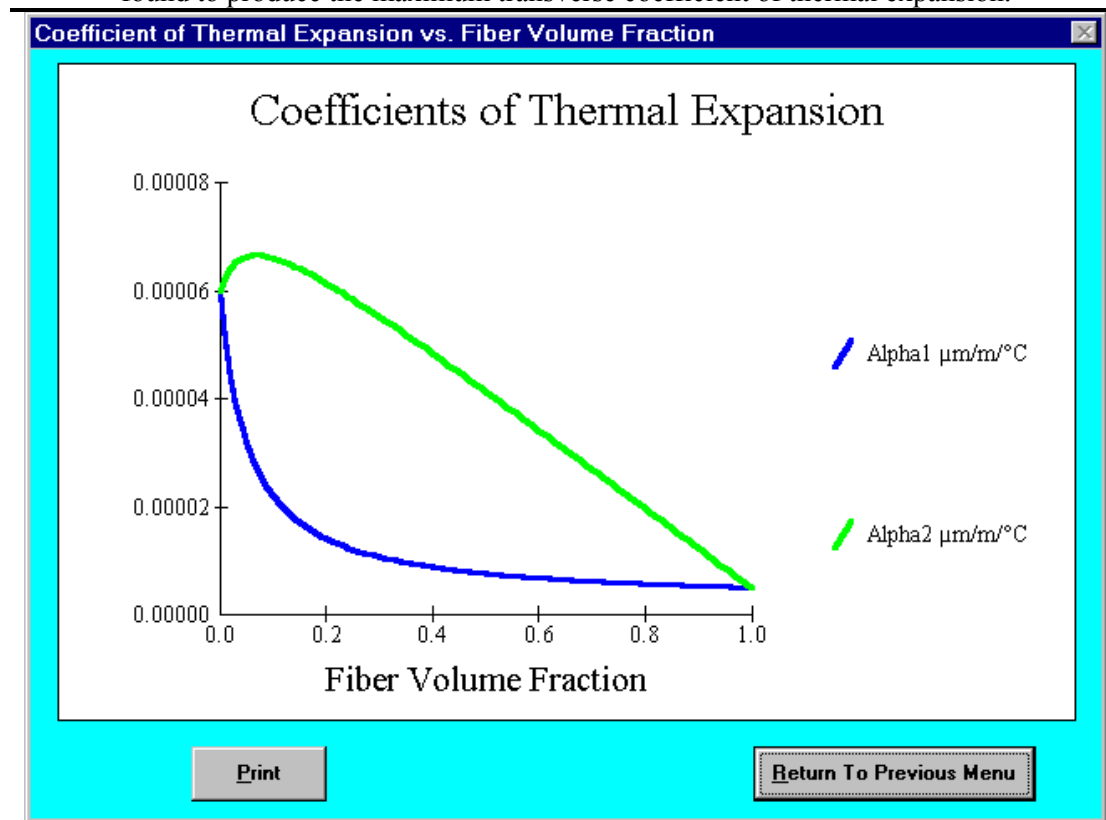
Fiber coefficient of thermal expansion ( $\alpha_f$ ) =  $0.5 \times 10^{-5}$  m/m/°C

Matrix coefficient of thermal expansion ( $\alpha_m$ ) =  $6.0 \times 10^{-5}$  m/m/°C

Find the fiber volume fraction for which the thermal expansion coefficient perpendicular to the fibers,  $\alpha_2$ , is a maximum.

### Procedure

1. Click on Input Elastic Moduli of Fiber and Matrix Button to enter the elastic moduli of the fiber and the matrix.
2. Click on Input CTE for Fiber and Matrix Button to enter the coefficient of thermal expansion for fiber and matrix. Note your units!
3. Click on the Graph: CTEs vs. FVF Button. From the graph, as shown in Figure 7, we see that the maximum transverse thermal expansion coefficient occurs when the fiber volume fraction is between 0.05 and 0.1. Next, using these values as the upper and lower limits, iteratively use the CTEs of Unidirectional Lamina Button to find the fiber volume fraction for which the thermal expansion coefficient is a maximum. Following this method, a fiber volume fraction of 0.071 is found to produce the maximum transverse coefficient of thermal expansion.



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Figure 7. Coefficients of thermal expansion as a function of fiber volume fraction for Task 4.

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## 10. MACROMECHANICAL ANALYSIS OF A LAMINATE

The sixth program conducts the macromechanical analysis of a laminate. The laminate can consist of a single type of lamina, and hybrids and sandwich panels. The material properties for the lamina are selected from the material data base of the second program. Next, you enter the orientation of the plies and the corresponding material number of each ply in the laminate. You can also read laminate stacking sequences from a data file. Now you can display the orientation and ply properties, the stiffness and the compliance matrices, and the equivalent plate properties of the laminate. Enter the mechanical and hygrothermal loads to calculate the global and local stresses and strains, strength ratios at the top, middle and bottom surface of each ply in the laminate. Figure 8 gives the main menu of the macromechanical analysis of a laminate.

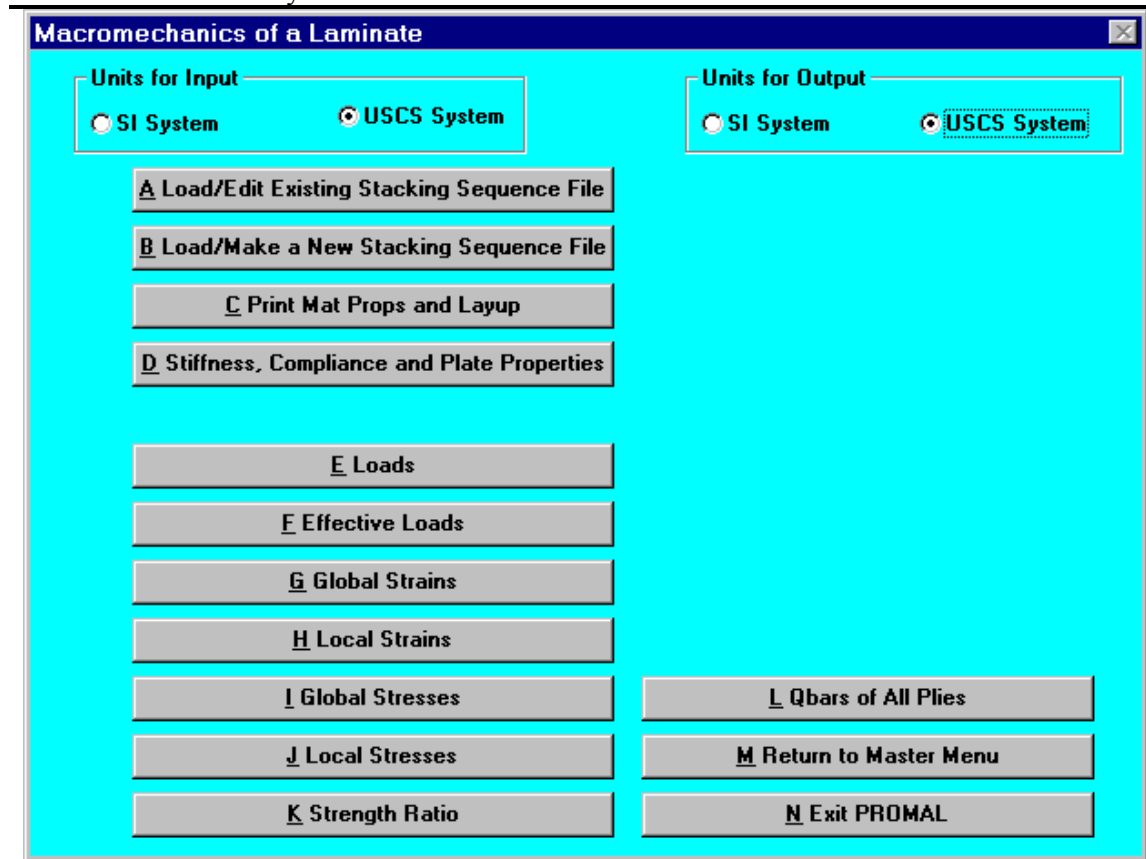


Figure 8. Main menu for macromechanical analysis of a laminate.

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### How do I create a new laminate sequence?

1. Click on the Macromechanical Analysis of a Laminate Button in the Master Menu.
2. Click on the Load/Make a New Stacking Sequence File Button.

3. Enter the number of plies. *The maximum number of plies allowed is 100.*
4. Select either a hybrid or single material laminate, AND either a symmetric or unsymmetric laminate sequence.
5. These choices reduce input required to make a laminate sequence. *The maximum number of different materials in a laminate is 10.*
6. Click on Enter Laminate Stacking Sequence Button and you will see a screen as given in Figure 9.
7. Starting from the top ply, put the material number and ply angle in degrees for each ply in the grid. For a symmetric matrix, the input is complete at the mid-plane of the laminate. For a single material laminate, you need not put the material number manually. Simply double click on the material in the Material ListBox and it floods the material number column. Sometimes, while entering a laminate stacking sequence, you may want to review or check the material properties of a material. A single click on a material in the Material ListBox allows you to review the material properties in both systems of units.
8. Click on Save File/Return to Main Menu Button to save the laminate stacking sequence in a file. Saving it with a suffix of .kaw is better since then you can distinguish them from other files. At this point, PROMAL saves and loads the stacking sequence. Even if you do not save the laminate stacking sequence, it will still be loaded.

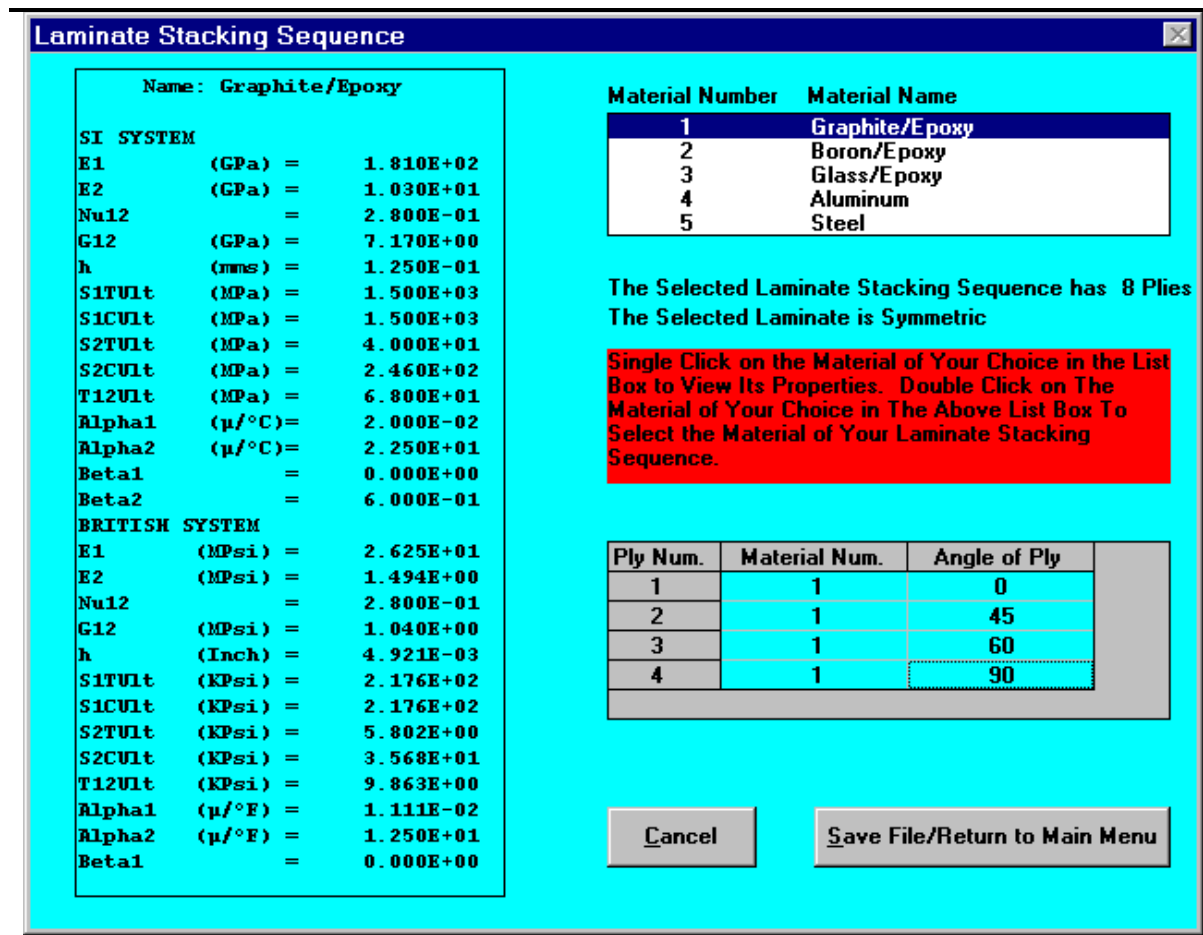


Figure 9. Menu for entering stacking sequence of a laminate for Task 6.5.

**How do I edit a previously saved laminate sequence?**

1. Click on Load/Edit Existing Stacking Sequence File Button.
2. Load the laminate stacking sequence file from the dialog box.
3. Change the material numbers and ply angles as needed.
4. Click on Save File/Return to Main Menu Button to save the laminate stacking sequence.  
 Save the new edited stacking sequence in the current data file or as a new data file. If you do not save the laminate stacking sequence, the new sequence will still be loaded bit the file will be left unchanged.

**How do I load a previously saved laminate stacking sequence?**

1. Click on Load/Edit Existing Stacking Sequence File Button.
2. Load the laminate stacking sequence file from the dialog box.
3. Click on Save File/Return to Main Menu Button to load the laminate stacking sequence.

**How do I run this program?**

1. Click on Load/Edit Existing Stacking Sequence File Button or Load/Make a New Stacking

- Sequence File Button and follow the procedure described in the previous three questions.
2. Buttons with access keys C through D allow you to view, print and/or dump the following - stacking sequence including the material names and angle of each ply; stiffness and compliance matrices including normalized matrices; equivalent plate properties such as in-plane and flexural elastic moduli, and thermal and moisture expansion coefficients.
  3. Click on Applied Mechanical and Hygrothermal Loads Button to enter the mechanical loads and the hygrothermal loads. The next five Buttons with access keys F through K allow you to view the effective loads, mid-plane curvatures and strains, ply by ply global and local strains and stresses, strength ratios at the top, middle and bottom of each ply, and transformed reduced stiffness matrices for each ply. *Note that if PROMAL shows the strength ratio as \*\*\*\*\*, it implies that strength ratio cannot be calculated.* Typical examples include when laminates are failing just due to hygrothermal loads, or when mechanical stresses are zero at a plane such as the mid-plane under pure in-plane bending.

### Task 5

Determine the maximum uniaxial stress you can apply in the x-direction to a  $[0/45/60/90]_s$  Graphite Epoxy laminate. The x-direction is parallel to the fibers in the  $0^\circ$  ply. Use the Maximum Stress failure theory as a basis for your answer. Use the properties of unidirectional Graphite/Epoxy lamina from the Lamina Properties Database. The thickness of each ply is 0.004921 inches.

### Procedure

1. Click on the Macromechanics of a Laminate Button in the Master Menu.
2. Click on the Load/Make a New Stacking Sequence File<sup>b</sup> Button to make a new laminate stacking sequence. Since the subscript  $s$  on the laminate stacking sequence denotes a symmetric laminate, enter eight for the number of plies. Choose the options of a single material and a symmetric laminate. Double click on Graphite/Epoxy in the Material ListBox to flood the material number column in the laminate stacking sequence grid or enter the material number manually in the grid. Enter the angle of the top four plies from top to bottom. Click on Save/Return to Main Menu Button to save the data file.
3. The task is to find the maximum uniaxial load you can apply in the x-Direction based on the Maximum Stress failure theory.

Click on Applied Mechanical and Hygrothermal Loads Button to enter a unit force per unit length in the X-direction, that is,  $N_x=1$  lb/in. Click on Strength Ratios Button to view

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<sup>b</sup> Clicking on Load/Edit Previous Stacking Sequence File Button can replace step 2. The laminate stacking sequence in Task 6.5 was loaded to the PROMAL directory during PROMAL setup as example.kaw.

the table of strength ratios (Figure 10).

Minimum obtained value of strength ratio

$$= 1.298 \times 10^3 \text{ (90}^\circ \text{ ply)}$$

Maximum value of uniaxial load  $N_x$

$$= \text{Load} \times \text{Strength Ratio}$$

$$= 1 \times 1.298 \times 10^3 \text{ lb/in}$$

$$= 1.298 \times 10^3 \text{ lb/in.}$$

Thickness of the laminate

$$= \text{Number of plies} \times \text{Thickness of one ply}$$

$$= 8 \times 4.921 \times 10^{-3}$$

$$= 0.039368 \text{ inches.}$$

Maximum allowable uniaxial stress in X-direction

$$= \text{Maximum value of load/Thickness of laminate}$$

$$= 1.298 \times 10^3 / 0.039368$$

$$= 32.971 \text{ Ksi.}$$

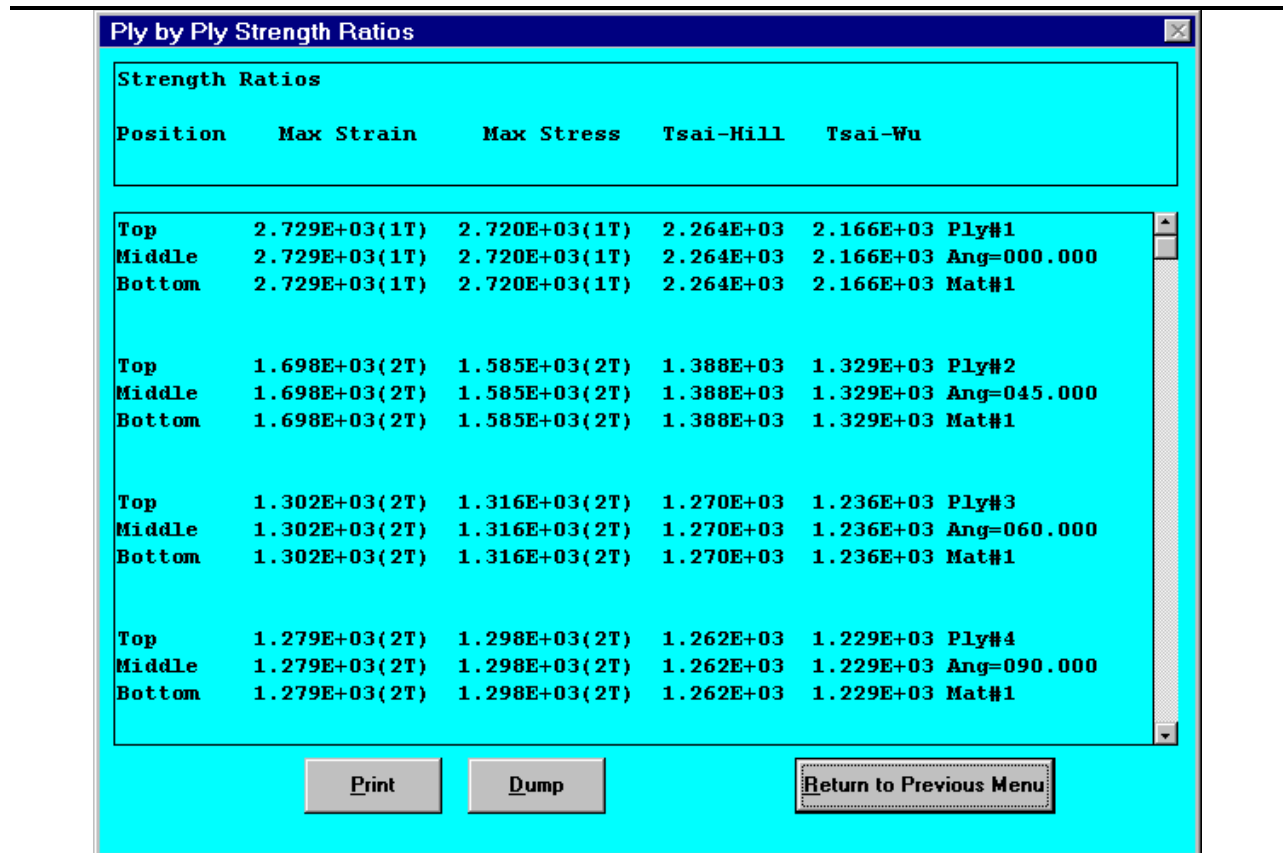


Figure 10. Table showing strength ratios at top, middle and bottom of each ply in laminate in Task

**REFERENCES**

1. Microsoft Visual Basic, Programming System for Windows, Version 3.0, Microsoft Corporation,

1993.