Development of a Modern Integrated Thermal Systems Design Laboratory

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ABSTRACT

The Department of Mechanical and Aerospace Engineering at the University of Florida is in the process of developing a modern thermal systems laboratory that integrates a broad range of topics from the engineering curriculum with the objective of improving the analytical ability, teamwork skills, and, most importantly, the design expertise of our students. This is accomplished by coordinating just-in-time lectures with hands-on, small-group laboratory experiences involving industrial-type equipment and data acquisition systems, a design objective for each experiment, and culminating in an open-ended group design project. The integrated lectures, laboratory experiments, and design experiences in such topics such as heat exchangers, pump/pipe system matching, pool boiling, cooling towers, and air-conditioning break down the traditional compartmentalization of these education experiences. During this development, we have received numerous requests for descriptions of the equipment and experiments used in our labs. Therefore, a discussion of the apparatus and the experiments is included in this paper as well as the novel method used to fund the laboratory. Feedback from our students and alumni has been very positive. Students have listed their experience in the lab on their resumes and have emphasized their lab and design proficiency with potential employers. Alumni have reported that the synthesis of their previous coursework gained in this laboratory has been directly applicable to their job duties in the workplace.

INTRODUCTION

All ABET accredited Mechanical Engineering programs are required to provide laboratory and design experiences in their curriculum. Instructors who are responsible for upgrading the laboratories have frequently requested information from our department as to the facilities we have available and how they are implemented. This paper is a description of what issues within the curriculum we are addressing in our laboratories, the actual equipment, and how the laboratories in funded. It is hoped that such information will facilitate other departments in the implementation and selection of their laboratory equipment.

Senior level students in Mechanical Engineering at the University of Florida are required to take two three-hour thermal systems design courses. One course is called "Thermo-Heats Design and Laboratory", and consists of thermodynamics and heat transfer integrated with design and laboratory that includes including heat exchanger design, phase-change heat transfer, thermodynamics of mixtures, psychrometrics, mass transfer and sensible heat recovery. The second course is called "Thermo-Fluids Design and Laboratory", and consists of design and laboratories for fluid flow systems, turbomachinery, compressible flow, chemical reactions and thermodynamic cycles.

The Thermo-Fluids/Thermo-Heats laboratories are opportunities for students to apply their knowledge of thermodynamics, fluid mechanics, and heat transfer to working equipment such as turbo-machines and heat exchangers that re-enforces, and frequently challenges, what they have learned in prior engineering courses. This is accomplished by coordinating just-in-time lectures with hands-on, small-group laboratory experiences involving industrial-type equipment and data acquisition systems, a design objective for each experiment, and an open-ended group design project. Improvement of communication skills, both written and oral, are strongly emphasized in lab reports and oral presentations. Students develop a detailed uncertainty analysis of each experiment that leads to a much more disciplined and sophisticated approach to the assigned tasks. The courses culminate with design projects which allow students the opportunity to explore new topics and gain confidence in creating solutions to difficult engineering problems.

LAB/LECTURE/CURRICULUM INTEGRATION

Each course consists of two lecture periods per week and five laboratory experiments. There are approximately one hundred students in each class. The labs, which occur every other week, begin in Week 3 of the course, and there are approximately five classroom lectures that accompany each experiment. There are five students in each lab section, thus, there are about twenty-five lab sections per experiment. Two sections (one from each course) are run simultaneously. Two teaching assistants (TA) are assigned to each course in addition to the instructor.

Each lab section also has a “pre-lab” section that is conducted during the week before the lab. Currently, the pre-lab is taught by a TA in groups of about twenty-five. In the pre-lab, students are taught the fundamentals of data collection for that particular lab, how to perform an uncertainty analysis, and how to operate the equipment. We are in the process of transitioning the pre-lab from a live session to a pre-recorded session to be delivered by WebCT.

When students report for their lab, they are expected to conduct the lab independently with only minimal input from their TA. The staff deliberately maintains a limited presence in the lab to promote independence, and we typically intervene only when there is an equipment problem that cannot be reasonably solved by the students within the time period of the lab.

Students write a detailed lab report in a form similar to a technical paper for each lab. The first four reports are individual reports, and the last report is a group report. The group report serves as an opportunity to develop a working relationship among the group members before commencing the design project described in the next paragraph.

The final assignment in the class is a group design project. Each group consists of the members of each lab section. A typical Thermo-Heats project is the design of a heat exchanger. Thermo-Fluids students usually design a fan/piping system. The students first present their work in a oral presentation, and then submit a detailed technical report.

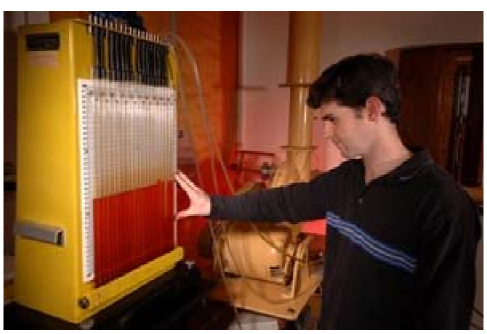
These two courses were introduced into the curriculum to complement our introductory courses in thermodynamics, fluid mechanics, heat transfer, and instrumentation and measurements classes. The instructors of these introductory courses developed the content for the two lab courses and originally taught these lab classes. As a result, the coordination between the introductory and lab classes is excellent, and students are very well prepared when they enter these courses. In order to maintain the continuity and ensure quality, the department has hired an instructor whose sole duties are to teach and maintain the structure of the lab, and ensure close association with the introductory classes.

LAB EQUIPMENT

A short description of each of the laboratories will follow in this section. The major hardware is listed in parentheses as well as an estimate of the original cost. The computer data acquisition systems are built by our students in a separate data acquisition independent study course. Annual maintenance costs average around $200 per piece of equipment, and all equipment should last a minimum of ten years. At first glance, the equipment may appear expensive and impractical for an engineering department to own. The section of this paper following this one will describe how funding is obtained. The first five labs described below are for *EML4304C Thermo-Fluids Design and Lab*, and the second five labs described are *for EML4147C Thermo-Heats Design and Lab*.

LABS FOR *EML4304C THERMO-FLUIDS DESIGN AND LAB*

Pipe loss experiment (constructed in-house, approximately $10,000) – In this experiment, students measure the head loss due to friction in selected pipes and fittings at different flow rates. From the data, students determine friction factors. Flow rate is measured using Proteus electronic flow meters integrated with Labview. Head loss is determined by measuring height of water in tubes with a tape measure.



Fan performance lab (Plint & Partners, original cost approximately $20,000) – In this lab, students measure the head gain at various flow rates, and rpm's and torque of a fan. Using the data, students develop a fan performance curve which is used to determine the correct size of a fan or pump for a given piping system. Head gain and flow velocity are determined by measuring pressure with a manometer consisting of a bank of tubes.

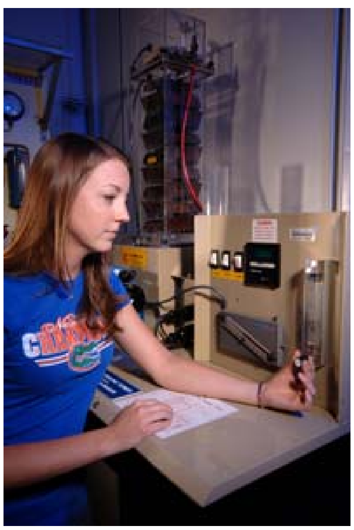
Tank discharge lab (constructed in house, approximately $10,000) – Students learn the principles of compressible flow, and they develop the theory of a choked orifice flow meter. Pressure and temperature are measured in a large tank at one millisecond intervals using an electronic pressure transducer and thermocouple connected to a computer. Mass flow rate is calculated, and comparisons are made between theoretical calculations and measured values.

Hydro-rocket lab (purchased from Glen Thorncroft, approximately $26,000) – In this lab, students learn to calculate the thrust from a rocket nozzle. The thrust of the rocket is measured for a number of initial pressures and propellant volume using a high speed pressure transducer and load cell connected to a computer using Labview. Students develop theory that allows them to determine the feasibility of using such a rocket as a jet assist to shorten the takeoff distance for a small aircraft.

Air conditioning lab (Technovate Air Conditioning and Refrigeration Lab, approximately $27,000) - In this lab, students learn the thermodynamics of the various refrigeration cycles. By measuring temperature, pressure, and flow rates at various points in the cycle, students calculate the performance and power requirements of an air-conditioner. Students manually record the temperature and pressures at the different state points.

LABS FOR *EML4147C THERMO-HEATS DESIGN AND LAB*

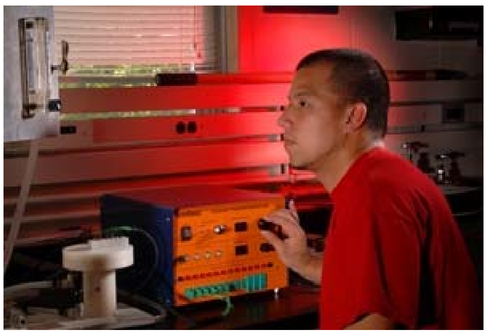
Pool Boiling Lab (P.A. Hilton, H655 Boiling Heat Transfer Unit, \$15,364) – The apparatus in this lab is a small-scale version of the equipment used to maintain the temperature of materials found in such places as in the core of a nuclear power plant. In pool boiling, a hot object in immersed in a non-flowing liquid which causes boiling. Students measure the heat transfer associated with the pool boiling from a stainless steel cylinder and develop a nucleate boiling curve. In addition, they measure the maximum (critical) heat flux above which safe boiling cannot be sustained, and plot the critical heat flux at various system pressures.



Cooling Tower – (P.A. Hilton, H892 Bench Top Cooling Tower, \$21,350) In this lab, warm water is pumped from a tank to the top of the cooling tower. The water flows over packing plates in the tower resulting in a thin film of water exposed to a stream of air. During its downward passage through the packing, the water is cooled, largely by the evaporation of a small portion of the total flow. Air enters at the bottom of the tower and flows upward increasing its moisture content while the water is cooled through evaporation. Students measure wet and dry bulb temperatures as well as flow rate and calculate the rate of heat transfer from the water to the air.

Heat Exchanger Lab (constructed in house, approximately \$15,000) – In this lab, students analyze a concentric double-pipe heat exchanger by measuring inlet and outlet temperatures of the two fluids as well as their flow rates. From this information, students calculate the heat flux and overall heat transfer coefficient.

Radiation Lab (constructed in house, approximately $10,000) – In this lab, students measure the radiative heat transfer from an oven at various distances. By comparing the measurements with theoretical predictions, students can determine the emissivity of the oven as well as the performance of the detector.



Heat Conduction Lab (HT10XC-B Heat Transfer Service Unit, HT11 Linear Heat Transfer, HT12 Radial Heat Transfer, $23,601) – In this lab, students are taught the principles of linear and radial heat conduction and how to use that theory to measure heat flux. They learn how to find contact resistance and how to determine the thermal conductivity of various materials. Thermal circuit diagrams are emphasized.

FUNDING SOURCE

The decline in the economy has led to severe budget cuts at the University of Florida. Ironically, this has greatly benefited the funding of the undergraduate laboratories in our department. In response to the loss of state funding, the University has established an "equipment fee" in addition to previously existing "lab fee". The lab fee, which has existed for many years, has been restricted to purchases for "expendables", i.e., items which are normally consumed within one semester. A typical lab fee is around $45 per student per semester. A new equipment fee was established in the 2008 Spring semester. The equipment fee averages about $200 per student per semester, and is intended to fund the purchase and maintenance of major laboratory equipment. An important feature of the equipment fee is that the funds can be used in support only of the classes for which the fee exists. Since the annual enrollment is approximately five hundred students per year, the result of the equipment fee is that the Thermal Systems laboratories now receive approximately $100,000 of funding for major equipment each year paid for totally from student fees and at no cost to the state. The replacement cost for a typical experiment is around $25,000. Within two years, we expect to have all new equipment in the labs with permanent funding to maintain state-of-the-art laboratories. The students in the courses benefit because their fees are spent in direct support of their education rather than distributed throughout the university.

RESULTS AND DISCUSSION

We developed a detailed long-range plan for equipment acquisition about a year ago without identifying funding sources. With the implementation of the equipment fee this past spring, the long-range plan has turned into a two-year program. At the time of this writing, we are about one year into the plan.

Our first goal has been to obtain duplicate sets of each experiment. The additional sets allow us to reduce the number of sections offered. As an example, currently we must offer twenty-five sections of each lab since we have only one of each experiment. With two copies of each experiment, we reduce the number of sections by half. This reduces the TA time by half, and frees the instructor to teach another course.

The extra equipment has another benefit in that occasionally the equipment fails during the experiment. If there is only one piece of equipment and it fails, and if repairs require more than twenty-four hours, it is likely that that lab session will be lost for the semester. The duplicate equipment provides a back-up and allows students to complete their experiments with a typical delay of no more than one hour. If there is only one piece of equipment and it fails, and if repairs require more than twenty-four hours, it is likely that that lab session will be lost for the semester.

CONCLUSIONS

It is the opinion of this author that the development of the lab experiments, student participation, scheduling, and equipment acquisition has proceeded very well. An important reason for the success was the development of the long-range plan which clearly identified the needed equipment, a detailed floor plan, and equipment costs. Key to the implementation of the plan was presenting the plan to the entire faculty early on and obtaining their support. The second reason for the success of the program was the establishment of the equipment fee. Probably the most important reason for the success of the program was the assignment of an instructor whose full-time duties are to lecture, develop, and maintain the laboratory facilities.

It may be questioned as to the practicality of assigning a single instructor to these courses. Due to the complexity of the maintaining the equipment, and especially the need to perform on-the-spot repairs, it becomes a necessity to have a full-time faculty member assigned permanently to these courses. It has been tried within the department previously to rotate faculty members through the courses, but the quality of the courses has been compromised due to the lack of familiarity of the faculty with the equipment. It has been shown that it takes about three semesters to become proficient with all the quirks and detailed knowledge required to keep the equipment fully operational within the limited lab periods available.

The program is certainly cost effective. By collecting equipment and lab fees, the monetary cost to the department is only the salary of the instructor. That expense would be incurred whether the course is a lab course or a lecture course, so it does not really qualify as any additional expense. The cost of space is certainly a consideration. The space requirement is greater than a lecture course, although that cost is mitigated by holding multiple sections that can be offered during low-demand times.

The future of the laboratories appears secure with the implementation of the equipment fee. The fee appears to have become a permanent part of the funding for the University of Florida, and, thus, will be available for maintaining the labs in the foreseeable future.

It is the opinion of the author that the program is a success and very sustainable. Informal conversations with other faculty have indicated their support also. Student and alumni feedback has been very positive. A sampling of the comments include: "I am (now) working with the Space Shuttle Main Engine… (The lab) was one of the best hands-on experiences during my education…", "I learned more practical engineering information in these two labs than I have in any other class I have taken at UF" ,"… the best lab I've taken at UF", "…class is one of the few that actually teach real world engineering concepts", "…teaches fundamental engineering skills", "…important for ME's and AE's", "…completes the practical part of the heats textbook", "I learned more in this class than in any other…", and "…supports creative thinking."

These two laboratory courses have become a valuable part of the Mechanical and Engineering program here at the University of Florida. The program described in this paper allows us to maintain the quality we have achieved, to continue to upgrade the facilities as equipment depreciates or as technology advances, and to easily adapt to any changes that may be required in the curriculum.