Miniature Wind Turbine Student Design Project

John Miller, Linda Olafsen
Department of Electrical and Computer Engineering
Baylor University
John_Miller1@baylor.edu, Linda_Olafsen@baylor.edu

Abstract

Design projects give students the opportunity to apply engineering concepts to open-ended problems with realistic constraints. They force students to consider multiple factors, identify trade-offs, and make judgments based on analysis and/or intuition. This paper will describe a project where students designed and constructed the blades for a miniature wind turbine with minimal restrictions on the design and materials used. Students documented their design process and the results of testing. Project details, assessment methods, results, and student reactions will be provided, along with a discussion of possible adaptations to other courses/programs. Links to online repositories of such projects are also provided.

Introduction

The purpose of this paper is to encourage educators to consider their teaching methods and explore new ways to teach the same concepts more effectively or integrate multiple concepts. The authors do not claim to be experts in pedagogy; rather, they serve as an example of typical engineering educators striving to help their students develop deeper understanding and thoughtfulness.

This project was conducted in the first-semester Introduction to Engineering course at Baylor University, but neither the project nor the larger discussion is limited to only freshman courses. Some adaptations to other courses will be discussed later. However, some background on the freshman course may be helpful to understand the context around the project.

The introductory course has a few objectives. First, students should come away with an understanding of what it means to be an engineer and what they can expect from a career in engineering. This includes an introduction to the engineering disciplines, as well as various job functions and career paths within those disciplines. Second, they should have some fundamental knowledge and tools they can carry forward into other courses, such as problem solving methods and presentation, unit conversions, and Microsoft Excel. Some students have these skills already, while others do not. Lastly, the content of the course should be rigorous enough that it distinguishes between students who will be successful in the program and those that will not. The goal is to *retain* as many students as possible, but this is a gateway course, with a minimum grade requirement for continuing in the program. Students are told "This is the easiest course you will take. If you cannot succeed here, you will most likely not succeed later in the curriculum."

The content of the course is a broad array of basic engineering topics, including the engineering design process, unit conversions, engineering notation, problem solving method, graphing, fluid mechanics, statics, circuits, digital logic, energy, and efficiency. Some topics have a related lab exercise, and these are conducted in weekly 75 minute lab sessions (in addition to the lecture times). Part of the purpose of the miniature wind turbine project was to integrate several of these topics together, as will be explained in the next section.

The next section covers the project assignment and expectations of the faculty. Following that is a discussion of the actual outcomes and lessons learned, including student feedback. The last section summarizes the lessons, applies them to a general context, and provides some ideas for implementation of this or other projects.

Project

Assignment

The project was to design and construct a turbine rotor (hub and blades) and determine its efficiency. Students worked in teams, with typically three students per team. They were told to document their design process by logging meeting times, listing references, taking notes during brainstorming sessions, and when identifying tradeoffs, recording pros, cons, their decision, and why that decision was made. They tested their designs and then wrote a final report. The project spanned four lab sessions (weeks):

- Week 1: Faculty assigned project and teams and discussed some design considerations. Teams exchanged contact information and began brainstorming.
- Week 2: Mandatory work time. Some teams began construction, some went to purchase materials, and some spent the time working on their design.
- Week 3: Test day 1 - Optimum Load Resistance (see below)
- Week 4: Test day 2 - Rotor Efficiency (see below)

Each team was provided with an aluminum shaft, around which they built their rotor. Faculty also provided a random selection of common household materials, such as paper plates, playing cards, plastic cutting mats, paper clips, brads, craft sticks, adhesives, etc. Teams were free to use any available materials for construction or purchase their own.

Student Outcomes

The primary objective was that students see the design process in action. They were to use the introductory knowledge that they had learned (about fluids, circuits, etc.) and supplement it with additional research and experimentation. The faculty expected that some teams would primarily design by trial and error, while others would iterate in brainstorming sessions before construction.

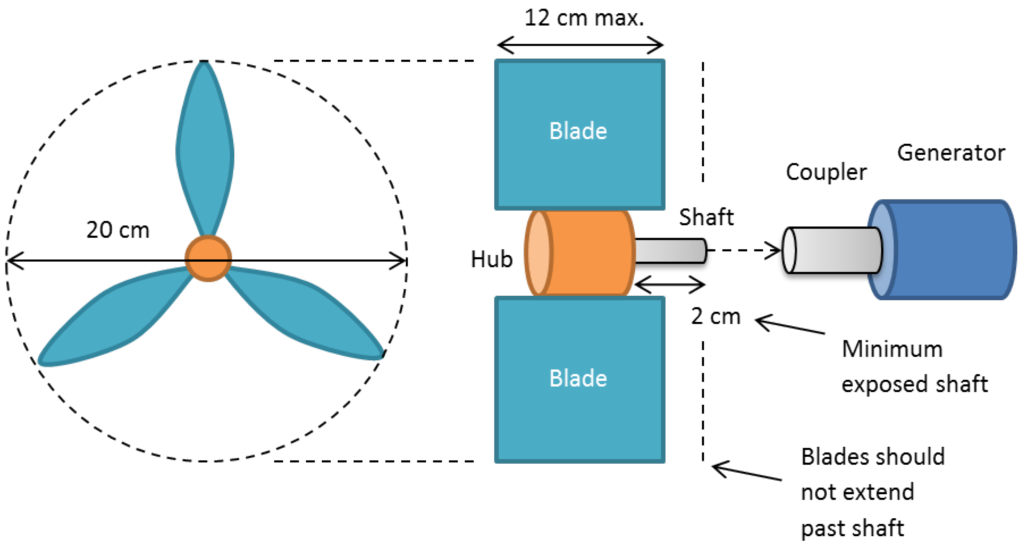

Figure 1: Turbine constraints and connection to generator.

Process documentation was assigned so that students would be more cognizant of the process they were employing.

In addition to the "soft skills" of teamwork, design, reporting, etc., the wind turbine project provided an integration of technical topics, including air flow (fluids), electrical resistance, voltage, and power (circuits), unit conversions, and efficiency. It also provided students the opportunity to use some basic electrical laboratory equipment (multimeter and decade box/variable resistor).

Test Setup

The shaft was inserted into a coupler connected to a DC motor-turned-generator. The physical constraints are shown in Figure 1. The test setup is shown in Figure 2. The generator was mounted on a stand, and its output connected to a variable resistance "decade box." The output voltage was measured with a multimeter. A standard 20 inch box fan generated the wind, and the wind speed could be varied by adjusting both the fan speed setting (1, 2, or 3) and the distance of the turbine from the fan.

Testing was divided into two parts. Test Day 1 focused on finding the optimum load resistance. The wind speed was held constant while the load resistance was varied and the output voltage measured. This allowed the students to calculate and plot a curve of power versus load resistance and find the optimum load (that produced maximum output power). It also provided teams an initial test of their rotor design, which they could subsequently modifiy. Ideally, they would re-run the optimum load test on their new design, but the course schedule did not allow sufficient time for this.

Test Day 2 was focused on finding the efficiency of the rotor. Each team set the load resistance

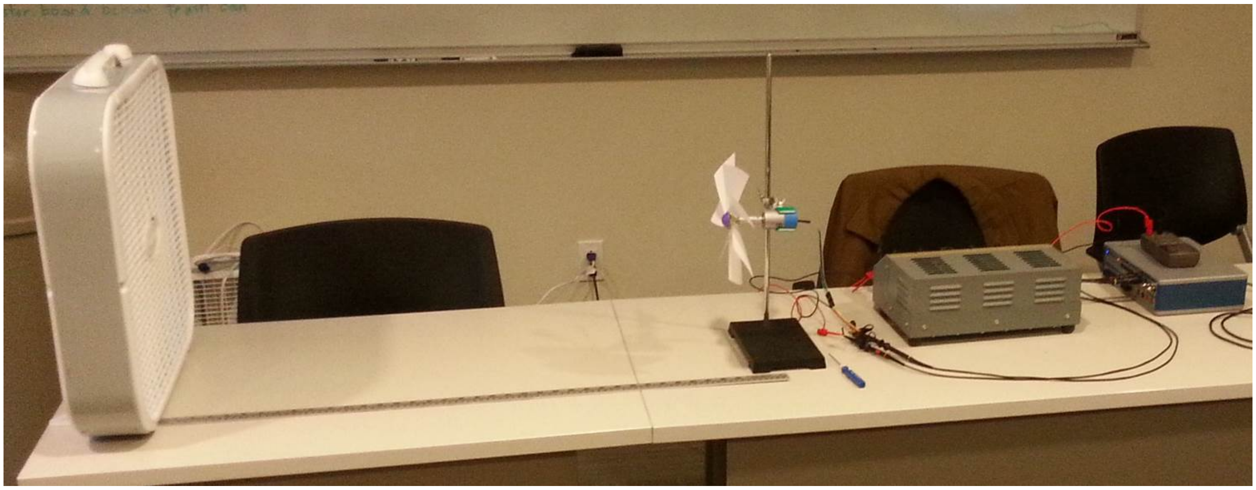

Figure 2: Test setup.

to their optimum value and then varied the wind speed. Faculty provided a table of average wind speed versus distance from the fan for each speed setting. Again, output voltage was measured to determine output power, and the students generated plots of power versus wind speed.

To find the efficiency, the students were to calculate the power in the wind using an equation for air flow through a circular cross-sectional area. This requires knowing the area, air density, and wind speed. The area could be determined for each rotor, air density was assumed to be a constant value, and wind speed was provided as discussed above. Faculty also provided a table of generator efficiency versus load resistance. Using all of this, each team could calculate the efficiency of their rotor.

Assessment

Two grades were assigned for this project, one for the turbine design and one for the report. The turbine design was largely a subjective grade based on the instructors' impression of the design but was also based on the results of testing (efficiency). The report was graded on a number of required elements, as well as the writing quality. The design process documentation was included as an appendix and was summarized in the report.

Results and Conclusions

According to both faculty and students, this project was overall a success, even though certain elements could use improvement. Faculty liked the fact that it allowed students to make use of some theory that had been discussed in class, work in teams, write a technical report, and be creative developing an open-ended design. Some student comments are provided next, followed by some positive aspects, and finally a discussion of implementation issues.

Student Comments
Of the small sample of students who responded to an informal survey, all of them enjoyed the project and would recommend doing it again. One student, who did not have the highest grade but is a very clear thinker, said, "I felt like the wind turbine project was beneficial. We got to take what we had been learning and apply it to a real life situation. It was also helpful to see how Excel can be used in data collection and analysis of a project. This project helped me to better understand the design process and how an engineer will go through the steps, sometimes multiple times." Another said, "It was a beneficial experience because we were able to get some hands-on experience and apply our knowledge. I learned how to work better in a team environment by putting everyone's ideas together into a final product."

Interestingly, one respondent commented "I did not enjoy the lack of constraints on the project. I enjoyed the freedom to design as we wanted, yet I also like specific instructions." While this might be deemed as a drawback, it can also be viewed as an excellent experience for students who feel this way. Because whether they pursue a career in academia or industry, they will almost certainly encouter situations where they are not provided specific instructions.

Positive Aspects
While this project required student teams to coordinate their schedules and to meet outside of formal lecture or laboratory time, students benefited from having a design and building meeting during one of the laboratory sections when their schedules naturally aligned and when the instructor and/or teaching assistant was available to answer questions.

During Test Day 1, some of the teams with functioning turbines took the opportunity to make modifications to their turbine designs, understanding how a larger output voltage at the optimal load resistance translated to greater power output, and they then worked to maximize that criterion. Other students struggled to modify designs so that their turbines would spin. Thus, at both ends of the spectrum, this exercise and the block of time alloted were valuable to all the groups, whatever their skill or success level.

Equipment Issues
To make the design, test, and measurement manageable for the students, substantial effort was made to provide the wind speed data and generator efficiencies for the equipment that was utilized. For example, wind speeds were measured at points around the cross-section of the fan to determine the best location for student testing. Measurements had to be averaged both over time and over area. The amount of variation greatly depended on the position, both around the cross-section and distance from the fan, as well as the fan setting. Speeds varied by as much as 30% over time and 50% over area. For the range of distances and fan settings used, average wind speeds ranged from 2.3 m/s to 4.3 m/s.

Even with that front-end investment, wind speed variability was a significant factor in the student experiments, as it caused the output voltage to fluctuate significantly. Thus, getting quality data proved to be difficult, particularly for teams with less efficient rotors. Students were instructed to take multiple measurements at each test condition and average them. An upgrade in equipment might reduce such wind speed variations and result in more uniform air flow. For example, there are heavier-duty 6800 CFM fans that have a 20 inch diameter, like the 2500 CFM box fan used. It may also be possible to add a shroud or "tunnel" around the fan to help direct the air flow.

Also, the selected generator was not ideal for this application. It was substantially over-sized. Its power rating (as a motor) is 4 W, while the largest output from the students' turbines was less than 10 mW. Measurements were made to determine the efficiency in this range, and it was found to be between 1-3%. A smaller generator would likely provide a higher efficiency in the range of output powers that these turbines were operating.

Reporting Issues

The design process documentation that students submitted varied from team to team. Some made a reasonable attempt at taking notes during their meetings and explaining their design decisions. Others submitted a list of references and nothing else. The next time this project is implemented, written and verbal instructions for documentation will be supported with examples of good and poor documentation.

The wind turbine project was the second multi-week group design project. From the content and quality of the written reports, faculty found that it would have been useful to provide them with more explicit and timely feedback on the report from the first design project and believe that would have positively impacted the wind turbine report. It would be beneficial to make written reporting a point of emphasis in the introductory course. This occurs in part through the content requirements listed in the assignment documentation, but could be supplemented through discussion in the laboratory or lecture sections.

While most final reports provided the basic elements that were requested in the assignment, the reports revealed that many students have little experience with organization of data and may lack the intuition for simple concepts, such as ordering results in either increasing or decreasing order of wind speed. Many failed to explain key elements of their design process, left out important data, did not properly format tables and figures, or did not write in a clear, concise manner. Adding a requirement for a draft or intermediate report would provide an additional feedback opportunity to the students.

One of the connections that faculty wanted the students to make was in calculating efficiencies. Students struggled to calculate efficiency values correctly and to relate them to the wind turbine system and the measurements they made. This is another potential point of emphasis when this project is repeated in the future.

Moving Forward

Here is a short summary of the previous discussion:

- Dedicated time, structured or unstructured, is helpful to students.
- Iteration is good, for both design and learning.
- Experimental variation does not have to be eliminated, but should be mitigated where possible.
- Better equipment often translates into better technical results. This improves student learning if the alternative is really poor. (e.g. If the data is so variable that there is no pattern, how is the student supposed to see a relationship?) It may also reduce faculty time (preparing or troubleshooting).
- Introductory students, in particular, need guidance on documentation and technical report writing. Providing feedback is key, so they can learn from mistakes. (This is iteration once again.)

Overall, this project accomplished its objectives. Students participated in the design process, and some were clearly aware of how their team progressed through the various stages. They were forced to apply concepts previously discussed in the class (if not in the design of the turbine, at least in the testing and calculations), and this helped to integrate several topics that would otherwise have stood distinctly separate (fluids, circuits, efficiency, and Excel).

As stated in the introduction, the goal of this paper is to encourage the reader to consider teaching methods that might engage students more deeply in his or her course. While lecturing is often the easiest teaching method, it is not always the most productive in terms of student learning and retention. Faculty should consider ways, such as projects like this one, to involve students more actively in the content. By doing so, their understanding increases significantly. The tradeoff is that it often requires more time of the faculty member and more time in the course schedule. In terms of course schedule, the question should be asked: Which is more beneficial, for students to learn a smaller percentage of a larger body of knowledge or a larger percentage of a smaller body of knowledge?

Projects are not relegated to freshmen and senior design courses. Nor do all projects have to be entirely open-ended. The authors have witnessed or implemented successful projects within “standard” technical courses, such as electronic devices, control systems, communications, and graduate-level engineering analysis. Other content areas where this particular project might be applicable are statistics (analysis of data), electrical circuits (Thévenin equivalence, maximum power transfer, DC motors), dynamic systems (rotational motion, torque), control systems (maximum power point tracking, velocity control), fluid mechanics (fluid flow, pressure gradients), and turbine blade design (airfoil shape, attack angle). Thinking about other related areas, one might consider thermal management systems using air flow for cooling (e.g. HVAC, “server farms,” and astronaut suits) or renewable energy systems, exploring energy generation from wind turbines and grid interfacing.

This project was born out of some seedling ideas that germinated after a number of discussions between faculty members and many hours of contemplation, and likewise, this paper is intended to be a seedling for the reader. Additional design project ideas can be found at:

- http://www.discovery-press.com/discovery-press/studyengr/projects.asp - This is a repository of projects maintained by Dr. Ray Landis (rlandis@calstatela.edu).
- http://www.realworldengineering.org/library_search.html - This list was compiled by IEEE and is focused on electrical and computer applications.