

## **Integrating MATLAB in Mechanics and Structural Analysis Courses**

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### Abstract

This paper describes the use of MATLAB in teaching mechanics and structural analysis courses in the engineering curriculum. MATLAB is being used extensively in engineering programs across the nation as a tool in enhancing student learning. In using MATLAB for mechanics and structural analysis courses, the author has encouraged students to solve a variety of problems. In all these cases students learn to write programs that are used with MATLAB to find the solutions to such problems. Since most of these are homework assignments, co-operative learning is encouraged to facilitate students working in small groups and thus enhancing the learning process. Some examples programs are presented in this paper.

### 1. Introduction

MATLAB [1] is a powerful software package with graphics presentation capabilities [2] and it is available for use on a wide range of computer platforms. Its computational capabilities are powerful, user-friendly and are very well suited for computer graphics applications. It is a language that simplifies the process of solving engineering problems in a variety of disciplinary areas with the help of a very extensive library of built-in functions. It has many special purpose toolboxes and Graphical User Interface (GUI) tools that make it convenient for application development. Because of all these nice features MATLAB has gained the recognition as the premier package and is being extensively used by the educational institutions, industries and government agencies all over.

Colleges and universities around the world are looking at ways to make learning interesting [3] and to get students engaged more in the learning process. This simply translates to large demands on educators to find more efficient ways of not only presenting the class materials but also to make sure students understand the concepts and

acquire the necessary skills. Computer-aided education and computer-aided learning tools, with the use of MATLAB and other software packages have become very popular among educators, particularly in the engineering areas [4]. Since its computational capabilities are powerful and user-friendly, students find it relatively easy to learn and use it effectively to solve problems particularly if it was introduced earlier in the curriculum. Using MATLAB earlier in the engineering curriculum for problem solving is also desirable for other reasons. It enhances better communication and leaning between students particularly when students are encouraged to work in groups on homework assignments and class projects. Mastering MATLAB earlier also helps students use it in other courses and thus save considerable amount of time in trying to learn several other problem-solving packages.

Students are given a detailed syllabus at the beginning of each semester in the mechanics as well as structural analysis courses which will have a listing of course objectives and learning outcomes. These objectives require an understanding of the engineering problem-solving technique and applying it in conjunction with technical skills to solve problems. These courses also require considerable work on the part of the students to do assigned readings before each class while class presentations are focused on solving problems rather than simply covering the course material. This encourages students to read and understand simple concepts and come prepared to the class. It helps students not only develop their abilities to read and understand technical material but also helps classroom learning environment since they are better prepared and tend to take a more active role in classes.

With the approach presented earlier, integration of MATLAB into the mechanics and structural analysis courses was easily achieved. It is noted that students consider MATLAB's learning curve to be less demanding. The availability of several easy-to-follow texts on MATLAB is also a great advantage. The topics that MATLAB capabilities support are discussed in class that includes solving a variety of problems using simultaneous equations, graphing, computer programming and others.

The author of this paper has been teaching mechanics and structural analysis courses for many years for students in large classes. In recent years, he has incorporated the use of modern software tools such as MATLAB and MAPLE in teaching these courses and in encouraging students to use these very versatile tools in the learning process. Typically homework assignments and group projects require the use of these tools that are easily accessible in the computer laboratories located across the campus. If group projects are done using these tools, students are required to make presentations and share the experience with others in the class. It has been the author's experience that such in-class presentations not only help students sharpen their communication skills but also bring out the benefits of using software tools in the learning process. These presentations also have helped less enthusiastic students to get excited about the use of such software tools and

help increase success in using these very useful software tools. In using MATLAB for  
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mechanics and structural analysis courses, the author has encouraged students to solve a variety of problems such as finding support reactions in a loaded pin-connected three-bar frame, finding second moments of areas of various shapes containing rectangular and circular sections, finding the bending moment and shear force distribution in a wing with parabolic lift loading, analysis of statically determinate and indeterminate structures, determination of principal stresses in the axle of an automobile subjected to combined loading conditions, analysis of loaded thin-walled open sections and formulation and solution of structural problems using the finite element method. In all these cases students learn to write programs that are used with MATLAB to find solutions to a variety of problems.

## 2. Example Problems

Some sample examples of programs developed for teaching mechanics and structural analysis courses are presented in this section. The first example is a program developed for the mechanics course that will calculate the second moment of area of composite sections consisting of rectangular and circular areas. The results obtained from the program have been verified with hand calculations for a thin rectangular tube, a thin-walled Z-section, semi-circular tube and several other cases as shown in problems 1 through 6. These six problems are included in the program given below:

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```

%this program can calculate the second moment of area of
%any shape containing rectangular and circular sections
clear
disp(' *****
disp(' |      this program solves      | ')
disp(' |      set 1-problem 1 to 6      | ')
disp(' |_____| ')
disp(' | Instructor: M. Sathyamoorthy | ')
disp(' | Written By: J.R. Marzban & N. Zohoor | ')
disp(' |      2001      | ')
disp(' ***** ')
pause
s1=menu('Choose the way of data entry:','Input now','As example');
if s1==2;
s2=menu('Choose the no. of problem:','1','2','3','4','5','6');
end
np=menu('Do you like to see polar moment of inertia?','yes','no');
ncg=menu('Do you like to see moment of inertia about the axis that goes through c.g.?','yes','no');

% -----
% s1=menu('Choose shape','Rectangular','circle','both')
mrxs=0;mrys=0;mcxs=0;mcys=0;mrps=0;mcps=0;
ars=0;acs=0;arxs=0;arys=0;acxs=0;acys=0;
cgmcx=0;cgmcy=0;
if s1==2 & s2==1;
% problem1:

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nr=4;
nc=0;
br(1)=360;hr(1)=20;drx(1)=90;dry(1)=0;trx(1)=0;
br(2)=360;hr(2)=20;drx(2)=-90;dry(2)=0;trx(2)=0;
br(3)=20;hr(3)=160;drx(3)=0;dry(3)=170;trx(3)=0;
br(4)=20;hr(4)=160;drx(4)=0;dry(4)=-170;trx(4)=0;
end
%
if s1==2 & s2==2;
% problem2:
nr=3;
nc=0;
br(1)=100;hr(1)=20;drx(1)=-70;dry(1)=40;trx(1)=0;
br(2)=20;hr(2)=120;drx(2)=0;dry(2)=0;trx(2)=0;
br(3)=100;hr(3)=20;drx(3)=70;dry(3)=-40;trx(3)=0;
end
%
if s1==2 & s2==3;
% problem3:
nr=2;
nc=1;
br(1)=10;hr(1)=3/4;drx(1)=0;dry(1)=5-1.5/4;trx(1)=0;
br(2)=3/4;hr(2)=9.25;drx(2)=5;dry(2)=0;trx(2)=0;
rco(1)=10+1.5/4;rci(1)=10-1.5/4;
tei(1)=0;tef(1)=90;
dcx(1)=0;dcy(1)=0;
end
%
if s1==2 & s2==4;
% problem4:
nr=0;
nc=1;
rco(1)=5.1;rci(1)=4.9;
tei(1)=90;tef(1)=270;
dcx(1)=0;dcy(1)=0;
end
%
if s1==2 & s2==5;
% problem5:
nr=5;
nc=0;
br(1)=.1;hr(1)=.5;drx(1)=1.75;dry(1)=0 ;trx(1)=0;
br(2)=1 ;hr(2)=.1;drx(2)=1.25;dry(2)=.433;trx(2)=30;
br(3)=.1;hr(3)=2 ;drx(3)=0 ;dry(3)=.866;trx(3)=0;
br(4)=1 ;hr(4)=.1;drx(4)=-1.25;dry(4)=.433;trx(4)=150;
br(5)=.1;hr(5)=.5;drx(5)=-1.75;dry(5)=0 ;trx(5)=0;
end
% problem6:
if s1==2 & s2==6;
nr=3;
nc=0;
br(1)=4;hr(1)=2;drx(1)=4;dry(1)=2 ;trx(1)=0;

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```

br(2)=2 ;hr(2)=10;drx(2)=0;dry(2)=5;trx(2)=0;
br(3)=4;hr(3)=2 ;drx(3)=-4 ;dry(3)=2;trx(3)=0;
end

if s1==1 ;
nr=input('Number of rectangular portions=');
nc=input('Number of circular portions=');
end
%rectangular
% Input your own datas:
if s1==1;
for i=1:nr
br(i)=input('length(parallel to x axis)=');
hr(i)=input('width(parallel to y axis)=');
drx(i)=input('distance of c.g. to x axis=');
dry(i)=input('distance of c.g. to y axis=');
trx(i)=input('angle between x axic and length axis(degree)');
end
for j=1:nc
rco(j)=input('outer raiouus=');
rci(j)=input('inner raiouus=');
tei(j)=input('beginning angle(degree)=');
tef(j)=input('ending angle(degree)=');
dcx(j)=input('distance of center of circle to x axis=');
dcy(j)=input('distance of center of circle to y axis=');
end
end
% -----
% Program's source:
%rectangular
for i=1:nr
trxr(i)=trx(i)*pi/180;
trxy(i)=cos(trxr(i));
ar(i)=br(i)*hr(i);
mrx(i)=br(i)*hr(i)^3*trxy(i)^2/12+ar(i)*drx(i)^2;
mry(i)=br(i)^3*hr(i)*trxy(i)^2/12+ar(i)*dry(i)^2;
mrp(i)=mrx(i)+mry(i);
mrxs=mrxs+mrp(i);
mrys=mrys+mry(i);
mrps=mrps+mrp(i);
ars=ars+ar(i);
arx(i)=ar(i)*drx(i);
arxs=arxs+arx(i);
ary(i)=ar(i)*dry(i);
arys=arys+ary(i);
end
if nr>0
cgrx=arxs/ars;
cgry=arys/ars;
end
%circle
for j=1:nc

```



```

end
if nc>0
disp('moment of inertia of circular parts around x axis=');
disp(mcxS)
disp('moment of inertia of circular parts around y axis=');
disp(mcys)
disp('dis. of cen. of gra. of circular parts to x axis=')
disp(cgCXi)
disp('dis. of cen. of gra. of circular parts to y axis=')
disp(cgCYi)
end
if nr>0 & nc>0
disp('area of whole shape =');
disp(at)
disp('moment of inertia of whole shape around x axis=');
disp(mxt)
disp('moment of inertia of whole shape around y axis=');
disp(myt)
disp('dis. of cen. of gra. of whole shape to x axis=')
disp(cgtXi)
disp('dis. of cen. of gra. of whole shape to y axis=')
disp(cgtYi)
end
if np==1;
prg=(mpt/(acs+ars))^0.5;
disp('moment of polar inertia of rectangular parts =');
disp(mrps)
disp('moment of polar inertia of circular parts =');
disp(mcps)
disp('moment of polar inertia of whole shape =');
disp(mpt)
disp('polar radius of gyration=');
disp(prg)
end
if ncg==1
disp('moment of inertia around x axis(c.g.) =');
disp(mtcgXi)
disp('moment of inertia around y axis(c.g.) =');
disp(mtcgYi)
end
end

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This is the only example for which the entire m-file listing is presented in this paper. Interested readers can access the file from [www.wvutec.edu/sathy/asee](http://www.wvutec.edu/sathy/asee).

The next two examples relate to the structural analysis course. The first one deals with the analysis of a statically determinate six-member truss loaded with forces at certain nodes to determine the internal forces in all the members of the truss as shown in problem 7. This program was written by two other students in the structural analysis class and the m-file for this problem can be accessed from the above hyperlink.

The second example for the structural analysis course is concerned with the determination of principal stresses and maximum shear stress an automobile axle subjected to combined loading as shown in problem 8. Again, a different set of students was involved in writing this program and the entire m-file is accessible from the hyperlink listed earlier.

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In both cases the results obtained from these programs were checked with hand calculations. When students solve these homework problems using MATLAB, they are required to support their results with other hand calculations. A summary of the homework assignments given in mechanics and structural analysis courses is presented in Table 1. It should be clear from listing that students taking these two courses did solve a variety of problems using MATLAB. Handouts were prepared for each of these courses with examples to clearly explain the use of MATLAB in solving several sample problems. It was the author's experience that such handouts were extremely useful to students in providing them with the necessary information on MATLAB and helping them learn the skills to develop script files for the assigned homework problems. Students were encouraged to use the capabilities of MATLAB to find solutions to problems with varying load conditions (in the structural analysis course), examine and compare results, and learn more from these studies. Unfortunately, no assessment information is available to show how MATLAB really helped retention and learning. Students, however, reported anecdotally through student evaluations done at the end of the semester that they really enjoyed leaning learning MATLAB and using it to solve engineering problems.

Table 1- Summary of course homework assignments

<b>Course</b>	<b>Homework Assignment</b>
ME 350, ES 222	Pin-connected three-bar frame
ME 350	Internal forces in a loaded bucket hoist
ES 222	Second moments of areas for composite sections
ME 350, ES 222	Support reactions in an aircraft passenger armrest
ME 350, ES 222	BM and SF diagrams for wing lift load
ME 350	Statically determinate six-member truss
ME 350, ES 222	Principal stresses in an automobile axle with combined loadings
ME 350, ES 222	Statically indeterminate beam-rod structure
ME 350	3-member truss made of dissimilar material
ME 350	5-member truss using energy method
ME 350	Displacements of a tubular lamp post

ME 350- Aircraft Structural Analysis, ES 222- Strength of Materials

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### 3. Animations

Since MATLAB integrates computation, visualization and programming, it provides a means of displaying the motions of dynamical systems in the form of animations [5]. Lectures combined with animation sessions are known to help students understand better the materials presented in classes. Such animations have been used by the author in teaching mechanics classes. For example, in the dynamics class animations have been used to illustrate and explain the motions associated with collision of particles, relative motion of block/weights attached to pulleys, motions associated with machinery systems such as a slider-crank mechanism and others. Although other animation packages such as Best Dynamics have been used in the past for this purpose, MATLAB graphic capabilities have been explored to do animations in some simple cases [5]. Creating animations may be a fairly easy task for an experienced MATLAB user but it is not so simple to do for students learning dynamics/kinematics for the first time. Therefore the homework assignments do not require students to write programs for animations. Typically students who take advanced level courses in engineering seem to appreciate the capabilities of MATLAB and continue to use it in those courses for modeling, computation, and visualization.

### 4. Conclusions

MATLAB has been used as a problem-solving tool in mechanics and structural analysis classes. It has also been used to a limited extent for animations involving dynamics of particles and machinery systems. The integration of MATLAB into these courses was a reasonably small effort compared to the huge benefits experienced by students and it also provided a very viable means for students to solve engineering problems using computers. It was noted that students exposed to MATLAB and its capabilities in modeling, computation, and visualization in their earlier years of their engineering education used them effectively in the advanced level engineering courses. It also helped students develop better reading and studying skills and a better understanding of the materials presented in engineering courses. Overall, this resulted in a positive, effective and efficient learning environment.

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Teaching of Engineering Dynamics, *Computer Applications in Engineering Education*, Vol. 3, No. 7, (1995), pp. 21-28.

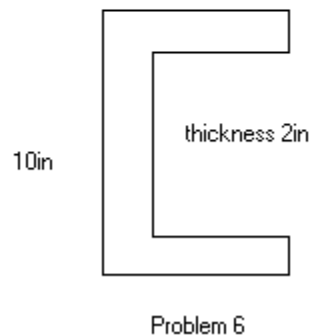
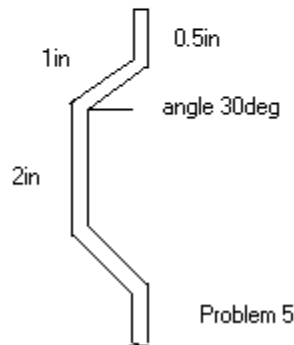
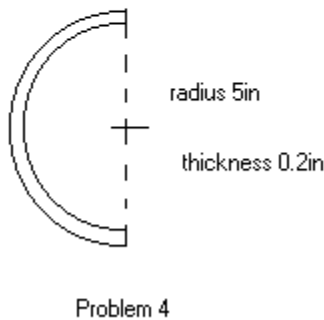
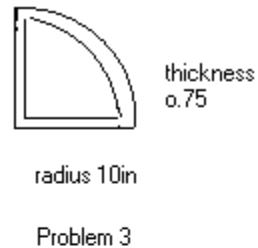
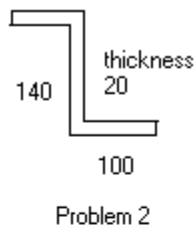
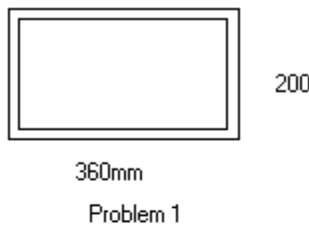
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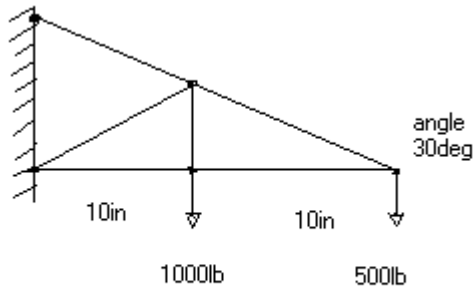
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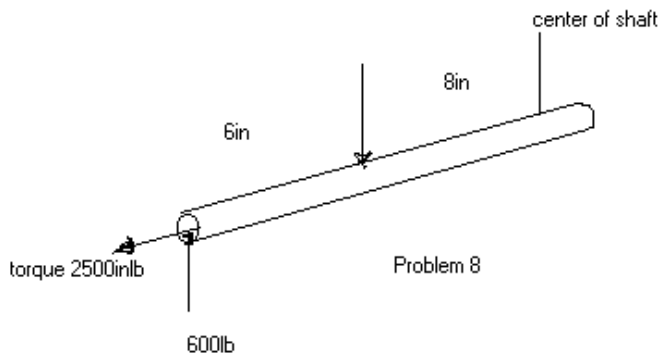
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Problem 7



Problem 8