
AC 2011-1916: USING THE COMPUTER AS A TOOL ACROSS THE CURRICULUM

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Using the Computer as a Tool across the Curriculum

Abstract

An introductory course in mathematical tools is a common freshmen engineering course. Students are exposed to various mathematical and computer tools which should strengthen their ability to solve engineering problems in future courses. Examples of these tools would be MATLAB and Excel. In a review of the current curriculum at a 4 year institution, it was revealed that no current course in the sophomore year specifically utilized these tools. The students were at liberty to apply their skills with the tools, but were not required to use them. A concerted effort is being made to adapt the sophomore curriculum to include the use of these tools working from the basis that the students have garnered some mastery of them. This also puts the tools into context more than the introductory course was able to accomplish. Specifically, a sophomore level Thermodynamics course is being modified to develop several homework assignments that require the use of the computer as a tool. This modification will also address the ABET Program Outcomes that requires graduates to possess an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice and a recognition of the need for and the ability to engage in life-long learning.

This paper presents the different specific tasks that the students were asked to accomplish in the context of Thermodynamics with the described tools. The students were pre surveyed with regards to their knowledge base with the described tools and their application. Resource implications for teaching a course in such a fashion are discussed. Finally, student feedback to this approach is provided.

Introduction

A sophomore level course such as Thermodynamics seems the appropriate vehicle to reinforce the concept of the computer as an engineering tool. In this particular curriculum in the College of Engineering, the Thermodynamics course is required for mechanical engineering majors as well as being utilized as a service course for 3 other majors in the College of Engineering: Civil Engineering, Electrical Engineering and Applied Engineering Science. This is the first course in the curriculum that focuses on energy and energy related concepts. As noted in the appendix, the course learning objectives clearly place the emphasis on the basics of Thermodynamics and energy related topics^{A1}. Beginning in the Fall of 2009, all of these majors are required to take the introductory course in mathematical tools utilizing MATLAB. There was an optional opportunity to enroll in the changed curriculum in the Fall 2008. The purpose of incorporating these tools in an engineering course is to showcase the uses of MATLAB in the context of engineering applications. Learning objectives were developed for the introduction of MATLAB to the course^{A2}. In courses focused on learning the tool, rather than the application, students can become muddled in the nuances of the tool rather than its overall usefulness to the discipline. This is the impetus for adding this component to a required class in the sophomore level. Students were informed on the syllabus that certain assignments would be computer intensive and the point value for these problems would reflect the amount of expected effort. It was also noted on the homework assignments which problems were considered to be computer intensive.

In regards to previous work, considerable software has been developed for thermodynamic applications. These include property evaluation¹, power plant analysis², turbomachinery³, cylinder-piston engines⁴, and diesel engines⁵. MATLAB has also been used to carry out projects in thermal/fluid courses^{6,7,8}. There have been some attempts to more fully integrate MATLAB into mechanical engineering courses and these include the efforts at Alabama A&M⁹ and Florida A&M University and Florida State University¹⁰.

Students Pre-knowledge

In the first week of the semester the students were surveyed as to their knowledge and comfort level with MATLAB^{A3}. The students were asked when they had taken the MATLAB course, who the instructor was and then a series of questions concerning specific functions and operations to determine immediate recall of the information. The most telling question was for the students was to assess their own comfort level with the material based on the 0-4.0 scale that is used for grading in the 4-year institution where this is being instituted. Table 1 gives the raw data sorted by comfort level selection

Table 1 Students Comfort level with MATLAB Mapped to Grading Scale

Level of comfort	4.0	3.5	3.0	2.5	2.0	1.5	1.0	0.0
Number of students	3	7	9	10	13	3	7	4

The average comfort level was 2.25 with the median being 2.5 of the 56 students surveyed. It is not unusual for non ME majors to be taking this 200 level course in a year different then their traditional sophomore year. The requirement at the college level for the freshmen level course in MATLAB is only 2 academic years old, replacing a more traditional programming course: 7 students fell into this category of not having taken the MATLAB course. Of the remaining students, 9 were either transfer students from another university or in a major that had given them credit for the freshmen level MATLAB course with other courses in their curriculum.

The results of this survey clearly indicated that time would need to be spent on the use of MATLAB to solve problems; however, the course content in the basics of property evaluation and energy analysis could not be comprised. The key was to determine a balance where the students were benefiting from the computer as a tool and not a hindrance to their mastering of the energy related concepts. The latter being the true objective of the course.

Examples of Assignments

To begin the introduction of the computer as a tool, the students were given 26 temperatures in various units and asked to present the data in table form in all 4 units of temperature. This reinforces the relationship between the relative and absolute temperature scales and illustrates that large amounts of data which are tedious to work with by hand can be easily conquered with the use of the computer. Several students approached the problem by first converting the temperatures to one scale and then creating a vector in MATLAB to convert to the remaining scales. The table was then created in Excel or MATLAB. Students were required to verify that

they used the appropriate computer application by printing the workspace window from MATLAB.

A second example of a computer intensive homework assignment is to have the students produce an ideal gas phase diagram for Nitrogen, N_2 . This is a P-v diagram for 6 values of temperature and includes lines of constant enthalpy. This diagram is created with a for loop in MATLAB filling a two dimensional pressure array for a range of specific volumes and one given temperature. These are then plotted in MATLAB creating a legend indicating lines of constant temperature and enthalpy. The values for enthalpy are taken from the ideal gas charts in the required textbook for the course. In thermodynamics, this introduces a simple phase diagram for a substance reinforcing the relationship between pressure and volume and for an ideal gas illustrating that enthalpy is a function of temperature only. In lecture, this assignment is supplemented with discussion of the solution being 'far, far' from the vapor dome for the particular substance making the ideal gas model valid. The graph produced is superimposed over the actual phase diagram showing the validity of the ideal gas model.

A third example of a computer intensive homework assignment would be giving the students a set of P-V data to accompany the introduction of boundary work as part of the 1st law of thermodynamics. The students learn the functional relations for integrating boundary work for a given process, such as isobaric, isothermal, or isentropic. The presentation of the P-V data in table form requires that the students generate a plot of the data and perform the numerical integration. This is done in a MATLAB script file written by the students where the area under the curve can be determined by several different estimations. This topic is revisited when cycles are introduced and class discussion focuses on indicator diagrams for Internal Combustion engines.

Further MATLAB work was done allowing the students to use compiled script files for property evaluation in cycle analysis for homework assignments only. This was useful in illustrating the cycle concepts without the students being bogged down in the tedious nature of property evaluation with traditional tables. Property evaluation is emphasized in the beginning portion of the course utilizing the tables. Problem statements for computer intensive portions of the homework assignments are available in the Appendix^{A4}, assignments not discussed in detail are also included^{A5}.

Homework Assessment

On the described computer homework assignments, the average grades were 80.7%, 72.1%, 70.5%, 81% and 85%. The overall homework assignments average for all assignments was 79.5% with a range of 64% to 91.6%. The students did not seem to be overly burdened by the computer intensive assignments nor were their grades adversely impacted. It would appear by a visual inspection of the tabulated data (not included) that certain students choose not to do the more intensive portion of the assignments though benefited from using the compiled script files for property evaluation in cycle analysis.

Anecdotally, students were using Excel and MATLAB simultaneously to verify calculations and set up of problem solutions. This is a very useful technique for problem solving and

development of intrinsic verification of calculations. To go hand and hand with this, solutions to the assignments were presented using both Excel and MATLAB. Further anecdotal evidence presented itself early in the semester with a strong resistance to inclusion of MATLAB in course homework assignments. Understandable to a certain extent; however, the current traditional age generation of sophomore students should be well versed in computer usage from an early age.

Resource Implications

The instructor for the course prepared homework hints^{A6} for supplement assistance with MATLAB, suggesting appropriate functions and tools to be used. Detailed solutions for the homework assignments were also prepared in both MATLAB and Excel to illustrate the usefulness of the computer for the intensive calculations. The inclusion of Excel was a decision made early in the term to compensate for the students whom, for various reasons already discussed, were not acquainted with MATLAB. There was minimal impact in office hours time spent on MATLAB assistance.

The grader for the course was well versed in MATLAB applications and held office hours to address homework and MATLAB questions. The College of Engineering supplied help hours in one of the computer labs on a weekly basis to address student issues with MATLAB as well.

Conclusions-Lessons Learned

The use of computer intensive tools in an introductory Thermodynamics course, in general, appeared to enhance the students learning of concepts without over burdening the students with the nuances of the software. Pitfalls that occurred were students who were out of sequence with the curriculum changes began the course with less preparation than other students. This is an aspect of the change in curriculum that should dissipate with time. Students initial resistance to the type of assignments appeared to abate throughout the semester as their comfort level increased with the use of MATLAB and the supplemental resources that were utilized. The main focus of the course remains an introduction to Thermodynamics including property evaluation, energy analysis and system analysis. These new concepts presented to the sophomore level students in the course were enhanced with the ability to perform intensive calculations beyond paper and pencil.

The overall benefit to the students is the continued use of the computer as a tool should increase the students expanding knowledge base of problem solving. This will then lead to the opportunity to expand the intensity of assignments in courses further down stream in the curriculum and increase the preparedness of the students to be working professionals. This institution as well as other institutions of higher learning must continually prepare students to work in the information and technology age without depreciating the fundamentals of engineering and problem solving skills.

References

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Appendix

A1 Course Learning Objectives

1. Basic Concepts
 - a. Students can identify control volumes, closed systems, and transient systems
 - b. Students can apply the state principle
 - c. Students can work in different unit sets
 - d. Students can identify intensive and extensive properties
 - e. Students understand the concept of equilibrium
 - f. Students can apply conservation of mass
2. Property Evaluation
 - a. Students can recognize three types of substances: ideal gas, compressible substance, incompressible substance
 - b. Students can use tables to evaluate the properties of compressible substances, including identifying the phase of the substance
 - c. Students can use tables to evaluate the properties of ideal gases

- d. Students can use equations to evaluate the properties of compressible substances
- 3. First Law Analysis
 - a. Students understand the principles of work and heat
 - b. Students can calculate boundary work for a system
 - c. Students understand the conservation of energy
 - d. Students can apply the first law to closed systems
 - e. Students can apply the first law to control volume systems
 - f. Students can apply the first law to transient systems
- 4. Second Law Analysis
 - a. Students understand and can calculate the thermal efficiency for a heat engine and the coefficient of performance for a refrigerator and heat pump
 - b. Students understand the Clausius statement and the Kelvin-Planck statement of the second law
 - c. Students understand the concept of reversibility
 - d. Students understand the principle of the Carnot cycle and can make calculations of Carnot thermal efficiency and Carnot coefficient of performance
 - e. Students understand the entropy property and can evaluate it for different types of substances
 - f. Students can calculate and interpret the entropy change of the universe for a process
 - g. Students can apply isentropic efficiencies for control volume work devices
 - h. Students can calculate reversible work, irreversibility, and availability/exergy.
- 5. Analysis of Thermodynamic Systems
 - a. Students can perform calculations for steam power cycles
 - b. Students can perform calculations for gas power and propulsion cycles
 - c. Students can perform calculations for piston/cylinder power cycles
 - d. Students can perform calculations for refrigeration cycles
 - e. Students can perform calculations for psychrometric systems

A2 MATLAB Course Learning Objectives

- 6. MATLAB
 - a. Students can perform simple calculations using the MATLAB workspace.
 - b. Students can access functions and use them in the workspace.
 - c. Students can use the vectorization properties of MATLAB.
 - d. Students can produce simple graphs.
 - e. Students can solve an iterative problem in the workspace.
 - f. Students can write a simple script file using a FOR structure.
 - g. Students can do integration and differentiation symbolically.
 - h. Students can access and use a graphical user interface.
 - i. Students are very comfortable using MATLAB as an analysis tool.

A3 Pre-knowledge Survey

MATLAB in ME 201 Pre-survey

In what course did you learn MATLAB?

CSE 131 ME 399 EGR 102 Did not take a course

When did you take your MATLAB course?

Who was your MATLAB course instructor?

Sticklen Hinds Mulkamala Boehlert None

Other (specify): _____

What is the MATLAB symbol for multiplication?

What is the MATLAB symbol for raising a number to a power?

Give an example of a MATLAB function.

What is a script file in MATLAB?

What does a FOR loop in MATLAB do?

What is a GUI?

Can you write a script file in MATLAB? (circle one)

Yes *Learned, but forgot* No

Did you learn about vectorization in MATLAB? (circle one)

Yes *Learned, but forgot* No

Can you graph in MATLAB? (circle one)

Yes *Learned, but forgot* No

Can you take a derivative in MATLAB? (circle one)

Yes *Learned, but forgot* No

Using our 0.0 to 4.0 grading scale, how comfortable are you in using MATLAB for engineering calculations?

4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.0

A4 Computer Intensive Homework Problems

Problem statement 1 Vectorization

Convert the following temperatures to °F, °C, K, °R, provide final answers in a Table-40°F

- a. 298 K
- b. 1649°R
- c. 2785°F
- d. 459°R
- e. 100°C
- f. 0°F
- g. 273 K
- h. 212°F
- i. 303 K
- j. 649°R
- k. 27°C
- l. 98.7°F
- m. 325°C
- n. 625°R

Problem Statement 2 Graphing

Carefully draw the following graph using Nitrogen (N₂) as an ideal gas (Matlab would work well for this problem).

Specific volume (x-axis) versus pressure (y-axis) showing lines of constant temperature in K and constant specific enthalpy (h) in kJ/kg. The volume should range from 0.1 to 12 m³/kg and the temperatures should be chosen consistent with Table A-23 from the text (for instance, 220 K, 500 K, 800 K, 1100 K, 1400 K, and 2000 K at a minimum).

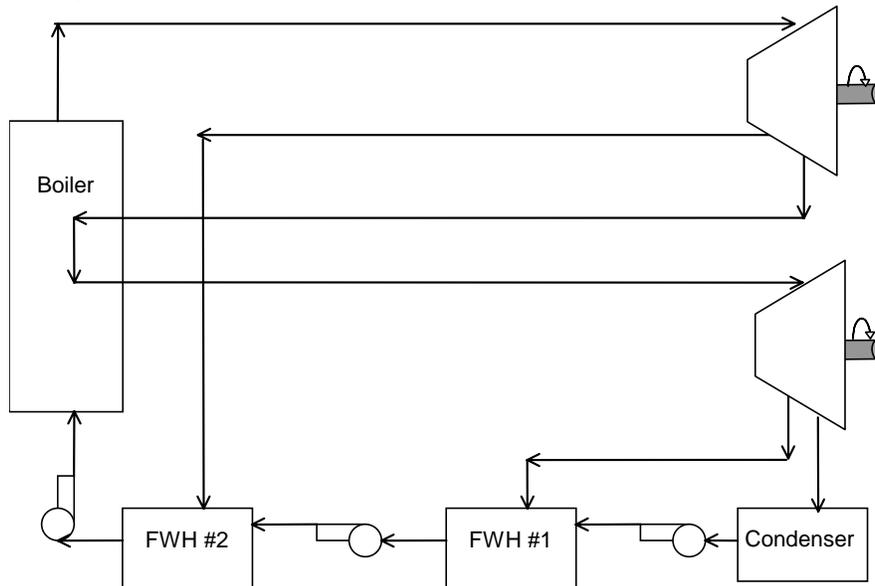
Problem Statement 3 Numerical Integration

Determine the boundary work done by a substance during a process if the pressure and volume values at various states are measured to be as follows:

P (kPa)	V (L)
1900	0.5
1350	0.62
1200	0.68
1000	0.75
875	0.86
780	0.9
684	1.02
575	1.1
536	1.19
480	1.25
450	1.3
300	1.5
294	1.6
276	1.7
200	2

Problem Statement 3 Use of compiled tables

A steam power plant operates on a reheat-regeneration (see diagram) Rankine cycle with one reheater and two open feedwater heaters. Steam enters the high-pressure turbine at 10 MPa and 650°C and leaves the low-pressure turbine at 12 kPa. Steam is extracted from the turbine at 1.5 MPa and at 215 kPa for use in the feedwater heaters. The reheat leg operates at 820 kPa and the steam is reheated to 650°C. The high-pressure turbine has an isentropic efficiency of 0.87 and the low-pressure turbine has an isentropic efficiency of 0.92. All pumps have an isentropic efficiency of 0.95. Determine (a) the net work of the system and (b) the thermal efficiency. The total mass flow rate out of the boiler is 10 kg/s.



A5 Additional Problem Statements

Additional Problem statement 1 Symbolic Integration

Using the integral approach, write a MATLAB function to calculate the internal energy (in kJ/kg) for propane as an ideal gas at any temperature in Kelvins between 273 K and 1500 K. Generating numbers from your own program, complete the following table:

T(K)	u(kJ/kg)
273	
290	
350	
555	
873	
1222	
1498	

Additional Problem statement 2 Use of compiled Tables

Using the MATLAB Steam Functions determine the enthalpy change (in kJ/kg-K) and final state as steam at 764°C and 10 MPa undergoes an isentropic process to 0.95 MPa

A6 MATLAB Hints and Tip Sheets

Matlab Hints

Some of you are very comfortable with Matlab and some not so much. It really is relatively straightforward to use, what follows is an outline that will work, however, it probably is not the only way to go about using Matlab to complete this task.

1st convert all the temperatures to one set of units, this can be done by hand or in Excel. Let's say you pick Celsius.

In Matlab, declare a vector by typing in the workspace (right panel in Matlab) and hit enter, it will return the vector as a statement. Below is an example of a vector statement that has the numbers 20, 40, 60, 80. This is what is known as 'vectorization'

```
>> TC=[20 40 60 80]
```

Now, to convert these temperatures in C to Kelvin in the same workspace type

```
>> TK=TC+273.15
```

This will return each entry in the vector TC plus 273.15 in a new vector with the name TK, then continue for Rankine and Fahrenheit.

As a note, if you have all the temperatures in Excel in a column in one set of units as numbers and copy them into the Matlab workspace, it will declare the vector as well.

```
>>TC=[ <paste column from excel>]
```

You can then copy the resulting data back to Excel and create a nice table of data. This is also a nice way to check your work, as the values that were originally in Fahrenheit, Rankine and Kelvin should convert back to the original values and then you know you did it right.

Guide to MATLAB Problem

The differential in the internal energy for an ideal gas is given by

$$du = c_v dT = (c_p - R) dT$$

To get the value of the internal energy at a specified temperature, T_1 , we will integrate this equation from a base or reference state (denoted by the subscript o) to the state for T_1 . This gives

$$\int_o^1 du = \int_{T_o}^{T_1} (c_P - R) dT$$

$$u_1 - u_o = \int_{T_o}^{T_1} (c_P - R) dT$$

Choosing the internal energy at the base state to be zero, we have

$$u_1 = \int_{T_o}^{T_1} (c_P - R) dT$$

Table A-2 (pg 911) provide us with a cubic expression for the c_P , which is

$$\bar{c}_P = a + bT + cT^2 + dT^3 \quad \text{in kJ/kgmole K}$$

Note that this is given on a mole basis, but we want our internal energy on a mass basis, so that we will need to use

$$c_P = \frac{\bar{c}_P}{MW}$$

We can then rewrite our integral as

$$u_1 = \frac{1}{MW} \int_{T_o}^{T_1} (a - R_u + bT + cT^2 + dT^3) dT$$

We can then carry out the integration to obtain an expression for the internal energy at a specified temperature (T_1). For the base or references state (T_o), it is suggested to use the smallest temperature for which the function can be used, 273 K.

To write this as a MATLAB function we must start our script file with the function command. This might take the form

```
function [u] = IntEnergy(T)
```

Next we should assign the numerical values to our constants

```
MW = 44.097
```

```
Ru = ...
```

```
a = ...
```

```
:
```

```
:
```

Finally, we calculate our internal energy

```
u = ((a-Ru)*(T-273) + b*(T^2-273^2)/2 + ...)/MW
```

For help in using functions in MATLAB, please review the Function MATLAB Tip Sheet on the course web site.

Guide to MATLAB Problem

From the ME 201 web site the student can download the MATLAB program steam.m and it user's guide.

MATLAB Function Tips

A very convenient way to handle a series of calculations that are going to be repeated several times in a MATLAB program is to utilize the MATLAB function capabilities. In MATLAB a function is a series of calculations that are put together in a single subprogram. The general form of a function is shown below

```
function [list of variables leaving the function] = Name of Function(list of variables needed in the function)
```

For example, say we want to create a function that will calculate the square and cube of a variable x. Then

```
function [xsqrd, xcubd] = square(x)
```

```
xsqrd = x^2  
xcubd = x^3
```

There are two possible places to position this code. If you are using MATLAB 5.0 or later this function code can be placed at the end of the main program, in the same file as the main program. It could also be placed in its own file which must use the function name or for our example, square.m. Of course this file must be in the MATLAB path.