Automated Laboratory Experience in an Undergraduate Mechanical Engineering Program

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Abstract

The mechanical engineering BS degree program at The University of Texas at San Antonio (UTSA) requires an experimental laboratory sequence that supports both stems of mechanical engineering (energy and structures/motion). Data acquisition systems are integrated into the required laboratory sequence. A 5-year laboratory plan is in place to repair and upgrade existing equipment, design and fabricate new equipment, procure basic measurement equipment including computers, programs and interfacing hubs to central computers, replacement of outdated equipment and acquisition of new laboratory benches. The laboratory experiments are designed to provide hands-on experience in application of classroom theory through use of state-of-the-art measurement and instrumentation techniques. Design of experiments is required in upper level laboratory courses. Laboratory experience is also included in elective courses using the same basic laboratory equipment in an "Open laboratory" approach. This paper describes the restructured laboratory sequence, explains how the data acquisition systems are integrated into the laboratory experience, and provides procedures for selected lab experiments.

I. Introduction

In Fall 2000, the mechanical engineering department at the University of Texas at San Antonio began implementing its most recently revised undergraduate curriculum.[1, 2] The required laboratory sequence in the revised curriculum was restructured in order to provide a better experimental laboratory experience for students in both stems of mechanical engineering (energy and structures/motion).

Prior to the Fall 2000 semester, the required stand-alone laboratory course sequence was ME 3241-Materials Engineering Laboratory, ME 3313-Measurements and Instrumentation, and ME 4802-Senior Laboratory. In addition there were laboratory components attached to such required courses as EE 2214-Electronic Circuits and ME 4523-Mechanical Systems and Controls.

In the revised curriculum, the basic materials laboratory course (ME 3241) remained the same. However, the course sequence EE 2214-Electronic circuits/Electronics and Laboratory, ME 3313–Measurements and Instrumentation, ME 4523-Dynamic Systems and Control in previous catalogs was restructured and renamed EE 2213-Electronic Circuits and Electronics, ME 3312-

Electronics and Data Acquisition Laboratory, ME 4523-Dynamic Systems and Control, and ME 4702-Mechanical Systems and Control Laboratory in the 2000-02 catalog.

The laboratory portion of EE 2214 was used to create ME 3312 to include an additional laboratory credit hour. The three (3) semester-credit hours of Measurements and Instrumentation (ME 3313), were used to create ME 3312 and ME 4702. In addition, STA 2303-Applied Probability and Statistics for Engineers was added to the degree requirement to give students a strong foundation in application of probability and statistics. This course has become a prerequisite for ME 3312-Electronics and Data Acquisition Laboratory. In turn, ME 3312 is a prerequisite for ME 4702-Mechanical System and Control Laboratory, and ME 4802-Thermal and Fluid Laboratory. Previously, topics in probability and statistics were incorporated into ME 3313-Measurements and Instrumentation.

In the restructured laboratory sequence, data acquisition systems are introduced in ME 3312, and its applications have expanded to other laboratories, including ME 4702 and ME 4802. To enhance laboratory teaching and development, instructors with backgrounds in experience in experimental work and enjoy teaching laboratories are assigned to these courses.

We took a multi-faceted approach in development, maintenance, and upgrade of our laboratories. A 5-year Laboratory plan was developed using the following means:

1. Repair and upgrade of existing equipment
2. Design and fabrication of experimental apparatus[3]
3. Purchase of basic measurement equipment (including PCs and printers)
4. Replacement of old equipment
5. Purchase of new experimental benches
6. Integrate data acquisition system in experimentation

Institutional resources committed to the program, in addition to the regular laboratory operational funds have been used for the implementation of the laboratory plans. The plans are designed to provide hands-on experience and to expose undergraduate students to modern measurements and instrumentation techniques. Design of experiments is integrated in electronics and data acquisition, mechanical systems and control, and thermal and fluid laboratories. Students can receive additional experimental experiences by selecting technical elective courses having laboratory components.

Although it is important to integrate data acquisition systems as a part of student laboratory experience, our philosophy is that one should be careful that laboratory experiments are not reduced to a series of "Black Boxes." We believe that an understanding of the physical laws underlying a process under investigation through hands-on experimentation should be the paramount objective. At the same time, students must also be introduced to modern tools used in engineering practice. If students' use of the automated data collection system is such that they are enamored only by the mechanics of its manipulation and not so much as to the experimental function and control of the test apparatus and as to its quality of data acquisition, then it is best **not** to automate the experimental process with a computer. On the other hand, if the student is using the computer as a device for expedience and at the same time performs the experiment with a real time understanding of the functionality and performance results of the experimental apparatus, then the use of the computer serves as a valued asset to the students' intended education.

II. New Laboratory Sequence

The following is a description of actions taken to develop, improve, and upgrade the experimental laboratories in the program.

ME 3241-Materials Engineering Laboratory: This is the first laboratory course in the curriculum, offered by the mechanical engineering faculty. The course contains experiments studying the microstructural behavior of materials and examination of the mechanical properties of materials. The major equipment used in this laboratory are the universal testing machine, hardness tester, micro-hardness tester, furnaces, polishing wheels, specimen molding devices, impact tester, fatigue machine, and microscopes. Additionally, computerized data collection devices have now been incorporated as a means to reduce the time for completion of certain experiments and to enhance the quality of data acquisition. The advantages thus far realized by use of such data acquisition devices is that two additional experiments can now be accomplished with an allowable increase in class size of 15%.

Although the apparatus used for processing and investigating materials is important, there appear to be no detrimental impact due to automating the operation and augmenting the data acquisition features of laboratory apparatus with regard to the educational value of the course. Students are experiencing just as much of the intended educational value of the course whether they manually operate the scientific test apparatus or whether the test apparatus is computer operated. It is the experience of observing the test specimen as it is being tested and the need to acquire its attendant data for processing and evaluation that is important. For this case, the use of a computer to achieve this objective is especially advantageous. For example, students learn no less of an experiment whether their photographic records of microstructures are obtained by way of conventional or by way of computer processed high-resolution digital photography.

Since the 1999-2000, new equipment including two computerized photo-digitized microscopes and a computerized MTS tensile/compression test system were acquired and implemented in the course curriculum. To date, data acquisition and control by way of computers have been implemented in the Materials Engineering Laboratory as indicated in Table 1.

An important feature of the use of computers as currently enjoyed in the Materials Engineering Laboratory is that experiments are not only conducted faster, thus enabling additional experiments to be included into the cur4icula but, the data is formulated in a much more orderly fashion. Also, by use of 3 ½" floppy disks and/or zip disks, each student readily has access to numerical and photographic data to be included in the laboratory reports

In summary, increased speed in data collection has allowed us to conduct two additional experiments in the course. The automated data collection not only has decreased the time to conduct experiments with enhanced quality of data, but also has facilitated reduction of students' time for recording, processing, and reporting. The multitudes of accumulated data provided students are now readily transported to their home-based computer spreadsheets (such as EXCEL) for processing and for converting to report formats of tables and graphs.

Table 1. Computer Assisted Operations in the Materials Engineering Laboratory

Experiment	Computer System	Type Computer Assist: Control & Data Acquisition	Type Computer Assist: Photography
#3 Tensile and Charpy Impact Testing #5 Heat Treatment of Steel #6 Phase Diagram, Microstructures, and Properties of Iron-Carbon Alloys	▪ Microscope/Digital Camera (UnitronMS2-IM2) with Computer ▪ Microscope/Digital Camera (Unitron 7876) with Computer ▪ Instron Mod. 1127 with SATEL controller & APEX NuVision II Software Tensile & Compression Tester ▪ MTS Computerized Qtest/5 Tensile System	Tensile Test	Microstructures
#2 Metallography and Grain Size Determination #4 Cold Work and Recrystallization #7 Precipitation Hardening of Aluminum Alloys	▪ Microscope/Digital Camera (UnitronMS2-IM2) with Computer ▪ Microscope/Digital Camera (Unitron 7876) with Computer	----------------	
#8 Viscoelastic-Plastic Behavior of ductile Polymers	▪ MTS 809 Axial/Torsional Computerized Test System with MTS 1098 Temperature Controller	Creep & Relaxation	----------------

With the use of digital cameras and computers for processing, all laboratory reports have taken on the style and quality of professional reports. This has turned out to be a better means of documentation than the use of conventional/instant camera, which was quite expensive for photo reproduction.

<u>ME 3312-Electronics and Data Acquisition Laboratory</u>: As described before, a part of this laboratory was previously integrated in the Electronic Circuits course. In the revised curriculum, the one credit hour electronics lab was separated from the lecture course and an additional credit hour was added to the course to include an introduction to data acquisition systems. The basic equipment for the electronic portion of the course already existed. In Fall 2000, LabVIEW data acquisition programs were instituted. Also a separate series of experiments have been instituted using Peltier junctions, thermistors, and improved new power supplies as a way to use D.C. electronics for important measurements.

New Laboratory computers have been provided with programs such as Matlab, Orcad Pspice, ProEngineer, LabVIEW 5.1, Mathmatica, Microsoft Word, Microsoft Works and Internet access. Other programs can be accessed via the central server.

The laboratory at present consists of twelve exercises: three in D.C. electronics, two in A.C. circuits, two in introduction to solid state amplifiers, two as introduction to use of operational amplifiers, two in applied measurements, and one as introduction to digital gates. One of the exercises makes use of small fan motors to introduce concepts of magnetic force and generators. All of these exercises employ the use of a digitizing oscilloscope, power supplies, curve tracers, DVAM (Digital Volt-Am Meter), a function generator and a new computer at each workstation. Lectures are given on elementary statistics limited to normal distributions, measurement of standard error, and use of a Students "t" test of significance.

A Peltier junction is obtained from M.P. Jones Assoc. as a Thermoelectric module with heat sink and fan. We used a thermistor for contact temperature measurement of the thermoelectric module after calibration of the thermistor with water temperatures containing an NTIS (National Technical Institute System) certified thermometer. Total heat transfer is measured by applying a thin layer of thermocoat between a flat-sided cuvette and the thermoelectric module. Using the contact surface area and the temperature change it is possible for the student to calculate total heat transfer between the solution and the peltier surface. Further, by measuring the temperature difference between the two surfaces, it is possible to extend the above measurements to the total heat transfer through the junction and calculate the efficiency of the junction when compared to the applied voltage and current through the junction. Use of LabVIEW automatic data acquisition makes it possible to automate the entire procedure. The latter has proceeded to the extent of introducing LabVIEW as a program. It has been found that using ***LabVIEW for Everyone***[4] is helpful for introducing LabVIEW processes and as introduction to object-oriented programming.

In order to understand the above experiment, students study diodes and some elementary D.C. circuitry used in the above experiment. Most engineering students have difficulty understanding the low voltages and currents derived from many forms of instrumentation. With some difficulty, and some losses, students are introduced to operational amplifiers in some detail. These are used to amplify the output of wheatstone bridges that may be attached to a thermistor or a photo detector. Later, they are used as instrumentation amplifiers for such applications as strain gauges.

A small experiment with D.C. fans usually causes some puzzlement at first, but gradually increases appreciation of the inductive responses of motors. Fans were obtained from the power supplies of long defunct computers. They are the "Brushless" type, with diodes controlling the energizing of driving inductors. The fans are driven by a D.C. power supply with a 100 Ohm resistor in the power feed. Oscilloscopes are used to follow the waveforms on the motor side of the 100 ohm resistor. A mark on the surface of the fan is used to synchronize the RPM with the fluorescent light over the desk, a poor man's strobe. After obtaining a clear image of the EMF at equilibrium, the motor is slowed to ½ speed and another clear picture of the back EMF is obtained. With this process the student is able to deduce the function of the back EMF and its origin by comparing the two sets of data. This entire procedure can be performed with LabVIEW.

The lectures that accompany these exercises should use the data derived from the exercise to explore the functions of circuit types and elements, and to emphasize their applications in instrumentation and machine control systems.

ME 4702-Mechanical Systems and Control Laboratory: This course was first taught after the restructuring of the laboratory curriculum in the spring 2001 semester. It covers two main areas: Measurements & Instrumentation (M&I) and Dynamic Systems and Controls.

The measurements and instrumentation component of this course focuses on the use of laboratory equipment and its role in setting up and performing a wide range of mechanical engineering experiments. They include the use of strain gages, accelerometers, displacement transducers, and thermocouples. These experiments focus on the use of transducers and how they are calibrated such that their electrical output is converted into physical quantities, such as force, strain, or temperature. The basic transduction mechanisms for these transducers is covered in a pre-laboratory lecture session in which the students learn the theory behind the operation of the transducer and then learn more about its application and operation in laboratory experiments.

A set of experiments involving a particular transducer may span beyond one laboratory session. For example, when investigating the use of strain gages, the students spend one laboratory session performing static experiments with a strain gage/cantilever beam setup to determine the modulus of elasticity of the beam by loading it with various weights and measuring tip deflections. The second experiment involves the application the strain gage in dynamic applications, such as measuring vibrations resulting from a disturbance force or using the strain gage/cantilever beam setup as a dynamic scale.

Throughout these experiments, students are progressively trained in the use of equipment such as DC power supplies, function generators, digital multimeters, and oscilloscopes in the instrumentation of various measurement systems. In addition, the construction and use of appropriate signal conditioning devices, such as bridge circuits and amplifiers, is also covered.

Experiments such as the characterization of a DC motor and a simple fluid dynamics experiment, provide a transition for the student into the area of dynamic systems and controls, as well as providing a platform from which to learn the fundamentals of data acquisition. These experiments are coupled with dynamic systems simulation exercises involving MATLAB and SIMULINK. Comparing simulation results with actual data taken in the laboratory allows the student to get a better appreciation of both the usefulness of computer-based simulation in engineering analysis and design, as well as its limitations.

Over the past two years, the M&I segment of this course has been developed and is now well laid out. It focuses on several experiments whose goals are to familiarize students with various sensors and transducers that are commonly encountered in the mechanical engineering field: strain gages, thermocouples, accelerometers, etc. The faculty member who coordinates this course feels that this segment of the course successfully meets its corresponding course objectives and foresees few changes in the near future.

Development of the second segment of the course, which focuses on dynamic systems and their control, is still ongoing. New equipment was purchased to develop hands-on experimentation in controls systems. They include:

1. Inverted pendulum and its control system
2. Dynamics of a mass-spring-damper system and its control system
3. Dynamics of a multi-DOF system
4. Ball and beam balancing
5. Control moment gyroscope

Several difficulties have been encountered with equipment setup and operation, laboratory activity development, and logistics. Under the direction of a former faculty member, five different pre-packaged dynamics and control systems experiments were purchased from various companies that specialize in such educational products. These setups promise to be very effective pedagogical tools, but many of them are not particularly user-friendly and have very complicated computer interface procedures. These issues present significant challenges in developing relatively simple procedures for students to follow, such that they can achieve experimental results in a two-hour laboratory session. In addition, since cost of each piece of equipment is prohibitively high, faculty foresee their use only in a "demonstration" mode, as opposed to the students actually operating them and obtaining their own experimental data. From a pedagogical standpoint, this "hands-off" laboratory environment leads to less retention by the student, thus weakening the effectiveness of this equipment in meeting course objectives.

Several solutions to rectify the above problems have been proposed. During the spring 2002 semester, faculty formed five groups of two or three students, each of which was assigned to work with one of the experimental setups. The groups were given eight laboratory sessions over four weeks to review documentation, develop procedures for setup and operation of the equipment, and perform simple experiments. This was done with faculty guidance and assistance in solving technical problems. At the end of the four-week period, each group was to give and oral presentation about the experiment and a demonstration of the equipment. Unfortunately, this approach was not very successful, as students had a lot of difficulty operating the equipment and obtaining technical assistance from the manufacturers. At this point, faculty decided that a laboratory assistant working under close faculty supervision would best achieve the task of setting up the equipment and developing experimental procedures. This approach will be taken in the spring 2003 semester.

As mentioned above, another issue is the limitation of having only one piece of equipment for each of the controls/dynamics experiment. This leads to resorting to "hands-off" demonstrations, which faculty feel are ineffective. To rectify this situation once the equipment is set up and laboratory exercises have been developed, is to develop a rotating schedule where each group is assigned to a different experiment each week. In this way, all students will have the opportunity to do hand-on experimentation with each of the five controls/dynamics experimental setups. This may prove to be a logistical challenge, but faculty feel that with careful advance planning and scheduling, this plan can be carried out successfully.

In the fall 2002 semester, a novel approach was taken in the coverage of MATLAB/SIMULINK instruction. After completing three weeks of tutorials and practice problems, the students were given a final project in which they selected a computer-based design problem from the System Dynamics and Controls textbook used in the lecture-based course. Such problems are not traditionally assigned in a lecture-based course, due to their broad scope and time restrictions. Thus, faculty saw as a good opportunity to use such problems as the basis for a longer-term project. Student groups were given a list of selected problems from a wide range of applications and asked to select their top three choices. Faculty then assigned the problems such that each group was working on a different problem. Three weeks of laboratory sessions were reserved for the students to work on the problems and implement computer-based solutions in either MATLAB or SIMULINK. During this time, the faculty member served as a "consultant" and met with the groups on a regular basis to provide direction and technical assistance. The student groups wrote a formal report in which they presented their mathematical model, simulation results, findings and conclusions. This approach was highly successful and had a very favorable student response.

ME 4802-Thermal and Fluid Laboratory: This laboratory course has been a required course in the ME curriculum since 1984. The age of some equipment in this laboratory requires special attention to repair and replacement. Since the spring semester 1999, we have been engaged in maintenance, repair, and replacement of the equipment in this laboratory. For example, a wind tunnel with automated LabVIEW software for control and data acquisition was acquired and implemented into the course curricula starting with the 1999-2000 academic year. To provide increased versatility regarding fluid pumps and their performance and to accommodate the increase in student enrollment, two additional test stands for conducting pump performance tests have been acquired.

Of the three modes of heat transfer (conduction, radiation, and convection) that are examined separately by students on three separate test stands, the one involving convection has now been totally renovated from a faulty state of operation to one that not only performs reliably but provides students insight of applicability. Before, the heated test article consisted of a very small thermister whereas now the heated test article is a sizable flat plate in which the heat rate is directly established by voltage-amperage measurements. Use of a thermister had required a more indirect process for establishing the heat rate. The other good thing about this renovation is that the basic test stand will now accommodate other types, sizes, and configurations of test articles that students may be demonstrating as part of their laboratory design project.

During the 2001-2002 academic year a small-scale steam power plant was acquired and implemented into the course curricula. By use of a steam generator, condenser, turbine and an electrical power generator, the thermodynamic principles of a *Rankine* vapor power cycle is quantitatively demonstrated. Students now have the opportunity to conduct steam power cycle tests and by way of a computerized data acquisition system, to collect actual data needed to perform thermal energy balance studies related to the "ideal reversible" *Rankine* cycle with that of the "real cycle". Their laboratory projects now include the development of a performance map of the power plant to establish the effects of power loads, boiler pressure, and superheat steam pressure on the cycle efficiency and turbine efficiency.

An example a student design project is the renovation and modernization of the old antiquated pipe flow test station (Technovate Fluid Circuit bench) shown in figure 1. The renovation consisted of replacement of all its piping and valves and its motorized pump. As indicated in figure 2, its modernization consisted of the addition of special pressure and flow rate transducers, an electrical throttle valve, and a LabVIEW-based data acquisition and control system. Functionally, the experimental process of this system can be performed manually or electronically.

Additionally, the laboratory has just received a programmable engine dynamometer for Otto cycle performance evaluations. Furthermore, to facilitate the needs of the increase in student enrollment, ancillary equipment such as manometers, hot wire anemometers, stroboscopes, pressure transducers, digital voltmeters, and the like have been acquired.

The Thermal Systems Laboratory also provides the capability for evaluating the effects of thermal contact resistance; finned versus non-finned tube heat exchangers; and the thermal performance and mass transport effects of both cross flow and counter flow heat exchangers.

To facilitate data acquisition, control and data processing, two mobile, PC-based microprocessor systems with LabVIEW software and DAC boards have been acquired and placed in service (Figure 2). Recently, modernization of the steady state and transient conduction test station by use of a LabVIEW-based data acquisition and control system has been achieved.

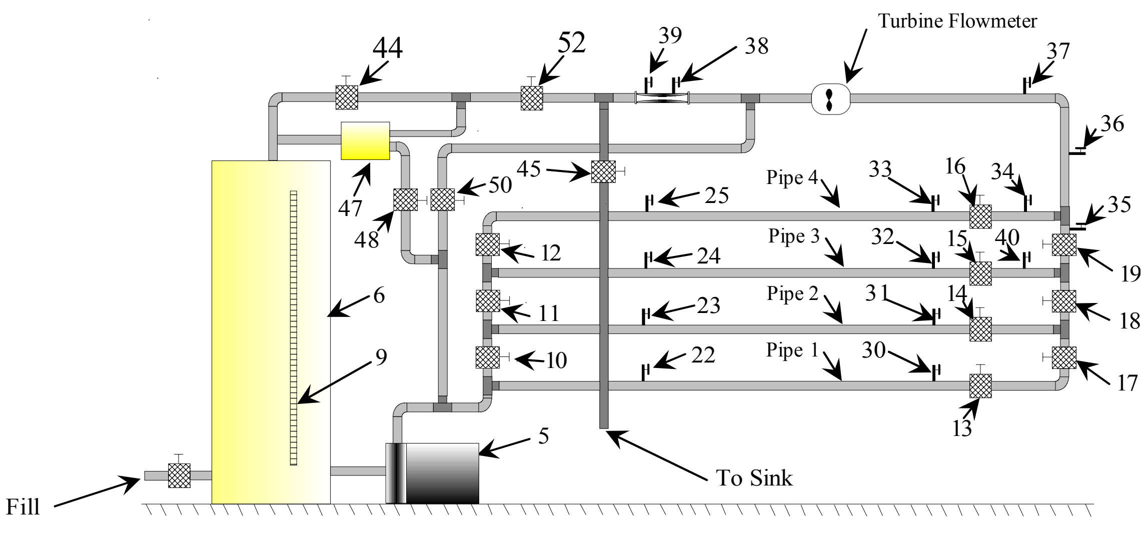

Figure 1, Pipe Network Schematic

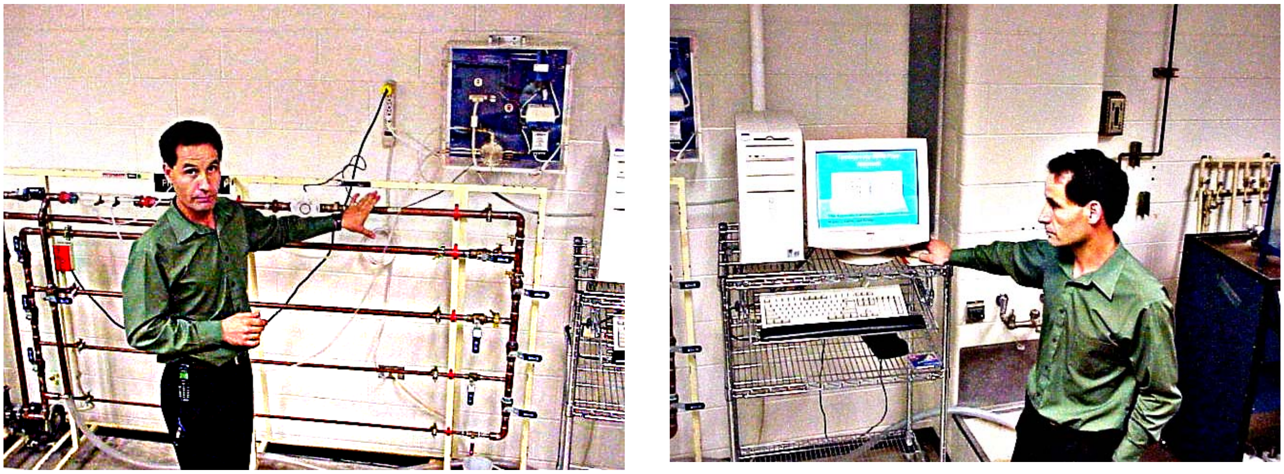

Fig. 2 Modified Pipe Network

For one-half of the semester (six-seven) weeks, each student team, consisting of no more than 3 students per team, *manually* perform twelve different series of tests covering many varieties of fluid statics and dynamics, thermodynamics, and heat transfer. This *manual* testing and data acquisition process enables students to acquire actual hardware systems experience. They not only test out much of the theory presented in the classroom, but also learn how to acquire test data utilizing the basic principles of instrumentation such as venturi meters and manometers. Use of such other instruments as hot wire anemometers, strobe light tachometers, current meters, volt meters, and thermocouple based temperature gauges are also an important part of the experience provided students. This *manual* form of experimentation is thus a very important educational process provided by this laboratory.

Computers do however provide a number of valued services during this *manual* phase of test operations by performing the following functions:

- Data Processing
- Photographic Processing from Digital Cameras
- Process Validation During Test Operations

The services listed above are performed at a workstation in the laboratory that consists of two computers that have such software programs as EXCEL, MathCad, MATLAB, Microsoft Word, PowerPoint, and others. As indicated, these computers perform the valued function of processing portions of the data obtained from a test in process to confirm whether or not the test is being performed properly or that the instrumentation is conveying the correct data values. Inasmuch as these two computers are not directly linked to the test instrumentation, only manually recorded data can be entered for this type of assessment.

The second half of the semester is then devoted to the design, test, and presentation of devices with emphasis on computerized processes for *data acquisition and analysis*. Listings of experiments at UTSA that are currently computerized are shown in Table 2. With exception of Experiment #13 and #15, all the experimental test stands are normally operated manually both in control and data acquisition. As part of their design projects, students have computerized these same experimental test stations. This ongoing student design process of automating UTSA's test rigs for data processing and test control is being carried out so as not to hinder in any way the ability to perform testing manually without the aid of computers. To date, LabVIEW software has been the primary media used by students for this design process. Another benefit of utilizing computerization as part of the design specification is the knowledge students obtain regarding the types of instrumentation inclusive of transducers, power converters, and electronics controls needed for their particular test apparatus.

III. Cost of Laboratory Upgrade

In the last four years, the Mechanical engineering department has spent $243,000 to support its undergraduate laboratories. In 1998 the university committed $50,000 per year for a period of five years to each engineering department to upgrade their undergraduate laboratories. Institutional resources committed to the program, in addition to the regular laboratory operational funds have been used for the implementation of the laboratory plans. So far $190,000 of the $250,000 institutional commitment to mechanical engineering has been spent. The five-year laboratory plan is reviewed and revised on an annual basis.

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Biographical Information

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Dr. Karimi is Professor of and Mechanical Engineering and Associate Dean of Engineering for Academic Affairs at The University of Texas at San Antonio. He received his Ph.D. degree in Mechanical Engineering from the University of Kentucky in 1982. His teaching and research interests are in thermal sciences. He has been the chair of mechanical engineering twice: the first time between 1987 and 1992 and again from September 1998 to January 15, 2003. Dr. Karimi has served on curriculum committees at all university levels and has been a member of the University Core Curriculum (1993-95 and 1999-present). He is the ASEE Campus Representative at UTSA and is the current ASEE-GSW Section Campus Representative. He chaired the ASEE-GSW section during the 1996-97 academic year.

Table 2. Computer Assisted Operations in the Thermal Fluids Laboratory

Experiment	Computer System	Type Computer Assist	
		Data Acquisition	Control
#3 Head Loss in Pipe Network	• Moble computer with NI DAC PCI-MIO-16E-4 Board (Data Acquisition & Control) • LabVIEW Software	Pressure drop across pipes & fittings (Sensotec Low Range Wet/Wet Differential Pressure Transducer) & flow rates (Seametric S-Series Low Flow Meter, AO55 Blind Analog Transmitter)	Flow Rate (Burkert 1094 24V DC Control Valve)
#5 Steady State & Transient Heat Conduction	• Moble computer with NI SCXI 1000 Chassis & SCXI 1100 32 Channel Analog Input Module Multiplexer data Acquisition System • LabVIEW Softtware	36 transient temperatures simultaneously recorded at selected time intervals	-----------------
#13 Airfoils in Flight	• Moble computer with NI DAC PCI-MIO-16E-4 Board (Data Acquisition & Control) • LabVIEW Software	16 pressures on test article & 1 pressure in tunnel	Air speed & angle of attack of test article
#14 Engine Otto Cycle Performance	• Moble computer with NI DAC PCI-MIO-16E-4 Board (Data Acquisition & Control) • LabVIEW & Magtrol M-Test Software	Engine speed, torque, combustion pressure-time cycle, intake/outtake air flow rates& properties	Engine speed and torque
#15 Steam Power Plant Performance	• Moble computer w/16 Channel Signal Conditioning Unit (NI DAC PCI-4351) & 68 Pin Rail Mounted Terminal Block (NI TBX-68T) • NI LabVIEW software & Microsoft Office 2000	Boiler, Turbine, Condenser Tower & Pump Fluid Temperature & Pressure; Generator Amperage & Voltage	--------------------
#16 Steam Convective Heat Transfer	• Moble computer with NI SCXI 1000 Chassis & SCXI 1100 32 Channel Analog Input Module Multiplexer data Acquisition System • LabVIEW Software	4 temperatures	-----------------

Notes:
1.Two computers on mobile test stands serve all six experimental stations (#3, #5, #13, #14, #15, & #16)
2. With exception of Experiment #13, all experiments can be totally conducted manually as well as by computer.
3. A digital camera with direct data record onto a 3 ½” floppy disk is provided for all 16 experimental stations.
4. Two stationary computers with a host of software (EXCEL, MathCad, MATLAB, Microsoft Word, PowerPoint, etc. and others) are provided in the laboratory for processing manually acquired data.

A. C. ROGERS
Mr. Rogers has served the past five years as a faculty member of the UTSA mechanical engineering department in the fields of heat transfer, fluid dynamics, materials engineering, thermodynamics, statics and dynamics. Much of

his interest, effort and responsibility currently apply toward the upgrade and modernization of the universities materials engineering and thermal fluids laboratories. Forty-one years of Mr. Rogers experience as a professional engineer at Boeing, Rockwell, and the Southwest Research Institute are utilized daily towards the educational processes of design, experimentation, and laboratory development. Mr. Rogers has a BS and MS degrees in Mechanical Engineering from Lamar University and Wichita State University, respectively. He is a registered professional engineer in Texas and serves as UTSA's Institutional Representative to the Texas Space Grant Consortium. He is the author of numerous published technical papers and has one patent and several patent applications.

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Dr. Frazer is an adjunct associate professor of electrical engineering at the University of Texas at San Antonio. He has filled this position for more than 10 years, with previous service at UT Cancer Center, Houston, and UT Health Science Center, San Antonio. He has been a National Research Council Senior Investigator at U.S. Army Medical Research Institute for Infectious Diseases, and for many years was an Investigator for Radio Frequency Bio-effects for the U.S.Air Force and other elements of the Department of Defense. Dr. Frazer's basic degrees are in basic medical sciences, but he has had more than 30 years experience in the design of radio frequency equipment. Dr. Frazer is best known internationally for his work on field interactions with many different types of biological systems. He is holder of several patents concerning RF interactions with tumors and has contributed to early work on Magnetic resonance of biological materials.