Purdue Heat Transfer Celebration
April 3-5, 2003, West Lafayette, IN

THERMAL SYSTEM DESIGN AT THE UNIVERSITY OF KANSAS

Louis C. Burmeister
Department of Mechanical Engineering
University of Kansas
1530 W. 15th Street
Lawrence, KS 66045

ABSTRACT

The development of a capstone thermal-fluid system design course in the Department of Mechanical Engineering at the University of Kansas is recounted. Next, a rearrangement of courses in the design sequence after that development is described. Finally, the need for flexibility in the definition of "design" in order to accommodate the new biomechanics interest of the department is discussed.

INTRODUCTION

It has long been recognized that research, in the words of Wickenden [1, p. 386],

> "… transforms the atmosphere of a college from that of a glorified sort of schoolhouse to a place where real things are happening…. An engineer is a man who spends his life in solving problems. He can best learn this art as a disciple, under men actively engaged in solving problems. I mean real ones, and not just exercises in the back of a book."

Design has a similar importance in the minds of many educators and accreditors, although its definition is less sure. As Sabersky [2] wrote in connection with accreditation requirements,

> "Now originally, I am sure, design simply meant "machine design" or "mechanical design" and it was typically a required course in a mechanical engineering curriculum. When the need for diversity and flexibility became evident it was realized that a course in "Machine Design," important as such a course may be, was not necessarily the right thing for every mechanical engineering student. The word design, however, carries a lot of tradition and even magic and there was great reluctance to remove it from the curriculum. Rather than dropping the word design entirely, therefore, design was redefined in a broad and rather complex manner. The definition is in fact open to a rather wide range of interpretations."

Because of these views, realistic problems have been a staple of engineering education for decades. Professional consulting, industrial experience and interaction, and research enable engineering professors to identify problems; involving students in contriving solutions is the final step.

The accreditation requirements of the Engineering Council on Professional Development (ECPD) in the 1970s included one-half year of engineering design without further specification. Beginning in the 1980s, the Accreditation Board for Engineering and Technology (ABET) further specified that there must be at least one course that was primarily design, preferably at the senior level, and listed open-ended problems as an important characteristic of the design component of a curriculum. To meet this requirement, design courses, often termed "capstone", of integrative nature to draw on all of the skills learned in prerequisite courses were added to many mechanical engineering curricula.

Opinions about these new requirements were mixed. On one hand, as discussed by Wesner [3], the "capstone" design course was thought of for the senior year because the most integrative experiences come when students have most of the skills and tools that are needed to prosecute the design process. Still, he opined that design experiences should appear throughout the program because one is always taken aback by new situations, and the design situation should not be sprung anew on even a senior. On the other hand, Sabersky [2] believed the design experience is most efficiently and effectively learned on the job in professional employment.

In the following, the creation in the 1980s and instruction of a thermal-fluid capstone design course in the Department of Mechanical Engineering at the University of Kansas will be recounted. Next, a rearrangement of courses in the design sequence after that development is described. Finally, the need for flexibility in the definition of "design" in order to accommodate the new biomechanics interest of the department is discussed.

BACKGROUND

At the University of Kansas in the post-WWII period, the Department of Mechanical Engineering had a curriculum that included one senior-level course devoted to design, usually of some sort of machine, always taught by the same professor. A laboratory emphasizing measurement of the performances of compressors, internal combustion engines and so forth was also always taught by the same professor. Shop and foundry experiences were provided in the separate Department of Metallurgy and Materials Engineering, mostly by instructor-level members of the faculty; the machine tools were available to undergraduate students, many working on projects.

In the 1970s the Department of Mechanical Engineering incorporated the former Department of Metallurgy and Materials and shop instruction was drastically reduced. Equipment remaining from a WWII program to train machinist mates for the United States Navy was used to provide a machine shop capability for the entire School of Engineering and a low-level machine-tool course for undergraduate mechanical engineering students. The laboratory course then emphasized measurements, rather than determination of machine performance. This pattern of adjustment to changed circumstances continued.

In the late 1960s, the School of Engineering started NASA-funded Master of Engineering and Doctor of Engineering programs that emphasized design and project management. The intent was to produce graduate-degree holding engineers who were able to function as members and leaders of design teams. Because only two of the five departments had Ph. D. programs and they were research oriented, these two programs were interdisciplinary so that the faculty and students of the entire School of Engineering could participate.

Through the 1980s and 1990s, the Department of Mechanical Engineering participated in a program funded by the U. S. Department of Energy to establish an Energy Analysis and Diagnostic Center at each of several universities to perform energy audits for regional manufacturing plants. A team of undergraduate and graduate engineering students under the leadership of an engineering professor would gather information at a manufacturing plant in the course of about a day. Their suggestions for reducing the amount of energy used to accomplish the manufacturing task were conveyed in a written report. In many instances, designs for energy management schemes were proposed and evaluated by the students. An energy management course was developed to support this program.

To meet the ABET design requirement of the 1980s, two measures were taken. The first was to revise many of the required mechanical engineering courses to include a special design problem of about one-week duration. The second was to require a capstone thermal-fluid design course, ME 656 Thermal Systems Design II, additional to the mechanical design course that had long been required, both to have a semester-long design project as a major component. The mechanical design course continued to emphasize the design of components, usually mechanical ones. The new ME 656 Thermal Systems Design II course emphasized the design of systems, usually thermal-fluid ones. After instituting these two measures, the Department of Mechanical Engineering received the maximum 6-year accreditation from ABET, compared to the 2-years-and-a-visit outcomes of several prior inspections.

ME 656 Thermal Systems Design II was first taught to a pilot group of 2 graduate students in the fall semester of 1987. This was done to assess the adequacy of preparations for support of the design projects as well as the adequacy of the time allowed for other activities. The textbook and its end-of-chapter problems, computer programs for thermal-fluid system simulation, computational fluid dynamics, and multi-dimensional optimization, reference materials in the School of Engineering library, and several design project topics were tried by and on the graduate students in the pilot group. Enrollments were 10 in the spring semester of 1988, 18 in the fall semester of 1988, and 71 at the peak in the spring semester of 1993.

PREPARATION FOR CAPSTONE DESIGN COURSE

Preparation for a capstone thermal-fluid design course began in detail as experience with the pilot group was accumulated. To support the thermal-fluid system design project that was the centerpiece of the course, it was found to be necessary to devote 40% of the course to adding to the information acquired by undergraduates in foregoing courses. The textbook by Stoecker [4], then in the first edition, was used. It was the only one then available, although others [5-8 – the most recent editions are cited for the convenience of the reader] were published later. Although Stoecker offered a good combination of some thermal-fluid design project topics, end-of-chapter problems, basic engineering economy, and basic optimization, it still required extensive supplementation.

It became apparent that the supplemental information would be more effectively imparted if it were incorporated into a textbook for each student to read at his convenience, reducing note taking and easing presentations. Materials that had been gathered, both during the prior 22 years of consulting, researching, and teaching at the University of Kansas and developed with the pilot group, were assembled into a draft for a textbook [9] that was adopted upon its publication. The information was largely taken from other sources in order to present the wisdom of the group, rather than the idiosyncrasies of an individual. Major supplemental topics and the typical number of periods in a semester of 16 weeks plus a 3-hour final exam period were (1) conceptual design and techniques for stimulating it - 3, (2) thermal-fluid equipment - 5, (3) financial figures of merit for competing projects - 4, (4) methods for optimal selection of design parameters - 3, (5) methods for assessing the reliability of a design - 3, (6) product liability and safety - 2. Of course, the details of the supplemental information depended upon the design project for that semester.

The final chapter of the textbook [9] is an illustration of the prosecution and reporting of a typical semester-long, thermal-fluid system design project. The intent of that chapter is more to provide the student with an example of how a design process can unfold, to be read at the student's convenience, than to provide the instructor with a series of presentations.

ADMINISTRATION OF CAPSTONE COURSE

Design project topics were developed in consultation with practicing engineers and technologists so that data would be realistic and resulting designs would be practical. Some past topics for ME 656 course system design projects are:

(a) Use of the Tonganoxie aquifer in a seasonal thermal energy storage scheme to help meet the heating and cooling needs of the University of Kansas campus – consider tree farms, cogeneration, energy from municipal waste, solar energy, and so forth in combination

(b) Use of the Ogallala aquifer to help meet the heating and cooling needs of a commercial building in Dodge City, KS in a seasonal thermal energy storage scheme – consider evaporative cooling, regenerative energy storage in rock beds, cogeneration, wind and solar energy, and so forth in combination

(c) Utilization of a blanket of inert gas to enable grain to be dried and stored on the producer's property for a period of at least two years – consider vacuum drying, microwave heating, cogeneration, and so forth

(d) Recovery or disposal of the solvent vapor from a process in which gold foil is affixed to paper (the vapor is incinerated now) – consider absorption, condensation by compression plus refrigeration, regenerative preheating of combustible air-vapor mixture, and so forth

(e) Reduction of the costs of cement plant energy and dust removal from its exhaust – consider solar energy (perhaps a laser beam from a geosynchronous earth-orbiting satellite) as an energy source, quenching effluent gases by evaporation of a water spray, storing heat in rock beds by regenerative heat exchange, and so forth

(f) Use of heat pumps to assist clothes driers - optimally select parameters to meet specified loading conditions, utilize continuous rather than batch processes, and so forth

(g) Improvement of the energy efficiency of an industrial laundry – consider solar energy, regenerative heat recovery, use of heat pumps to recover heat from humid exhaust air, microwave heating for driers, counterflow washers, and so forth.

Design of a component, really just a small system, can also be undertaken, of course. McCoy [10] provided an example of such a topic that can be obtained from the engineering work place:

(h) A pump to purge non-condensable gases and water vapor from the condenser of a distillation assembly – consider a peristaltic pumping mechanism among others, account for heat flow from the environment and the motor, and so forth.

While supplementation in elements of each of the six topical areas listed previously was indispensable, a satisfactory base for understanding the information needed to address one of these project topics had been obtained in prerequisite science and engineering science courses, for the most part. However, the use of computer programs for system simulation (TRNSYS [11]), computational fluid dynamics (FLUENT [12]), and optimization (Design Optimization Tools [13]) was new to each student.

Each class was divided into design teams, all working on the same design topic so that the instruction given to one would apply to all. The number, between four and 10, of student members on a team needed to be large enough that working with and coordination of a group was experienced, but small enough that each member had to make a substantial contribution. Each team submitted a description of its design in a written report that included, in addition to the common features of a report, a description of a simulation of the unsteady performance of the system, optimal selection of system parameters, and a computational fluid dynamics evaluation of some aspect of the system.

Each team made five oral presentations. The first presentation described the team organization along with the schedule for project activities. The second and third presentations were of progress and difficulties encountered. The fourth presentation, made during one of the last days of the semester, was of the written final report of the design for the project. Shortcomings of this report were pointed out in a written critique. The fifth and final presentation during the final examination period was of revisions to the design and report to meet adverse criticisms. The instructor's suggestion that teams work on different solutions to the same design problem to ease comparison of alternatives was never adopted.

The semester grade for the course was based on homework (30%), oral presentations (10%), and final report (60%). The homework comprised end-of-chapter problems from the textbook, computer program familiarization exercises, and short problems contrived to illustrate application of information and techniques to the design project.

Limiting the time spent by a student on design projects in a semester required special arrangements. The ME 656 course was scheduled for the fall semester while the mechanical design course was scheduled for the spring semester. And, the ending point of a design team in one semester was often used as the starting point for a design team in the succeeding semester.

REARRANGEMENT OF THE DESIGN SEQUENCE

Assessment of the success of an educational scheme should be done with consideration of the thought, said by Hinton [14] to be due to Sir Charles Inglis (professor of engineering at Cambridge University),

> "The spirit of education is that habit of mind which remains with the student long after he has forgotten everything that he has been taught."

Boelter [15] thought that such a state occurs about 25 years after graduation. The specific accreditation requirements imposed by ABET for design might have strayed from this thought as excerpts from a paper by Sabersky [2] illustrate. He wrote,

> "…,for the education of a present-day-engineer a flexible curriculum would be most suitable. A flexible curriculum which requires a group of fundamental courses and which would teach the student not only certain subjects but also teach her or him how to learn by her or himself and how to absorb new knowledge on her or his own initiative…. Unfortunately as just pointed out, the engineering accreditation process in the last 10 or 15 years has become more rigid rather than more flexible. This trend has been particularly evident in the attitude toward the requirement of "design."… The only thing that is definite in the view of the accreditors is that whatever design means, it is required, and the equivalent of ½ years of an engineer's education has to be devoted to design. This requirement has been a major cause of trouble for many schools who are attempting to develop forward-looking course programs…., and an even more inflexible policy has been adopted which now requires in addition that each program contain a course -- preferably given in the senior year -- which is largely devoted to "design". This kind of course has been called a "capstone" course by some.…It is very hard to understand what brought about this step towards rigidity."

In 2000, the design sequence was rearranged in response to new ABET accreditation criteria that specify only that (1) graduates have an ability to design a system, component, or process to meet desired needs and that (2) in the curriculum graduates must have demonstrated the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems. In the rearranged design sequence, all students are instructed in the basics of the design process, emphasizing mechanical design, under the instruction of always the same professor in a required junior-level course. Previously, these basics were nominally covered in each of the two required capstone design courses. Each student is still required to take one capstone-design-project course in either mechanical design, thermal-fluid design, or biomechanical design. These latter three courses are taught by three or four different professors and are concerned only with design projects.

POSSIBLE FUTURE REARRANGEMENTS

In 2002 the University of Kansas began emphasizing applications to human health in conjunction with the announced desire of the metropolitan Kansas City region to become a center of such activity. The Department of Mechanical Engineering hired its first faculty member in biomechanics in 1996 and by 2001 had five, most of whom have research programs in collaboration with colleagues at the University of Kansas Medical Center, 50 miles away. This shift in educational direction requires the flexibility called for by Sabersky in the definition of "design", perhaps to the extent of giving "design" credit for undergraduate participation in some research projects.

It is expected that there will be another revision of the design sequence in the next several years at the University of Kansas. That design sequence might resemble that of the 1960s with only one required "design" course.

REFERENCES

[1] Wickenden, W. E., 1944, "Post-War Goals In Engineering Education", AIChE Trans., V. 40, pp. 379-388.

[2] Sabersky, R., 1986, "Obsolescent Curricular Materials", Proc. 1986 ASME Education Conf., ASME United Engineering Center, 345 E. 47th St., New York, NY 10017, pp. 281-288.

[3] Wesner, J., 1986, "Engineering Design", Proc. 1986 ASME Education Conf., ASME United Engineering Center, 345 E. 47th St., New York, NY 10017, pp. 245-253.

[4] Stoecker, W., 1989, Design of Thermal Systems, 3rd ed., McGraw-Hill.

[5] Boehm, R., 1987, Design Analysis Of Thermal Systems, Wiley.

[6] Hodge, B., and R. Taylor, 1999, Analysis And Design Of Energy Systems, 3rd ed., Prentice Hall.

[7] Bejan, A., G. Tsatsoronis, and M. Moran, 1996, Thermal Design & Optimization, Wiley.

[8] Jaluria, Y., 1998, Design And Optimization Of Thermal Systems, McGraw-Hill.

[9] Burmeister, L., 1998, Elements Of Thermal-Fluid System Design, Prentice Hall.

[10] McCoy, K., 2003, private communication, ED25/ Thermodynamics and Heat Transfer Group, NASA Marshall Space Flight Center, Huntsville, AL 35812.

[11] TRNSYS A Transient System Simulation Program Reference Manual, V. 15, 2002, Solar Energy Laboratory, University of Wisconsin—Madison, WI 53706.

[12] FLUENT 6, Getting Started With, December 2001, and Getting Started With GAMBIT 2, December 2001, Fluent Inc., Centerra Resource Park, 10 Cavendish Court, Lebanon, NH 03766.

[13] Design Optimization Tools Users Manual, V. 5.0, 1999 and VisualDOC Design Optimization Software, V. 1.0 Reference Manual, 1998, Vanderplaats Research & Development, Inc., 1767 S. 8th Street, Suite 210, Colorado Springs, CO 80906, (719)475-4998, http://www.vrand.com.

[14] Hinton of Bankside, Lord, 1983, "Anonymous No Longer", Mechanical Engineering, V. 105, N. 7, July, p. 4.

[15] Kreith, F., "Dean L. M. K. Boelter's Contribution To Heat Transfer As Seen Through The Eyes Of His Former Students", History Of Heat Transfer, eds.: E. Layton and J. Lienhard, 1988, p. 121.