A Successful Interdisciplinary Engineering Design Experience

by
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ABSTRACT

An interdisciplinary team design experience has been successfully integrated into the senior engineering laboratory effort at Western New England College. The project objective was to introduce the students to the design process typically associated with new product development. The approach was to have student teams develop a solar powered vehicle prototype which can transport bottled water between two points on a sloped parking surface as quickly as possible. The effort required the parallel development of a computerized performance prediction system for future product optimization. Several constraints were specified for the design effort. The vehicle had to be untethered, had to be powered by a specified solar panel, had to be fabricated at the College with the help of the College machinist, and had to cost less than $200. The effort had to result in both a working prototype model and a computerized performance prediction system for future optimization of the product. Mechanical, electrical and computer engineering students were combined into teams with five to six members. Each team was required to: conduct a product design feasibility study, conduct design brainstorming sessions, investigate energy storage procedures, conduct conceptual design studies, conduct component optimization tests, design and fabricate a product prototype, develop a prototype prediction system, design and fabricate on board procedures to collect, store and analyze performance data, and to use collected prototype data to optimize a computerized performance prediction system for the product. Weekly meetings were held where each team would give a brief oral presentation describing both, the work status with respect to their program schedule, and the team-spending summary. This interdisciplinary team design program has been conducted successfully for several years at Western New England College. The students enjoy the effort and learn a lot about real world product design and development problems including team dynamics. This paper describes the details of the design experience, discusses efforts that were found to be successful, presents sample team prototype results, and discusses student comments and feedback.

I. INTRODUCTION

Western New England College has a long history of incorporating engineering design into its laboratories and courses. This year marks the College's 41^{st} annual capstone design effort. In addition, interdisciplinary team efforts are initiated in the freshman year and continue for all four years [1]. This paper describes one such interdisciplinary lab exercise, performed in the fall of the student's senior year. This focused effort brings together students from Mechanical (ME), Electrical (EE) and Computer Engineering (CPE). The main objective is to allow our students to experience a typical design process generally associated with new product development. The design activity focuses on a predictive energy model for a solar vehicle as well as a fully functioning prototype vehicle. Teams are formed during the first week of the semester with design goals and constraints made clear at that time. The teams are subjected to a *shortened development cycle* of about ten weeks. Hence, it is imperative for the students to maintain a sense of urgency and to quickly assimilate as a team. Discipline specific efforts are supervised by appropriate faculty members during weekly meetings. In the following sections, we detail the course delivery method as well as a breakdown, by discipline, of team effort. We end with a discussion of results and observations on improving the experience.

II. COURSE STRUCTURE AND LOGISTICS

The design experience is offered as a required portion of a senior level Lab course. All students participating in the solar car project and the three faculty advisors from each discipline meet weekly as a group for one hour. The faculty select the teams prior to the first of these group meetings, in which the project is defined, constraints are given and the overall course procedures are outlined. Teams are required to keep a logbook which details the though processes, methodologies and design considerations which evolve during the experience. During subsequent group meetings, each team provides a 10-minute project status report, including a Gantt chart describing the project timeline. Logbooks are also reviewed and approved by the faculty. The faculty play the role of the Employer and critique all status reports, provide suggestions and voice concerns, as would an employer. Each team is also required to have their own weekly meetings where individual tasks are assigned and team integration is achieved. Additionally, team members from each discipline met weekly with their corresponding faculty advisor to discuss possible approaches to problems which arose during the product development, and to listen to a lecture on relevant technical topics and receive input and guidance.

During the design process, students are allowed the use of an in-house machine shop and machinist. Component drawings are to be approved by a faculty member prior to submission to the machinist to ensure that all required information is present. Students are allowed to operate equipment under the supervision of the machinist and can fabricate assemblies themselves.

The participating faculty conduct a mid-semester project review where each team is to demonstrate their vehicle and describe relevant issues and next steps. This provides the faculty with a good indication on the progress of each team and allows faculty to identify those who may be in danger of not completing the project by the required deadline.

Race day is scheduled for the first week in November, which allows only 10 weeks for the design, fabrication and testing of the prototype. The solar car race is a campus wide event, including media coverage, which serves as an excellent motivator for success and timely completion of the project. Each car is required to complete the track twice, and the best of trial time is taken to determine the fastest car. A single race involving all cars is also run. Several weeks after the actual race, each team is required to develop a formal oral presentation, which is open to the entire school of engineering. Each team is allowed 10 minutes to provide an overview of the methodology used to design and develop the car, problems and successes seen during the course of the project, and the results of the effort. All students and faculty attending the presentations are asked to critique each presentation for technical content, quality of visuals used and general effectiveness of the presentation.

At the end of the semester, a formal, written report which documents the entire project is then to be submitted in both electronic and hard copy, along with the team log books. The report highlights the objectives and constraints of the project, the methodology and analytical efforts used by each discipline to arrive at the final design, and a comparison of the predicted vs. actual results demonstrated on race day. These documents are archived in the school of engineering and serve as the historical record of the experience. The report is a joint effort, with the Mechanical Engineering students serving as report coordinators. The final grade each student receives is largely based on the quality of the design and the performance of the car as demonstrated on race day. The quality of the oral presentations and the final report is also a major portion of the grade. Finally, an assessment of the contributions of each student during the course of the experience is also taken into account.

III. EFFORTS BY DICIPLINE

A. Mechanical Engineering Effort

The process of developing the prototype began with a series of brainstorming sessions with the entire team and the mechanical members. From a team perspective, preliminary concepts for frame configuration, mounting of boards, motor and solar panel, and the required sensors are discussed. MEs focus on frame fabrication and materials, drive systems, steering concepts and wheel configurations.

As a first task, a complete elevation contour of the racetrack was developed using a transit. Then, two energy models were developed to serve as an aid in designing the power requirements of the vehicle, and as a predictor of vehicle performance. A single step model was considered first, where losses were neglected and the track was assumed to have a constant slope. This was used primarily to determine if the energy available from the solar cell was adequate to move the vehicle and payload across the track, and for preliminary estimates of potential vehicle mass and approximate completion time. A more detailed model was then developed which incorporated multiple steps, thus more accurately reflecting the actual track contour, as shown in equation (1):

$$0 = \frac{2\cdot\Delta S}{\left(V_i + V_{i+1}\right)} - \frac{\frac{1}{2}\cdot m\cdot\left[\left(V_{i+1}\right)^2 - \left(V_i\right)^2\right] + We\cdot\tan(\theta)\cdot\Delta S + \mu\cdot We\cdot\Delta S + \frac{1}{2}\cdot A\cdot C_d\left[\frac{\left(V_i + V_W\right)^2 + \left(V_{i+1} + V_W\right)^2}{2}\right]}{P} \tag{1}$$

Where:

ΔS = Incremental distance along the track (ft)
V_i= Initial velocity (ft/sec)
V_{i+1}= Velocity at an incremental distance from initial point (ft/sec)
V_w= Wind velocity (ft/s)
m= Mass of the solar car (lb_m)
We= Weight of the solar car (lb_f)
θ = Slope of the course (rad)
P= Power of the solar panel (ft-lb/sec)
μ = Coefficient of friction
A= Projected Cross-sectional area of the solar car (ft^2)
Cd= Coefficient of drag

Here, losses such as friction, aerodynamic drag and wind effects are considered. This more detailed energy model was solved for the incremental velocity and used to perform a parametric study to quantify the effects of mass, drag, friction, wind velocity and available power on the vehicle, indicating which parameters should be optimized.

An estimate of the starting and running torque was then developed to aid in the selection of the motor. It was assumed that the vehicle must start while under the influence of a 15 mph head wind and a track slope of 5 degrees. This information was passed along to the Electrical Engineers who were ultimately responsible for selecting the motor, as described below. A value analysis of various drive systems was performed to study the pros and cons of each. Among the systems under consideration were direct drive, v-belt and cogged belt drives and direct drive. All teams selected cogged belt drive based on its ease of implementation, relatively low friction losses and ease of modification. The appropriate cogged pulley ratios were then calculated based on the starting and running torque of the motor.

A detailed design of the frame, computer/ electrical board and motor mounts, wheels and bearings was then completed, along with the solar panel mount. All teams used a flexible mounting scheme, which allowed for adjustment of the panel inclination on race day. Once all components were fabricated, a radio controlled steering systems acquired from commercially available kits were purchased and mounted on the vehicles to confirm that the steering servos were capable of steering the vehicles when at rest. Connecting rods and steering pivots were designed to be compatible with the purchased components.

B. Electrical Engineering Effort

The electrical engineering students' effort was divided into three separate tasks. First, they were responsible determining the power characteristics of the solar panel. Second, they needed to select a motor that would be capable of consuming the available power and deliver enough power to propel the vehicle up the racecourse hill. Finally, the EE students needed to acquire and condition a minimum of four signals. These signals were necessary to provide the data for post-race analysis to compare the actual vehicle performance to the prediction that the ME students calculated.

To determine the power characteristics of the solar panel, the students measured the voltage across and current through a parallel resistive load while the panel was orthogonal to the incident solar radiation. After acquiring the data, the students determined the peak power that the panel could produce. The power vs. current curve was nonlinear and fell sharply after the current exceeded the point where the power peaked. Therefore, the students needed to be careful to select a motor that, while operating under the load conditions of the race, would not draw more current than the current at the peak power operating point.

The motor selection process involved the students learning about the torque-current relationship of dc-brushed motors. The EE and ME students had to work together to ensure that the motor selected was compatible with the startup and nominal torque requirements of the vehicle and the available current/power from the solar panel.

The minimum four signals that the EEs acquired were: motor voltage and current, solar intensity, and vehicle speed. The motor voltage and current signals required moderate and considerable filtering. The students learned that the signals from the motor were not very clean. Also due to the brushes making and breaking, they had to design a circuit to convert the motor current signal to an average current. Some of the students' filters time constants were too long and the EEs learned how to loose pertinent information. The students used op-amps to buffer their signals before connecting to the CPEs' data acquisition boards. The solar intensity signal was not very sensitive to the variance of light intensity during the race, so the students learned how to use gain and offset to stretch the resolution in the range of interest. The speed sensors were either hall-effect sensors or beam break sensors. In either case the students needed to decide how many "clicks" per wheel revolution the needed. This interaction involved the MEs, EEs and CPEs. The number of devices to attach to the axel impacted the ME design, and the number of data collections per wheel revolution affected the CPE memory usage. The memory available was the limiting factor for most of the teams, so most vehicles had one or two clicks per revolution. The data for speed was calculated as first-order differences between linear distance and data sample time. Because of the low resolution, the speed data was not very smooth.

C. Computer Engineering Effort

The main focus of the computer engineers was the development of the on-board data acquisition system. This 8052-based, wire-wrapped board gathered race day information that was used to verify the energy prediction model. This system was the second, complete microprocessor system built by the students. The first was a breadboard system built in the second semester of their junior year. As a result, it was not uncommon for the data acquisition boards to be fully operational in three weeks. Construction challenges included learning to wire-wrap and improving soldering techniques. Students were also required to consider component layout, cabling, connectors and mounting issues at the start of the design. A complete, up to date schematic was required throughout the entire design cycle. Students utilized ORCAD® schematic capture. The system itself consisted of an 8052 processor, EPROM, an 8-bit, 8-channel ADC, RAM and RS232 interface. Other design efforts included designing a voltage regulator and reset circuitry. Some teams substituted EEPROM or Flash memory.

The system was designed to interface to the signal conditioning board developed by the electrical engineers. Students became aware of ground loop issues as well as the benefits of keyed connectors. The systems were designed to be interrupt-driven. During standalone, unit test, the CPE's used a variety of test equipment to verify the correct operation of their systems. The labs are well equipped with function generators (interrupt source), power supplies, logic analyzers and DVM's. Perhaps the most challenging time for the CPE's was during integration test. Students were advised, early in the semester to be prepared to schedule testing time on the vehicle. The availability of a scarce, critical resource (the solar vehicle) provided the teams with a valuable lesson.

The on-board data acquisition systems generally were designed for a race-mode as well as a post race-mode. The modes could either be hardware (switch) based or software (specific bit patterns in memory) based. During race-mode, as the vehicle traverses the course, parameter data was acquired and stored. At the end of the race, the system software was reset to post race-mode. The sampled data was then transferred to a PC via RS232 serial cable for analysis. Typical data included solar panel voltage and current and light intensity. Other analog parameters may include wind speed and frame vibration. Sensing axel rotation and utilizing an on-board timer determined Road speed. Typical sensors include beam-interrupt as well as Hall Effect.

IV. RESULTS

Figure 1 shows a completed solar powered car. This particular car had changeable drive wheels allowing the team to change the overall gear ratio, and therefore the startup torque, in the case that there was a strong headwind on the race day.

Each car was tested prior to race day to confirm the function of the integrated components. Vehicles were tested for steering performance, performance of the acquisition system, steering performance and vehicle control and general structural integrity. The time required to complete the track was also recorded and adjustments to the drive system were made as required.

Figure 2 shows a typical comparison of the data collected on race day to the analytical model discussed earlier. Most vehicles outperformed the analytical models due to a tail wind, which varied in intensity.

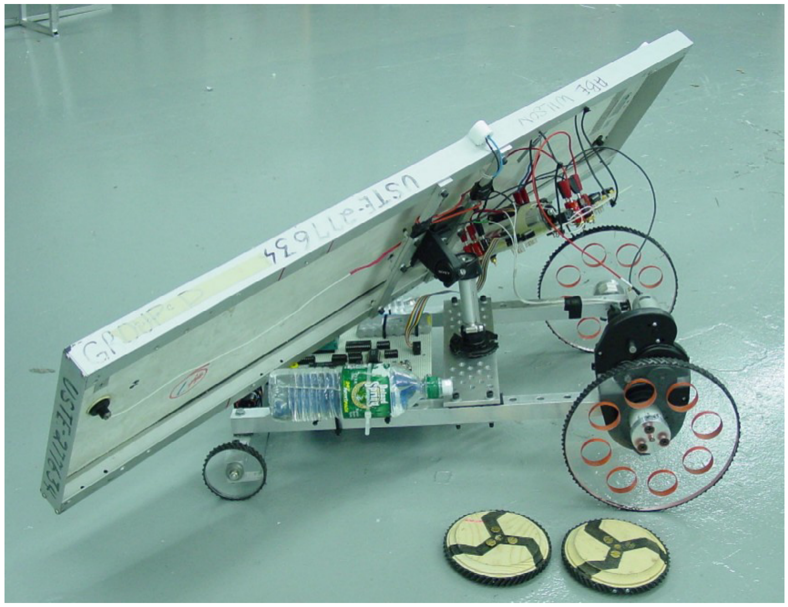

Figure 1. A completed solar powered vehicle is show with two wheel sizes that could be switched to alter the gear ratio.

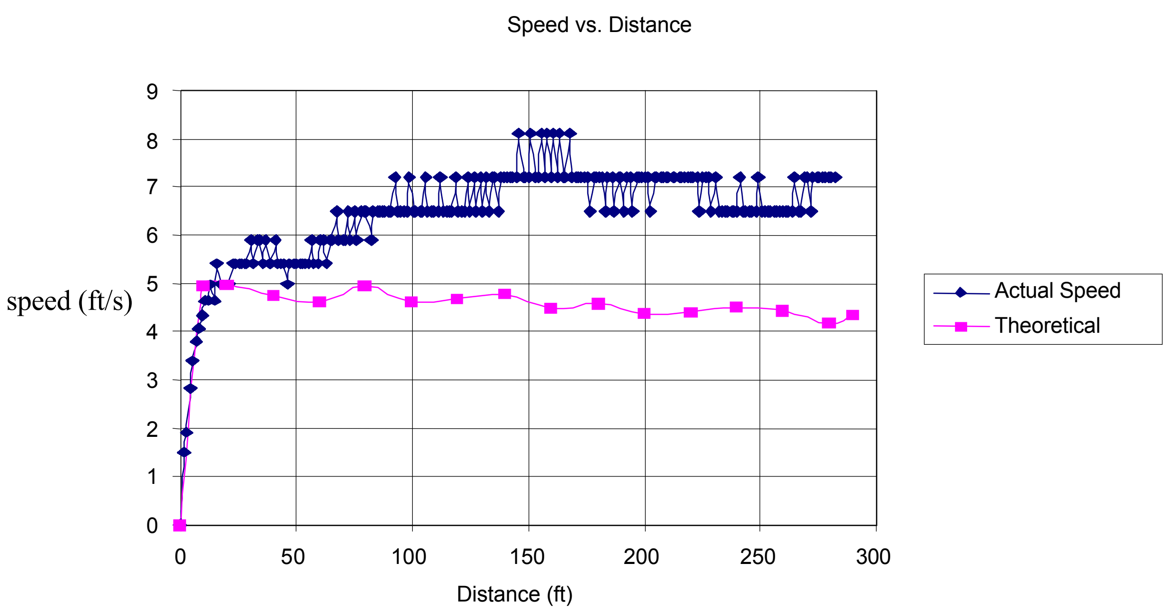

Figure 2. Actual and theoretical vehicle speed plotted against the distance traveled.

V. STUDENT FEEDBACK AND RECOMMENDATIONS

All students participating in the project were asked for their feedback at the end of the semester. Overall, all students saw the experience as a positive exercise which exposed the participants to real world issues which confront practicing engineers every day. The interaction between the various disciplines and the team dynamics, which developed throughout the course of the project, were seen as some of the most valuable lessons learned. The importance of teamwork, planning and the value of up-front engineering calculations under a very tight time constraint were also realized. The students appreciated that this project required the participants to utilize the entire engineering development process from concept through prototype fabrication, culminating in a tangible, working model.

There were also several recommendations made by the students. For example, a number of students believed that the solar car project should be a class in itself, perhaps offered as a three credit, professional elective. They would also like to see more deadlines established by the faculty throughout the course of the semester, as some students commented that by the time they learned the true value of religious adherence to the project schedule, it was too late. Some students believed that bi-weekly status reports would be more practical, with the alternating weeks used as team meeting periods. Finally, increased access to the engineering machine shop was requested, particularly in the late afternoon and early evening.

The participating faculty also recommended some improvements in the project. Guidelines for the creation of detailed drawings, creation and maintenance of logbooks and a standard for Gantt chart development will be given to the students at the beginning of the next project cycle. Also, specific rules for connector types, board layouts, etc. will be used to allow more interchangeability of circuit boards between the cars. This would provide the various disciplines the opportunity to test certain subsystems on other cars if their particular team found themselves behind schedule. For example, if a motor was backordered, the data acquisition board could be tested on another car.

VI. CONCLUSIONS

The interdisciplinary design experience, the design of a solar powered vehicle, was and continues to be an extremely valuable learning process for the students at Western New England College. The course structure and the design process are industry-like in many aspects. The engineering teams experience the entire design process - complete from their initial brainstorming sessions and product feasibility study to product prototyping and testing. Additionally, the teams must provide weekly progress updates to the management team (the ME, EE, and CPE professors). Being questioned about discrepancies between their statements and their Gantt charts is invaluable in their preparation for industry employment.

The project culminated in a race held the first week of November. The students were afforded the opportunity of seeing the environmental effects upon their designs; vibration and wind have significant impact on the vehicle's ability to collect data. Some of the humorous observations (humorous to the faculty, but indelibly etched in the students' design memory) were:

- Skinny wheels: great for rolling resistance, but seem to get stuck in the parking lot cracks.
- The wind can rotate your poorly mounted solar panel away from the sunshine.
- When you mount the circuit board upside down, vibration can make components fall out.

Overall, the design experience was extremely good for the students. The calculated velocity predictions for all seven teams correlated quite well with their race day data. The race times ranged from 47 seconds to around two minutes. The team with the slowest car was not disappointed about their slow time because their race time was only a few seconds from their predicted race time. So, even though they designed a slow car, they were quite successful in their engineering analysis.

Reference:

[1] Ronald Musiak, Eric W. Haffner, Steve Schreiner, Alan K. Karplus, Mary B. Vollaro, Richard A. Grabiec, Forging New Links: Integrating the Freshman Engineering Curriculum, Proceedings of the 2001 ASEE Annual Conference & Exposition, June 2001.

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