Cross-Discipline Projects Prepare Students for Industry

Tim Ronco, Gerald Brown, Tim Dewhurst

[*] Department Engineering and Computer Science, Cedarville University, Cedarville, OH 45314, USA

Email: TimRonco@gmail.com, gbrown@cedarville.edu, Dewhurst@cedarville.edu

Abstract

Engineering Projects have played an instrumental role in both my education and in preparing me for industry. As an undergraduate mechanical engineering student at Cedarville University, I took on the responsibility of developing a Maximum Point Power Tracker (MPPT) for our solar boat team. This cross-discipline engineering project enabled me to learn how to solve electrical and computer engineering problems in which I had little background. Additionally, I learned to deal with ambiguity, solve problems, work on a team at a systems level, work with schedule and budget constraints, communicate with project management, and develop alternate solutions. My experience with the solar boat project taught me how to approach an engineering problem more effectively than the classroom. This paper discusses details of my specific design project but focuses on how I approached a project that was outside of my formal discipline.

Keywords: cross-discipline; multi-discipline; problem solving; problem approach.

1 Introduction

The typical engineering graduate will enter industry with a relatively minimal amount of experience that is confined to one discipline. This creates a large disparity for the young engineer as he is guaranteed to encounter projects in which he has little to no background. Moreover, the growing role of systems engineering in modern industry requires the engineer to be able to work with a sundry of disciplines. Therefore, to be a valuable employee, one must understand how to approach a project for which he may not have specific training. Cross-discipline projects are an essential part of the engineering education experience as they equip students with practical skills not covered in the classroom and develop the student's ability to be successful in an unfamiliar field of work.

As an undergraduate mechanical engineering student at Cedarville University, I took on the responsibility of developing a Maximum Point Power Tracker (MPPT) for our solar boat team. While my curriculum involved courses in circuits and instrumentation, digital logic design, electrical machines, and control systems, I had no courses in printed circuit board design, power electronics, microcontrollers, or photovoltaic arrays, all of which are fundamental to the design of an MPPT. However, by undertaking this "cross-discipline" project, I learned invaluable lessons that would better prepare me for industry.

Designing and building the MPPT helped me develop the ability to approach a project outside the scope of a traditional mechanical engineering program. Additionally, I learned to deal with ambiguity, solve problems, work on a team at a systems level, work with schedule and budget constraints, communicate with project management, and develop alternate solutions. More effectively than the classroom, the experience with the solar boat project taught me how to approach an engineering problem for which I had little supporting coursework. This paper discusses details of my specific design project but focuses on how I approached a project that was outside of my formal discipline.

This paper seeks to demonstrate the importance of cross-discipline projects in engineering education through the personal experience of the primary author, Tim Ronco. The paper has been written in the first person in order to effectively communicate this experience. Gerald Brown and Tim Dewhurst were advisors to the solar boat project and have been listed as co-authors.

2 Literature

Multiple papers have been written on the importance of cross-discipline projects. Campos, Lima, and Fernandes discuss the increasing need for students to be able to work on multidisciplinary and multicultural teams. They present a study performed on a purposefully cross-discipline and cross-cultural engineering design team composed of students (2012). Though not a cross-cultural project, the MPPT project is cross-discipline and not in the ordinary sense. Here, I am doing the cross-discipline work rather than learning how to work with students in a different

discipline. I am learning to work on a project outside scope of my expertise. This brings a new meaning to the term cross-discipline.

Safyannikov, Vehter, and Vyuzhanina relate the transition in the Russian education system from competency-oriented to a qualification oriented system as a result of the Bologna Process. The focus is being shifted from equipping students with theoretical knowledge to developing a set of universal competencies that make students more competitive and equipped for industry. As a result, engineering projects are taking a much larger role in the engineering curriculum (2010). This paper concurs with Safyannikov et al. regarding the need for developing skills beyond the theoretical knowledge that typically drive engineering education. Skills like project management, critical thinking, and teamwork, though not technical skills, are fundamental skills for success in industry. However, this paper also emphasizes the role of cross-discipline projects in developing the student's ability to succeed in a technical skill for which he has not had formal training.

Gaska and Gauss propose expanding discipline-specific engineering process patterns that are used to develop requirements to apply for cross-discipline projects (1998). Their paper discusses a different topic than this paper, yet the two have a significant commonality. The engineering process patterns that Gaska and Gauss propose require experience with cross-discipline projects. Without such understanding, they would not be able to adequately propose a solution to the need for a cross-discipline process pattern. This paper proposes that working on a project in a cross-discipline capacity can equip a student to deal with industry problems in ways that a project in a familiar discipline cannot.

3 Project Background

3.1 DONG Energy Solar Challenge

The DONG Energy Solar Challenge (DSC) is the self-described world cup of solar boating. This solar-powered boat race spans 200 km of canals in Friesland, Netherlands. Over 40 teams from 10 different countries competed in the 2012 race through all weather conditions over six days. The competition was split into two categories—Top Class and Challenge Class. All teams in the Challenge Class were given the same standard solar panels. Top Class had broader design requirements and were responsible for providing their own solar panels.

Eleven mechanical engineering students from Cedarville University decided to develop an entry for the Top Class of the 2012 DSC. Our project goals included the design and manufacture of a carbon fiber boat, lightweight solar panels, custom Maximum Power Point Tracking devices (MPPT), a brushless DC motor, a propeller, and hydrofoils.

After a year of preparation and countless hours of work, we travelled from the U.S. to the Netherlands to compete in the DSC. Our team took third place overall and ranked first among collegiate teams.

3.2 Maximum Power Point Tracking Device (MPPT)

Figure 1 gives a visualization of the power flow through our solar boat system. Solar power is harvested by solar panels that span the boat's deck. The solar power is regulated and converted by the MPPT's in order to either drive the motor controller or charge the Li-Ion batteries. The motor controller converts DC power to a 3-phase signal that drives a custom built brushless DC motor. Dewhurst and Brown (2013) give a more detailed description of this power budget. The boat was constructed out of carbon fiber with an aramid fiber honey comb core. Figure 2 gives pictures of our team and the boat.

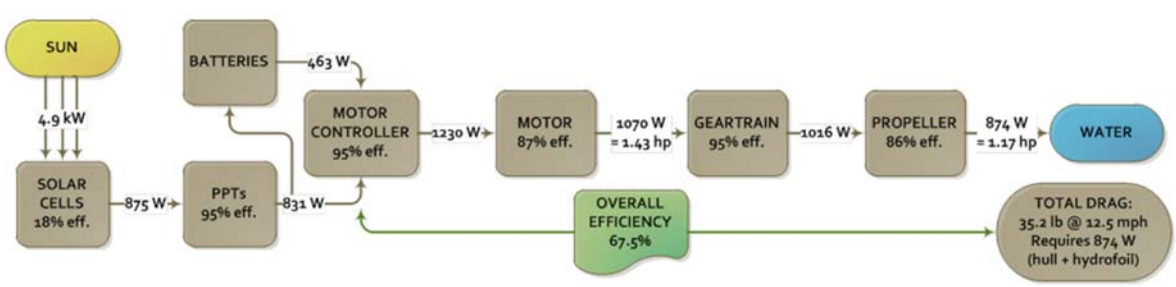

Figure 1: Power Flow through Solar Boat System

Figure 2: Cedarville University Solar Boat Team

A Maximum Power Point Tracking device continuously monitors and optimizes the power delivered from a solar panel to a load (batteries and motor controller for our application). For any given sun condition, the relationship between current drawn from the solar panel and the panel's operating voltage is nonlinear. Figure 3 demonstrates that a solar panel will be able to produce the most power at a point on the current-voltage curve called the maximum power point. In order to efficiently harvest solar power, it is imperative that we draw the appropriate current that will result in operation at the panel's maximum power voltage (although voltage is typically labeled as the independent variable on these curves, it is more accurate to think of current as the independent variable that determines the operating voltage). An MPPT uses a microcontroller to collect data regarding the voltage and current of the solar cells, determine the maximum power point, and limit the current drawn in order to extract maximum solar power.

Because the load typically operates at a lower voltage than the solar panels, MPPT's generally contain a DC-DC step-down converter. If the panels were connected directly to the load, the panels would operate at load voltage which is rarely the maximum power voltage, and the panels would never deliver their maximum available power.

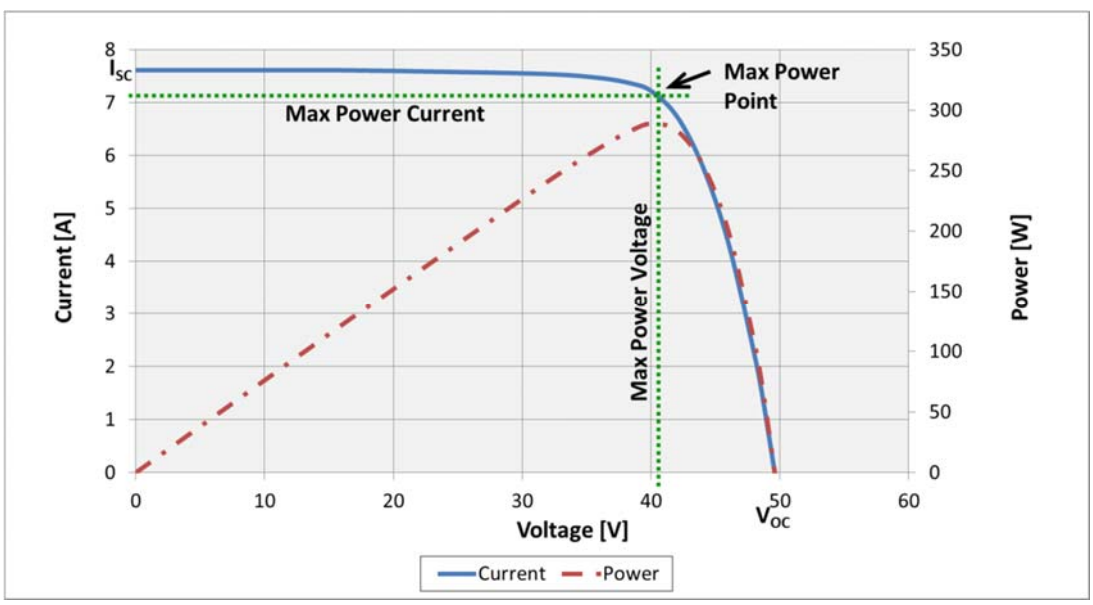

Figure 3: Current-Voltage and Power-Voltage relationships for a typical Solar Boat Team solar panel. An MPPT uses a controller to determine and operate a solar panel at its maximum power point

I was tasked with determining an MPPT solution that fit several requirements beyond regulating the panel voltages to provide maximum power. My plan was to have between three and six MPPT's regulating power from the solar array. For regular operation the MPPTs were required to supply power at ≈24.5 V to the 24 V motor controller bus. For

scenarios where available solar power exceeded the required motor power, some MPPT's would be required to switch to charging the Li-Ion battery system at 21 V (the Li-Ion battery charge controllers were not rated above 24 V).

At the beginning of the project I performed a survey of commercially available MPPT units. The goal was to find a commercial MPPT that could meet the solar boat system requirements. Most of the commercial MPPT's I found were designed to charge lead-acid batteries. A few had the capability to charge a battery and run a load but were not designed to work with the more complex Li-Ion battery technology. Our MPPT application was very dissimilar to the market that MPPT companies were targeting, and I could not find a commercial unit that could arbitrarily switch its output voltage level in response to a control signal.

In 2010 the Cedarville solar boat team had developed a prototype MPPT circuit based on a design they had received from a firm specializing in custom engineering (see Figure 4). Unfortunately the 2010 team was unable to produce a functional unit. Therefore, the faculty advisors and I decided to continue the development of the custom MPPT design from the 2010 team. This decision was made based on the lack of commercially available MPPT's and the great educational opportunity presented by doing such a cross-discipline project. Thus the scope of my project became to understand the design, diagnose problems, and design additionally functionality into an existing custom MPPT design.

Figure 4: MPPT Prototype developed by the 2010 Cedarville Solar Boat Team

4 Methodology

The challenges inherent to this cross-discipline project enabled me to develop my ability to approach other complex engineering problems for which I had minimal background experience. My engineering curriculum has stretched my understanding and critical thinking skills. This cross-discipline project supplemented the classroom by developing additional skills that will be vitally important in industry. My work on the MPPT and the solar boat system helped me to learn how to climb a steep learning curve, deal with ambiguity, solve problems, work on a team at a systems level, work with schedule and budget constraints, communicate with project management, and develop alternate solutions.

4.1 Project Approach

Oftentimes in industry an engineer will be given a project where the requirements are not fully defined or the methodology for solving the problem has not been developed. In these situations it is imperative that the engineer be able to effectively deal with ambiguity. He must be able to employ critical thinking and take initiative to blaze a path forward. Typical work required for engineering classes cannot instil this ability because of its very nature; homework problems are clearly defined, have at least one proven solution, and result in one correct answer. Real life is not so neat. The MPPT project is a perfect example of this kind of problem. With no background in power electronics, microcontrollers, or programming, I had to take initiative and develop a plan of attack. My approach can be broken up into three phases: 1) Understanding the problem, 2) understanding possible solutions, and 3) executing the chosen solution.

The obvious first step was to understand the engineering problem that I had been assigned to solve. By researching, reading through past teams' reports, and meeting with my electrical engineering project advisor, I developed a

working knowledge of the problem to the degree that I could explain it to my teammates who also had little background in the field. It would not have been possible to achieve this level of understanding in a field outside my normal coursework in such a short time apart from the mentoring relationship of the project's electrical engineering advisor. This is described by Dewhurst and Brown (2013).

My second step was to determine the options available for solving the problem. Our need was pretty specific and I was confident that the solution would look like a DC-DC power conversion system that tracked and regulated the solar panels efficiently. My next decision was to determine if I would attempt to purchase a solution and integrate it with our system or develop the solution myself. As previously mentioned, I performed a search and concluded that a product that met our requirements was not currently available. In my background research, I had documentation from a student team and a hobbyist who had both successfully developed MPPT's. This gave me confidence that I could develop a solution. In 2010 the Cedarville solar boat team had acquired an MPPT design from a firm specializing in custom engineering. The company's application had significantly different power requirements, and therefore the task had been to redesign their MPPT to meet our requirements. A student from that team had redesigned the MPPT and built a prototype, but was unable to achieve a working unit. Given these facts, my faculty advisors and I decided that I would work to complete the previous team's MPPT design. This process was a great exercise in using critical thinking to make a crucial decision based on the information that was available at that time. These kinds of decisions come up constantly in industry as a result of time and resource constraints. Engineers have to make difficult decisions using engineering judgment to evaluate limited data.

With a solution method chosen, the bulk of the work lay ahead of me. I needed to learn the skills necessary to understand, analyse, troubleshoot, and redesign the 2010 MPPT design. I took the complete MPPT design and broke it into two primary modules that I could work on in parallel: the power circuit and the microcontroller. This approach turned out to be very beneficial for several reasons. I had a very large learning curve to climb on each front and this method allowed me to climb each one step at a time. Additionally when I got stuck on one task I could start working on the other until I was able to get help.

I worked with the project's electrical engineering advisor to break the circuit module into smaller sections. My circuit analysis skills had not been used in two years and this approach allowed me to tackle one small portion at a time. I worked with my advisor to derive the circuit equation for each section and then we tested the control relationship using a power supply. As I learned the circuit, I also verified each section of the prototype printed circuit boards (PCB's). Eventually I reached a point where I understood all auxiliary control circuits and could begin testing the entire DC-DC power conversion circuit.

I undertook learning the microcontroller module in a similar manner. I divided the task into learning C++ programming and understanding how microcontrollers work. I borrowed textbooks from electrical engineering students and began working through programming exercises. Additionally, I began attending the sophomore level microcontrollers lab sessions to get practical experience programming and performing tasks with microcontrollers.

4.2 Systems Engineering

Systems integration proved to be a major challenge for this project. Four mechanical engineering students were in charge of integrating the four electronics subsystems: MPPT's, Li-Ion batteries and charge controllers, the data acquisition system, and the energy management system. A major design consideration for the MPPT's was accommodating the two output modes. As previously mentioned, in regular operation the MPPT's needed to supply power at ≈24.5 V to the 24 V motor controller bus. For scenarios where available solar power exceeded the required motor power, some MPPT's would switch to charge the Li-Ion battery system at 21V. A problem arose because the Li-Ion battery charge controllers were not rated above 24 V. Therefore we had to determine a method for supplying power to the 24 V output bus while shutting off the 21 V bus and vice versa. The problem puzzled us for a while but eventually we came up with a simple circuit that took care of the problem.

Additionally, there were a large number of sense and communication lines between the four subsystems. The MPPT and battery systems had to be designed to measure the parameters of interest. The energy management system (EMS) needed to communicate with all three systems to acquire information for the energy optimization algorithm. Then the EMS needed to communicate and direct the MPPT's to output power at either 24.5 V or 21 V.

Systems integration has become an increasingly important field throughout the 20th century. A high profile example from recent history is the Boeing 787 Dreamliner – the most technologically advanced commercial aircraft ever built. Instead of building the airplane themselves from scratch, Boeing took the role of systems integrator and contracted out the design and manufacture of many subsystems historically developed internally. The subsystems were then brought to Everett, WA, USA to be assembled.

The 787 has attracted worldwide attention in the news due to issues with their new Lithium-Ion battery technology (Cooper, 2013). On January 16th, the FAA grounded the 787 fleet until the problem was solved (Press Release, 2013). The cost incurred by this issue is substantial and continues to grow. Steve Eppinger argues that Boeing's issue does not lie in the Lithium-Ion battery technology. Rather, he believes that "Boeing's battery failure derives from the fact that this new technology is embedded in a highly complex system," (2013). The issue lies in the highly intricate energy management system and the complexities of how it interacts with the other aircraft systems.

Although simpler and far less costly, the issues encountered with our electronics system are analogous to Boeing's. The batteries worked as designed during standalone testing. But when we installed the system, we experienced problems with the charge controllers and communication between our subsystems. It took significant time and dialog with the manufacturer to troubleshoot these system issues.

4.3 Project Management

One often hears engineers in industry comment how little of their time is spent doing actual engineering. Much of the work required of engineers involves reporting to management, interacting with customers, writing requirements, creating budgets, and tracking schedules. The typical engineering curriculum does not cover these topics in much depth, as they are not very applicable outside of the project environment. At the beginning of the solar boat project, however, our team created project schedules and budgets that served as our roadmap for the project. We also had milestones and design reviews along the way to check progress and weekly team meetings to discuss progress and technical issues within the team. These activities were a vital part of the cross-disciplinary scope of the project, going far beyond normal classroom learning activities.

4.4 Resource Constraints

Resource constraints are one of the most important factors that govern a company's decisions. Most engineering companies develop products as a result of contracts they have won. An agreement is made that the supplier will deliver certain milestones to the customer throughout the life of the project culminating in the delivery of the final product. Companies agree to these contracts and execute projects based on time, money, and people resource constraints. Throughout the life of a project, resources are evaluated and allocated in order to enable the company to make progress and meet deliverables.

I learned the weight of resource constraints first-hand through the solar boat project experience. Our team had a limited amount of time and money to complete the project. As the competition came closer, we realized more and more the reality and impact of our deliverable. We came to a point in the project where we had to decide whether or not we had made enough progress toward our deliverable to justify going to competition. We had invested an incredible amount of time, effort, and personal energy in the project and yet it was not clear if we should even proceed and go to the competition. The risk of technical failures in our largely untested systems was so great that the probability of successfully even finishing the race was shrinking as the deadline to ship the hull and later to purchase plane tickets was fast approaching. The gravity of this situation cannot be realized in the classroom. This lesson had to be learned in the field through personal experience. The solar boat project provided the opportunity to learn this lesson before ever entering industry.

4.5 Alternative Solutions

Development projects are exciting because engineers get the opportunity to create and explore new ideas. A difficult aspect of these projects is that oftentimes they can take drastic turns. Engineers are given a task to develop some technology for a given application. However, depending on factors that are outside of the engineer's control, company leadership may decide to take a different approach to solving the problem or may decide to stop the project altogether. This can be difficult because the engineer has invested significant time and effort into his work.

In the case of the MPPT, I had worked on the design for eight months and spent countless hours troubleshooting the device with the project's drive systems electrical engineering advisor, but could not get the power conversion circuit to work. Two weeks before competition I was simply out of time and had to come up with an alternate solution even if it came at the expense of some of the required functionality we needed.

Based on my initial research, I knew I could find a commercial MPPT that would regulate the solar panels and deliver power to the motor controllers, but as I mentioned earlier in this paper, it looked like I would have to sacrifice the ability to switch each MPPT between the 24.5 V and 21 V output modes. We would be unable to charge batteries during the race or would have to have additional MPPT's dedicated to this function.

As I reviewed the specifications for a commercial unit that would meet the simplified requirements, I realized that I had overlooked a key feature of one particular MPPT unit. It had a function that would make minor adjustments to output voltage based on resistance-based battery temperature measurements. I might introduce an outside signal on that input and drive up the measured "temperature" and so manipulate the unit to lower the output voltage. A technical representative from the company confirmed that though the feature was not designed for this function, it would perform as I had hoped. In fact, I was able to dynamically adjust the MPPT output voltage over a range of more than 8 V using a simple PWM/analog output signal from the microcontroller. By integrating this commercial unit with some of the circuitry I had designed, I was able to develop an MPPT solution that met all of the original requirements we had created. In the course of a week I had performed the legwork to produce an alternate solution to an approach I had been working on for eight months. This was only possible because I had learned to think beyond my classroom training and work across disciplines, coping with constraints similar to those found in real-life engineering projects.

4.6 Endurance through Setbacks

Engineers typically go through a design process to develop a product. The design is then confirmed through analysis. But only once the design has been validated through physical testing can the design be considered successful. Oftentimes engineers will come up with a design that looks great on paper but demonstrates major flaws in testing. These kinds of setbacks can be extremely discouraging and require perseverance to push through.

After I had become very familiar with the MPPT design and had spent significant time testing the prototype boards, my electrical engineer advisor and I determined that I needed to populate and test a new MPPT circuit board. This being my first PCB, it took a lot of time and energy to populate all the components. When I finally completed the first MPPT board and began to test it I experienced a setback. I was using two lead-acid batteries as input power to simulate power that would normally come from the solar panels. Two large capacitors on the input drew a large amount of current from the lead-acid batteries causing a small fire that destroyed the fundamental components in the circuit (this scenario had not been anticipated as solar panels would not be capable of delivering such a large current). I had no choice but to remove many of the components and repopulate the MPPT board.

An enormous amount of work remained to be done after the school year had ended, and many on the team worked full time on the project for over a month. I spent countless hours discussing the MPPT circuit with several electrical engineering professors. They gave me many good ideas to try, but none of them worked. Though I never got the MPPT circuit to work, I was able to achieve a working solution because of perseverance through setbacks.

5 Conclusion

The challenges inherent to an engineering project of a cross-discipline nature have enabled me to develop many skills that are imperative to success in industry. The solar boat project bridged the gap between academia and industry because it created opportunities to encounter issues I had not experienced via the classroom. The cross-discipline aspect of the project forced me to develop the ability to approach a complex problem in which I had minimal background. The solar boat project gave me confidence that I could enter industry and contribute significant value to any engineering project.

Upon completion of my undergraduate studies, I began working in United Technologies Aerospace Systems' Leadership Development Program. Engineers in the program spend a duration of two years working at three different business units. Each of the three rotations presents entirely new experiences in terms of engineering roles, products, and geographic location. With only eight months per rotation, it is imperative that I be able to jump into a project and come up to speed quickly. At the end of my first rotation I had become proficient in performing several different types of thermodynamic analysis and was commended for how swiftly I had picked up my group's analysis work. I am starting my second rotation and I am confident that I will be able to do the same. I attribute much of the success I have experienced thus far during my time in industry to the skills and lessons that I learned through the cross-discipline MPPT project.

References

Campos, D., Lima, R. M., & Fernandes, J. M. (2012). Identification and assessment of behavioural competences in multidisciplinary teams within design projects. In *Proceedings of the Fourth International Symposium on Project Approaches in Engineering Education* (pp. 16-22). Retrieved from http://paee.dps.uminho.pt/

Cooper, A. (2013, January 8). Fire aboard empty 787 Dreamliner prompts investigation. *CNN.* Retrieved from http://edition.cnn.com/2013/01/07/travel/dreamliner-fire/index.html

Dewhurst, T., & Brown, G. (accepted for publication). Mentoring Students in a Capstone Design Experience. In N. van Hattum-Janssen, R.M. Lima and D. Carvalho (Eds.), *Proceedings of the Fifth International Symposium on Project Approaches in Engineering Education PAEE 2013*, Eindhoven, the Netherlands.

Dewhurst, T., & Brown, G. (accepted for publication). The Preliminary Design Phase – The Key to Achieving Project Objectives. In N. van Hattum-Janssen, R.M. Lima and D. Carvalho (Eds.), Proceedings of the Fifth International Symposium on Project Approaches in Engineering Education PAEE 2013, Eindhoven, the Netherlands.

Eppinger, S. (2013, March 4). A systems engineering view of the Boeing 787 Dreamliner. *MIT Sloan Experts Blog & Commentary on Today's Business Issues*. Retrieved April 17, 2013, from http://mitsloanexperts.mit.edu/a-systems-engineering-view-of-boeings-787-dreamliner-steve-eppinger/

Gaska, M. T., & Guase, D. C. (1998). An approach for cross-discipline requirements engineering process patterns. *Third International Conference on Requirements Engineering* (pp. 182-189). Retrieved from http://paee.dps.uminho.pt/

Press Release – FAA Statement. (2013, January 16). Federal aviation administration. Retrieved April 17, 2013, from http://www.faa.gov/news/press_releases/news_story.cfm?newsId=14233

Safyannikov, I. A., Vehter, E. V., & Vyuzhanina, N. Y. (2010). Project-organised learning method in the system of engineering education of Russia by the example of national research Tomsk Polytechnic University. In *Second Ibero-American Symposium on Project Approaches in Engineering Education* (pp. 97-100). Retrieved from http://paee.dps.uminho.pt/