A Truss Analyzer for Enriching the
Learning Experience of Students

Matthew G. Sutton, Ing-Chang Jong
University of Arkansas

Abstract

This paper is written to contribute a software, named *WinTruss*, with illustration, for analyzing trusses. The software is a resulting product of a design project by a senior student in a sequence of two courses in Creative Project Design for mechanical engineering students at the University of Arkansas. *WinTruss* runs on PC Windows 95 and later. Being easy-to-use, intuitive, flexible, and powerful, this software is in the process of being made available to instructors and students at Arkansas for enriching the learning experience of students in courses that involve the analysis and design of trusses. The built-in "User Name and ID" dialog box, to be filled out by the user just before submitting the input truss for computer solution, and the "time stamp" on the hard copy of the solution are special pedagogical features. These features allow an instructor to better monitor the actual computer usage by individual students as assignments in a course.

I. Introduction

In most engineering courses, the majority of time is usually devoted to the teaching and learning of a vast body of core information that emphasizes the solution of close-ended problems. This tends to leave a student skilled in analysis, but not in the art of design. An expert engineer creates through design what once was not, and skillfully quantifies the worthiness of his or her design through solid engineering analysis. The difficulty facing tomorrow's engineers is that the problems they will be asked to solve necessitate increasing complex design solutions. Complex design solutions require even more complex design analysis. These complexities and resulting myriad of details often consort to bring about an overwhelming level of analytical complexity. Powerful software programs often have a steep learning curve because they have been generalized to solve a wide range of problems. Nevertheless, future benefits of being exposed to such software can be tremendous.

WinTruss is written in C++[1] using the Microsoft Visual C++ V6.0 compiler.[2–4] Being tailored to a certain staple class of problems, namely truss analysis, much of the complexities associated with more general software programs have been eliminated. Therefore, students are free to focus the majority of their mental energy on mastering the main body of engineering knowledge, while simultaneously gaining experience in computer applications. *WinTruss* is intended to provide engineering students exposure to computational design analysis in easily digestible servings, and to grow with them as they progress through the engineering curriculum.

The purpose of this paper is to describe and illustrate the use, rather than the programming,[5–6] of *WinTruss.* For educational purposes, we are making it freely available to other interested educational professionals and their students. We shall use a simple triangular truss, shown in Fig. 1, as well as a simply supported compound truss, shown later in Fig. 15, as illustrations of solution by *WinTruss*. Various pertinent screen shots are provided for illustrations in the paper.
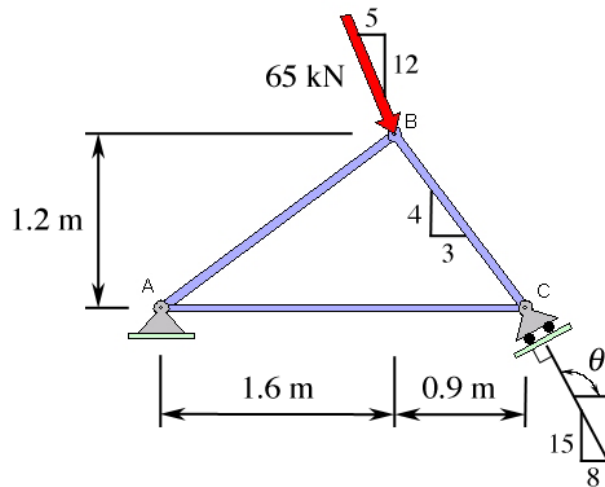

Fig. 1 A triangular truss for solution by *WinTruss*

II. Setting Up the Environment

The start-up window of *WinTruss* is shown in Fig. 2. To solve a given truss, we first execute the software and initialize the parameters in the dialog boxes contained in "Options..." under "Edit" in the menu, as illustrated in Figs. 3 through 8.
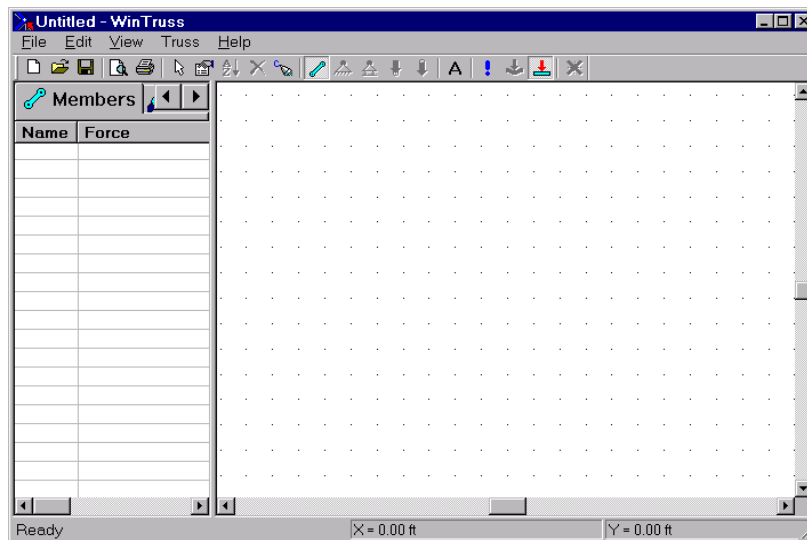
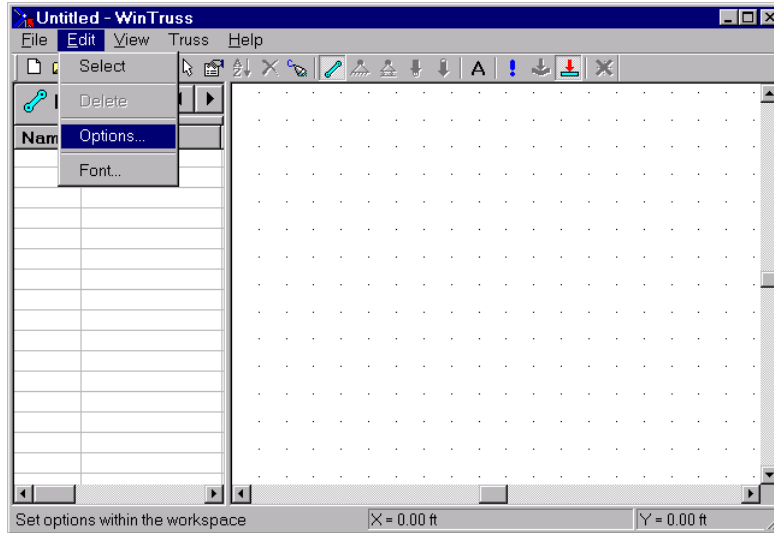

Fig. 2 Start-up window of *WinTruss*

2

Fig. 3 Selecting "Options..." in the drop-down menu of "Edit" in *WinTruss*

The first dialog box found under "Options..." is the "Physical Units" as shown in Figs. 4 and 5, which are property sheets allowing the user to select the units for the dimensions of the truss and the applied forces. Two systems of units are available for selection; they are the "English Units" (i.e., the U.S. Customary System of Units), and the "SI Units." For example, to prepare for solving the triangular truss shown in Fig. 1, we click on the "SI Units" button in Fig. 4 and then select the "Meters, kN" option to result in a screen as shown in Fig. 5. Appropriate units must be selected at the beginning of solution for each new truss modeled in *WinTruss*.
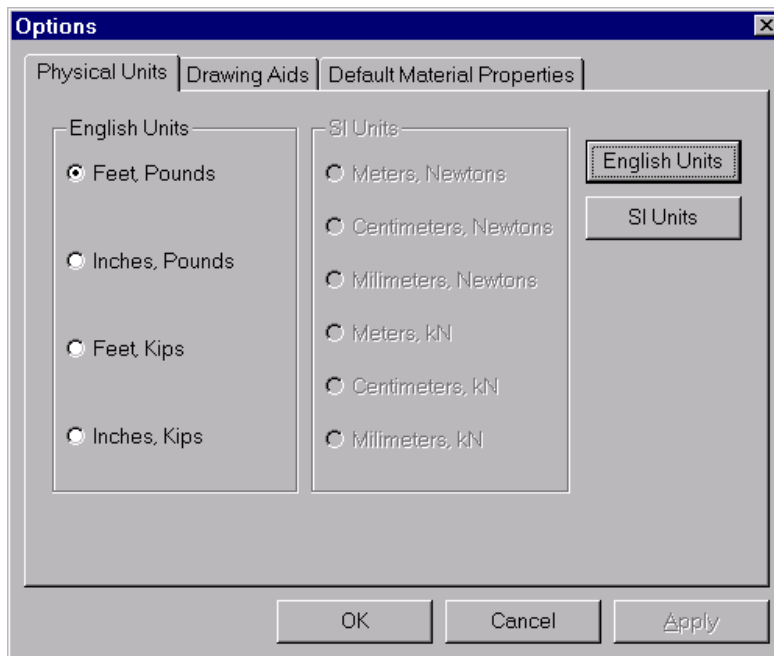

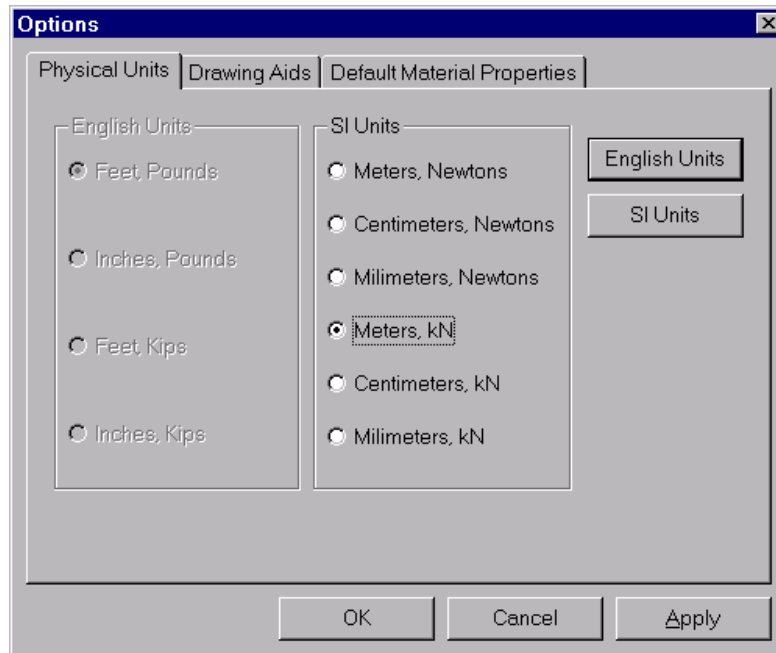**Fig. 4** The "Physical Units" tab among the three tabs in "Options" dialog

Fig. 5 Selection of "SI Units" with "Meters, kN" checked on the "Physical Units" tab

The next tab is for the "Drawing Aids" as shown in Figs. 6 and 7. Here, a user specifies how the schematic of a truss is scaled on the screen. *WinTruss* allows drawing on a virtual sheet of graph paper. The "Drawing Units" grouping allows specifying units of the paper, the "Drawing Limits" grouping allows specifying the actual size of the paper, while the "Grid Resolution" grouping allows specifying the coarseness of the grid spacing.
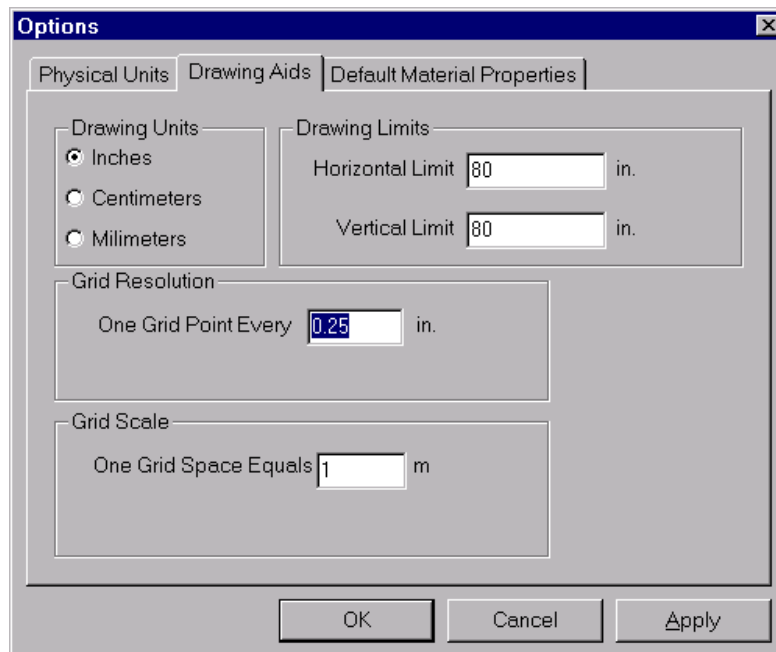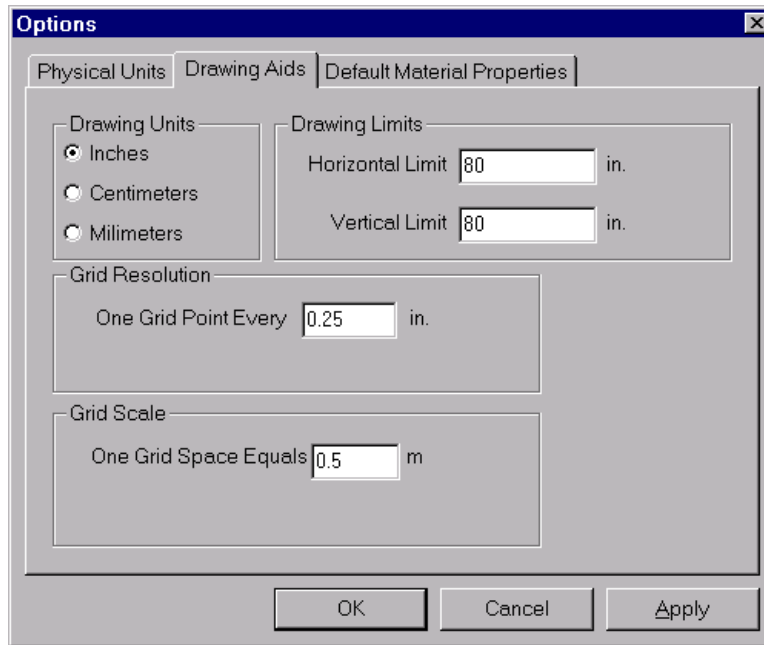

Fig. 6 Specifying parameters on the "Drawing Aids" tab

4

Fig. 7 Adjusting grid scale on the "Drawing Aids" tab

WinTruss is programmed using the finite-element method[7] and is capable of solving a statically indeterminate truss beyond the scope of Statics. For this reason, we click on the "Default Material Properties" tab to set Young's Modulus to 200 GPa and the cross-sectional area to $0.001m^2$ for all truss members as shown in Fig. 8. When the "OK" button is pressed to accept the values in this figure, the screen will return to the start-up window as shown in Fig. 2.
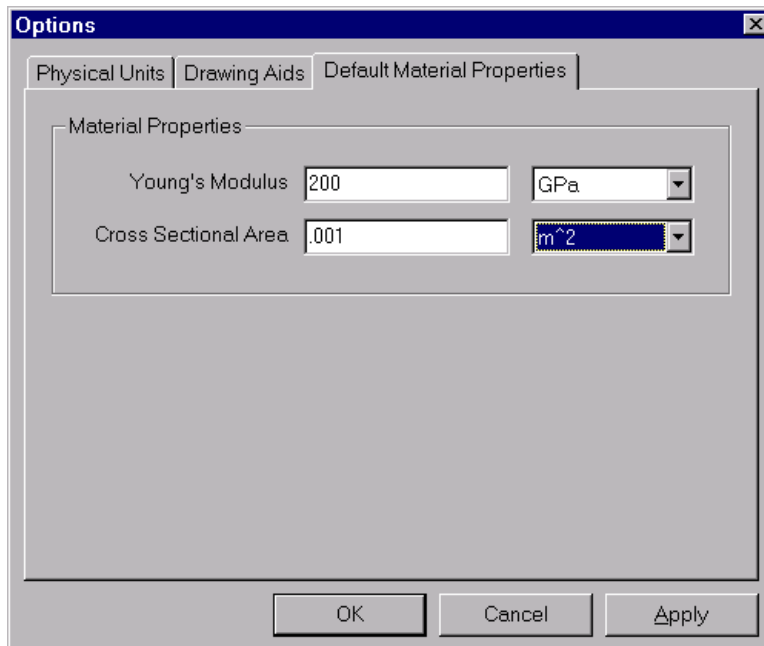

Fig. 8 Setting the "Default Material Properties" in the "Options" dialog

Table 1   Tool buttons available in *WinTruss*

Button	Name (in boldface) and Purpose	Button	Name (in boldface) and Purpose
	Create a **new** document		Sketch a **member**
	Open an existing document		Add a **hinge** support
	Save the active document		Add a **roller** support
	Print preview of the document		Add a **head-on-joint** force
	Print the active document		Add a **tail-on-joint** force
	Select a truss element		Toggle joint **labels**
	Display **properties** of a truss element		**Solve** for unknowns
	Sort the list of members alphabetically		See the truss in its **deflected-view** configuration
	Delete a selected truss element		See the truss in its **undeflected-view** configuration
	Redraw the entire screen		Add a joint at **intersection** of two truss members

III. Sketching the Truss Members

There are 20 tool buttons available to the user of *WinTruss*. The icons of these buttons as well as their names and purposes are shown in Table 1. *WinTruss* has the *Grid/Snap* function that implements *dimension-as-you-go* technology. Since we have already specified the grid spacing and grid scale in setting up the environment, *WinTruss* will use the grid to dimension the schematic for us as we sketch it. We shall first sketch the triangular truss in Fig. 1 as input to *WinTruss*.

First, depress the "Member" button (resembling a truss member) on the toolbar to begin drawing truss members. The first member *A-B* of the truss may start in the lower left-hand corner of the graphics pane and proceed up and to the right. In sketching it, we press and hold down the left mouse button at the origin as the beginning joint (Joint *A*), as shown in Fig. 9. Continue to hold the left mouse button down as we drag the truss member up and to the right until the status bar panes read X = 1.60 m and Y = 1.20 m, which are the coordinates of the ending joint (Joint *B*).

Once the ending joint is reached, release the mouse button. Next, place the mouse cursor over the ending joint (Joint *B*) of the first member on the screen. Press and hold down the left mouse button on the ending joint of the first member, and drag the mouse to the lower right until the status bar panes read X = 2.50 m and Y = 0.00 m, which are the coordinates of the ending joint (Joint *C*) of the second member. Finally, place the mouse cursor over the ending joint (Joint *C*) of the second member on the screen, and press and hold down the left mouse button to drag the mouse to the left until it reaches the joint *A*. The status bar panes should read X = 0.00 m and Y = 0.00 m when we are finished, and the truss members will resemble those shown in Fig. 9. The adding of supports at *A* and *C* and the adding of the applied force at *B* will be explained in subsequent sections of this paper.
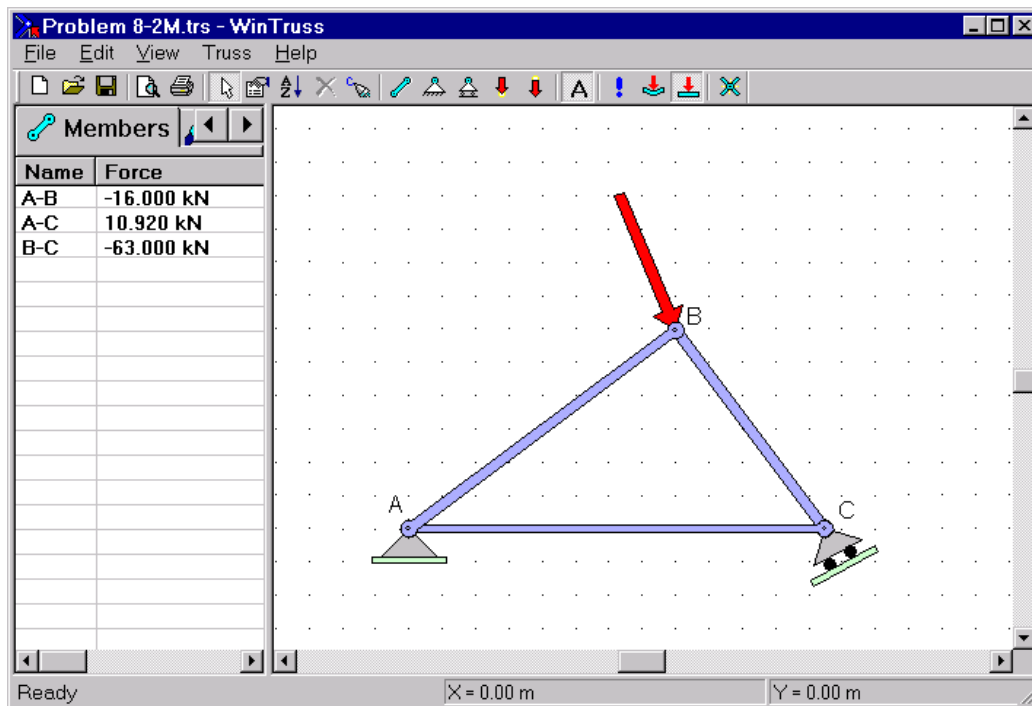

Fig. 9 A screen shot, with solutions, for the triangular truss input to *WinTruss*
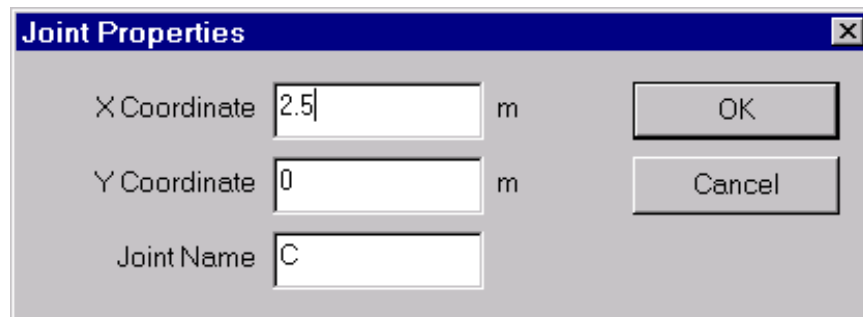

Fig. 10 Dialog box for changing, if needed, the "Joint Properties" under context menu

7

To view the labels that have been automatically assigned for the joints by *WinTruss*, press the "Labels" button, which has the letter "A" on it, on the toolbar. Depending on the order in which we sketched the truss schematic, the labels generated automatically by *WinTruss* may or may not match the labels given in the original problem. If the labels do not match, we can change them by moving the mouse pointer over the joint whose label we wish to change, then right clicking on the joint. This action will bring up a *context menu* for the joint. Select the "Properties" item from the context menu. We should see a dialog box that resembles the one shown in Fig. 10, where we can change, if needed, the joint name as well as the coordinates of the location of the joint.

The positions of the labels initially generated by *WinTruss* are always slightly below and to the right of the centers of the joints. We can move the joint labels to better locations. To do so, press the "Select" button (resembling an arrow pointer) on the toolbar. Once we are in "Select" mode, we can left click on the center of a joint label and, while holding down the left mouse button, drag the label individually to a new location, as shown in Fig. 9. Fonts may be changed under "Edit" on the menu bar.

IV. Adding the Supports

The addition of a hinge support to the joint "*A*" in Fig. 9 is relatively easy. Move the mouse to select the "Hinge" support button from the toolbar. Then move the cursor over the joint "*A*." A box will surround the joint indicating that we may add a hinge support to the joint. Press the left mouse button down and hold it down while the cursor is over the joint "*A*." Drag the mouse downward and from side to side until we have the support foundation perfectly horizontal. When we have it where we want it, release the mouse button. If we happen to release the mouse button while the hinge support is at an angle, it will not affect the validity of the solution. If we do not like how the hinge support looks though, we can delete the support and add a new one. To delete the hinge support (or other truss item), we need to use the "Select" tool to first click on the hinge support to select it. Then, press the "Delete" button (a red *X* button on the toolbar) to delete the selected item.

Next, we proceed to add a roller support to the joint "*C*" that rests on an inclined surface. We choose the "Roller" support button from the toolbar. To add a roller support to the joint *"C,"* repeat the same process we used for adding a hinge support to the joint *"A."* Try to draw the roller support at an angle similar to the schematic shown in Fig. 1, but do not be overly concerned with the precise orientation of the roller support now. Once we have drawn the *roller support* at the joint *"C,"* our window should resemble the one shown in Fig. 9.

Now that we have sketched the roller support in Fig. 9, we need to tell *WinTruss* the precise *directional angle* of the normal to the surface of the incline on which the roller support rests. Move the mouse cursor over the roller support and right click the mouse. A context menu will pop up prompting us for action. Select "Properties" from the context menu to bring up the "Roller Support Angle" dialog box, as shown in Fig. 11.
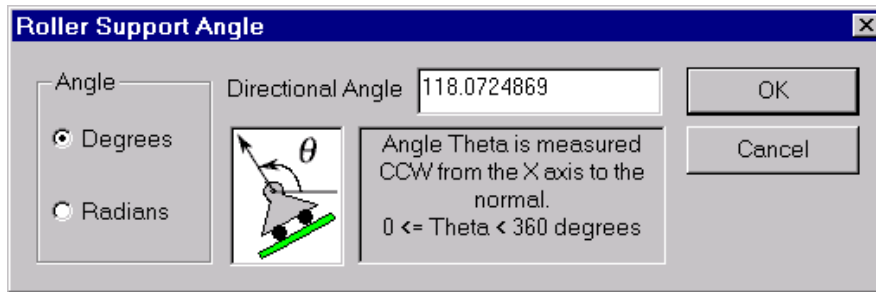
8

Fig. 11 Dialog box for specifying the *directional angle θ* o f the normal to the incline on which a roller support of the truss rests

The "Roller Support Angle" dialog box in Fig. 11 allows us to specify an accurate value of the directional angle of the normal to the incline on which a roller support of the truss rests. The angle is measured counterclockwise from the positive direction of the horizontal *x* axis to the normal to the incline. This angle can be specified in either degrees or radians by selecting an appropriate option in the "Angle" group in this dialog box. The default setting is degrees.

Using a calculator, we find that the directional angle of the normal to the incline in Fig. 1 is

$$\theta = 90° + \tan^{-1}(8/15) = 118.0724869°$$

In the "Directional Angle" edit box in Fig. 11, we type in the number 118.0724869, or whatever precise number the calculator can give. It is recommended that more significant digits be input to the computer in specifying the value of the directional angle, even though the final answers are usually reported to only three or four significant digits. We press the "OK" button in Fig. 11 to input the entered value and close the dialog box. The computer will redraw the roller support with an accurate orientation in Fig. 9 as in Fig. 1.

V. Adding Applied Forces

There is an inclined applied force at the joint "*B*" of the truss in Fig. 1. We need to add this external load to the truss schematic. Press the "Head-on-Joint" force button on the toolbar. Move the mouse cursor until it rests on top of the joint "*B*." We will see a box surrounding the joint signifying that we may add a force to that joint. Press and hold the left mouse button down. Drag the cursor to the upper left while keeping the left button depressed. Just as with the roller support, we do not need to be overly concerned with making the force have the exact inclination. The screen should show a force resembling the one shown in Fig. 9.

We see that the inclined force acting on the truss at the joint "*B*" has a magnitude of 65 kN. From the slope triangle shown, we note that the analytic expression of this force is

$$\mathbf{F} = 25\mathbf{i} - 60\mathbf{j} \text{ kN}$$

9

Move the mouse cursor somewhere over the force and right click to bring up a context menu. Select the "Properties" option to open the "Force Components" dialog. The dialog resembles the one shown in Fig. 12, where we enter 25 in the "Horizontal Component" edit box, but enter -60 in the "Vertical Component" edit box.

Fig. 12 Dialog box for "Force Components" under context menu

Pressing the "OK" button in Fig. 12 to input the indicated values, we see that *WinTruss* automatically realign the force to its exact inclination in Fig. 9 as in Fig. 1. *WinTruss* makes no attempt to scale the length of the force to match the magnitude of the force. Any attempt by the software to do so would not be practical and could result in the adjusted force covering over some part of the truss schematic that we wish to leave uncovered. It is therefore up to us to draw the force as long as we wish it to be.

VI. Solution for the Truss

Now that the schematic of the truss and pertinent parameters have been entered into *WinTruss*, we may let *WinTruss* solve for the forces in the truss members and the reactions at the supports. Press the "Solve" button (a button with a red exclamation mark) in the toolbar menu. This will initiate the solver[8] within *WinTruss*. First, it will bring up a dialog asking for User Name, User ID, Course ID, and Problem ID, for the truss to be solved, as shown in Fig. 13. The data entered in this dialog are later reproduced for identification purposes in the hard copy from the printer, as shown in Fig. 14.

Fig. 13 Dialog box for entering user name, user ID, course ID, and problem ID

After filling out the proper information in the various fields of the dialog in Fig. 13, the user may press the "Solve" button on the dialog box. *WinTruss* will record the time and date of submittal for solution for its "time stamp" and then solve the problem for the user. *WinTruss* will display the results in the output pane, on the left side of the screen, as seen on Fig. 9.

The coordinates of the various joints of the truss may be viewed by using the right arrow button at the top of the output pane to scroll the output tab over. Once the "Joints" tab is visible, click on it to display the "Joints" output page. Similarly, the reactions at the supports can be viewed by using the right arrow button at the top of the output pane to scroll the output tab over. Once the "Supports" tab is visible, click on it to display the "Supports" output page.

We may use the scroll bar directly above the "Ready" prompt in the status pane to scroll left or right in the output window. We may press the "Print Preview" button on the toolbar for a view of what the printed output will look like. Finally, to obtain a printed hard copy of the output containing a "time stamp," simply press the "Print" button (one with a printer icon) on the toolbar. A printed hard copy of the output for the truss in Fig. 1 is illustrated in Fig. 14.
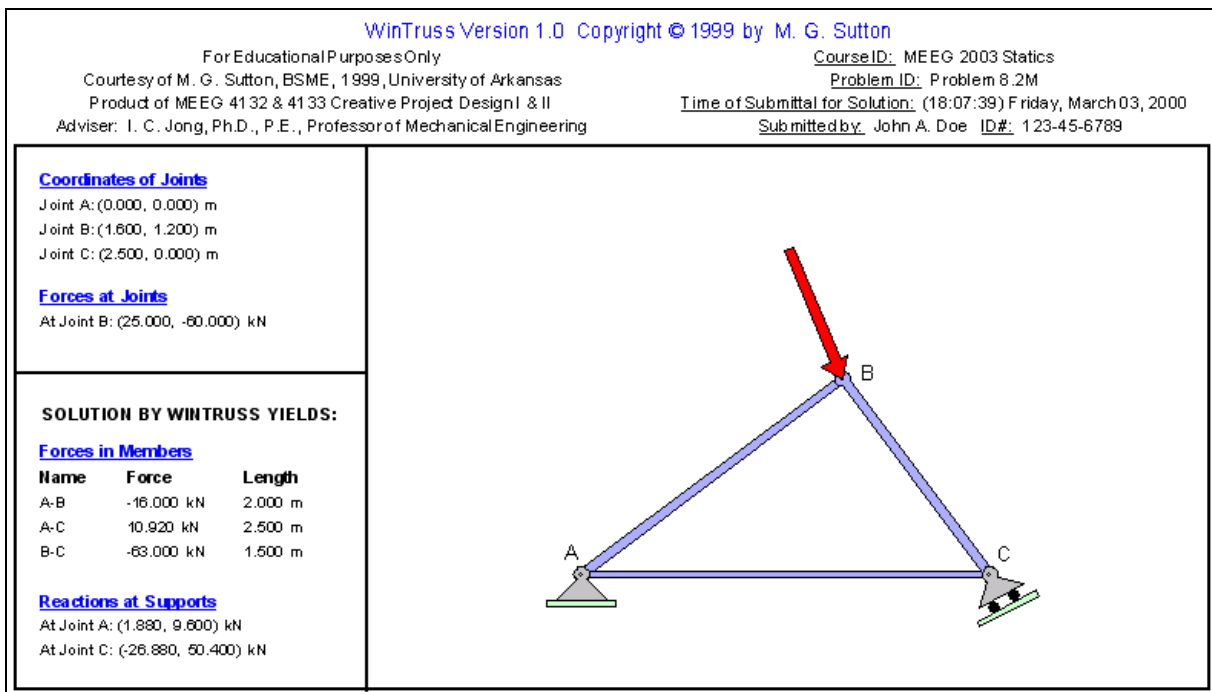

Fig. 14 A copy of the output of *WinTruss* through the printer

Note in Fig. 14 that the coordinates of all joints of the truss and the applied force at the joints*,* as well as the solution found by *WinTruss,* are shown. The identifying data on the upper right part in this figure were input by the user in Fig. 13. However, the *time stamp* under "Time of Submittal for Solution" was generated by the computer when the "Solve" button on the dialog box was clicked. These features allow an instructor to better monitor the actual computer usage by individual students as assignments in a course.

VII. Solution of a Simply Supported Compound Truss

As an additional illustration, we similarly input a compound truss,[9] as shown in Fig. 15, for solution by *WinTruss*. The screen shot of the results is shown in Fig. 16. Since the size of the truss in Fig. 15 is considerably larger than the triangular truss in Fig. 1, the listing of the solution by *WinTruss* requires two hard-copy pages to complete. They are shown in Figs. 17 and 18.
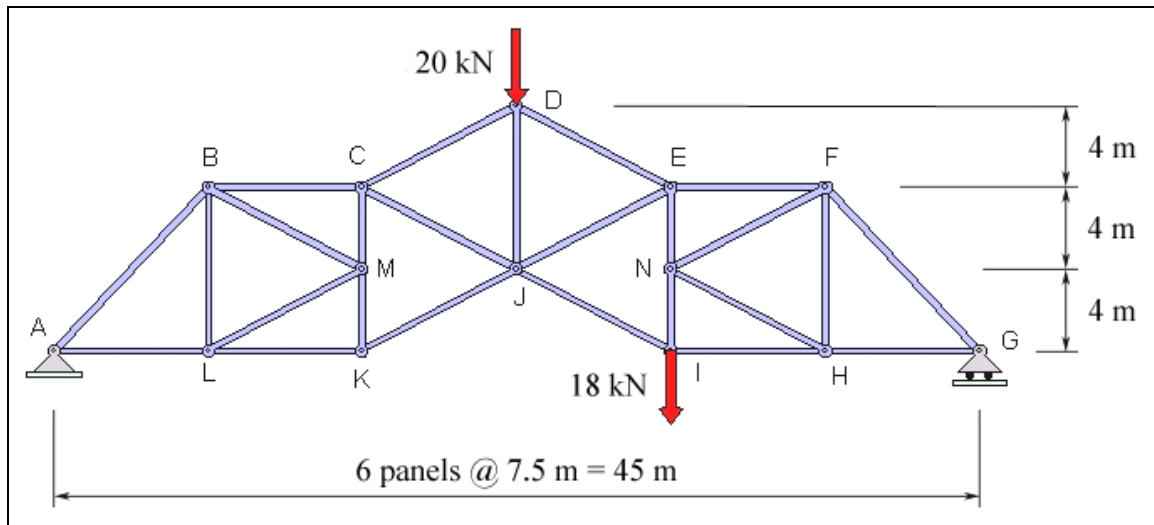

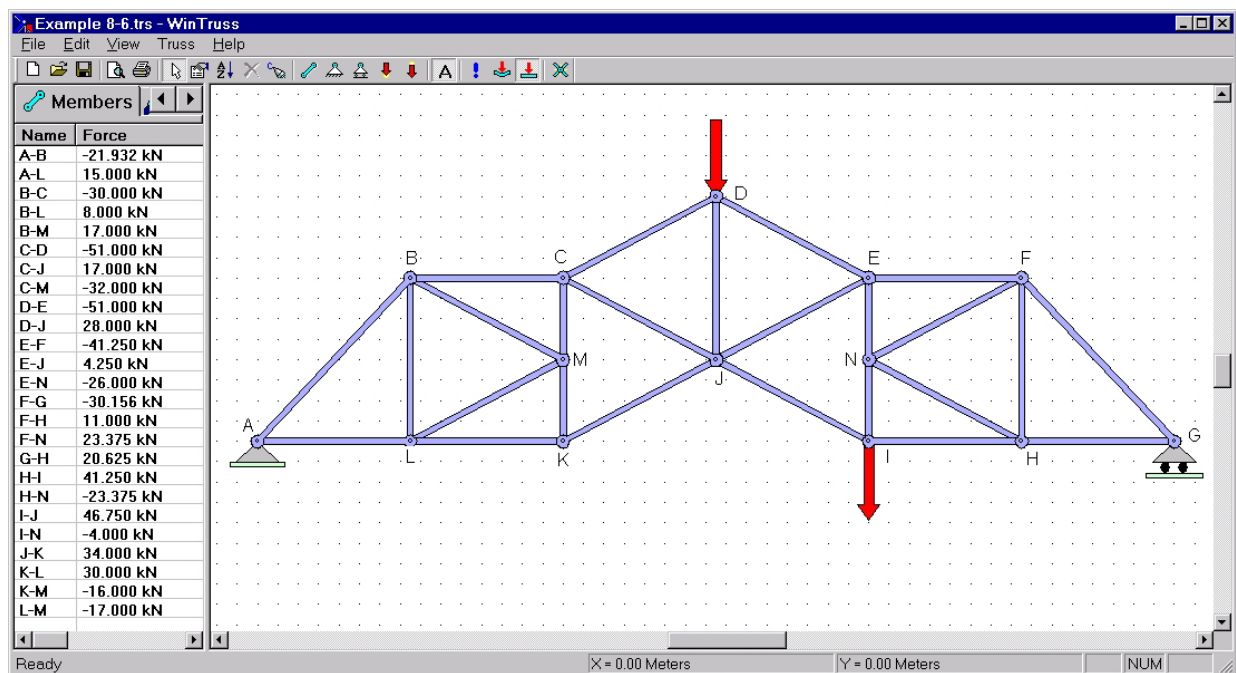**Fig. 15** A compound truss for solution by *WinTruss*

Fig. 16 A screen shot, with solution, for the compound truss input to *WinTruss*

Note that the available tools listed in Table 1 were used to input the truss in Fig. 15 to *WinTruss*. The coordinates of joints and the forces at joints *D* and *I* of the truss in Fig. 15 are found to be in complete agreement with those output by *WinTruss* in Fig. 17. Thus, the truss in Fig. 15 has been correctly input to *WinTruss*.

We have chosen the compound truss in Fig. 15, which is the same truss in Example 8.6 of the textbook by Jong and Rogers,[9] for the purpose of checking the solutions by *WinTruss* with those solved in an example of a certain Statics textbook. We note that the solution for the force in member *EJ* of this truss as given by Jong and Rogers is

$$F_{EJ} = 4.25 \text{ kN} \ \text{(tension)}$$

The solutions by *WinTruss,* as listed in Figs. 16 and 18, give the *same* result

Force in member E-J = 4.250 kN (Positive force is a tensile force in *WinTruss*.)
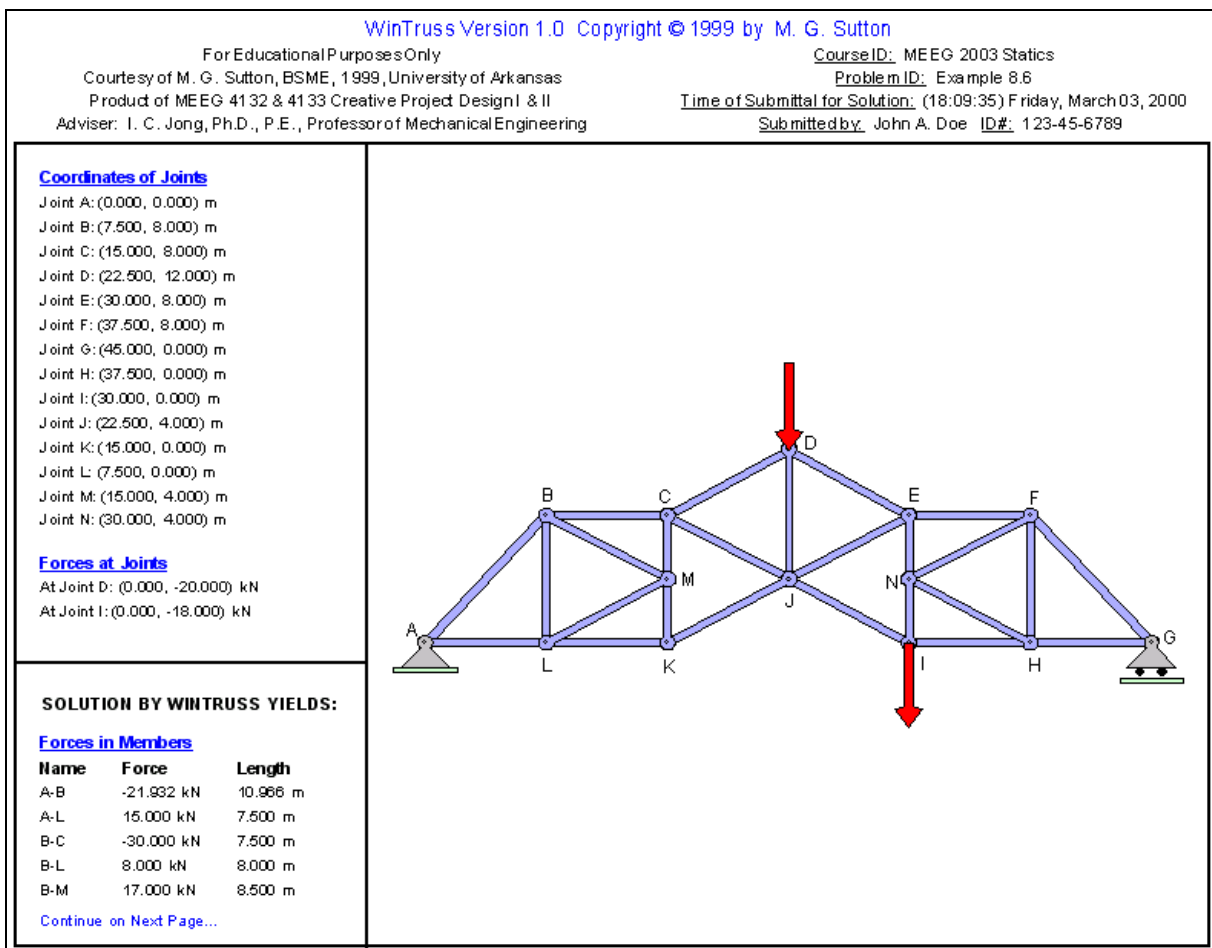

Fig. 17 First page of the output of *WinTruss* through a printer for the truss in Fig. 15

13

Fig. 18 Second page of the output of *WinTruss* through a printer for the truss in Fig. 15

VIII. Concluding Remarks

This paper describes an easy-to-use, intuitive, flexible, and powerful truss analyzer software — *WinTruss*, with illustrations. *WinTruss* uses finite-element method to solve trusses and is written in C++ using Microsoft Visual C++ V6.0 compiler. It is capable of solving both statically determinate and statically indeterminate trusses. It is being made freely available to other educational professionals and their students in courses that involve the analysis or design of trusses. To download *WinTruss.exe* and *WTtutorial.pdf,* which is a tutorial for using *WinTruss*, visit the web site: http://comp.uark.edu/~icjong/.

Tomorrow's engineers will be asked to solve increasingly complex design problems, which require more complex design analysis. *WinTruss* is intended to provide engineering students exposure to computational design analysis in easily digestible servings, and to grow with them as they progress through the engineering curriculum.

The built-in "User Name and ID" dialog, to be filled out before solution of any truss, and the "time stamp" on the hard copy for each user are special pedagogical features, which instructors can use to better monitor the actual computer usage by individual students as assignments in a course. It is hoped that *WinTruss* will enhance both the art and science of design of students in modern engineering education.

References

1. Stroustrup, B., *The C++ Programming Language*, AT&T Labs, Murray Hill, NJ, 3rd Ed., 1997.
2. *Microsoft Visual C++ MFC Library Reference Part 1*, Microsoft Press, Redmond, WA, 1997.
3. *Microsoft Visual C++ MFC Library Reference Part 2*, Microsoft Press, Redmond, WA, 1997.
4. Blaszczak, M., *Professional MFC with Visual C++6*, Wrox Press Ltd., 1999.
5. Meyer, B., *Object-Oriented Software Construction*, Prentice Hall PTR, Upper Saddle River, NJ, 2nd Ed., 1997.
6. Knuth, D.E., *The Art of Computer Programming, Vol. 1 / Fundamental Algorithms*, Addison-Wesley, Reading MA, 3rd Ed., 1997.
7. Chandrupatla, T.R., and A.D. Belegundu, *Introduction to Finite Elements in Engineering*, Prentice Hall, Upper Saddle River, NJ, 2nd Ed., 1997.
8. Chapra, S.C., and R.P. Canale, *Numerical Methods for Engineers*, McGraw-Hill Book Company, 2nd Ed., 1988.
9. Jong, I.C., and B.G. Rogers, *Engineering Mechanics: Statics and Dynamics*, Saunders College Publishing, 1991, Oxford University Press, 1995.

MATTHEW G. SUTTON
Matthew G. Sutton is currently an M.S. student at the University of Arkansas at Fayetteville. He graduated with honors from the University of Arkansas in 1999 where he obtained a BSME. His primary interest lies in desktop software development solutions for mechanical engineering analysis and educational enrichment.

ING-CHANG JONG
Ing-Chang Jong is currently a Professor of Mechanical Engineering at the University of Arkansas. He received a BSCE in 1961 from the National Taiwan University, an MSCE in 1963 from South Dakota School of Mines and Technology, and a Ph.D. in Theoretical and Applied Mechanics in 1965 from Northwestern University. He served as Chair of the Mechanics Division, ASEE, in 1996-97. His research interests are in mechanics and engineering education.