AC 2008-2435: BACK TO BASICS: INCREASING STUDENT UNDERSTANDING OF AEROSPACE ENGINEERING EXPERIMENTATION AND INSTRUMENTATION

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Back to the Basics:
Increasing Student Understanding of Aerospace Engineering Experimentation and Instrumentations

Abstract

An aerospace engineering laboratory sequence is revised as the introduction to experimental methods is pushed down into the undergraduate curriculum from the final upper division year into the beginning of the upper division. The course has been extensively revised to insure that experimental methods are introduced and reviewed as well as introducing technical content for laboratories which may lead the academic introduction of this content. Courses which have been eliminated from the curriculum as the scope of the curriculum is broadened must be supplanted with increased and refined content in other courses, such as this lab sequence. Electronic and computer programming content which heretofore had been covered with separate courses must be replaced by a concerted effort to not only review, but introduce and provide a firm basis of understanding of material necessary particularly toward understanding of instrumentation in the computer age. Concerted efforts are required to insure that the material is thoroughly introduced prior to experimentation which will require a fundamental knowledge of the principles involved. The use of National Instruments introductory courseware for programming and experimentation is reviewed and adoption of the NI ELVIS system is described. The immediate and continued success of students involved in this two course sequence is described, as they put their lab skills to work in the lab, at home, and on individual research projects. The evolution and expansion of laboratory instrumentation is described and the assessment of this laboratory sequence is discussed.

Introduction to Experimental Methods

In the aerospace engineering curriculum at many universities, laboratory exercises are either included as an integral part of various classes, or separated into a sequence of courses taught in the upper division. Previously at Mississippi State University, laboratory courses were offered only in the senior year, with one course being a lecture/lab class introducing experimental methods, and the other concentrating only on various laboratory tasks. Additionally, individual research projects required of all undergraduates in the program were conducted as adjunct to the first course in the sequence. Over the past decade or so, a few lab experiments were implemented into first, the upper division, in the Aircraft Structures Design course, and later into several other classes including fluid mechanics, statics, dynamics, and controls courses, but only infrequently and with limited success. A web based virtual laboratory for the study of mechanics was developed[1,2], and as the web matured, so did the use of this venue for supplementing classroom studies. Mississippi State University began to centralize online course offerings by supporting two primary applications developed expressly for this purpose, WebCT and Blackboard. Simultaneously with efforts to increase virtual lab experiences, there was an increased emphasis on including experiential learning into traditional lecture-based classes. Eventually one aircraft panel design project was refined to the point of being a repeatable exercise of the final senior structures design course (Figure 1).

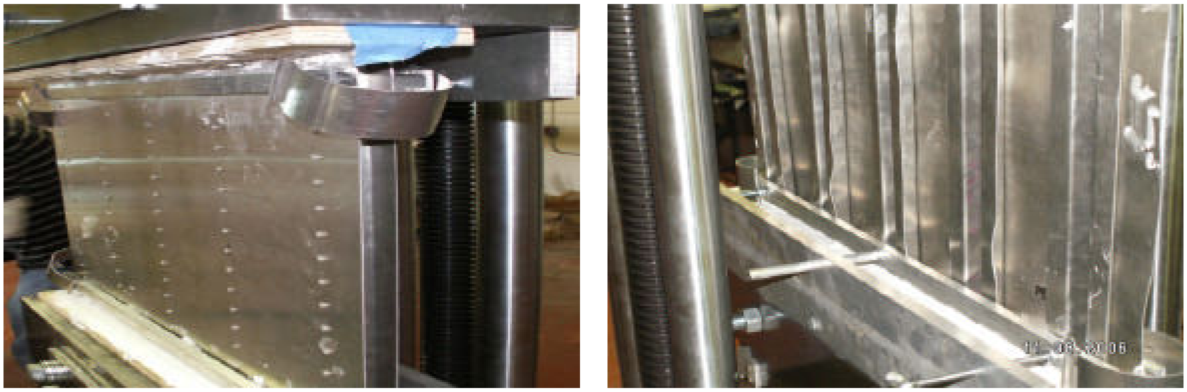

Figure 1: Panel Test in the test fixture (Left), showing failure mode (right)

Beginning in 1999, an experimental sequence of courses was developed in an effort to increase student retention and to introduce the use of computer technology taught within the department beginning in the first semester of the freshman year. The sequence of courses continued into the sophomore year, when the students would traditionally begin their study of aerospace engineering with the first courses in engineering mechanics. These courses depended heavily upon experiential components to provide a level of interest that would help the students identify with the department[3]. During a significant revision of the curriculum, the aerospace engineering laboratory sequence was revised and the introduction to experimental methods was pushed down into the undergraduate curriculum from the senior year into the junior year as part of a general curriculum overhaul during the establishment of separate tracks for aeronautical and astronautical studies. This was necessary to make room in the senior year for an expanded design course, and to insure that students were getting a better grounding in laboratory procedures prior to senior level courses to which laboratory components have been added. Another primary goal was to insure that seniors were prepared to complete an independent individual research project for their senior seminar presentations. The laboratory classes had been under considerable review for some time, in an effort to allow teaching of the lecture portion of the lab class via distant learning or as a self-paced course to be administered through WebCT[6]. Virtual laboratory exercises had been developed for use in the regular laboratory classes as well as by students in lecture courses in controls, fluid mechanics, and structures[7]. This was done to allow greater use of the lab facilities and also to prepare for a possible extended displacement from the lab facilities due to renovations. All of the lab equipment would have been moved to an off-campus site, but interfacing equipment to the web would allow limited access to most of the lab experiments conducted in the on-campus facility[5]. The hardware equipment consists of a small tunnel and associated digital control hardware illustrated below, and the access to this hardware is accomplished by exporting the control program to the web using the standard LabVIEW publishing tools. (Figures 2, 3)

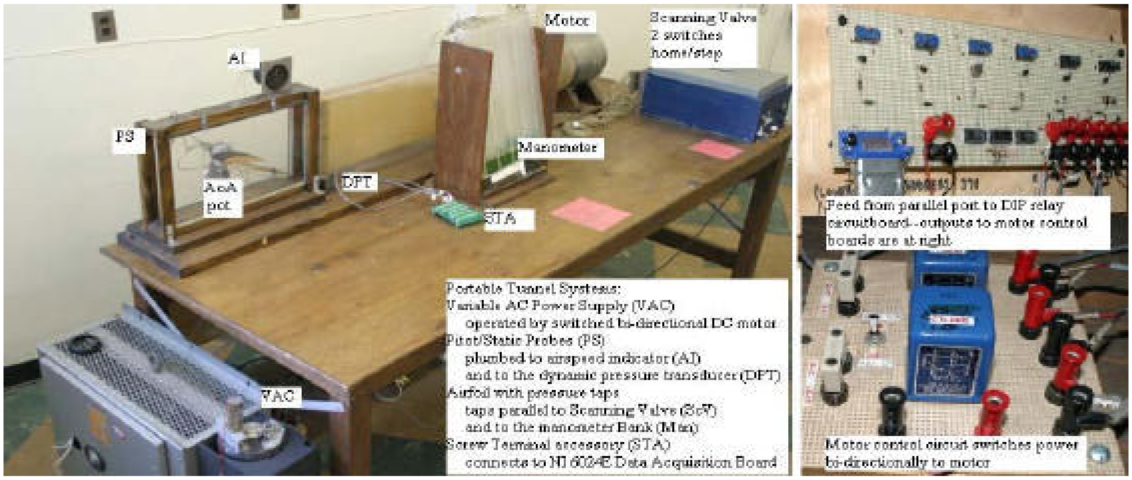

Figure 2: The portable wind tunnel used in testing remote access programming.

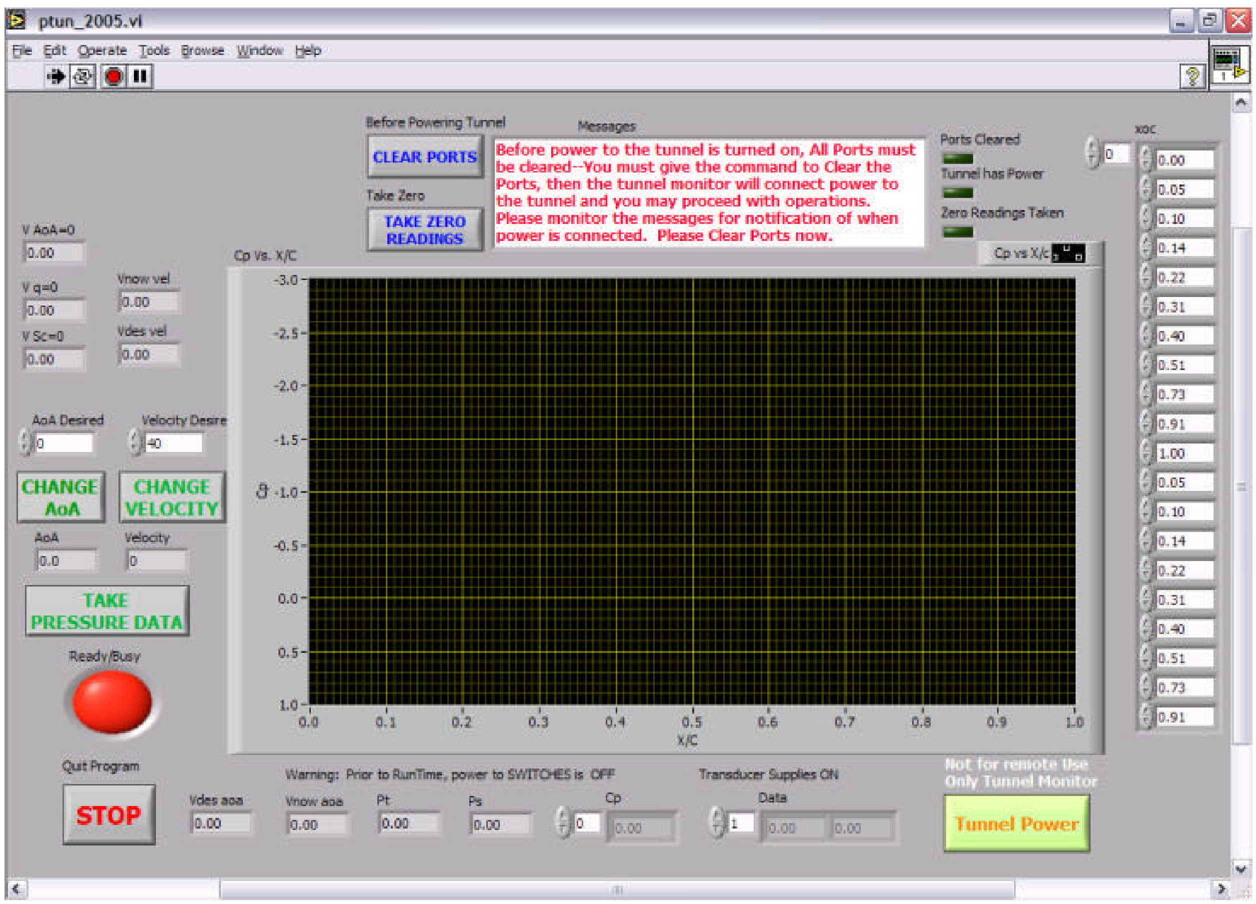

Figure 3: The Graphical User Interface of the Exported Tunnel Program

Up until four years ago, the first laboratory class for seniors consisted of six contact hours accomplished in two three-hour periods per week. The first was a common lecture period for all lab students introducing laboratory experimental procedures and reviewing appropriate technical analysis. The second 3-hour session was conducted in small sections so that all of the students in each section could be involved in hands-on research and testing. In 2004/2005, the lab sequence was moved into the junior year, and it became apparent that there were several difficulties stemming from the fact that students were not adequately prepared to perform basic aerospace experiments at that level. The root causes were varied, as the introduction to digital electronics had been eliminated from the curricula, the programming courses had been eliminated, and the students were to perform aerodynamic experiments for which they had just begun receiving detailed classroom training at the junior level. The obvious solution was to make a concerted effort to teach experimental methods in a much more detailed fashion, along with elements of digital electronics, computer programming, and uncertainty analysis as well as reviewing the essentials of technologies related to experiments[8].

Revision of Laboratory Content

As the new format for the course was implemented, electronic workbenches were purchased to allow bread-boarding of simple electronic circuits as necessary to teach fundamentals of electronics related to data acquisition and control systems used in the labs. Additionally, two-channel Windows Digital Storage Oscilloscopes were also installed at each laboratory workstation, along with Digital Multi-Meters. Various experiments were used to teach the basics of peripheral control and measurement principles and limitations. Several laboratory experiments involving calibrations, digital control of peripheral devices and analysis of the pressure distribution around an airfoil at low subsonic speeds were combined into a benchmark task. Completion of this task by the lab students of the first course would indicate that they had reached a minimum level of proficiency[9]. The course has been extensively revised to insure that experimental methods are introduced and reviewed as well as introducing technical content for laboratories which often led the academic introduction of this content.

The following outlines the general tasks that are accomplished in the aerospace engineering laboratory courses as individual, team, or individual research projects. Revisions/additions to tasks are annotated by underline, tasks eliminated are by ~~strikethrough~~.

Flight mechanics/stability & control:

- Velocity and angle-of-attack control of a portable wind tunnel
    - Including development of a LabVIEW control program
- Startup, control and monitoring of a large subsonic wind tunnel
    - Review of algorithm development and LabVIEW implementation
- Static longitudinal stability study with a force model
    - Obtaining stability derivatives
    - Aerodynamic center determination
- ~~Determination of the fixed stick neutral point of an aircraft from flight test data~~
- Control of computer peripherals with fundamental and higher order programming
    - Machine language, assembly language, BASIC demonstrations
    - Student programming in LabVIEW

Fluid mechanics:

- Pressure measurements in a converging nozzle (Bernoulli's principle)
    - Using digital pressure scanners with LabVIEW
- Velocity measurements with a pitot-static probe and water manometers
- ~~Velocity profiles in pipe flow~~

- ~~Volume flow rate through a pipe~~

Aerodynamics:

- Flow through a converging/diverging nozzle
  - Schlieren imaging, pressure distribution, design validation
  - LabVIEW image processing, digital pressure scanner use
- 1-D and 2-D boundary layer measurements on a flat plate
- Flow measurements with hot wire anemometry
- Boundary layer profiles on a spinning plate
  - Hot film & Laser-Doppler measurements
- Pressure distribution about an airfoil at an angle of attack
  - Water manometer and transducer measurements
  - Theoretical predictions of viscid/inviscid flow solvers
  - Development of a LabVIEW data acquisition and control program
  - Exporting LabVIEW experiments via the internet, remote access control

Propulsion:

- Pulse-jet engine
  - Pressure and temperature distributions
  - FFT analysis
- Hybrid/Gaseous rocket engine
  - Thrust determination
  - Nozzle degradation effects
  - Combustion considerations
  - Extensive revision of the control program and interface hardware

Vibrations:

- Harmonic vibration of a cantilevered beam
  - Euler & Dunkerly calculations of natural frequencies of loaded/unloaded beam
  - Computational determinations with Myklestadt's Method
  - Finite element method modal analysis with Unigraphics
  - Experimental verification of modal analysis
  - Automation of experimental frequency sweep
  - Use of LabVIEW for experimental control, data presentation and analysis
- Harmonic vibrations of a propeller blade
  - Modal analysis with Unigraphics
  - Experimental verification of modal analysis
  - Automation of experimental frequency sweep
  - Use of LabVIEW for experimental control, data presentation and analysis
- Vibration/displacement measuring instruments
  - Piezo & Spring mass damper accelerometers
  - Linear variable differential transformers
  - Use of LabVIEW for experimental control, data presentation and analysis

Structures:

- ~~Aluminum beam stress experiment – shear center determination~~
  - ~~centered/uncentered loading of a symmetric beam~~
  - ~~determination of the shear center of an non-symmetric beam~~
- Failure mode shapes of stable columns
  - predicting failure of stable columns with varied end conditions

Stress/strain/deflection versus load for a cantilevered beam
    Mechanics of materials investigation with a strain gage
    Transducer design experiment
    <u>Use of LabVIEW for experimental control, data presentation and analysis</u>

General/special topics:

Using a computer data acquisition card <u>PCI and USB</u>
    Digital/analog input/output
    Counter/timer operations
Signal analysis
    Frequency and amplitude determination
    Signal to noise ratio
    Aliasing
Portable data acquisition devices
    data logging/event reconstruction
    GPS tracking
<u>Introduction to LabVIEW (6 hours)</u>
<u>Introduction to NI ELVIS (12 hours)</u>

Further Additions to the Lab Courses.

Courses which had been eliminated from the curriculum as the scope of the curriculum was broadened had to be supplanted with increased and refined content in other courses, such as the lab sequence. As was mentioned previously, this included programming, electronics, numerical analysis, and statistics related to determining uncertainty of measurement. Initially, the requirement for individual research projects was retained in the first course, but after two offerings of the course, it became apparent that the students were not prepared to select appropriate topics and work independently. They lacked a fundamental knowledge of experimental methods, and had just begun the upper division coursework that would form the basis for selection of topics of individual interest. The formal procedures required to redefine course objectives and course content were completed, and the individual seminar requirement was moved back to the senior year as part of the second laboratory course. Additionally, the experimental methods topics were further defined as the essential core of the lecture for the first course. National Instruments Electronic Laboratory Virtual Instrument Suite workstations were purchased to replace the Electronic Workbenches and Windows Digital Storage Oscilloscopes and Fluke Digital MultiMeters used at the lab workstations. Additionally, USB based data acquisition units (NI 6251 USB) were purchased to allow interface to the NI ELVIS units from the individual students laptops.

The programming required for data acquisition and control has always been a principal component of the aerospace engineering laboratory classes, and as the computer systems evolved, a continuous transition took place as interface technology transitioned from the Hewlett Packard Interface Bus to the General Purpose Interface Bus which later became the IEEE 488.2 standard. Parallel and serial communications were gradually pushed aside by the development of the USB standard. Operating systems and programming environments evolved from DOS based

Figure 4: Workstation upgrades replaced electronic workbenches with NI ELVIS units

programming in BASIC, PASCAL, and machine language to higher level programs such as ASYST and Lab Windows. In turn, this gave way to object based programming and graphical programming environments Testpoint and LabVIEW. Since LabVIEW from National Instruments rapidly became the new industry standard for the interface of data acquisition and control units to personal computers, this environment was adopted as the standard for the Bagley College of Engineering, Mississippi State University.

Programs and equipment utilizing the older equipment and environments were retained and used as the basis to teach data acquisition and control programming techniques by having the students become familiar with working codes and equipment. They would then be required to translate programs into LabVIEW, or prepare LabVIEW programs to interface with replacement hardware that would offer greater flexibility in configuring measurement and control systems. Thus the students would be able to work on legacy systems as well as being postured to implement new replacement technology. In fact, several graduates were hired by companies specifically because of this added expertise in programming.

Increasing Fundamental Studies as Precursors

Electronic and computer programming content which previously had been covered in separate courses was replaced by a concerted effort to not only review the manner in which technical content was presented, but to introduce and provide a firm basis of understanding of material particularly necessary to understand digital instrumentation in the computer age. The new NI ELVIS units were first introduced in the second lab course, due to the timeliness of their purchase with end of year funds, but the immediate indication and feedback from the students indicated that this rightfully should have introduced at the start of the first lab course. The review of programming and digital electronics offered by the completion of the Introduction to LabVIEW and Introduction to NI ELVIS courses available for download from National Instruments gives the students a very complete exposure to, and a deeper understanding of this powerful graphical programming environment, interfacing the data acquisition unit with the programming for experiment control, as well as a good working familiarization with commonly used laboratory equipment. Add to that the very complete review of the principles of digital electronics used for data acquisition and control, and quite clearly, four or five weeks spent completing these courses were well worth the time invested! These are conducted during the weekly lab period, while lectures parallel the completion of the two self-paced courses with details of related issues and technologies. A listing of the tasks required to complete these two courses is used to track completion of the course requirements. Lab teaching assistants verify the completion of tasks by initialing the task listings for each student, while also recording individual task completion on a spreadsheet so that the progress of the entire class can be gauged at a glance. If a particular problem seems common to the group, that exercise is discussed during the next lecture period. The different technologies and tools are summarized in Table 1.

Table 1: Contents of the Introduction to NI ELVIS Exercises

NI ELVIS Workspace Environment Measuring resistance, voltage, current Voltage dividers, RC circuit behavior	**Digital Thermometer** Measuring resistors, thermistor circuits Variable power supplies, virtual thermometer
AC Circuit Tools Measuring impedence, Function generator, Oscilloscope use, Gain/phase Bode plots	**Op Amp Filter** Frequency response, characteristics, High/low/band pass filters
Digital I/O Visualizing byte patterns, clock circuits, Building counters, analyzers	**Magnetic Field Sensors/Switches** Testing sensors, hysteresis characteristics, Counting switch pulses, Labview automation
LEDs Testing diodes, polarity, characteristics, LabVIEW Testing/control of timed circuit	**Free Space Optical Communication** Phototransistors detector, Infrared optical Source, AM/FM analog modulation
RF Wireless Communication Transmitter, receiver, testing, Unique test signals, Marconi's RF signal	Mechanical Motion Tachometer operation, Rotary motion detector, Testing, LabVIEW Measurement of RPM

Assessing Fundamentals

Conscious efforts are required to insure that the material is thoroughly introduced prior to experimentation which will require a fundamental knowledge of the principles involved. By the completion of the introduction to LabVIEW programming and a review of data acquisition and control and digital electronics fundamentals through the NI ELVIS tasks, each student can demonstrate a basic understanding of these principles prior to moving on to more traditional laboratory exercises. In addition to completing these tasks during their lab periods, the students will also have quizzes in the lecture classes, and homework assignments to design and code data acquisition or control programs incidental to future labs. Finally, they will be writing detailed abstracts of the work accomplished as a precursor to writing complete lab reports for later lab exercises.

An enthusiasm for experimental studies was immediately noted during the semester when these two NI introductory courses were used at the beginning of the semester. Most students previously required a good bit of help in designing experiments that were related to their individual research projects. The Intro to LabVIEW course has three parallel tracks for each exercise, one for execution on computers with data acquisition hardware installed, another for programming with simulated hardware, and a third track that illustrates how to use the sound card for data acquisition. By having the students simulate the labs hardware configurations on their own laptops, they could easily complete all programming on their own computers, then merely port the software over to a lab computer where it was run with no further modifications. Additionally, the students learned how to export a LabVIEW program so that equipment could be operated remotely. During the conduct of individual research projects, other than discussing various options with students, very little additional detailed instruction was required despite the fact that most students had little to no previous actual experience with technologies of measurement systems. Likewise, little additional help was required for the students to be able to complete the NI ELVIS work, and then they were able to proceed directly to more advanced programming assignments incidental to other labs. Of particular interest is the number of individual projects requiring NO additional help in programming some fairly involved and detailed projects as summarized in table 2.

Table 2: ASE 4721 Seminar (Individual Research) Projects Fall 2007

Linear Aerospike Performance Testing Modifications with Entrainment Techniques	*Use of a Digital Pressure Transducer Scanner Module using LabVIEW for data acquisition*
Initial Feasibility Study of a Velocity Determination System for High-Speed Projectiles Fired from a Micro Light Gas Gun	*Application of an NI ELVIS exercise to motion detection in experimentation. LabVIEW program for event control, detection, data acquisition*
RotorCraft Blade Design: Lift and Drag Prediction	*Application of NI ELVIS exercises to data acquisition for experimental verification of rotor blade designs*
Shock Tube Analysis for the Purpose of Developing a Pneumatic Engine Concept	*Application of programs developed during the Intrr to LabVIEW as basis for data acquisition programming*
Testing Sailplane Tow Ropes for a Prediction of Safe Lifespan	*Use of LabVIEW programs during the Intro to LabVIEW as basis for data acquisition programming*
Updating the LABROC Test Stand: Development of a LabVIEW Data Acquisition and Control Program Implementing Existing Program Algorithm	*LabVIEW programming for test stand control and for data acquisition from flow valves, thermocouples and pressure transducers*

Conclusions

Graduating students completing their exit interviews were unanimous in their positive opinion of the formal reintroduction of the basics of digital technology in hands on labs as a means of reviewing the basics prior to engaging in more complex labs. The time required to explain the technologies used for data acquisition and control systems was definitely shortened. Bringing back the basics of electronics and programming for experimental data acquisition and control is a definite positive improvement of this course. The intuitive nature of the current LabVIEW versions, coupled with the many Express Virtual Instruments and complete instructions and examples has practically eliminated the mystique of DACS. The individual student evaluations of the lab courses have jumped to an all time high.

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