ENERGY CONVERSION TOPICS IN AN UNDERGRADUATE THERMODYNAMICS COURSE AT THE UNITED STATES MILITARY ACADEMY

CPT Blace C. Albert, MAJ Shawn E. Klawunder, and Dr. A. Özer Arnas

Department of Civil and Mechanical Engineering
United States Military Academy
West Point, NY 10996

Abstract

The mission of the United States Military Academy (USMA) is "To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country; professional growth throughout a career as an officer in the United States Army; and a lifetime of selfless service to the nation."[1] In order to accomplish this mission, USMA puts their cadets through a 47-month program that includes eight academic semesters. Upon graduation, the cadets receive a Bachelor of Science degree and are commissioned as officers in the United States Army.

A very unique aspect of the academic program at USMA is that each cadet is required to take a minimum of five engineering classes regardless of their major or field of study. This means that about 500 cadets will have taken the one-semester course in thermodynamics. The thermodynamics course taught at USMA is different from others throughout the country. Within every class there is a mixture of cadets in engineering and non-engineering majors, i.e. languages, history, and others.

The unique mixture of students has prompted instructors at USMA to work hard to design a course that is very physical and hands-on. This has been achieved particularly in the area of energy conversion systems. Topics covered include vapor power cycles, internal combustion engines, gas turbine engines, and vapor-compression refrigeration cycles. Four laboratories and a tour of a cogeneration facility supplement the thermodynamic concepts. The course is also brought to life by some very unique teaching aids. These teaching aids include the following: reference cards for solving problems, turbine/compressor blades, jeep engine cutaways, distributor caps, cam shafts, fuel injectors, gas turbine engines (T-53, T-700, AGT-1500, and Mars), V2 rocket (scramjet), J85 jet engine (with and without afterburner), Broadhead-Garrett trainers, and cutaways of air-conditioners and refrigerators. Finally, students majoring in Mechanical Engineering (general mechanical and aeronautical systems), Civil Engineering, Engineering Management, or Environmental Engineering, complete a design of a cogeneration facility for USMA.

Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition

Introduction

The United States Military Academy (USMA), located in West Point, NY, about 50 miles north of New York City, was founded in 1802 as an academy that educated officers for the United States Army. In 1812, upon recognizing the need for engineers, USMA changed its curriculum to educate engineers for the Army and a young nation. In addition to offering a broad variety of majors, it is still known primarily for its engineering programs. USMA also remains one of the ways to become a commissioned officer in the United States Army.

There are approximately 4,000 cadets at USMA. Although about 10,000 applications are received annually, they are screened for grades, athletics, extra-curricular activities, and physical fitness. They must also receive a nomination from one of their state's congressmen. This lengthy process results in about 1,300 cadets being admitted to USMA each year.[2]

Today USMA offers a wide variety of majors that cadets may choose. Twenty-four majors and seventeen fields of study are offered in the mathematics, science, and engineering disciplines.[3] Forty-four majors and fifty-two fields of study are offered in the humanities and public affairs disciplines. All cadets take a core curriculum that makes up the majority of their first two years, however.

In addition to the core curriculum, every cadet must take a minimum of five engineering courses. Cadets choose this five course engineering sequence during their second year at USMA, at the same time they are choosing a major or field of study. There are seven engineering sequences from which they may choose. They are as follows: Civil Engineering, Computer Science, Electrical Engineering, Environmental Engineering, Mechanical Engineering, Nuclear Engineering, and Systems Engineering. The twenty-six core courses and five engineering courses make the academic experience at USMA a very unique one.

The Department of Civil and Mechanical Engineering is one of thirteen departments at USMA. Its mission is to "educate and inspire cadets in civil engineering, mechanical engineering, and engineering mechanics such that each of these cadets is a commissioned leader of character who is committed to duty, honor, country; a career in the United States Army; and a lifetime of service to the nation.[4] The Department accomplishes this mission while offering an extensive engineering curriculum to add to the comprehensive core curriculum. The Mechanical Engineering Division offers a degree in General Mechanical Systems and one in Aeronautical Systems.

There is a unique blend of faculty that executes this academic program. There are four permanent military faculty, eighteen rotating military faculty, and four civilians within the Mechanical Engineering Division. The academic ranks of the faculty include instructor, assistant professor, associate professor, and professor. The rotating military faculty are officers, to include one from the Navy and two from the Air Force, that have an average of thirteen years of service in the military. Thirteen of these officers are teaching at USMA for three years and will then rotate back to the Army to continue serving as an officer in the Armed Forces. Three of the rotating faculty members are at USMA for the second time in their careers.

Energy Conversion Education

The fact that many cadets choose to major in engineering, along with the fact that all cadets have to take a five course engineering sequence, results in almost 500 cadets taking EM301-Thermodynamics (480 cadets were enrolled in academic year 2000-2001). Of these 500 cadets, approximately 50% are not engineering majors. They are cadets majoring in another discipline, but have selected the mechanical engineering five-course sequence. These majors could be English, foreign languages, history, general management, leadership, political science, geography, chemistry, and the list goes on. Teaching a course with this type of student population has to be thought out carefully. A lot of mathematics, equations, and derivations do not appeal to this group. The right mix of these, along with many demonstrations, examples, and training aids, must be put into the course in order to make it real, understandable, and relevant to the cadets.[5]

Another one of the challenges that thermodynamics instructors are faced with is that there is only one semester of Thermodynamics offered. The reason for this is the number of core curriculum credits that cadets must take, and the fact that cadets should graduate in four years. This is less time to present the material when compared to the two quarters or two semesters that many mechanical engineering programs offer. Topics must be chosen carefully so that the cadet experience is broad enough to understand the many applications of Thermodynamics, but also in depth enough that our mechanical engineering majors gain the necessary experience to be successful in subsequent courses and to be competitive engineers in the Army or after they leave the service. Table 1 shows what topics are covered in this one semester Thermodynamics course.

SUBJECT	NUMBER OF LESSONS
Properties and Introductory Concepts	2
Work, Heat, and the 1st Law of Thermodynamics	3
Ideal Gas Law and Specific Heats	1
Steam Tables	2
Steady Flow Engineering Devices	1
Thermodynamic Cycles and the Carnot Cycle	2
2nd Law of Thermodynamics	4
Isentropic Relations and Efficiencies	1
Rankine Cycle	**5**
Otto and Diesel Cycle	**5**
Emissions	**1**
Gas Turbine Engines and the Brayton Cycle	**2**
Regenerative Gas Turbine Engines	**1**
Gas Turbines for Aircraft Propulsion	**1**
Power Cycle Applications	**1**
Vapor Compression Refrigeration Cycle	**2**
Psychrometrics	2

Table 1: Subjects Taught in Thermodynamics

One will notice from looking at Table 1 that energy conversion is the focus of this Thermodynamics course (lessons shown in boldface). Using energy conversion makes the course relevant to the cadets, regardless of what their major is. They all see a real-world vapor power application when they tour a cogeneration facility on West Point. They will all own automobiles and be responsible for maintenance of diesel engines while in the Army. They will all come in contact with gas turbine applications, whether on Army helicopters or on tanks. Finally, everyone uses refrigeration daily. Motivating the cadets' learning with these real-world energy conversion topics has proved to be very successful. Non-engineering students will not have a passion for learning without being motivated by the fact that they will encounter these things after they leave the classroom.

Choosing these energy conversion topics makes the course relevant, but it is not, however, the last step in making it real and understandable for the cadets. A class that is heavy with theory, derivations, and equations does not appeal to many students, much less those that major in the humanities instead of the sciences. The Thermodynamics course taught at USMA makes use of two strengths in order to appeal to all of our diverse students' desire to learn. These two strengths are our teaching aids and our laboratories. The following sections of the paper will describe how and what teaching aids and laboratories have been incorporated into these various energy conversion topics.

Vapor Power Systems

There are five lessons covering vapor power systems. We begin first with an ideal Rankine cycle and then discuss the differences in an actual cycle. We then move on to cycles that include regeneration (open and closed feedwater heaters) and reheat. Instructors make this block of instruction real and understandable by first introducing students to the physical components that make up this cycle. Pump, turbine, compressor, and boiler sections are passed around the class. Many students can't visualize what is physically occurring in these thermodynamic devices until they actually see the devices. The cadets also gain an appreciation for the amount of engineering design that goes into these components. For example, seeing the airfoil shapes of the turbine blades makes them realize that a great deal of engineering design went into manufacturing the most efficient turbine possible. Some of these devices are shown in Figure 1.

Figure 1: Thermodynamic Devices

The second way that cadets gain an understanding of vapor power cycles is in the laboratory. Cadets complete a pre-laboratory exercise before coming to class. This assignment helps them understand what they will see in the laboratory, practices First and Second Law of Thermodynamic calculations, and makes them think about what type of gages and sensors would be needed to collect the necessary data. Cadets then conduct a two-hour laboratory that involves collecting data from two different steam turbines. One turbine powers a rack of light bulbs and students measure the current and voltage outputs. The other turbine's shaft is connected to a dynamometer allowing the cadets to measure torque and revolutions per minute. Temperature and pressure data is taken at all of the state-points, and mass flow rates of steam and condenser cooling water are measured. The cadets complete a report involving First and Second Law calculations. They also discuss ways in which the cycle efficiencies can be improved. Figures 2 and 3 show a picture of this laboratory.

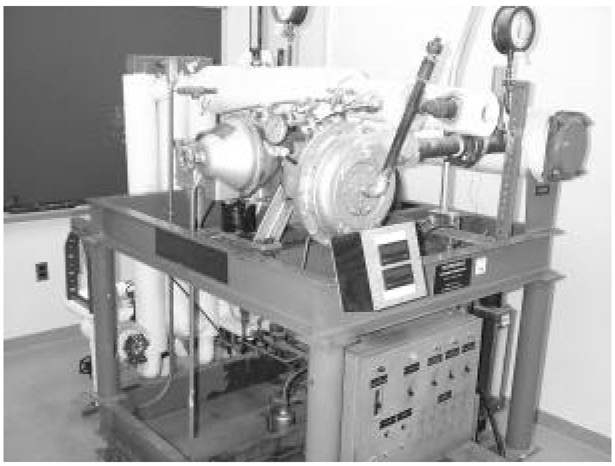

Figure 2: Westinghouse Steam Turbine

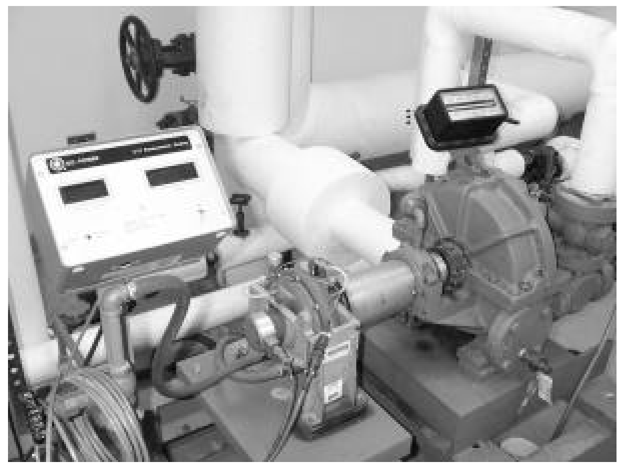

Figure 3: Carling Steam Turbine

The third way instructors bring vapor power systems to life is by touring a cogeneration facility located on West Point. This facility produces some electricity used for "peak-shaving" and process heat used for building heat, cooking, and showers in the cadet area. By touring this facility, cadets get a feeling for the magnitude of these thermodynamic devices. The turbines, pumps, boilers, and feedwater heaters are certainly bigger than any device they saw in the laboratory exercise. They also learn about real-world concerns such as adding make-up water to the cycle to replace condensate loss and the chemistry that is required. Finally, the tour allows them to verify assumptions they have previously made. For example, whether or not the pipes are adiabatic.

Figure 4: Inside Power Plant Boiler

One of the boilers was recently replaced in this cogeneration facility. This year students also received the benefit of seeing the inside of these large boilers as one of them was being disassembled. This is shown in Figure 4.

Internal Combustion Engines

The second major block of energy conversion instruction comes in the area of internal combustion engines. This includes three classes on spark-ignition and compression-ignition engines, one class on automotive emissions, and two laboratories. In the first class, an in-line six cylinder Jeep engine cut-away is used to explain how the engines in the cadets' cars work. The students find this very relevant to their lives. There is no better way to learn how the engine works than actually seeing a real piston moving up and down interacting with the valves, fuel pump, oil pump, water pump, cam shaft, drive shaft, distributor, and carburetor. This particularly useful training aid is shown in Figure 5. Instructors also have an array of additional training aids such as fuel injectors, distributor caps, and small models of 2-stroke and 4-stroke models to use in their presentation of this material.

Figure 5: In-line Six Cylinder Jeep Engine

During the second lesson, instructors discuss the air-standard and cold air-standard assumptions and model the spark-ignition and compression-ignition engines as the Otto and Diesel cycles. The third lesson is a problem solving session in which students work a variety of Otto and Diesel problems. The automotive emissions class includes topics such as where emissions come from, what emissions are considered pollutants, and what we can do to reduce pollution. Once again instructors make use of real catalytic converters, exhaust gas recirculation (EGR) valves, carbon canisters, and positive crankcase ventilation (PCV) valves to discuss these topics. The automotive emissions training aids are shown in Figure 6.

Figure 6: Automotive Emissions Training Aids

Cadets conduct two laboratories on internal combustion engines. The first is a laboratory that compares a spark-ignition engine to a compression-ignition engine of equal bore/diameter and stroke/length. Cadets complete a pre-laboratory, once again preparing them for the actual exercise. Measurements for mass flow rate of fuel, shaft revolutions per minute, and shaft force are taken for each of the engines at five different speeds for a given moment arm. This allows students to compare parameters such as torque, power, and thermal efficiency between the two engines. In addition to this, mass flow rate of air and emissions are recorded for the spark-ignition engine, allowing cadets to plot graphs of certain pollutants versus the air-fuel ratio. Cadets answer several questions pertaining to the data they collected in a written laboratory report. A picture of this laboratory is shown in Figure 7.

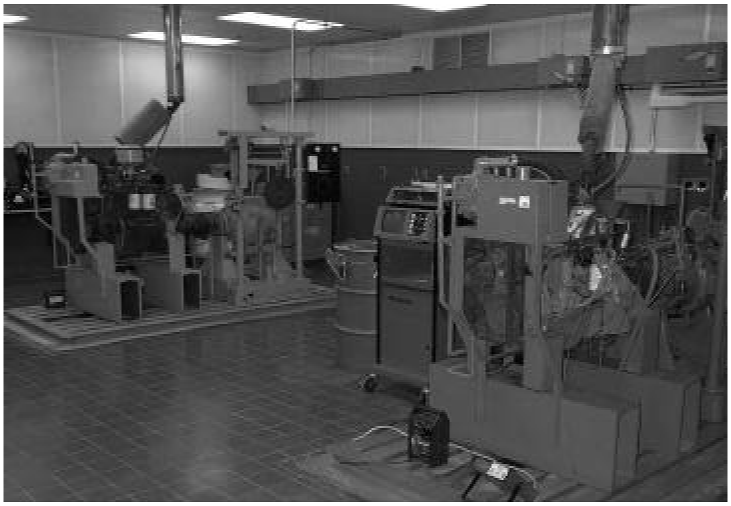

Figure 7: Spark Ignition-Compression Ignition Laboratory

The second laboratory is conducted utilizing the same methodology – pre-laboratory, collect data, analyze data, and submit a written report. This laboratory utilizes Cooperative Fuels Research (CFR) engines that allow cadets to vary compression ratio, spark-timing angle, and type of fuel. The torque for a given speed and compression ratio is measured at six different spark-timing angles using 86 octane fuel. The experiment is repeated with a racing fuel that has a 110 octane rating. Data for both fuels is then collected a second time, for six spark-timing angles each, at a different compression ratio. As the data is collected, the students make a note of what operating conditions result in the auto-ignition of the fuel (engine knock). This allows the cadets to understand the effects of fuel octane, spark-timing angle, and compression ratio on engine performance. A CFR engine is shown in Figure 8.

Figure 8: Cooperative Fuels Research Laboratory

Gas Turbine Engines

The third major block of instruction covers gas turbine engines. There are four lessons covering this topic. The first lesson introduces students to a simple gas turbine cycle using several different training aids. There are helicopter engines from the UH-1 “Huey” helicopter

(T-53 Gas Turbine) and the UH-60 "Blackhawk" helicopter (T-700 Gas Turbine). These are two helicopters that the cadets will encounter in the Army after they graduate. The engine housings have been cut away so the students can see the compressor sections, the combustion chamber, and the turbine sections. They have also been modified so that they can be plugged into the wall and all of the sections turn as they would in operation, only much slower so the cadets can see it happening. These two training aids can be seen in Figures 9 and 10.

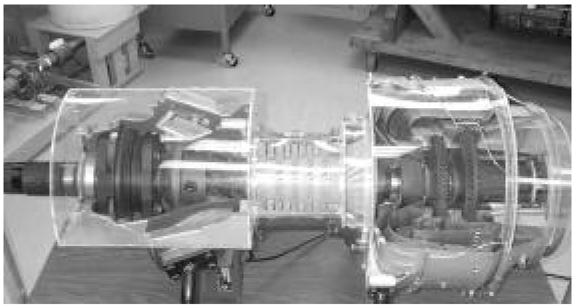
Figure 9: T53 Gas Turbine

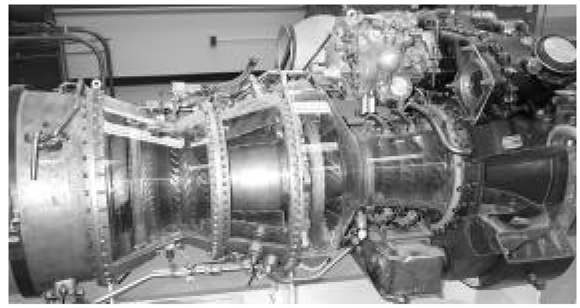
Figure 10: T700 Gas Turbine

After discussing actual gas turbine operation, the engines are modeled according to the air-standard and cold air-standard assumptions to make Brayton cycles. Students then practice working problems for simple Brayton cycles.

The second gas turbine lesson describes how these engines can be improved through regeneration. There is another direct application of this in the Army. The AGT-1500 gas turbine engine with regeneration is found in the Army's main battle tank, the M-1 "Abrahms". Cadets view a movie describing how the AGT-1500 works and why it was designed the way it was. They view an actual engine that has also been cut away to observe the internal operation. This can be seen in Figure 11. Students also work several problems for Brayton cycles with regeneration.

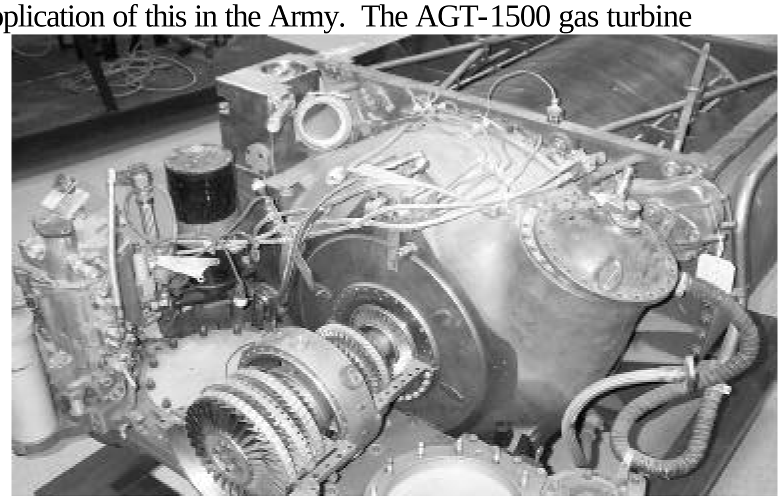
Figure 11: AGT 1500 Gas Turbine with Regeneration

The third gas turbine lesson covers jet propulsion. The methodology for this class is the same as it was for the simple gas turbine cycle. Instructors first begin by covering the operation of an actual engine, then model the engine as a Brayton cycle, and finally students finish by working jet propulsion problems with and without an after-burner. Instructors use several training aids for this lesson that are shown in Figures 12 through 15.

Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition

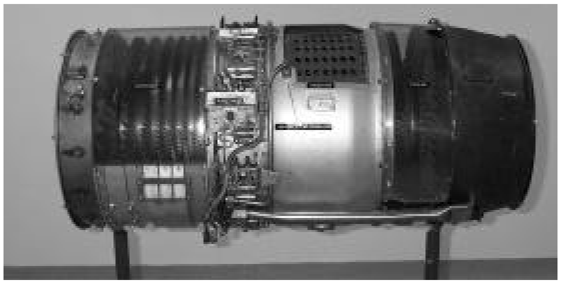

Figure 12: J85 Jet Engine

Figure 13: J85 Jet Engine with After Burner

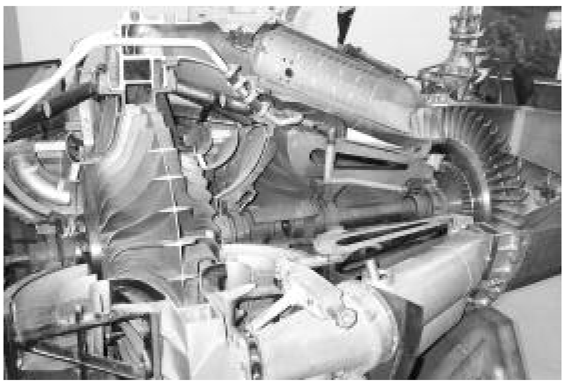

Figure 14: J33 Jet Engine

Figure 15: V2 Scram Jet

The final lesson in this block is a laboratory in which students collect data from the auxiliary power unit (APU) of the UH-60 Blackhawk helicopter. This is another real-world, relevant application for the future Army officers. The APU is a T62-40-1 gas turbine engine. After completing a pre-laboratory exercise before coming to class, the students review the differences between an ideal Brayton cycle and the actual gas turbine engine. They are then shown some of the advantages of gas turbines (can operate on different fuels, simplicity, high power-to-weight ratios) by disassembling a Mars gas turbine that was used on Navy ships for operating fire-fighting pumps. Cadets then examine the experimental setup of the APU, allowing them to verify the proper way of taking data that they addressed in their pre-laboratory report. Data is collected from the turbine and cadets use this data to answer questions in a laboratory report. The APU is shown in Figure 16.

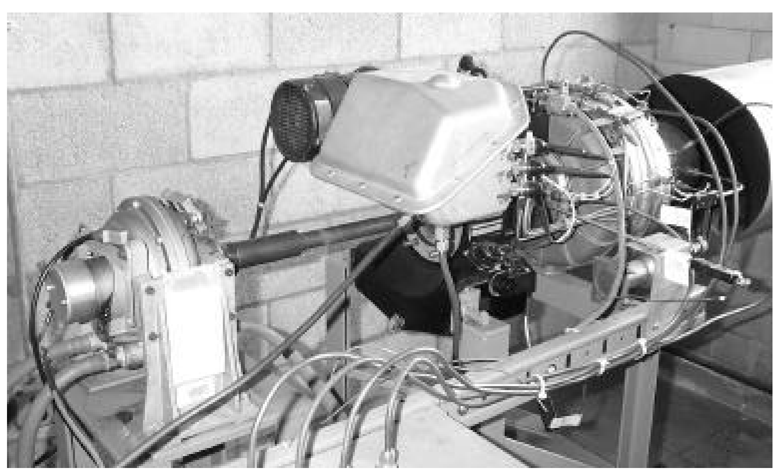

Figure 16: Auxiliary Power Unit (APU) for the UH-60 Blackhawk

Vapor Compression Refrigeration Cycles

Cadets complete their energy conversion topics by learning about the vapor compression refrigeration cycle. Once again this topic is useful in making thermodynamics real and relevant to the cadets as all of them are familiar with household refrigerators, air conditioners, and, in many cases, heat pumps. We devote two lessons to this topic. The first lesson describes the ideal vapor compression refrigeration cycle and teaches students how to use a pressure-enthalpy diagram. Performance parameters are also discussed. These include terms common to refrigeration applications in the United States such as energy efficiency rating and tons of refrigeration.

The second lesson teaches cadets the differences between ideal cycles and actual cycles. Instructors make use of a Broadhead-Garrett trainer to teach the cadets about an actual cycle. This training aid is shown in Figure 17. Real air conditioners and refrigerators are also available to instructors. These appliances have also been cut away so that students may examine the internal operation of each.

Figure 17: Broadhead-Garrett Trainer

Energy Conversion Design

Students majoring in Mechanical Engineering, Civil Engineering, Engineering Management, or Environmental Engineering take the same thermodynamics course as all of the other cadets majoring in other areas. In addition to these course requirements, however, the cadets in the above mentioned engineering majors complete a design project for an additional half credit-hour. The scenario for this design is that the cogeneration facility at West Point has burned down. Cadets design a new cogeneration plant providing some electricity for peak shaving and process heat for showers, cooking, and building heat in the cadet area. Cadets begin by designing a basic vapor power cycle. They calculate temperature, pressure, enthalpy, and entropy for each state point in the cycle. The design is optimized so that only the minimum required electricity and process heat is produced. Cost analysis is also done for the design. Cadets then design an improved cogeneration cycle which allows them to make comparisons in cost and efficiency. The most common designs are Rankine cycles with regeneration and topping cycles. The average time spent on this project, for a four-person design team, is 80 total man-hours, thus justifying the additional half credit that they earn. The final product is a full written technical report and an oral briefing to their instructor.

The Future of Energy Conversion Topics at USMA

The five-course engineering sequence, mentioned at the beginning of this paper, will become a three-course sequence beginning with the class of 2005. Engineering majors will continue to take the Thermodynamics course as described in this paper. Non-engineering majors, with a mechanical engineering sequence, will not take the traditional Thermodynamics course anymore. This has caused the department to take a look at what courses should be taught to these cadets not majoring in engineering. One of the three courses selected is going to cover the thermal sciences.[6] Although there is a large amount of material that could be put into this course, there is only one semester to work with. Despite having all of our fluids, thermodynamics, and heat transfer courses to select topics from, one topic that remains the backbone of this new thermal science course is energy conversion. The instructors that are developing this new thermal science course, understanding the applicability of internal combustion engines and gas turbines to an Army officer, have left these two blocks of instruction nearly intact. Actual spark-ignition and compression-ignition engines, the Otto and Diesel cycles, and the CFR laboratory will be covered in this new course. Actual gas turbines will be discussed, followed by the idealization of the engine into the Brayton cycle. Cadets will still learn regeneration in gas turbines and jet propulsion. The gas turbine laboratory will also remain in this new course. It is always important, and often times challenging, to motivate student learning. Keeping non-engineering students interested and motivated while taking a class like Thermodynamics is even more challenging. Due to the wide range of applications in today's world, and the Army, energy conversion topics are an excellent way of doing this.

References

1. Office of the Dean, 1998, "Educating Army Leaders for the 21st Century," United States Military Academy, West Point, New York, p. 5.
2. Albert, B., Arnas, Ö., 2002, "Integration of Gas Turbine Education in an Undergraduate Thermodynamics Course," Proceedings, ASME Turbo Expo, Land, Sea, and Air 2002, Amsterdam, Holland, accepted for publication.
3. Office of the Dean, 2000, "Academic Program AY 2000-2001: Field Tables and Course Descriptions," United States Military Academy, West Point, New York.
4. Internet, United States Military Academy, Department of Civil and Mechanical Engineering, Web-page, Oct. 2001, http://www.dean.usma.edu/cme/Mission/Mission.htm.
5. Albert, B., Arnas, Ö, Bailey, M., Klawunder, S., Klegka, J., Wolons, D., 2001, "A Unique Approach to Teaching Thermo dynamics," Proceedings, ECOS '01, Istanbul, Turkey, Vol.1, pp. 181-193.
6. Klawunder, S., Albert, B., Arnas, Ö., 2002, "Systematic Thermal Science Course Development at the United States Military Academy," Proceedings, ASEE National Conference, Montreal, Canada, to be published.

CPT BLACE C. ALBERT has been an instructor at the United States Military Academy (USMA) for two years. He graduated from USMA in 1991 with a B.S. in Mechanical Engineering (Aero) and received a Master of Science Degree in Mechanical Engineering from the Georgia Institute of Technology in 2000. He has served in the United States Army for eleven years.

MAJ SHAWN E. KLAWUNDER has been an instructor at the United States Military Academy (USMA) for two years. He graduated from USMA in 1990 with a B.S. in Mechanical Engineering and received a Master of Science Degree in

Mechanical Engineering from the Georgia Institute of Technology in 2000. He has served in the United States Army for twelve years.

DR. A. ÖZER ARNAS has been at the United States Military Academy (USMA) since 1998. Prior to that, he has held academic positions at Louisiana State University, 1962-1985, California State University System, 1986-1993 and has been a Visiting Teaching/Research Professor in Turkey, Costa Rica, Belgium, Italy and the Netherlands and was a recipient of the ASEE Centennial Certificate in 1993.