AC 2010-1474: BENEFIT OF STUDENT PARTICIPATION IN ADVANCED VEHICLE TECHNOLOGY COMPETITIONS

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Benefit of Student Participation in Advanced Vehicle Technology Competitions

Abstract

For the past 21 years the U.S. Department of Energy has sponsored more than 45 Advanced Vehicle Technology Competitions (AVTCs) with management provided by Argonne National Laboratory. Through partnerships between government, industry, and academia, engineering students have had the opportunity to explore sustainable vehicle solutions while at the same time enriching their educational experience. In this paper the benefit to students is described based on experience gained in the recently completed Challenge X competition and the ongoing EcoCar challenge. In both competitions students from 17 universities throughout North America have had the opportunity to re-engineer a production vehicle to improve the fuel economy, reduce emissions, and increase performance. Additional support has been provided by General Motors, the Natural Resources Canada, and numerous automotive parts suppliers.

The competitions are intense, profound endeavors for the students that result in technological developments, proficiency with today's engineering tools and methodology, and a unique team experience. They serve as a means for students to acquire practical engineering experience in an environment that requires cooperation and team work from students in several engineering fields. In addition to the technical concepts, students are required to consider the aesthetics of design, consumer acceptability, and how the vehicle would be marketed. Students from disciplines outside engineering, such as in business and communications, add another dimension to the competition. While the coordination of these diversified groups of students can be a challenge for the faculty advisor, the students develop an understanding and appreciation for what each discipline can contribute. Students quickly learn that the breadth and depth of the project requires a multi-faceted approach where team work is essential.

In a relatively short period of time, students must acquire specialized automotive knowledge and proficiency with numerous software tools. In recent AVTC competitions students are required to emulate the design and development process employed by automotive manufacturers. Students compare vehicle architectures and various advanced technologies so as to select components that enable them to satisfy vehicle technical specifications (VTS) that they have fine tuned from the original vehicle criteria established by the competition organizers. Throughout the competition, the VTS serves as a baseline for comparing design objectives with actual vehicle performance. Students are provided with advice and mentoring throughout the process by engineers engaged in the automotive industry. The actual construction of the vehicle and eventual competition provides a unique experience that enriches their educational experience and provides employment opportunities.

Introduction

Student competitions have been frequently used to motivate students and promote such concepts as multidisciplinary interactions and teamwork. Some of the more intense competitions have been supported by the Department of Energy (DOE) through Argonne National Laboratory where students have been challenged to design and construct vehicles using the newest technology so as to explore sustainable vehicle solutions. For the past 21 years in conjunction with industrial partners, Argonne has managed more than 45 Advanced Vehicle Technology Competitions (AVTC). The benefits of these unique coalitions of government, industry, and academic partners have provided numerous students with hands-on experience, exposure to processes and methodologies utilized in industry, and familiarization with the newest engineering tools. This paper describes the lessons experienced by a university team that participated in Challenge X and is currently participating in the on-going competition EcoCAR.

"Challenge X: Crossover to Sustainable Mobility" culminated in the spring of 2008 in which 17 universities from throughout North America competed to re-engineer a Chevrolet Equinox so as to minimize energy consumption, emissions, and greenhouse gases while maintaining the vehicle's utility, safety, and performance. With additional sponsorship from General Motors (GM), the Natural Resources Canada, and numerous automotive parts suppliers, students engaged in a four year competition in which they emulated the design process utilized by automobile manufacturers. The current competition, entitled "EcoCAR: The Next Challenge", again has 17 universities from throughout North America participating where three of the teams are from Canadian universities. A Saturn Vue crossover vehicle is used as the platform for this three-year competition that is similar in scope to Challenge X but has greater emphasis on concepts such as plug-in, range-extending, and fuel-cell vehicles. The universities that participated in Challenge X and those currently involved in EcoCAR are listed in Table I.

Competition Format

Both of the competitions use a similar format so the primary focus will be on the current one. The first year of the competition emphasizes the use of software tools such as PSAT (Powertrain Systems Analysis Toolkit) to facilitate architecture selection so as to address issues such as the choice of fuels (biodiesel, reformulated gasoline, E85, and hydrogen) and vehicle configurations that include mild hybrid, full hybrid, plug-in, range-extended and specific configurations such as series, parallel, and other combinations. Students use math-based modeling tools for vehicle design and controls development and then selected components that would enable them to satisfy the vehicle technical specifications (VTS) that they had fine tuned from the original vehicle criteria established by the competition organizers. Throughout the competition, the VTS served as a baseline for comparing design objectives with actual vehicle performance.

Table I. University Participants in Challenge X and EcoCAR

Challenge X Participants		EcoCAR Participants	
Michigan Technological University	University of Michigan	Embry Riddle Aeronautical University	Rose-Hulman Institute of Technology
Mississippi State University	University of Tennessee	Georgia Tech	Texas Tech University
Ohio State University	University of Texas at Austin	Howard University	University of Ontario Institute of Technology
Pennsylvania State University	University of Tulsa	Michigan Technological University	University of Victoria
Rose-Hulman Institute of Technology	University of Waterloo	Mississippi State University	University of Waterloo
San Diego State University	University of Wisconsin-Madison	Missouri University of Science and Technology	University of Wisconsin
Texas Tech University	Virginia Tech	North Carolina State University	Virginia Tech
University of Akron	West Virginia University	Ohio State University	West Virginia University
University of California, Davis		Pennsylvania State University	

During the second year of competition, students are challenged to convert the design into a functional prototype vehicle where they are given the opportunity to evaluate the actual vehicle performance at a GM proving ground. It is in the third year of the competition where students continue the vehicle development and calibration so as to realize their full vehicle performance. The competition requirements evaluate not only the powertrain efficiency, performance, and emissions but consider consumer factors such as drive quality, noise-vibration, and utility. The necessity for the car to perform in adverse driving conditions emphasizes to the students the necessity for the consideration of fault tolerance and failure modes that might affect the integrity of the vehicle and possibly the safety of the driver and passengers. The Challenge X competition was extended for a fourth year where students were expected to bring the vehicle to a 99% buy-off readiness level.

Throughout the competitions, the teams are evaluated not only on the actual vehicle performance but on other criteria often considered to be inconsequential by the students. For example, students are required to write numerous technical reports that are evaluated not only from the perspective of technical accuracy but format, grammar, presentation style, and quality of writing. Similarly, the students are required to give numerous presentations, some of which are highly technical and others directed to the consumer. Engineering students appreciate the contributions of fellow students in non-technical disciplines, such as marketing and journalism where they are required to emulate the entire vehicle development process from the conceptual stages to the final marketing and branding of a product. This also serves another purpose, which is to promote the underlying hybrid electric vehicle technology to regional consumers, thus addressing larger governmental energy and industrial policy goals through proactive university outreach.

Engineering Tradeoffs in Energy Conversion and Conservation

As previously noted, the competition objectives include improving fuel economy and reducing emissions. One of the first major design decisions pertains to the selection of the fuel. To fully evaluate the impact, it need be considered from “well-to-wheels”. For example, how much energy is consumed in bringing the fuel from its original source to refueling the vehicle? This could include pumping the oil from the ground, growing the corn to produce ethanol, or mining the coal to produce electricity. Furthermore, energy is expended in the conversion process. For example, refining the oil or converting biowastes to biodiesel requires large expenditures of energy. Transporting the fuel to the consumer is another issue that contributes to the total energy expended. Each of these phases not only impacts the total energy expended but it also contributes to the total green house emissions. An all-electric vehicle itself may be emission free but there are emissions from the coal when it is burned at the electrical generating plant.

The students quickly learn that the selection of the vehicle architecture dictates the energy conversion processes incurred and that there are numerous tradeoffs involved in the selection. Minimizing the number of conversion processes certainly impacts the efficiency. Students also learn that there is a considerable difference in a “charge sustaining” mode and a “charge depleting” mode. Such selections are best evaluated using modeling and simulation tools as required in the competition.

Team Organization

The student team at our university is organized into six groups each of which is led by a student who is typically a senior or graduate student. A graduate student serves as the team leader who has overall responsibility for the direction and coordination of the various activities. A team organization chart is shown in Fig. 1. The major faculty advisor, who is the author of this paper, has the primary responsibility for interfacing with the university administration, providing resources as required, and technical leadership as may be required. Overall, however, the team is managed by the students themselves and they have proven that they are capable of rising to this level of responsibility. Students from throughout the university are invited to participate regardless of major or classification. The leadership has proven effective in mentoring the younger students and on occasion removing students from responsible roles when they repeatedly fail to fulfill their commitments.

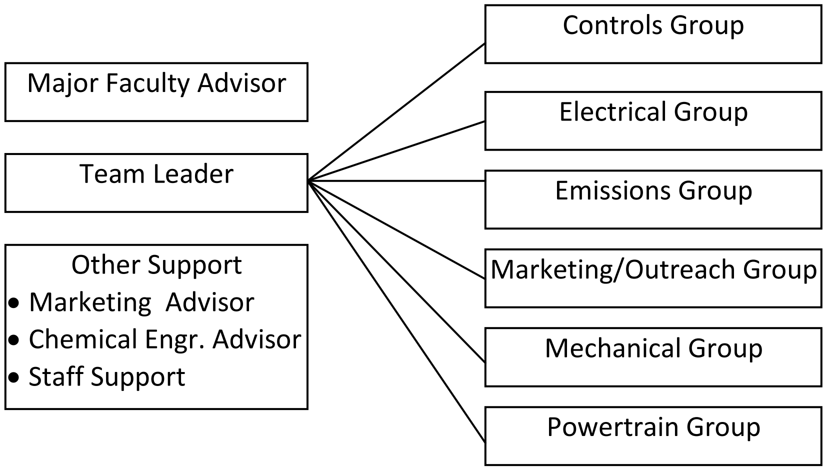

Fig. 1. Team organization

Membership on the team fluctuates throughout the academic year and at times exceeds 75 students. Weekly meetings are held by the team and students are informed of the current status and tasks that need be addressed each week. The team leader maintains an overall Gantt chart for the various tasks to be performed, and specific tasks for each group are developed by the individual group leaders. An example of a chart for the Mechanical Group is shown in Fig. 2.

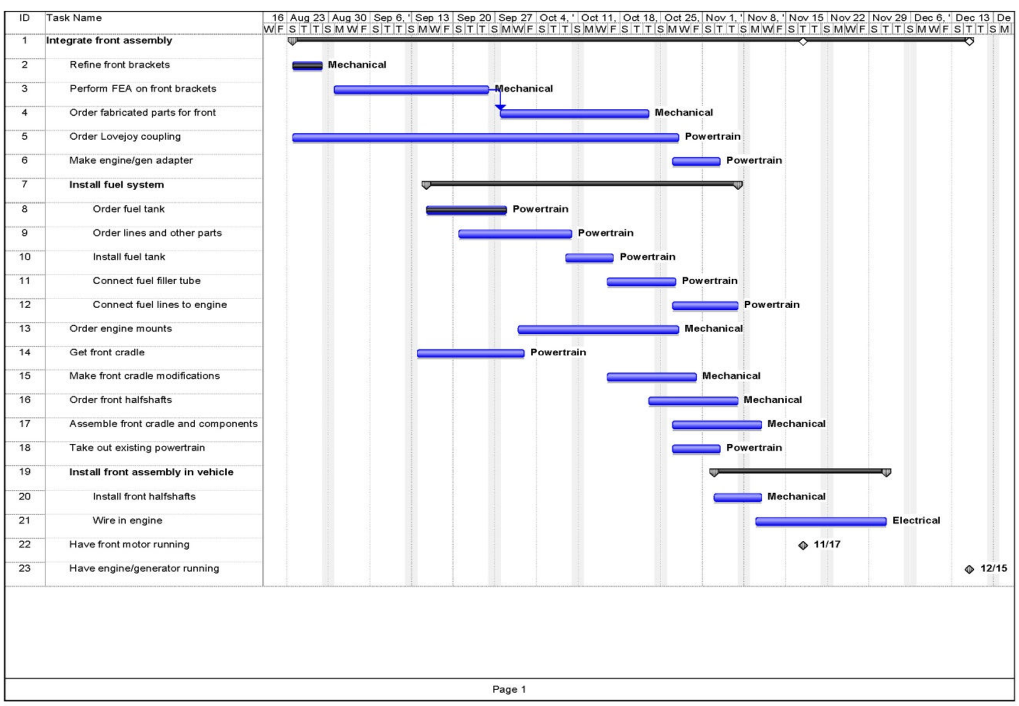

Fig. 2. Mechanical track Gantt chart

Benefits to Student Team Members

Students who participated in Challenge X or the current EcoCAR competitions have realized numerous benefits from these exciting opportunities. These have included technical experiences as well as practical concepts such as team work and familiarization with procedures and methodologies employed in industry. Specific examples of benefits that many of our students have realized are described as follows.

a. Proficiency with engineering tools

So as to minimize time as well as costs from concept to production, math-based system design concepts are employed to model and simulate vehicle performance. Students involved in this aspect of the competition are provided with the full suite of MatLab/Simulink software tools and extensive "hands-on" training at The Math Works in Natick, Massachusetts. Many students also receive advanced training in automotive specific toolboxes by application engineers. As previously noted, students are provided access to PSAT software to evaluate the economy of their various vehicle designs and receive specific training by Argonne engineers.

An important aspect in the design of modern vehicles is the vehicle controller that provides supervisory control of the numerous vehicle processors and components. Generous contributions were provided by automotive industries such as dSPACE, MotoTron/Woodward, and National Instruments who donated vehicle controllers and supporting equipment. In addition, these companies gave extensive training in the use of their products. A photograph of a hardware-in-the loop (HIL) configuration is shown in Fig. 2; this enabled students to actually demonstrate control algorithms developed for their ECUs.

b. Practical experience

The competitions require students to not only conduct detailed modeling and design, but they must implement these designs in hardware so as to develop a functional vehicle that they must compete. For many students this is their first experience in actually fabricating a complex system. They quickly learn lessons in component selection, interacting with vendors, and the importance of detailed scheduling. Although there are at times many frustrating hours, students gain self-satisfaction and confidence when their contribution is finally realized.

c. Team work

Students quickly learn that the tasks involved in the development and construction of a vehicle are far greater than a single individual, or even a small group of students, can manage. Several tasks, such as the controls development, likewise require the contributions of several students working effectively together. For many students, this is initially a challenge as many have never worked in groups larger than two students. These are oftentimes difficult lessons for students to learn as they may not initially recognize the extensiveness at which they are expected to function. Eventually, students develop a sense of pride in their team that further motivates them to excel.

Fig. 3. A dSPACE hardware-in-the-loop configuration using their Microautobox and their simulator chassis

d. Mentoring and exposure to practicing engineers

As previously noted, several of the sponsors provided mentors and advisors who serve as resources for the students. In particular, General Motors designated an advisor who patiently responds to numerous questions from the students and introduces them to other GM engineers who may provide specific advice. Another example is support provided by engineers from A123 Systems who donated lithium-ion battery modules for the battery pack. Although the students are required to actually design and fabricate the pack, A123 engineers critique the design and ensure that safe practices are followed. Throughout this process, however, these individuals only serve in an advisory role and students are required to conduct the actual design and fabrication. There are other benefits that accrued from the interaction of students with industrial sponsors, most notably in Challenge X, were job opportunities resulted for many of the students.

e. Communication skills

Throughout the competition, students are required to prepare detailed reports that describe their progress, activities, and technical design. These reports are graded by judges who evaluate not only the technical merits but other aspects such as grammar, format, and writing style. Extensive documentation is required. Likewise, the students are required to give numerous presentations that address technical issues such as control strategy and mechanical design. Non-technical presentations focus on outreach, website design, communication plans, and financial issues. The presentations are evaluated by panels of judges who are experts in their respective fields. The importance of effective communication skills was not initially recognized by some team members who found their overall score reduced despite having a vehicle that had superior performance.

f. Anticipate failure modes

Safe practices are emphasized throughout the competition not only in terms of the students' individual safety but the performance of the vehicle as well. Students are required to anticipate potential fault scenarios resulting from issues such as the presence of high voltage, potential fire hazards pertaining to the high voltage batteries, structural faults resulting from vehicle body modifications, electric power failures, and the failure modes associated with conventional vehicles that could potentially result in catastrophic effects. Examples would include a "stuck" accelerator, defective cruise control, failure of the traction control, and loss of regenerative braking, to name only a few. Students learn to employ Design Failure Mode Effects Analysis (DFMEA) techniques to identify potential problems affecting personal and vehicle safety as well as reliability. Methods are implemented to remove or mitigate such failures. The effectiveness of their DFMEA is first demonstrated in the laboratory using the HIL and later on a chassis dynamometer before finally being driven on the road.

Vehicle Competition

While the first year of the competition emphasizes the evaluation of the modeling and simulation skills of the students, later years of the competitions emphasize vehicle performance that is critically evaluated and includes static and dynamic tests such as:

- ✓ Acceleration, 0 – 60 mph and 50 – 70 mph
- ✓ On-road energy use
- ✓ Drive quality
- ✓ On-road and green house gas emissions
- ✓ Static consumer acceptability and noise reduction
- ✓ Engineering and fabrication workmanship
- ✓ Traction control and handling
- ✓ Braking and dynamic safety
- ✓ Trailer tow

Second year competitions are typically held at proving grounds such as in Mesa, Arizona, and Yuma, Arizona, where the temperature may exceed 115° F so as to stress the vehicles.

Improved Student Learning

The competitions involve numerous events throughout each year of the competition in which they are competing with the other 16 teams. Each year there are a total of 1000 points available; however, the distribution of points between the different activities varies from year to year. For example, in the first year of each competition there is not an actual vehicle so the emphasis is greater on written reports, presentations, and demonstrations. During the last year of each competition, a greater emphasis is placed on outreach.

Compiled in Table II below are statistical data that represent the performance of our team in the various types of events. The data are based upon the total points available. The percentage score is not always indicative of the team's performance relative to other teams. For example, in year four of Challenge X (2008) the MSU team won 81.7% of the total available points; however, the team in second place had an overall score of 74.2%. This data can be evaluated in terms of a comparison with other teams as well as how the MSU team compared year to year. For example, the team went from 9th place in year 1 to 1st place in the last two years. One may note an improvement each year in the quality of technical reports prepared by the students as well as an overall positive trend throughout the competition. It is noteworthy that in year 2 (2006) the MSU students had the best performing vehicle but the lack of attention to reports and presentations resulting in them placing 3rd overall. As the Challenge X competition lasted for four years, there was obviously student turnover; however, it is apparent that students were able to build upon the experience of prior successes.

Table II. Student Performance in Challenge X

	2005	**2006**	**2007**	**2008**
Reports	50.0%	74.8%	86.3%	97.2%
Presentations	79.6%	77.9%	95.4%	82.3%
Dynamic vehicle performance	--	87.8%	85.8%	88.8%
Overall score	66.5%	85.3%	89.5%	81.7%
Overall team rank	9th	3rd	1st	1st

Scores based upon total points available

Conclusion

Student participation in Challenge X and EcoCAR has been a rewarding experience that has enriched their education through "hands-on" automotive development. Not only has this exposed them to the most recent technology, but the team experience has emphasized how large, multi-faceted projects are undertaken in industry. For many of the students, this has also resulted in a familiarization with the industry and job opportunities.

There were likewise benefits to the universities as they gained recognition and visibility because of the success of their students. At our university this has resulted in numerous media events and has assisted in the recruitment of students interested in the automotive field. In addition, several university-industrial partnerships have been formed that have provided incentives for research endeavors.

Acknowledgment

The support of GM and DOE, the headline sponsors for Challenge X and EcoCAR, is gratefully acknowledged as well as the numerous other industrial sponsors who contributed resources and advisement to our students.