AC 2007-431: ORGANIZATION OF A MULTI-DISCIPLINARY CAPSTONE DESIGN PROJECT FOR THE SAE FORMULA HYBRID COMPETITION

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Organization of a Multi-Disciplinary Capstone Design Project for the SAE Formula Hybrid Competition

Abstract

Many real-world projects require the application and knowledge of multiple disciplines and most professional engineers are required to regularly interact with co-workers with various backgrounds. Since capstone senior design projects are intended to prepare students for real world situations, the adaptation of multi-disciplinary teams to fulfill the senior design requirement has several advantages. For the project described in this paper, a capstone design team was organized for three degree programs; Mechanical Engineering (ME), Electrical Engineering (EE) and Engineering Physics (EP). Aerospace Engineering students were included in the project through participation in a minor course of study in 'High Performance Vehicles," administered through the Mechanical Engineering program.

The design goal of the project was to analyze, design and build a functioning parallel hybrid-electric race car. The vehicle will compete at an event endorsed by SAE International and IEEE, called the SAE Formula Hybrid Competition on May 1^{st}-3^{rd} 2007. This design project was selected as a multi-disciplinary project because it has sufficient technical challenges in each of the three degree areas. The primary challenges presented by this design project are:

- High-Power Electronics (electric motors, actuators)
- Mechanical system design (suspension, chassis, drivetrain)
- Energy storage and management (energy storage device and control)
- Regenerative electric/hydraulic braking systems
- Digital control systems
- Data acquisition
- Project management

This paper presents the objectives and organization of the project, the lessons learned from the project and a brief assessment of how well the project meets the requirements of the capstone senior design project.

<u>Background</u>

Embry Riddle Aeronautical University adapted a college system a few years ago and recently added several engineering degree programs. Among the new programs are the Mechanical Engineering and Electrical Engineering programs, which began accepting students in August 2005 and are part of the College of Engineering. The Engineering Physics program is an established degree program that is part of the College of Arts and Sciences. The Aerospace Engineering program is an established degree program that is part of the College of Engineering.

The established degree programs have offered single discipline capstone senior design projects but have not attempted cross-disciplinary projects. The new programs, in particular ME and EE, needed to initiate capstone projects starting in the 2006-2007 academic year to accommodate their initial graduating classes of students. Although offering multi-disciplinary senior projects was a significant paradigm shift from the status quo, the three programs, ME, EE and EP, were able to organize and offer an integrated senior design project this year. Implementing multi-disciplinary design projects from the programs inception is advantageous for several reasons. The number of upperclassmen in a new degree programs is relatively small and partnering with an established degree program helps to fill out the student design team, while meeting the educational objectives of a multi-disciplinary team. Combining the background of multiple programs, allows a more complex and realistic design project.

There have been many studies conducted that suggest integrated multi-disciplinary projects have benefits for students. The purpose of this paper is not to duplicate those studies but to highlight the organization and preparation required to successfully integrate the capstone project and participate in the SAE Formula Hybrid competition. 2007 will be the first year that SAE International and IEEE have endorsed a hybrid-electric vehicle competition and other universities may benefit from our example as they field teams for the competition in the coming years.

The three degree programs, ME, EE and EP have significantly different focus areas at Embry Riddle. Embry Riddle is a private institution orientated toward the aviation and aerospace industries. As a result, many of the degree programs have focus areas related to both the academic discipline and the aerospace and aviation industries. For example, the EE program has focus areas in avionics and systems engineering. The EP program has a focus on space physics. The ME program has focus areas in high performance vehicles and robotics. The term 'high performance vehicles' refers to a range of vehicle types including race cars, high mileage (hybrid-electric, low drag, etc.) cars, jet-powered vehicles, etc. The fact that the university and each degree program are specialized adds an extra level of complexity to the organization of the project. Since each of the three programs have what would appear to be mutually exclusive focus areas, the task of finding a common, integrated senior design projects was especially challenging. A project in the area of robotics would have been a logical choice but there was a higher level of student interest in pursuing the hybrid-electric race car project this year and the project also builds on several years of progress related to vehicles. In this case, student interested was determined by informally surveying rising seniors to determine which project they preferred. The purpose of the survey was to determine if there was sufficient interest to offer a multi-disciplinary course and demographics were not analyzed. The results of a similar survey could be analyzed next year.

Progressive Project Development

It took several years to build the facilities and expertise to analyze, design, build and test the SAE Formula Hybrid vehicle. The first vehicle project was conducted during 2004-2005, which is a year before the ME program began officially accepting students. The

ME program and AE program, which is a very large, well established program, are identical for the freshmen and sophomore terms. Meaning there were ME students in the pipeline before the program officially accepted students, which is why the ME program has a senior class after only two years. The progression in vehicle projects is summarized below and shows the building process initiated in 2004.

Baja SAE →	Formula SAE →	Formula Hybrid (modified chassis) →	Formula Hybrid (custom chassis)
2004-2005	2005-2006	2006-2007	2007-2008
•Pilot program •Secured lab space •Minimal tooling •Special topics credit offered	•Expanded tooling •CNC mill and lathe added to student machine shop •Created minor in High Performance Vehicles	•First senior class of Mechanical Engineering students •First multi-disciplinary project •Recycled some of the previous Formula SAE car	•First senior class of Electrical Engineering students •Complete vehicle redesign and construction

The 2004-2005 Baja SAE vehicle and 2005-2006 Formula SAE vehicle projects were not capstone student projects. The projects were effectively mono-disciplinary projects and the teams were predominately composted of Mechanical and Aerospace Engineering students participating on the projects as either an independent study or extra-curricular project. The projects were organized with minimal but expanding resources. The primary advantage of promoting these projects prior to the first senior ME class was the identification of resource requirements, expertise and the relationship between the projects and ABET certification.


2004-2005 Baja SAE Project


2005-2006 Formula SAE Project

Since the initial Baja project, the university has created a student machine shop with new CNC equipment (CNC mill, CNC lathe and TIG welder), employed a lab assistant to oversee use of the equipment, and created a new, equipped student project area. A minor course of study, called high performance vehicles, was created to provide non-Mechanical Engineering students an opportunity to learn about advanced vehicle systems and apply the topics covered to vehicle projects.

Formula Hybrid Project Description

The concept behind the SAE Formula Hybrid project is to design and build a high performance hybrid-electric open-wheel race car. At the conclusion of the project, teams from various universities compete in design and performance events to determine the 'best' vehicle. The competition scoring is weighted toward drivetrain innovation, fuel economy and on-track performance. SAE and IEEE endorse the Formula Hybrid competition and students are required to be members of one of the organizations. While the SAE Formula Hybrid competition is based on the very successful Formula SAE competition, there are a few very significant differences. For example, a new chassis is not required every year for Formula Hybrid, which allows more time to be invested in advanced drive system designs.

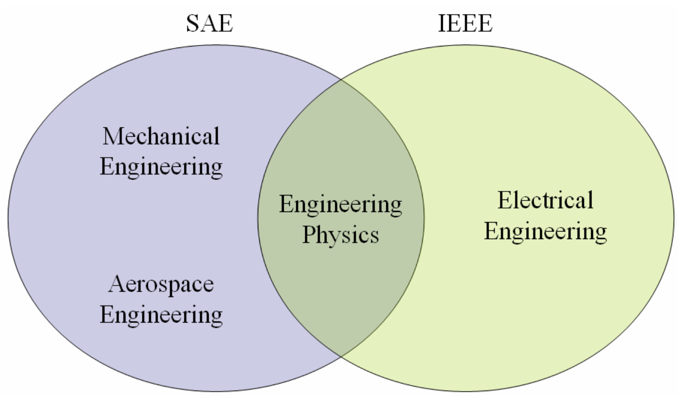

Figure 3: Relationship between Degree Programs and Professional Societies

There were approximately 35 students participating on the SAE Formula Hybrid design project but only about one have of them are taking the project for senior design credit. The breakdown of students from each discipline is shown in figure 4. The number of students participating from the Electrical Engineering is relatively small because the enrollment in the new EE program is also relatively small. As the EE program continues to grow, it is expected that the number of EE students participating on the project will also grow. The number of students participating from the Aerospace Engineering program is subject to fluctuation. The Aerospace Engineering program is very large but has a limited number of opportunities for students to take technical electives or independent study courses. The Engineering Physics and Mechanical Engineering programs are likely to maintain constant enrollment levels in the project. The EP program is rather large but supports many senior design sections, each about the current size of the EP Formula Hybrid group. The ME program is growing but is adding additional senior design projects, whereas SAE Formula Hybrid is the only ME senior design project for 2006-2007.

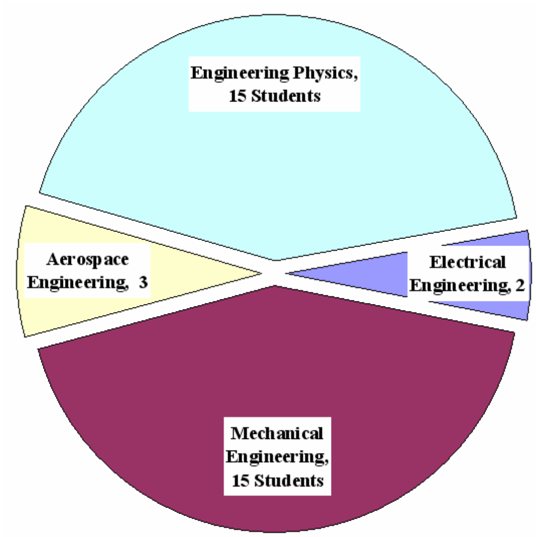

Figure 4: Breakdown of Student Project Team

Given that the university has a unique outlook, that some of the participating degree programs are new, and that multi-disciplinary design projects have not been attempted before at Embry Riddle, the Formula Hybrid project presented numerous organizational challenges.

Project Organization

As an integrated senior design team, a single project structure was needed. As shown by figure 5, the team was divided into three groups based on task, with a single project leader and advisory committee composed of faculty from each of the three departments. Students were allowed to select the topic and task group in which they participated, regardless of their degree program. For example, an electrical engineering student could work on the internal combustion engine or an aerospace engineering student could design the control system. So, students from each degree program were dispersed through the design groups. Similarly, the faculty advisors supervised the team as a whole and not only their program's students but faculty were responsible for determining grades for their program's students.

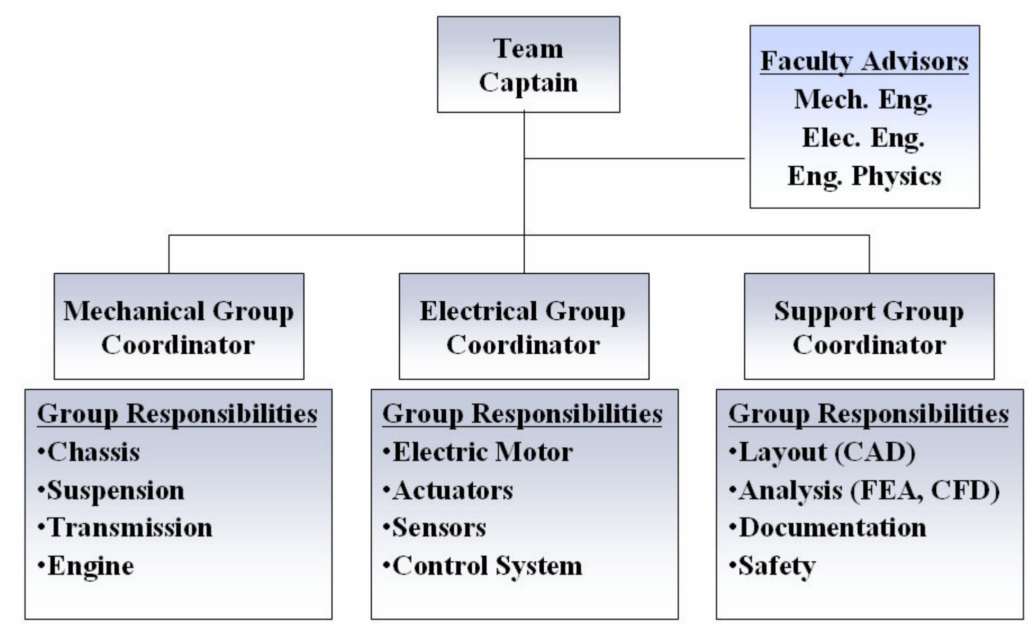

Figure 5: Student Design Team Structure

The design process was established after consulting with individuals from the industrial advisory board of the three degree programs. The general design process for the project was customized based on the design process from several companies. As shown in figure 6, the process includes several opportunities for the faculty advisory board to review the designs, analysis and documentation. The design reviews, reports and weekly progress meetings are important both as a method for project oversight and as a method to assess student performance.

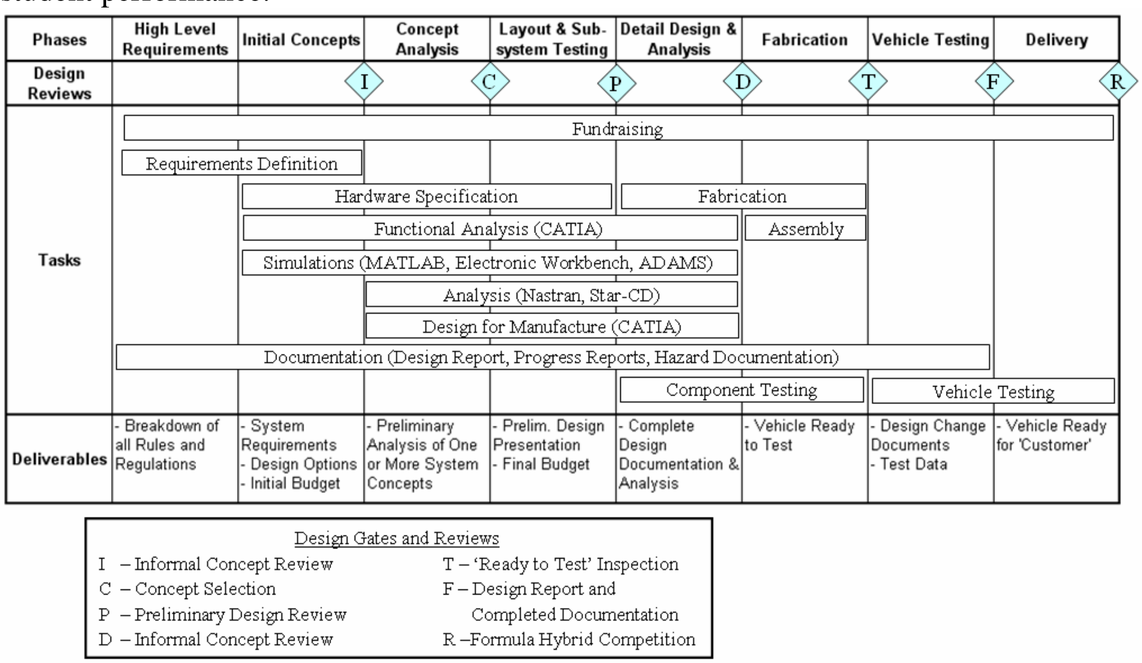

Figure 6: Project Decision Process

Student Assessment

Student assessment can be described in three categories; group performance, individual performance and peer evaluations. Assessment of the group is based on meeting project goals, such as deadlines and design goals. Individual performance is based on presentation performance, design reports and correct utilization of engineering tools. Peer evaluation is a subjective score based on responses from peer members of the design group and constitute less than 25% of the overall grade.

Sample Grading Scheme:

Oral Presentation	25%
Design Report	25%
Peer Evaluations	20%
Progress Reports	20%

As with many group projects, student assessment was difficult to perform on an individual basis. The ability of a student to meet individual design and project objectives was one component of the overall grade. The ability of the tasks groups to meet design and project objectives was another component of each student's grades. Overall, assessing student performance has approximately the same issues that most senior projects have.

Opportunities for Improvements

The SAE Formula Hybrid project is extremely complex and requires a significant investment of time from the students and faculty and a significant amount of resources. Faculty interaction with the students has been largely focused on the technical aspects of the project, by necessity. Ideally, the project would include more formalized lectures addressing professional ethics, environmental aspects, project management, and documentation. These topics have been conveyed to the student throughout the project but not in an organized format.

As in any organization, there are individuals that are able to contribute greatly to the project and other that contribute to a lesser degree. Because the project was both technically challenging and interesting, some students were motivated to invest many hours beyond what is expected for a senior design course. Other students were motivated only to complete their degree requirement. Allowing the students to select their senior design topic did not guarantee alignment between the student's interest and project scope. The discrepancy in student effort requires a detailed method to quantitatively determine and assign student grades.

Documentation for the project needs to be improved. Uniformity of format, style and distribution of effort was difficult to convey and enforce with a large and diverse group. The student teams were not used to working on large teams or working on the same project for an extended period of time. This project was often the first time that many students have been asked to come to a consensus and agree on decisions. Improving documentation and communication skills are features that should be stress on future projects.

The authors plan to survey the students to gauge the students' impression of the combined project at the conclusion of the project. The result of the survey will be helpful in adapting the course. The timing of the survey, if the survey is conducted in the middle of the project or at the conclusion of the project, could have a significant impact on the results.

Relationship to ABET

The SAE Formula Hybrid project related to all the ABET required outcomes (A-K) and is a better match to the requirements than previous single disciplinary projects. The project significantly improves the relationship for outcomes (d), (g) and (j).

(d) An ability to function on multi-disciplinary teams.
(g) An ability to communicate effectively.
(j) A knowledge of contemporary issues.

Outcome d was achieved very easily with this project but not with single disciplinary projects. As noted above, communication and documentation were large parts of the project. The need for better documentation and communication were clearly reinforced. Contemporary issues, such as US energy security, were addressed as part of the project.

Because of the complexity of the project, outcomes (c), (e) and (k), which require student to be able to use modern engineering tools, solve engineering problems, and design systems and components, were clearly satisfied. Because many students found the project interesting, the students would drive much of the learning of the modern engineering tools (Nastran, Fluent, etc.) as part of their efforts to design the systems and components. To augment this natural development, there were some tutor session on the equipment and frequently students were required to back up the results of the computer calculations with hand calculations.

In addition to ABET required outcomes, Embry Riddle has an additional outcome of fostering meaningful student involvement in professional societies. Since the project requires students to be members of either SAE International or IEEE, the project satisfies this internal requirement. By allowing underclassmen to assist the senior project team, enrollment in the professional chapters was also improved. While Embry Riddle has an overall enrollment of about 4500 students, the Embry Riddle SAE chapter has grown within the last few years to have one of the larger SAE enrollments in the US.

Conclusions

The SAE Formula Hybrid Project has been extremely rewarding for the faculty and student involved. The project reinforced the need for multi-disciplinary projects and demonstrated that it could take a couple of years to fine tune the project to meet all the educational objectives. While the project is technically challenging, the greatest challenges were overcoming the inertia of current practices and the logistics required for the project. Finding faculty members willing to take on the additional load of a multi-disciplinary project was not difficult in this case but it might be difficult to expand the practice to other degree programs for this reason. Continuing to refine the format of the program and formalizing the presentation of project management, documentation, and systems engineering techniques to the students should result in a more efficient project.

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