

MATLAB Graphical User Interfaces (GUIs) for Problem Solving in Thermodynamics

Priya T. Goeser and Anderson Duong

*Professor, Department of Mechanical Engineering, Georgia Southern University / Undergraduate student,
Mechanical Engineering, Georgia Institute of Technology*

Abstract

In courses on thermodynamics students routinely consult and interpolate many values from several property tables for problem solving. This can become very tedious and time consuming leaving little room for problem solving with applications. Hence, several MATLAB functions were developed by the first author over the past few years to ease this process. While the functions significantly improved the learning process they did require a fundamental understanding of MATLAB's advanced features such as using different data types and user-written functions. In this work, graphical user interfaces (GUIs) are developed in MATLAB that can replace the functions. The use of the GUIs require little prior knowledge of MATLAB and also enable the instructor to allow students to work on complex problems in-class and facilitate active learning without spending significant amounts of time determining properties required for each problem.

Keywords

Thermodynamics tables, thermodynamic properties, MATLAB GUI 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.

Most engineering curriculums require students to complete a course covering programming in MATLAB. MATLAB is a technical programming software that offers a wide variety of computational tools. Thermodynamics is another required course for all mechanical engineering students and an elective for other engineering disciplines. Currently, all students who take this course are quite familiar with MATLAB. However, as part of recent changes the new engineering curriculum does not require all students to take the MATLAB programming course. Hence most engineering students will not be as familiar with programming in MATLAB in the future as they have been in the past.

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.

A few years ago, it was proposed by the first author that using a 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 material⁸. After these were successfully developed and implemented, a significant change was made to the overall engineering curriculum involving the programming requirements. Students are now only introduced to the fundamentals of programming using MATLAB. The MATLAB functions however require a certain proficiency in MATLAB's data types such as structures and the use of user written functions.

This project involves developing a GUI in MATLAB that can use any two independent thermodynamic properties to determine the other properties. The use of such a tool enables students to not only solve problems such as the power plant analysis mentioned above in about an hour but also perform design analysis for certain applications. In addition, the GUI developed herein will be made available freely for students and would also serve as another application of MATLAB which students are introduced to 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 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 GUI, assessment based on student surveys, and a few concluding remarks with an outline of future work.

Course Description: Thermodynamics

Thermodynamics is a 3-credit hour course taken by sophomore and junior engineering students at Georgia Southern University (GSU). 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. 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. The use of MATLAB functions/GUI allows students to focus on the problem solving and analysis and make realistic design recommendations.

Overview of the GUI

The original 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 engineers⁹. These have been used consistently at GSU – Armstrong Campus as well as in a few other schools globally. The GUI's however were made available only to the students enrolled in the course at GSU-Armstrong Campus in Spring 2018 and Fall 2018. Once tested and evaluated thoroughly these will also be made available on the VLE.

The thermodynamics GUI uses these functions to determine properties at a given state. MATLAB's built-in GUIDE was used to create the initial layout for the GUI. An example layout is shown in Figure 1. The GUI has 3 main drop down menus: (1) Substance: water, refrigerants R22 and R134a, ammonia or air (2) Appropriate region in the phase diagram such as superheated, saturated or subcooled (3) Unit system used – SI units or English units. The dynamic input boxes change based on the options selected for the menu (1) and (2). These input boxes require a combination of text inputs for the names of properties and data inputs for the known property values. The option for the superheated region is 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. The option for the saturated region takes 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). Linear interpolation is used for data that are not directly available in the tables. The GUI reads the properties using Excel worksheets and computes the relevant properties based on the menu options as well as the data in the input boxes. All outputs are displayed in the corresponding output boxes including units as shown in Figure 1. There is also an export

functionality on the GUI that allows the user to export all data as a structure which is saved in the current workspace in the MATLAB IDE. A Boolean variable message is displayed as 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 the GUI to determine whether the given state is in a given region or not.

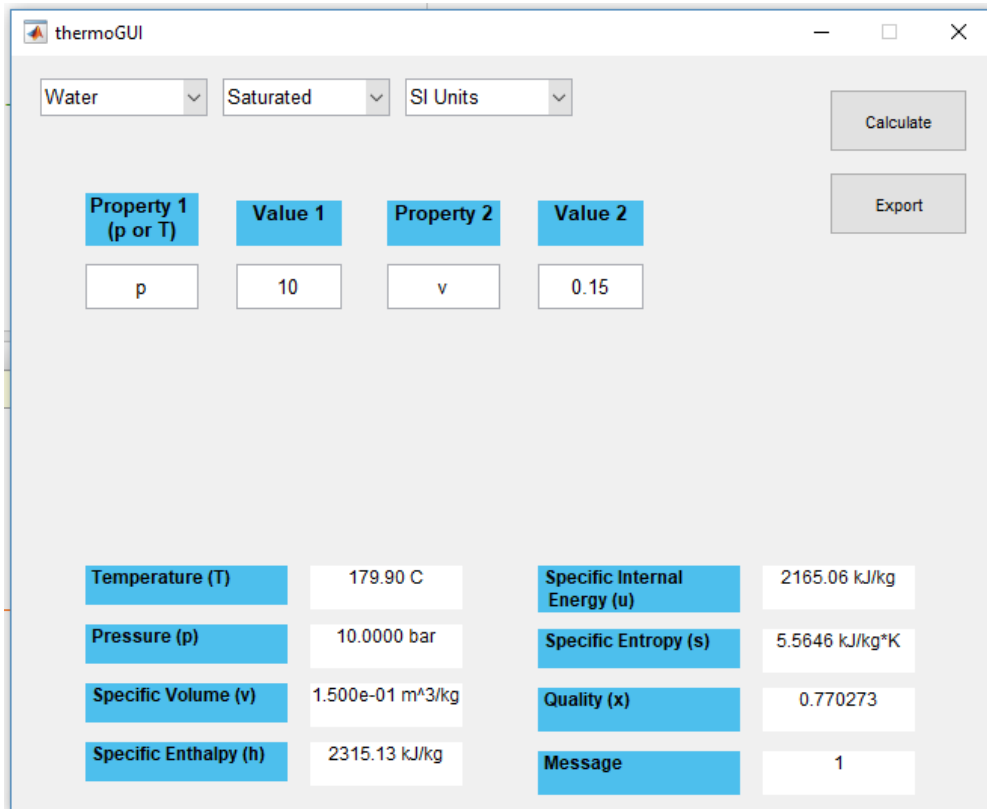


Figure 1 Example layout of the GUI with calculations completed

Assessment

To assess the effectiveness of the GUI, 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 form of the GUI was available at the end of the semester in Spring 2018. A more complete form of the GUI was provided to the students mid-semester in Fall 2018.

Unfortunately, due to recent changes in the university, the engineering program has had a significant drop in enrollment hence the sample sizes are very small (4 students in Spring 2018 and 3 in Fall 2018 and 6 of them have completed the survey as of January 7, 2019). Hence, any observations are preliminary. It is observed from the results, that all 6 respondents found the GUI very or extremely helpful for assignments, projects and exams. In addition, 5 of the 6 respondents said that they would have used the GUI very often or extremely often if they had been provided at the beginning of the semester.

Table 1: Summary of results from the survey for Spring 2018 and Fall 2018.

<i>Questions</i>	<i>Options</i>	<i># of responses (% of N=6)</i>
How helpful was the MATLAB GUI for assignments/projects/exams in Thermodynamics?	Extremely helpful	3 (50%)
	Very helpful	3 (50%)
	Moderately helpful	0 (0%)
	Slightly helpful	0 (0%)
	Not at all helpful	0 (0%)
If the MATLAB GUI was provided at the beginning of the semester, how often would you have used them for assignments/projects?	Extremely often	2 (33.33%)
	Very often	3 (50%)
	Moderately often	1 (16.67%)
	Slightly often	0 (0%)
	Not at all often	0 (0%)

A few student comments and answers to specific questions are shown in Table 2. While these comments certainly support the efficacy of these GUIs, 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 GUIs are 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.

Table 2: Summary of comments from students in Spring 2018 and Fall 2018.

<p><i>Q. In your opinion, what other MATLAB GUI would be useful for Thermodynamics?</i> “Perhaps a GUI for design problems that would allow the user to select a cycle type (carnot, rankine, otto, diesel, etc.) as well as process/devices that can be selected and added to the basic cycle. From there the GUI would calculate important values such as efficiency and quality and can be used for very complex, real world designs.”</p>
<p><i>Q. Based on your experience, what was or would be the primary advantage of using the MATLAB GUI?</i> “Spending less time in the charts. (time management)” “The GUI allowed me to work through much more problems in my studies simply because I did not have to flip through pages and look through tables, thus saving time and allowing for more opportunity to understand/practice new concepts. That being said, it is not a cheat sheet (you still have to understand what is going on in the problem and how to fix states) , but an effective way of utilizing technology that allowed me to work through a larger variety of problems in the limited time that I have to dedicate to this course.” “It speeds up the initial, time consuming solution processes. This is significantly important because thermo problems can take multiple class periods” “It finds every property pretty quick so it shortens the time I spend to solve a problem.” “Quickly obtaining information about the species pertaining to the problems”</p>

Q. Based on your experience, what was or would be the primary disadvantage of using the MATLAB GUI?

“Potential glitches or miscalculations”

“In terms of learning the course material, there are no disadvantages of the GUI.”

“Some inputs were, at one point, not returning the right outputs when I was taking the class, but this may have been fixed since.”

“GUI Display Layout”

Q. How would you compare the effectiveness of the GUI vs. the functions themselves?

“the GUI provides a more user friendly experience”

“Both are quick and easy to use, however, the GUI is quicker and thus more effective considering that everything is contained in one interface rather than having to manually call functions for every use. Also, I believe the GUI will be much easier/effective for people that are not familiar with MATLAB to use in comparison to the functions.”

“The GUI allows users who are not as proficient in MatLab to be able to use a tool to speed up the problem solving process”

“Functions take less time overall to utilize, the GUI offers convenience to switch substances and show units”

“Both were very effective, however, the GUI was more user friendly. I believe one without any prior knowledge of matlab would find this simple to use.”

Other comments and suggestions

“I have spoken with friends and other peers that either took thermodynamics prior to the GUI or at a different university (most of them saw me using to GUI in the ELC and asked me about it). They all seemed to agree that their main impedance while studying was due to the amount of time it takes to fix states in these problems prior to actually solving/ focusing on the "meat" of the problem.”

Concluding Remarks and Future Work

In this paper, the authors present the development and implementation of a thermodynamic GUI using MATLAB that allow the user to determine properties at particular states. The GUI serves as a vital supplement to the course Thermodynamics and will improve student’s understanding and appreciation of concepts, student performance and retention rate. Preliminary assessment results and student comments show that the GUI has been beneficial to and well received by students.

The GUI developed has been in use since Spring 2018 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 GUI will be extended to include analysis of certain processes such as isothermal, isobaric, isentropic etc. in the future. The success rates of the course will be compiled and studied to identify potential improvements. After successful implementation and assessment, the GUI will be made available for use in similar courses at other universities.

References

- 1 Dukhan, N. and Schumack, M., “Understanding the Continued Poor Performance in Thermodynamics as a First Step toward an Instructional Strategy”, American Society for Engineering Education Annual Conference, Atlanta, GA, June 2013.
- 2 McClain, S., “A MATHCAD Function Set for Solving Thermodynamics Problems”, American Society for Engineering Education Annual Conference, Chicago, IL, June 2006.
- 3 McClain, S. and Smitherman, C., “MATHCAD Functions for the Thermodynamic Properties of Moist Air, Ammonia, Propane and R-22”, American Society for Engineering Education Annual Conference, Honolulu, HI, June 2007.
- 4 Stanley, R. and DiGiusepee, G., “An Efficient Way to Increase the Engineering Student’s Fundamental Understanding of Thermodynamics by Utilizing Interactive Web Based Animation Software”, American Society for Engineering Education Annual Conference, Louisville, KY, June 2010.
- 5 C. C. Ngo and F. C. Lai, “Web-Based Thermodynamics Tables Wizard”, American Society for Engineering Education Annual Conference, Montreal, Canada, June 2002.
- 6 Tebbe, P.A., “Development of Software Applications for Thermodynamics Related Courses: The THERMOVIEW Project”, American Society for Engineering Education Annual Conference, Albuquerque, NM, June 2001.
- 7 Craig W. Somerton, Chiew-Ping Bong, Laura J. Genik, “A MATLAB Toolbox for Thermodynamic Property Evaluation”, American Society for Engineering Education Annual Conference, St. Louis, MO, June 2000.
- 8 Goeser, P., and Ruiz, S., “The Development of MATLAB Functions for Effective Use and Improvement of Student Learning in a Thermodynamics Course”, 2015 ASEE Southeast Section Annual Conference, Gainesville, FL, April 12th-14th, 2015. (Refereed conference proceedings, regional).
- 9 MATLAB Marina: www.matlabmarina.com

Priya T. Goeser

Priya T. Goeser is a Professor in the Department of Mechanical Engineering, Georgia Southern University – Armstrong Campus, Savannah GA. She received her Ph.D. in Mechanical Engineering from the University of Delaware and her B. Tech in Mechanical Engineering from the Indian Institute of Technology, Chennai, India. Her current research interests are structural health monitoring, functionally graded materials and innovative teaching methods in engineering education. She is the primary instructor for the thermodynamics course at the Armstrong Campus and is the project director of MATLAB Marina.

Anderson Duong

Anderson Duong is an undergraduate (junior) student currently pursuing a B.S. degree in Mechanical Engineering at the Georgia Institute of Technology, Atlanta, GA. He completed his first two years of the Engineering Curriculum as a part of the Region Engineering Pathways Program (REPP) at Georgia Southern University – Armstrong Campus. He worked as an engineering student tutor during his sophomore year at the Armstrong Campus. His current interests include working on power systems and turbomachinery. His future plan is to pursue an M.S. degree in Mechanical Engineering with a concentration on thermal sciences.