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UNDERGRADUATE EDUCATION IN THERMODYNAMICS-FLUID MECHANICS-HEAT TRANSFER-ENERGY CONVERSION

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ABSTRACT

Mechanical Engineering education in thermodynamics, fluid mechanics, heat transfer and energy conversion comprise the minimum studies of an Accreditation Board for Engineering and Technology (ABET) accredited undergraduate mechanical engineering programs, both in the United States and internationally. Unfortunately in the last three decades, thermodynamics education has deteriorated causing certain changes in the follow up courses in fluid mechanics, heat transfer and energy conversion systems. The cause of this has been the lack of graduates with advanced degrees in thermodynamics since research in thermodynamics has left a vacancy filled with computational studies and other application areas. If thermodynamics cannot be taught well, then the fundamental understanding of the follow up courses lose as well. This further strays educators away from teaching these topics in a mathematically rigorous way, resulting in "cook book" approaches to problem solving. Unfortunately, the problems we are facing today and in the future are not the ordinary type thus requiring even more fundamental understanding and precise and rigorous applications in the design of engineered systems. Before it is too late, this situation must be reversed so that future engineers will be comfortable in attempting to solve difficult problems in materials science and engineering and their use in energy systems that are sustainable that leave the smallest footprint. Otherwise we will be facing real difficulties in our lives and those of our children throughout the world.

INTRODUCTION

Studies in the combined sequence of thermal sciences have acquired increased importance due to the general problem of energy sustainability throughout the world. In looking at the situation realistically, the world has got to attempt creative approaches to solutions. However, these solutions must depend on nature and what she permits us to do. In this context, two combined courses, ME311 and ME312, Thermal-Fluid Systems courses have been developed. These courses are taken during the third year of study. The details of such a course and how it was developed is given in [1]. The typical outline of the course as it is taught in 2010 is given in Table 1 for ME311 and Table 2 for ME312. Although different texts [2,3] or combined texts [4] have been used in the past, our dissatisfaction with them has caused us to embark on a text of our own which is in its very preliminary stage of development. However, it is much more precise in its presentation; for example in sign convention [5], without making remarks like "relaxed sign convention" [2]. Also, the emphasis is placed on correct and precise teaching of the second law of thermodynamics, entropy and exergy, [6]. The analyses of cycles are based on the second law and exergy as is the design project. In ME311, the design is that of a power plant using only steam cycles. In ME312 this same design is extended to combined cycle cogeneration systems using the definition of performance parameters and other information as discussed in [7]. In this fashion, the students come to appreciate the importance of engineering design in thermo-fluid systems.

As is seen from Table 1 and Table 2, there is experimental work incorporated into these two courses to solidify the theory presented in the lectures. A laboratory report is required after the exercises in the experimental venue. This aspect of the courses is very important for the students' understanding of the fundamentals presented in the lectures. Also, as is seen in Table 2, two lectures are presented in designing experiments that relate to the course; we believe this is a first in this type of a course.

Now that we are in the third year of this new sequence, we are rather comfortable with the content of these courses. Once the textbook issue is resolved, we believe that we will have a very strong, meaningful and educationally sound sequence in Thermo/Fluids. Of course, small adjustments are made each and every semester based on the feedback from the students and the faculty alike in our weekly lesson conferences. Since our classes are limited to eighteen students, we have a number of faculty members teaching the same course.

In view of the fact that our students may select to be aviation officers as well as select the Corps of Engineers, we feel that we should group our discussions so that they can all relate to these different branches that they will serve in. That is why the various blocks have been generated to accommodate all possibilities. It is of course just as easy to discuss these topics generically for a mechanical engineer as it is for all engineers. That is why in ME311 the groupings were made accordingly. This is a course sequence that is taken by all ABET accredited engineering programs.

In the case of ME312, the groupings are for automotive systems and high performance aircraft. This course is not taken by all engineers, such as systems engineering. Therefore, the content is left to be robust that would best relate to our own students. Again, appropriate laboratories are included as well as experimentation by similitude and modeling. This way the students understand how things are done in industry to support development work. Also, the aviation students must take the appropriate flight lessons; for this they need the theory to better appreciate why things happen in an aircraft the way they do.

The ME 480-Heat Transfer course, as shown in Table 3, has been using the same textbook for a number of years [8]. Although we feel there are some shortcomings in the form of inconsistencies, the text nevertheless is a good one that we continue to use. This course also incorporates a design component where the students continue with the same problem they had in ME311-312 but this time design the condenser for the power plant, Fall 2009 semester. Additionally, experimental methods are discussed and numerical methods are introduced for the transient heat transfer cases since the steady state is a trivial case of that. Additionally, they perform a problem in the CAD laboratory to verify their equations. The intent is to show that solutions could be analytical, numerical and experimental to determine the empirical equations using dimensional analysis. In this fashion they are exposed to the important methodologies of solutions.

LSN	Block	Topic
1	Introductory Concepts	Introduction to Thermal Fluids
2		Total Energy
3		Ideal Gas Law, Internal Energy, Enthalpy
4	Hydrostatics	Hydrostatic Pressure
5		Hydrostatic Pressure on Submerged Surfaces
6		Conservation of Energy – Closed System
7	**Exam #1**	
8	Conservation Laws	Conservation of Mass and Momentum
9		Conservation of Energy – Open System
10		Bernoulli Equation
11		External Flow
12		*Open Channel Laboratory*
13		Problem Solving
14	**Exam #2**	
15	Power Plants	Steam Properties
16		Introduction to Cycles
17		Introduction to Losses
18		Second Law of Thermodynamics
19		Steady Flow Devices
20		*Engineering Equation Solver Workshop*
21		Vapor Power Cycles
22		*Steam Turbine Laboratory*
23		Improving Vapor Power Cycles
24		Feedwater Heaters
25	**Exam #3**	
26	Pipe Flow	*West Point Power Plant Tour*
27		Introduction to Pipe Flow
28		*Class Drop for Design Work*
29		Turbulence and Major Losses
30		Minor Losses
31		Pipe Networks and Pumps
32		Surface Tension and Capillary Action
33		Problem Solving
34	**Exam #4**	
35	Air Conditioning	Vapor Compression Refrigeration Cycles
36		**Design Briefing**
37		Psychrometry
38		Air Conditioning Processes
39		**Final Design Briefing**
40		Term End Review

TABLE 1. ME 311- Thermo/Fluids I course outline for Spring 2010 semester.

LSN	Block	Topic
1	Fundamentals	Review of ME311
2		Ideal Gas Relationships
3		Introduction to Exergy
4		Exergy Balance
5		Problem Solving
6	**Exam #1**	
7	Automotive Engines	Introduction to Internal Combustion Engines
8		Air Standard Otto Cycle
9		Air Standard Diesel Cycle
10		Introduction to Combustion
11		Enthalpy of Formation / Enthalpy of Combustion
12		Problem Solving
13	**Exam #2**	
14	Airfoils	*CFR Lab*
15		Dimensional Analysis
16		Modeling and Similarity
17		Experimental Methods
18		Experiment Planning
19		External Flow / Boundary Layers Review
20		*Wind Tunnel Lab*
21		Drag
22		Lift
23		Differential Conservation of Mass
24		Differential Conservation of Momentum
25		Differential Navier-Stokes Equations
26		Problem Solving
27	**Exam #3**	
28	Aircraft Propulsion	Gas Turbine Engines and the Brayton Cycle
29		*Gas Turbine Lab*
30		Improving Gas Turbine Engine Performance
31		Combined Cycle Analyses
32		Aircraft Propulsion and Jet Engines
33		Compressible Flow I
34		Compressible Flow II
35		Compressible Flow III
36		Problem Solving
37	**Exam #4**	
38	Special Topics	Advanced Topics Presentations I
39		Advanced Topics Presentations II
40		Term End Review

TABLE 2. ME 312-Thermo/Fluids II course outline for Spring 2010 semester.

Heat transfer is not an easy course because it incorporates all –ics ending fundamental courses, such as mathematics, physics, mechanics, optics, et cetera, into design of safe and economical systems that are used in industry. It is naturally easy for the student to do "compartmentalized" rather than integrated studies. Also, they seem to have forgotten the fundamentals that they need to model engineering systems. This seems to be an international phenomenon that seems to bother instructors all over the globe. The advent of "cookbook" computational programs give the wrong impression that anything can be solved using them. This, however, is not correct since they do not know or understand the details of the programs since they have not written them themselves. They are afraid of physical/mathematical analyses even if they knew the mathematics required. This naturally creates an adversary situation in the classroom; on the one hand the instructor emphasizing mathematical rigor and on the other hand the student resisting it. This attitude is particularly evident in teaching of conduction where mathematical rigor is always required.

In convection studies, the problem continues with mathematical rigor. To write the generalized equations of conservation of mass, momentum, energy for a given equation of state, characterizing the fluid, and watching out for the second law of thermodynamics, completely upsets the student. Although they have studied these in ME312, the memory span is unfortunately short. Of course, we as instructors, have to carry some blame too. If we do not practice what we discuss in class, then the students lose interest and try to find shortcuts to solutions whether they exist or not. The fact that these equations must be simplified based on the physics of the problem, boundary/initial conditions must be written that are truly modelling the physics of the given situation. Then analytical, numerical and/or experimental solutions can be intelligently discussed and based on the level of the course, appropriate solutions are obtained.

LSN	Block	Topic
1	Conduction I	Intro to Heat Transfer
2		Conservation of Energy and Fourier's Law
3		The Heat Diffusion Equation
4		Steady 1-D Conduction
5		Thermal Circuits
6		Thermal Circuits in Radial Coordinates
7		Extended Surfaces - Fins
8		Fins with Non-Uniform Cross-Sections
9		Heat Exchangers: LMTD Method
10		Heat Exchangers: Effectiveness- NTU Method
11	**Exam #1**	
12	Radiation	Blackbody Radiation
13		Real Surface Radiation
14		View Factors
15		Radiation Exchange
16		Multimode Heat Transfer
17		Radiation Review
18	**Exam #2**	
19	Conduction II	Steady 2-D Conduction
20		Separation of Variables
21		Lumped Capacitance
22		Transient 1-D Conduction
23		The Semi-Infinite Solid
24		Numerical Methods
25		Design Lab
26		Conduction Review
27	**Exam #3**	
28	Convection	Boundary Layers
29		B.L. Equations
30		Poiseuille Flow
31		Couette Flow
32		Internal Flow Correlations
33		Blasius' Solution
34		External Flow Correlations
35		Free Convection
36		Boiling
37		Condensation
38		Convection Review
39	**Exam #4**	
40		Term End Review

TABLE 3. ME 480-Heat Transfer course outline for Spring 2010 semester.

LSN	Block	Topic
1	Chemical Thermo-dynamics	State of World Energy
2		Adiabatic Flame Temperature
3		Chemical Exergy I
4		Chemical Exergy II
5		Chemical Equilibrium
6		Hydrogen
7		Fuel Cells
8		Batteries + Electric Vehicles
9	**Exam #1**	
10	Solar Energy	*Class Drop for Movie Lunch*
11		Biofuels – Guest Speaker
12		Global Warming
13		Solar Energy Fundamentals
14		Solar Collectors I
15		Solar Collectors II
16		**Geopolitical Review Presentations**
17		Photovoltaic Effect
18		Photovoltaic Devices
19		Solar Thermal Power
20		Solar Heating / Cooling
21	**Exam #2**	
22	Power Plants	Advanced Power Plants
23		Thermo-economics
24		Clean Coal and Carbon Capture
25		Nuclear Power
26		**Trip - Indian Point Nuclear Power Plant**
27	Direct Energy Conversion and Renewable Energy	Thermionics
28		Magnetohydrodynamics
29		Geothermal Energy – guest Speaker
30		Thermoelectric Power
31		Thermoelectric Cooling
32		Wind Power
33		TBD
34		Ocean Energy and Hydropower
35		**Trip - GE and Glenheim Pumped Hydro**
36	**Exam #3**	
37	Related Topics	Energy Storage
38		Military Energy
39		Water Resources
40		Term End Review

TABLE 4. ME 472-Energy Conversion Systems course outline for Spring 2010 semester.

The shortcoming of the text does manifest itself in various places. The one that is so very obvious is in the section on condensation heat transfer. In engineering, we try to teach the fact that intelligent assumptions must be made to simplify the problem so that a solution can be obtained. However, the requirement is that these assumptions must be validated at the end. As is seen in the text, the assumptions are made and a result for the convective heat transfer coefficient is given. However, the student has no way to know if for a given problem the assumptions made are actually valid. To alleviate this situation, we have made a study [9] and we pass this to the students so that they see what must be done. Also, they have a copy from literature that goes from the fundamentals to the solution of a real problem emphasizing what is being taught in the course. We also feel that there are other important topics in heat transfer that are not covered or even mentioned in the text. To resolve this situation, another study that we have made is also copied and passed on to the students which they can easily follow through and appreciate the importance of meaningful analysis, [10].

The topic of heat exchangers must be presented early, in our case, due to the fact that the design component of the course is on the design of a condenser for the power plant that they have worked on during the ME311-312 courses. This not only satisfies the ME480-Heat Transfer design requirement but also shows that these courses are indeed interrelated and that a power plant is a very good engineering model to study thermodynamically, from a fluid mechanics point of view as well as heat transfer. Talking about this interaction and proving it are two different things; we do both. The emphasis is solving these type of problems using both the LMTD method and the NTU method. This also increases their confidence in solving problems.

The block on radiation is also covered analytically, to a certain extent. After a study of the physics of radiation, engineering applications are discussed as they relate to design of engineered systems. Ideal blackbody radiation is followed by actual surface radiation, the determination of geometrical factors-shape factors, using the reciprocity relation and the summation rule of these factors. Once a relative ease is established, then engineering problems are discussed including combined heat transfer processes used in the design of terrestrial and spatial systems. The course has five review sessions and four tests and a comprehensive final examination.

The course ME472-Energy Conversion Systems is one that has been taught for many years. It has undergone changes and these have been reported in literature, [11] and [12]. Since then, some changes have been incorporated in the course as shown in Table 4. These changes are not cosmetic but are in response to the responsibilities our students will have as officers upon graduation two of which are the geopolitical implications of world energy resources and the military use of energy. The other topics are more general in nature like chemical thermodynamics and thermoeconomics, advanced combined cycle cogeneration systems, direct energy conversion systems and renewable energy resources. These are augmented by visiting speakers who amplify certain topics because of their expertise. Two visits are made; one to a nearby 2000 MW nuclear power plant and the General Electric Global research Centre and the nearby pumped hydro power plant. In this fashion they get to see firsthand what they have been studying over the two years is applied and what designs were incorporated and how these systems operate safely and economically, as they should, from an engineering point of view.

CONCLUSION

It is obvious that studies in Thermo/Fluids, Heat Transfer and Energy Conversion systems have received the necessary attention over the years here at the United States Military Academy at West Point. We have shown the details of these studies in various publications nationally and internationally and have learned from the discussions that took place to implement the changes in a satisfactory fashion during the last decade. We also believe that this is an ongoing process and changes, when justified, will be implemented appropriately as the need arises. Our intent is and has always been to teach the undergraduates in engineering, mechanical engineering in particular, the topics in Thermal Sciences in a unified, meaningful and "precise" fashion so that the students learn the basic fundamentals which they can build upon, if necessary. Since some of them will return after receiving their Master's and/or Doctoral degrees to teach at West Point, these courses form a solid foundation for their further studies. Upon their return for three years, their most up-to-date knowledge will further update and improve the content of this sequence of courses. In this fashion, we will continue to offer the best courses for our purposes.

As was referred to before, we are not totally satisfied with the textbooks that we have used in the past. To alleviate this situation, we have started to write, put together and possibly publish our set of textbooks in due time. We may be more critical of this situation than others but our firm belief lies in the fact that whatever we teach has got to be correct and "precise".

The teaching methodology is the best there is since all of our instructors go through an eight week active instruction in "teaching" called the Instructor Summer Workshop prior to starting their careers in teaching which does not exist in too many institutions that we are aware of. In this fashion, all instructors cover the same material on a given day for uniformity, because as was mentioned before our sections are limited to eighteen students and that result in many people teaching the same material on any given day for uniform examinations. To further guarantee this, there are weekly "course meetings" with all instructors under the leadership of a "course director" where the course is critically observed for the past week, what must be covered the following week, and what "problem sets" and examinations must be prepared. Due to the large number of sections, more than one examination must be prepared which should cover the same material but yet be different: a challenge in itself. In this fashion we are able to sustain uniformity in all aspects of the courses.

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