AC 2012-3726: TURBOFLOW: INTEGRATED ENGINEERING DESIGN THROUGH AN ENERGY EFFICIENT BUILDING COMPETITION

Dr. Tony Lee Kerzmann, Robert Morris University

Tony Kerzmann received both a bachelor's of arts in physics from Duquesne University and a bachelor's of science in mechanical engineering from the University of Pittsburgh in 2004. After graduating, Kerzmann enrolled in graduate school at the University of Pittsburgh, where he graduated with a master's of science and a doctorate of philosophy in mechanical engineering in 2007 and 2010, respectively. Kerzmann is currently an Assistant Professor at Robert Morris University, where he teaches mechanical engineering courses, as well as courses on alternative energy. His research interests include hybrid concentrating photovoltaic systems, energy system life cycle assessment, renewable energy product development, and active learning.

Mr. Eugene Joseph Werner Jr., GAI Consultants, Inc.

Eugene Joseph Werner, Jr., is a recent graduate of Robert Morris University, May 2011. He is currently working for GAI Consultants in the Mechanical/Electrical Department and is a member of ASME.

TurboFlow - Integrated Engineering Design through an Energy Efficient Building Competition

Abstract

Students learn best when there is interest in the topic and what better way to induce interest than to couple classroom theory with real-world application in the form of a competition. Senior engineering students at Robert Morris University established a design team to compete in the 2011 Energy Efficient Building Technologies Challenge which is sponsored by the Mascaro Center for Sustainable Innovation. The students were not only excited to be a part of a design competition that rewarded a cash prize, but there was a remarkable level of enthusiasm associated with the sustainability aspect of the design project.

The Energy Efficient Building Technologies Challenge was held over the fall and spring semesters of the 2010-2011 school year. During the fall semester the design team developed an idea for the competition and submitted a proposal. After being accepted into Stage 2 of the competition, the students designed, analyzed and fabricated the “TurboFlow” generation device for their Integrated Engineering and Design course. This prototype was demonstrated for the competition and the design team won first place, with a $5000 cash prize. Because of the competition, the design team went above and beyond the classroom expectations to design, analyze, fabricate and demonstrate a device with considerable market potential. The students not only analyzed the TurboFlow from an engineering standpoint, but from economic and sustainability standpoints as well. The famous saying, “Competition Breeds Excellence,” could not be more true for this group of students.

Introduction

Studies have pointed to the notion that engineers are active learners and therefore hands-on experiences are an important part of their education.[1] In order to increase hands-on activities and to promote engineering enthusiasm at Robert Morris University, a group of students entered into a regional Energy Efficient Buildings Challenge. This competition challenged the students to create an innovative product for existing buildings that reduces the demand for energy from non-renewable sources while exhibiting a payback time of less than two years. This challenge immediately sparked excitement and intrigue on the topic of sustainability.

At the onset of the competition the students were not very knowledgeable about the topic of sustainability. Their lack of familiarity with the subject matter led the students to research as much information on sustainability as possible during the brainstorming portion of the design process. The excitement toward sustainability was shown when the first brainstorming meeting was held and there were a substantial number of ideas encompassing all walks of sustainability. To further the active learning environment at RMU, it is very important to encourage engineering students to formulate their own ideas and designs about the subject matter using hands-on experiences.[2] The research and brainstorming sessions served as a platform for the students to introduce new ideas or concepts and to debate whether these ideas would fulfill the challenge requirements. The criteria set forth by the challenge provided a structured venue for the students to teach each other about engineering and sustainability concepts that they were individually researching. The advisor acted as a mediator for these discussions, with the purpose of assisting the students in the weeding out of good and bad ideas, but the students were the researchers, designers, presenters, and critics. These discussions inherently led students to participate in cognitive synthesis as well as evaluation; the two highest levels of Bloom Taxonomy.[3] The fact that the TurboFlow project was based on a competition with a cash prize gave the students more motivation than any classroom grade could offer. One of the students said, “The group showed a lot of initiative and from the very beginning we were willing to work hard on this project.” Intertwining the competition with the Integrated Engineering Design course challenged the students to develop an innovative design that would not only be graded by the professor, but be graded by a panel of judges at the annual Engineering Sustainability Conference. One of the students said, “We definitely used the competition to excel in the project where we otherwise may not have been as motivated to present such an outstanding project.”

Student Design and Methodology

The students’ project for the 2011 Energy Efficient Building Technologies Challenge was to design an in-pipe turbine to recover wasted energy that is normally lost through a building’s pressure regulator and turn it into electricity. The result was the TurboFlow design concept and prototype. For the challenge, the group opted to develop a hydro-turbine that rotates within a pipe when flowing water passes by the turbine. As illustrated in Figure 1. The turbine spins the rotor of a permanent-magnet induction motor, creating electricity that could be either stored or sent back into the energy grid. This design can harness energy as a function of the pressure drop across the turbine blade and would be used in place of a conventional pressure regulator. It was with great pride and pleasure that the student group accepted a first place finish and a $5000 prize in the competition.

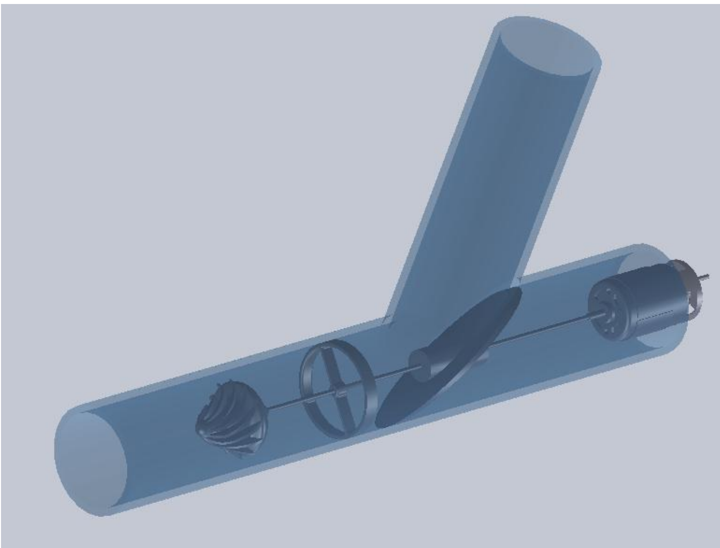

Figure 1: 3D View of the TurboFlow Assembly Drawn by the Student Design Team using SolidWorks

The rational for designing the water turbine was based on the idea that commercial and industrial buildings such as offices, factories, and hotels use a large amount of water. In order to determine a realistic building water supply flow rate, hotel water usage information was gathered from a study completed by the American Water Works Association, "Commercial and Industrial End Uses of Water Report."[4] The average yearly hotel water usage in California was 18.8 million gallons, which translates to a constant flow rate of approximately 35.8 gallons per minute (under the assumption that the flow rate remains constant throughout the year). This water usage information, in combination with Bernoulli's Principle for Inviscid Flows, indicated that the concept would indeed lead to significant energy generation.[5]

After many design iterations, design team evaluations, and prototype developments, the final design was finalized. The final design, which can be viewed in Figure 2, is made up of several parts; all of these are listed in the Bill of Materials in **Error! Reference source not found.**Table 1. Table 1 also contains parts that were used to fabricate an experimental flow loop that the students had to design and build to perform tests on their prototype. Of the thirteen items on the Bill of Materials, the student had to create 3D renderings for nine parts using SolidWorks. Some of these parts, especially the four different turbine designs, were very challenging to render. The students had previous experience with SolidWorks in some of their courses, but the drawings necessary for the TurboFlow project far exceeded any in-class assignments. The students, once again, taught themselves and one another. They did it with enthusiasm, interest and comradery, all qualities that were brought out by the challenge and the common goal of winning the competition.

Figure 2: 3D TurboFlow Design Rendering

	Bill of Materials	
Item	**Description**	**No. of items**
1	Pump	1
2	Turbine	1
3	PVC Pipe	2
4	PVC 90° Elbow joint	2
5	Support Bracket	1
6	45° Bracket	1
7	Water tight seal	2
8	Shaft	1
9	Transparent Acrylic Pipe	2
10	Rubber pipe fittings	2
11	Adjustable clamps	4
12	DC Moter	1
13	Set Screws	7

Table 1: TurboFlow Final Design Bill of Materials

The first major component that was designed by the students was the piping. This was fabricated in the Robert Morris University Machine Shop by cutting two clear acrylic tubes and epoxying them with acrylic adhesive into a Y-shaped juncture. The next part of the design was the turbine blade. Four turbine designs were fabricated in RMU's a rapid prototyping laboratory, and were created similar to the turbine blades that were researched for the concept.[6]. All of the students on the design team had little or no experience in rapid prototyping or with RMU's fused deposition 3D modeler. The students had to learn how to use the 3D printer, determine its limitations, and diagnose any issues with their prototyped parts. The shaft was made of Stainless steel and was purchased from a major distributor, while the shaft support was designed in SolidWorks with the major design criteria of preventing vibration in the turbine and shaft, thereby maintaining efficiency. The seal bracket was the next part in the assembly design. It acts as a protective barrier between the pressurized water inside the piping, and the motor which is held exterior to the piping system. This was designed using two parts that had to fit together very tightly for the design to not leak: a dividing wall and a shaft seal that also acts as a bushing. One of the challenges was in combining the dividing wall, which was a rapid prototype part, and the shaft seal, which was an off the shelf product. The wall was designed and manufactured in the rapid prototyping laboratory by the design team members and the seal was purchased from a major distributor. The final piece of the design was the electric motor that would be used to generate electricity. Several motors were purchased and tested in the TurboFlow experimental flow loop to test for maximum power output. One of the students summed up this project best when he said, “This challenge taught us how to manage our time effectively and drove us to become better engineers by pushing us to use everything we had at our disposal, which included the machine shop, CAD programs, and the rapid prototyping machines.” The students responded very well to the challenges of the competition and even went above and beyond the criteria by fabricating a flow loop used to test the TurboFlow.

The students designed and built a flow loop, shown in Figure 3, to test combinations of induction motors and turbine blade designs in order to maximize power output. Two inch schedule eighty pipe was used to maintain a high flowrate, similar to that of a building. A two inch ball valve was located before the test section to control the flow rate. Two pressure taps located on the TurboFlow test section; one located before the turbine and one located after, allowed for accurate pressure difference monitoring. A PASCO pressure sensor was used as well as a PASCO voltage and current sensor. A Dayton 2JGA5 Pump was used to propel the water at a maximum flow rate of 105 GPM in the 2” pipe at 5 feet of head.

Figure 3: TurboFlow Experimental Flow Loop

To reinforce the data collected empirically, simulations were run using the FEA capabilities in SolidWorks. A CAD assembly of the TurboFlow design was modeled in SolidWorks and flow testing was conducted. The flow simulation suite within the software allowed the students to input boundary conditions such as inlet and outlet pressures, velocities, and flow rates. Using values that approximated the experimental setup, the design group was able to attain results that were similar to the experimental test results of the prototype in the flow loop. An example of the resulting computer aided flow simulation results can be seen in Figure 3, where flow trajectory (top), velocity (middle) and pressure gradient (bottom) profiles can seen throughout the prototype section. These results plots visually illustrate where the highest and lowest flow velocities are located as well as the highest and lowest dynamic pressures are located. The results plots also show the pressure drop through the TurboFlow system, which is important based on the proposal and initial intentions of replacing a pressure regulator in a building with the TurboFlow design. The pressure gradient profile shows that the pressure is higher entering the system and decreases to a lower pressure after the turbine blade. This analysis allowed for quick and effective design changes without actually fabricating every concept alteration, saving the group from building and rebuilding multiple prototypes. Therefore the flow simulations helped reduce prototyping cost and fabrication time. The flow simulations that the students created were once again above and beyond what was necessary for both the competition and for the Integrated Engineering Design class. This provides another example of how the students chose to exceed what was asked of them for the sake of winning the competition. The students gained valuable Finite Element Analysis experience and some of the students discussed the skills that they learned in this project while interviewing for job positions.

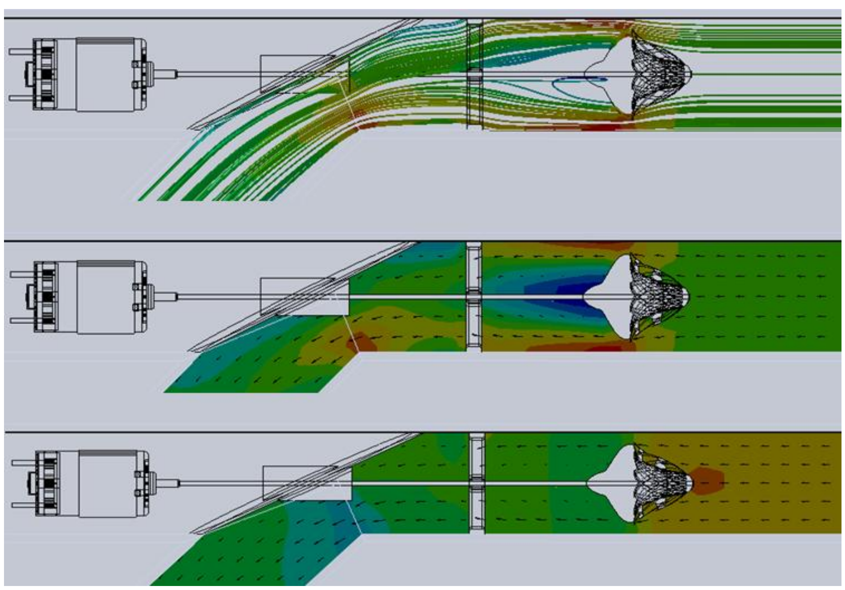

Figure 3: SolidWorks Flow Simulation Results - Flow Trajectory (top), Velocity Profile (middle), and Pressure Gradient (bottom)

Educational Elements

Throughout the design, fabrication, and testing processes the students were constantly challenged to solve engineering problems and they solved these issues with great passion knowing that their efforts could win them a first place prize. The design and fabrication of the TurboFlow required understanding of sustainability and renewable energy concepts as well as knowledge from many engineering courses. Students learned that consideration for the life cycle of a product must be taken into account during the design process. Throughout the design, students had to make use of thermodynamic and fluid dynamic concepts in the flow and energy calculations. They had to use their knowledge of machine design, dynamics, finite element analysis, and materials in the design of the TurboFlow prototype. Additionally, the design of the experimental flow loop made use of their electric circuits understanding in converting from AC current to DC current for electricity power output measurement. Finally the students had to evaluate the economics of the system in order to determine whether the system would have payback period of less than two years.

There were important learning aids that the team was involved with during the life of the project, which included design, simulation, hands-on prototyping and testing, the conference presentation and cost analysis. The design process included multiple brainstorm sessions and conceptual designs from all of the group members. Through discussion of the pros and cons of each design and considerations as to what the students were capable of fabricating, the proposed designs narrowed down until only one remained. The students used their final design to fabricate the TurboFlow as well as multiple turbine designs to test for efficiency. Simulations of the final design were carried out using SolidWorks to determine how well the designs should work theoretically. The fabrication of the TurboFlow and the flow loop was quite a learning curve for most of the students, as they didn't have any real manufacturing experience.

The hands-on approach gave the team the experience in problem solving and the project reached the students' cognitive synthesis and evaluation learning levels. Because the fabrication of individual components was divided up amongst the group members, there was a lot of collaboration necessary between the students. Weekly meetings were conducted by the students to maintain communication and the integration of multiple subcomponents that were fabricated by different students was an almost seamless process. The students communicated very well together as well as when they presented their design and prototype. The presentation at the conference allowed the students to gain exposure to presenting engineering information in front of their peers. This exposure also allowed the students to interact with professionals who were interested in sustainability and very knowledgeable about both engineering and sustainability. The cost analysis showed the students that product design is not only about engineering concepts, but they also have to consider environmental impacts, cost feasibility, installation, and maintenance to determine an effective design.

The competition and the Integrated Engineering Design course worked hand in hand in that the design course's goal was for students to have an opportunity to experience a real world working situation and the competition defined a set of criteria for the students. The course objectives expected the students to follow a real world project from conception to prototype and present the product or idea to a panel of experts. The Integrated Engineering Design course was designed to help the students see the many aspects of engineering that go beyond the concepts taught in the classroom. The competition added some extra elements to the course that otherwise would not have been of such importance to the students. The competition pushed the students to consider sustainable design, be innovative, professional and use the knowledge that they had gained throughout their years as an engineering student. Gaining a better understanding of engineering was important to the students as one of the students said, "I can finally put the knowledge that I've learned to use by applying it to the project and I can see how a group of people would work together in the real world." The competition allowed the students to be actively engaged in their learning which is a lot different than if they had solely worked on a class project. It was that extra incentive to win that brought out the best in the students. Most of the students worked extra hard to build a successful and impressive project to present at the 2011 Engineering Sustainability conference. The team did not want to have their names associated with a subpar design and prototype. The students had an additional incentive because they wanted to show that a smaller and less acclaimed engineering school could not only compete with the larger and more prestigious schools, but they a could also win.

Conclusion

A group of students from Robert Morris University's Engineering Department competed in the 2011 Energy Efficient Building Technologies Challenge where the students won first place and a $5000 prize. The students gained valuable hand-on project experience and far exceeded the criteria laid out by the competition due to the inherent will to win. The TurboFlow prototype was designed, 3D modeled, FEA simulated and experimentally tested while the students used an array of engineering concepts. Engineering concepts in thermodynamics, fluid dynamics, machine design, dynamics, finite element analysis, materials, electric circuits, and life cycle analysis were necessary throughout the project. The design and analysis of the TurboFlow prototype reached the students in the upper levels of Bloom's Taxonomy, namely the synthesis and evaluation levels, where students are thought to have a more full understanding of the subject matter. The use of the competition as a motivating tool gave the students the drive to perform above and beyond the necessary criteria and assisted students in fully understanding many engineering concepts on multiple educational levels.

Overall the students used the competition to gain a better insight into the world of engineering and will be more prepared for what the engineering world has in store for them. Since the competition the students have all expressed interest in sustainability and some are even becoming more involved in sustainable programs. A couple of the students even pursued the possibility of patenting the idea, going as far as contacting local investors to fund a market-ready prototype. As stated by one of the students, "This competition definitely elevated the level of education that we received from the course and showed how effective students can work on something when we're passionate about what we're working on." In this case the engineering students at RMU proved that competition really does breed excellence.

References

1) Dunn, R., & Carbo, M. (1981). Modalities: An Open Letter to Walter Barbem Michael Milone and Raymond Swassing. *Educational Leadership* , 381-382.

2) Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development.* Englewood Cliffs, New Jersey, U.S.A.: Prentice Hall.

3) Bloom, B. S., & Krathwohl, D. R. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York, NY, U.S.A.: David McKay Co. Inc.

4) Dziegielewski, B., Kiefer, J. C., Opitz, E. M., Lantz, G. L., Porter, G. A., (2000). *Commercial and Industrial End Uses of Water*. Washington, DC: American Water Works Association.

5) Oertel, H., Prandtl, L. (2004). *Prandtl's Essentials of Fluid Mechanics*. Boehle, M., Mayes, K., (Eds.). New York, NY: Springer.

6) Calvert, J. B. (2003). *Turbines.* In Tech Index, University of Denver. Retrieved from http://mysite.du.edu/~jcalvert/tech/fluids/turbine.htm#Refs