

# Attributes of a Modern Mechanical Engineering Laboratory

Dr. Charles V. Knight, Dr. Gary H. McDonald  
Mechanical Engineering  
The University of Tennessee at Chattanooga

## Abstract

Senior level mechanical engineering labs have traditionally been devoted to investigating energy utilization systems while providing little support for mechanical systems. This created mechanical engineering graduates who had varying degrees of fundamental experimental knowledge. The thermal science graduates were taught principles of experimental design, experimental analysis and uncertainty, properties of measurement systems, and oral/written communication that was not similarly emphasized for the graduates who concentrated in mechanical systems. The mechanical engineering program at UTC began offering a mechanical engineering laboratory (one hour lab plus one hour design project) in 1997 that provides balanced support for both thermal and mechanical systems. This laboratory provided a major component of support for the mechanical engineering program meeting ABET 2000 Criterion 3 Outcomes a through k and UTC's mechanical engineering program receiving accreditation on first request this past year. The paper will describe the various types of laboratories and design projects being used in the new lab that supports all areas of mechanical engineering. All labs utilize modern electronic instrumentation and LabVIEW for data acquisition, analysis, control, and presentation. Some of the lab systems are older renovated/upgraded systems while others were fabricated at UTC or purchased from vendors then upgraded. The design projects typically involve design, fabrication, and testing of an experimental system related to mechanical engineering, for example, a comprehensive comparative testing of two Stihl leaf blowers one with and the other without a catalytic converter for exhaust emission control.

## Introduction

Attributes are qualities or characteristics ascribed to or inherent in a person or thing. Engineering programs in general and specific courses have attributes that are generally shared with constituents through university catalogs and web sites and other means. But, specific attributes associated with defining the "REAL" qualities of a course and/or laboratory may be more difficult to define due to inadequate interest and sustainability being provided by the university and faculty. The senior mechanical engineering (ME) laboratory at UT-Chattanooga as described in this paper has both ME faculty, university, and external support required to sustain the many positive attributes associated with the laboratory.

## Attributes

The attributes of the senior ME Experimentation Laboratory are:

### (1) Utilizes Modern Engineering Tools

The ME laboratory uses Microsoft's Word, Excel, and Power Point along with TK Solver and/or Maple software in completing data analysis and preparation of final reports (written and oral). The lab also uses National Instrument's LabVIEW software for performing data acquisition, analysis, presentation, and control.

### (2) Delivers a Broad Based Curriculum

Senior level mechanical engineering labs have traditionally been devoted to investigating energy utilization systems while providing little support for mechanical systems. This effort has provided mechanical engineering graduates with varying degrees of fundamental experimental knowledge. The thermal graduates were taught principles of experimental design, experimental analysis and uncertainty, properties of measurement systems, and oral/written communication that was not similarly emphasized for the graduates who concentrated in mechanical systems. The mechanical engineering program at UTC began offering a ME lab (one hour lab plus one hour design project) in 1997 when a one hour senior heat transfer laboratory was renovated and upgraded to include modern electronic instrumentation and data acquisition. This ME lab provided **balanced** support for both thermal and mechanical systems [1].

In 2000 when the opportunity came to develop a new ME curriculum that was to seek program accreditation, the older two hour laboratory course was expanded into two 2-hour courses: a junior level lecture-type course (ME Experimentation) and senior level course (ME Experimentation Laboratory). In the junior course, students are taught principles of experimental measurements, basic computer data acquisition, error and uncertainty analysis, data reduction and presentation, and principles of modern electronic sensors. The ME Experimentation Laboratory is a two-hour course, having a three hour laboratory experience in addition to a one hour lecture period weekly. Ten laboratory experiments are conducted during the first ten weeks of the lab course with a comprehensive design project being completed during the remaining four weeks. Design of experiments, error and uncertainty analysis, LabVIEW [2] programming, and integration of modern data acquisition system activities are completed in the first half of the one hour lecture period associated with the laboratory course. Both lecture and laboratory periods are used to support the design project during the last five weeks of the course.

## ***Thermal-Mechanical Laboratory Systems***

The ME laboratory experiments consist of three modules (common, thermal, and mechanical) with the common experiments being related to thermodynamics, fluid mechanics, and heat transfer that is taken by all mechanical engineering students. The thermal experiments cover thermal design curriculum content while the mechanical systems experiments cover content that is related to the design of machinery. ABET Criteria 8 requires that all mechanical engineering graduates have a general understanding of both mechanical and thermal system areas.

The content of each of the lab areas was established to stress the basic fundamentals taught in the mechanical engineering curriculum while demonstrating the unique potential of experimental measurements using computer data acquisition [3]. These considerations provide the opportunity for integration of many forms of instrumentation into a single experiment. As may be noted above, more topics related to thermal sciences than machinery are included in the laboratory systems operated in the laboratory. But, the development of and/or purchasing of suitable additional mechanical design experiments represents a challenge as thermal science systems with extensive electronic instrumentation and data acquisition capabilities are common while mechanical design systems are less common.

The laboratory experiments included in the course are presented below.

Common: (1) Transient Heat Transfer, (2) Heat Exchangers, and (3) Refrigeration Trainer. Thermal: (1) Internal Combustion Engines Mass & Energy Balances, (2) Internal Combustion Engines Emissions and Pollution Control, (3) Natural Gas Boiler Study at the UTC energy plant. Mechanical: (1) Static-Dynamic Behavior of Spring Suspension System, (2) Static & Dynamic Balancing, (3) Journal Bearing Lubrication System, (4) Spring Mass Damper Vibrations System, (5) Kinematics of Motion for Piston-Cam of Briggs & Stratton Engine. Two of these experiments will be described below to illustrate how instrumentation, fundamental experimentation, and report writing are integrated into each lab.

### ***Refrigeration Trainer***

The objectives of this experiment are to complete overall energy and mass balances for the heat pump-air conditioning system, to utilize many forms of electronic instrumentation, to introduce LabVIEW data acquisition, analysis, presentation, and to develop spreadsheet analysis skills.

A Model 900 Heat Pump-Air Conditioning Trainer manufactured by Lab Science is used in the experiment. The Trainer was retrofitted with two electronic pressure sensors to establish the high and low side pressures, electronic dry bulb-relative humidity sensors on both sides of the condenser and evaporator coils, a hot wire anemometer on the discharge side of the condenser coil, and a turbine flow meter at the exit of the condenser to measure the Freon-12 flow rate. The six existing thermocouples in the system were connected to signal conditioning devices to support data acquisition. A LabVIEW

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application was developed to analyze and present the experimental data for the modified Trainer. The students complete an extensive spreadsheet for the experiment with energy balances being performed on the evaporator and condenser using the Freon-12 refrigerant properties and flow rate. An air side energy balance is conducted for the condenser and evaporator using local psychrometric conditions. Traditional coefficients of performance and energy efficiency values are computed for each test. The Trainer is operated in both heating and air conditioning modes. Its performance with undercharge and overcharge of refrigerant is also investigated. The results are presented in a formal report developed by the lab group.

### ***Kinematics of Motion for Piston-Cam***

The objectives of this experiment are to investigate the motion of piston-connecting-rod-crank as a slider crank mechanism through displacement, velocity, and acceleration analysis and experimentation. Also, these kinematics quantities are measured and analyzed to investigate the cam follower system that controls the intake and exhaust valves. Both LabVIEW and TK SOLVER are used in the experiment and technologies required to operate the experiment ON-LINE over the Internet have been developed and are actively utilized. The Piston-Cam System shown in Figure 1 was developed and fabricated at UTC.

A 3.5 horsepower Briggs & Stratton engine is used to produce the slider-crank motion while the cam driven exhaust and intake valves are used for cam follower study. LVDT displacement sensors are connected to the piston and intake valve with data acquisition, analysis, and presentation being completed by LabVIEW and motion simulation computations being done using TK SOLVER or MAPLE.

Three different engines are used in the lab, one being torn apart so students can have hands-on experiences with each component, a second having cut-away sections removed from the engine block so the student can view each internal component as the engine crank is driven by a crank handle, and the third engine having electronic sensors mounted that provide piston and valve displacement as the engine is driven by an external, variable speed electric motor. LabVIEW displays the measured displacements from the LVDT sensors and differentiates that data to show the velocity and acceleration for the piston and follower motion. The breakdown engine and cut-away engine provide first hand exposure to the "ultimate" mechanical engineering system as an internal combustion engine incorporates all fundamental mechanical engineering design concepts.

Most of the experiment time is committed to the hands-on and cutaway engine exploratory learning and introduction to TK SOLVER, with inadequate time left to complete full testing. Therefore, this lab has been put ON-LINE [4]. In utilizing this feature, each student can complete testing at different engine speeds outside of the lab experience. The group members share their experimental results. The capability to obtain and analyze experimental data and present the findings over the Internet represents a major challenge that most undergraduate engineering students do not get. This experience

provides the student with a background that challenges their capabilities in experimental design and information dissimulation.

Information related to operating this system ON-LINE along with information about other modern laboratory systems can be found at web site: [www.Reallabs.net](http://www.Reallabs.net) . This web site is maintained by Creative Engineering, a company that is building turnkey modern laboratory systems like those described in this paper.



Figure 1. Kinematics of Motion for Piston-Cam System

### **(3) Supports Written and Oral Communication**

The ME laboratory contributes a component of the university requirement for graduates to demonstrate written and oral communication skills. A comprehensive written report is required for each of the ten experiments completed. The report is a joint effort being completed by the student lab group, commonly 3 or 4 students, with each student being assigned a unique content role that rotates among the group. The student manager for the laboratory assigns a grade for each supportive student member. This grade is used by the lab instructor in assigning the grade for individuals contributing to the final written report. Similarly, a comprehensive report is developed for the design project completed by each design group. Oral reports from each group member are made for the design projects. These oral reports are presented before the faculty and/or before the Chattanooga Engineers Club as was the case for the chainsaw and weed trimmer final reports this past fall.

#### **(4) Provides a Comprehensive Design Project**

The five week long design projects typically involve design, fabrication, and testing of an experimental system related to mechanical engineering. During fall 2004, the class was divided into four design groups with the mission of each group being to demonstrate the difference in exhaust emissions comparing old and new technology devices for one of the following devices: chainsaws, weed trimmers, leaf blowers, and lawn mowers. Both four and two stroke internal combustion engines, some with catalytic converters, were included in the comparative testing project. This effort was related to EPA requiring that the Chattanooga area begin tailpipe emission certifications in 2005.

Generally speaking, graduating student responses show that the design project is most beneficial in that it enables the students to see how their college experience can be used in developing a new product or designing a modern experimental testing program. Students taking the mechanical engineering lab are leaders in their capstone senior design project due to their having the capability to use fundamental engineering analysis tools and develop sophisticated data acquisition, analysis, and presentation systems.

#### **(5) Delivers University Payback**

The five week long design project is typically an incubator for developing similar modern lab systems for other programs in the College of Engineering and Computer Science at UTC. Fluid mechanics and strength of materials lab systems along with other mechanical engineering lab systems have been renovated-upgraded through the student design projects. Our Dean has never found a problem with funding these lab upgrades.

A new experimental laboratory can be developed by purchasing new equipment that includes modern computer data acquisition systems with the entire package being purchased from a single supplier who is responsible for its design and construction [7]. This is generally the easiest way to expand an older lab or develop a new lab. But, this procedure does generate many problems that must be addressed with the operation and long term maintenance of the systems.

An alternate way to develop a new lab is to take older, proven systems and retrofit them with modern electronic measurement and computer data acquisition systems with a faculty member being responsible for the development.

The purchase of a totally new system is typically far more expensive than an older model that had no data acquisition, analysis, control, or presentation capabilities. The large increase in costs is primarily associated with instrumentation and computer hardware and software development. A major portion of the increased cost is related to developmental expenses required to produce small sale volume systems typical of laboratory equipment. The production of a new lab through retrofitting older equipment is less expensive than a turnkey purchase as the developmental costs associated with selection of the new instrumentation and computer data acquisition software are reduced due to faculty performing the tasks. The original UTC purchase cost of the lab systems that are used in

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the new lab was about \$105,000. Another \$75,000 was spent in upgrading those lab systems. But, these fully renovated lab systems would have cost over \$650,000 if purchased as turnkey systems from commercial vendors. This represents a saving of 73% when compared to outfitting the new lab with totally new systems purchased at today's cost.

### **(6) Has Sustainable University & External Support**

The ME Experimentation Laboratory equipment and upgrade costs were shared by the state of Tennessee, UTC's Center of Excellence for Computer Applications, University of Chattanooga Foundation, and industrial sponsors National Instruments, Tennessee Valley Authority, MicroMotion, Analog Devices, DuPont, Saturn Corporation, Nissan Motors, Stihl, and Tecumseh.

### **(7) Supports Faculty Development**

A most important advantage to retrofitting laboratory systems is that the faculty member is involved in developing and operating the new system. The commitment to developing the specifications for selecting the new instrumentation and writing the computer data acquisition applications offers a rewarding learning experience. The faculty members have a greater understanding of the complexities and day-to-day problems that will be faced during the operation of the lab if they have been responsible for renovating the older systems [5].

The faculty members who were responsible for developing the new laboratory attended a five-day workshop taught by National Instruments. Three days were used in teaching basic LabVIEW programming [6], and two days were used for teaching data acquisition fundamentals [7]. Attending the LabVIEW workshop was most helpful as it provided a jump-start that could not have been obtained readily through use of National Instruments' publications. University faculty developmental grants were used to support travel and workshop expenses.

Faculty members involved in the ME laboratory have developed new skills that make them more productive in support of research, public service, and consulting roles.

### **(8) Supports Accreditation Needs**

The ME Experimental Laboratory provided a major component of support for the UTC mechanical engineering program meeting ABET 2000 Criterion 3 Outcomes a through k [8] and receiving ME program accreditation on first request in 2003. The laboratory course was found to be our major contributor to four of the criteria outcomes: b (an ability to design and conduct experiments, as well as to analyze and interpret data), c (an ability to design a system, component, or process to meet desired needs), e (an ability to identify, formulate, and solve engineering problems), g (an ability to communicate effectively), and k (an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice) as well as Criteria 8 ME program outcomes requiring

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that students have the ability to apply advanced mathematics through multivariable calculus and differential equations and the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems. Several other courses in the new ME program curriculum contributed to the program meeting Criteria 3 e and k outcomes. But, the ME Experimentation Laboratory was used exclusively to demonstrate that the new ME program graduates had met ABET Criteria 3 outcome b.

## Conclusions

The Mechanical Experimentation Lab attributes noted above have provided for the lab fulfilling many of its ABET outcomes. The written communication outcomes of the lab are the most difficult features of the laboratory to sustain; and hence, it requires special attention each time the laboratory is taught. The faculty who teach the lab have become adaptive to modern instrumentation and computer data acquisition, and the mechanical engineering students who take the lab have demonstrated improved skills in other senior level course work and related job experiences. Graduates of the ME program at UTC are competing very well in the modern engineering world due in part to experiences they have acquired in the Mechanical Experimentation Laboratory.

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## Biographical

CHARLES V. KNIGHT

Charles V. Knight received B.S., M.S., and Ph.D. degrees in mechanical engineering from The University of Tennessee at Knoxville. Dr. Knight has been a member of The University of Tennessee at Chattanooga faculty since 1979, having taught at University of Tennessee campuses in Nashville and Knoxville ten years previously. His teaching interests are associated with fluid mechanics and thermal sciences. He completed six years of research for Tennessee Valley Authority associated with combustion and exhaust

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gas emissions and indoor air quality influences for wood burning heaters and boilers. He served as president of the Chattanooga Section of American Society of Mechanical Engineers in 1990 and chairman of Mechanical Engineering Division in 1986 and 1999 and chairman of 1981 host committee and general program chairman in 1988 for Southeastern Section of American Society for Engineering Education. More recently Dr. Knight has been responsible for mechanical engineering curriculum renovation, lab development, and directing the development of the ABET self-study for the newly accredited mechanical engineering program at UTC. He is a registered Professional Engineer.

#### GARY H. MCDONALD

Gary H. McDonald is currently a UC Foundation Associate Professor of Engineering in the Mechanical Engineering program at University of Tennessee at Chattanooga. His teaching responsibilities include statics, dynamics, mechanics of materials lecture and laboratory, kinematics and dynamics of machinery, dynamics, machine design, junior ME Experimentation lecture course, and senior ME Experimentation Laboratory. He received his B.S.M.E. in 1977, M.S.M.E. in 1979, and Ph.D. in Engineering in 1984 from Tennessee Technological University. Dr. McDonald was a NASA-ASEE Summer Fellow for four summers at the Marshall Space Flight Center in Huntsville, Alabama. He is a member of ASEE, ASME, NSPE, and is a registered Professional Engineer in Tennessee.