Integrating Computer Tools into Sophomore-Level Engineering Mechanics Courses

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Abstract

Computer tools have been integrated into two sophomore-level Engineering Mechanics courses at The Pennsylvania State University DuBois Campus. Those two courses are strength of materials and dynamics. In the prerequisite statics course, computer tools are not used because the author believes that doing so could compromise the students' understanding of basic engineering concepts. In strength of materials, the computer tools were directly integrated into the existing course. In particular, the students used Microsoft Excel to graph, numerically integrate, and perform composite moment of inertia calculations. In the dynamics class, the computer-tool integration was accomplished through an additional honors section. In this case, students studied numerical approaches to differentiation, integration, and differential equation solution, and wrote their own programs to perform these operations. It was found that the students used computer tools, even when it was optional. The students are much more likely to use the computer tools when they understood two important facts. Namely, that the tools provide a release from tedious repetitive tasks and the opportunity to solve problems that would be extremely difficult or impossible to solve without them. The decisions about computer tool usage in the courses were based upon the author's 14 years of experience as a practicing engineer. This experienced included both using and developing computer-aided engineering tools. A number of general concerns and choices relate to the use of computer tools in any engineering class. The general concerns include the aforementioned possible compromise of the students' basic engineering understanding, plus student computer background and fitting additional content into an already full curriculum. The choices are between general purpose and discipline specific software, as well as between the use of existing applications or the use of programs that the students write themselves.

I. Introduction

The use of computer applications in engineering practice has grown significantly in the past 15 years. At the same time, the nature of computer applications has changed. The mass adoption of desktop personal computers and the development of powerful applications for them have provided many useful alternatives and/or replacements for traditional mainframe applications that have existed since the mid 1960's. At the same time, the need to understand traditional analytical engineering theory and problem solving techniques has not diminished. This presents a dilemma to for instructors teaching basic sophomore-level engineering mechanics courses. Namely, early introduction to computer-aided engineer tools is more important than ever, however, the curriculum of the courses is already full with subject matter that is absolutely essential to the students' education. This dilemma is further complicated by the fact that choices of computer-aided engineering tools continue to expand. Furthermore, 20 years ago, this issue would generally have been dealt with in the junior year, because using computer tools required that students know a computer language, usually FORTRAN. The students would be introduced to it during their sophomore year. Now, students can use personal computers with easy to use generic applications in their freshman year. The purpose of this paper is threefold. First, to discuss the philosophical considerations that guided the decisions the author made relative to computer tool usage in three sophomore-level engineering mechanics classes; statics, dynamics, and strength of materials. Second, discuss the tools integrated into the strength of materials and dynamics courses. Third, discuss insight that the author gained during that integration.

II. Philosophical Concerns

The author believes that there are three basic philosophical considerations affecting an instructor's decisions about integrating computer-aided engineering tools into engineering classes in general, and a fourth that applies specifically to existing theory courses, such as sophomore-level engineering mechanics courses.

First, the use of computer tools must not compromise the students understanding of any basic engineering concepts. This concern generally limits the use of computer-aided tools to the performance of tasks that the students already know how to do, or ones than can only be done with computational tools. This limitation should not be of great concern, as these two categories permit removing tedious repetitive hand operations, and expanding the complexity of problems that students can solve. The concern does limit the opportunities to integrate computer-aided tools into the lowest level courses.

Second, the instructor must choose between general-purpose programs or discipline specific programs. Given the inter-disciplinary nature of students in sophomore-level engineering mechanics courses, this concern drives the instructor in the direction of general-purpose programs.

Third, the instructor must choose between the use of existing applications or ones that the students write themselves in some computer language. This concern is closely tied to the students' computer programming background and the amount time that the students can be reasonably expected to put into computational assignments.

Fourth, in order to add something to an existing course, something else must be taken away, unless addition class time can be made available. As mentioned earlier, the basic content of statics, dynamics and strength of materials hasn't changed in over 20 years and the curriculum for each is already quite full. As a result, new computational aspects added directly to an existing course must have very low overhead. An alternative is to make more class time available, one possibility is through a special honors section. Another option for gaining additional class time would be to make the course worth more credits; this is not possible for at least two reasons. First, the author/instructor is not responsible for overall curriculum changes.

Second, even if he were, requiring additional credits in baccalaureate degree programs already requiring up to 137 credits, at Penn State, would be very difficult to justify.

III. Course Specific Integration Decisions

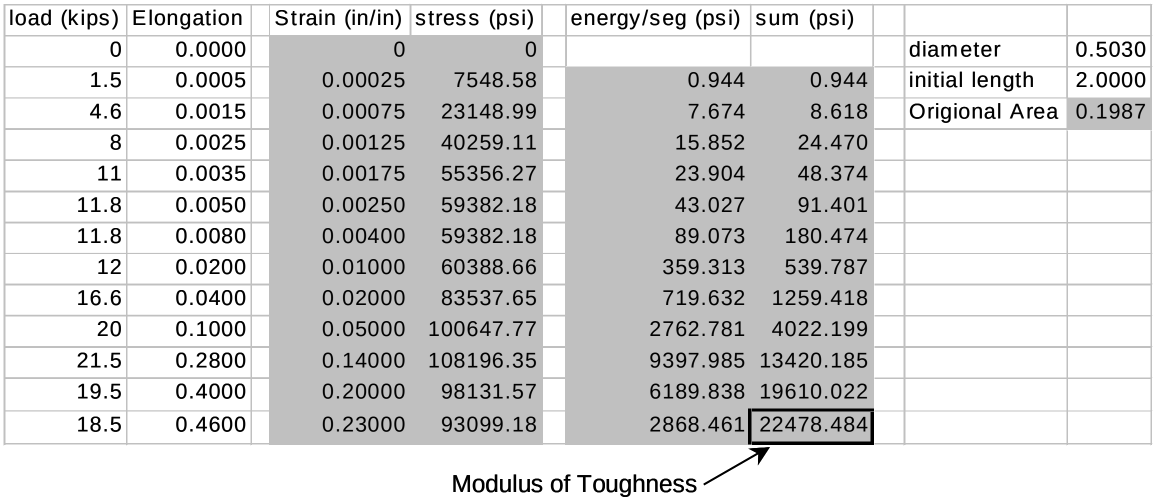
In light of the proceeding philosophical discussion the author decided not to integrate computer-aided tools into his engineering statics course. Given that the only prerequisite course is differential calculus, the engineering concepts may all be new. As a result, the possibility of compromising the students understanding of these basic concepts exists.

For the strength of materials course is was decided to add the use of personal computer spreadsheet applications directly to the existing course. The students learned to perform the following tasks: graph stress-strain diagrams, numerically integrate the stress-strain diagrams to obtain the modulus of toughness, and perform composite moment of inertia calculations. In each case, the task performed was either a purely mathematical operation, or a skill from a prerequisite course. Use of an existing generic application was chosen for three reasons; computer language programming is not a prerequisite course, it is not discipline specific, and it has very low overhead.

For the dynamics course it was decided to offer a special honors section. This was necessary because it was decided to introduce the students to several numerical methods topics (Hornbeck[1]), which parallel analytical topics from the standard dynamics course. The students demonstrated their understanding of these topics by writing computer programs to perform the various tasks: numerical differentiation, numerical integration, and solutions to 1st and 2nd order ordinary differential equations. The honors section provided the opportunity to overcome several barriers that would prevent this from being done in the regular dynamics course. First, the students could be limited to those who had prior programming experience; overcoming the fact that a computer-programming course is not a prerequisite for the regular dynamics course. Also, with additional class time, the new theory could be covered and the additional student workload could be justified.

IV. Spreadsheet Application Examples

The first computer-aided application that was incorporated in to the strength of materials course was plotting stress-strain diagrams. This was done using a problem from Hibbler[2], where load and deflection data is given for a test specimen with an initial diameter of 0.503 in. and an initial length of 2.00 in. Use of the spreadsheet frees the students from plotting as well as the repetitive calculation for stress and strain. Figure 1 shows the spreadsheet used to calculate the stress and strain that was then plotted. It also shows the calculation of the modulus of toughness using the trapezoidal rule, which will be discussed shortly. In the spreadsheet, the shaded cells show values that were calculated by the spreadsheet using formulas provided by the user. The stress-strain data was then plotted to show both the entire stress-strain diagram (Figure 2) as well as an expansion of the linear region (Figure 3) as was specified in the problem statement. All the stress-strain data is used in Figure 2, while a subset is used in Figure 3. The calculation of the modulus of toughness is shown in Figure 1 in the columns labeled energy/seg (psi) and sum (psi). The first of these columns uses the trapezoidal rule to calculate the area under the curve defined by the stress-strain pair at that row and the preceding one. The second of these columns is the sum of all entries in the energy/seg column up to that row. Thus, this represents the total area under the curve to the location of the stress-strain pair in that row. As a result, the final entry corresponds to the modulus of toughness. The last two rows of the spreadsheet show the values of constants used in the calculation of stress and strain.



load (kips)	Elongation		Strain (in/in)	stress (psi)		energy/seg (psi)	sum (psi)			
0	0.0000		0	0					diameter	0.5030
1.5	0.0005		0.00025	7548.58		0.944	0.944		initial length	2.0000
4.6	0.0015		0.00075	23148.99		7.674	8.618		Origional Area	0.1987
8	0.0025		0.00125	40259.11		15.852	24.470			
11	0.0035		0.00175	55356.27		23.904	48.374			
11.8	0.0050		0.00250	59382.18		43.027	91.401			
11.8	0.0080		0.00400	59382.18		89.073	180.474			
12	0.0200		0.01000	60388.66		359.313	539.787			
16.6	0.0400		0.02000	83537.65		719.632	1259.418			
20	0.1000		0.05000	100647.77		2762.781	4022.199			
21.5	0.2800		0.14000	108196.35		9397.985	13420.185			
19.5	0.4000		0.20000	98131.57		6189.838	19610.022			
18.5	0.4600		0.23000	93099.18		2868.461	22478.484			

Modulus of Toughness

Figure 1 – Spreadsheet for Numerical Portion of Stress-Strain Diagram Problem

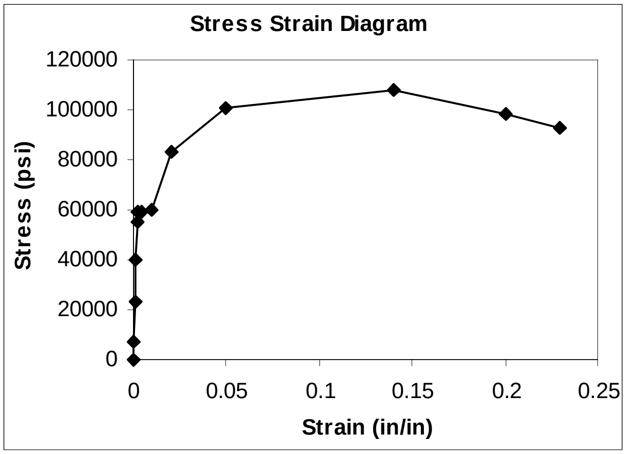


Figure 2 – Complete Stress-Strain Diagram

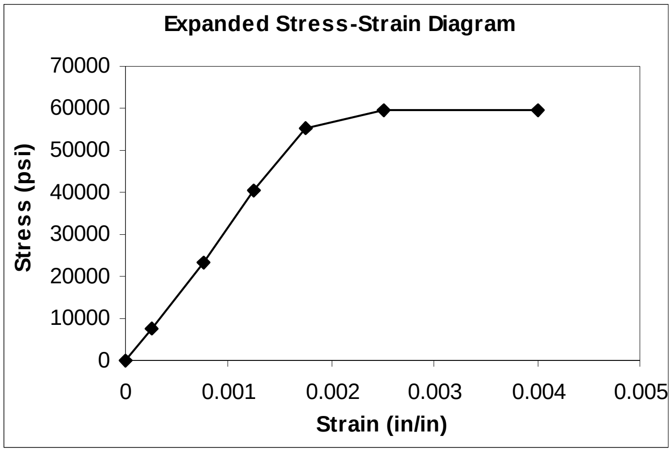


Figure 3 – Expanded Stress-Strain Diagram Highlighting the Linear Region

	b	h	A	y’bar	A*y’bar	dy	a*dy**2	Izz bar	Izz
1	0.012	0.376	4.512E-03	0.2	9.024E-04	0.000E+00	0.000E+00	5.316E-05	5.316E-05
2	0.150	0.012	1.800E-03	0.394	7.092E-04	1.940E-01	6.774E-05	2.160E-08	6.777E-05
3	0.150	0.012	1.800E-03	0.006	1.080E-05	-1.940E-01	6.774E-05	2.160E-08	6.777E-05
sum			8.112E-03		1.622E-03				1.887E-04
		ybar	2.000E-01						
	b	h	A	z’bar	A*z’bar	dz	a*dz**2	Iyy bar	Iyy
1	0.012	0.376	4.512E-03	-0.006	-2.707E-05	3.062E-02	4.231E-06	5.414E-08	4.285E-06
2	0.150	0.012	1.800E-03	-0.075	-1.350E-04	-3.838E-02	2.651E-06	3.375E-06	6.026E-06
3	0.150	0.012	1.800E-03	-0.075	-1.350E-04	-3.838E-02	2.651E-06	3.375E-06	6.026E-06
sum			8.112E-03		-2.971E-04				1.634E-05
		zbar	-3.662E-02						
			Product	of	Inertia				
			A	dy	dz	A*dy*dz			
1			4.512E-03	0.000E+00	3.062E-02	0.000E+00			
2			1.800E-03	1.940E-01	-3.838E-02	-1.340E-05			
3			1.800E-03	-1.940E-01	-3.838E-02	1.340E-05			
sum						0.000E+00			

Figure 4 – Spreadsheet for Numerical Portion of Composite Moment of Inertia Problem

The use of spreadsheets to perform composite moment of inertia calculations is shown in figures 4 and 5. Figure 4 shows the calculations performed, and Figure 5 shows the coordinate system used to define the input parameters. As before, shaded cells correspond to calculated values. Note that only four entries are required for each piece of the composite area. This example shows the number of hand calculations that can be eliminated in this type of problem using a spreadsheet application. In addition, the last section of the spreadsheet shows the calculation of possible product of inertia terms. While the *z* and *y* axes may be principle axes for each piece of the composite cross-section, they may not be for the composite cross-section itself. If not, then the final entry, which results from the use of the parallel axes theorem for products of inertia, would not be zero. This spreadsheet can easily be changed to accommodate more rectangular pieces. This values for this example come from a problem in reference [2].

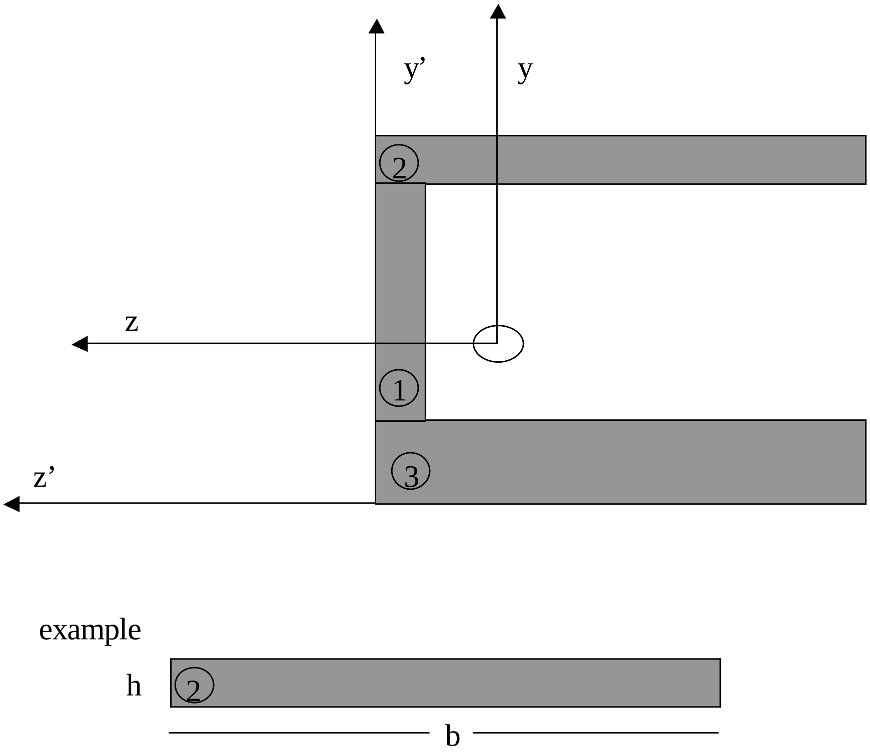


Figure 5 – Depiction of Coordinate System used for Composite Moment of Inertia Problem

V. Numerical Methods Overview and Examples

With the additional class time afforded by establishing an honors section for the dynamics course, more in-depth computational subjects were pursued. The topics of numerical differentiation, numerical integration, and solutions to ordinary differential equations were covered. First the students were introduced to a dominant issue associated with numerical approaches, namely that only function values are available. This was followed by a discussion of numerical differentiation, which covered, forward, backward and central differences as well as step-size. The students were asked to write a program to calculate the derivative of a simple function using the three approaches for two different step sizes. The function and step sizes were:

$y = \sin(x)$ where x is in radians and for the following step sizes, h:
$h = \pi/4$ and $h = \pi/12$.

The results of this investigation are shown in figures 6 and 7. Figure 6 shown the estimate of the derivative, $y'(x)$, for the three approaches and the larger step size. Figure 7 shows the plot for the smaller time step. These two figures show the following basic characteristics associated with numerical differentiation. Backward and forward differences have comparable accuracy (order of h), while central differences have greater accuracy (order of h^2). Backward differences lag the correct solution while forward differences lead the correct solution. A curve that is to the right of the solution is said to lag the solution because it predicts the correct behavior at a larger value of the independent variable. Of course the reverse is true for a curve that is to the left of the correct solution, to which the term lead is applied

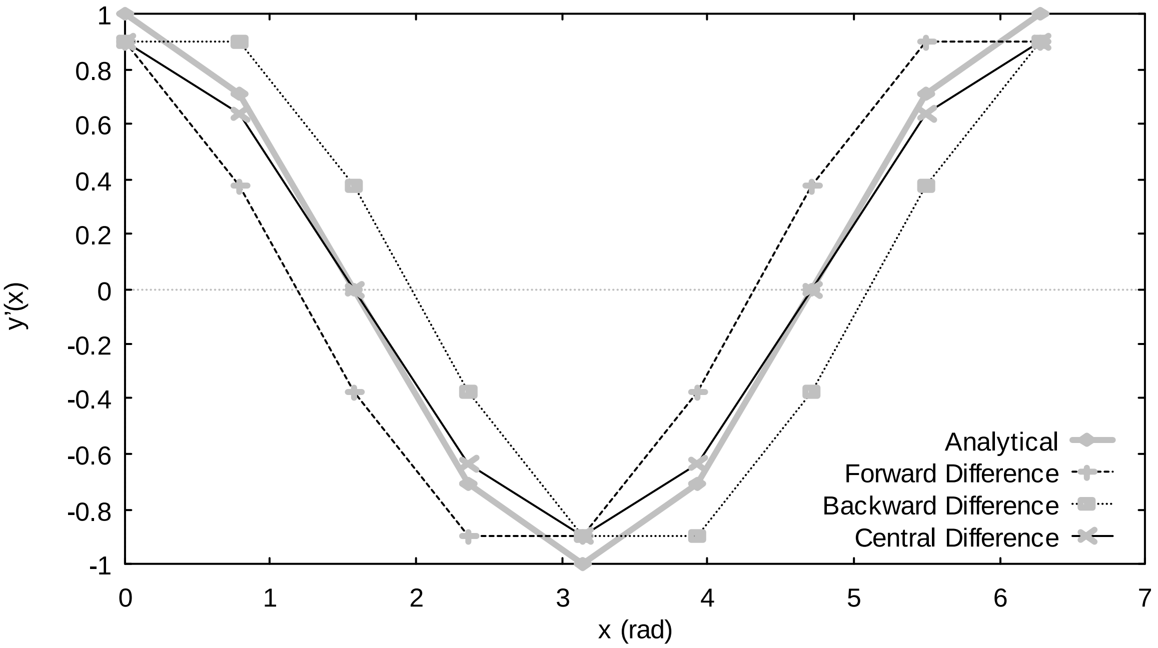


Figure 6 – Comparison of Numerical Differentiation Approaches (large Δx)

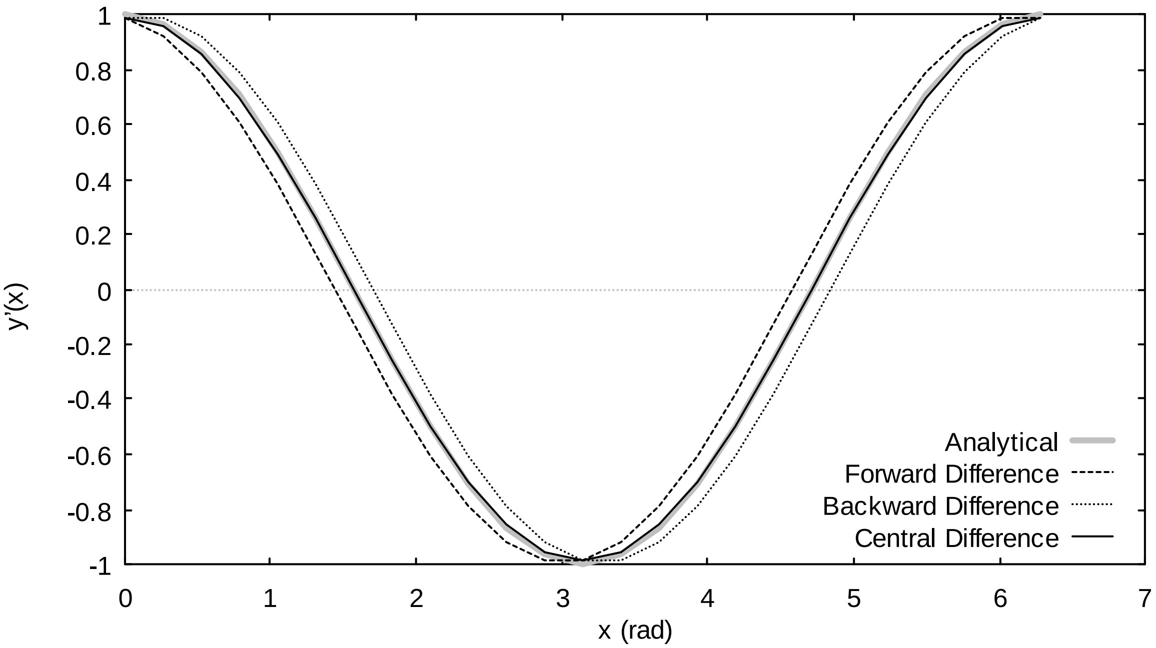


Figure 7 – Comparison of Numerical Differentiation Approaches (small Δx)

The students were next introduced to numerical integration. The detailed part of this discussion was limited to the trapezoidal rule and Simpson's rule along with improvements to each with end correction. Other popular approaches, such as quadrature, were mentioned but not discussed in depth due to time limitations. The students wrote programs to evaluate the integral of a simple function for the second order trapezoidal rule, as well as two 4th order approaches, trapezoidal rule with end correction, and Simpson's rule. They were instructed to do this for an increasing number of panels (number of discretizations) and to compare the results. These can be seen in figure 8. The integral the students were asked to evaluate was

$\int_0^{\pi} \sin(x)dx$, where x is defined in radians.

Figure 8 shows the absolute values of the percentage difference between the approximate answer and the correct analytical answer. The two 4th order approaches show much more accurate solutions than the 2nd order approach. This figure also shows the effect of round off error, which begins to degrade the solution after a certain number of panels. The round-off effect becomes significant for the two 4th order approaches between 1,000 and 10,000 panels. For the 2nd order approach this does not appear to occur until after 100,000 panels. For all three approaches, the round off error dominates the solution and they all have equal accuracy by 1 million panels.

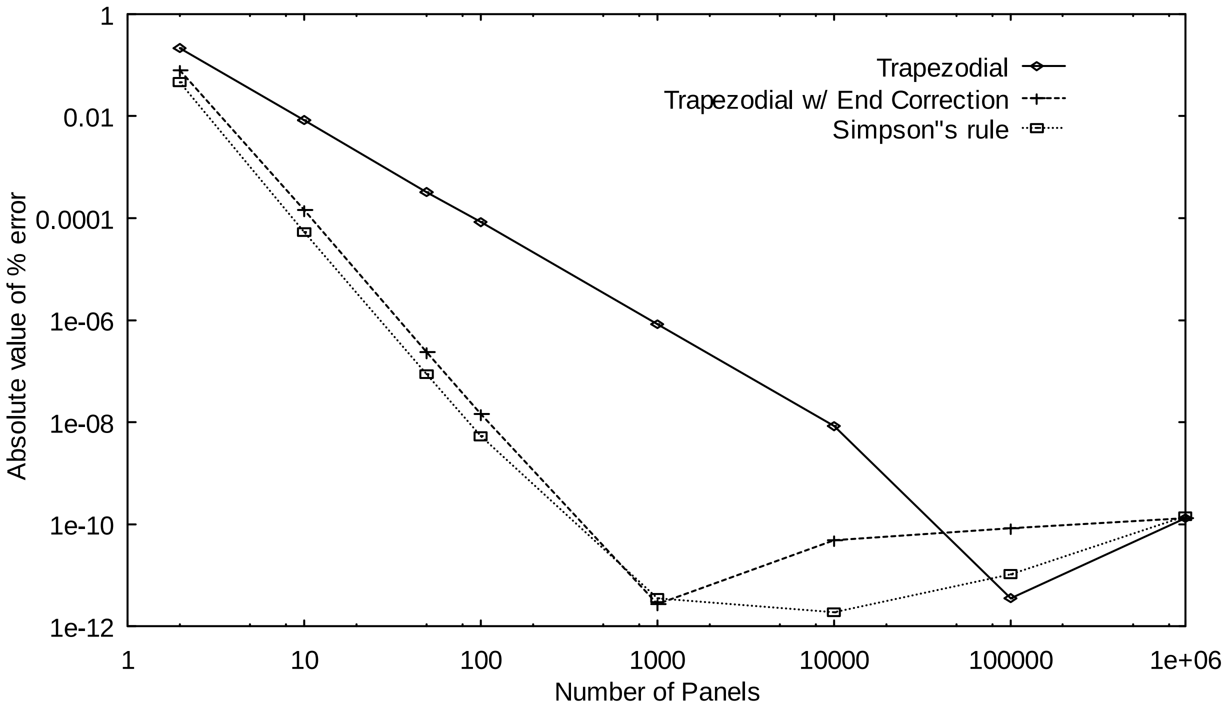


Figure 8 – Accuracy versus number of Panels for Several Numerical Integration Approaches

The honors section also dealt with the subject of numerical solution to ordinary differential equations. This included 1st and 2nd order linear and nonlinear equations. Extensions to higher order equations were discussed. The in-depth discussion focused of Euler's method and Runge-Kutta methods. More complex, but commonly used approaches were also mentioned. The students wrote programs to solve 1st order and 2nd order ordinary differential equations using a 4th order Runge-Kutta formula.

VI. Unexpected Student Resistance and It's Resolution

This paper discusses the author's initial experience integrating computational tools into sophomore-level engineering mechanics courses. He was generally pleased with the students' acceptance of the tools and their willingness to use them. While integrating computational composite moment of inertia calculations into the strength of materials course; an unexpected roadblock, which was resolved, arose that deserves discussion. The students were very reluctant to use the spreadsheet application to perform composite moment of inertia calculations. This reluctance was due to the their concern that use of the application would make them less proficient on similar questions on an examination. Given this concern and the fact that composite moment of inertia calculations were introduced in a prerequisite class, the author/instructor chose to remove composite moment of inertia calculations from the scope of possible examination questions. With this minor change in the testing procedure the students enthusiastically embraced the use of the application in the solutions of homework problems.

VII. Summary

Integration of computer tools into sophomore-level engineering mechanics courses has been discussed. This discussion included the philosophical underpinnings behind the decisions that have been made, including a course where such tools were not integrated. The tools included generic applications integrated into the existing strength of materials course, as well as user written programs in a special honors' section in the dynamics course. Examples of the tools used and the results generated have been presented. In addition, an unexpected roadblock to student usage and the resolution of it have been discussed. In closing the author believes that the computer tool integration was successful and the students have benefited from the experience.

Bibliography

1. Hornbeck, Robert W., *Numerical Methods*, Quantum Publishers Inc., New York, NY, 1975.
2. Hibbler, R.C., *Mechanics of Materials*, Prentice Hall, Upper Saddle River, NJ, 1997.

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