AC 2009-48: TWO IS BETTER THAN ONE: EXPERIENCES REVITALIZING A CAPSTONE DESIGN COMPETITION PROGRAM

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Abstract

This paper examines the steps taken to revitalize the Baja SAE program at the United States Military Academy (West Point). Due to some significant issues with the 2007 Baja SAE team, West Point did not compete in the 2007 competition. Because Baja SAE is conducted as a senior capstone design project, the lack of competitiveness led the senior faculty advisor to examine the program and take steps to prevent future failures. A brief history of the West Point Baja SAE program, course framework, and steps taken to revitalize the program are discussed in detail.

In order to bolster students' technical knowledge, the lessons of a related vehicle dynamics course were re-sequenced to better align with the steps taken to build the Baja vehicles. To heighten motivation for the project, early brainstorming sessions were conducted with limited success. The most successful change to the program was the creation of a second team for the 2008 season. The friendly competition between the two teams was a tremendous motivational tool that led to the successful completion of two vehicles for the 2008 competition. Individual feedback about the usefulness of the two team concept is discussed in detail.

Background

The Baja SAE competition first started in 1976. In this competition, engineering students from around the world are challenged to design, build, and test a robust, single-person, off-road vehicle designed for the "weekend enthusiast"[1]. Today, all vehicles are designed around the same 10 hp gasoline engine donated by a prominent engine manufacturer, making the design aspects of the vehicle very important. Students compete in one of three domestic competitions: East, Mid-West, and West. A unique aspect of the Baja SAE East competition that West Point habitually attends is that the vehicle must also be amphibious.

Figure 1. One of two West Point Baja teams at the 2008 Baja East competition.

The Baja SAE program at West Point has a long history dating back to 1991. Unlike some institutions where the Baja program is an extracurricular activity, at West Point, the Baja SAE program started as an independent study project, and more recently, has been incorporated into the mechanical engineering curriculum as a senior capstone design project. Baja teams at West Point typically range from 6 to 10 students. Because the competition is treated as a senior design project, students at West Point are forced to completely design a vehicle from the ground up during the two semesters of their senior year. This often puts the team at a disadvantage due to the lack of continuity and experience when compared to other colleges and universities where baja is an extracurricular activity. The faculty transition model at West Point also provides unique continuity challenges. Junior rotating faculty at West Point typically serve three-year assignments before assuming new positions in the operational Army; the faculty advisors for the West Point Baja SAE program are therefore in a constant state of change.

Throughout the history of the program at West Point, teams typically finish in the top half of the 90+ schools competing in a given year. The best team result was a 7th place finish in 1997. Unfortunately, the 2007 Baja team experienced some challenges during the production of their prototype vehicle and for the first time in the history of Baja SAE at West Point, the team did not bring a vehicle to competition. These challenges will be discussed in more detail later in the paper.

Participation in the Baja SAE competition is typically sought out by mechanical engineering majors at the academy, with some admitting that participation in the competition is the main reason they chose to major in mechanical engineering! The 2008 team consisted of an exceptionally large group of 15 mechanical engineering and one systems engineering major. The systems engineer was employed as a project manager for one of the cars built. Over the last several years the inclusion of at least one systems engineer has been common in order to provide a multidisciplinary team for the capstone design project.

The 2008 academic year brought new Baja SAE Faculty advisors as well as a new instructor for the automotive electives taught at West Point. In order to re-establish the Baja team with the Department of Civil and Mechanical Engineering after its prior year performance, the new head faculty advisor took it upon himself to revitalize the Baja SAE program at West Point and create a healthy, competitive environment for students during their capstone design experience.

Course Framework

The mechanical engineering capstone design projects at West Point are conducted in the students' senior year under a two course sequence. ME404 *Mechanical Engineering Design* is the first of the two courses, taken in the fall of the senior year. In this course students are introduced to the design process in the first 15 lessons. Students work on small individual projects to practice the design process. It is during this introductory period that capstone teams are formulated. Work on capstone projects really begins in earnest around mid October by lesson 17. ME496 *Mechanical System Design* is the second of the two courses. Taken in the spring of the senior year, this course primarily provides work time for the cadet design projects and incorporates various review classes to prepare students for the Fundamentals of Engineering Exam, a graduation requirement for all engineering majors at West Point.

In addition to the capstone design sequence required of all West Point mechanical engineering majors, automotive sub-discipline students take two automotive courses. ME491 *Mechanical Powerplants* is taken in the spring of the junior year. This course introduces students mainly to Otto and Diesel cycle engines with a short lesson block on fuel cell technology. ME492 *Mechanical Powertrains and Vehicle Dynamics* is taken in the fall of their senior year. This course introduces students to concepts in vehicle dynamics, powertrain components, and terramechanics. It is important to note that based on course timing, the Baja SAE teams are simultaneously learning the engineering design process, studying basic vehicle dynamics, and designing their Baja vehicles from the ground up. In addition to their rigorous course load, required military training, athletics, and daily military duties provide exceptional time constraints often not felt by the cadets' civilian peers.

Revitalization Plans

A number of issues plagued the 2007 Baja SAE team. First, a general lack of motivation was witnessed among the students from the outset. This lack of motivation was evident in a number of ways, including missed production deadlines, lack of follow-through tracking ordered parts, and the inability to have a completed vehicle ready for competition. Although motivation was a contributing factor to the ultimate demise of the 2007 team, the main issue with the vehicle arose from a fundamental flaw in the design of the steering system. When the vehicle was finally ready to drive just days before traveling to competition the team discovered a fatal flaw in the steering system design, ultimately leading to an unstable vehicle. Ultimately, this flaw was not correctable in the short time available prior to competition, and the team did not travel to competition.

The senior advisor to the 2008 Baja program served as a co-advisor during the 2007 season in addition to taking over the ME491 and ME492 courses for the 2008 academic year. Despite several attempts to coach the 2007 team towards success, the team struggled. It was at this point that the new senior advisor determined that fundamental changes had to be developed to ensure successful 2008 season.

The first change made was the rearrangement of the ME492 curriculum. The fatal steering flaw in the 2007 vehicle was traced back to the ME492 curriculum that the students received the previous fall. Looking at the sequence of the course, many of the crucial vehicle dynamics lessons (i.e. steering, suspension, etc.) were taught late in the fall semester, well after the students should have had a completed design for the Baja vehicle and begun frame fabrication. The students just did not have the knowledge necessary to make an adequate vehicle design. For the 2008 academic year, the course was re-sequenced to better support vehicle design decisions made throughout the fall semester. The results of this course redesign were positive from all students polled.[7]

The next major change for the Baja program was to increase the motivation and will to succeed. In any given year, the Baja team is put under tremendous time constraints to produce an effective vehicle. They are truly not able to start work on their vehicle until mid-October for a competition typically held in early May. In order to tackle this challenge, the senior advisor started early. First, a series of weekly "brainstorming" sessions were held starting in August of

2008, two months in advance of when formal design work began. The purpose of these sessions was to get interested students aware of the project and to begin discussing design possibilities. These meetings were voluntary and held in a "happy-hour" setting to entice students to attend. Attendance for these events was sporadic. Other than furthering the interest of some students, nothing really useful materialized from this attempt. Unexpectedly, however, some credit may be given to these sessions for generating interest that ultimately paid off by mid-semester, with 15 students making it their top choice on the ME404 preference sheets. In comparison, in past years interest was limited to less than 10.

Higher interest than in years past did raise concerns over the ideal size of a team, though. Based on previous experience it was determined that an optimal team would consist of 6-8 students, which coincides with other faculty experiences.[4,5,6] Because so many students were interested, the faculty determined that two teams would be formed for the 2008 season. These teams were formed by the head faculty advisor by ensuring a roughly equal average grade point average for the teams as well as taking into consideration student preferences for design partners. An issue with initial funding meant that although two teams would produce vehicles, only one would be able to travel. In order to determine which of the two vehicles would travel to competition, an internal competition was scheduled for early April. The more capable vehicle at the internal competition would be the one to travel to competition. This solution became the key to solving the motivation problem. Not only were the students competing against other universities around the world, they were competing against their friends and classmates. This friendly rivalry provided enough incentive throughout the academic year for teams to design and built their vehicles for competition at a quicker pace than in 2007.

Each team was assigned a faculty advisor and two co-advisors, who had either participated in a previous Baja competition, or had significant automotive knowledge. The decision to create two Baja teams generated some discussion among the advisor team. Concerns were raised over whether the competitiveness of the two teams would ultimately lead to "unfriendly" rivalry. Another concern was the best way to coach the teams towards success without inadvertently influencing the teams to produce two identical vehicles. Finally, the question was raised as to how secretive both teams should be about their designs. Ultimately, the advisor team decided to provide minimal constraints on any aspects of the vehicle design and fabrication, and the level of information sharing between the two teams. The advisors also provided technical feedback and facilitated cross-talk among the team members, but, ultimately did not change their advisory techniques because there were two teams.

Final Competition Outcome

The 2008 Baja teams experienced many of the challenges endemic of most undergraduate design teams. Deadlines came and went, budgets were underestimated, and poor communication led to some incompatible designs. Ultimately, because the teams each could see the same challenges happening to their classmates, they gained a certain level of comfort. The rivalry throughout the semester remained healthy and constructive, with teams seeking advice from each other on how to overcome various design hurdles. Interestingly enough, each team ultimately gauged success not by their Gantt chart, but by comparing their progress to the other team's progress.

The internal pre-competition took place about 3 weeks later than originally planned due to incomplete vehicles. When the competition was finally held, both vehicles were far from complete, but, were adequately complete for safe land-based operation. Shortly before the pre-competition, funding became available to send both teams to competition. Despite this fortunate turn of events, both teams were still required to compete in the pre-competition in order to ensure adequate progress had been made on the vehicles prior to the competition date. This event proved to be a tremendous success as both teams identified design flaws in their systems that needed to be fixed prior to competition. The event culminated with a celebratory barbecue and a winner crowned for bragging rights, if nothing else.

Figure 2. Both Baja teams at the pre-competition.

Performance of each team at the final competition was impressive. Both teams passed the rigorous technical inspection and were able to compete in all dynamic events. Both teams earned laudatory comments from the technical inspectors for the sound design work done by a first-year team. The vehicles placed 39th and 44th in a field of 94. They remained competitive in all events. It was interesting to note that the more reliable vehicle demonstrated during the pre-competition turned out to be the one with the most problems during the actual competition due to mechanical failure of the gearshift mechanism. Both vehicles completed minimal laps in the final endurance event due to metal fatigue failure of the steering system. It was encouraging to see that at competition, the friendly rivalry ended and the teams worked to together to ensure the success of both vehicles. As one team completed an event, information regarding the course and format were relayed to the other team to help ensure their success. This was the first time in the history of Baja SAE at West Point that two teams successfully completed and competed in the Baja East competition in the same year.

Student Feedback

In order to capture some of the reasons behind why both teams were successful, an end-of-course survey was conducted. Of the 16 participants in the Baja program (15 mechanical engineers, 1 systems engineer) for 2008, 12 responded. When asked whether they were successful, all responded positively, attributing that success mainly to hard work and support from the department's technical staff. Of particular interest were the responses to the question on the use of multiple teams for 2008:

Q: How did having multiple Baja teams this year help or hurt your success?

1. *It helped inspire an internal competition.*
2. *It helped by creating internal competition. It hurt by dividing people and assets.*
3. *Helped- competition kept us driven and let us see other alternatives to problems. Hurt- split up the members that really wanted to work on the vehicle and not choosing members hurt team dynamics.*
4. *Helped- teams were able to show the other difficulties and problems that would be applicable to both. Required increased insight to produce two separate products.*
5. *I think it helped because we fed ideas off one another, but a consolidated team with those that worked would have been more productive.*
6. *Helped because of friendly competition.*
7. *It helped that we could constantly be reminded of the competition aspect of this project; we wanted to win.*
8. *It was beneficial overall, because this allowed each team to bounce ideas off of each other throughout the competition and design process; it also served as a motivation factor to do better throughout.*
9. *I think it pushed us to compete with each other, allowed us to get designs approved faster, minimized team bickering. However, trying to find tools was tough in 2 rooms.*
10. *Hurt, most teams at competition had a least 2 man teams for each subsystem. Also for fabrication the number of people with experience was very low on each team but combined would have been good.*
11. *It didn't hurt, gave us another thing to work towards.*
12. *Help – sense of competition between teams & also a good benchmark at progress. If the other team started to pull away from us in terms of progress it would motivate us to work more.*

The one drawback noted by the students was the dividing of assets among the two teams. Two mentioned that additional help would have greatly decreased fabrication times and allowed for less work necessary by all team members. Ultimately experience has shown that teams greater than eight students typically degrade into six to eight real workers, producing the lion's share of the work with the rest taking a passive role and not truly contributing to the final product[4,5,6].

Due to the success of the two team concept during the 2008 academic year, two teams were planned for the 2009 season as well. Unfortunately, the team registration policy of SAE changed for the 2009 season, allowing each school to only register one team initially. Schools could only register a second team 2 weeks after the start of registration. All registration slots were filled before West Point could register a second team. For this reason, West Point was forced to create only one team for the season. Due to this change in SAE policy, future two-team seasons may not be possible.

Conclusions

Experiences in the 2008 Baja SAE competition have shown that some simple steps taken to revitalize the Baja program at West Point produced positive results. Re-examining the presentation of course material helped better prepare students for the decisions necessary during the design process. An attempt at voluntary early participation in Baja related activities

ultimately did result in increased awareness rather than productivity which was the original intent. The use of multiple design teams created a healthy rivalry among the students. This rivalry helped increase student productivity and excitement about their design competition experience. Pitting both teams against each other for funding to compete at competition effectively spurred them toward greater success. The use of an internal pre-competition was an effective way to ensure both teams had produced a driving, functioning vehicle well in advance of the competition dates.

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