AC 2011-1826: INTEGRATING THERMODYNAMICS AND FLUID MECHANICS INSTRUCTION: PRACTICAL SOLUTIONS TO ISSUES OF CONSISTENCY

Bobby G Crawford, U.S. Military Academy

Bobby Grant Crawford is a Colonel in the United States Army and the Director of the Mechanical Engineering Program in the Department of Civil and Mechanical Engineering at the United States Military Academy, West Point, NY. He graduated from West Point with a B.S. degree in Mechanical Engineering in 1985. He holds MS and Ph.D. degrees in Aerospace Engineering, is a Senior Army Aviator in fixed and rotary wing aircraft, and is a licensed Professional Engineer.

Daisie D. Boettner, U.S. Military Academy

Colonel Daisie Boettner graduated from West Point in 1981 with a Bachelor of Science degree. She earned a Master of Science in Engineering (Mechanical Engineering) from the University of Michigan in 1991 and a Ph.D. in Mechanical Engineering from The Ohio State University in 2001. She has taught courses in thermal-fluid systems, heat transfer, and design. She is currently Professor and Deputy Head of the Department of Civil and Mechanical Engineering, United States Military Academy, West Point, NY.

Integrating Thermodynamics and Fluid Mechanics Instruction: Practical Solutions to Issues of Consistency

Abstract

Historically, the disciplines of fluid mechanics and thermodynamics have been taught as separate courses using separately developed textbooks. Most undergraduate students form an early belief that these two aspects of thermal-fluid science and engineering are as far removed from each other as cats are from dogs. It is not until the senior year or even into their graduate school experience that the student begins to understand and appreciate the underlying physical conservation laws upon which both of these disciplines are based. As a result of mechanical engineering curriculum revision at the United States Military Academy at West Point, New York, separate courses in thermodynamics and fluid mechanics were integrated into a two-course sequence, Thermal-Fluid Systems I and II, in academic year 2005-2006.

While succeeding in developing the two disciplines together under one overarching set of physical laws, there was still an issue with finding a suitable textbook. After four years of instruction using available textbooks from publishers, the mechanical engineering faculty developed a text tailored specifically to the integrated two-course sequence. The experience in writing a text that integrates concepts in thermodynamics and fluid mechanics highlights the need for consistency between the two disciplines.

Issues identified include logical organization of topics, selection of appropriate variables, consistent use of sign convention throughout all topics, recognition of various forms of the same fundamental principle, and definition of performance parameters. This paper explores these issues and how they were addressed for integrated instruction of thermodynamics and fluid mechanics. Feedback gleaned from student surveys and faculty comments with regard to the initial implementation of the text was used to modify the text and examples. Performance feedback and newly identified issues are presented.

Introduction

In 2005-2006 faculty integrated the fluid mechanics and thermodynamics courses at the United States Military Academy at West Point, New York into a two-course sequence of thermal-fluid systems to gain efficiency in coverage of the underlying foundations of both fields and to reinforce the global nature of the fundamental conservation laws[1]. The two courses have achieved the objectives of integration, however, not without some challenges. Many of these challenges center around the lack of a suitable text that includes all required topics and truly integrates course material to the degree desired.

The faculty produced an integrated text in 2009 that addressed many of the consistency issues identified in integrating the thermal-fluid disciplines[2]. This paper covers those issues, presents feedback from the initial implementation of the integrated text, discusses text modifications and subsequent feedback, and presents issues the faculty members have identified during the course of assessing this implementation.

Description of the Thermal-Fluid Systems Courses

The lesson content of both 40-lesson courses is shown in Table 1. A review of the first course in the sequence (ME 311) shows content in the areas of the fundamental properties, the ideal gas equation of state, hydrostatics, conservation principles, cycle analysis, the 2nd Law of Thermodynamics, the Rankine cycle, internal flow, vapor compression refrigeration cycles, and total air conditioning. This clearly represents a thorough mix of fluid mechanics and thermodynamics topics that have been traditionally taught in separate courses. The second course (ME312) continues this practice, including exergy, reciprocating internal combustion engine cycles (Otto and Diesel cycles), combustion, modeling and similitude, experimental methods, external flow/boundary layers, differential development of the conservation laws for mass and momentum, Brayton cycle, combined cycles, and compressible flow.

Table 1. Syllabi for Thermal-Fluid Systems I & II

Lsn	**ME311 Lesson Topics**	**ME312 Lesson Topics**
1	Introduction to Thermal Fluids	Introduction to Thermal Fluids II / Review ME311
2	Intro Concepts and Total Energy	Ideal Gas Relationships
3	Ideal Gas Law, Internal Energy, Enthalpy, Specific Heat	Introduction to Exergy
4	Hydrostatic Pressure / Manometry	Exergy Balance
5	Hydrostatic Pressure on Submerged Plane Surface / Buoyancy	Problem Solving
6	Surface Tension, Capillary Action	**WPR 1**
7	Conservation of Energy for a Closed System/Moving Boundary Work	Introduction to Internal Combustion Engines
8	**Writ I** / Introduction to Reynolds Transport Theorem	Air Standard Otto Cycle
9	Reynolds Transport Theorem / Conservation of Mass and Momentum	Air Standard Diesel Cycle
10	Conservation of Energy for a Control Volume / Shaft Work	Introduction to Combustion
11	Bernoulli Equation	Enthalpy of Formation / Enthalpy of Combustion
12	***Open Channel Lab***	Problem Solving
13	Problem Solving	**WPR 2**
14	**WPR 1**	***Internal Combustion Engine CFR Lab***
15	Power Plant Overview, Steam Properties, Vapor Dome	Dimensional Analysis
16	Introduction to Cycles	Modeling and Similarity
17	Introduction to Losses (2nd Law)	Introduction to Experimental Methods
18	Increase in Entropy Principle	Experiment Planning
19	Steady Flow Devices	External Flow / Boundary Layers Review
20	EES Workshop	***Wind Tunnel Lab***
21	Vapor Power Cycles	Drag

22	***Steam Turbine Lab***	Lift
23	Improved Vapor Power Cycles	Differential Approach: Conservation of Mass
24	Regenerative Vapor Power Cycles	Differential Approach: Conservation of Momentum
25	**Writ II**	Differential Approach: Navier Stokes
26	***Powerplant Tour***	Problem Solving
27	Intro to Pipe Flow	**WPR 3**
28	Turbulent Pipe Flow and Major Losses	Introduction to Gas Turbine Engines and the Brayton Cycle
29	Design Studio (IPR #2)	***Gas Turbine Lab***
30	Minor Losses	Improving Gas Turbine Engine Performance
31	Pipe Networks and Pumps	Combined Cycle
32	Problem Solving	Aircraft Propulsion and Jet Engines
33	**WPR 2**	Compressible Flow I
34	Ideal Vapor Compression Refrigeration (VCRC) and Refrigerant Properties	Compressible Flow II
35	Actual VCRC	Compressible Flow III
36	Design IPR #3	Problem Solving
37	Psychrometrics	**WPR 4**
38	Air-Conditioning Processes	Advanced Topics Presentations
39	Design Briefings	Advanced Topics Presentations
40	Problem Solving/Course Review	Course Review

Textbook Options

To teach the integrated courses the faculty initially used a “combined” textbook, *Fundamentals of Thermal-Fluid Sciences* by Çengel and Turner[3]. We refer to the text as a “combined” text based on the manner in which it was produced: by combining sections from existing fluid mechanics, thermodynamics, and heat transfer texts with no attempt to harmonize variable nomenclature or integrate the presentation of foundational concepts (conservation equations and applications).

While not ideal, this text was considered acceptable initially. The text was sufficient for the first course, but the second course required a 442-page custom text supplement to cover all desired subjects. New editions of the text relegated some material used in the course to electronic media, requiring additions to the supplemental text. The supplemental text became so cumbersome that a new text was sought as recommended by results of the annual faculty assessment of the two courses.

The initial result of this new text search was a return to separate fluid mechanics and thermodynamics texts used when the courses were taught as distinct topics. Available “combined” and “integrated” texts[4-6] either did not include all topical coverage required and/or relegated some coverage to web access only. While use of separate thermodynamics and fluid mechanics texts removed the requirement for a supplemental text, the drawbacks to this approach were significant.

We traded two books for two books, required students to navigate non-sequentially through these books for two semesters, and reinforced student perception that fluid mechanics and thermodynamics are vastly different fields of study. This last result struck at one of the core principles which initially drove the integration of the two courses into one two-course sequence.

These frustrations fueled the decision to develop a text tailored to the integrated two-course sequence as taught at West Point. It was during this writing project that many of the integration and consistency issues which had been easy to criticize, now had to be addressed and resolved, a much more difficult undertaking than merely identifying the issues. This paper presents these issues, describes available choices, and relates how the faculty chose to resolve issues for instruction in the integrated thermal-fluid systems sequence.

Logical Organization of Topics

The primary objective of the course, integrating the principles from the traditional disciplines of fluid mechanics and thermodynamics into a single thread of thought, development, and application, was accomplished in the classroom through a year of careful planning and several subsequent years of teaching, assessment, evaluation, and modification. While using two textbooks, the faculty had developed effective syllabi, detailed lesson notes, appropriate example problems, and laboratory experiments to support the integrated teaching of the material. Order of the material was determined by the object of analysis, not the tools used in the analysis. Material is presented in a sequence that supports introduction of concepts from complex thermal-fluid system case studies such as a helicopter, the West Point power plant, a total air conditioning system, an automobile, and high performance aircraft.

Study of most thermal-fluid mechanical systems requires knowledge from both traditional disciplines. Integration of topics reinforces the fundamental principles that span both disciplines and gains efficiency since presenting fundamental properties and conservation principles occurs only once. An added benefit to some majors from non-mechanical engineering disciplines is students no longer need to take two courses to prepare for their follow-on courses and the Fundamentals of Engineering examination[1].

Early in the text writing process, the faculty decided to organize and sequence material coverage in the text in the same order that it is taught in the two courses. Given the goals for the course and the text, this was a logical choice.

Selection of Appropriate Variables

Thermodynamics and fluid mechanics incorporate numerous variables to represent properties, energy transfers, dimensions, etc., in mathematical expressions. While most variables are consistent between the two topics, there are exceptions. Ultimately the student must recognize the context in which a variable is being used to identify what the variable represents. However, to minimize confusion, adjustments were made where possible. Thermodynamics uses the variable, h, to represent specific enthalpy while fluid mechanics uses the same variable to represent vertical height. For clarity, height is represented by the non-italicized, lower-case "h" while specific enthalpy is represented by the italicized, lower case "h." Other uses of h in fluid mechanics such as pump head (h_p), turbine head (h_t), and head loss (h_L) incorporate a subscript, thus distinguishing these variables from others.

The variable, Q, represents heat transfer in both thermodynamics and fluid mechanics, but it also represents volumetric flow rate in some fluid mechanics texts. For parallelism with mass (m) and mass flow rate ($\dot{m}$) used by both thermodynamics and fluid mechanics, we adopted the symbol, $\dot{V}$, to represent volumetric flow rate (since V represents volume) while maintaining heat transfer as Q. A complete list of variables used in this paper is included in Table 2.

Table 2. Nomenclature Used in this Paper

COP	coefficient of performance
EES	Engineering Equation Solver
g	gravitational acceleration
h	specific enthalpy
h	height
h_L	head loss
h_p	pump head
h_t	turbine head
IPR	In-Progress Review
m	mass
$\dot{m}$	mass flow rate
P	pressure
Q	heat transfer
$\dot{Q}$	heat transfer rate
r_bw	back work ratio
u	specific internal energy
v	specific volume
V	volume
$\dot{V}$	volumetric flow rate
V	velocity
WPR	written partial review (an examination)
W	work
$\dot{W}$	power
z	elevation
Greek Symbols	
η	efficiency
ρ	density
Subscripts	
cc	combustion chamber
e	exit
elect	electric
gen	generator
HP	heat pump
i	inlet
ie	inlet-to-exit
R	refrigeration

Consistent use of Sign Convention Throughout All Topics

"Consistency in presentation and use of concepts in any engineering course is important as it will enhance student learning"[7]. A consistent sign convention for heat transfer and work is imperative when truly integrating thermodynamics and fluid mechanics. Based on a sampling of thermodynamics and fluid mechanics texts currently available, various strategies for energy transfer sign convention are in use, with more than one strategy sometimes used within the same text.

Commonly in thermodynamics texts a sign convention for heat transfer and work, such as *heat transfer in is positive and work in is negative*, is introduced with the First Law of Thermodynamics. The sign associated with the value for the energy transfer indicates the direction of that energy transfer. Later in the text when cycles are introduced, the sign convention is abandoned in favor of energy transfer direction denoted by arrow direction or “in” and “out” designations with all values positive. The direction of energy transfer is “known” based on the type of cycle being analyzed.

In fluid mechanics texts a sign convention for heat transfer and work also is introduced with the First Law of Thermodynamics. Later when the mechanical energy form of conservation of energy is introduced, work expressed in terms of head is treated as a magnitude. It appears that in both disciplines there is no attempt to maintain one explicit sign convention throughout a text or to necessarily standardize energy transfer sign conventions between thermodynamics and fluid mechanics. Samples of sign convention strategies being used are described next.

In the preface to the seventh edition of their thermodynamics text, Çengel and Boles speak of a “relaxed” sign convention. “The use of a formal sign convention for heat and work is abandoned as it often becomes counterproductive. A physically meaningful and engaging approach is adopted for interactions instead of a mechanical approach. Subscripts “in” and “out,” rather than the plus and minus signs, are used to indicate the directions of interactions”[8]. They suggest assuming heat transfer is into a system and work is produced by the system when solving for an unknown energy transfer. If the result has a negative value, the assumed direction is incorrect and should be in the opposite direction. However, later when cycles are introduced, energy transfer direction is denoted using the subscripts “in” and “out” with all associated values positive.

Moran and Shapiro in their thermodynamics text introduce heat transfer in as positive and work in as negative. However, when introducing cycles, sign convention is abandoned in favor of magnitudes associated with arrow directions. “Carefully observe that in using the symbols Q_{in} and Q_{out} on Fig. 2.17 we have departed from the previously stated sign convention for heat transfer”[9].

In their fluid mechanics text, Çengel and Cimbala use an energy transfer sign convention of net rate of heat transfer in is positive and net power in is positive[10]. However, they symbolically express both types of net energy transfers as the difference between the energy transfer in and the energy transfer out, applying the sign convention before substituting any values and by default switching to a magnitude- and direction-based sign convention.
Munson, Young, Okiishi, and Huebsch introduce the sign convention, “Heat transfer and work transfer are considered “+” going into the system and “–” coming out”[11].

The use of a standard sign convention represents the beauty of the consistency of mathematics and an approach that transcends any one particular application. Thus, once a sign convention for energy transfers was established in our course, we chose to maintain the same sign convention throughout all topics in the study of thermal-fluid systems. This practice impacted expressions for some performance parameters discussed later in this paper.

Two Forms of the Same Fundamental Principle

Although based on the same fundamental principle, conservation of energy for steady flow through a one-inlet, one-exit control volume is expressed in different forms in thermodynamics and fluid mechanics. In thermodynamics when the sign convention used is *heat transfer in is positive and work in is negative,* Eq. 1 is a standard expression for conservation of energy or the first law of thermodynamics. The units associated with Eq. 1 are energy per time such as kilowatts, horsepower, or British thermal units per hour.

$$\dot{Q}_{ie} - \dot{W}_{ie} = \dot{m}\,[(h_e - h_i) + \tfrac{1}{2}\,(\mathrm{V}_e^{2} - \mathrm{V}_i^{2}) + g\,(z_e - z_i)] \qquad (1)$$

In fluid mechanics conservation of energy typically is expressed in terms of head with associated units of length such as meters or feet. Maintaining a consistent sign convention of *heat transfer in is positive and work in is negative* for energy transfers, conservation of energy from a fluid mechanics perspective is expressed by Eq. 2.

$$\frac{P_i}{\rho_i g} + \frac{\mathrm{V}_i^2}{2g} + z_i = \frac{P_e}{\rho_e g} + \frac{\mathrm{V}_e^2}{2g} + z_e + \frac{\dot{W}_{ie}}{\dot{m} g} + h_L \qquad (2)$$

Note in this form, if pump power (work in) is present, the value for $\dot{W}_{ie}$ is negative as done in the first law of thermodynamics. If turbine power (work out) is present, the value for $\dot{w}_{ie}$ is positive. The term $\frac{\dot{W}_{ie}}{\dot{m} g}$ corresponds to pump head (h_p) if negative and turbine head (h_t) if positive.

It is a simple exercise for the student to demonstrate the equivalence of Eqs. 1 and 2. One must apply the definition of specific enthalpy, $h = u + Pv$; express specific volume in terms of density, $v = 1/\rho$; define head loss (h_L) in terms of internal energy change and heat transfer rate, $h_L = \frac{u_e - u_i}{g} - \frac{\dot{Q}_{ie}}{\dot{m} g}$; and rearrange terms to achieve Eq. 2.

Equation 3 is a commonly used alternative expression for conservation of energy from a fluid mechanics perspective. In this form all terms are based on magnitudes, and the consistency of an explicit sign convention is lost. The head terms for both the pump and the turbine have positive values, regardless of whether the associated power is provided to or provided by the system.

$$\frac{P_i}{\rho_i g} + \frac{\mathrm{V}_i^2}{2g} + z_i + h_\mathrm{p} = \frac{P_e}{\rho_e g} + \frac{\mathrm{V}_e^2}{2g} + z_e + h_\mathrm{t} + h_L \qquad (3)$$

Definition of Performance Parameters

Maintaining a consistent sign convention for heat transfer and work throughout thermodynamics and fluid mechanics rather than adopting the use of magnitudes, impacts performance parameter expressions. If a performance parameter has a positive value by definition and its mathematical expression includes energy transfer terms that have a negative value based on sign convention, a negative sign may need to be incorporated when defining the mathematical expression for the performance parameter. The requirement is apparent when comparing use of the *heat transfer in* *is positive and work in is negative* sign convention with use of magnitudes for cycle performance analysis. As indicated in Table 3, thermal efficiency of a power cycle is the same for both sign conventions since all terms are positive using either convention. Coefficient of performance for a refrigeration cycle requires a negative sign in the mathematical expression when using the *heat transfer in is positive and work in is negative* sign convention since one of the two terms is negative. This is not the case when using magnitudes only. Coefficient of performance for a heat pump cycle is the same for both sign conventions since both terms are negative using the *heat transfer in is positive and work in is negative* sign convention while both terms are positive when using magnitudes only.

Other performance parameters affected include net work, back work ratio, cogeneration cycle utilization factor, device mechanical efficiency (e.g., generator efficiency, motor efficiency), and combustion chamber efficiency. Any efficiency expressions that compare energy transfer input with the same energy transfer output will by default require a negative sign to be associated with the mathematical expression. For the vapor power cycle shown in Fig. 1, Table 4 compares the difference in mathematical expressions for some performance parameters based on the sign convention chosen.

Table 3. Performance Parameters For Cycles

Cycle Performance Parameter	**Sign Convention (heat transfer in is positive, work in is negative)**	**Magnitudes only**
η_{th} (power cycle thermal efficiency)	$\eta_{\text{th}} = \frac{\dot{W}_{\text{Net}}}{\dot{Q}_{\text{in}}}$	$\eta_{\text{th}} = \frac{\dot{W}_{\text{Net}}}{\dot{Q}_{\text{in}}}$
COP_{R} (refrigeration cycle coefficient of performance)	$\text{COP}_{\text{R}} = -\frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{Net}}}$	$\text{COP}_{\text{R}} = \frac{\dot{Q}_{\text{in}}}{\dot{W}_{\text{Net}}}$
COP_{HP} (heat pump cycle coefficient of performance)	$\text{COP}_{\text{HP}} = \frac{\dot{Q}_{\text{out}}}{\dot{W}_{\text{Net}}}$	$\text{COP}_{\text{HP}} = \frac{\dot{Q}_{\text{out}}}{\dot{W}_{\text{Net}}}$

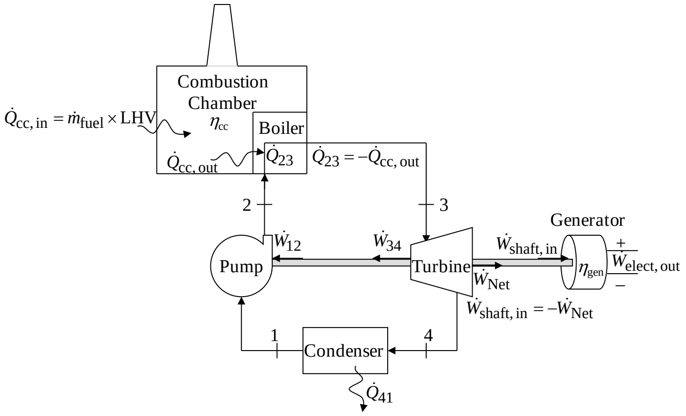

Figure 1. Vapor Power Cycle Schematic

Table 4. Vapor Power Cycle Associated Performance Parameters

Performance Parameter	**Sign Convention (heat transfer in is positive, work in is negative)**	**Magnitudes only**
Net Power ($\dot{W}_{\text{Net}}$)	$\dot{W}_{\text{Net}} = \dot{W}_{12} + \dot{W}_{34}$	$\dot{W}_{\text{Net}} = \dot{W}_{\text{turb}} - \dot{W}_{\text{pump}}$
Back work ratio (r_{bw})	$r_{\text{bw}} = -\dfrac{\dot{W}_{12}}{\dot{W}_{34}}$	$r_{\text{bw}} = \dfrac{\dot{W}_{\text{pump}}}{\dot{W}_{\text{turb}}}$
Combustion Chamber Efficiency (η_{cc})	$\eta_{\text{cc}} = -\dfrac{\dot{Q}_{\text{cc, out}}}{\dot{Q}_{\text{cc, in}}}$	$\eta_{\text{cc}} = \dfrac{\dot{Q}_{\text{cc, out}}}{\dot{Q}_{\text{cc, in}}}$
Generator Efficiency (η_{gen})	$\eta_{\text{gen}} = -\dfrac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{shaft, in}}}$	$\eta_{\text{gen}} = \dfrac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{shaft, in}}}$

The device performance parameters, pump isentropic efficiency and turbine isentropic efficiency, are introduced in thermodynamics. In fluid mechanics the device performance parameters, pump mechanical efficiency and turbine mechanical efficiency, are introduced. Rarely does one find both forms of efficiency for each device discussed in the same text. By presenting both forms of efficiencies when introducing the device, the student can better grasp and distinguish between the meanings of these efficiency concepts.

Student Feedback and Newly Identified Issues

The integrated text was used for the first time in spring term of 2010 in the first course of the sequence. When asked for comments about the textbook as part of the anonymous course end survey, students provided the following representative responses:

- *Much more applicable and useful than a national book.*
- *The book was easy to follow. I really liked the equations table at the end of each chapter. The example problems are also the best of all of my class texts.*
- *Organized in a great manner with great example problems.*
- *Keep using it. It is well written and works well for teaching students from a wide variety of disciplines.*
- *I loved the textbook!*

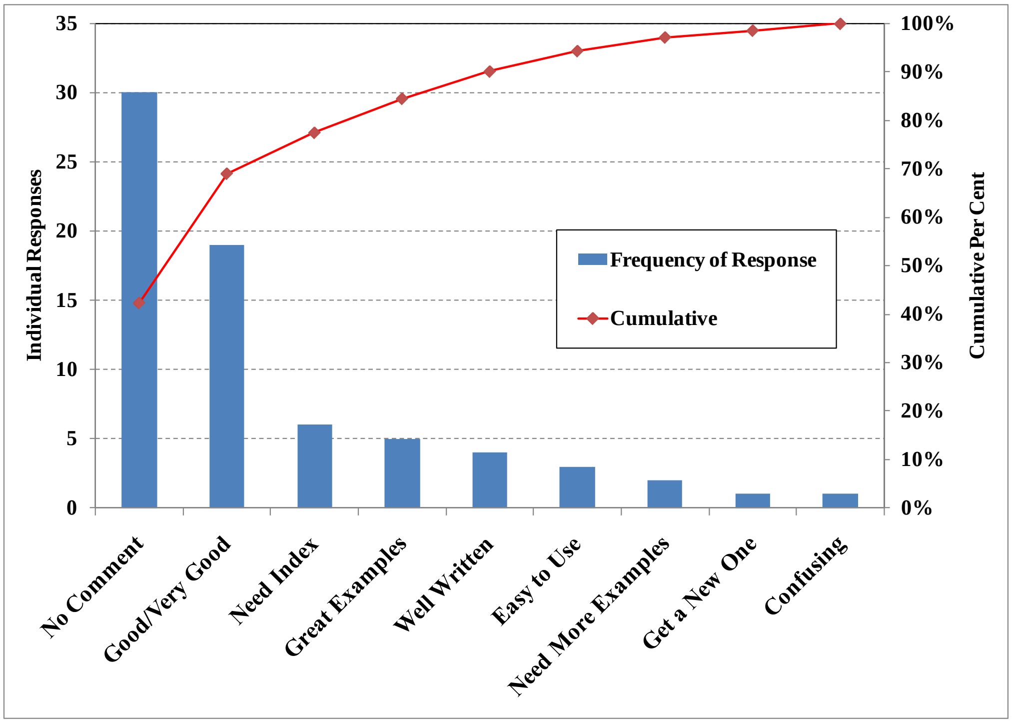

Figure 2. Pareto Chart of Spring 2010 Student Text Feedback

A Pareto chart of student feedback about the integrated text is shown in Fig. 2. Sixty-six students completed the course-end survey. The most common feedback is “no comment” followed by rating the text as “good or very good.” Based on frequency of response, students had a positive overall experience with the text. The most common suggestion to improve the text is to incorporate an index in the back of the text in lieu of the table of contents provided at the beginning of each chapter. In the summer of 2010, the faculty added an index at the back of the book by combining the indices from the beginning of each chapter. Student feedback from the fall of 2010 is shown in Fig. 3. With nearly 90% positive feedback, the most significant recommendation to improve the text is to produce it in hard cover to make it more durable.

Fundamentals of Engineering Examination

Early in the implementation of the new text, the faculty members realized there would be some confusion among the students when it came time to take the Fundamentals of Engineering Examination (FEE). The National Council of Examiners for Engineering and Surveying publishes the Supplied-Reference Handbook which is the reference authorized for use on the FEE[12]. Some of the sign conventions, conservation laws, and performance parameter expressions are different from how they have been developed in the integrated text.

This is hardly a new problem. As shown in our survey of current texts, there is no standard sign convention employed in thermodynamic analysis. This is an issue that all programs have to address at some point. During our presentation of the sign convention used in this textbook, we make mention of the fact that there are other conventions used in other references. To avoid confusion at this point in the students’ instruction, we do not discuss any of the particulars of these alternate sign conventions at this time.

The first students using the new text who will take the FEE are members of the class of 2012. Faculty members will address this in the spring semester of the senior year by conducting a series of FEE review sessions. The differences in the text and the FEE reference manual will be highlighted and explained. At this point in their intellectual development, the students should be able to quickly grasp the reasoning behind these differences and their performance should not be affected by the implementation of the new text. Time will tell and the faculty will be watching this closely.

The only area where students are not meeting the program goals for FEE performance is in the area of Heating, Ventilation, and Air Conditioning (HVAC). This follows a national trend and faculty members have attributed the low performance in this area to the minimal amount of coverage afforded in the course syllabi for the Thermal-Fluid courses (Table 1). We will address this through our FEE review forum and continue to monitor HVAC performance on the FEE to ensure it is not adversely impacted by the new text.

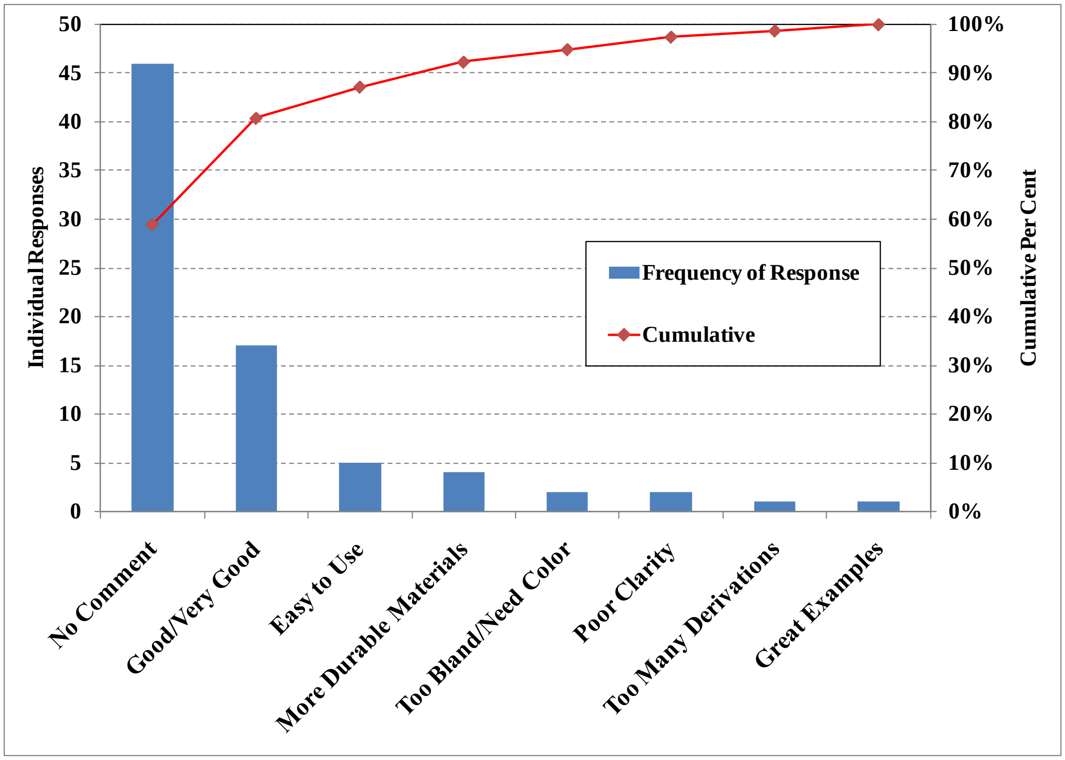

Figure 3. Pareto Chart of Fall 2010 Student Text Feedback

E-Text Possibilities

A natural extension of faculty discussion on implementing the new text was the possibility of making the text available in electronic form. Will the students embrace an electronic engineering text? What features will they desire in an e-text that will make it an attractive alternative? The faculty has collected several semesters of data in an attempt to determine how ‘digitally native’ today’s students are. We began with asking them how they get their news. Results from this survey are shown in Fig. 4. As expected, the vast majority of today's students rely on the internet for their news.

We also queried the students to determine how many are using electronic reading devices such as the Kindle, Nook, etc., as well as how many are currently using the internet to do some portion of their Math, Science, and Engineering (MSE) homework. For this survey, we included a group of our non-engineering majors who are taking a thermal-fluids course for non-engineers, ME 350. These students are humanities majors that must take a three-course engineering sequence as part of their program of study. They use the same integrated text as the engineering students, but only take one thermal-fluids course. As expected, we found the vast majority of all students are using the internet for homework. Surprisingly, we found that significantly more humanities majors use an electronic book reader. These results are shown in Fig 5.

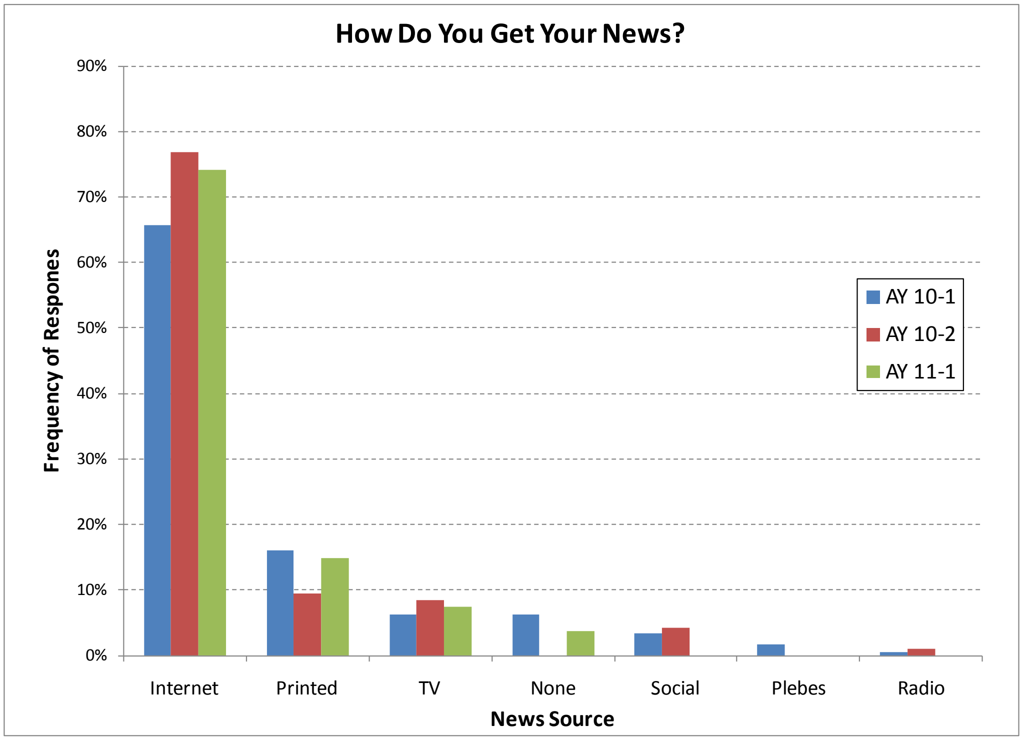

Figure 4. Frequency of Media News Sources Used by Students

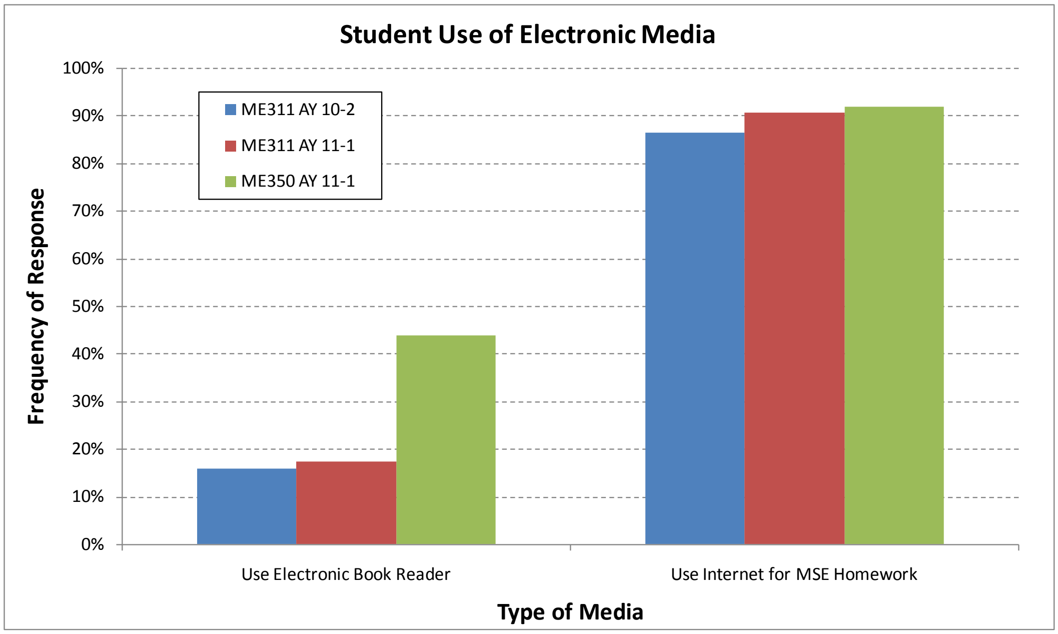

Figure 5. Frequency of Media Use by Students

Finally, we queried the engineering majors with regard to their preference of text media as shown in Fig. 6. We asked the students, “If there were no difference in price, would you prefer an e-text (electronic text) or a printed text for this course?” When we did the initial survey in the fall of 2009, almost 90% of the engineering majors preferred a printed text. The faculty nearly conceded the issue, but decided to continue surveying students. The subsequent results indicate that preferences may be rapidly shifting. We must now ask ourselves how to implement an engineering e-text and what features must it include if we are going to be ready to meet the preferences of future learners.

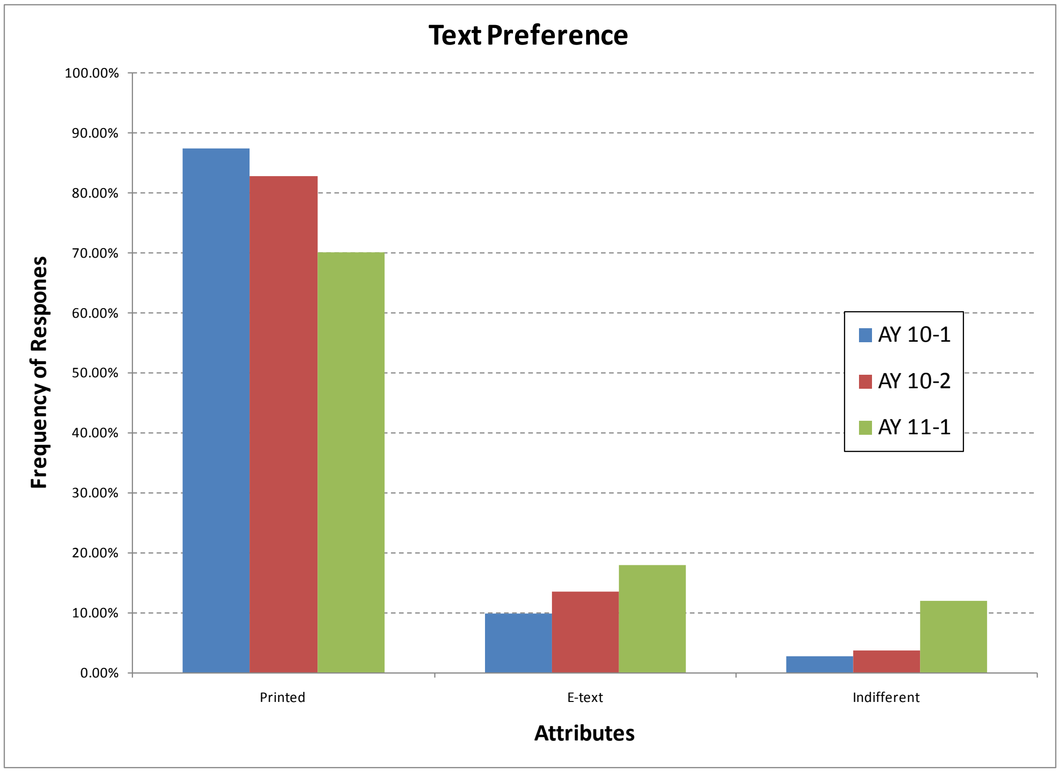

Figure 6. Frequency of Text Media Preferred by Students

Conclusion

There are many challenges to combining thermodynamics and fluid mechanics into an integrated course of study. This paper briefly identifies some of these issues and describes the rationale for decisions the mechanical engineering faculty at West Point made to accomplish this integration. Assessment results of using a textbook written specifically for the two-course thermal-fluid systems sequence are preliminary and part of an ongoing, longitudinal study on the effectiveness of this approach.

Future assessment will include comparison of performance on the thermodynamics and fluid mechanics portions of the Fundamentals of Engineering examination that all mechanical engineering majors are required to take. Another consideration will be providing students an electronic version of the text with the printed text to measure student preference for electronic versus written textbooks. Based on student and instructor feedback, the faculty will incorporate suggestions to improve the text with the goal to provide the most effective tool for student learning.

Acknowledgments

The views expressed herein are those of the authors and do not purport to reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

Bibliography

1. Boettner, D., Norberg, S., Melnyk, R., Highley, J., Rounds, M., and Arnas, A. Ö., 2006, “Teaching the Fundamentals of Thermodynamics and Fluid Mechanics through an Integrated Systems Approach,” *Proceedings of the International Mechanical Engineering Congress and Exposition*, November 5-10, 2006, Chicago, IL, Paper #: IMECE2006-13815.
2. Boettner, D.D. and B.G. Crawford, “Consistency Considerations for Integrated Thermodynamics and Fluid Mechanics Instruction,” *Proceedings of the ASME 2010 International Mechanical Engineering Congress & Exposition*, Vancouver, British Columbia, Canada , November 12-18, 2010.
3. Çengel, Y. A. and Turner, R. H., 2005, *Fundamentals of Thermal-Fluid Sciences*, 2nd Edition, McGraw Hill, New York, NY.
4. Turns, Stephen R., 2006, *Thermal-Fluid Sciences: An Integrated Approach*, Cambridge University Press, Cambridge, England.
5. Kaminski, D. A. and Jensen, M. K., 2005, *Introduction to Thermal and Fluid Engineering*, John Wiley & Sons, Inc., Hoboken, NJ.
6. Moran, M. J., Shapiro, H. N., Munson, B. R., and DeWitt, D. P., 2003, *Introduction to Thermal Systems Engineering*, John Wiley & Sons, Inc., Hoboken, NJ.
7. Boettner, D. D., Bailey, M. B., and Arnas, A. Ö., 2006, “On the Consistent Use of Sign Convention in Thermodynamics,” *International Journal of Mechanical Engineering Education*, Vol. 34, No. 4, Oct 2006, pp. 330-348.
8. Çengel, Y. A. and Boles, M. A., 2011, *Thermodynamics: An Engineering Approach*, 7th Edition, McGraw Hill, New York, NY, 2011, p. xx.
9. Moran, M. J., Shapiro, H. N., Boettner, D.D., and Bailey, M.B., 2011, *Fundamentals of Engineering Thermodynamics*, 7th Edition, John Wiley & Sons, Inc., Hoboken, NJ, p. 71.
10. Çengel, Y. A. and Cimbala, J. M., 2006, *Fluid Mechanics: Fundamentals and Applications*, 1st Edition, McGraw Hill, New York, NY, p. 213.
11. Munson, B. R., Young, D. F., Okiishi, T. H., Huebsch, W. W., 2009, *Fundamentals of Fluid Mechanics*, 6th Edition, John Wiley & Sons, Inc., Hoboken, NJ, p. 223.
12. National Council of Examiners for Engineering and Surveying, *Supplied-Reference Handbook*, 8th Edition, 2nd Revision, NCEES, Clemson, SC.