Abstract

The Aeronautics Department at the United States Air Force Academy has found some success using workshops in its regular offering of introductory classical Thermodynamics. This course is taught annually to about 900 cadets, less than a third of whom are engineering students. To help motivate student interest and improve student learning, in-class workshops have replaced 8 of 42 lecture periods. The workshops engage small teams of students in hands-on learning experiences. For instance, the first workshop requires student teams to start from a general form of the 1st Law of Thermodynamics and obtain a proper reduced energy statement for a common household device such as a bicycle pump or a hair dryer. Other workshops are more rigorous and include data-reduction, graphing, analysis, and design activities. Good teamwork and communication are essential elements in the workshops. Some workshops require the student teams to present and explain their results to the class thereby allowing the students to learn from each other. Thus far, workshops have been piloted in two Summer 98 sections and used in 25 sections of the Fall 98 term and 18 sections in the Spring 99 term. Student assessments of the workshops are mixed. Summer term students viewed the workshops as valuable, fun, and a good way to learn. Fall and Spring term student opinions are less positive. Even though student attitudes towards the subject (normally low) and test performance improved, the issue of time became a problem for the fall term. In the fall sections, the strict 50-minute class period creates a time constraint that is not present in the Summer sessions. Some provisions have been developed to better cope with the time constraint, but preliminary feedback from the Spring term indicate more changes are necessary. Overall, the use of workshops appears to be an improvement because students are actively involved and more directly responsible for their learning, resulting in a better understanding of thermodynamic principles.

I. Introduction

The purpose of this paper is to describe how the use of workshops may improve the learning experience of United States Air Force Academy (USAFA) cadets taking an introductory course in classical thermodynamics. The course is titled Energy Systems and is denoted Engr310. Following a newly designed departmental course assessment program\(^1\), the goal of Engr310 is to instill in the students the fundamental principles of thermodynamics and the relevance of these principles to energy systems. The goal is attained by requiring students to successfully complete the objectives presented in Table 1.
Table 1  Course Goal and Objective Statements

<table>
<thead>
<tr>
<th>Goal</th>
<th>By completion of Engr310, you should understand the fundamental principles of Thermodynamics and their relevance to energy systems.</th>
</tr>
</thead>
</table>
| Objectives | By the end of the course, you should be able to:  
1. Explain the 1st and 2nd Laws of Thermodynamics.  
2. Explain the concepts and terms of Thermodynamics.  
3. Use the 1st and 2nd Laws of Thermodynamics to solve problems.  
4. Complete an ill-defined energy systems design project.  
5. Constructively participate in group work.  
6. Effectively communicate technical information. |

Presuming that students learn best by “doing” (hands-on), workshops became a desired pedagogical approach to engage students in active learning and were incorporated in the course structure in Summer 98, Fall 98, and Spring 99. The workshops are designed as in-class activities that allow students to learn from experiences rather than exclusively from lectures, homework, and texts.

This paper explains the design and application of the workshops. It also presents some assessment results. Before describing the workshops, however, a brief background on the academic program at USAFA is provided as a basis to understand the academic challenges confronting the design and presentation of this fundamental engineering course.

Background- USAFA is a military professional service school with the singular mission of producing Air Force Officers. The four-year program at USAFA is based on four elements: academics, officer development, physical conditioning, character development. In the academic element, cadets select a major area of study from 23 separate programs grouped into four divisions: basic sciences, engineering, humanities, social sciences. Regardless of the major field of study, however, all cadets must complete a core of courses (USAFA Core) that provide the background and foundation of their undergraduate degree.

The USAFA Core - USAFA graduates earn one degree, the Bachelor of Science degree. The core consists of 31 courses comprising about 65 percent of the academic requirements. The core provides coverage on subjects sponsored and taught by the basic sciences, social sciences, humanities, engineering, and military arts and sciences divisions. Cadets complete their academic program by taking an additional 16 courses, nominally, in their chosen major. For the engineering core, cadets take foundation courses in aeronautics, astronautics, air base civil engineering, electrical circuits and systems, statics and materials, and thermodynamics and energy systems.

The Challenge - Engr310 is responsible for providing a background on energy, entropy, power production, thermal efficiency, and cycle analysis to technical and non-technical students alike (approximately 900 students annually). This mixed student population creates a challenge for course design, content, and conduct. Engr310 must provide engineering students specific technical rigor defined as prerequisites for upper level courses and simultaneously provide all the other students only the subject background needed as future Air Force officers.
Student interest and motivation are historically strong factors affecting student learning in Engr310. Content, administration, and student preparedness are issues regularly confronting the instructors. Approximately one year ago, a faculty panel began to review the course to determine alternate presentation methods. Guided, in part, by the ABET EC-2000 Criteria\textsuperscript{2}, three items became apparent: (1) Course content needed to be reduced and it had to be more relevant and practical for the students. (2) The course needed to have an explicitly stated goal and a set of companion objectives that needed to be accomplished to realize the goal. (3) In-class, hands-on learning experiences needed to be designed and used to engage students in active learning experiences. Eliminating detailed coverage of certain traditional topics (for instance, steam power generation and the Rankine cycle) accomplished item (1). A working group of professors involved in the course development completed item (2), as shown in Table 1. The replacement of 8 lecture periods with workshops achieved item (3).

II. Workshops

Eight workshops have been designed for use in Engr310.

Table 2 Workshops: Title and Goal

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Title</th>
<th>Goal</th>
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<tbody>
<tr>
<td>1</td>
<td>1\textsuperscript{st} Law of Thermodynamics</td>
<td>Understand how to apply 1\textsuperscript{st} Law to fundamental devices</td>
</tr>
<tr>
<td>2</td>
<td>Specific Heats of Air</td>
<td>Understand and use (C_p) and (C_v) to solve problems</td>
</tr>
<tr>
<td>3</td>
<td>Gibb’s Relationships for Air</td>
<td>Understand and use ideal gas models for entropy to solve problems</td>
</tr>
<tr>
<td>4</td>
<td>Internal Combustion Engine Laboratory</td>
<td>Understand Thermodynamics for ICEs and the Otto Cycle</td>
</tr>
<tr>
<td>5</td>
<td>Gas Turbine Engine Design</td>
<td>Understand the Thermodynamics of Gas Turbine Generators and the Brayton Cycle</td>
</tr>
<tr>
<td>6</td>
<td>Jet Engine Laboratory</td>
<td>Understand the Thermodynamics of the Jet Propulsion Cycle</td>
</tr>
<tr>
<td>7</td>
<td>Jet Engine Selection</td>
<td>Understand Engine Selection Process Meeting Mission Specifications</td>
</tr>
<tr>
<td>8</td>
<td>Air Conditioner Design</td>
<td>Understand the Vapor Compression Refrigeration Cycle</td>
</tr>
</tbody>
</table>

While administration of the workshops varies, the general format is similar:
(1) A cover page containing administrative information
(2) A description section that presents background information
(3) A goal statement and companion objective statements
(4) The task statement defining the work to be done
(5) A time management indicator to guide the students
Appendix A shows Workshop 1 as it was given to the cadets in the Fall 98 term. Three lecture lessons preceded the workshop. The lectures acquainted students with the conservation of energy principle, basic terminology, thermodynamic processes and properties, and notation. In the past, the instructor would use the fourth lesson to present applications of the 1st Law for “closed” and “open” systems. Instead, Workshop 1 was used to give students an opportunity to learn how to apply and reduce the 1st Law for some familiar devices. Here, each student team was tasked to obtain a correct energy statement from the 1st Law for a relatively common household device such as a hairdryer, an electric blender, an electric space heater, or a bicycle pump. Each team had to identify a system, describe the energy transfer and storage conditions, use the 1st Law to obtain a reduced energy balance statement, and present their results orally to the rest of the class.

The goal and objective statements of each workshop are important for the students. Prior to starting the workshop, the instructor reviews the goal and objective statements to be sure the students understand the educational outcome to be gained. The instructor emphasizes that obtaining the outcome depends on how well they complete the objectives. The objectives define the specific items that need to be done, and as such, they define how the student’s work and performance are evaluated. Note: the evaluation and feedback sheet contains the objectives exactly as they appear in the workshop instructions.

Workshops 2 and 3 (Workshop 2 for Spring 99 is presented in Appendix B) are more rigorous. Given temperature, pressure, and power consumption data for a fixed volume of air being heated by a light bulb, the students determine the specific heats, the magnitude of the heat transfer, and changes in stored energy. Between Workshops 1 and 2, lecture periods are used to apply the 1st Law to traditional entry-level closed and open systems involving only air. Statements involving internal energy and enthalpy are obtained, but at this point, the use of specific heats and temperature are postponed until Workshop 2 is completed. Instead, the students are made to realize that additional information is required to quantify the energy levels, and to complete the problems. Then Workshop 2 is used. Similar to a “just in time” approach, while Workshop 2 introduces the specific heat relationships for ideal gases, it is designed as a hands-on opportunity for the students to compute the specific heats for air from the measurable quantities of temperature, pressure, and power.

Follow-on workshops engage student teams in progressively more rigorous work. Thermodynamic fundamentals for ideal heat engine cycles are reinforced with workshops following a lecture series. Using a sequence of lectures on each system, student learning is strengthened by team participation in a workshop designed specifically for that system. For the Otto cycle (ideal model of internal combustion engines), students observe an instrumented Chevy 454 engine in operation, collect data, and interpret and reduce that data in Workshop 4 the following class period. For the Brayton cycle (ideal model for gas turbine generators),
students are required to apply concepts in Workshop 5 to design an engine for a hydroplane racing boat. They merge technical information and iterative design techniques to optimize performance for such an engine. Workshop 5 is done both in class and outside of class. For the jet propulsion cycle (ideal for jet engines), students observe an instrumented turbojet engine in operation, collect data, and analyze system performance by completing ideal cycle calculations for Workshop 6 in the next class period. Then in Workshop 7 (Appendix C), student teams are tasked to apply their knowledge on jet engine systems to recommend a certain type of engine needed to meet specific mission requirements.

The course concludes with the study of heat pump systems, specifically, vapor compression refrigeration systems. The final workshop engages students in a design exercise for a refrigerator. Workshop 8 serves to reinforce the previous lecture presentations on vapor compression refrigeration cycles (including phase diagrams, quality, coefficients of performance, and property tables) and to give students the opportunity to complete a design exercise.

III. Results

Assessment information was collected from student questionnaires during the Summer 98 session (approximately 30 students), twice during the Fall 98 (about 75 students at midterm and again at the end of the course), and during the Spring 99 (about 80 students at midterm only at time of publishing). On a scale of 1 (low) to 5 (high), the students were asked to rate the value of the workshops, and to include a comment supporting the numerical evaluation. Following this, the student teams answered the same questions to determine a team-consensus, and lastly, the entire class answered the questions to produce a class consensus. Appendix D provides a copy of the questionnaire used in the Fall 98 term.

The results on the workshops are mixed. For the Summer sections, students rated their workshop experiences very high (about 4 on average), and included comments indicating that they viewed the workshops as a good, interesting and challenging, and fun way to learn an otherwise difficult topic. They claimed the hands-on practical experiences of the workshop allowed them to obtain genuine understanding of the principles discussed in lectures and in the readings. Some students felt that without the workshops, they would have neither learned very much about thermodynamics nor been able to use the concepts to solve problems. Quite a different finding was obtained for the Fall 98 term sections. Students rated the workshops about 2.5 on average primarily because they were always rushed to complete the exercise. They commented that the information in the workshop is valuable, but that they always felt rushed to get the work done, and so the exercise tended to degenerate into a “square-filling” activity.

The evidence indicated time was the basic problem. During the Fall and Spring terms, academic periods are 50 minutes, whereas the Summer sections have no definite time constraint. Summer sessions meet for 3-4 hour blocks of time everyday. The workshops were designed for use in the typical 50-minute period but the execution showed the amount of work to be too much for one class period. Very often, student teams would get bogged down in some activity that was
thought to be a minor task. For example, in Workshops 2 and 3, students were troubled by units and tended to devote more time than planned for in the workshop design. Falling behind on coping with units created a snowballing effect, and very quickly the students became frustrated; just about when they figured out how everything went together, the period was over leaving them with an incomplete workshop. The Summer-school students also had problems with units, but once they dealt with it, they were able to continue and complete the workshop successfully because they did not have the same time constraint.

Since extending the time proved to not be an option, the student comments and assessment results have been used to redesign the workshop activities so they can be more realistically accomplished in a 50-minute class period. For example, in workshop 2, if power input were given in English Engineering units the students would not be required to perform the unit conversion, thus they would have more time to complete first law analysis.

Based on our assessment from Fall 98, changes in the structure and administration of the workshops were in order. In the Fall, students appeared to get bogged down reading the lengthy objectives for the first time and found themselves pressed for time to complete them. To try to combat this problem, the workshop handouts were given to the students the lesson prior to the in-class workshop and the objective statements were vastly simplified. This gave all students the opportunity to be better prepared and use class time more effectively. By observation, no hard data, we see this being a benefit to the students who prepared for class.

In the Spring 99 term, qualitative data indicate similar student attitudes as found in the Fall. When students were allowed time outside of class for workshop activities, only the more conscientious students did the work. Since the take-home work was voluntary and did not count directly for grade evaluation, the less conscientious students did not work on the project, hence, it was of little or no value to their learning.

IV. Conclusions

Thus far, the following conclusions can be made regarding the use of workshops in the USAFA core course Engr310:
1. The workshops engage students in active learning that can produce improved retention of fundamentals and basic principles.
2. The workshops can create a learning environment that improves student interest and attitude toward a subject that would otherwise be regarded as boring and of no value.
3. The 50-minute class period creates a constraint that can diminish the educational value of the workshop.
4. The purpose and application of each workshop needs to be tightly focused on a single educational objective thereby allowing the student to genuinely benefit from the experience.

Bibliography

JANET L. GOODER
This 1988 graduate of the United States Air Force Academy holds a Bachelor of Science in Engineering Mechanics. She earned Master of Science in Aeronautical Engineering, Structures and Materials from the Air Force Institute of Technology in 1993. She is currently the course director for Engr 310, Energy Systems, at the US Air Force Academy.

BRENDA A. HAVEN
Brenda Haven has a BS in Aerospace Engineering from the University of Minnesota, Minneapolis (1983); an MS in Aeronautical Engineering from the Air Force Institute of Technology (1988); and a PhD in Aeronautical and Astronautical Engineering from the University of Washington, Seattle (1996). She is currently the energy systems discipline director and teaches the propulsion design course at the Air Force Academy.

A. GEORGE HAVENER
Associate Professor, Aeronautical Engineering, AIAA Fellow, PhD Aerospace Engineering, Air Force Institute of Technology, 1969. Currently Director for Assessment, Department of Aeronautics, USAF Academy.

RONALD L. JAMES
This 1992 graduate of the United States Air Force Academy holds a Bachelor of Science in Aeronautical Engineering. He earned Master of Science in Mechanical Engineering from the University of Washington in 1994. He is currently an instructor in the Aeronautical Engineering Department at the US Air Force Academy where he teaches Engr 310, Energy Systems and Aero Engr 361, Propulsion I.

CHARLES F. WISNIEWSKI
This 1988 graduate of the Illinois Institute of Technology holds a Bachelor of Science in Mechanical Aerospace Engineering. He earned a Master of Science in Mechanical Engineering from the University of New Mexico in 1995. He is currently an instructor in the Aeronautical Engineering Department at the US Air Force Academy where he teaches Engr 310, Energy Systems and MechEngr 467, Energy Conversion.
APPENDIX A

WORKSHOP 1

Engr 310 Course Director
Fall 1998 Capt Gooder

UNITED STATES AIR FORCE ACADEMY
Department of Aeronautics

WORKSHOP 1

1ST LAW OF THERMODYNAMICS
(Application to fundamental systems)

Evaluation: 30 points

Time Management:
  Introduction: 5 minutes
  Analysis and written work: 25 minutes
  Oral Presentations: 10 minutes (2 minutes each, nominally)
  Summary (highlights & vocabulary): 10 minutes

ASSIGNMENT GUIDELINES

"For this assignment, you may work with the following persons in addition to an instructor in this course:"

YOUR ASSIGNED PARTNER(S)
NOTE: No more than Four people in one group

"For this assignment, you may use the following materials produced by other cadets:"

NO MATERIALS PRODUCED BY CADETS OUTSIDE YOUR GROUP

Each member is responsible for the content and quality of the entire assignment submitted. Your individual grade on team assignments will be based on your instructor’s assessment of your effort on the assignment.
I. WORKSHOP 1
1ST LAW OF THERMODYNAMICS
(Application to fundamental systems)

**Description:** The 1st Law of Thermodynamics is one of the Laws of Nature that, in the most basic sense, requires the rate of energy transfer between a system and its surroundings to always be balanced by the rate of change in the energy stored in the system. The illustration below depicts this law. Being a Law of Nature, this phenomenon can never be violated. Thus, for all processes, the energy is always accountable. Most often, application of the 1st law to a system is done conveniently using a “power-balance” format. By definition, power is the *transfer of energy per unit time*. Table 1 below shows the standard units of energy and power for both the SI and EE unit systems.

This workshop is designed to give you foundation skills to analyze and evaluate more complex energy transfer systems. By itself, Workshop 1 is insufficient to obtain mastery of these skills. To strengthen these skills, you should practice the Workshop 1 methodology on a variety of traditional, textbook-type problems (see Suggested Follow-ons). Note that the emphasis here is to develop basic problem solving skills, not to seek numerical solutions. Performing detailed numerical analyses comes later. For now, you’ll encounter “stuck-points,” points where you’ll need more information to continue your analysis. Identifying “stuck-points” is a crucial element of problem solving, so work diligently on this aspect. In sum, the emphasis of Workshop 1 is learning to use the power equation in developing good “problem set-up” procedures applicable to energy transfer systems. Section 3-6 of the text is a good reference.

**Goals:** By completing Workshop 1, you should:

1. have a sound understanding on how to use the 1st Law of Thermodynamics (power-balance form) to obtain general energy statements for a variety of classical systems undergoing fundamental energy transfer processes.
2. possess good foundation problem solving skills applicable for energy transfer systems.

**Objectives:** Upon satisfactory completion of Workshop 1, you should have:

1. Demonstrated that you understand the physical meaning of the terms in the power-balance equation.
2. Demonstrated an ability to use foundation problem solving skills to analyze basic energy transfer devices by:
   a. Correctly defining a system for a common “household” energy transfer device.
   b. Making a neatly drawn system sketch showing all energy transfers and changes in stored energy.
   c. Starting with the power-balance equation, obtain a reduced energy statement that is consistent with your system sketch.
3. Demonstrated an ability to recognize needed, but unknown information.
4. Demonstrated good oral communication of the energy transfer issues for a basic device.
5. Demonstrated good teamwork and cooperative interaction with all team members.
6. Demonstrated professional completion of Workshop 1.

![Figure 1 Illustration of the 1st Law “Conservation of Energy” Principal](image)
Task: Given a fundamental energy system, your team is to perform an energy analysis that fulfills the above stated objectives. Entries for Table 2 should be written in the cells provided. Table 3 is designed to guide you through the process of reducing the power-balance equation for your system. Your team must write the reduced form of the 1st Law of Thermodynamics in the box following Table 3. Your team’s oral presentation will be presented to the class as 2 minute summary by one of your teammates. Everyone will get to brief during the semester. Your individual and team performance will be evaluated according to satisfactory completion of the objectives. A copy of the Evaluation and Feedback Sheet is included for your information. Make sure each member’s name is on the turned-in package (one per group).

Suggested Follow-ons: Upon completing Workshop 1, begin reinforcing your newly acquired skills by:

I. Answering textbook problems 3-1 thru 3-12, and 3-61,62.
II. Setting up a variety of textbook problems 3-74 thru 3-117, and 4-11 thru 4-39.
   Setting up means
   (1) Define a system.
   (2) Neatly sketch and label a system diagram.
   (3) Starting with the power-balance equation, obtain an energy statement for the system.
   (4) Identify the stuck points.

Time management:
   a. Introduction: 5 min
   b. Analysis and written work: 25 min.
   c. Oral presentation: 15 min.
   d. Summary: 10 min.

References:

* denotes sections of special importance

Table 3. Energy & Power Units

<table>
<thead>
<tr>
<th>Units</th>
<th>SI Units</th>
<th>EE Units</th>
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<tbody>
<tr>
<td></td>
<td>Joule (J)</td>
<td>British Thermal Unit (BTU)</td>
</tr>
<tr>
<td>Watt = Joule/Sec (W)</td>
<td>Horsepower = 2545 BTU/hr (hp)</td>
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W
E
R

SI Units | Joule (J) | Watt = Joule/Sec (W) |
---|---|---|
EE Units | British Thermal Unit (BTU) | Horsepower = 2545 BTU/hr (hp) |
<table>
<thead>
<tr>
<th>Question</th>
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<tbody>
<tr>
<td>1. What is “your” device?</td>
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<tr>
<td>2. Explain the purpose and general operation of “your” device.</td>
</tr>
<tr>
<td>3. (a) Define and sketch a system for “your” device.</td>
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<td>(b) Using a dotted line, sketch the system boundary.</td>
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<td>(c) Using labeled arrows, show all energy interactions between your system and the surroundings.</td>
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<tr>
<td>(d) Describe the specific type of energy interaction</td>
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<tbody>
<tr>
<td>WHY?</td>
<td>WHY?</td>
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</table>
Given the First Law Equation:
\[
\frac{dE}{dt}_{sys} = \dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} + \dot{m}\theta_{in} - \dot{m}\theta_{out},
\]
obtain a reduced form that represents the energy transfer of your system by completing Table 3.

**Table 5 Power-Balance Analysis**

<table>
<thead>
<tr>
<th>KEEP</th>
<th>KILL</th>
<th>JUSTIFY</th>
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<tbody>
<tr>
<td>The time rate of change of energy stored in the System.</td>
<td>( \frac{dU}{dt} )</td>
<td></td>
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<tr>
<td></td>
<td>( \frac{d(KE)}{dt} )</td>
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<td></td>
<td>( \frac{d(PE)}{dt} )</td>
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<td></td>
<td>( \frac{dU_0}{dt} )</td>
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<tr>
<td>Heat and Work Transfer Rates</td>
<td>( \dot{Q}_{in} )</td>
<td></td>
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<tr>
<td></td>
<td>( \dot{Q}_{out} )</td>
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<td>( \dot{W}_{in} )</td>
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<td>( \dot{W}_{out} )</td>
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<tr>
<td>Energy transfer due to mass flow into the Sys.</td>
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<td>Energy transfer due to mass flow out of the System.</td>
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### SUMMARY SHEET

<table>
<thead>
<tr>
<th>Device</th>
<th>Purpose</th>
<th>System Sketch</th>
<th>Type: Open or Closed</th>
<th>Reduced Power Eqn.</th>
<th>“Stuck” Points</th>
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</table>
Title____________________
Team
Members_____________________________________________

Each Objective is Scored Subjectively from 1 (low) to 5 (high)

Objectives:
(1) Demonstrated understanding the physical meaning of the terms in the power-balance equation.
Comment ________________________________________________________________

(2) Demonstrated an ability to use good foundation problem solving skills to analyze basic energy transfer devices by:
   a. Correctly defining a system for a common “household” energy transfer device.
   b. Making a neatly drawn system sketch showing all energy transfer and energy changes.
   c. Simplifying a the power equation to obtain a reduced statement that is consistent with your system sketch.
Comment ________________________________________________________________

(3) Demonstrated an ability to recognize needed, but unknown information.
Comment ________________________________________________________________

(4) Demonstrated good oral communication of the energy transfer issues for a basic device.
Comment ________________________________________________________________

(5) Demonstrated good team work and cooperative interaction with each team member.
Comment ________________________________________________________________

(6) Demonstrated professional completion of Workshop 1.
Comment ________________________________________________________________

INSTRUCTOR FEEDBACK

Strengths:                                                  Items to Work On
1._________________________________________________________   1._________________________________________________________
2._________________________________________________________   2._________________________________________________________

Overall Score

Completed by Instructor
WORKSHOP 2
DAY 1

SPECIFIC HEATS FOR AIR
@ NORMAL TEMPERATURES AND PRESSURES

Time Management:
1st Day
Introduction: 10 minutes
Analysis and written work: 35 minutes
Summary: 5 minutes
II. **WORKSHOP 2**  
**Specific Heats for Air @ Normal Temperature and Pressure**

**Description:** Energy transfer between an ideal gas system and its surroundings can cause the internal energy and the enthalpy of the gas to change. In order to understand the thermodynamic response of the system, these changes must be quantified. While internal energy and enthalpy are thermodynamic properties of matter, they are not measurable properties (internal energy and enthalpy meters do not exist!). However, temperature and pressure are measurable properties, and so we seek to understand how a knowledge of these measurable properties can be used to determine changes in internal energy, or changes in enthalpy, for an ideal gas as it undergoes an energy transfer process.

Workshop 2 is of fundamental importance because it introduces the functional relationships between internal energy & temperature and enthalpy & temperature for air at normal temperatures and pressures. These relationships are thermodynamic properties. They are called the specific heat at constant volume ($C_v$), pronounced “see-sub-vee,” and the specific heat at constant pressure ($C_p$), pronounced “see-sub-pee.”

The specific heats are defined as the amount of energy transfer between the system and its surroundings required to change the temperature of the system by one degree. Mathematically, these definitions are stated as partial derivatives as shown in a. and b. below. However, for ideal gases, the specific heats depend only on temperature, so the representations are ordinary derivatives:

a. Specific heat at constant volume:

\[
C_v = \left( \frac{\partial u}{\partial T} \right)_v = \left( \frac{du}{dT} \right)_{\text{ideal gas}}
\]

b. Specific heat at constant pressure:

\[
C_p = \left( \frac{\partial h}{\partial T} \right)_p = \left( \frac{dh}{dT} \right)_{\text{ideal gas}}
\]

**Comments:**

1. The dimensions of the specific heats are energy per unit mass per degree temperature (energy/mass-temperature). Units consistent with these dimensions are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 6 Specific Heats for Air (book values)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SI Units</strong> (kJ/kg-K)</td>
</tr>
<tr>
<td>(C_p)</td>
</tr>
<tr>
<td>(C_v)</td>
</tr>
</tbody>
</table>

| Ratio of specific heats \((C_p/C_v)\) = ______________ |

2. Specific heats vary from one substance to another. For applications in Engr 310, only the specific heats for AIR will be considered. Both $C_v$ and $C_p$ will be treated as constants in this course.

3. Being derivatives, the specific heats are the slopes of the functions defining the relationship between specific internal energy and temperature ($C_v$), and the specific enthalpy and temperature ($C_p$).

4. To understand the relationship between internal energy and enthalpy with temperature, the specific heat functions must be integrated. With both $C_v$ and $C_p$ held constant, the integration is straightforward and results in,

\[ \int du = \int C_v dT = C_v \int dT \]

or,

\[ \Delta u = C_v \Delta T \]

\[ \int dh = \int C_p dT = C_p \int dT \]

or,

\[ \Delta h = C_p \Delta T \]

Thus, the values for $C_v$ and $C_p$ and temperature allow for determination of both the internal energy and the enthalpy of the gas.
Goal: Upon completing Workshop 2, you should understand specific heats for ideal gases, particularly for air.

Realizing this goal depends directly on your satisfactory completion of the following objectives:

Objectives: Upon satisfactory completion of Workshop 2, you should be able to:

1. Explain the meaning of $C_v$ and $C_p$ for air.
2. Explain the need and importance of $C_v$ and $C_p$.
3. Determine $C_v$ and $C_p$ for a set of experimental data.
4. Demonstrate an ability to graphically communicate experimental data.
5. Demonstrate an ability to use the $C_v$ and $C_p$ in energy systems analyses.
6. Demonstrate good teamwork and cooperative interaction with all team members.
7. Demonstrate professional completion of Workshop 2.

References:
4. WWW (suggested search engines: (1) ALTA VISTA. (2) METACRAWLER)
Task

Given that the data in Table 2 are for a perfectly insulated 1 ft³ fixed volume, constant air mass system that was energized by a 20 watt light bulb (see illustration below), perform an energy analysis to complete the objectives stated above. Boxed-workspaces are provided to guide your analysis. Spaces are provided for making calculations. Complete your study by making entries in Tables 1 and 2.

Time management: Workshop 2 spans two days. The 1st day activity will include an introduction (10 min), teamwork (35 min), and a summary (5 min). The team goal for the 1st day is to complete work up to and including Table 2.
The Experiment

A specially designed box has been built to acquire the measurement data shown in Table 2. The box is an aluminum case that surrounds 4 inches of Styrofoam insulation on the 6 sides. A 20W light bulb is used to add energy to the air. The sealed volume of the air inside the box is \(1\text{ft}^3\). When the light bulb is turned on, the temperature and the pressure of the air in the box are 68 °F and 11.39 psia, respectively. The data have already been taken, you are required to reduce some of it and record your values in Table 2.

Useful Information:
Table 2 is partially completed. Use these entries to verify your data reduction process.

Psia means is the absolute pressure in pounds-force per square inch. The absolute pressure \(p_{abs}\) is the addition of the gage pressure \(p_{gage}\) and the atmospheric pressure \(p_{atm}\),

\[p_{abs} = p_{gage} + p_{atm}\]

Specific enthalpy = specific int. energy + (press) x (specific volume): $h = u + pv = (u + RT)_{\text{ideal gas}}$

\[R_{\text{air}} = 53.34 \text{ (lbf-ft)/(lbm-R)}\]
1 BTU = 1055 J = 778 lbf-ft
1 watt = 1 J/sec

1. Define the system. Sketch the system boundary on Figure 1 using a dotted line. Draw arrows crossing the system boundary to indicate energy transfer. Using this information, write the team’s response for a reduced 1st Law for the air in the box. Be sure to identify “stuck points.”
2. Compute the mass of the air (lbm) in the box shown in Figure 1. Assume the volume given accounts for the space taken by the light bulb.

3. Sketch the light bulb and identify it as a system. Write the reduced 1st Law for the light bulb. State your assumptions. Write the relationship between the terms in this equation and the one you wrote for the air in the box.
### 1st Day

**Table 7 Measured Data for Air-Box Experiment**

<table>
<thead>
<tr>
<th>Time, ( t ) (sec)</th>
<th>Temp, ( T ) (°F)</th>
<th>Temp, ( T ) (°R)</th>
<th>Press, ( P_{gage} ) (psig)</th>
<th>Press, ( P_{abs} ) (psia)</th>
<th>Power, ( W_{in} ) (watts)</th>
<th>Internal Energy, ( U ) (BTU)</th>
<th>Specific Internal Energy, ( u ) (BTU/lbm)</th>
<th>Specific Enthalpy, ( h ) (BTU/lbm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>68</td>
<td>528</td>
<td>0</td>
<td>11.39</td>
<td>20</td>
<td>5.2548</td>
<td>90.2312</td>
<td>126.4311</td>
</tr>
<tr>
<td>10</td>
<td>92.7</td>
<td>552.7</td>
<td>0.49</td>
<td>11.88</td>
<td>20</td>
<td>5.4444</td>
<td>93.4864</td>
<td>131.2437</td>
</tr>
<tr>
<td>20</td>
<td>107.8</td>
<td></td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>30</td>
<td>124.6</td>
<td>584.6</td>
<td>1.17</td>
<td>12.56</td>
<td>20</td>
<td>5.8235</td>
<td>99.9968</td>
<td>139.9153</td>
</tr>
<tr>
<td>40</td>
<td>158.1</td>
<td>618.1</td>
<td>1.68</td>
<td>13.07</td>
<td>20</td>
<td>6.0131</td>
<td>103.2521</td>
<td>144.7914</td>
</tr>
<tr>
<td>50</td>
<td>164.4</td>
<td>624.4</td>
<td>2.05</td>
<td>13.44</td>
<td>20</td>
<td>6.2027</td>
<td>106.5073</td>
<td>149.2225</td>
</tr>
<tr>
<td>60</td>
<td>178.3</td>
<td>638.3</td>
<td>2.39</td>
<td>13.78</td>
<td>20</td>
<td>6.3922</td>
<td>109.7625</td>
<td>153.5583</td>
</tr>
<tr>
<td>70</td>
<td>198.1</td>
<td>658.1</td>
<td>2.82</td>
<td>14.21</td>
<td>20</td>
<td>6.5818</td>
<td>113.0177</td>
<td>158.1801</td>
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<tr>
<td>80</td>
<td>224</td>
<td>684</td>
<td>3.3</td>
<td>14.69</td>
<td>20</td>
<td>6.7714</td>
<td>116.2729</td>
<td>162.9609</td>
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<tr>
<td>90</td>
<td>241.1</td>
<td></td>
<td>3.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>263.1</td>
<td>723.1</td>
<td>4.14</td>
<td>15.53</td>
<td>20</td>
<td>7.1505</td>
<td>122.7833</td>
<td>172.1410</td>
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<tr>
<td>110</td>
<td>271.6</td>
<td>731.6</td>
<td>4.37</td>
<td>15.76</td>
<td>20</td>
<td>7.3401</td>
<td>126.0385</td>
<td>176.1272</td>
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<tr>
<td>120</td>
<td>288.8</td>
<td>748.8</td>
<td>4.72</td>
<td>16.11</td>
<td>20</td>
<td>7.5297</td>
<td>129.2937</td>
<td>180.4948</td>
</tr>
</tbody>
</table>

Complete the entries in Table 2. Show your calculations here.
APPENDIX C

WORKSHOP 7

JET ENGINE SELECTION

You are tasked to determine the appropriate engine type that meets the mission requirements tabulated below. You will base your decision on the two primary engine performance characteristics: Thrust Specific Fuel Consumption (TSFC) and Specific Thrust.

TSFC defines how efficiently the engine converts fuel into thrust-power, and as such, TSFC determines the allowable range or endurance for a given amount and type of fuel. By definition,

\[
\text{TSFC} = \frac{\text{fuel used / time in hours}}{\text{total thrust produced}} = \frac{\dot{m}_{\text{fuel}}}{F}.
\]

Specific Thrust is an indication of the engine size (diameter) required for a given thrust level. It is defined as

\[
\frac{F}{\dot{m}} = \frac{\text{total thrust produced}}{\text{total mass flow rate of air through engine}}.
\]

In this exercise you will
1. use the tabulated data to calculate the TSFC for the mission requirements.
2. use Chart 1 to determine the engine type(s) that meets (or beats) that TSFC requirement.
3. refer to Chart 2 to identify the Specific Thrust (Thrust/Airflow) associated with the engine type(s) selected in #2.
4. brief your decision to the class as to the “best” engine type for this mission. Things to consider are: (1) does the engine meet the TSFC requirement; (2) is engine size important (for the same thrust, a smaller \( F / \dot{m} \) will increase engine diameter so it can pass more mass flow); (3) turboprops are limited to a Mach number around 0.85 because a large portion of the prop experiences shock waves (greatly reducing performance); (4) for supersonic aircraft you want a compact yet somewhat fuel efficient engine because they are typically embedded in the fuselage or inside a specially designed nacelle (SR-71) - the bigger the engine diameter, the more drag; (5) consider how the Air Force may change its mission requirements - maybe increasing the desired range or requiring the aircraft to spend more time at a higher Mach no. You should also attempt to determine the type of AF aircraft using this engine.

The mission requirements and aircraft characteristics stated in the cases below are similar to current/future AF systems.

<table>
<thead>
<tr>
<th>Case-1</th>
<th>Mach</th>
<th>Velocity (knots)</th>
<th>Range (nm)</th>
<th>Endurance (hr)</th>
<th>Engines (#)</th>
<th>F/engine (lbf)</th>
<th>A/C max wt (lbf)</th>
<th>Fuel wt (lbf)</th>
<th>TSFC (lbm/hr/lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>423</td>
<td>5000</td>
<td></td>
<td></td>
<td>4</td>
<td>1500</td>
<td>155,000</td>
<td>36,000</td>
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</table>

<table>
<thead>
<tr>
<th>Case-2</th>
<th>Mach</th>
<th>Velocity (knots)</th>
<th>Range (nm)</th>
<th>Endurance (hr)</th>
<th>Engines (#)</th>
<th>F/engine (lbf)</th>
<th>A/C max wt (lbf)</th>
<th>Fuel wt (lbf)</th>
<th>TSFC (lbm/hr/lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>423</td>
<td>2</td>
<td>2</td>
<td></td>
<td>2</td>
<td>4,800</td>
<td>51,000</td>
<td>13,500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case-3</th>
<th>Mach</th>
<th>Velocity (knots)</th>
<th>Range (nm)</th>
<th>Endurance (hr)</th>
<th>Engines (#)</th>
<th>F/engine (lbf)</th>
<th>A/C max wt (lbf)</th>
<th>Fuel wt (lbf)</th>
<th>TSFC (lbm/hr/lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>1150</td>
<td>1500</td>
<td></td>
<td></td>
<td>2</td>
<td>12,700</td>
<td>70,000</td>
<td>40,000</td>
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</table>

<table>
<thead>
<tr>
<th>Case-4</th>
<th>Mach</th>
<th>Velocity (knots)</th>
<th>Range (nm)</th>
<th>Endurance (hr)</th>
<th>Engines (#)</th>
<th>F/engine (lbf)</th>
<th>A/C max wt (lbf)</th>
<th>Fuel wt (lbf)</th>
<th>TSFC (lbm/hr/lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>550</td>
<td>1000</td>
<td></td>
<td></td>
<td>2</td>
<td>1,080</td>
<td>12,100</td>
<td>4,930</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case-5</th>
<th>Mach</th>
<th>Velocity (knots)</th>
<th>Range (nm)</th>
<th>Endurance (hr)</th>
<th>Engines (#)</th>
<th>F/engine (lbf)</th>
<th>A/C max wt (lbf)</th>
<th>Fuel wt (lbf)</th>
<th>TSFC (lbm/hr/lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>2550</td>
<td>1000</td>
<td></td>
<td></td>
<td>1</td>
<td>2,000</td>
<td>3,200</td>
<td>1,600</td>
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</tbody>
</table>
Chart 1

Thrust Specific Fuel Consumption Characteristics of Typical Engines

- Turboprop
- High BPR TF
- Low BPR TF
- Turbojet
- Ramjet

Based on typical cruise conditions

Chart 2

Specific Thrust Characteristics of Typical Engines

- Turboprop
- High BPR TF
- Turbojet
- Ramjet
- Low BPR TF

Based on typical cruise conditions
APPENDIX D
STUDENT QUESTIONNAIRE
ENGR 310
End of Course Assessment
Fall Term-98, First Half

Numerical Scale: Please enter a number in each Box. 1=low, 5 =high.
Please provide a comment to go with your number entry.

All questions should be discussed and answered with respect to
THE EDUCATIONAL BENEFIT TO YOU.

I. COURSE MATERIALS:
   a. The Text.
      Comment ________________________________________________________________

   b. The Notes.
      Comment ________________________________________________________________

   c. Others.
      Comment ________________________________________________________________

II. ACTIVITIES
   a. Midterm
      Comment______________________________________________________________

   b. Workshops:
      1. Box for $C_p$ and $C_v$
      Comment______________________________________________________________

   c. ICE: Chevy 454 engine
      Comment______________________________________________________________

III. COURSE GOAL: The course goal is being obtained:

   “By course completion, I should have a sound intellectual understanding of classical thermodynamics
   and its relevance to energy systems of importance to the Air Force.”
IV. COURSE OBJECTIVES: The course objectives are being accomplished: “By course completion, I should be able to.....”

a. Explain the 1st and 2nd Laws of Thermodynamics in verbal and symbolic terminology.

Comment ________________________________________________________________

b. Define and discuss fundamental concepts, terms and definitions embodied in classical thermodynamics.

Comment ________________________________________________________________

c. Demonstrate an ability to solve a variety of classical deterministic thermodynamics problems to include cycle analyses of heat engines and heat pumps.

Comment ________________________________________________________________

d. Participate in group work as a contributing team member to frame and resolve ill-defined energy system problems.

Comment ________________________________________________________________

e. Demonstrate competence to communicate energy system issues in written, oral, and graphical formats.

Comment ________________________________________________________________

f. Demonstrate competence to perform independent research on energy system issues.

Comment ________________________________________________________________

g. Demonstrate competence to complete tasks in a timely and professional manner.

Comment ________________________________________________________________

V. INSTRUCTION

a. The overall quality of instruction is good.

Comment ________________________________________________________________
b. The instructor is knowledgeable on the subject.

Comment______________________________________________________________

c. The instructor is concerned about learning.

Comment______________________________________________________________

d. The instructor is teaching more than the scope of the subject.

Comment______________________________________________________________

VI. EDUCATIONAL VALUE

a. I consider the educational value of the course to be: 1= Low, 5=high.

Comment______________________________________________________________

b. The best part of the course is: _______________________________________
_____________________________________________________________________

c. The worst part of the course is: _______________________________________
_____________________________________________________________________

VII. FINAL COMMENT (Optional) Please make any additional comments pertinent to the course.
In thermodynamics one has the following basic quantities, each of which is a function of $x, t$ depending on a given ow: $p =$ pressure $\tilde{T} =$ density $T =$ temperature $s =$ entropy $w =$ enthalpy (per unit mass). $= w - \frac{p}{\tilde{T}} =$ internal energy. (per unit mass). These quantities are related by the First Law of Thermodynamics, which we accept as a basic principle: $\frac{dw}{dt} = T$. The traditional teaching of thermodynamics and statistical mechanics as distinct subjects has often left students with their knowledge compartmentalized and has also left them ill-prepared to accept newer ideas, such as spin temperature or negative temperature, as legitimate and natural. (d) Since a unified presentation is more economical, conceptually as well as in terms of time, it permits one to discuss. The book is intended chiefly as a text for an introductory course in statistical and thermal physics for college juniors or seniors. The mimeographed notes on which it is based have been used in this way for more than two years by myself and several of my colleagues in teaching such a course at the University of California in Berkeley. No prior knowledge of heat or thermodynamics is taught by Dr. Wolverson. Statistical mechanics is where we admit that thermodynamic systems (such as an ideal gas) are in fact made up of atomic-scale constituents, the motion of which is not known. Nevertheless the results of classical thermodynamics arise from averages of their properties. Revision: You will need material from previous units, including: discrete statistics: factorials, the nCr formula, averages anything you may know about continuous distributions and probability density functions will be very useful series: Taylor series, binomial theorem, geometry The Euclidean path integral approach to black hole thermodynamics, on which this thesis heavily relies, will be reviewed in Chapter 3. 1.2.2 String theory and the AdS/CFT correspondence. Only a theory of quantum gravity can identify the microscopic degrees of freedom which give rise to the Bekenstein-Hawking entropy. A new insight is gained by studying gravity using the spacetime dimensionality $D$ as a parameter. Indeed, many properties of black hole solutions are specific to four dimensions. In Newtonian gravity, the attractive gravitational force is suppressed with the radial distance as $r^{-2}$, while the repulsive centrifugal force is suppressed as $r^{-3}$ (for given mass and angular momentum) independently of $D$ since it acts on a plane of rotation.