Proceedings of IMECE 2007
2007 ASME International Mechanical Engineering Congress and Exposition
November 10-16, 2007, Seattle, Washington, United States

IMECE2007–44066

INTRODUCING MODERN LABORATORY EXPERIENCES TO MECHANICAL AND AEROSPACE ENGINEERING STUDENTS

Frank K. Lu, Philip K. Panicker, M. Byron Webb
Aerodynamics Research Center, Mechanical and Aerospace Engineering Department,
University of Texas at Arlington
Arlington, Texas 76019
U.S.A.
franklu@uta.edu, philipkpanicker@uta.edu, mbwebb@uta.edu

ABSTRACT

Amongst some of the more challenging aspects of engineering education is in imparting hands-on experience. Despite the fact that engineering requires practical know-how, this challenge is in itself being compromised as the engineering curriculum over the past few decades moves away from workshops and laboratories toward classroom lectures and software domination. This paper describes a laboratory experience early in a mechanical and aerospace engineering student's career which provides an adequate preparation for understanding all aspects of modern, digital data acquisition systems. This laboratory experience is coupled with classroom lectures and projects. The laboratories comprises of modules that cover a variety of topics which exposes the students to digital data acquisition techniques, data processing and analysis, uncertainty analysis and comparison with theory. Moreover, instead of generic experiments, most of the experiments were built around ordinary items and processes. The laboratory experience is based around National Instruments hardware, controlled via LabView™. Data processing is via MS EXCEL. These platforms are ubiquitous and provide good exposure to similar hardware and software.

INTRODUCTION

Practically all of the undergraduate engineering curricula in the U.S. are subjected to policies and procedures formulated by the Accreditation Board for Engineering and Technology, or ABET, for short. (www.abet.org). While not explicitly stated, most curricula include a minimum of three semester hours of engineering laboratory experience, with the introductory laboratory offered in the sophomore year [1].

The three semester hours of engineering laboratory experience, together with typically two to three hours of laboratory experience in physics and chemistry, adds up to about 4–6 percent of an engineering undergraduate's education, a small proportion, indeed. With pressure to impart fundamental knowledge and a curriculum of 120–130 semester credit hours, efficient use of the limited laboratory experience requires an innovative approach for imparting a modern laboratory experience.

Amongst some of the more challenging aspects of engineering education is in imparting hands-on experience of the latest technologies in measurements and testing. Despite the fact that engineering requires practical know-how, this challenge is in itself being compromised as the engineering curriculum over the past decades moves away from workshops and laboratories toward classroom lectures and computer simulations, including virtual laboratories and web-based learning strategies [2–5].

The last decade or so has seen an escalating increase in the use of technology in the undergraduate teaching laboratory. The trend started slowly and in fits and starts, with progress being paced by the availability and the cost of technology. The trend most likely began with the requirement that laboratory reports be submitted as a computer-generated document, usually using Microsoft Word. The next step likely involves processing data, recorded by pen and paper, using Microsoft Excel [5–8]. Once the students and instructors became comfortable with these approaches, the stage is then set for the next stage which is an entirely seamless computer-based approach. During this time, the cost of computer-based data acquisition systems, both hardware and software, started to plummet to make it feasible for educational institutions to consider their implementation in teaching laboratories. For example, Ertugrul [3] commented that recent technological advances in computer technology and software make it feasible develop such laboratories efficiently and at low cost. To these two features, one may also add effectiveness and adaptability, amongst others. Despite similar proclamations [9–12], the experiences have been varied and may even be less than expected. Thus, even though there is broad consensus on the desire to implement technology in teaching laboratories, the extent and nature of the technology may be open to fine tuning. For example, such laboratories may inadvertently allow students to plagiarize from previous students, a seemingly widespread problem with the convenience afforded by the Internet [13,14]. Such laboratories may be too automated that the learning process may become extremely passive, with students being merely spectators. Thus, safeguards must be implemented and conscious effort must be placed to ensure that students have a rich learning experience and not consider experimentation to be stringing together a bunch of "magic" boxes. There appears to be much room for experimentation in developing teaching laboratories to ensure that engineering students are trained in the latest experimental techniques, from a purely pedagogical to a highly interactive approach [15], including active, project-based ones [16–18]. Despite the latter, at the introductory freshman or sophomore level, a more structured approach is most likely necessary to successfully introduce students to the tools of the trade and to provide guidance in understanding what these tools are capable of. Guidance is also needed in data reduction and data analysis.

Table 1. Topics covered in the lectures

1. The scientific method and purposes of experiments
   - Experimental planning and design
   - Qualitative and quantitative observations
2. Measurement systems
   - Characteristics of measurement systems
   - Fourier transforms
   - Sensors, transducers, signal conditioners, digitizers
   - Characteristics of digital systems – sampling, aliasing, resolution
   - Noise and interference
   - Methods to improve signal quality
   - Calibration
   - Regression
   - Precision, accuracy and bias
3. Dynamic performance of instruments
   - Zeroth order
   - First order
   - Second order
4. Engineering statistics
   - Purposes of statistical analysis
   - Causes and types of error
   - Uncertainty analysis
   - Error propagation in a measurement chain
   - Variability in a quantity that is dependent on others
   - Control of error
5. Random data
   - Statistical measures
   - Probability
   - Histograms and distributions
   - Infinite statistics – Gaussian distribution
   - Finite statistics – T distribution, chi-squared distribution
   - Hypothesis testing, goodness of fit

This paper describes a laboratory experience early in a mechanical and aerospace engineering student's career which provides an adequate preparation for understanding all aspects of modern, digital data acquisition systems. This course is also offered for pre-biomedical engineering graduate students at the authors' institution. This laboratory experience is combined with classroom lectures and projects. The laboratories comprise of modules that cover a variety of topics which exposes the students to digital data acquisition techniques, data processing and analysis, uncertainty analysis and comparison with theory. Moreover, instead of generic or "canned" experiments, most of the experiments were built around items and processes that were deemed to be meaningful as simple extensions of ordinary experiences the students may have had.

COURSE STRUCTURE

The objectives of the course are

- To provide a background in engineering measurements and measurement system performance
- To convey the principles and practice for the design of measurement systems and measurement test plans, including the role of statistics and uncertainty analyses in design
- To introduce data analysis and reduction

The objectives are accomplished through two hours of lectures per week plus a total of nine laboratory sessions. The course currently follows the text by Figliola and Beasley [19] although it had also used the text by Holman [20]. The text materials are supplemented by notes posted online as well as a downloadable laboratory manual of over 130 pages. The prerequisites are that the student must have previous exposure to differential and integral calculus. The topics covered in the lectures are highlighted in Table 1. Of necessity, the coverage in general is of an introductory nature. It can be noted that the lectures consciously attempt to move the students away from the pen-and-paper concept of data recording and force the students to think of data as spatial and temporal signals to be gathered electronically. Fortunately, the advent of ubiquitous electronic devices, such as the mobile telephone, digital still and video cameras, and so forth have made it easy to discuss these concepts.

The laboratory experience is based around National Instruments hardware, controlled via LabView™ through the implementation of virtual instrumentation [21]. Data processing is via EXCEL. These platforms are ubiquitous and provide good exposure to similar hardware and software. Each class during the regular semester is from 70–80 students, broken into three sessions. In summer, there are 30–40 students which can be handled in one session. Students work generally in groups of two or three. At present, there are nine laboratory modules (see Table 2), including one where students develop the LabVIEW interface. Thus, the students are rotated through these modules in no particular order except that Basic Digital Measurements 1 and 2 must be taken back to back. Since the instructions are self-contained, there is no serious danger of the students learning out of sequence. The number of laboratory modules is being increased so that, eventually, the students will be able to choose certain modules in addition to having a fixed number of mandatory modules. In addition to the physical experiments, each module has a "pre-lab" section which includes reading notes or an appropriate section of the text, and requires the student to answer a number of questions. The pre-labs assist the students in preparing for the laboratory and in grasping the concepts to be introduced. Based on experience, not all students are motivated to complete the pre-labs. Thus, the approach now is to give bonus points to students who answer the pre-lab assignments correctly.

Table 2. The laboratory modules

1.	Metrology
2.	Basic Digital Measurements 1
3.	Basic Digital Measurements 2
4.	Structural Dynamics Analysis
5.	Flow Rate Measurement
6.	Heat Transfer 1 (Free/Forced Convection)
7.	Heat Transfer 2 (Forced Convection)
8.	Heat Transfer 3 (Conduction)
9.	Introduction to LabVIEW™

BRIEF DESCRIPTION OF THE OBJECTIVES OF EACH MODULE

The laboratory sessions are organized into an introductory briefing followed by the nine laboratory modules. The introductory briefing familiarizes the students with the laboratory rules, including safety rules, report writing and other administrative details. The students are also assigned into their groups during this time. The laboratory sessions begin the following week. Since the workload is heavy, only skeleton reports are required from the students. A brief summary of the lesson objectives in each module is provided below.

Metrology

This module is of basic mensuration using a ruler, a vernier caliper and a micrometer. Students dimension a representative engineering part employing a machine drawing as a guide. This serves not only to acquaint the student with the use of various measurement devices, but also introduces the metrics required by a machinist to manufacture a particular component. The multiple measurements are then used to compute an average and a standard deviation. This module provides students with a basic skill that appears to be diminishing amongst engineering students, namely, the ability to make a simple measurement and apply some judgment on the precision. While the actual laboratory is quite straightforward once the students have a grasp of the techniques of reading a vernier scale, extra time is spent by the instructor to guide the students on what is now a not-so-obvious procedure. The precision aspect is also important and is reinforced throughout the lectures and assignments since most students reproduce the results from their pocket calculator or the computer to an excessive number of significant figures. Finally, this laboratory requires the students to consciously record the dimensions, whether in inches or millimeters. This reminds the students of the need to include units to their numerical results.

Basic Digital Measurements 1

This module digitizes a sine wave generated by a function generator. The same signal is displayed on an analog oscilloscope and a computer screen, via a so-called virtual instrument. The set-up is shown in Fig. 1a while the virtual instrument interface is shown in Fig. 1b. The display in Fig. 1b shows a number of operator functions, such as the sampling rate, the application of data windowing, filtering and display settings. An interesting feature is the deliberate ability to produce a noisy signal, thereby allowing the students to gauge how noise deteriorates a signal.

This module covers many learning goals. It introduces students to three major items of hardware. First, the students are acquainted with a function generator as an indispensable piece of electronics in any laboratory. Next, it introduces students to an oscilloscope. Finally, it shows how a computer-based, digital data acquisition system is connected; reinforcing what is learned in the classroom.

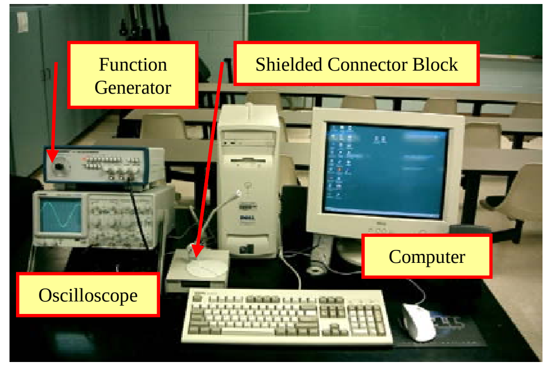
In terms of digital signal processing, this module demonstrates the problem of aliasing and the related concepts of sampling, oversampling, the Nyquist criterion and the Shannon sampling theorem. The module also introduces software filtering methods. Care is taken to explain that anti-aliasing filtering can only be performed via hardware filters and software filtering is a post-processing procedure. How filtering improves the signal-to-noise ratio is also demonstrated.

Basic Digital Measurements 2
This is an extension of Basic Digital Measurements 1 and introduces students to the potential complications that can arise in gathering a field signal, as opposed to a "pathological" signal whose characteristics are somewhat known. The field signal is one of the group's voice recorded by a microphone. Thus, the previous concepts are reinforced. Further, the concepts of bandwidth, Fourier transforms and spectrograms are introduced. The hardware for implementing this laboratory module is generally similar with those of Basic Digital Measurements 1, as seen in Fig. 2a. The differences include the microphone as the signal source, an amplifier and speakers to playback the recording. The virtual instrument interface is shown in Fig. 2b.

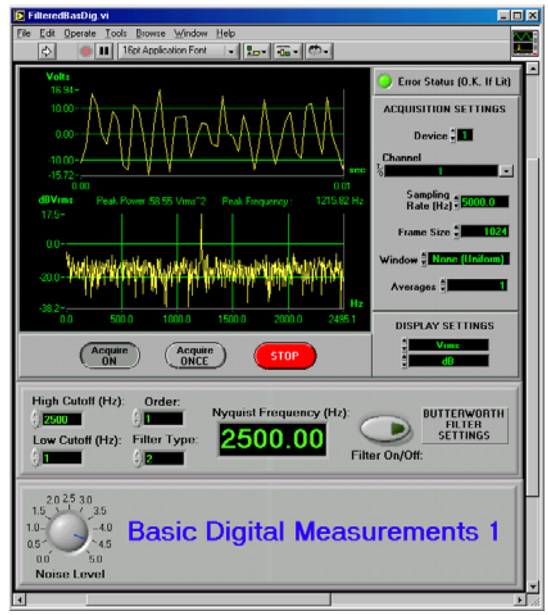
An example of a field signal and its spectrogram is presented in Fig. 2c. Aliasing is brought to the attention of the students when they playback their recorded voices at sampling rates below the Nyquist frequency. Analogously, the students have an understanding of practical limitations in dynamic data acquisition, where both large sample sizes and high sampling rates may not be available or necessary. The students also gain a better appreciation of the need to record the best data possible since any subsequent filtering cannot remove the noise already present in the signal bandwidth. Since the data are captured by a piezoelectric transducer, the students also learn about dynamic data acquisition. Finally, the large datafiles obtained are used in a qualitative sense since the data processing is beyond the scope of the course.

Structural Dynamics Analysis
The aim of this experiment is to determine the natural vibrational frequencies of a space-truss test model. This type of study has many important applications across various engineering disciplines such as: fatigue analysis, structural earthquake response, vibration suppression, modal analysis, aerospace structural design, machine design, etc. This laboratory provides basic insight to modal analysis, an important tool in understanding structural behavior. A major difficulty encountered with this type of analysis is the application of an appropriate input signal, which will fully excite the natural dynamics of a given system over a selected region of the vibration spectrum. Specifically, the input signal should be selected such that the given structure is instantaneously excited at all frequencies across the desired range and then allowed to relax to equilibrium while the output "free" response is monitored.

The truss is shown in Fig. 3a. It is constructed such that there is no plane of symmetry. An accelerometer is visible on the upper left of the truss and another accelerometer is mounted on the impact hammer, visible in the foreground. High-speed SCXI-based data acquisition is required for this module, with sampling rates of 50 kHz, Fig. 3b. Figure 3c is a screenshot of



a. Hardware.

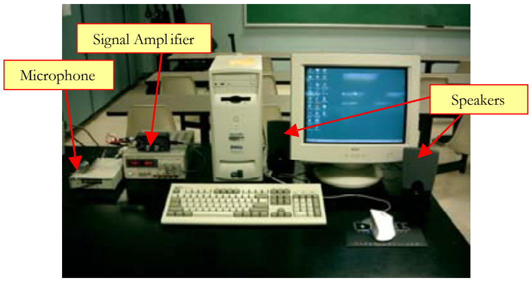


b. Sample screenshot of virtual instrument.

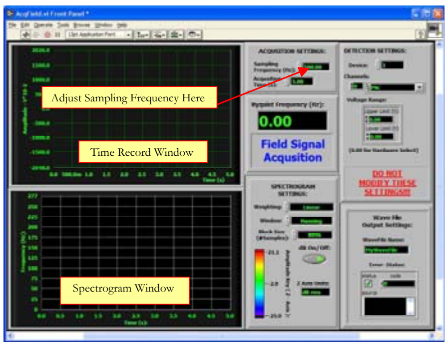
Figure 1. Set-up for Basic Digital Measurement 1

the virtual instrument. The figure shows that the students are able to choose various windows and sampling parameters to understand their effects. A sample output is shown in Fig. 3d. This module reinforces the concepts of dynamic data recording, the use of time-domain windowing techniques to improve the spectrum, and engineering applications of fast Fourier transforms.

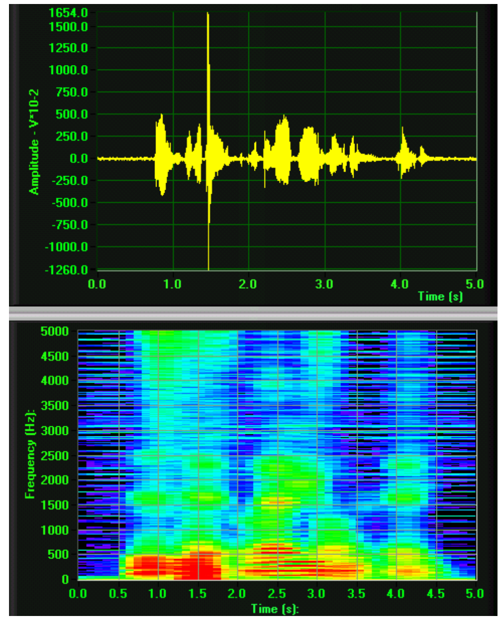
Flow Rate Measurement
This experiment uses a vacuum cleaner to provide an air flow. Using such an ordinary household appliance for instruction appears to make a favorable impression on the students, especially when the students realize that the test equipment costs more than ten times the vacuum cleaner. Moreover, an interesting feature of the set-up is that the original wiring of the vacuum cleaner was replaced to incorporate an auto-transformer. This auto-transformer enables the vacuum cleaner to operate with variable speeds. A venturi is attached into the middle of the vacuum cleaner tube. Pressures are measured upstream and



a. Hardware.

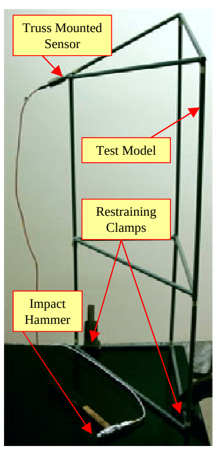


b. Sample screenshot of virtual instrument.

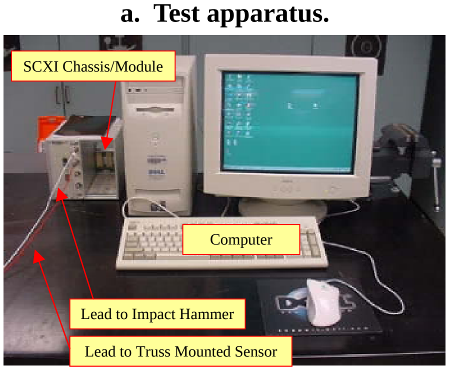


c. Example of microphone time record and corresponding spectrogram

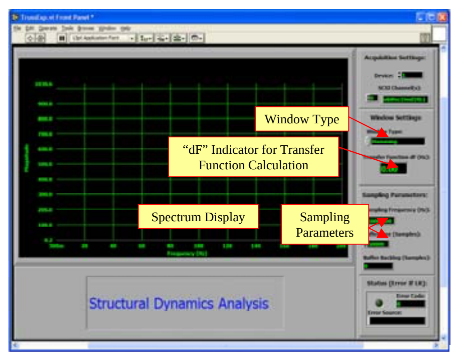
Figure 2. Basic Digital Measurement 2 for acquiring audio signals.



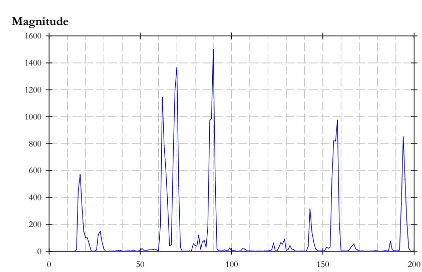
a. Test apparatus.



b. Data acquisition system

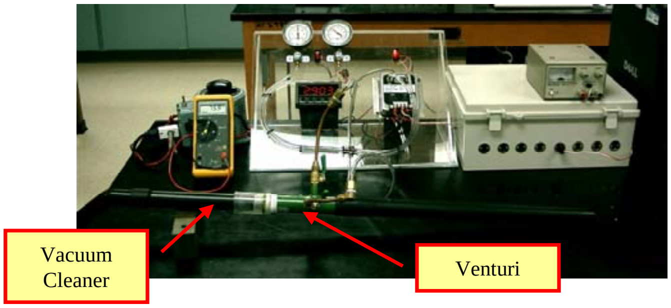


c. Sample screenshot of virtual instrument.

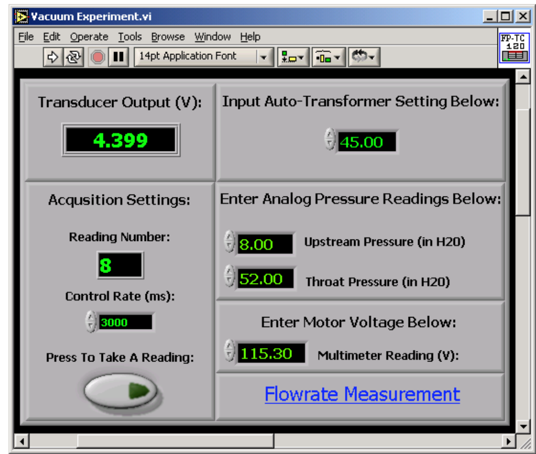


d. Sample spectrum.

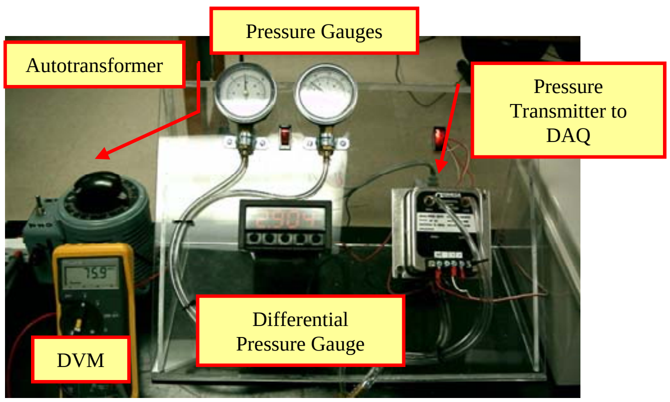
Figure 3. Truss experiment.



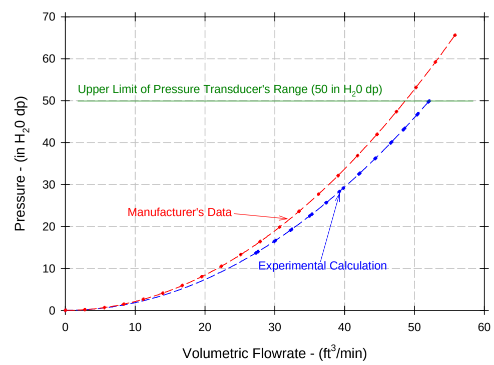
a. Overall view of the experimental hardware,



c. Screenshot of virtual instrument,



b. Close-up view showing the pressure gauges, the pressure transmitter and an auto-transformer (left).



d. An example of data reduction requirement,

Figure 4. Flow rate experiment.

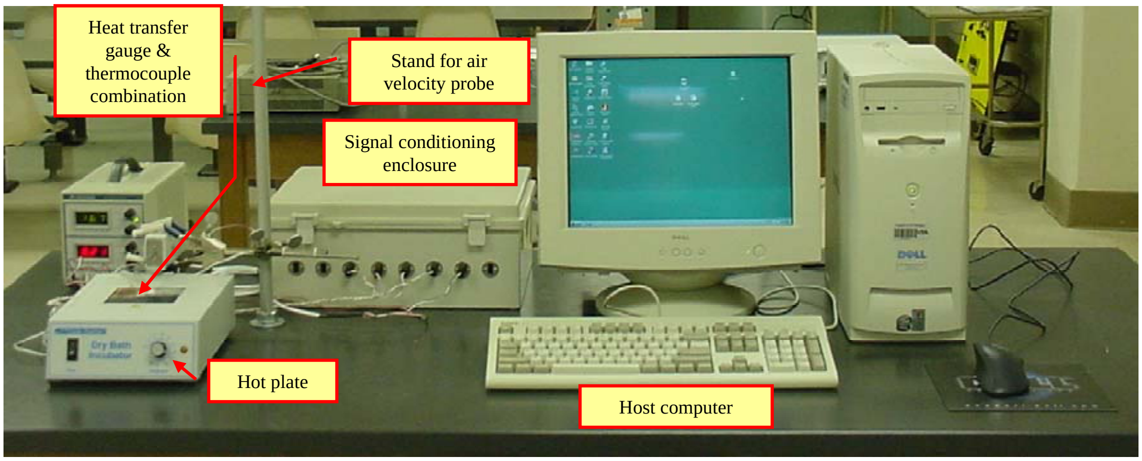
at the throat of the venturi. These pressures are displayed on two analog pressure gauges, a digital differential gauge and a voltmeter, as well as acquired for computer display and storage via a pressure transmitter. In other words, four different ways of acquiring and presenting the data are provided. The experimental setup is shown in Figs. 4a and b. A sample screenshot of the virtual instrument is shown in Fig. 4c. The students are required to calibrate the venture during the experiment. Following the calibration, the students are then able to obtain the volumetric flow rate from the differential pressure measurement, an example of which is shown in Fig. 4d. Another requirement is a crossplot of the flow rate for various voltage settings of the auto-transformer.

Learning goals of this experiment include the application of Bernoulli's equation for flowrate measurements through measuring differential pressures, instrument calibration, and the empirical adjustments required to match experiment with theory. An uncertainty analysis is also performed by the students. Students also learn the tradeoffs between the sophistication of the instrumentation, the capabilities afforded by the sophistication, and the initial and operating costs involved. The principles illustrated in this experiment are also useful for helping students when they take the fluid mechanics course.

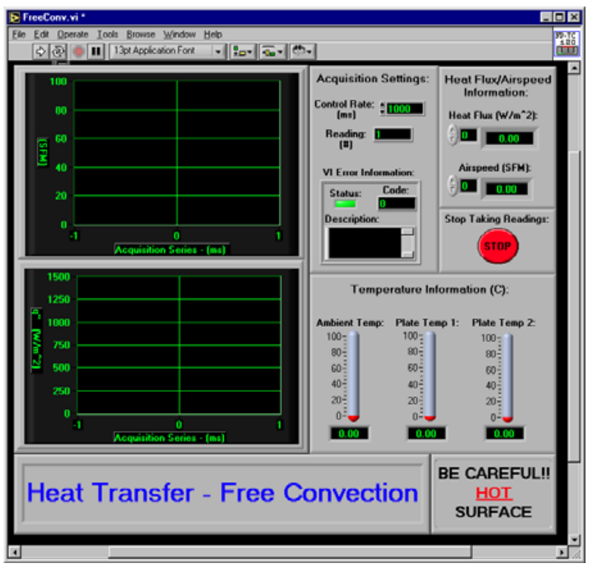
Heat Transfer 1 (Free/Forced Convection)

This is one of three heat transfer experiments. Only convection and conduction are introduced in this course, although radiation may be incorporated in the future. The setup for this experiment is shown in Fig. 5a. This experiment involves the determination of the heat transfer coefficient via Newton's law of cooling. The type of convection problem explored here is pertinent to HVAC applications.

The experiment utilizes thermocouples and a heat transfer gauge, as well as a flow measurement device based on forced convection (not shown in Fig. 5a). Other than free convection, forced convection is demonstrated by blowing air past the hot plate via a portable household fan to the left of the test apparatus but not visible in Fig. 5a. Figure 5b shows the virtual instrument interface. To the left are two strip charts for displaying the temperature and heat flux. Three temperature level in-



a. Overall view of the experimental hardware.



b. Screenshot of virtual instrument.

Figure 5. Free/forced convection experiment.

dicators are seen on the lower right. In addition to exposing students to thermal measurements, this module also exposes them to displaying data in nondimensional form in a plot of Nusselt number against Rayleigh number. For example, the free convection data are reduced into an average Nusselt number and a Rayleigh number and compared against a commonly used correlation:

$$\overline{Nu}_L = \begin{cases} 0.54 Ra_L^{1/4} & 10^4 \le Ra_L \le 10^7 \\ 0.15 Ra_L^{1/3} & 10^7 \le Ra_L \le 10^{11} \end{cases}$$

The students are also made to realize that free convection data are fraught with a large amount of uncertainty and that plots found in textbooks are meant for guidance only. Caution should be exercised when such standard data are used for design purposes. A discussion of the interaction between test data and design is, in fact, provided in classroom lectures.

Heat Transfer 2 (Forced Convection – Hot Impinging Jet)
The experiment is to determine the heating rate of an impinging hot jet. The setup is shown in Fig. 6. The measurement techniques here are similar to those of Heat Transfer 1. The students are further exposed to heat flux and temperature measurements. A goal of this laboratory is to demonstrate how experiments can be used to provide insight to a seemingly simple problem but which is not easy to solve analytically or numerically. Students learn that even though there may be experimental limitations, such as the amount of data, the test results may be adequate for design applications.

Heat Transfer 3 (Conduction)
In this experiment, an array of eight thermocouples is embedded equally along the centerline of a lexan plug and at the top and bottom surfaces. The plug is 76.2 mm in diameter and 40 mm thick and it is wrapped with insulation. The plug is placed on a hot plate. The thermocouples measure the temperature along the plug and the one-dimensional heat conduction equation is then used to obtain the heat flux, given the conductivity of lexan. Linear regression analysis is applied to the experimentally determined temperature distribution to obtain the temperature gradient. An uncertainty analysis is also performed. The boundary conditions at the heated surface and the free surface are different and, thus, only four data points nearest the heated surface can be used for the linear fit.

This is a straightforward experiment. Students learn data reduction, uncertainty analysis and curvefitting. They also learn how thermocouples function and how modern thermocouple signal conditioners have a built-in ice point reference. Students also understand that physical constants, in this case the thermal conductivity of the material, need to be known. Such knowledge may be hard to come by, a fact that is some-

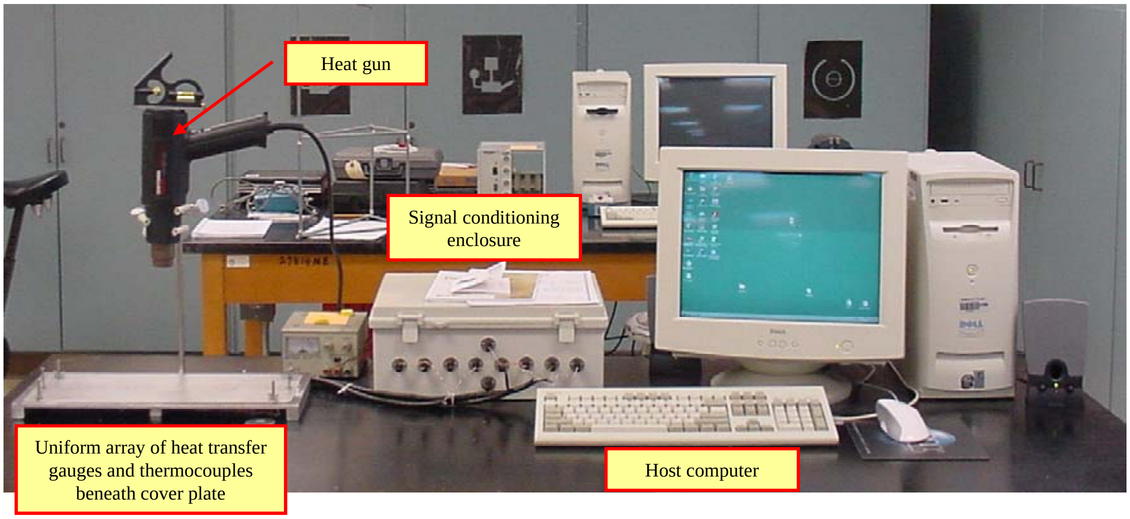


Figure 6. Impinging hot jet experiment.

times overlooked in classroom lectures and homework exercises.

Introduction to LabVIEW™

Students have an opportunity to perform a simple exercise in LabVIEW programming to round up their laboratory experience. This exercise requires them to acquire data from a thermocouple. A skeleton LabVIEW interface with certain elements missing is provided to the students. They follow instructions on how to add and connect these elements to obtain a functional program.

APPRAISAL AND OUTLOOK

This introductory course is fairly grueling. On average, about 20 percent of the students either fail or drop the course. Feedback on the course has been mixed and difficult to quantify at the moment. Anecdotal evidence suggests that the students are able to use the experiences in subsequent laboratory courses including, when necessary, the senior design projects.

There were a few reasons that can be given for the high rate of failure. One is the lack of preparation and another is the lack of time. The latter is a common reason, even before the revamped laboratory was introduced. On the other hand, the feedback from visitors, including the Industrial Advisory Board and ABET evaluators have been positive. It therefore appears that there is appreciation for such a laboratory professionally although students may be overwhelmed by the material. Continuous "product improvement" is called for and expected.

On a side note, there is concern that plagiarism may be a problem as students pass materials from one semester to the next [14]. Scanlon suggests that educational institutions have been lax in addressing problems of academic dishonesty [22]. Instead of sophisticated techniques, some simple safeguards are implemented to prevent plagiarism. Deterrence, clearly spelt out at the beginning of the semester, in the form of policy statements and requiring students to acknowledge the policy by signing a form at the beginning of the semester help to raise awareness [23,24]. In addition, the laboratory assistants sign a laboratory sheet to ensure that the students attend the laboratory for their assigned sessions. Next, since the students work in groups, it is relatively easy to determine if they copy from each other. Other inconsistencies, such as different results that may be due to merely copying from a previous semester can also cause suspicion. In some situations, students are required to submit their electronic files for further checking. Plagiarism, at least whatever that is detectable, has been negligible.

At the authors' institution, there are no other sections or instructors for this course. In other words, unlike most sophomore courses with multiple sections and instructors, this course appears as a bottleneck. This may also be partly the reason for the relatively large number of students who fail or drop the course. The zero tolerance policy appear to limit options that student have in fraudulent excuses [25] or in registration choices [26].

CONCLUSIONS

A comprehensive summary of a laboratory development to introduce modern, computer-based experimentation for undergraduate mechanical and aerospace engineering students is provided. The laboratory experiences cover the essential material for understanding how software and hardware are interfaced to develop powerful capabilities. Other skills taught include an understanding of the intricacies of digital data acquisition. The laboratory experiences supplement the course materials. The instructions provided allow the laboratories to be independent of one another so that a large number of students can be accommodated in the laboratory. Moreover, the instructions are self-contained so that they do not depend directly on the lectures. Instead, as the students progress through the semester, the synergism between classroom and laboratory strengthens each other.

ACKNOWLEDGMENTS

The authors acknowledge the generous support provided by the Mechanical and Aerospace Engineering Department, the College of Engineering, the University of Texas System via the LERR fund for supporting the laboratory development. The authors thank Professor Kent Lawrence for donating the frame for the structural dynamics experiment and Professor A. Haji-Sheikh for his advice on the heat transfer experiments. They also acknowledge the large number of students, undergraduate and graduate, who have helped to develop the laboratory, as well as the many students who provided feedback. Finally, the authors thank Conan McHugh and Joel Garner of National Instruments for their patience and endurance as they helped us recommend equipment and troubleshoot our setup time and time again.

REFERENCES

[1] Felder, R.M. and Brent, B., "Designing and teaching courses to satisfy the ABET engineering criteria," *Journal of Engineering Education*, Vol. 92, No. 1, pp. 7–25, 2003.

[2] Yarbrough, S.E. and Gilbert, R.B., "Development, implementation, and preliminary assessment of virtual laboratory," *Journal of Professional Issues in Engineering Education and Practice*, Vol. 125, No. 4, pp. 147–151, 1999.

[3] Ertugrul, N., "Towards virtual laboratories: a survey of LabVIEW-based teaching/learning tools and future trends," *International Journal of Engineering Education*, Vol. 16, No. 3, pp. 171–180, 2000.

[4] Shin, D., Yoon, E.S., Lee, K.Y., Lee, E.S., "A web-based, interactive virtual laboratory system for unit operations and process systems engineering education: issues, design and implementation," *Computers and Chemical Engineering*, Vol. 26, No. 2, pp. 319–330, 2002.

[5] Lee, H.P., "Comparison between traditional and web-based interactive manuals for laboratory-based subjects," *International Journal of Mechanical Engineering Education*, , Vol. 30, No. 4, pp. 307–314, 2002.

[6] Liengme, B.V., *A Guide to Microsoft Excel for Scientists and Engineers*, 2nd ed., Butterworth Heinemann, Oxford, U.K., 2000.

[7] Kalkani, E.C. and Boussiakou, L.G., "Observations on an introductory engineering course and suggestions for enhancement," *European Journal of Engineering Education*, Vol. 28, No. 3, pp. 317–329, 2003.

[8] Tabor, G., "Teaching computational fluid dynamics using spreadsheets," *International Journal of Mechanical Engineering Education*, Vol. 32, No. 1, pp. 31–53, 2004.

[9] Cyr, M.N., Miragli, V., Nocera, T., and Rogers, C.B., "A low-cost, innovative methodology for teaching engineering through experimentation," *Journal of Engineering Education*, Vol. 86, No. 2, pp. 167–171, 1997.

[10] Splitt, F.G., "The challenge to change: on realizing the new paradigm for engineering education," *Journal of Engineering Education*, Vol. 92, No. 2, pp. 181–187, 2003.

[11] Lyons, J.S. and Brader, J.S., "Using the learning cycle to develop freshmen's abilities to design and conduct experiments," *International Journal of Mechanical Engineering Education*, Vol. 32, No. 2, pp. 126 Apr2004134, 2004.

[12] Abdel-Salam, T. Kauffman, P.J. and Crossman, G., "Does the lack of hands-on experience in a remotely delivered laboratory course affect student learning?" *European Journal of Engineering Education*, Vol. 31, No. 6, pp. 747c756, 2006.

[13] García, A., Rodríguez, S., Rosales, F. and Pedraza, J.L., "Automatic management of laboratory work in mass computer engineering courses," *IEEE Transactions on Education*, Vol. 48, No. 1, pp. 89–98, 2005.

[14] Etter, S., Cramer, J.J. and Finn, S., "Origins of academic dishonesty: ethical orientations and personality factors associated with attitudes about cheating with information technology," *Journal of Research on Technology in Education*, Vol. 39, No. 2, pp. 133–155, 2006.

[15] Truax, D.D., "Restructuring the undergraduate laboratory instructional process," *Journal of Professional Issues in Engineering Education and Practice*, Vol. 133, No. 3, pp. 192–198, 2007.

[16] Shekar, A., "Active learning and reflection in product development engineering education," *European Journal of Engineering Education*, Vol. 32, No. 2, pp. 125–133, 2007.

[17] Costa, L.R.J., Honkala, M. and Lehtovuori, A., "Applying the problem-based learning approach to teach elementary circuit analysis," *IEEE Transactions on Education*, , Vol. 50, No. 1, pp. 41–48, 2007.

[18] Vera, C., Félez, J., Cobos, J.A. Sánchez-Naranjo, M. and Pinto, G., "Experiences in education innovation: developing tools in support of active learning," *European Journal of Engineering Education*, Vol. 31, No. 2, pp. 227–236, 2006.

[19] Figliola, R.S. and Beasley, D.E., *Theory and Design for Mechanical Measurements*, 4th ed., Wiley, 2006.

[20] Holman, J.P., *Experimental Methods for Engineers*, 7th ed., McGraw-Hill, 2001.

[21] http://www.ni.com/labview/whatis/intuitive_graphical.htm

[22] Scanlon, P.M., "Student online plagiarism. How do we respond?" *College Teaching*, Vol. 51, No. 4, pp. 161–165, 2003.

[23] Brown, V.J. and Howell, M.E., "The efficacy of policy statements: do they change students' views?" *Research in Higher Education*, Vol. 42, No. 1, pp. 103–118, 2001.

[24] Passow, H.J., Mayhew, M.J., Finelli, C.J., Harding, T.S. and Carpenter, D.D., "Factors influencing engineering students' decisions to cheat by type of assessment," *Research in Higher Education*, Vol. 47, No. 6, pp. 643–684, 2006.

[25] Roig, M. and Caso, M., "Lying and cheating: fraudulent excuse making, cheating, and plagiarism," *The Journal of Psychology*, Vol. 139, No. 6, pp. 485–494, 2005.

[26] Levy, E.S. and Rakovski, C.C., "Academic dishonesty: a zero tolerance professor and student registration choices," *Research in Higher Education*, Vol. 47, No. 6, pp. 735–754, 2006.