Design of a Wind Tunnel Facility for Hands-on Use by Beginning Engineering Students

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Abstract

The best way to learn engineering is by doing engineering. To foster appropriate types of experiential learning, we have created a unique project called a *Design for Lifetime Learning (DL^2)* project. This paper addresses one element of this overall effort—the design and construction of a wind tunnel facility to support hands-on learning by beginning engineering students. The wind tunnel facility was designed so each student can operate the tunnel with less than ten minutes of training. The wind tunnel, powered by a 37 kW motor, can generate air velocities of 70 m/s in the 45-cm square test-section. A state-of-the-art electronic force balance provides lift, drag, and pitching moment data. The control and instrumentation systems are designed to promote ease of use. Assessment data from students participating in a pre-college summer camp indicated that the wind tunnel was easy to use and that the wind tunnel enhanced the students' educational experience.

Introduction

Training leads to desired behaviors. When a professor teaches so a student can get the correct answer on an engineering problem, this is training. *Meaningful learning* leads to a change in the meaning of experience, which is a fundamental shift in the point-of-view of the learner[5]. To promote meaningful learning, we have created a unique project called a *Design for Lifetime Learning (DL^2)* project[2]. One element of this overall effort is the design and construction of a wind tunnel facility. In this context, meaningful learning involves typical skills such as engineering documentation in a lab notebook, use of math and scientific concepts, and creation of an appropriate procedure for acquiring data. Also, the learning is structured to foster teamwork, to help students realize the value of good experimental practice and to help students learn the distinctive features of good engineering practice. The key purpose of the wind tunnel and each associated project is to create an environment in which meaningful learning can occur.

Integrating wind tunnel experiments into engineering science or laboratory courses has been done for many years. Experiments can reinforce concepts taught in the classroom and provide experiences for future learning[3]. To reinforce concepts taught in a first engineering science course, Foss developed a wind tunnel facility in which the students performed experiments

related to pressure and velocity fields, and conservation laws. Venkataraman and Nilsen motivate wind tunnel tests with real-world problems[6]. Students perform experiments related to fluid concepts, such as the coefficient of drag, but the experiments are motivated by the real-world design of an air gun pellet[6]. The educational methods suggested by Foss, and Venkataraman and Nilsen use predetermined experimental procedures for the students to follow. Wind tunnels have also been used to teach validation of math models. For example, Lasher, Young, and Progelhof developed undergraduate CFD courses and wind tunnel experiments in conjunction with each other[4]. One of Lasher, Young, and Progelhof's project goals was to promote understanding of basic concepts, so students could solve open-ended problems[4].

This work combines the characteristics of reinforcing basic concepts so students can solve open-ended problems, motivating student learning with real-world problems, applying math modeling, and teaching engineering soft skills. The main contribution of this work is the focus on creating an environment for meaningful learning with a focus on the technical aspects of wind tunnel experimentation. This paper describes and documents the wind tunnel facility, and describes how the facility was designed to enhance meaningful learning.

Objectives for the Wind Tunnel Facility

The wind tunnel project team determined four goals for the University of Idaho's new wind tunnel facility. The first objective was creation of a facility that is appropriate for class projects, while still being useful for scientific research. For the wind tunnel to be accessible by beginning students, the tunnel must be simple, easy to use, and appealing. To fulfill research and upper level engineering project needs, the tunnel needs an adequately sized test section, a generous air velocity range, and appropriate instrumentation for research quality measurements.

The second objective for the wind tunnel was an environment that exposes students to realistic research and working environments. Students must use communication and teamwork to work effectively in this environment. Communication, project management and professional decision making are a few attributes we hope to instill in beginning engineering students through the integration of this new facility in class projects.

The third design objective was the wind tunnel instrumentation should promote engineering analysis by students. When students observe, record and apply engineering analysis to experimental data, rather than relying on a computer for data analysis, their learning is enhanced. For example, students record wind speed (displayed in meters per second) and drag force (displayed in Newtons) in a project notebook. Students then calculate their specimen's coefficient of drag rather than having a computer calculate the value for them.

The fourth objective was enriching and increasing the time students spend performing hands-on experiments. A typical wind tunnel test includes model fabrication, mounting of the model in the tunnel, wind tunnel start-up and speed adjustment, visual observations (e.g.- a vibrating model), and use of a project notebook for documentation of the experiment.

The Wind Tunnel

The wind tunnel, Fig. 1, was made by Engineering Laboratory Design. It is an Eiffel type wind tunnel 10.36 m long and 2.16 m tall overall. The motor is a 37 kW AC induction motor controlled by a variable frequency controller. The motor drives a 1.22 m, axial fan, which can produce air velocities of 70 m/s in the test section. The test section is made of 1.91 cm thick Plexiglas, and has a 45 cm square cross-section that is 91.44 cm long. According to the manufacturer, the velocity variation across the test section is less than 1% of the mean velocity and the turbulence intensity in the test section is less than 1%.

Figure 1: The user-friendly wind tunnel facility at the University of Idaho.

Floor Plan

The room was completed before the wind tunnel was purchased. As a result, the wind tunnel had to fit into a predetermined space rather than the space being built to house the wind tunnel. We determined that a wind tunnel with a 45 cm square test section would meet the room constraints.

The room can accommodate up to eight team members and a mentor during a test, Fig. 2. Other groups can observe activities in the wind tunnel room and test section through a window, Fig 3, between the room and the hallway.

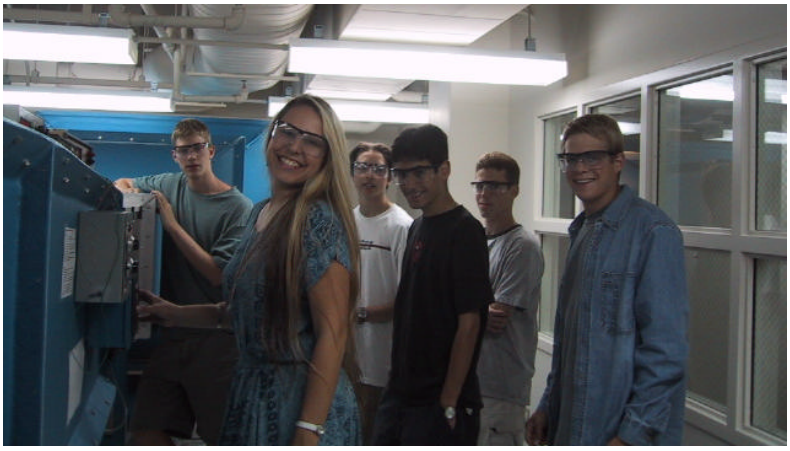

Figure 2: JEMS summer camp students using the wind tunnel with their mentor.

Figure 3: Students watching the action in the wind tunnel.

Air Velocity Measurement

The air velocity measurement device is a Dwyer Smart Air Velocity Transmitter. It is a thermal anemometer with a velocity range of 0 – 76 m/s and outputs a DC voltage signal, proportional to the air velocity at the sensor. We calibrated the device against a pitot tube standard. The anemometer has an accuracy of 1% of full scale.

Force Measurement

We use an electronic internal force balance, made by Aerolab, to support models in the test section and measure forces on the model, Fig 4. The force balance consists of a support beam with strain gages for three channels – lift, drag, and pitching moment. The lift force channel has

an accuracy of 0.00385N, and the drag force channel has an accuracy of 0.00454N based on the sum of the square of the residuals from calibration data[1].

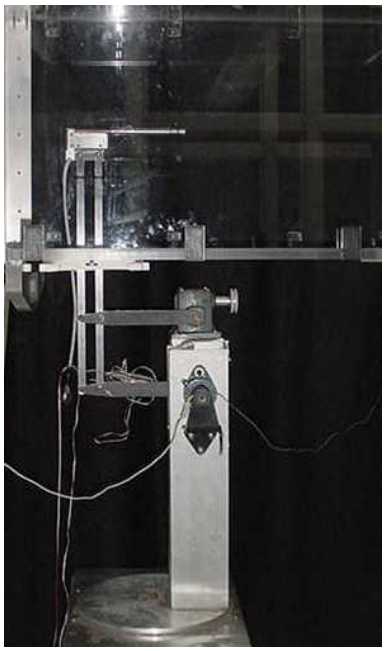

Figure 4: The force balance mounted in the test section. The strain gages are located in the cylindrical section of the balance, mounted horizontally and facing to the right in the top center of the picture.

Digital Displays

The digital displays, which are made by Newport Electronics, convert the voltage signal from the anemometer, force balance, and angle of attack potentiometer into a reading in SI units, Fig 5. There are 3 strain gage displays, one display for the anemometer, and one display for the angle of attack potentiometer. The strain gage displays have an accuracy of 0.005% full scale, and the other displays have an accuracy of 0.03% full scale. The displays also provide excitation voltage for the strain gages. The displays are 9.20 cm wide, 4.50 cm tall and 17.78 cm deep.

The digital displays also output an analog DC voltage signal proportional to the displayed value. Menus in the digital display allow the user to set the output signal to a desired proportionality. The voltage output is intended for use in research applications, so it is not configured for user-friendly applications.

The Newport digital displays meet European Union standards for electromagnetic interference (EMI) noise rejection and production. EMI was a problem for a custom circuit and an OTEK panel meter we used to measure strain gage voltage. We used a Vishay strain gage reader and found that this system was completely immune to the EMI that the custom circuit and OTEK meter experienced, but the Vishay was too large and difficult to use to satisfy the user-friendly wind tunnel design. We found the Newport displays using a web search, acquired a trial display and found that the display was completely immune to the EMI.

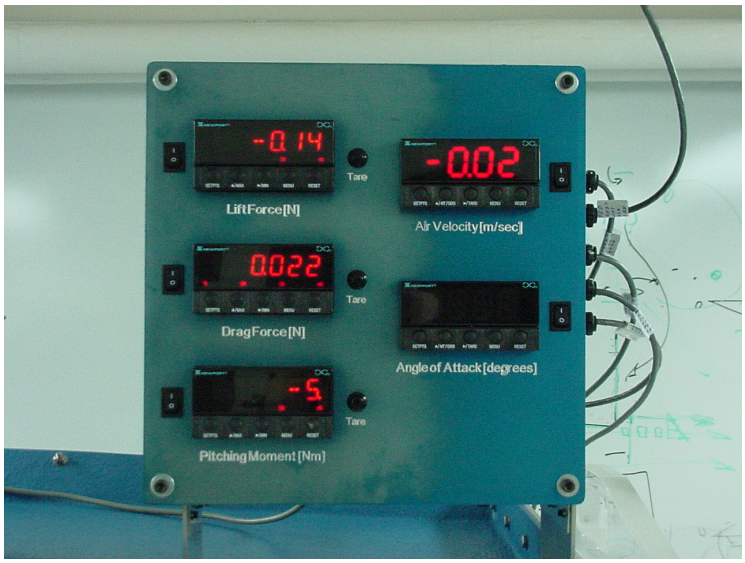

Figure 5: The digital displays in their enclosure.

We calibrated the strain gage displays using a 20-point calibration. The slope is input into the meter using two settings calculated from calibration. The displays are set to zero before each test using a tare button on the front panel of the display enclosure. The anemometer display range is set by setting the zero point as zero voltage and zero display, then the upper limit is set to display 69.3 m/sec with a 5 VDC input.

Safety

Safety is important in the wind tunnel laboratory, especially when undergraduates and pre-college students use the facility. While the students assemble, perform, and disassemble their experiments, a mentor supervises their activities. The mentor is responsible for keeping all students in a safe location, especially while the wind tunnel is in operation. To prevent access to potentially hazardous areas, such as the entrance and exhaust sections of the tunnel, the mentor installs safety barricades before testing begins. Without the safety barricades in place, screens and a honeycomb, Fig. 6, prevent access to the test section through the wind tunnel entrance, and the acoustic diffuser, motor and stator vanes, Fig. 7, prevent access to the fan blades. The wind tunnel is inherently safe, robust, and difficult to damage in a manner that would cause an injury to the students or mentor. If the wind tunnel malfunctions, or a model begins to break during a test, a stop button on the wind tunnel control panel immediately ramps the motor and fan to a complete stop. In the event that a model breaks apart during testing, a model catching screen, mounted directly upstream from the fan, prevents the broken model from reaching the fan. To prevent eye injuries, possibly caused by broken models leaving the exhaust section at high speed, everyone in the room wears safety glasses during testing, and to prevent hearing injuries, the acoustic diffuser limits the maximum operating noise level to 85 dB.

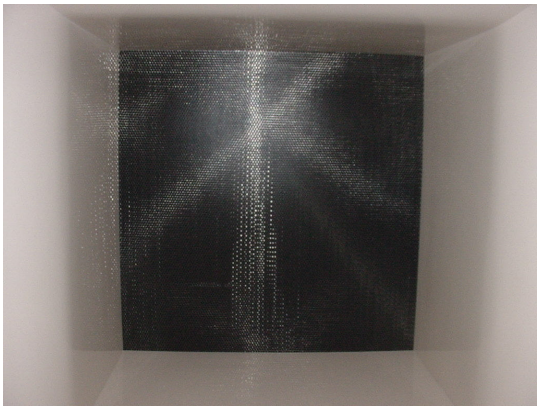

Figure 6: The intake screens and honeycomb.

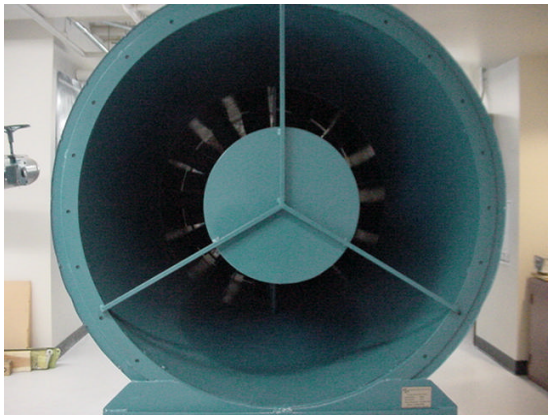

Figure 7: The exhaust end of the tunnel, showing the acoustic diffuser, electric motor, stator vanes and fan.

Pedagogical Goals for the Wind tunnel

Previous pedagogical strategies for integrating wind tunnels into engineering fluid mechanics courses are discussed by Foss, and Venkataraman and Nilsen. Integrating wind tunnel testing into a design course to teach "soft" skills is a new concept. Soft skills include interaction within teams, written communication skills, effective documentation and professional decision-making. Until recently, teaching the engineering "soft" skills has not been a primary concern, but ABET 2000 requirements are leading to change. Our goal is to introduce the wind tunnel as a tool for developing these "soft" skills while also teaching correct experimentation procedures, documentation, and validation of mathematical models.

Competition Projects

DL^2 projects are competition-based. They are used in conjunction with the wind tunnel and are geared so they create environments that simulate real world situations while establishing a setting for meaningful learning of "soft" skills. Student motivation is generated by competition with other teams. This promotes self-directed learning and encourages students to use every

resource available, including the wind tunnel, to be victorious. The students must use these resources to develop their own experimental procedures and perform their own experiments. Students are also responsible for determining the validity of their experimental results and making design decisions based on their experimental analysis.

During a project, using the wind tunnel is one of the first tasks that a team performs together. Our goal is that by sharing this experience students gain understanding of the group. Students gain knowledge of team member capabilities, strengths, and areas of relative weakness during testing. Because this activity is wholly project goal oriented, it is very difficult for individuals to reap benefits from personal triumphs. It takes at least three people to effectively use the tunnel, Fig 8; everyone is included in the team's success or failure. During wind tunnel testing, the students begin to understand real teamwork, and begin to interact at a level that elicits synergism. Our goal is that a holistic view of teamwork is established, and the students realize that they cannot complete the project without working as team.

Figure 8: JEMS 2001 summer camp students placing their rocket in the wind tunnel.

Example

During the summer of 2001, students in a pre-college engineering camp, called JEMS, competed in a DL^2 project centered on a model rocket. For the competition, the rocket had to carry a payload to a specified height. Educators introduced the wind tunnel to the students as a tool for rocket design. Students created several prototype rockets and modeled each design's performance using a coefficient of drag generated from wind tunnel data. They developed their own procedure, for example, how many tests to perform and at what velocity. Students then performed their own experiments and analyzed the experimental results. Students often learned the adverse affects of fluid dynamic forces acting on their designs when model rocket parts were deposited against the model catching screen.

After the students design, build, test, and model their designs, the entire class test flies their rockets, Fig 9. Students are always astonished at how accurate the test data and math model often are. Students in a sophomore design class found the math model's prediction of rocket altitude was usually within one meter of the actual altitude when they used experimental data acquired with the wind tunnel.

Figure 9: A JEMS 2001 student launches her team's rocket.

Assessment

We performed an assessment of the DL^2 project used in the 2001 JEMS camp. The assessment was based on student responses to a survey, which was designed to evaluate the project and the wind tunnel's role in the project in four categories, shown in table 1. Between two and four questions were developed for each category and the students were asked to respond to the questions using a scale with zero being strongly disagree and four being strongly agree. A rating of four was the highest score for all of the questions.

Table 1: Results from the 2001 JEMS student survey

Category	Score
User friendly	3.5
Appealing	3.8
The wind tunnel facilitated experimental documentation	3.5
The wind tunnel increased your learning	3.2

Table 1 summarizes the results from the 2001 JEMS assessment data. The students considered the wind tunnel facility to be user friendly and appealing. More importantly, the students thought the wind tunnel helped them to document their experiments and increased their overall

learning. This data shows wind tunnel based DL^2 projects help the students perceive an increase in their own performance. Results from the survey and observation of student performance show that DL^2 projects using the wind tunnel increased student learning related to project goals and increased general interest in engineering.

Conclusions

With careful design, it is possible to configure a complex experimental facility to foster hands-on use by beginning engineering students. The wind tunnel facility provides an environment in which meaningful learning takes place. Students want to learn, so they apply good engineering practice, such as lab notebooks, application of math and science, experimental procedures, and teamwork, to the use of the wind tunnel. This type of facility allows students to perform as engineers and promotes a rich learning experience where students engage in self-directed learning. The students connect with the engineering process through use of the wind tunnel. They constantly thirst for more knowledge on the use and application of the engineering process, within the context of the wind tunnel facility and their competition project.

Acknowledgements

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