

The Development of MATLAB Functions for Effective Use and Improvement of Student Learning in a Thermodynamics Course

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Abstract

One of the most time consuming and tedious aspects of problem solving in thermodynamics is looking up properties within extensive tables and using them for various computations. Many students view this aspect of thermodynamics to be an abstract collection of data that are difficult to understand and apply to engineering problems. Currently there are software available for purchase that can be used to determine thermodynamic properties. However, these are limited to specific inputs and outputs. This project involves developing several functions in MATLAB that can use any two independent thermodynamic properties to determine the other properties. The use of such functions enables students to not only solve problems such as the power plant analysis but also perform design analysis by varying one property versus another and observing its effect on relevant outputs.

Keywords

Thermodynamics tables, thermodynamic properties, MATLAB functions for thermodynamics.

Introduction

Many students view thermodynamics to be an abstract course to understand and appreciate¹. In addition to the difficult concepts in classical thermodynamics, one of the most time consuming and tedious aspects of problem solving in such courses is looking up properties within extensive tables and using them for various computations. This task becomes even more tedious, when the desired properties are not exactly in the tables and interpolation is required. For example, a typical power plant analysis may involve finding 2-3 properties at 20 different states and then using these to compute the efficiency, power developed, fuel used, etc. for the power plant. Such a problem can take about 2-3 hours to complete.

Currently there are several software available for educational use to determine thermodynamic properties²⁻⁷. However, these are limited to specific inputs and outputs, which have then to be either re-defined as inputs into another program in order to perform any other computation or used in hand-calculations. This project involves developing several functions in MATLAB that can use any two independent thermodynamic properties to determine the other properties. The use of such functions enables students to not only solve problems such as the power plant analysis mentioned above in about an hour but also perform design analysis by varying one property versus another and observing its effect on relevant outputs. In addition, the functions developed herein will be made available freely for students and would also serve as another application of MATLAB which students learn in their freshmen year. This intra-disciplinary approach to student learning has also been proven to be effective in long-term retention of

concepts across courses. Surveys including individual comments from students and relative student performance are used to evaluate and assess the impact this work.

The following sections present a description of the course under consideration, an overview of the thermodynamics module in MATLAB Marina, assessment based on student surveys, and a few concluding remarks with an outline of future work.

Course Description: Fundamentals of Thermodynamics

Fundamentals of Thermodynamics (ENGR3322) is a 3-credit hour course taken by sophomore and junior engineering and physics students at Armstrong State University (Armstrong). The main objective of this course is to study the fundamental concepts of thermodynamics, properties of substances, principles of conservation, entropy, second law analysis of systems, gas and vapor cycles.

The following are specific course outcomes that students should be able to demonstrate after successful completion of the course:

1. An understanding of the basic principles of classical thermodynamics:
 - Concepts of conservation of mass, conservation of energy, and the second law of thermodynamics;
 - Concepts of work interaction and heat transfer; and
 - Methods for determining thermodynamic properties of simple compressible substances.
2. The ability to identify, formulate and solve engineering problems in classical thermodynamics:
 - Closed and open systems for steady state and transient process;
 - Work interactions and heat transfer;
 - Thermodynamic properties of simple compressible substances including incompressible substances and ideal gases; and
 - Principles of conservation of mass and conservation of energy.
3. The application of the second law of thermodynamics:
 - Entropy as a property;
 - Reversible vs. irreversible processes; and
 - Entropy produced as a measure of irreversibility.
4. The analysis of power, refrigeration and heat pump cycles:
 - Vapor power systems based on the Rankine cycle;
 - Gas power systems based on the Brayton cycle; and
 - Refrigeration, Air-conditioning and heat pump applications.

An approach to objective 1 is through the use of these principles in the specific topics covered under objectives 2 and 3. Objectives 2 and 3 are met by in-class problem solving and homework assignments. An overview of Objective 4 is met by in-class problem solving with further details covered in 1-2 projects.

Many students view this course to be a collection of abstract concepts, laws and data that are difficult to understand and apply to engineering problems. It is proposed that using a supplement

set of MATLAB functions to read and use the data and solve realistic problems would be beneficial to student's learning and appreciation of the course material. For example, students complete a computational project involving power plant design towards the end of the semester that addresses a significant portion of the concepts learned through the entire semester. In past semesters, such a project was limited in scope due to the tedious calculations required. The use of these functions allows students to focus on the problem solving and analysis and make realistic design recommendations.

Overview of the Thermodynamics Module

The functions are currently housed as an application module on MATLAB Marina – a Virtual Learning Environment (VLE) that comprises of modules that introduce programming using MATLAB for engineers⁸. MATLAB Marina is the primary resource used in the course Computing for Engineers (ENGR1371) where engineering students learn programming using MATLAB at Armstrong. It also serves as a supplemental resource for several sophomore courses such as Computational Modeling (ENGR2010), Signal Processing (ENGR2030) and Statics (ENGR2001). Hence, all students at Armstrong are familiar with the VLE and use it extensively to also review MATLAB as needed.

The thermodynamic property tables were converted to Excel worksheets and include properties in both SI and English units. These worksheets are also available on the above mentioned module. The MATLAB functions have been converted to an executable and encrypted format (p-code) and posted on the website along with detailed syntax information. This allows users to use but not edit the functions.

Currently, the functions encompass the superheated and saturated regions for water, refrigerants R 22 and R 134a, ammonia and propane. The functions for the superheated regions are set up to take as inputs two independent properties: (i) the pressure and (ii) temperature, specific volume, internal energy, enthalpy or entropy at the given state and compute as the output a structure with all properties at that state. The functions for the saturated regions take as inputs: (i) either the temperature or pressure (dependent properties in said region) and (ii) one of the other independent properties: specific volume, internal energy, enthalpy, entropy or quality (mass fraction). The output is computed as a structure with all properties at that state. Linear interpolation is used for data that are not directly available in the tables. A Boolean variable message is set to 1 (true) if the given state is in the region as assumed (superheated or saturated) or 0 (false) if the state is not in the region assumed. This feature allows the user to also use these functions to determine whether the given state is in a given region or not.

Assessment

To assess the effectiveness of the functions, surveys were given to students to complete and return anonymously. A summary of results of this survey is provided in Tables 1 and 2. Note that only a preliminary set of functions (for water only) were available at the end of the semester in Spring 2013. A more exhaustive set (water and other refrigerants) was provided towards the mid-semester in Spring 2014. It is observed from the results, that 90% of the respondents in Spring 2013 and 100% in Spring 2014 found the functions very or extremely helpful for assignments, projects and exams. In addition, a majority of the respondents said that they would

have used the functions often if they had been provided at the beginning of the semester. A significant number of the respondents do see the benefits of extending these functions to include ideal gas properties as well.

<i>Questions</i>	<i>Options</i>	<i>Spring 2013 # of responses (% of N=10)</i>	<i>Spring 2014 # of responses (% of N=8)</i>
How helpful were the MATLAB functions provided for the assignments/project/exams in Thermodynamics?	Extremely helpful Very helpful Moderately helpful Slightly helpful Not at all helpful	6 (60%) 3 (30%) 1 (10%) 0 (0%) 0 (0%)	4 (50%) 4 (50%) 0 (0%) 0 (0%) 0 (0%)
If these MATLAB functions were provided at the beginning of the semester, how often would you have used them for assignments/projects?	Extremely often Very often Moderately often Slightly often Not at all often	2 (20%) 2 (20%) 5 (50%) 0 (0%) 1 (10%)	5 (62.5%) 2 (25%) 0 (0%) 1 (12.5%) 0 (0%)
In your opinion, what other user-written MATLAB functions would be useful for Thermodynamics? (pick one or more as applicable)	Compressed liquid tables Ideal gas tables Saturated vapor: Pressure tables Saturated vapor: Temperature tables Other (please specify)	7 (70%) 9 (90%) 5 (50%) 4 (40%) 0 (0%) 	5 (62.5%) 8 (100%) 2 (25%) 3 (37.5%) 0 (0%)

Table 1: Summary of results from the survey for Spring 2013 and Spring 2014.

A few sample student comments and answers to specific questions are shown in Table 2. While these comments certainly support the efficacy of these functions, they do show the need to continue the use of hand calculations using the tables prior to the implementation of these functions in order to develop a good understanding of the concepts. Hence, the functions will be introduced only after the fundamental topics have been covered in the class (after mid-semester). This ensures that students will continue to learn and appreciate the importance of property characterization in thermodynamics. This approach is implemented in the current semester (Spring 2015) by using hand calculations with the tables for all in-class problem solving, homework assignments and the mid-term exam. After the mid-term, the functions will be used for all these student assessment and learning tools including future exams.

<p><i>Q. Based on your experience, what was or would be the primary advantage of using these MATLAB functions?</i></p>
<p>“Ease and efficient fixing of states. More ordered method of solving problems rather than flipping through pages and getting bogged down with writing down numbers. Also being able to setting each state as a structure variable in matlab was very advantageous of keeping track of states.”</p> <p>“By using the functions, the time to work the problems is cut down extremely.”</p> <p>“learning the power cycles very well.”</p> <p>“I would use these functions to check the practice problems I complete in the book.”</p>
<p><i>Based on your experience, what was or would be the primary disadvantage of using these MATLAB functions?</i></p>
<p>“The only possible problem would lie in whether the student is knowledgeable in MATLAB.”</p> <p>“Students could develop a reliance on the functions.”</p> <p>“not learning how to read the tables correctly, the functions moderately stated there was an error and to check if state is 'inside' the vapor dome...which can make you second guess yourself”</p> <p>“hands on learning is probably a little more effective than just punching numbers into the function”</p> <p>“The disadvantage might be that you would use these functions to often and not have enough experience setting states on your own with the given information.”</p>
<p><i>Other written comments</i></p>
<p>“At the beginning of the semester, by hand calculations helped me see what was happening in the problems and get a feel for the tables. I would mostly use these to check my answers at that point. Later in the semester they would definitely get used.”</p> <p>“Not as advantageous as towards the end of the class because you need to learn the basics before you can get "lazy.””</p> <p>“Using the functions during projects and assignments provided for great practice in the exam when there are 12 state.”</p>

Table 2: Summary of written comments from students in Spring 2013 and Spring 2014.

In addition to the surveys, relative student performance has also been evaluated to assess the effectiveness of the supplement on student learning. It was observed by the instructor that 90% of the students developed an excellent understanding of the use of these properties in practical applications such as power plant design and analysis. Anecdotally it was also noted that all students began to focus primarily on understanding the concepts better and not complain about the time consuming, tedious, ‘plug and chug’ problems.

Concluding Remarks and Future Work

In this paper, the authors present the development and implementation of a set of thermodynamic functions using MATLAB that allow the user to determine properties at particular states. These functions serve as a vital supplement to the course ENGR3322 and will improve student's understanding and appreciation of concepts, student performance and retention rate. Assessment results and student comments show that the functions have been beneficial to and well received by students. The primary advantage of these functions is that they provide a balanced understanding of both determination of thermodynamic properties at given states and their use in engineering applications such as power plant design. Pedagogically, this project represents current trends in an intra-disciplinary approach to education where tools learned in prior courses (MATLAB) are directly used in current courses to reinforce concepts.

At least one section of ENGR3322 is taught every year at Armstrong with an average enrollment of 25 students. The functions developed have been in use since Spring 2013 and will continue in subsequent years. Future assessments including student surveys and relative student performance will be used to evaluate and assess the impact of this work. It is proposed that the functions will be extended to include the compressed liquid (sub-cooled) regions. Similar functions for ideal gases as well as functions that can be used for certain processes such as isothermal, adiabatic, isobaric, etc. will also be developed in the future. The success rates of the course will be compiled and studied to identify potential improvements. Traffic on the website where the module is housed is also monitored using Google Analytics. After successful implementation and assessment, the module will be made available to the global engineering education community.

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