ME 575
Two-bar Truss OptdesX Tutorial

Name_____

1. Skim Section 2 in the OptdesX manual. Execute all of tutorial 1 in Section 3 (105 steps). Also read Section 10.3, pgs. 10-5 thru 10-12.

2. Define the following design problem: With height and thickness as design variables, minimize deflection, subject to weight less than 26 pounds, stress less than 90 ksi, and stress minus buckling stress less than zero (i.e. no buckling). (Other variable values as given in page 3-28, except diameter, which will be 2.0 Set lower bound of thickness to 0.05, upper bound to be 0.20; lower bound of height to be 10; upper bound to be 50.)
    a. Optimize the design.
    b. Turn in a hardcopy of the starting design and the optimal design**. (Use the hardcopy button in the Variables window.**)
    c. What is the optimal solution? What constraints are binding?

3. Keeping the same problem description (given in Part 2), construct 2d and 3d contour plots (similar to plots on pg. 3-47, 3-48, but with height and thickness as variables, deflection as the function contoured, and weight included as a constraint with stress and buckling).
    a. Turn in hardcopy of the plots (Use the hardcopy button on the bottom of the plot and then send this file to the printer, or you can first convert to pdf or png format using system routines explained on the next page and can then paste into Word.)
    b. Shade the feasible region. Show the optimum point.
    c. Do the optimum variable values on the plot match the optimum values given in Part 2?

4. Keeping the problem from 3 above, change the value of diameter from 2.0 to 3.0 Re-optimize the problem. Redo the 2d plot.
    a. Include hardcopy. Show the feasible region and optimum.
    b. What has changed? Why?
    c. Why does the buckling constraint boundary no longer show up? Verify your explanation.

5. Select width and load as variables for a 2d <u>optimal</u> contour plot (similar to pg. 3-55).
    a. Turn in hardcopy of the plot.
    b. How is this plot different from the 2d plots in parts 3 and 4 in terms of the variables we can select? Could we have chosen height and thickness as the graph variables? Why or why not?
    c. How is this plot different from the 2d plots in parts 3 and 4 in terms of the computational expense? Explain your answer.
    d. Why don't we usually plot constraint boundaries on such a plot?

To Run OptdesX from a CAEDM MS Windows Machine Using RGS

1. In the 'Start' menu, run 'Programs' > 'Internet Programs' > 'HP Session Allocation Client'

2. When prompted, enter your CAEDM username and password

3. Select, 'RGS Linux' from the list of roles, and click 'Ok'

   You should be given a CAEDM Linux login screen. (Note: touch the mouse if it doesn't respond.)

4. Log in with your CAEDM username and password

5. Open a terminal window (click on a small gray terminal icon on the menu bar)

6. Make a new directory for this assignment:
   ```
   mkdir twobar
   ```
7. Move to this directory,
   ```
   cd twobar
   ```
8. Copy the following file to this directory,
   ```
   cp /uxapps/OptdesX/examples/TwobarC TwobarC
   ```
9. Execute the tutorial:
   ```
   OptdesX TwobarC
   ```

To quit OptdesX, push Quit in the Main OptdesX Window. To end the session, type 'Exit' in the terminal window and logoff using the 'Logoff' command on the menu bar (or 'System' > 'Logout')

To Run OptdesX from a CAEDM Linux Machine

You should be able to start directly from step 4 above.

Converting a Hardcopy (.PS) File to PNG

If you've saved a hardcopy of a graph using OptdesX's 'Hardcopy' button, you can convert it into a PNG image (for use in a word processor like MS Word) with the 'convert' command. For example, to create a MyGraph.png image based on the Graphic1.ps hardcopy file:
```
$ convert Graphic1.ps MyGraph.png
```

If you want a bit higher resolution, use the '-density' option:
```
$ convert -density 150 Graphic1.ps MyGraph.png
```

The higher the number you specify after '-density', the greater the resolution (and size) of the image created.

Converting a Hardcopy (.PS) File to PDF

You can also make a PDF out of a hardcopy file; PDFs may be easier to work with for printing and saving for later use. To do this, use the 'ps2pdf' command. For example:
```
$ ps2pdf Graphic1.ps MyGraph.pdf
```

Capturing the Contents of a Window into a PNG File

If the black-and-white images the hardcopy button produces aren't spiffy enough for you, or if you'd like to save something OptdesX is displaying that doesn't have a hardcopy button, you can get a PNG image of any open window using the 'import' command. For example, you could save the contents of a window to the file 'MyWindow.png' like so:
```
$ import MyWindow.png
```

Type this command, hit Enter, and click somewhere in the window you want a picture of. The contents of that window will be saved to the file you specified.

Obviously, OptdesX must be running in order to take a picture of it. So you'll need to run 'import' from a second terminal or else run OptdesX in the background (as described above in the 'Running OptdesX' section).

Viewing a PNG File

You can check that your PNG file looks the way you want by viewing it using 'display':

```
$ display MyWindow.png
```

Viewing a PDF File

You can check that your PDF file looks the way you want by viewing it using 'evince':

```
$ evince MyGraph.pdf
```

The 'display' command can also be used to view PDF files.

Viewing a Hardcopy (PS) File

The 'evince' command also works for viewing PS files (like those produced by the hardcopy button):

```
$ evince Graphic1.ps
```

The 'display' command can also be used to view PS files.

Editing a PNG File

If you want to edit a PNG file you've created (perhaps to crop out unnecessary borders or to add annotations), you can use 'gimp' (the GNU Image Manipulation Program):

```
$ gimp MyWindow.png
```

You may be presented with a few setup screens the first time you run the GIMP; selecting the defaults should be fine.

Closing Up Shop

Once you're done, close the terminal by typing 'exit' and hitting Enter.

```
$ exit
```

Starting OptdesX

For this tutorial, the OptdesX routines are linked with the Twobar example analysis program provided with the software. The tutorial program should have already been created by the installer of OptdesX; it is usually placed in a directory such as `/usr/local/OptdesX/ tutorial/` with the default name `OptdesX`. Instructions for the creation of the tutorial program are given in Section 1.

The tutorial displays presented in this manual were developed on a Unix-based DECstation 3100 computer. If you are executing OptdesX on another type of computer, there may be minor differences between the numerical values in this manual and the values on your screen.

1 Begin execution of the OptdesX software.

On a UNIX machine, assuming the tutorial is placed in the directory given above, you would type `/usr/local/OptdesX/tutorial/OptdesX`. The following three windows open:

This is the Main Window Selection box. All other windows are opened from here.

This is the "parent" window of all OptdesX windows. The title includes the model name. This window can be used to iconify the whole application.
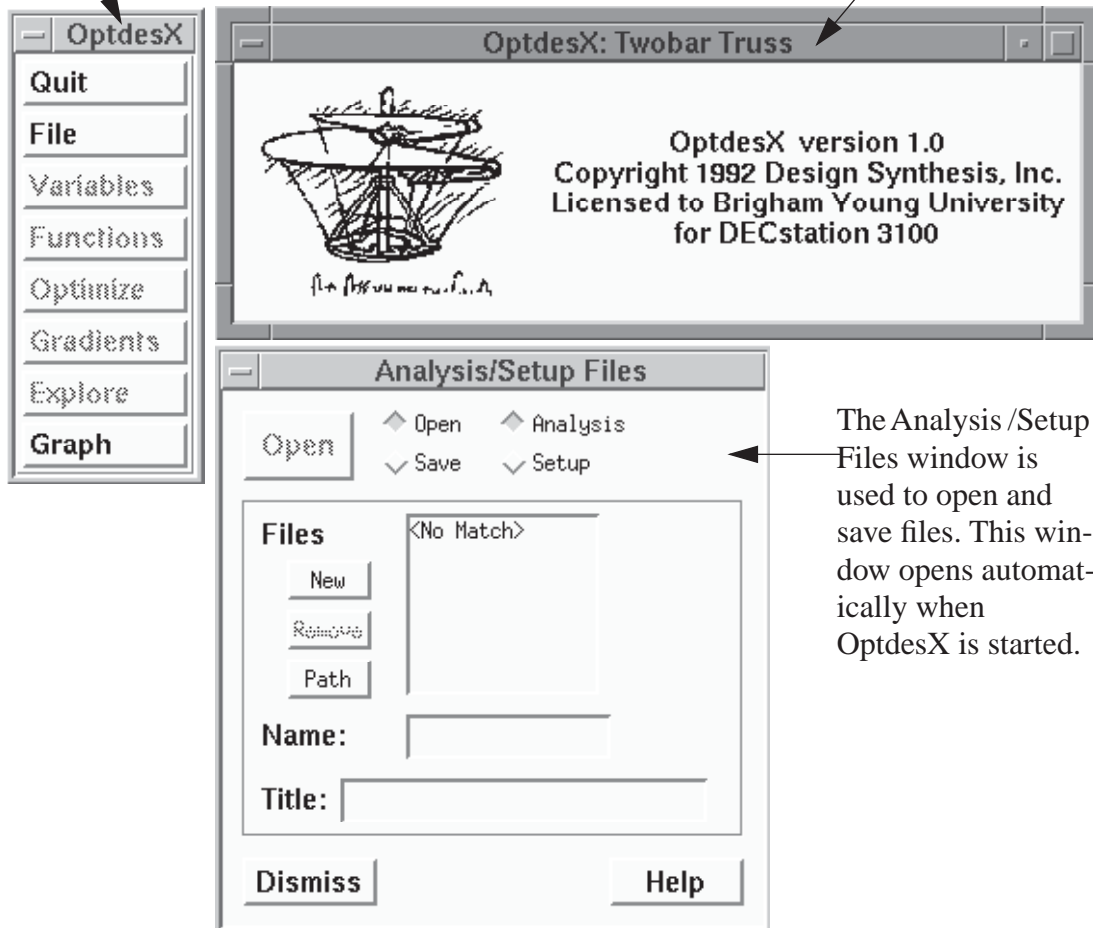
The Analysis /Setup Files window is used to open and save files. This window opens automatically when OptdesX is started.

Reference information for the File window is given on the next page.
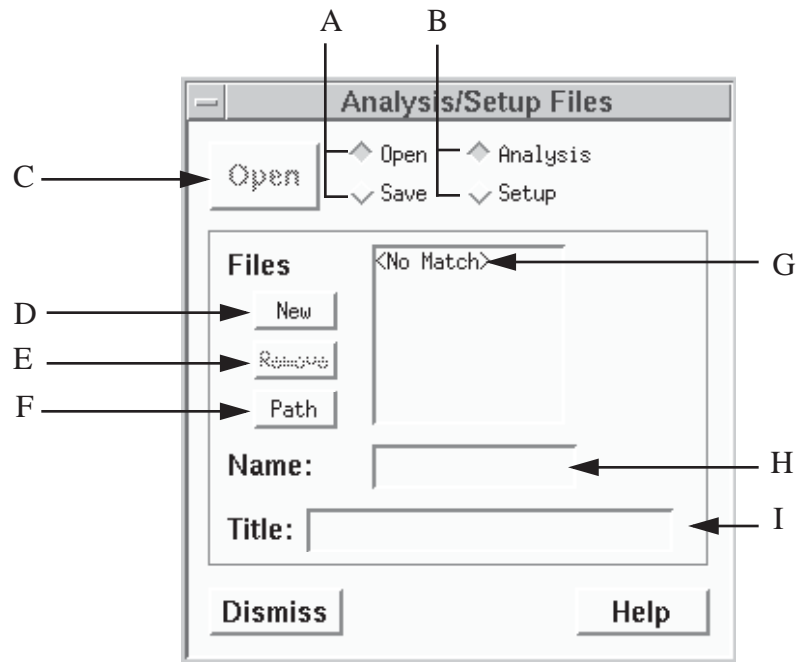
A - Open-Save Radio box.

B - Analysis-Setup Radio box.

C - File pushbutton used to open or save an Analysis or Setup file.

D - New pushbutton used to create a new Analysis file.

E - Remove pushbutton used to remove or delete the selected file. This button is dimmed in the figure because a file has not been selected.

F - Path pushbutton used to change the current directory by opening the Path window.

G - Scrollable list of Analysis or Setup files (depending on the state of the Analysis-Setup radio box) in the current directory. The "No Match" message indicates there are no Analysis files in the current directory.

H - Name text field used for the Analysis or Setup file name. File names are limited to 16 characters.

I - Title text field used for the Analysis or Setup file title. Titles are limited to 60 characters. The special characters <Date> cause the current date and time to be inserted into the title.

File operations in all windows in OptdesX follow the same protocol: one click on the file name selects it. Its name and title are then shown in the Name and Title text fields. After selecting a file, it can be opened by clicking the Open pushbutton, or deleted using the Remove button. Alternatively, two clicks will select and open a file.

Creating an Analysis File

At the start of a new problem, an Analysis file must be created that contains initial values for variables and functions. This Analysis file can be created in two ways: by typing the file manually using your system editor or by using the OptdesX "New File" facility. In this section you will use the New File facility to create an Analysis file.

The New File facility is usually only used the first time OptdesX is executed with a particular

analysis model. Afterwards Analysis files are more easily created by changing the design in OptdesX and pushing the "Save" button.

2. Select the New pushbutton in the Analysis/Setup Files window. Click OK in the Confirmation box.
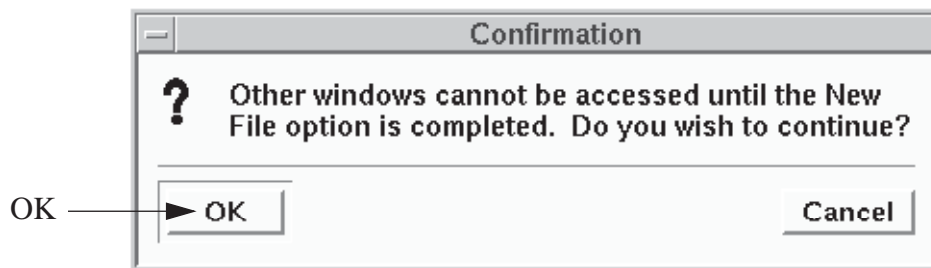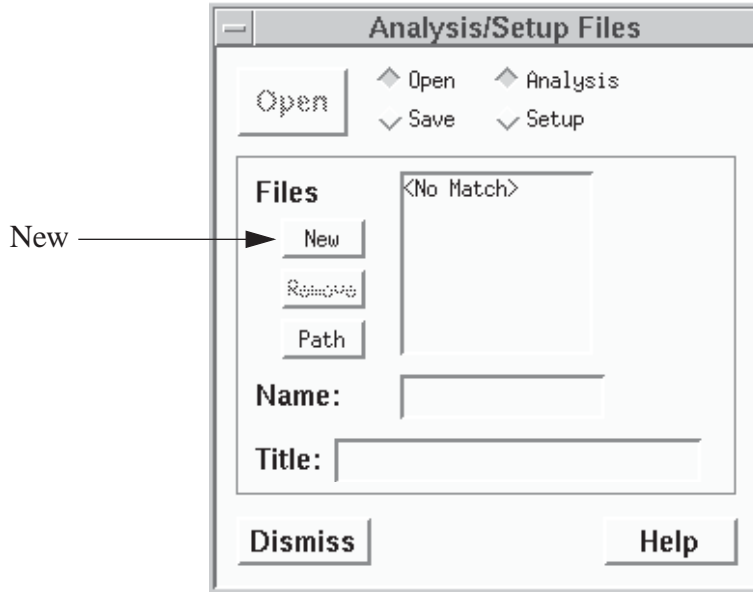
The New File window is modal, meaning that once this option is selected it must be completed before anything else can be done. The Confirmation box allows you to confirm that this is what you wish to do. The New File window will open on your screen.
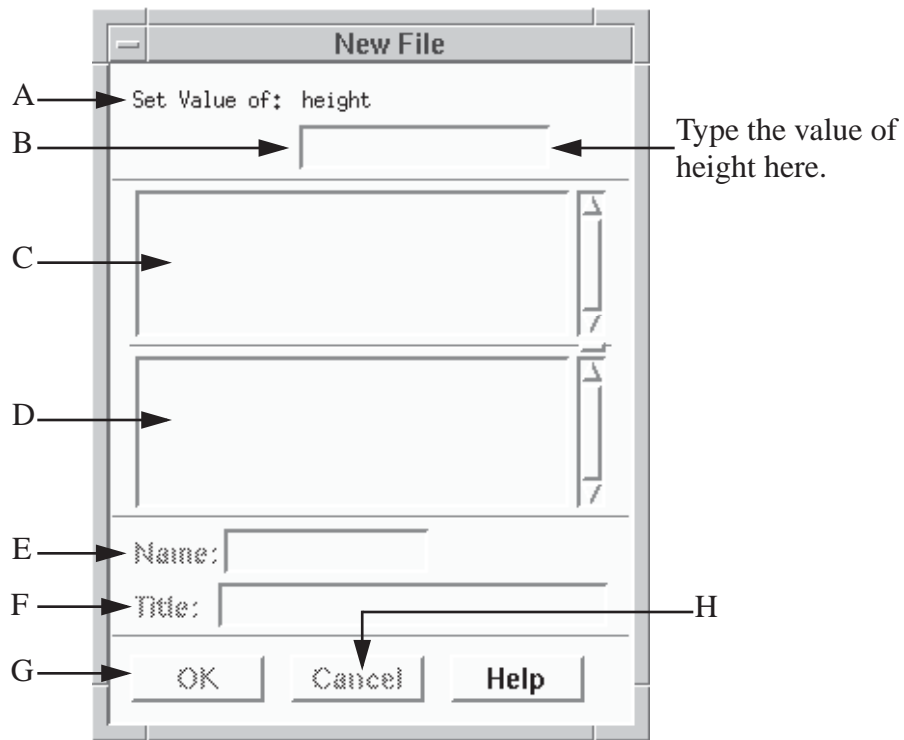
A - Name text field. This field acts as a prompt--you are to type the value for the variable in the value field below it.

B - Analysis variables value field.

C - Scrolled window of analysis variables already entered.

D - Scrolled window of analysis function values. These are computed after all variables are entered.

E - Analysis file name. The file name is limited to 16 characters.

F - Title text field. The title is limited to 60 characters (only 30 are displayed--to see the rest of a long title, place the cursor at the right boundary and drag).

G - OK pushbutton used to save Analysis file after all values have been entered.

H - Cancel pushbutton used to close the New File window without saving the analysis file. This option cannot be selected until all the variable values have been entered.

3. Insert the following values into the analysis variable value fields: height=30.0, width=60.0, diameter=3.0, thickness=0.15, density=0.30, modulus=30000.0, and load=66.0.

The New Window opens with only the value field for the first analysis variable displayed. Insert the value in the field by typing. Register the value by entering a carriage return. The variable will be displayed in the scrolled window below it, and you will be prompted for a new variable value. If you make a mistake but do not notice it until after the carriage return is entered, you cannot correct the error. You must enter values for the rest of the variables and then cancel and start over again.

Once all the variable values have been entered, the functions are calculated and displayed in the middle box of the New File window as shown below.

4. We will use the default name ("Analysis1"). Enter the title, "Twobar starting design."

Analysis file name (Analysis1) and title (Twobar starting design).

OK
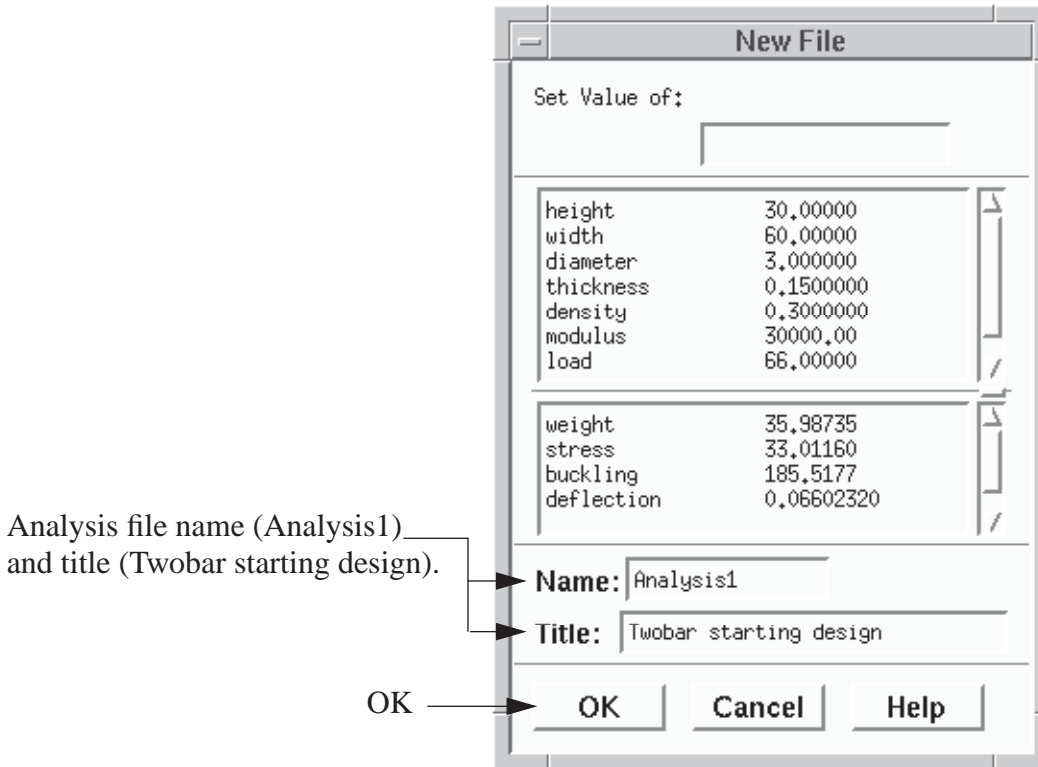
5. Select the OK pushbutton to save the new Analysis file.
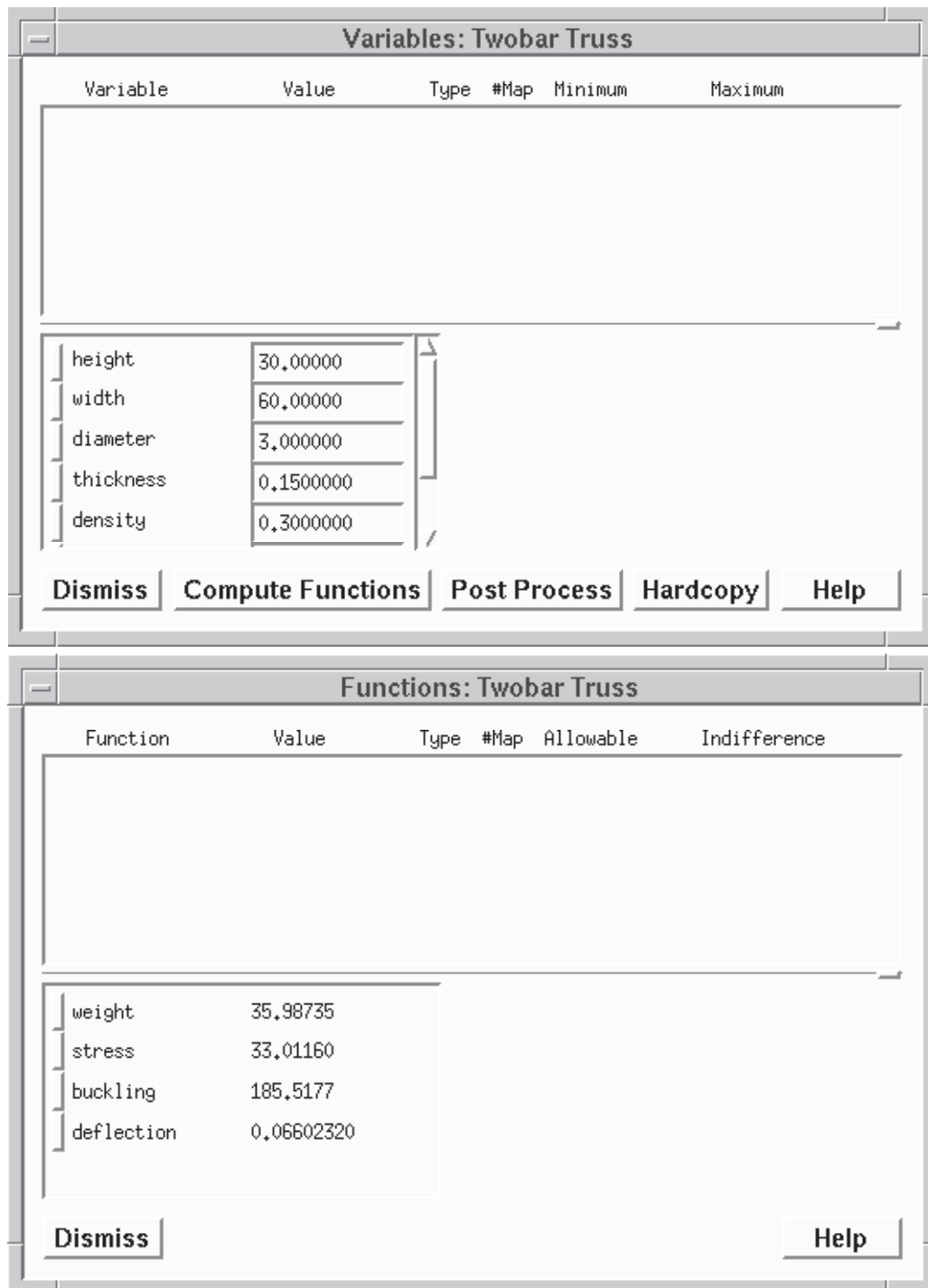
The file "Analysis1.ana" has now been created. The "ana" extension is added by OptdesX and indicates that this is an analysis file. Note that Analysis1 has now been added to the Files List in the Analysis/Setup Files window (the .ana extension is not shown). The Analysis1.ana file could also have been created manually by typing the file using your system editor. A listing of the file is as follows:

```
Twobar starting design
Twobar Truss
d 0 0 height
30.0
d 0 0 width
60.0
d 0 0 diameter
1.00
d 0 0 thickness
0.150
d 0 0 density
0.30
d 0 0 modulus
30000.0
d 0 0 load
66.0
```

This file looks straightforward--it contains names and values--except for the "d 0 0" that precedes every name. This notation indicates to OptdesX that the name which follows is for a double precision scalar. All variables must be preceded by these characters. As mentioned, you could have skipped the "New File" option and just written this file manually using your system editor.

The Variables and Functions Windows are now opened. Note that the variables appear in a scrolled list.

Variable	Value	Type	#Map	Minimum	Maximum
height	30.00000				
width	60.00000				
diameter	3.000000				
thickness	0.1500000				
density	0.3000000				

Dismiss   Compute Functions   Post Process   Hardcopy   Help

Functions: Twobar Truss

| Function	Value	Type	#Map	Allowable	Indifference
weight	35.98735				
stress	33.01160				
buckling	185.5177				
deflection	0.06602320				

Dismiss   Help

Design Trial-and-Error

Design trial-and-error is the process of selecting new analysis variables and computing the corresponding analysis functions. This is easily done in the Variables and Functions windows. You may wish to compute functions for several different designs.

6. Change height and diameter to 10.0. and 1.0 respectively.

Analysis variable values can be changed by placing the cursor in the value field and deleting/ changing the value character by character, or by double clicking to select the entire field and replacing it with a new one. As with all numerical values entered in OptdesX, register each value by typing a carriage return after it is entered. Alternatively, tabbing to a new field will register the number for the current field.
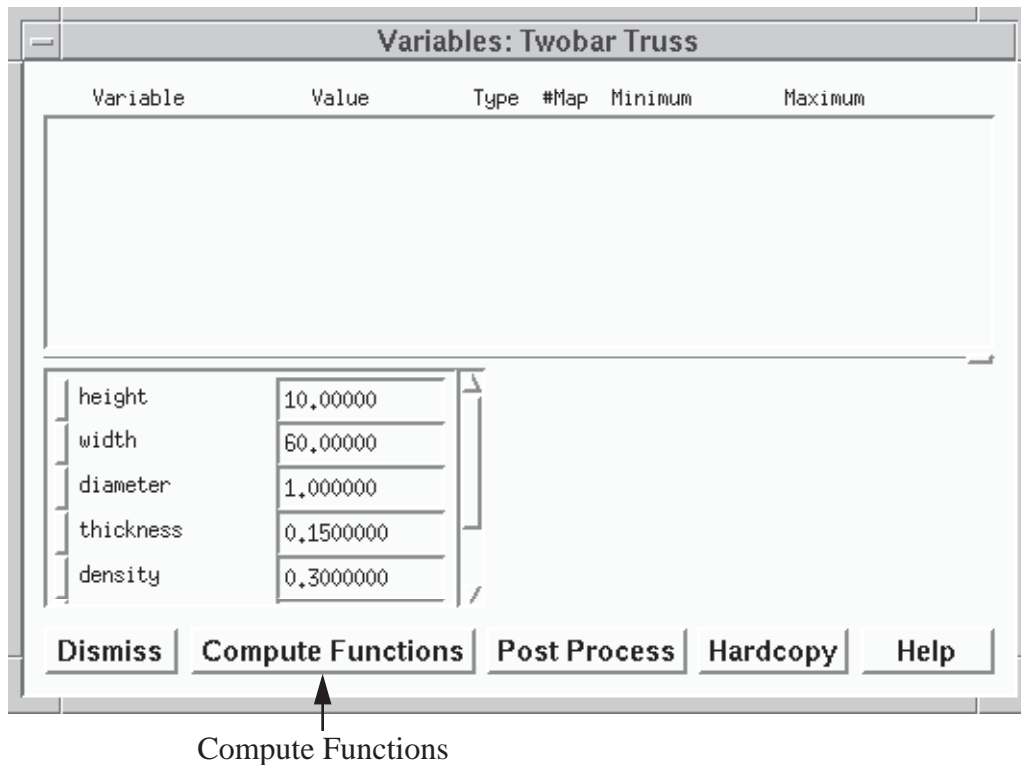

Compute Functions

7. Press the Compute Functions pushbutton.

Compute Functions calls the ANAFUN routine to calculate the analysis functions. The analysis function values change to reflect the new variable values. Try changing the analysis variables values and computing functions on your own.

Restoring an Analysis File

At some point in the optimization process you may wish to use analysis variable values set previously and stored in an analysis file. We will restore the initial design we created when we first started the software.

8. Open the Analysis1 file by double clicking the file name, or clicking once and pressing the Open button.
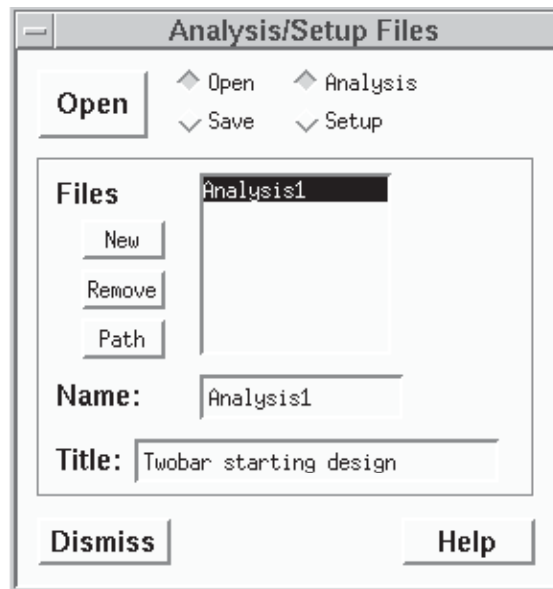
After selecting the file, the File Name and Title are displayed. When the file is opened, a "Restoring Analysis" message is printed, and the variable and function values restored from the file are displayed in the variable and function windows.

Optimization Problem Setup

An optimization problem is defined by specifying design variables, objective(s) and constraints. For this problem we will initially set diameter and height to be design variables; we will make weight the objective function, and we will select three constraints:

       Stress must be less than or equal to 100 ksi
       Stress minus buckling stress must be less or equal to than zero
       Deflection must be less than or equal to 0.25 inches.
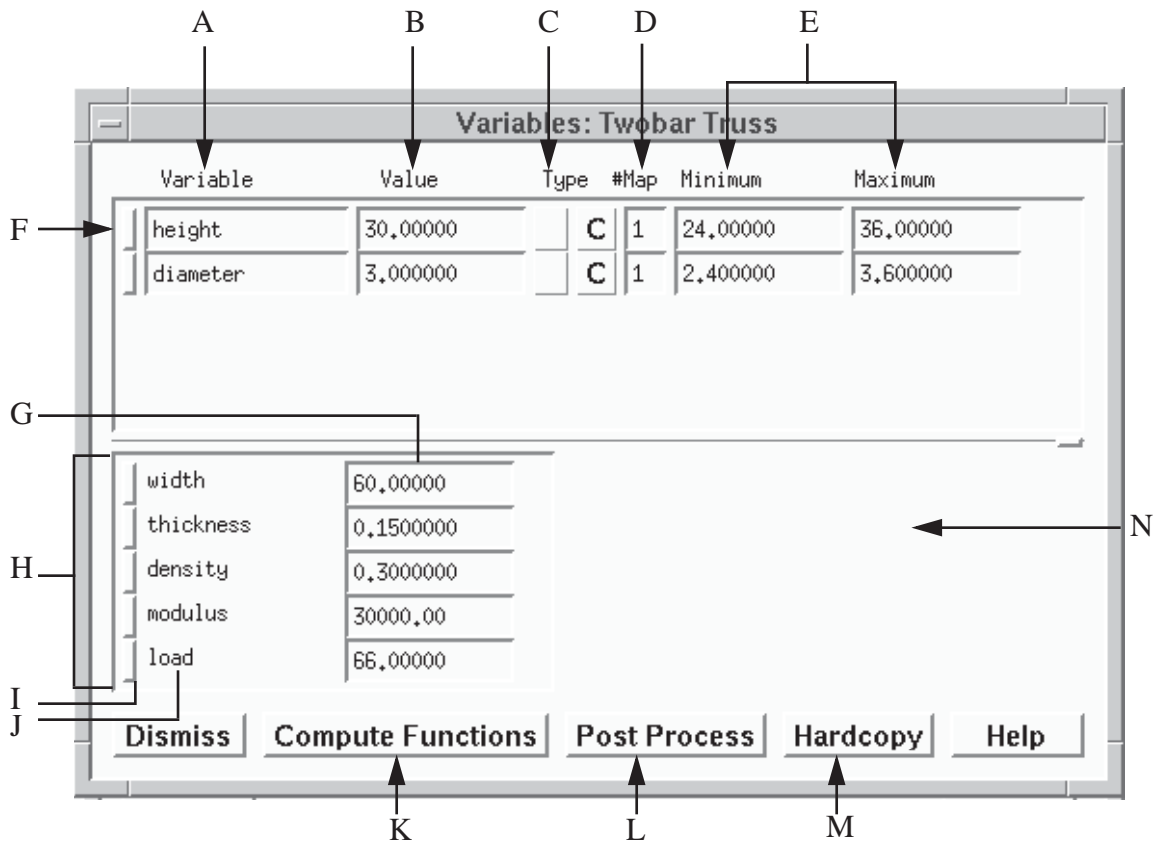
Variable Setup

9. Select height and diameter to be design variables by pressing their Mapping buttons.
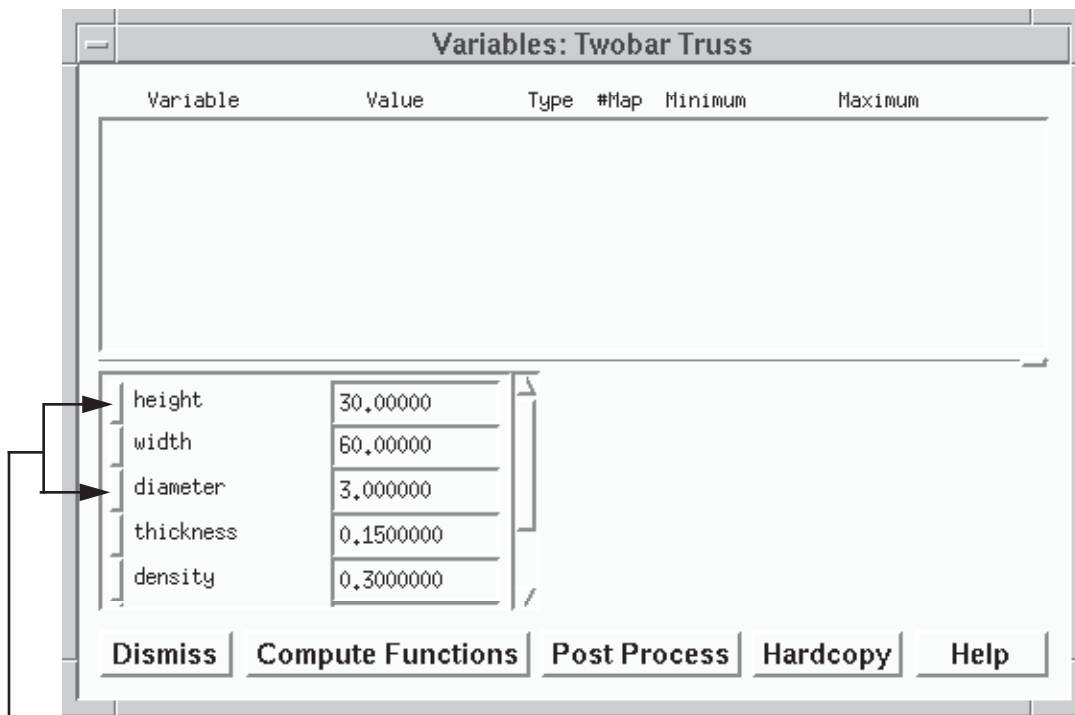
Mapping buttons.

When mapping buttons are pressed, the variables are deleted from the list of unmapped analysis variables (the list shown) and appear in the upper half of the window as design variables.

A reference diagram for the Variables window follows.

A - Design Variable Name text field. This can be edited as indicated by the frame
    around it. Names are normally changed only when the "#Map" field is made
    greater than one.

B - Design Variable value field. This field can be edited.

C - Type pushbuttons which indicate that a variable is at its upper or lower bound (left
    side) or that a variable is continuous or discrete (right side). Bound icons are
    shown below. A "C" indicates a continuous variable and a "D" indicates a discrete
    variable.

 Bound icon indicating the
variable is at its upper bound.

 Bound icon indicating the vari-
able is at its lower bound

D - # Map value field which displays the number of analysis variables mapped to one
    design variable.

E - Minimum and Maximum value fields. Default values are +/- 20% of the current
   value.

F - Unmapping pushbutton. Pushing this button deletes the design variable; it disap-
    pears from the list in the upper half of the window and reappears in the list for
    unmapped analysis variables.

G - Analysis Variable value field. This value remains constant during optimization.
    The value can be edited as indicated by its frame.

H - List of Unmapped Analysis variables.

I - Mapping button used to map an analysis variable to a design variable.

J - Analysis Variable Name text field. This text field can not be edited.

K - Compute Functions pushbutton used to call ANAFUN to calculate the analysis functions.

L - Post Processing pushbutton used to call ANAPOS.

M -Hardcopy pushbutton used to obtain hardcopy of the setup information.

N- Discrete variable information space. Discrete variables are discussed in the next tutorial.

10. Set minimum and maximum values to those shown in the window below.
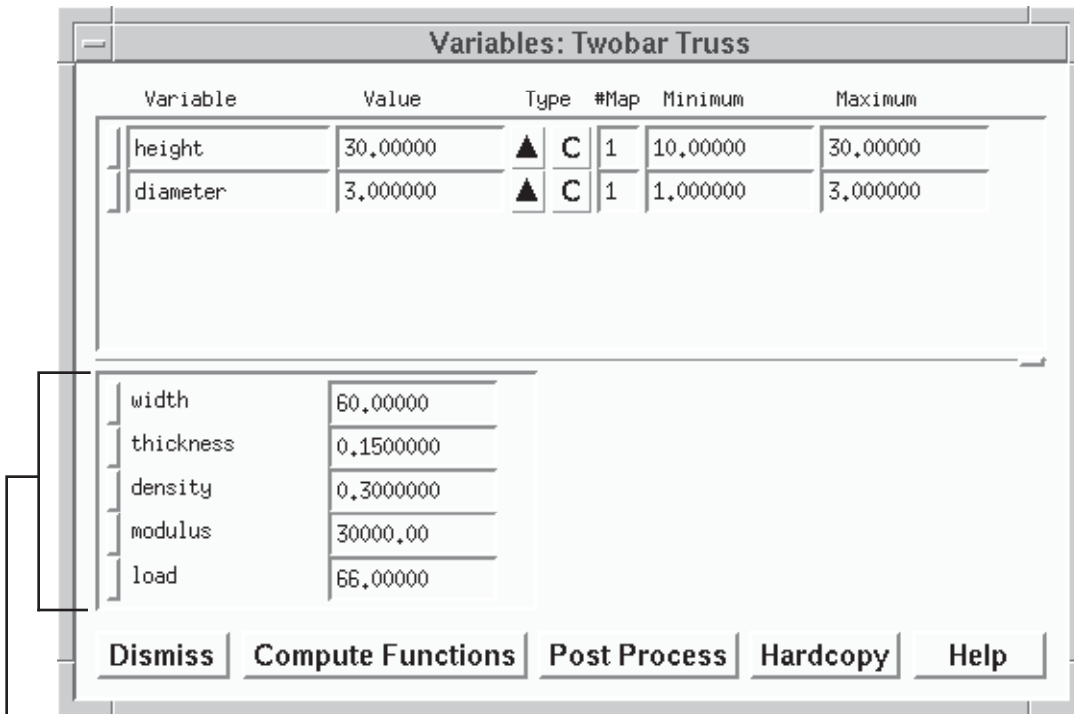
Unmapped analysis variables

The triangle icon, called the "Bounds icon," that appears under "Type" indicates that the variable is at its upper bound. A triangle icon pointing down would indicate that the variable is at its lower bound. Once the analysis variables are mapped to the design variable list both the name and value may be changed--although names would normally be changed only when the "# Map" field is made greater than one. The unmapped analysis variables remain constant during optimization; however, the constant value can be changed.

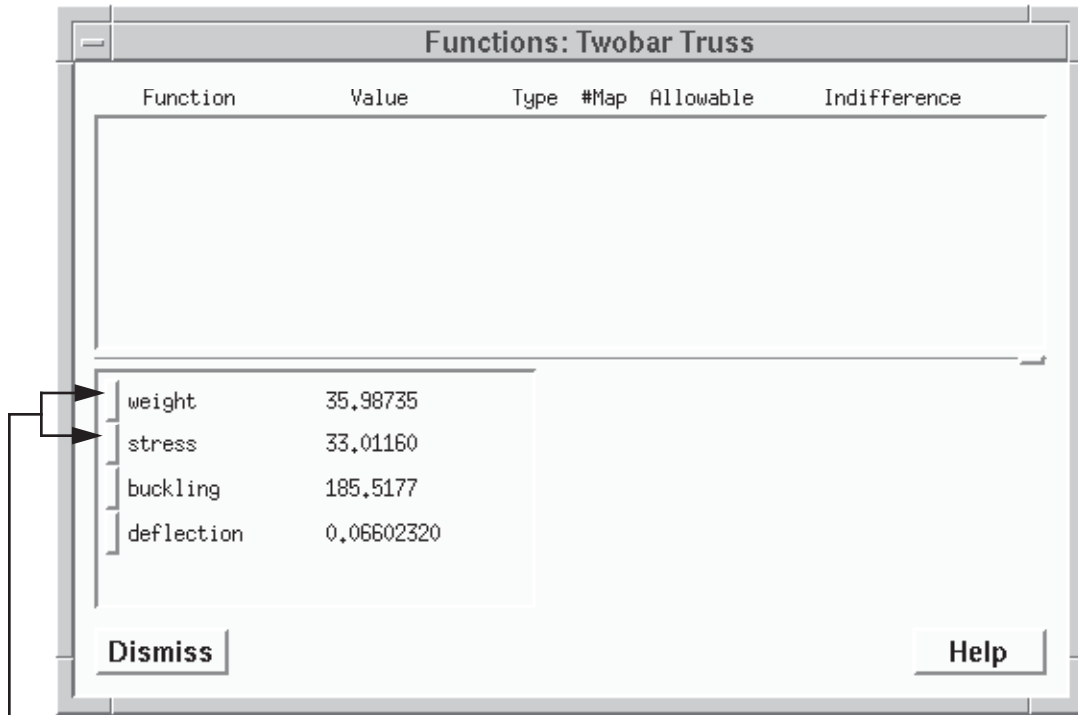## Function Setup

11. Map weight to be a design function by pressing the weight Mapping button.

12. Map and <u>copy</u> stress into the design function list by holding down the shift key while pressing the stress Mapping button.
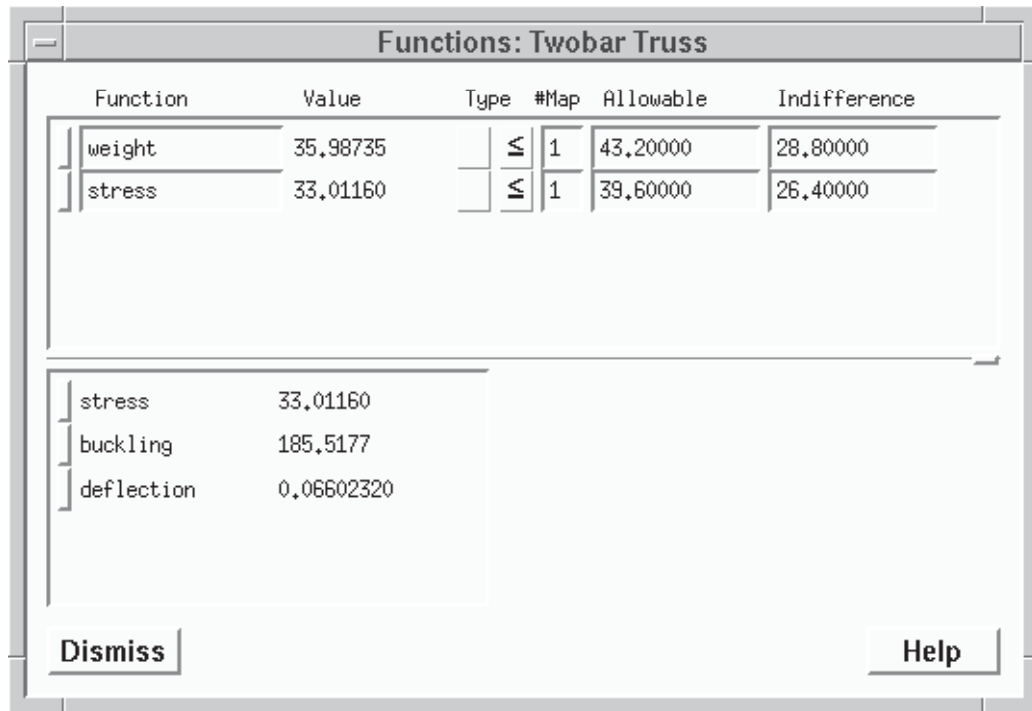
The stress function will be used in two constraints. It is therefore necessary to copy stress into

the design function list. A function is copied into the design function list by pressing the mapping button while holding down the shift key.

Function	Value	Type	#Map	Allowable	Indifference
weight	35.98735				
stress	33.01160				
buckling	185.5177				
deflection	0.06602320				

Weight and stress mapping buttons.

Your window should now look like:

Function	Value	Type	#Map	Allowable	Indifference
weight	35.98735	≤	1	43.20000	28.80000
stress	33.01160	≤	1	39.60000	26.40000

Function	Value				
stress	33.01160				
buckling	185.5177				
deflection	0.06602320				
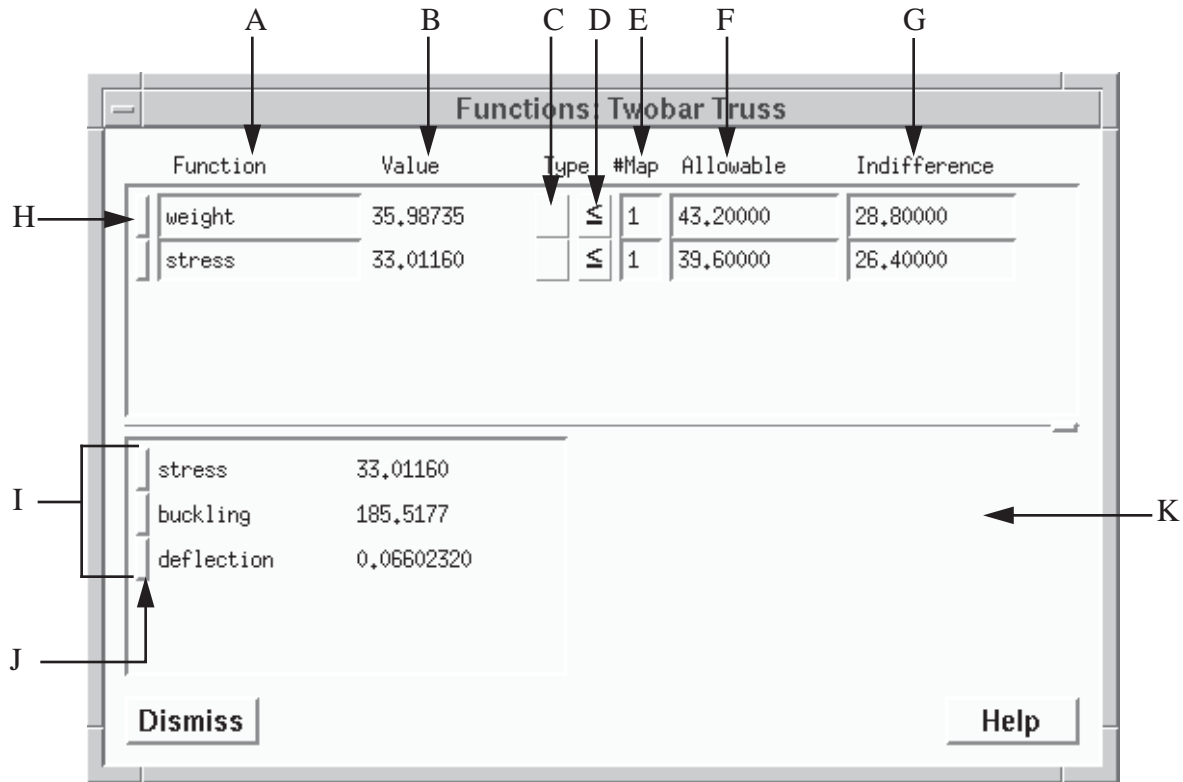
A - Design Function Name Text field. The name can be edited as indicated by its frame, although usually it is not edited unless #Map is greater than one.

B - Design Function value fields. These values are calculated in ANAFUN.

C - Objective button. The objective button is pressed until the appropriate icon is selected: downward arrow to minimize, upward arrow to maximize, and blank if not an objective. If an objective is at its indifference value its icon is boxed; if it is better than its indifference value it is highlighted.

 Objective at Indifference Value

 Objective better than Indifference Value

D - Constraint button. Constraints can be blank (not a constraint), "≤," "≥," or "=." The constraint button is pressed until the appropriate icon is selected. If a constraint is binding the constraint icon is boxed; if a constraint is violated the constraint is highlighted.

 Binding Constraint

 Violated Constraint

E - #Map value field used to map two or more analysis functions to one design function.

F - Allowable value field used as a limiting value for a constraint, or the "worst" value you will accept.

G- Indifference Value field used as a goal value for an objective and beyond which

you are "indifferent" to further improvement, preferring instead that other objectives were improved.

H- Unmapping button used to unmap a design function.

I- List of Unmapped Design Functions.

J - Mapping button used to map analysis functions to design functions.

K- Multiple Objective Space--This space is reserved for objective weighting coefficient scales used with multiple objectives, as shown later in the tutorial.

13. Make weight an objective to be minimized by pressing the Objective button (left button under Type) until it is a downward arrow.

Functions are made objectives using the Objective button. Press the Objective button until the downward arrow is displayed. When you click on the Objective button, you will see blank (not an objective) or downward arrow (minimize), but not upward arrow (maximize). This is because the allowable value is greater than the indifference value. If you wish to maximize, you must first make the indifference value greater than the allowable value.

14. Remove weight as a constraint by pressing the Constraint button (right button under Type) to show "blank."

Functions are made (or removed as) constraints using the Constraint button. Press the Constraint button until "blank" is displayed. When you press the Constraint button, you will see blank (not a constraint), "≤" or "=", but you will not see "≥". This is because the allowable value is greater than the indifference value. If you wish to make a function a "≥" constraint, you must first make the indifference value greater than the allowable value.

15. Change allowable and indifference values to those shown in the window below.

The allowable value is the limiting value for a constraint, or the worst value you will accept. The indifference value is the value below which you are "indifferent" to further improvement, and would prefer instead that other objectives were improved. It is the goal value you wish to achieve.

All functions must have allowable and indifference values. OptdesX uses the difference of these values to define a range for scaling. Even, if, for example, a function is not an objective, you should pick an appropriate indifference value (as if it were an objective) so that OptdesX can scale the function. Scaling is important! If you are uncertain what appropriate indifference or allowable values should be, another rule to use is this: the absolute value of the difference in the allowable and indifference values, when divided into the function value, should give a number between 1 and 10.

As noted, for "minimize" objectives or less than (≤) constraints, the allowable value must be greater than the indifference value. The reverse is true for "maximize" objectives or greater than (≥) constraints. Hopefully the reasoning behind this is apparent: for minimize objectives or less than constraints the goal value (indifference value) is less than the worst acceptable value (allowable value) and vice versa for maximize objectives or greater than constraints.
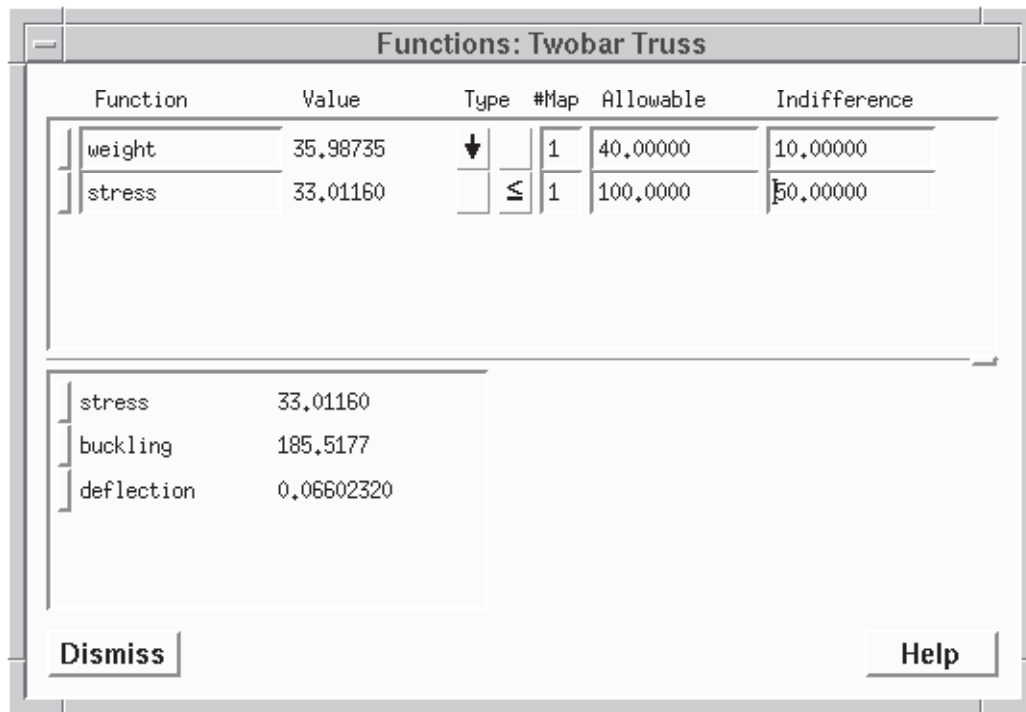
16. Make a second constraint using stress by pressing the Mapping button for stress.

17. Change #Map to "2" for stress in the design function list. Register this value with a carriage return.

This operation will map two analysis functions to one design function. This is necessary because the buckling constraint is the difference of two analysis functions (stress minus buckling stress).
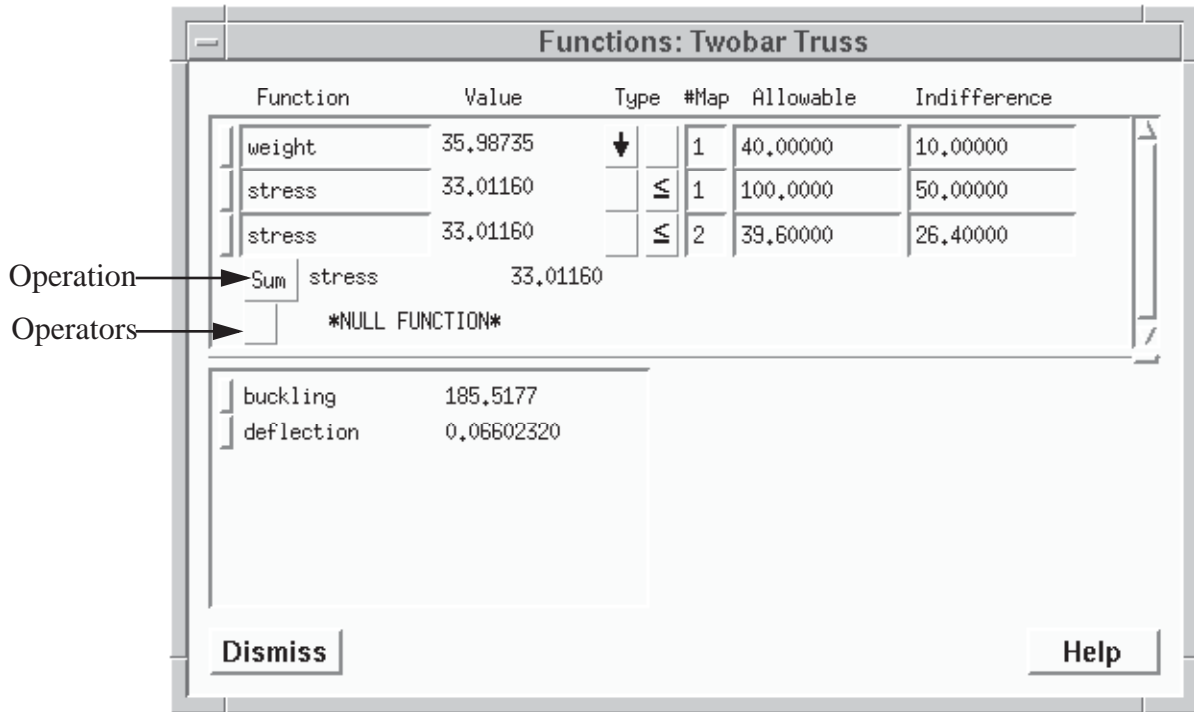
When two or more analysis functions are mapped to one design function, the design function value is calculated as the sum, product, min or max of these functions, depending on the state of the Operation pushbutton. "Sum" specifies that the functions which follow will be added or subtracted; the operators are "–" and "+." "Prod" specifies that the functions which follow will be multiplied or divided; the operators are "*" and "/." "Max" or "min" return the maximum or minimum values of the functions respectively.

When #Map is changed to 2 or more, NULL FUNCTION labels are displayed for each function to be mapped. The next function(s) selected replace NULL FUNCTION.

18. Change the Null Function to buckling by clicking on the buckling Mapping button.

19. Change the sum operator to "~".

20. Change the name of the design function to "stress-buckling" by double clicking in the name field and typing this new name.
There is a general rule being applied here. All of the design and analysis functions must have unique names. The design function defined as the difference of stress and buckling stress cannot be called "stress" because "stress" is already being used.

21. Set the allowable and indifference values to those shown in the window below.

22. Enlarge the design function box with the paning handle.
The Variable and Functions windows are separated by a fine horizontal line that ends on the right side in a "handle." When the cursor is placed on this handle and dragged (the cursor

changes to a "+") the relative sizes of the windows are changed.

23. Make deflection a constraint by pressing the Mapping button for deflection. Set the allowable and indifference values to those shown in the window below.

Paning handle
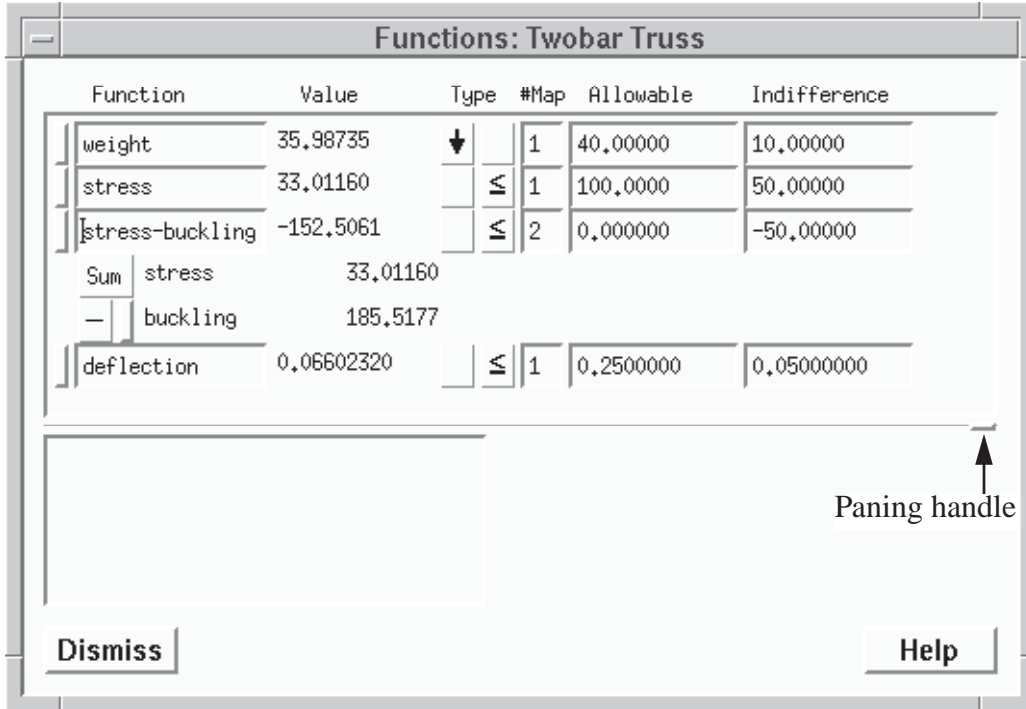
Save Setup

A Setup file is saved to store the definition of the optimization problem. Once saved, a Setup file can be restored again at any time. It is important to understand the difference between a Setup file and an Analysis file. The Setup file contains the definition of the optimization problem; the Analysis file contains variable names and values. For a given analysis model, any Analysis file can be restored with any Setup file and vice versa. If a Setup file is opened prior to opening an Analysis file, the variable and functions values from the most current Analysis file are restored.

24. Set the Analysis/Setup Files window to "Save, Setup."

25. Save and setup radio boxes.

Name (Setup1).

Title (Twobar truss starting setup).
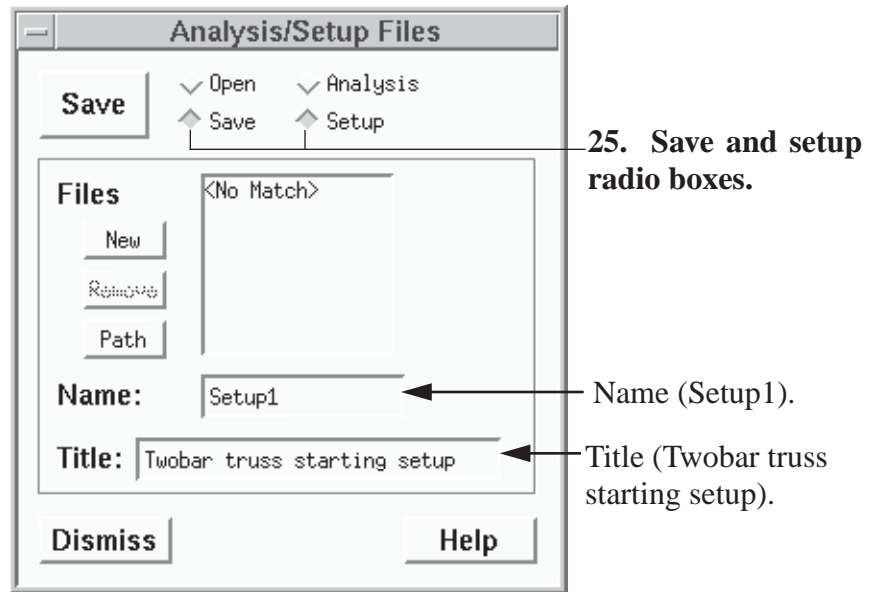
26. We will use the default name ("Setup1"). Type the title, "Twobar truss starting setup."

27. Press the Save pushbutton.
Setup1.opt has now been created and added to the Files list. When the Analysis-Setup radio box is set to "Setup," only the Setup files are shown. In like manner, when the radio box is set to "Analysis," only Analysis files are shown.

Optimize

After the problem is defined, the next step is optimization. OptdesX has five optimization algorithms--two for problems with continuous variables, and three for problems with discrete variables. In this tutorial we consider only continuous variables (in the next tutorial, we make the twobar truss discrete). The continuous algorithms in OptdesX require derivatives, or more precisely, gradients, which are vectors of derivatives. Gradients are calculated numerically by the software. In this section you will learn how to determine the best method for calculating gradients, and then you will optimize the truss using the generalized reduced gradient and sequential quadratic programming methods.

28. Select Gradients from the OptdesX main menu.
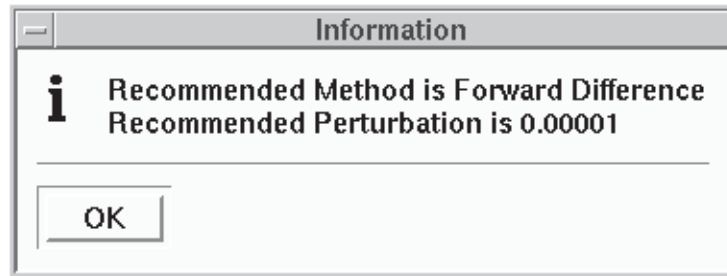A reference diagram for the Gradients Window follows.
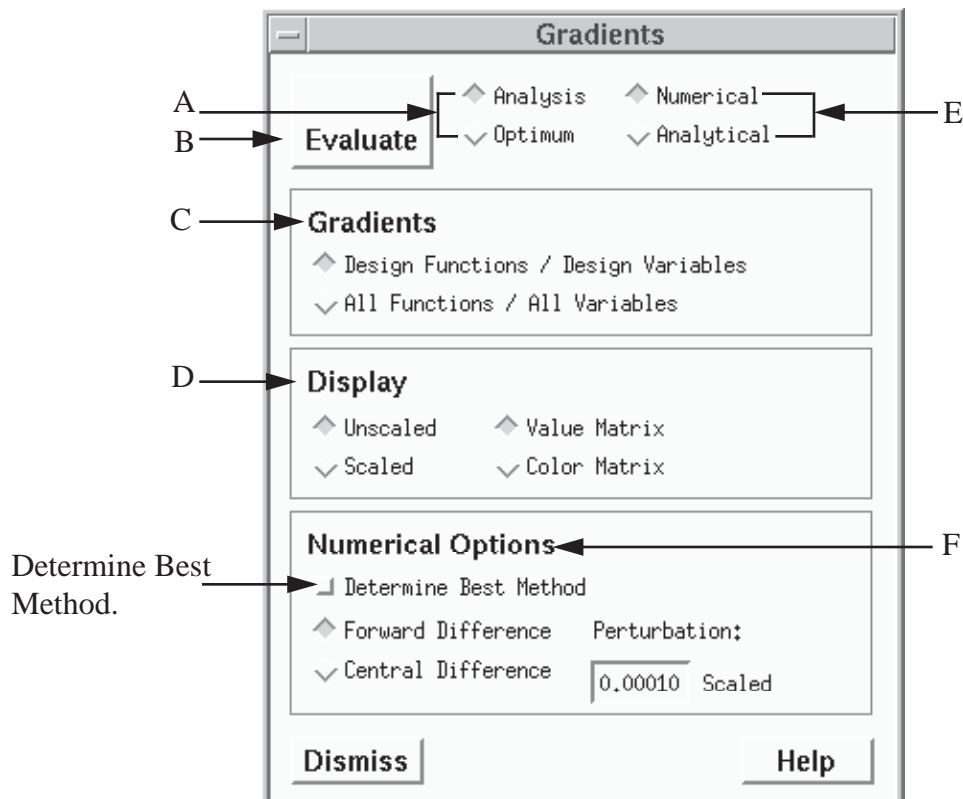
A - Analysis-Optimum radio box used to select gradients of the analysis model or gradients of the optimal objective. To evaluate gradients of the optimal objective an optimization must first be performed.

B - Evaluate pushbutton that causes the gradients to be evaluated. If the gradients are current the pushbutton changes to "Display." Once gradients are taken, they remain current as long as the design point, the numerical method and perturbation are not changed.

C - Gradients box used to select the gradients to be evaluated. Choices in this box are dependent on the state of the Analysis-Optimum radio box. When set to "Analysis" (the usual case) choices are "Gradients of design functions with respect to design variables" (the gradients the algorithms use) or "Gradients of all functions with respect to all variables."

D - Display box used to select the way gradients are displayed--either in scaled or unscaled form, and either as a matrix of values or a matrix of colors.

E - Numerical-Analytical radio box used to select analytical or numerical gradients. The analytical gradients capability is currently not functional.

F - Numerical Options box used to select the type of numerical method and perturbation value. The Determine Best Method toggle button is used to estimate the best numerical method and perturbation for a particular model.

29. Set the Determine Best Method toggle button in the Gradients window.

30. Press the Evaluate pushbutton.

An information box shown below will open with the recommended method and perturbation.

```
 ┌─────────────────────────────────────────────────┐
 │ ─ │              Information                     │
 ├─────────────────────────────────────────────────┤
 │  ●                                               │
 │  ▪   Recommended Method is Forward Difference    │
 │  █   Recommended Perturbation is 0.00001         │
 │                                                  │
 │  ───────────────────────────────────────────────│
 │  ┌───────────┐                                   │
 │  │   OK      │                                   │
 │  └───────────┘                                   │
 └─────────────────────────────────────────────────┘
```

The Determine Best Method feature helps you to determine the best numerical method (central or forward difference) and the best perturbation for your particular analysis model. Analysis models are often "noisy," meaning the function values lack significant figures because of approximation, solution method error (such as would result from the finite element method or numerical integration), or round-off error. When noise is present, it is often amplified in the derivatives, causing premature termination or failure of the optimization algorithms.

Using the design variable at the top of the design variable list, OptdesX will test your model for noise and then report what it believes the best method is. If you suspect noise is present, you should determine the best method for several variables (by modifying the design variable list so different variables are at the top). The worst case should then be chosen.

In this case, we have smooth functions, so a forward difference derivative with a small perturbation is recommended. The perturbation and method are automatically set to these values.

31. Press the OK pushbutton to dismiss the information window.

32. Dismiss the Gradients window by pressing the Dismiss button.

33. Select Optimize from the OptdesX main menu.

34. Select the Options pushbutton in the Optimize window.

Reference diagrams for these two windows are given on the next page.
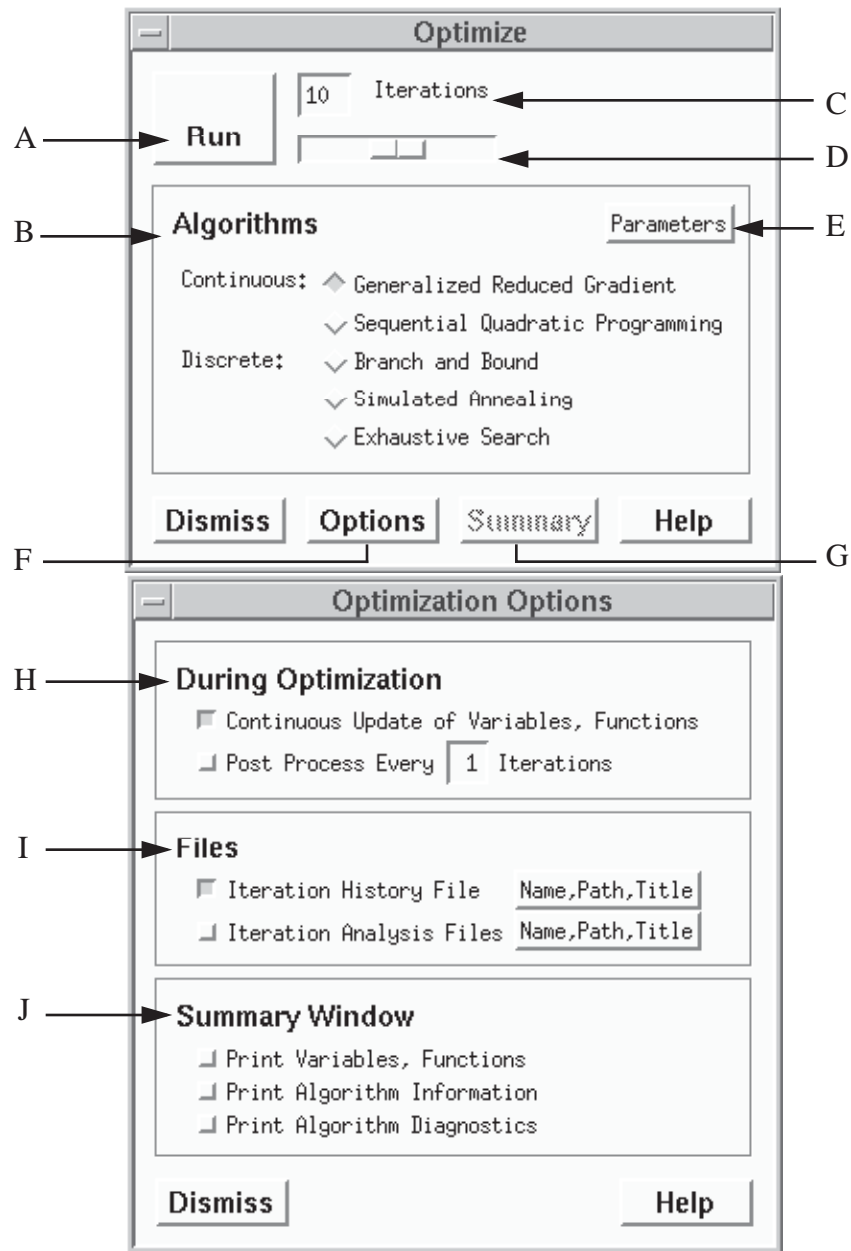
A - Run pushbutton used to begin execution of an optimization algorithm. After execution is started, the button label changes to "Stop," and pushing it will stop execution. In general, execution will continue until an optimum is reached or until the specified number of iterations/combinations/cycles has been completed.

B - Optimization Algorithm radio box.

C - Iteration value field used to set the number of optimization iterations. This number can be changed with the cursor or the scale in D.
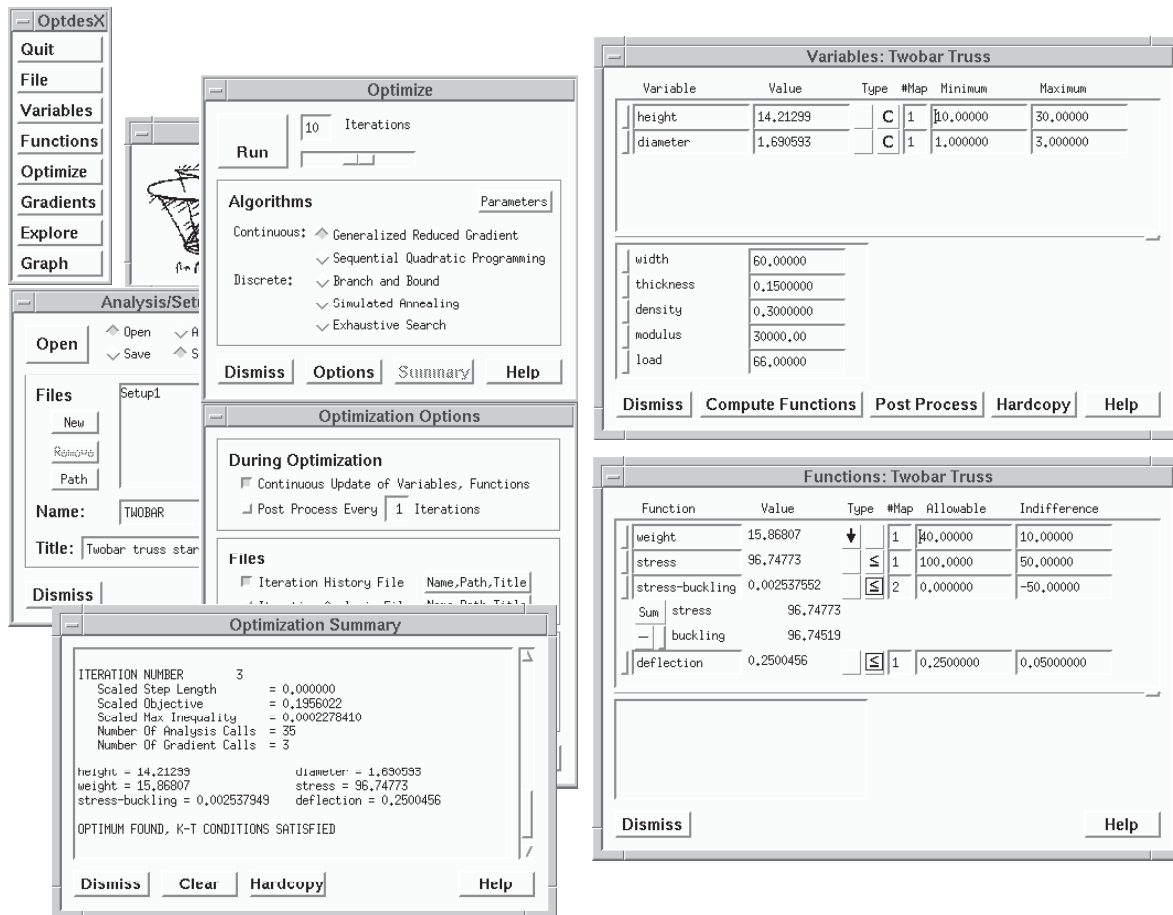
D - Iteration scale.

E - Parameters pushbutton used to display and set algorithm parameters. Each algorithm has associated with it tolerance and/or convergence parameters. In this tutorial we will use the default parameters.

F - Options pushbutton used to display Optimization options.

G - Summary pushbutton which opens (or if open, brings forward) the Summary window, which shows optimization information. The button is dimmed because we have not optimized yet.

H - During Optimization box used to specify whether variables and functions will be continuously updated and/or whether ANAPOS should be called during the optimization.

I - Files box used to specify what files will be created during an optimization. The default is to generate a History file (with the default name "History"), which can then be plotted. Intermediate designs created during the optimization can also be stored.

J - Summary Window box. When an optimization is started, a summary window is opened to inform you of the progress made. Additional information beyond the default can be printed to the summary window by selecting the appropriate toggle buttons.

35. Select the Print Variables, Functions toggle button in the Optimization Options-- Summary Window box.

36. Select the Run pushbutton in the Optimize window.

Your screen should look similar to the screen above. The Optimization Summary window

prints scaled step length, scaled objective, scaled max inequality, and the number of analysis and gradient calls for each iteration of the optimization. Variable and function values are also printed because that option was selected in the Options window. The stopping message, "Optimum Found, K-T Conditions Satisfied," indicates that the mathematical conditions for a local optimum have been satisfied. It is the strongest stopping message OptdesX will report. As the optimization proceeds, the values in the Variables and Functions windows are changed--the final values are the optimal values. The boxed constraint icon indicates that the stress-buckling and deflection constraints are binding. We can see, however, that these two constraints are slightly violated. This is because there is a constraint tolerance that is used to determine if a constraint is binding--as long as the function value is within plus or minus this tolerance of the allowable value, the constraint is considered binding and satisfied. In GRG the default constraint tolerance is 0.001 in scaled space, or about one part in one thousand. Weight has decreased from approximately 36 pounds to 15.8 pounds. Height and diameter decreased from 30 and 3 inches to 14.2 and 1.7 inches respectively. These changes can be plotted using the History file that was written during the optimization.

Saving the Optimum Design

Once an optimum has been found, you may wish to save the optimum design for future reference.

37. Set the Analysis/Setup Files window to "Save, Analysis."

38. Use the default File name ("Analysis2"). Type the title, "Twobar truss GRG optimum."

39. Press the Save pushbutton.

Optimizing with Sequential Quadratic Programming

We will now try a different optimization algorithm, Sequential Quadratic Programming. In order to start this algorithm from the same starting point as GRG (for comparison), we will restore the Analysis1 file with the initial analysis variable values.

40. Set the Analysis/Setup Files window to "Open, Analysis."

41. Open the Analysis1 file by clicking on it twice or clicking once and pressing the Open button.
The initial analysis variable and function values are displayed in the variable and function windows.

42. Select Sequential Quadratic Programming in the Optimize window.

Sequential Quadratic Programming

43. Press the Run pushbutton in the Optimize window.
The variable and function values at the end of the optimization are shown.

The optimum is the same as with the GRG algorithm.

History Files and Plots

A History file is a file used to store data generated during optimization. This data can be plotted to show how things changed during the optimization. In this section you will learn how History files are generated and how to graphically display history information.

44. Select the History File Name, Path,Title pushbutton in the Optimization Options window. (The Optimization Options window is opened by pressing the Options pushbutton in the Optimization window.)
This will show you the options which can be set for History files.
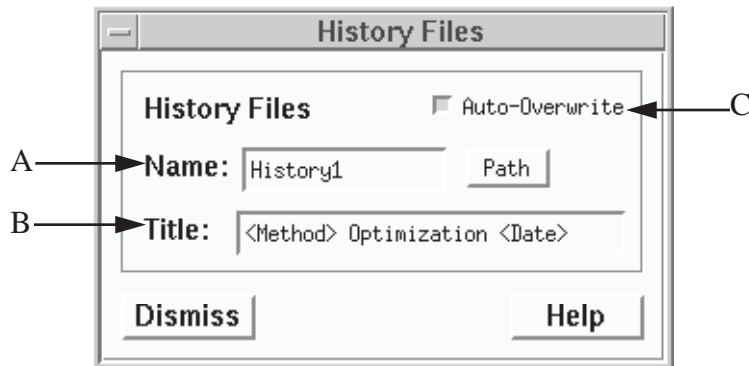
A - Name text field. If Auto-Overwrite is on (the default), a file named "History1" is created during an optimization and overwrites any previous History files of that

name. If Auto-Overwrite is off, a history file is created and saved for each optimization. The file names are numbered sequentially, i.e. History1, History2, etc. The History file name is limited to 16 characters.

B - Title text field. The default title includes the optimization method and the date and time. The title is limited to 60 characters, although only 30 are displayed here.

C - Auto-Overwrite toggle button.

45. Select the Dismiss pushbutton in the History Files window.

46. Select Graph from the OptdesX main menu.
An Analysis or Setup file does not have to be opened to access the Graph window. The Graph window is used to plot previously generated files such as History files.
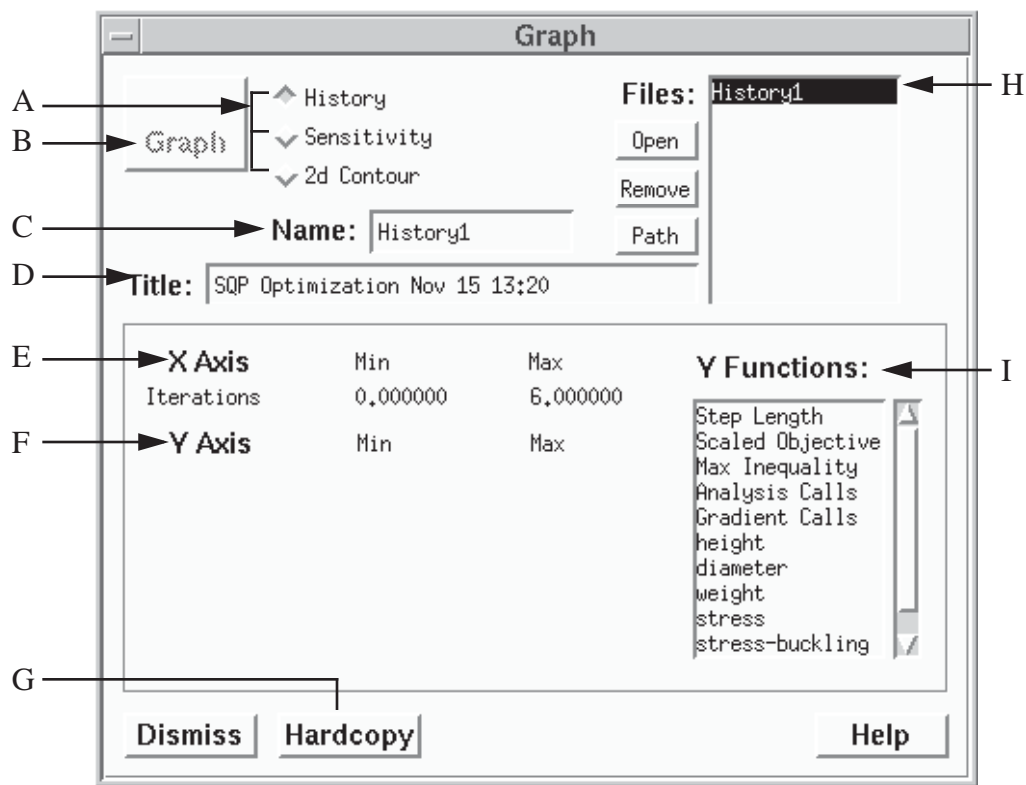
A - File type radio box. Choices are: History (one variable changing), Sensitivity (one variable changing), and 2d Contour (two variables changing). Sensitivity and 2d Contour files are created using the Explore window.

B - Graph pushbutton used to open a graphics window and plot the data from the selected file.

C - Name text field indicating the name of the file selected in the Files list.

D - Title text field displaying the title of the file selected and opened in the Files list.

E - X Axis information. This is read from the file.

F - Y Axis information. For a sensitivity or history plot the Y axes are determined by the functions selected in the Y Functions list. Up to five functions can be plotted.

G - Hardcopy pushbutton used to open the Hardcopy window and obtain a hardcopy of the plot.

      H - Files scrollable list displaying the appropriate data files in the current directory for the   option   selected   (History,   Sensitivity   or   2d   Contour).

      I - Y Functions scrollable list showing functions which can be plotted along the Y Axis.

47. Set the File type radio box to "History."

48. Select and open the History file created during the optimization process.

49. Select height, diameter, weight, stress, and stress-buckling from the Y Functions list.
You can select up to five functions to be plotted at a time.
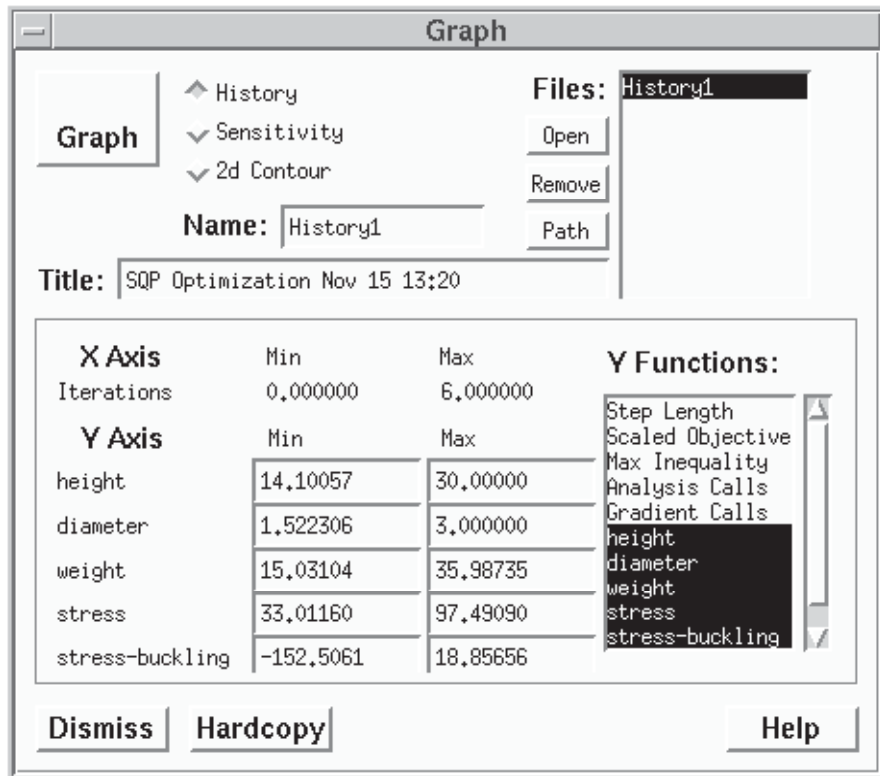
50. Press the Graph pushbutton in the Graph Window.

51. Enlarge the graph by placing the cursor in any corner and dragging.
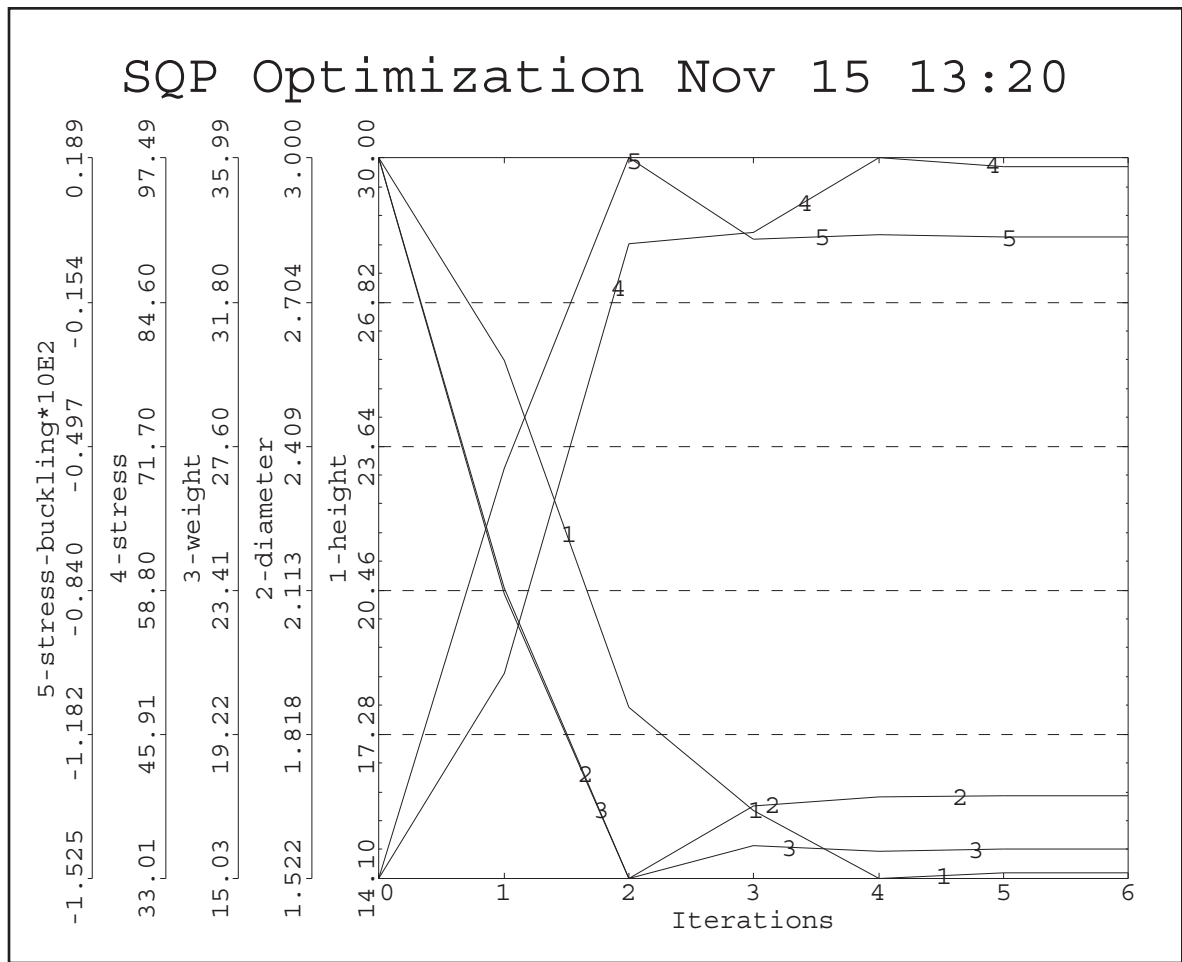
This plot shows how the selected variables and functions changed during the optimization. Both height and diameter started at their upper bounds and decreased. Weight and stress are conflicting functions: as one decreased the other increased.

52. Press the Dismiss pushbutton in the Optdes Plot and Graph windows.

Modifying an Optimization Problem

At this point we will illustrate how you can easily change the optimization problem definition. In this section you will modify the twobar truss problem setup by:

- Adding a design variable
- Using multiple objectives
- Changing objective weighting coefficients.

Adding a Variable

The optimization problem definition will be modified by adding thickness as a design variable; up to this point thickness has been held constant at 0.15 inches.

53. Add thickness to the design variable list by pressing its mapping button.

Variables: Twobar Truss					
Variable	Value	Type	#Map	Minimum	Maximum
height	14.21345	C	1	10.00000	30.00000
diameter	1.690558	C	1	1.000000	3.000000
thickness	0.1500000	C	1	0.05000000	0.5000000

width	60.00000
density	0.3000000
modulus	30000.00
load	66.00000

Dismiss   Compute Functions   Post Process   Hardcopy   Help
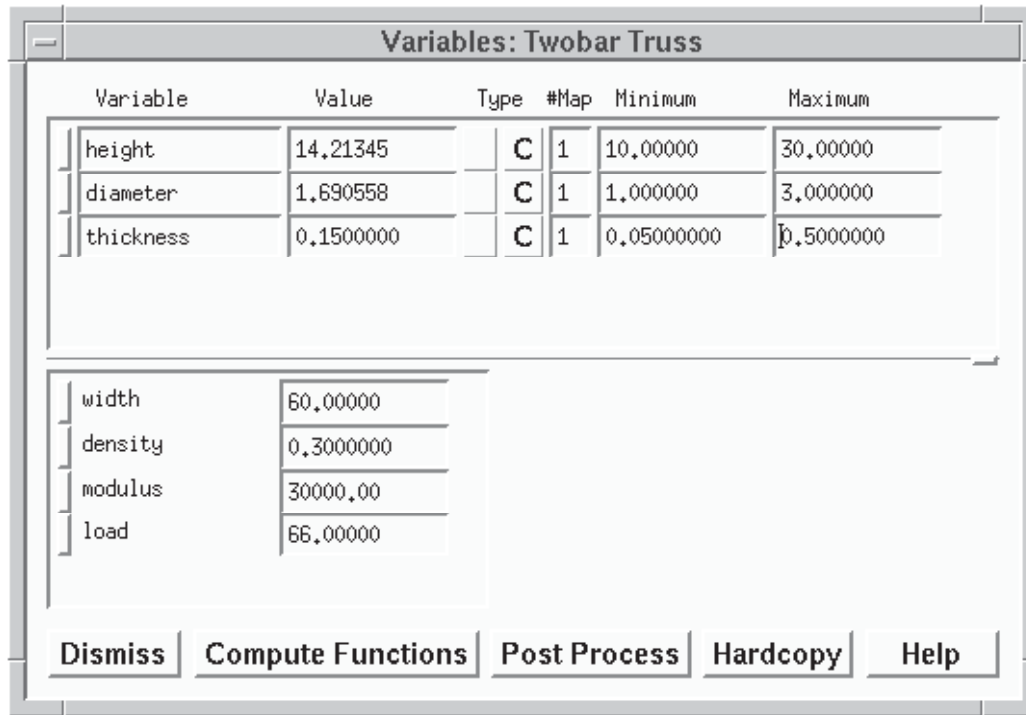
54. Set minimum and maximum values to those shown in the window above.

55. Select the Generalized Reduced Gradient algorithm in the Optimize window.

56. Press the Run pushbutton in the Optimize window.
Values at the optimum are shown in the following windows.

Variables: Twobar Truss

Variable	Value	Type		#Map	Minimum	Maximum
height	30.00000	▲	C	1	10.00000	30.00000
diameter	2.204429		C	1	1.000000	3.000000
thickness	0.06740422		C	1	0.05000000	0.5000000

width	60.00000
density	0.3000000
modulus	30000.00
load	66.00000

Dismiss **Compute Functions** **Post Process** **Hardcopy** **Help**

Functions: Twobar Truss

Function	Value	Type		#Map	Allowable	Indifference
weight	11.88285	↓		1	40.00000	10.00000
stress	99.97601		≤	1	100.0000	50.00000
stress-buckling	-0.03705780		≤	2	0.000000	-50.00000
Sum stress	99.97601					
— buckling	100.0131					
deflection	0.1999520		≤	1	0.2500000	0.05000000

Dismiss **Help**

As expected, adding thickness as a design variable improved the optimum. When thickness was held constant at 0.15 inches, the optimum weight was 15.9 lbs; now it is 11.9 lbs. Stress and stress-buckling are binding constraints; previously stress-buckling and deflection were binding.

Adding Another Objective

The optimization problem will now be modified by adding stress as an objective. Stress has been used as a constraint thus far in the tutorial. Weight and stress are competing objectives: in order for one to decrease, the other must increase and vice versa. OptdesX makes it easy to explore trade-offs such as this using point and click operations.

57. Add Stress as an objective by pressing its Objective button.
Stress is now an objective and a constraint. We will expect stress and weight to trade-off against each other.

Slider bars are displayed for each objective in a multiple objective problem. The slider bar is used to set the objective weighting coefficient and thereby weight or rank the importance of the objectives. The default values of 1.0 mean that each objective is equally weighted or ranked.

58. Press the Run pushbutton in the Optimize window.
Values in the windows will change to those shown below.

Variables: Twobar Truss

Variable	Value	Type	#Map	Minimum	Maximum
height	30.00000	▲ C	1	10.00000	30.00000
diameter	2.218758	C	1	1.000000	3.000000
thickness	0.1043102	C	1	0.05000000	0.5000000

width	60.00000
density	0.3000000
modulus	30000.00
load	66.00000

Dismiss | Compute Functions | Post Process | Hardcopy | Help

Functions: Twobar Truss

Function	Value	Type	#Map	Allowable	Indifference
weight	18.50863	↓	1	40.00000	10.00000
stress	64.18629	↓ ≤	1	100.0000	50.00000
stress-buckling	-37.26021	≤	2	0.000000	-50.00000
Sum stress	64.18629				
— buckling	101.4465				
deflection	0.1283726	≤	1	0.2500000	0.05000000

			weight	1.0	
			stress	1.0	

Dismiss | Help

Note the compromise made between stress and weight. Weight increased from 11.9 to 18.5 lbs; stress started at 99.98 ksi and decreased to 64.18 ksi. At this new optimum there are no binding constraints, although height is at its upper bound.

Changing an Objective Weighting Coefficient

In the previous optimization problem weight and stress were equally weighted or ranked. We

will further experiment with the trade-off of these functions by reducing the weighting coefficient of stress using the slider bar. By decreasing the importance of stress we expect that at the new optimum stress will increase and weight will decrease.

59. Change the weighting coefficient of stress to 0.5.
With a weighting coefficient of 1.0 for weight and 0.5 for stress, the function weight is given twice as much emphasis as stress during the optimization.
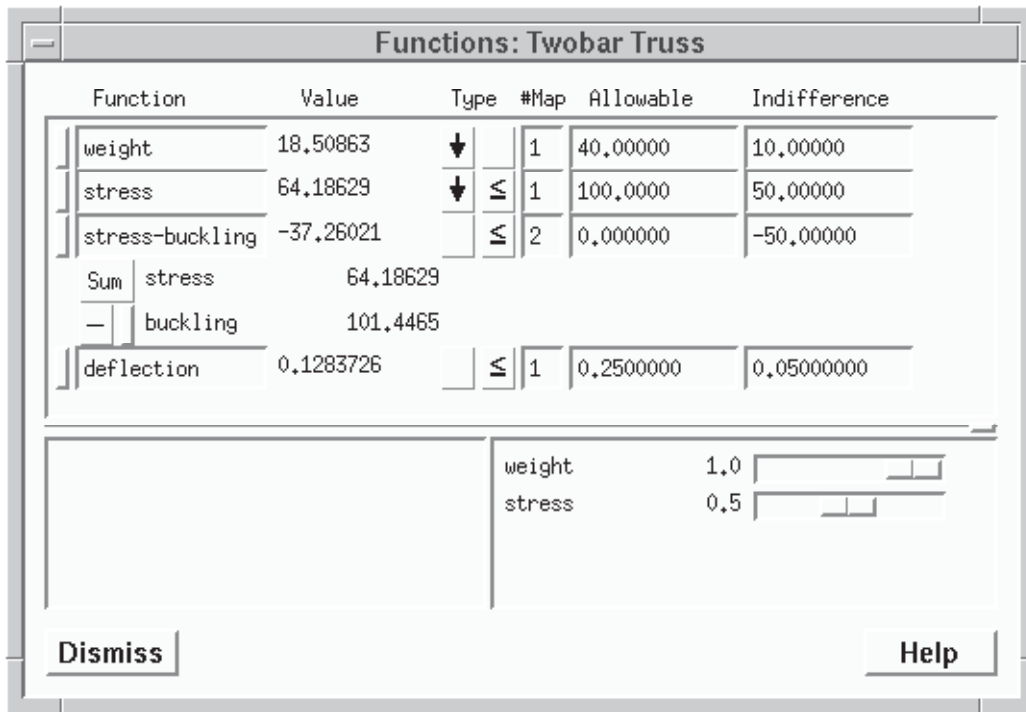
Sometimes a slight change in the weighting coefficients is not enough to cause the algorithms to move when they are at an optimum. If you find this to be the case, start the problem from a point some distance from the optimum.

60. Select the Run pushbutton in the Optimize window.
The optimal values are shown.

Variables: Twobar Truss

Variable	Value	Type	#Map	Minimum	Maximum
height	29.96350	C	1	10.00000	30.00000
diameter	2.208888	C	1	1.000000	3.000000
thickness	0.09365964	C	1	0.05000000	0.5000000

width	60.00000
density	0.3000000
modulus	30000.00
load	66.00000

Dismiss | **Compute Functions** | **Post Process** | **Hardcopy** | **Help**

Functions: Twobar Truss

Function	Value	Type		#Map	Allowable	Indifference
weight	16.53481	↓		1	40.00000	10.00000
stress	71.84847	↓	≤	1	100.0000	50.00000
stress-buckling	-28.77847		≤	2	0.000000	-50.00000
Sum stress	71.84847					
— buckling	100.6269					
deflection	0.1436970		≤	1	0.2500000	0.05000000

weight	1.0
stress	0.5

Dismiss | **Help**

Weight has decreased to 16.53 lbs. from the previous optimum of 18.50 lbs. Also, as was expected, stress increased from 64.18 to 71.84 ksi. Again no constraints are binding.

Restoring a Setup File

At some point in the optimization process you may wish to use a previous optimization setup.

61. Set the Analysis/Setup File window to "Open, Setup."

62. Open the Setup1 file by double clicking the file name, or clicking once and pressing the Open button.
When the file is opened, a "Restoring Setup" message is printed, and the optimization setup is restored from the file and displayed in the variable and function windows. We will now open an Analysis file previously saved. Remember that any Analysis file can be restored with any Setup file.

63. Set the Analysis/Setup File window to "Open, Analysis."

64. Open the Analysis1 file by double clicking the file name, or clicking once and pressing the Open button.
Note that the initial analysis and function values are now displayed in the Variable and Function windows.

Exploring Design Space

Design space can be graphically explored by creating sensitivity plots (plots showing how functions(s) change with respect to one variable) or contour plots (plots showing how function(s) change with respect to two variables). The first step is to create an Explore file by overlaying design space with a grid and evaluating the analysis model at each grid point. This is done in the Explore window. Once an Explore file is created, it can be opened in the Graph Window and plotted. In this section of the tutorial you will learn how to generate:

- One Dimensional Explore Analysis files and Sensitivity Plots
- Two Dimensional Explore Analysis files and Contour Plots
- One Dimensional Explore Optimum files and Sensitivity Plots
- Two Dimensional Explore Optimum files and Contour Plots.

One Dimensional Explore Analysis files and Sensitivity Plots
65. Select Explore from the OptdesX main menu.
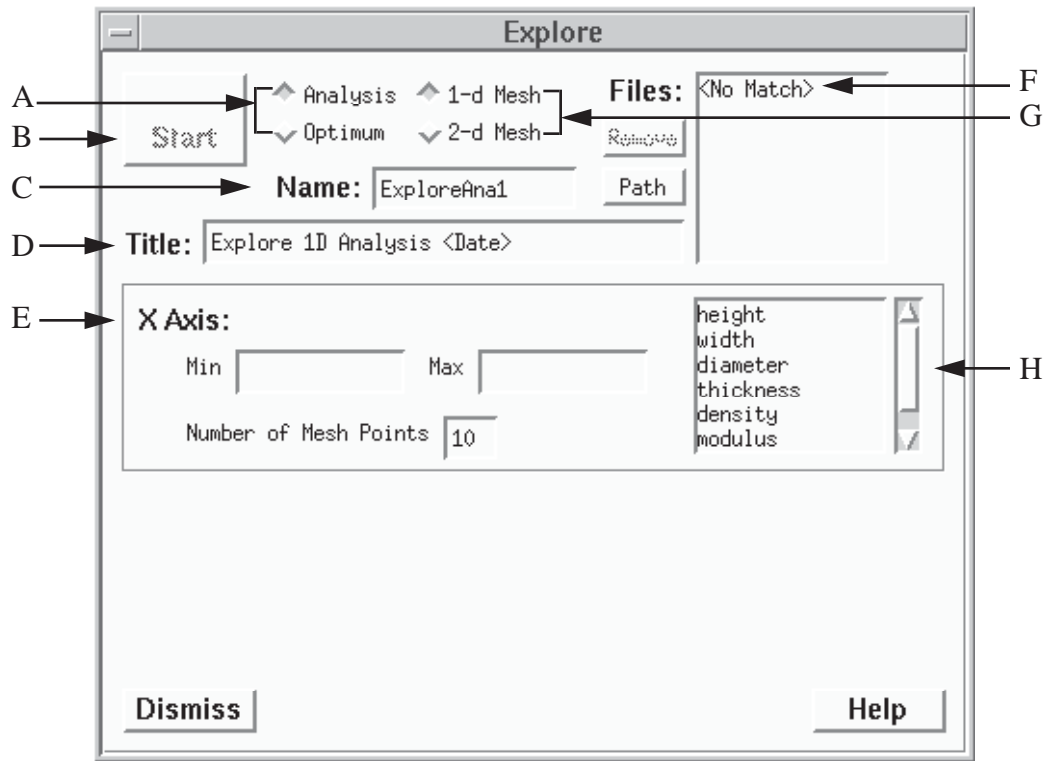
A - Analysis-Optimum radio box used to specify whether the analysis model is to be evaluated or an optimization is to be performed at each grid point.

B - Pushbutton that causes the design space to be meshed, performing an optimization or analysis at each grid point, according to the option selected.

C - Explore File Name text field. The default name is "ExploreAna1." Each successive default file name is incremented, i.e. "ExploreAna2," "ExploreAna3," etc. The file name is limited to 16 characters. An extension ".ex1" or ".ex2" is appended to the file name depending of the state of the 1-d, 2-d Mesh radio box.

D - Explore File Title text field. The title is limited to 60 characters--40 are shown.

E - X Axis Box used to specify the meshed variable for the X Axis. Default Min and Max values are taken from the design variable list, if the variable is a design variable, or they are set to be a percentage of the current value. These, of course, are editable. You should collapse the Min and Max values around a particular point if you wish to "zoom in" on the region surrounding the point. The Number of Mesh points determines the number of analyses (or optimizations) done. Mesh points are spread evenly between the Min and Max values.

F - File scrollable list used to see the other Explore files already in the directory. The message shown here indicates that there are no other Explore files in the directory.

G - 1-d, 2-d Mesh radio box. For a 1-d mesh, only one variable is changed; for a 2-d mesh, two variables are changed. When a 2-d mesh is selected, a Y Axis Box appears in the lower part of the window. The total number of grid points that will be evaluated is the product of the mesh points for the X and Y axes.

H - Mesh Variable scrollable list showing variables that can be selected as mesh variables.

66. Select diameter in the Mesh Variable scrollable list in the X Axis box.
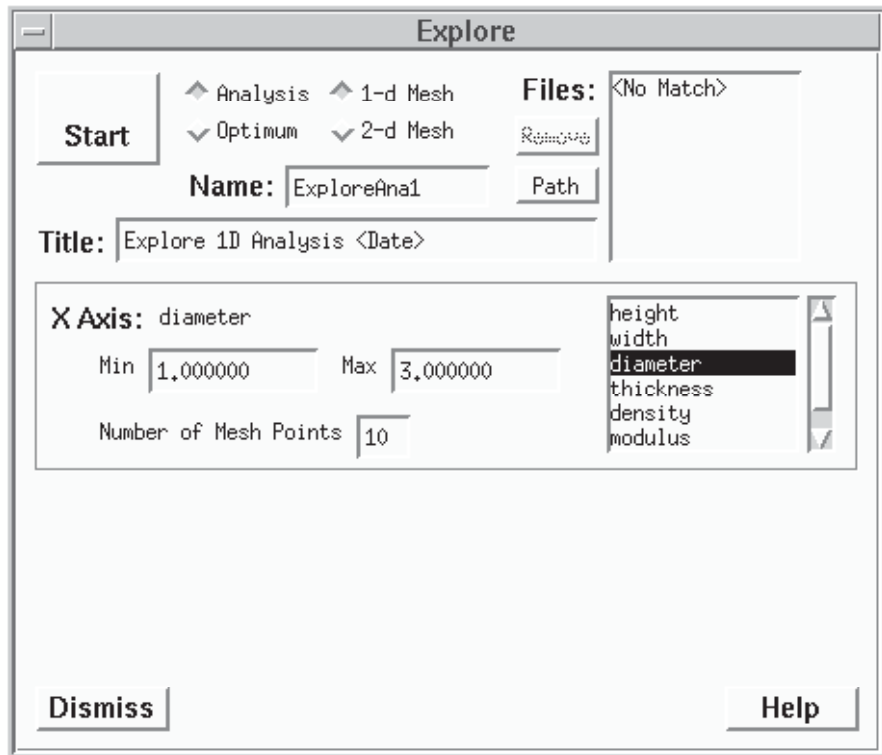
The Minimum and Maximum values in the Variables window are used as the default minimum and maximum values in Explore. You can change these values. We will use the default name ("ExploreAna1") and title ("Explore 1D Analysis <Date>"). The keyword <Date> will be replaced by the date and time the Explore file is made.

67. Press the Start pushbutton in the Explore window.
An information box will be displayed letting you know that the Explore file is being generated.
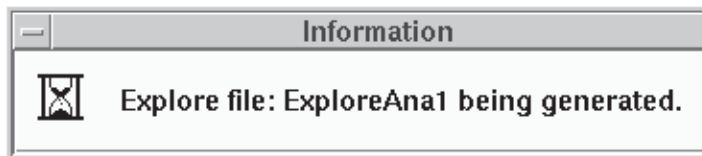
68. Select Graph from the OptdesX main menu.
Refer to the section on History Files and Plots for a detailed description of this window.

69. Set the File type radio box in the Graph window to "Sensitivity."

70. Select the 1-d file just generated (ExploreAna1) in the Files list and open it.
Files can be opened by pressing the open button or by double clicking the file name.

71. Select the following functions to graph from the Y Functions scrollable list: weight, stress, stress-buckling, and deflection.

For a sensitivity plot up to five functions can be plotted at a time.
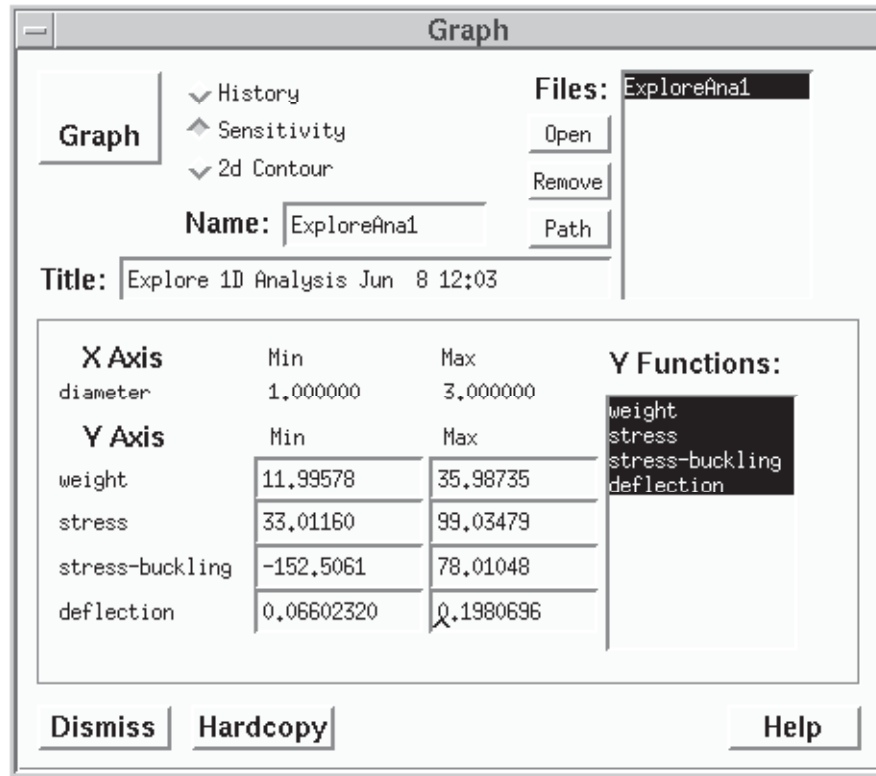
These functions will be plotted on the Y axis. Each function will be plotted separately to show how it changes with respect to the X axis variable (diameter). The minimum and maximum values of Y axes can be edited.

72. Press the Graph pushbutton in the Graph window

Enlarge the graph by placing the cursor in any corner, clicking and dragging.

```
       Explore 1D Analysis Jun   8 12:03
```
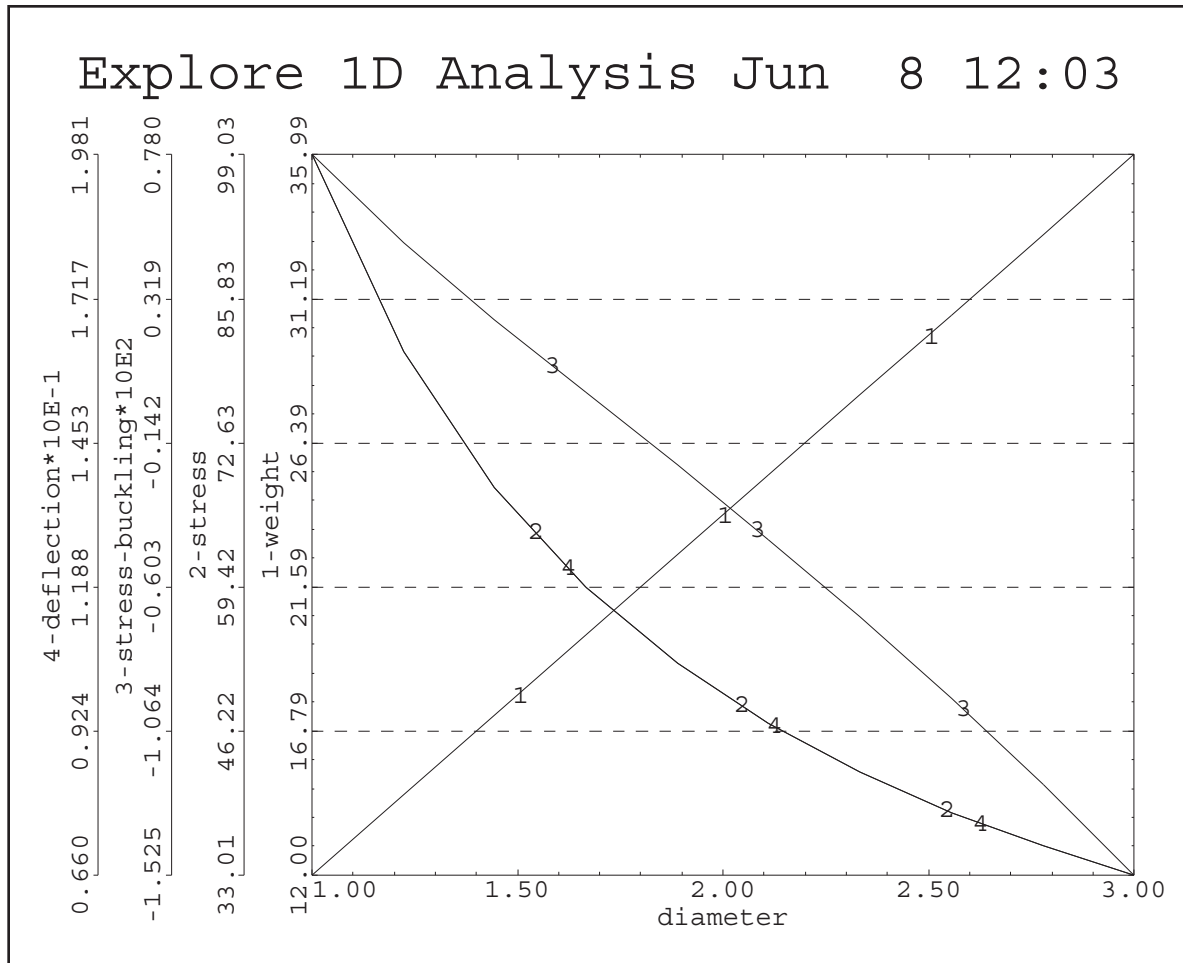
This plot shows how each of the functions varies with diameter. The functions along the Y axis are numbered and correspond to the curves in the plot. As diameter increases, weight increases and stress, stress-buckling, and deflection decrease.

73. Press the Dismiss button for the graph.

Two Dimensional Explore Analysis file and Contour Plot

A sensitivity plot shows how functions change with respect to one variable. A contour plot shows how functions change with respect to two variables. We will now generate the data for and graph a contour plot.

74. Activate the Explore window.
Windows can be activated by clicking anywhere inside the window or selecting the window (Explore in this case) from the Main Window Selection box.

75. Select "2-d Mesh" in the 1-d, 2-d Mesh radio box in the Explore window.
A contour plot is interpolated from a two dimensional mesh in design space. The total number

of analyses done is equal to the product of the number of mesh points for the X and Y axes.

76. Select diameter from the scrollable list in the X Axis box and height from the scrollable list in the Y Axis box.

When 2-d Mesh is selected a box for the Y Axis variable is displayed
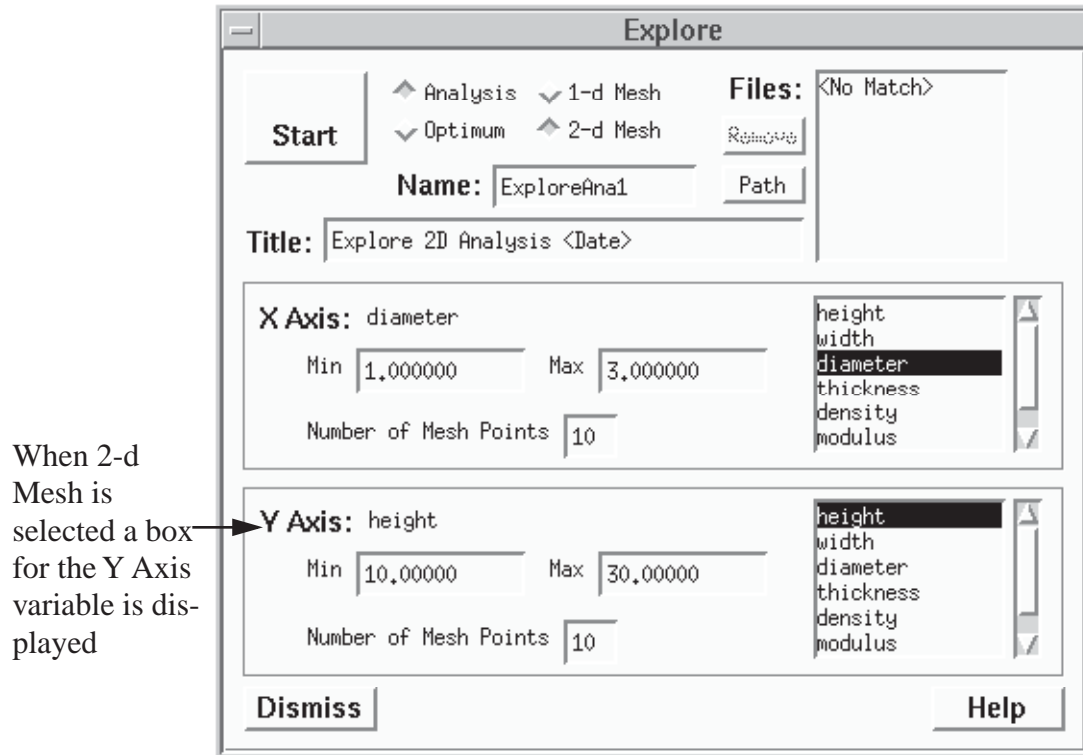
We will use the default name ("ExploreAna1") and title ("Explore 2D Analysis <Date>"). Since this is a 2-d Explore file, it will not overwrite the 1-d Explore we previously created with the same name.

77. Select the Start pushbutton from the Explore window.
An information box will be displayed letting you know that the Explore file is being generated.
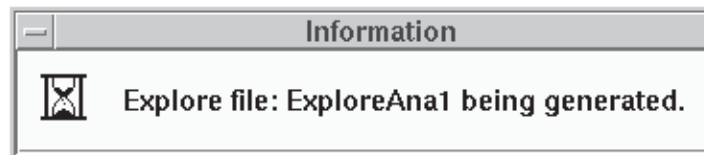
78. Activate the Graph window.

79. Select "2-d Contour" in the radio box in the Graph window.

80. Select the 2-d Explore file just generated (ExploreAna1) and open it.
A reference diagram for Graph when plotting 2d Contour files follows.
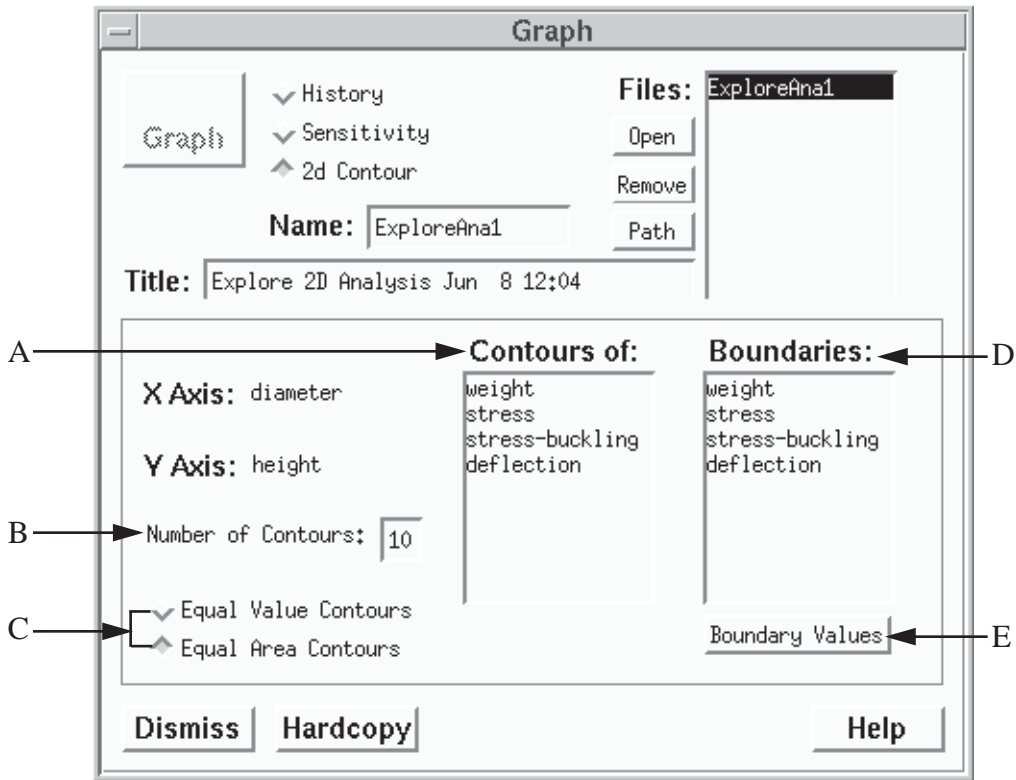
A - Contours scrollable list of design functions. One of these functions can be selected to have its contours drawn on the plot.

B - Number of Contours value field.

C - Contour Type radio box used to select the spacing of the contours. Equal Value Contours sets the spacing to be numerically equal intervals of the function being plotted. Equal Area Contours sets the physical spacing of the contours to be approximately equal across the graph.

D - Boundaries scrollable list. As many functions as desired can be selected. Typically the constraints in the problem are selected.

E - Boundary Value pushbutton used to open the Boundary Values window. This allows you to change the boundary values for each function. Typically the allowable values for the constraints are made the boundary values.

81. Select weight from the Contours scrollable list and the remaining functions from the Boundaries scrollable list.

Usually you will want to graph contours of the objective function and see boundaries of the constraint functions. On any particular plot only one function can be contoured, but as many boundaries as are listed can be selected. Thus the Contours list requires a single selection, but the Boundaries list allows multiple selections.
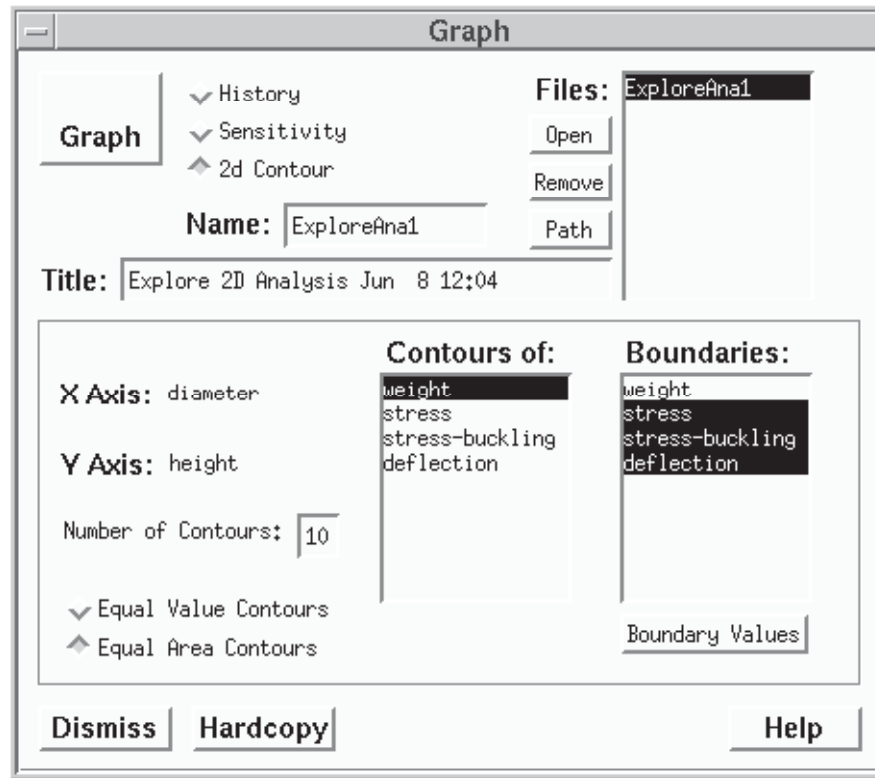
82. Press the Graph pushbutton from the Graph window.
You should enlarge this graph on your screen by placing the cursor in any corner and dragging.
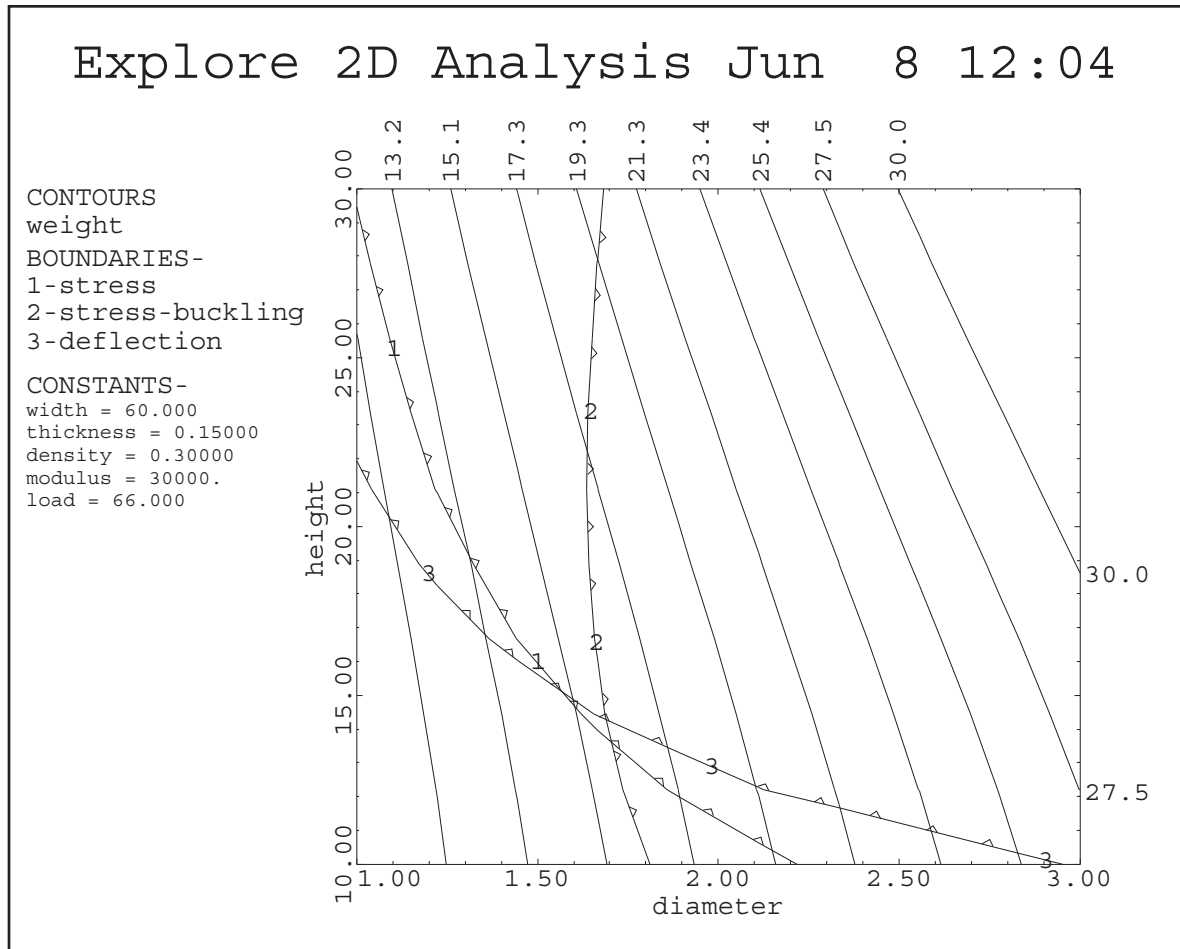
The solid lines show contours of weight. The lines with arrows are boundaries of constraints. The arrows point to the feasible side of design space. In this case the optimum weight occurs at the intersection of constraint 2 and constraint 3, where weight has a value of 15.8 pounds.

83. Press the Dismiss button for the graph.

One Dimensional Explore Optimum and Sensitivity Plot

The previous two explore plots showed how the analysis functions change as we change one or two variables. At each grid point of the explore mesh, we called the analysis routine.

Now we will go one step further--we will examine how the *optimal weight* changes as we change values that are held constant during an optimization, such as unmapped analysis variables and constraint allowable values. At each grid point of the explore mesh, we will perform an optimization.

84. Activate the Explore window.

85. Set the radio boxes in the Explore window to "1-d, Optimum."

86. Select load from the scrollable list in the X Axis box as the variable to be explored.
We will examine how changing load changes the optimal value of weight.
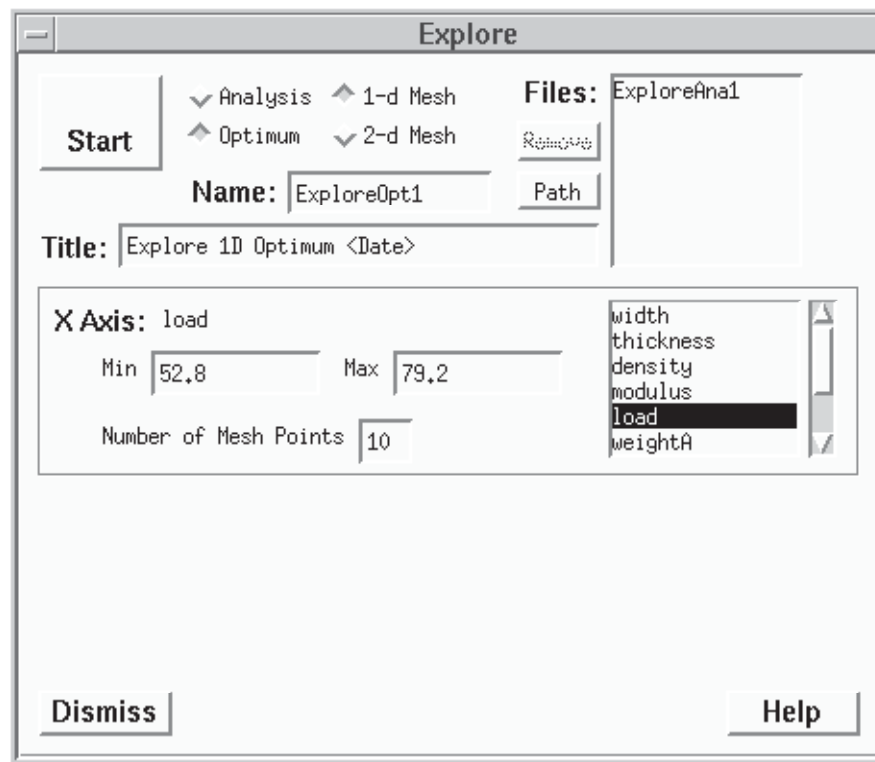
We will use the default file name ("ExploreOpt1") and title ("Explore 1d Optimum <Date>").

87. In the Optimize window, set the number of iterations to be 100.
We need to make sure the algorithm does not terminate because it hits the iteration limit. A rule of thumb is that the number of iterations should be at least 25 times the number of design variables.

88. In the Optimization Options window, During Optimization box, turn off the continuous update of variables and functions. (The Optimization Options window is opened by pressing the Options pushbutton in the Optimization window.)
This will make the Explore Optimum run significantly faster.

89. Press the Start pushbutton from the Explore window.
An optimization will be done at each of the ten mesh points. The Optimization Summary window will open and display brief information concerning each optimization. Doing an Explore Optimum has its risks! First of all, it obviously will take much more computer time because an optimization is done at each mesh point. Secondly, the software does not discriminate between optimizations that end successfully and those that do not. For example, if a feasible point cannot be found, the design point at the end of the optimization (which is infeasible) is entered in the Explore file. You should select ranges carefully, making sure they are not too extreme, before doing an Explore Optimum. Also, check the Summary window carefully to make sure each mesh point is valid.

```
┌─────────────────────────────────────────────────────────────┐
│  ─                    Optimization Summary                   │
├─────────────────────────────────────────────────────────────┤
│  I                                                           ┌┐│
│  1-d explore optimum: beginning grid point 7                │││
│  OPTIMUM FOUND, K-T CONDITIONS SATISFIED                    └┘│
│                                                               │
│  1-d explore optimum: beginning grid point 8                 │
│  OPTIMUM ASSUMED--MINIMUM STEPSIZE REACHED                   █│
│                                                              █│
│  1-d explore optimum: beginning grid point 9                █│
│  OPTIMUM FOUND, K-T CONDITIONS SATISFIED                    █│
│                                                              █│
│  1-d explore optimum: beginning grid point 10                │
│  OPTIMUM FOUND, K-T CONDITIONS SATISFIED                     │
│                                                               │
│  ** Completed 1-d explore optimum: 10 grid points **        ┌┐│
│                                                             └┘│
├─────────────────────────────────────────────────────────────┤
│   Dismiss      Clear    Hardcopy              Help           │
└─────────────────────────────────────────────────────────────┘
```

After an Explore Optimum you should check to make sure each optimization terminated successfully

90. Activate the Graph Window.

```
┌─────────────────────────────────────────────────────────────┐
│  ─                          Graph                            │
├─────────────────────────────────────────────────────────────┤
│                                     Files: ExploreAna1       │
│                    ˅ History              ExploreOpt1        │
│     Graph          ˄ Sensitivity      Open                   │
│                    ˅ 2d Contour       Remove                 │
│              Name:  ExploreOpt1       Path                   │
│   Title:  Explore 1D Optimum Jun  8 12:06                    │
│  ┌───────────────────────────────────────────────┐          │
│  │   X Axis        Min        Max      Y Functions:│         │
│  │   load        52.80000   79.20000               │         │
│  │                                     ┌──────────┐│         │
│  │   Y Axis        Min        Max      │weight    ││         │
│  │                                     │stress    ││         │
│  │   weight     14.71109    17.03395   │stress-buckling│     │
│  │                                     │deflection││         │
│  │   stress     87.20535    100.0482   └──────────┘│         │
│  │                                                 │         │
│  │   deflection 0.2354262   0.2501947              │         │
│  └───────────────────────────────────────────────┘          │
│   Dismiss   Hardcopy                          Help           │
└─────────────────────────────────────────────────────────────┘
```
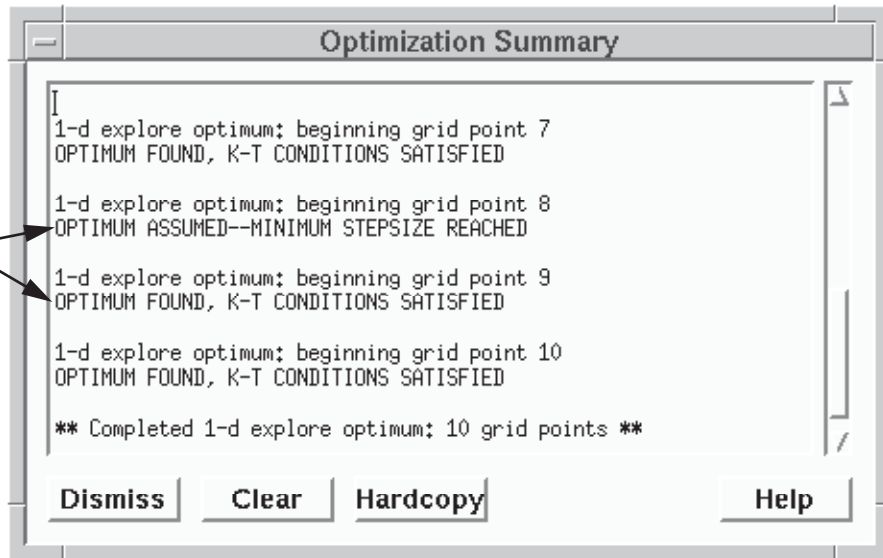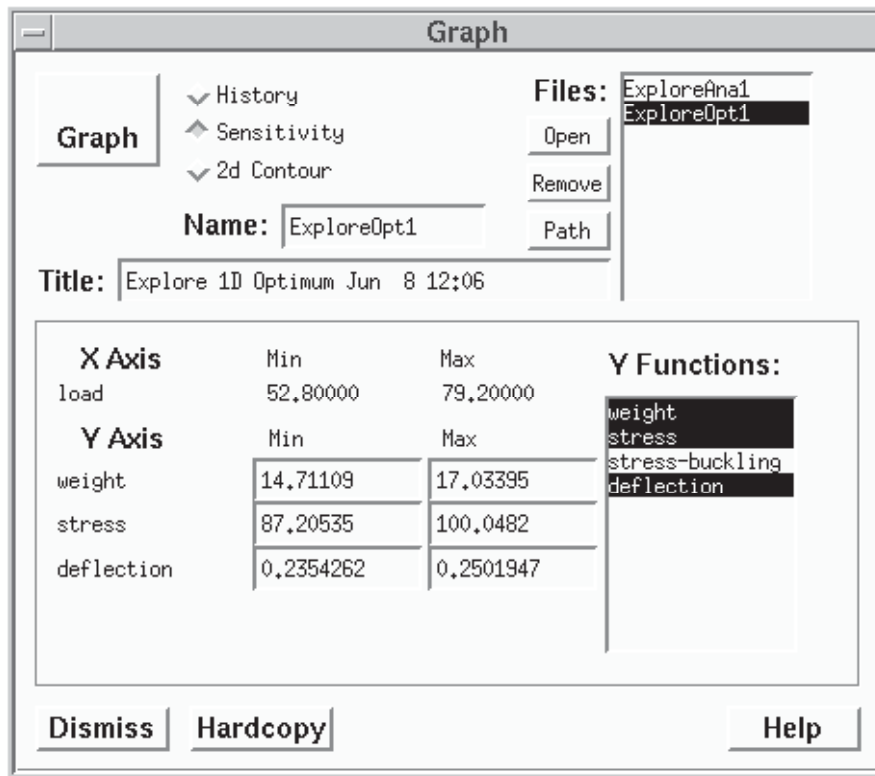
**91. Select "Sensitivity" in the File type radio box in the Graph window.**

92. Select the 1-d Explore Optimum file just generated (ExploreOpt1) and open it.

93. Select weight, stress, and deflection from the scrollable list of Y functions.

Usually it does not make sense to plot constraints that are always binding in a 1-d explore optimum plot. This is because they only range within plus or minus the constraint tolerance of the allowable. For this case, stress-buckling was binding at each optimum, so we won't plot it here. (How did we know stress-buckling was always binding? You can ascertain this by examining the min and max values of the function when it is selected. If the difference is less than one part in one thousand, then the change is smaller than the constraint tolerance. After observing this, you can de-select the function by clicking on it in the functions list. After obtaining the graph below, you may want to graph stress-buckling as an experiment.)

94. Select the Graph pushbutton from the Graph window.
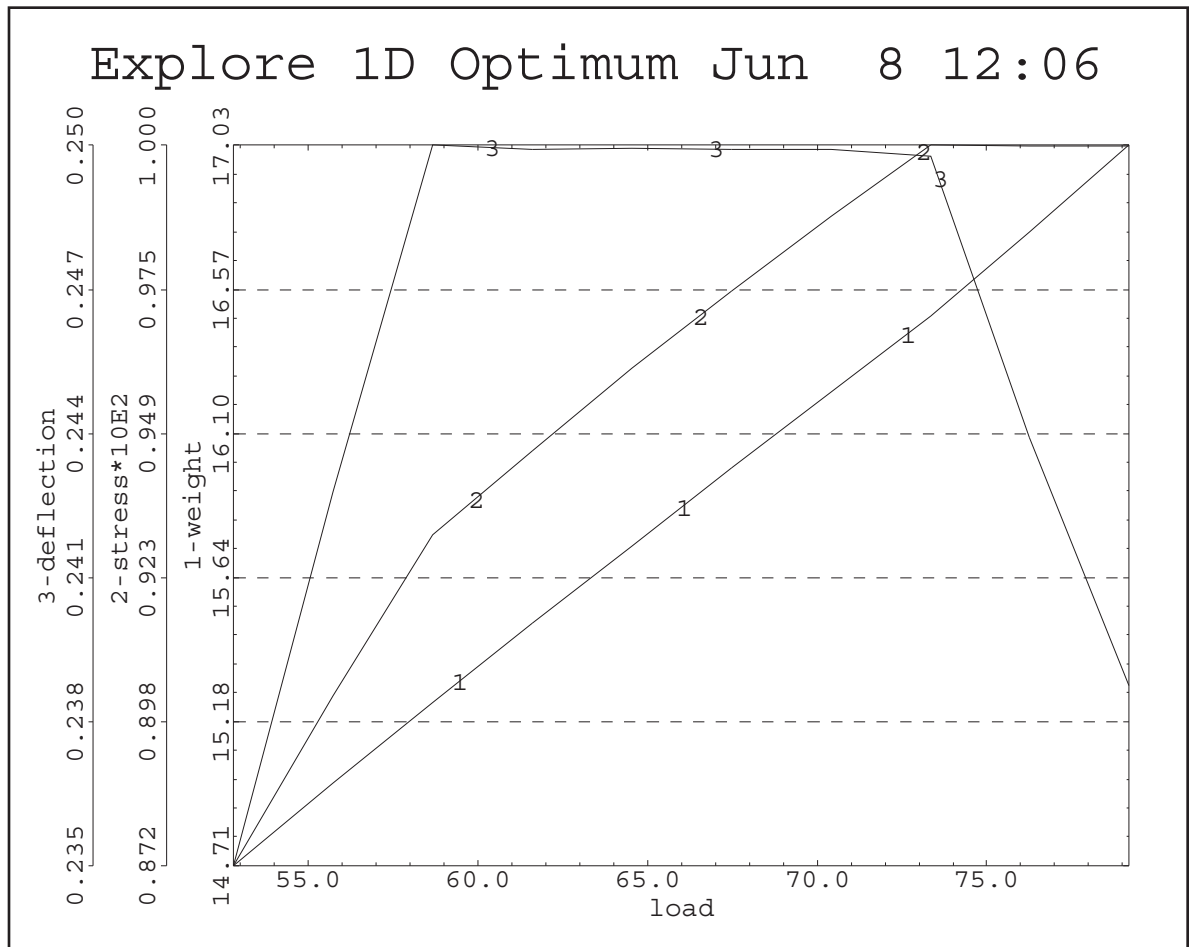
This plot shows that as we increase load, the optimal weight increases nearly linearly; stress increases until it is binding at a load of approximately 73 ksi, and deflection is binding for loads of about 58 to 74 ksi.

95. Dismiss the graph.

Two Dimensional Explore Optimum and Contour Plot
Now we will see how the optimum weight changes as we change two variables--load and thickness.

96. Activate the Explore window.

97. Select "2-d" in the 1-d, 2-d radio box in the Explore window.

98. Select thickness as the X-Axis variable and load as the Y-Axis variable to be explored. Set the ranges of thickness and load to be those shown.
We will use the default file name ("ExploreOpt1") and title ("Explore 2D Optimum <Date>").
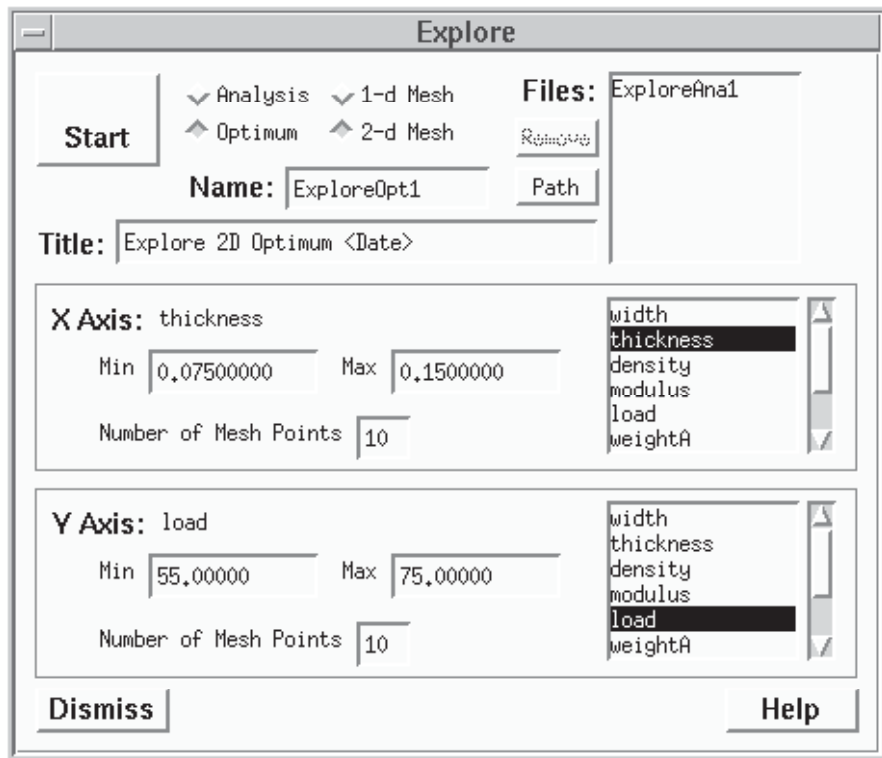
99. Press the Start pushbutton in the Explore window.
An optimization will now be done for each of the mesh points in two dimensional design space. Since we have selected 10 mesh points for each variable, 100 optimizations will be done. The Optimization Summary window will give brief information about each optimization.
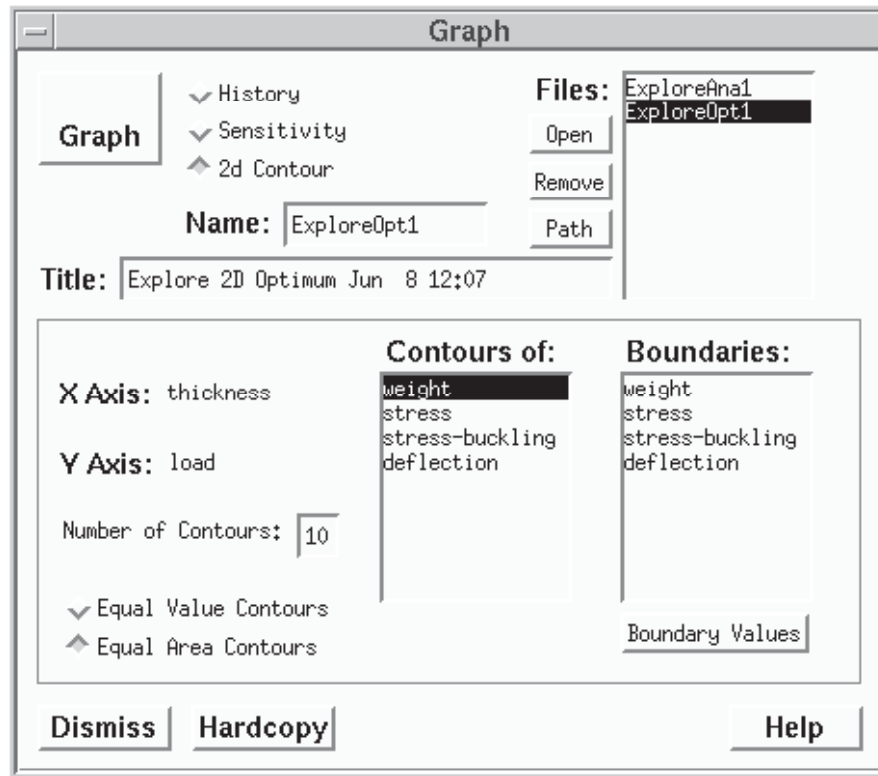
100. When the explore is finished, activate the Graph Window.

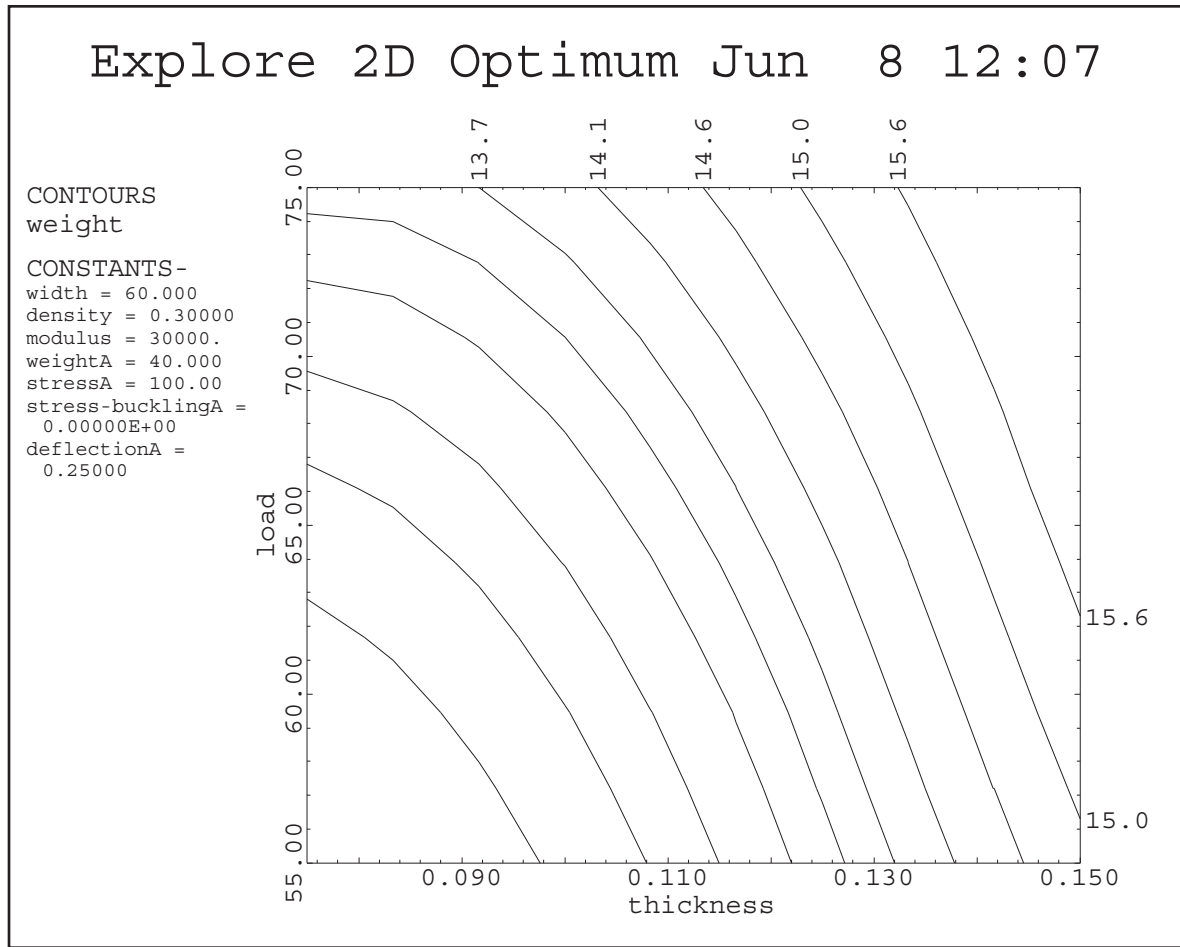**101. Select "2d Contour" in the File type radio box in the Graph window.**

102. Select and open the file just created (ExploreOpt1).

103. Select weight as the function to be contoured.
Usually for a 2-d Explore Optimum it only makes sense to plot the objective. By definition each of the mesh points is feasible (at least they better be, if we want a useful plot!), so we can't show boundaries that demarcate feasible and infeasible space.

104. Press the Graph pushbutton

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```
     Explore 2D Optimum Jun  8 12:07
```

CONTOURS
weight

CONSTANTS-
width = 60.000
density = 0.30000
modulus = 30000.
weightA = 40.000
stressA = 100.00
stress-bucklingA =
  0.00000E+00
deflectionA =
  0.25000

load

thickness

13.7   14.1   14.6   15.0   15.6

15.6

15.0

75.00   70.00   65.00   60.00   55.00

0.090   0.110   0.130   0.150

The solid lines show contours of the optimal weight. The graph shows how the optimal value of weight changes as we change load and/or thickness.

105. Press Quit in the main selection box to exit OptdesX.

Congratulations! You made it through the first OptdesX tutorial.