Renovating an Ancient Low Speed Wind Tunnel: A Student Team Project Case Study

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Abstract

This study describes how a team of aerospace engineering students planned, organized, implemented and recorded a fast-paced project in support of the repair and renovation of a very old, major university low speed wind tunnel. This is a case study in learning within and across disciplines, involving students at all levels from freshman to PhD. The problem involved having to learn a wide variety of topics on the job with very tight deadlines. Solution methods had to be developed and implemented. Experiments had to be conceived, designed and refined. Analysis methods were used, with innovations required to adapt classical methods to the particular needs of the problem. The pedagogical aspects of interest include how modern students learn under such circumstances, the methods of teamwork, the role of technology, and the methods needed to ensure safety and competent completion of projects.

Introduction

The purpose of this Case Study paper at the ASEE conference is first considered. The School’s low-speed wind tunnel, an 80-year-old facility, suffered a long shutdown while a breakdown was investigated, options were considered, and a new replacement system was acquired and installed. The crew available on the School side consisted of the professor and a team of students at all levels from freshman to PhD. The undergraduates in the team generally signed up for one semester at a time. The student team took on several tasks that in the past would have had to be outsourced to outside experts, the cost of which would have been unaffordable because of the high uncertainties and long delays inherent in these tasks. However, with cross-disciplinary learning resources, student project organization tools and a culture of solving problems across disciplines, the team was able to accomplish all the required tasks. The Case Study reviews what was done and how and then attempts to derive lessons.

Team-based project learning has long been recognized as an effective way of enhancing comprehension and retention of lessons in the undergraduate curriculum. Coyle discusses a vertically integrated curricular experience in electrical engineering, constructed from a project running through a sequence of courses. Ohland discusses multiple approaches to multidisciplinary design experiences in the undergraduate curriculum. Devgan discusses how research experiences are used to meet ABET EC2000 criteria. Pionke describes using a NASA student competition as an intense multidisciplinary project experience. While the experience...
discussed in this paper was not designed as a curricular experience, it was a real-world project dealing with professional entities within and outside the institution, as well as a host of issues that came up in implementing the project.

The John J. Harper low speed wind tunnel was built in 1931 as the core of the Guggenheim building housing the School of Aerospace Engineering at Georgia Institute of Technology. On November 1, 2011, the water-cooled clutch of the drive system developed a leak. The Facilities department personnel could not stop the leak. Any further repair involved disconnecting and removing the multi-ton clutch through the roof of the motor room to a company site, requiring several weeks of shutdown at minimum. Original drawings of the clutch system from 1960 were found from the tunnel archives but over the next several months, the Institute approved the option of replacing the entire DC motor/water-cooled clutch with a modern air-cooled variable-frequency AC motor. The shutdown period posed many challenges and some opportunities. The student team had to acquire the knowledge and skills needed to do all the tasks that were not outsourced to the Institute’s Facilities department or their contractors. Below, the technical problem statement is given first, followed by educational aspects of interest in this conference.

**Technical Problem Statement**

1. Given the unknowns in dealing with 80-year-old components, the effort started tentatively. The approach had to be compatible with precautions that students could implement, and with location inside a classroom building. The needed skills had to be learned.
2. Developing a cell-phone compatible Inventory Organization and Control System.
3. Finding the inertia of the fan/shaft system: Since the tunnel was inoperable, an experiment had to be devised to measure system inertia as part of specifying the new motor drive.
4. Tunnel control system and control panel development.
5. Predicting tunnel performance to specify the motor emergency braking parameters.
6. Calibrating the open tunnel motor performance.
7. Repairing the honeycomb in the settling chamber.
8. Calibrating the turbulence in the test section.
9. Planning a new fan system.
10. Each of these activities was systematically documented, and the resulting Case Study is summarized in this paper.

**Educational Problem Statement**

The aerospace engineering student team has members ranging from PhD candidates to freshmen. Many issues involved technical content that is not in the AE curriculum, and students cannot be presumed to have already taken the required courses even for topics that are in the AE curriculum. Questions of interest are:

1. Where and how do the students find the required technical knowledge?
2. How do we ensure correctness of use of the knowledge?
3. How do students communicate within and across task teams?
4. How are project timelines met, with a diverse team of students?
Approach

Our team consisted of 11 students in the summer of 2012, including 2 rising sophomores, 3 juniors, 3 rising seniors, and 3 graduate students. The majority of the work reported here was accomplished during the summer, with the tunnel being started up again with the new motor installed before the start of the Fall semester. In the Fall, all of these students continued on. The total of 26 now consisted of 5 freshmen, 3 sophomores, 6 juniors, 6 seniors, and 6 graduate students. While these numbers may appear large, it should be noted that the tunnel repair activity was shared among the student team as a needed effort, and was not the primary focus of activity of any of the students. They were all involved in degree-granting, publication-generating research activities quite apart from the efforts described here. Substantial class scheduling and travel commitments made it essential to maintain progress and communications using electronic means.

Team organization

At the start of the summer, following the practices refined in our group over the years, students and projects were organized in a matrix, with each student being involved in 2 to 3 project teams. Each project team thus had more than one student working on it. The tunnel improvement project had all team members participating. This project did take high priority because meeting the schedules to match the work of the professional team involving outside contractors, was critical to success. The long shutdown had doubtless created very difficult pressures in all of our research and degree programs, so it was critically important to make sure that we could start operating the tunnel at the start of Fall. Project teams were empowered to set their own meeting and work schedules consistent with their classes. Progress reporting used several tools:

a) A Project Document was constructed for each aspect of the project using the LaTeX software, providing all details of procedures, images, and results.

b) Weekly meetings of the whole team were scheduled, with considerable flexibility for students to come in at different times based on their class schedules.

c) A Facebook page was constructed for the team, to provide a visual record of progress.

d) Paste-on whiteboards were fixed to the walls wherever space permitted, and these quickly became filled with the task lists, derivations, diagrams and equations needed. The team developed clear assignments, down to who was to get the boards cleared and cleaned each day.

Obviously, new students had to be given time and a boost to learn the LaTeX software for the report documents. This was the first rapid-learning exercise, and appeared to get done well inside 1 week for all the students. This lesson inspired us to require students in core courses in Spring 2012 to learn and use LaTeX in submitting assignments.

Inventory System

The rising sophomores, coming with feelings of inadequate technical preparation, were assigned to learn LaTeX, and to organize the inventory using their postulated (correctly as it turned out) expertise in organizing parties and other events. As they progressed quickly, they were asked to
organize and delegate tasks to the rest of the team, who were to take orders from them on this important aspect.

One of the rising seniors obtained the software to generate a QR-code reader system, and then developed that with the help of a teammate, to be installed on a smartphone. A pictorial representation of the contents of each storage container (cabinet shelf or drawer) was loaded on to an internal website along with descriptions, as part of the inventory system. Thus most items could be located quickly using this system, and students with the smartphone app can quickly read the codes off a given item and see what it is, by going to its description on the web-based inventory. This addresses the issue of new students having difficulty identifying items when trying to do inventory, or just searching for an item. (Postscript, April 2013: the buddy of the rising senior suddenly took his website off the web, leaving the rising senior with no backup, then tried to extract money to bring the site back up. As a result we are re-doing the inventory with a more reliable website- ours. Lessons (a) Back up computer files on reliable systems and (b) reduce reliance on external suppliers of unproven reliability. )

Determining the inertia of the fan/shaft and gear system

To specify the motor and its controls, the Institute’s professional team and contractors needed to know the torque that would be required of the system. To understand this, the moment of inertia of the fan/shaft and gear system (whatever would be coupled to the motor) had to be determined. Since there was no motor connected, it was not possible to turn the fan mechanically. To solve this problem, the student team turned to their courses and initiative. A weight was tied to one of the fan blades, and the string suspending the weight was positioned at each of several radial positions in turn. The blade was held up at the 90-degree position (horizontal) and the weight was allowed to drop down to a Styrofoam block set up to absorb the shock. The fan was illuminated from downstream, and the dynamics of the blade were captured using a video camcorder. Detailed manual analysis of the video, after appropriate calibration of the image geometry, provided the angular acceleration. The students described the procedure as follows:

“A video segment shows a blade accelerating as the weight tied to the next blade is dropped. A pink-taped spot moves by. A single-pixel orange dot is placed during processing (using Paint software) on each video frame to get a precise measurement of the angular position of the blade in each image. By repeating that on the 30 images per second of video (29.96 per second, precisely) a record is made of angular position theta versus time t. Angular velocity thetadot is found by differentiating theta, and acceleration by differentiating again. Differentiating experimental data is always a tough thing, because any errors get hugely magnified through two differentiations. So a lot of averaging is needed.”

The required averaging was accomplished to obtain stable averages. Repetitions of the experiment with different radial positions on the blade provided another check. On top of this, the mass of the system and its distribution, and the moment of inertia, were calculated from drawings as a sanity check. These results were then provided to the team specifying the motor and drive. Subsequent operation data showed that the measurement was quite accurate.
Developing a Countdown List

Following the aerospace practice of a countdown to a specific startup time, we developed and detailed countdown lists, and examined them to determine critical paths and look-ahead scheduling to determine priorities in knowledge acquisition and purchasing. This countdown list was posted on the front of the Project Document, updated every day, and communicated to all team members.

The following sets of pictures summarize different aspects of the project. Figure 1 shows the various aspects of the repairs. Clockwise from the top left, the process of removing the old motor and clutch is shown, with a crane being brought to the street outside to first lift off the roof of the motor room and then remove the items. The new motor, though smaller, was installed the same way. The new transformer and variable frequency drive are shown in the next image. The third image shows the view looking downstream from the test section of the tunnel. The tunnel had been pressure-washed, and the diffuser primed and painted white. The first set of turning vanes can be seen, showing substantial attrition and wear. The student team developed an Inventor Pro model of how the turning vanes and diffuser would look with correct lighting, and various schemes of colors and stripes, to ensure that a full-white painting would not cloud details. The vanes are shown in close-up (bottom row, left) and the damage can be seen. The result after the vanes were sanded, coated with Bondo™, fiberglass and epoxy, then primed and painted, is shown next. The last picture shows the new motor installed.

Figure 2 shows aspects of the student team’s work. Again, clockwise from top left, the setup to measure the fan inertia is shown, with the illumination from downstream of the fan. The next image shows the students training with operating the safety equipment and protective gear including full HEPA-filtered breathing apparatus and full-body disposable coveralls, before dealing with the vane repairs. The third image is of one of the lists, in this case sensors, developed on one of the paste-on whiteboards, prior to finding or ordering new ones. The bottom left image shows the smartphone-based inventory system being tested. The last image is of students developing the tunnel operating/control systems using LabView and MatLab/Simulink.

Figure 1: Tunnel repair and renovation aspects. To L-R: Crane lifting old motor out. New transformer and VFD system in motor room. CAD rendering to preview paint schemes. Bottom left: damaged vanes, and after repair. New motor.
Figure 3 shows the level of detail needed when developing documentation for a rotating team of undergraduates. These pictures are from the instruction manuals developed by the students for the tunnel data acquisition and control system instrumentation. The image at the bottom shows a screen snapshot from one of the video segments used in measuring the moment of inertia of the fan system.

Figure 2: Student work. L-R, top: Illumination to measure fan inertia. Training with safety equipment. Whiteboard use for organization. Cellphone inventory system in testing. Control system development.

Figure 3: Detailed descriptions of data acquisition system used in documentation for students. Frame from video segment used to measure fan inertia.
Emergency braking profile

Electric motors are decelerated by operating them as generators, producing a large current flow. A set of resistors had to be specified and ordered, to absorb and safely dissipate the heat that is generated in case of an emergency stop. A simulation had to be developed, to verify the braking profiles, and ensure that the heat dissipation would be well within limits. Figure 4 shows the results, with various cases where the limit may come from the torque that the motor can generate, or from the deceleration and resulting stresses that we dared impose on the ageing fan/shaft system. The torque imposed by flowing air profoundly affects the results, especially at the start of the braking when the flow velocity is highest. As the braking proceeds, there is a substantial response time for the flow to decelerate, so that the flow will be countering the braking torque during the initial stages. This requires more torque from the motor to decelerate at a specified rate. This project required a good deal of thought and knowledge from different fields, including aerodynamics, dynamics, system analysis and simulation. Quick estimates were initially developed using Microsoft Excel, but then a more detailed simulation with the time response of the flow was developed using MatLab/Simulink.

Tunnel Operator’s Checklist

This list had to be developed after understanding the detailed procedures from the motor and control system installations, as well as including our standard safety checks. Figure 5 shows the team taking data on the tunnel’s characteristics, to verify the parameters that we had assumed. This was during the first run where the tunnel was taken up to normal operating speed, at the start of Fall semester. As seen in the image, some students had the task of recording everything manually, as backup and to provide corroboration of the electronic data acquisition. The intense, well-prepared effort of the previous 4 months had paid off, in an on-schedule startup of the facility. When the Countdown ran down to zero, the team was obviously ready.

Figure 4: Developing the emergency braking profile. The constraints on fan torque, motor torque, flow brake power and time to shutdown, are considered.
Analysis of Educational Aspects

We now consider each of the educational questions in turn.

1. Where and how do the students find the required technical knowledge? Table 1 attempts to capture the breadth and complexity of issues on which the students had to gain in-depth knowledge. In this regard we note that there was no correct answer known a priori in setting these problems to the students. Instead, the professor was dealing with many of the issues for the first time as well, and hence it was a joint learning exercise.

Some years ago, we would not have been able to undertake such an exercise with the young and inexperienced team that we had in Summer 2012. The idea of putting two first-year students in charge of organizing and developing the inventory management system for a research facility and a large university wind tunnel, would have appeared quite impractical. The issue of repairing the turning vanes, obviously deferred for several decades due to fear of the cost and difficulty, posed several uncertainties. Experts were indeed brought in to discuss approaches, but this did not lead to any useful solution, except to rule out several conventional solutions.

What then has changed? We are using the cross-disciplinary learning resources that we have been developing since 1998. As we postulated, the experience of using these in classes, and indeed of developing them, has made students and faculty much more confident about their ability to pose the right questions and find the answers. Our emphasis on depth in cross-disciplinary endeavors is paying off, since students are not content to obtain superficial solutions. Instead they delve deeper to find thorough solutions.

2. How do we ensure correctness in using the knowledge? This question becomes quite frightening when dealing with real-world projects, such as the specification of a motor system for an ancient and large wind tunnel fan. Models had to be developed for the losses encountered in the closed circuit of the tunnel, and these models would have profound impact on the system when installed. It was not feasible to run the tunnel to obtain such data, so we had to use a combination of ancient run-time logs, textbook estimates, estimates from papers on slightly related subjects that we were able to find, and our own intuition. The process involved frequent discussions with and among the student team, repeated calculations by several people, and finding corroborative evidence by careful posing of questions.

3. How do students communicate within and across task teams? Observations provide some surprises. As expected, cellphones and text messages have replaced email from fixed or laptop computers as the primary means of communication away from the lab. Students still believe strongly in setting up team gatherings to do projects, and this has positive and negative aspects. The positive is of course the benefit of full participation, with ideas coming from everyone. The negative is that the scheduling of meetings itself takes more time than is needed for a useful meeting, and often one or more team members simply
fail to show up for meetings, resulting in everyone wasting their time. For whatever reason, complaints about team members are rare, although the professor would in some cases very much like to obtain some such input to help nudge an underperforming team member. The paste-on whiteboards are a revelation, since they are so swiftly filled with in-depth discussions involving derivations and equations. This would be an eye-opener to most faculty who have tried teaching such depth content to undergraduate classes. The whiteboards are thus a primary aid in communicating knowledge between students.

4. Several aspects of the tunnel’s operating features had to be extracted from archived drawings, reports and log books going back to 1929, itself an intense learning experience in the value, methods and future plans for documentation and archiving.

5. Empowerment pays. Often one or two students would walk into the professor’s office to convey the team’s thinking, get opinions and convey them back. Several critical errors have been found because the juniormost member of the team thought to ask the professor why his/her teammates were doing something in a certain way.

6. *How are project timelines met, with a diverse team of students?* Through constant monitoring, reminders, questions and insistence from the professor, despite misgivings about pushing students too hard on top their coursework. The timeline is very hard to enforce, and ideas such as the Countdown List are extremely important.

7. Some reviewers wanted to see a listing of which ABET criteria were met by what actions. Much more important is our finding that with modern resources and guidance, undergraduates are able to solve very involved problems, and do it within tight time constraints. One point of Table 1 is that the issues truly went far outside what we can teach, or even know, in the standard curriculum. Thus the important observation is that our students are indeed succeeding in going out and learning what they need, a highly gratifying demonstration towards the goal of instilling lifelong learning skills. With such a multi-level team environment, and especially one that is structured with the youngest team members empowered to delegate and insist on timelines, there is very little room or patience for egocentric issues. This appears to be well understood among the team, and as a result they truly have learned to work as a very cohesive and mutually supportive, if somewhat mutually demanding, team.
Table 1: Issues, knowledge, sources

<table>
<thead>
<tr>
<th>Issue</th>
<th>Knowledge area</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan inertia</td>
<td>Dynamics</td>
<td>Courses, innovation.</td>
</tr>
<tr>
<td>Tunnel power requirement; Braking profile</td>
<td>Fluid &amp; thermodynamics; fan aerodynamics, electric machines.</td>
<td>Books, papers on closed circuit tunnel loss; calculations, EE textbooks.</td>
</tr>
<tr>
<td>Pressure washing</td>
<td>Sizing equipment and procedures, drainage rigging.</td>
<td>Retail outlets, equipment specs</td>
</tr>
<tr>
<td>Inventory organization</td>
<td>Smartphone apps, QR code system</td>
<td>Friends in ECE/ computing, cellphone ads, web</td>
</tr>
<tr>
<td>Painting options; Safety issues; Vane repair options</td>
<td>Chemical toxicity, application difficulties, surface nature, cost, color selection. Toxicity, protection, sealing and removal. Metal vs. wood vs. Bondo /fiberglass. Safety, equipment, training.</td>
<td>RTK certification &amp; Research ethics courses, MSDS of all chemicals, discussion with airline experts, paint manufacturer sites; equipment specs, discussions with experts &amp; team, textbooks, safety manuals, practice. Composite blade making experience</td>
</tr>
<tr>
<td>Sensors &amp; data acquisition</td>
<td>Pressure, temperature, velocity, torque, strain. A/D conversion, signal processing.</td>
<td>Our group, vertical transfer.</td>
</tr>
<tr>
<td>Feedback control system</td>
<td>System dynamics, control systems, dynamics.</td>
<td>AE courses, textbooks, discussions</td>
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</table>
Concluding remarks

In this paper we present a case study of a project done to an exacting timeline. The team has students with various levels of academic and research experience. Success was essential, and the team did what was needed to succeed. The paper lists various methods and tools that were used to carry out the project. Some findings:
1. The use of a countdown list with a firm deadline, and plenty of leeway for contingencies, is an essential ingredient.
2. Students are able to learn the LaTeX software quite quickly, opening the way to developing team-authored documentation of the project that can be quite deep and thorough, with minimal time spent on formatting issues.
3. With contemporary skills with cellphone apps, the students were able to develop a smartphone/QR-code based inventory control system.
4. Focusing on the youngest and least experienced team members, finding tasks that are suitable to their experience and taste, and then asking them to delegate tasks and track timelines, appears to be an effective tactic.
5. Paste-on whiteboard space is an effective aid to communication between students, and in fact encourages them to cast their thinking in technical terms with detailed derivations, calculations, task lists and planning diagrams.
6. There is a huge and proven improvement in the effectiveness and depth with which our students are able to pose and solve problems that cut across disciplines.

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References


