2006-320: THE ASME SPONSORED HUMAN POWERED VEHICLE CHALLENGE - FRAMEWORK FOR A SENIOR DESIGN PROJECT

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The ASME Sponsored Human Powered Vehicle Challenge Framework for a Senior Design Project

Abstract

During the senior year, mechanical engineering technology students take a two-course sequence in senior design. Each year, students are challenged to formulate a project that is complex enough to meet the requirements but not so complex that it cannot be completed. Selecting a project is further complicated by most students' lack of industrial experience, and the associated feel for what is appropriate and manageable.

An annual design competition that makes an excellent framework for a senior design project is the American Society of Mechanical Engineers (ASME) sponsored Human Powered Vehicle (HPV) Challenge. Held each spring, the HPV Challenge is a competition in which teams of students design and build a vehicle powered solely by human power. Vehicle classes include single rider, multi-person, and practical, each with their own design goals and constraints. The competition includes design, sprint, endurance, and utility events.

The HPV Challenge provides an excellent framework for a senior design project for many reasons. Planning typically begins in the fall, where early decisions must be made with regard to vehicle type, configuration, and overall design goals. The competition's rules structure provides necessary constraints, and the competition dates, typically late in the spring semester, necessitate adherence to a strict timeline. Participants must prepare and submit a comprehensive design report that is reviewed by competition judges, typically experienced design engineers. They must also make a formal presentation to the judges as part of the competition weekend. In short, the HPV Challenge provides students a detailed, real-world, hands on engineering design project that is also an excellent framework for a senior design project.

Introduction

During the senior year, mechanical engineering technology students take a two-course sequence in senior design, which acts as a capstone course for the program. The capstone course exposes the students to open-ended problems and also provides a framework for their evaluation.[1] Each year, students are challenged to formulate a project that is complex enough to meet the requirements, but not so complex that it cannot be completed. The ubiquitous car jack has been designed numerous times, while an aircraft that runs on hydrogen fuel is probably too ambitious for even the most dedicated team of students. Selecting a project is further complicated by most students' lack of industrial experience, and the associated feel for what is appropriate and manageable. To help with this difficulty, students are often given a list of proposed senior design projects, one of which is the American Society of Mechanical Engineers (ASME) sponsored Human Powered Vehicle (HPV) Challenge.

Human Powered Vehicles

HPVs are aerodynamic, highly engineered vehicles designed to operate solely on human power. They may have two, three, or even four wheels, and are normally equipped with some type of aerodynamic fairing. Although most HPVs are designed to be ridden in a semi-recumbent position, other rider positions are not uncommon. HPVs are commercially available from many manufacturers, as shown in Figure 1, and are also designed and built by many backyard enthusiasts[2].

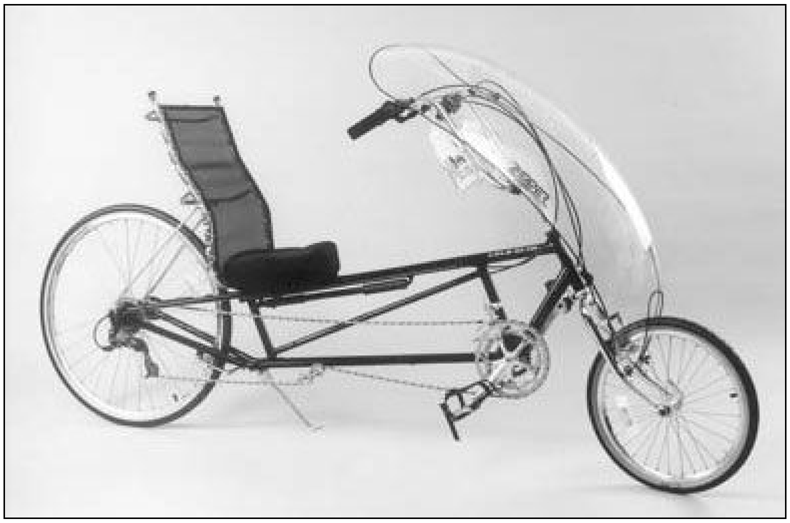

Figure 1 – Commercial Recumbent HPV[3]

HPV related events are frequently held throughout the world, including rallies, speed championships, and other awareness events. The Human Powered Vehicle Association sanctions most North American events, while the International Human Powered Vehicle Association (IHPVA) is an international organization that promotes innovation and creativity in the design and development of human-powered vehicles. The IHPVA also publishes a technical journal titled *Human Power*.

Human powered vehicles may be designed for practical uses, such as an efficient means of transportation, or for pure speed. Although rider ability certainly has an impact, the key to the attainable speed of an HPV is its aerodynamic fairing. For a traditional upright bicycle at race speeds, 90 percent of the rider's power is used to overcome aerodynamic drag[4]. Reducing drag through the use of a fairing allows HPVs to travel at much greater speeds than would otherwise be possible. The current speed record[5] for a single rider HPV (200 meter trap with flying start) is 81.00 mph (130.36 kph), while the current hour endurance record is 52.33 mph (84.22 kph). Both records are held by Sam Whittingham piloting the Varna Diablo, pictured in Figure 2.

The HPV Challenge

The American Society of Mechanical Engineers sponsored Human Powered Vehicle Challenge is an annual competition for which teams of students design and build a vehicle powered solely by human power. Vehicle classes include single rider, multi-person, and practical, each with their own design goals and constraints. Held each spring, the HPV Challenge includes design, sprint, endurance, and utility events, pitting teams of engineering students from across the country against each other in a friendly contest of engineering (and human power) abilities.

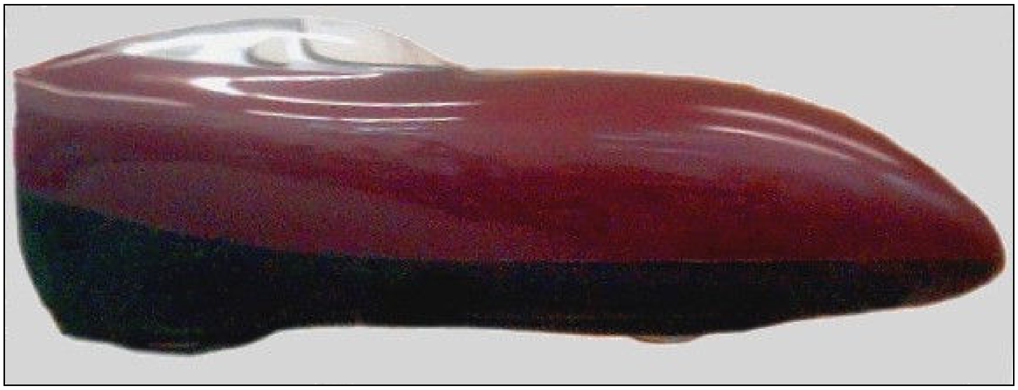

Figure 2 – The Varna Diablo[6]

Single rider vehicles are obviously piloted by a single person, while multi-person vehicles may accommodate two or more riders. Bikes in these categories are typically built for speed, a key element in the competition. An example of a single rider HPV is shown in Figure 3. Practical vehicles may be single or multi-rider, and are intended to demonstrate the vehicle's usefulness for daily activities such as shopping, transportation or recreation. Examples of practical vehicles are shown in Figure 4.

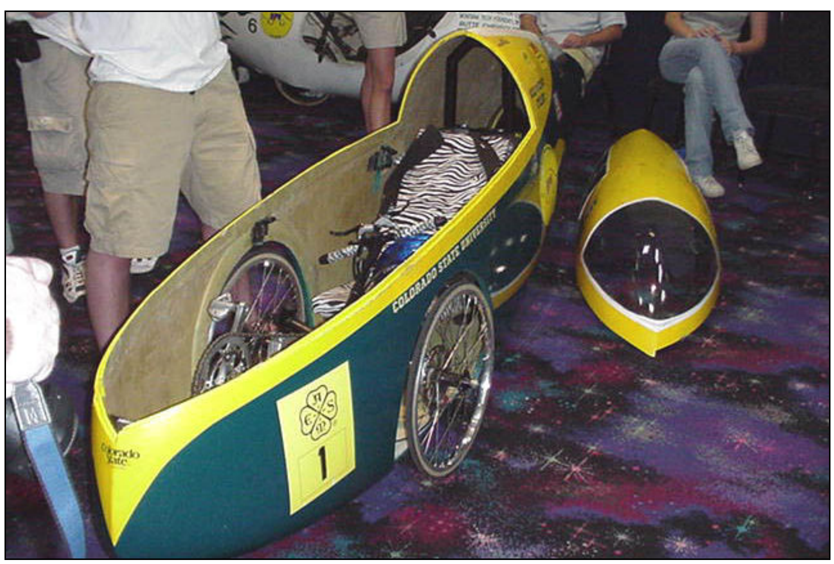

Figure 3 – Single-Rider Vehicle from Colorado State University

The competition rules[7] provide basic design constraints for the various vehicle classes and include requirements related to safety and performance. Examples include specifications for roll-over protection, criteria for stopping distance and turning radius, and the prescribed use of helmets and safety belts.

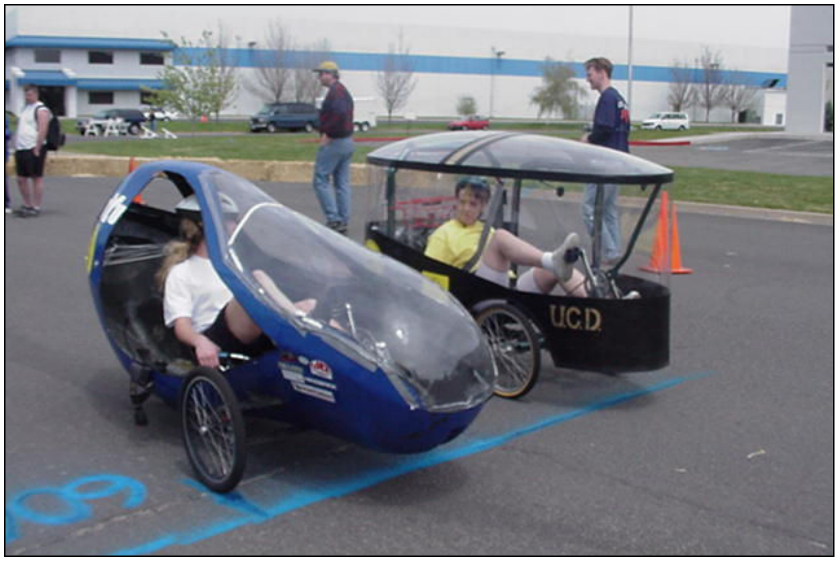

Figure 4 – Practical Vehicles from Brigham Young University (foreground)
and the University of Colorado at Denver

The three-day competition includes design, sprint, endurance, and utility events. Single and multi-rider vehicle classes participate in design, sprint, and endurance events, counting 40 percent, 30 percent, and 30 percent respectively towards the team's final score. Practical vehicles participate in design and utility events, counting 40 percent and 60 percent respectively. A team's result in the design event is determined by three elements: a detailed design report submitted in advance of the competition, a presentation to the panel of judges, and the static display of their vehicle. The presentations and static display typically occur on Friday evening.

Figure 5 – UNC Charlotte Team Members and Vehicle at Design Presentation

Saturday morning brings the sprint event, where vehicles are given a running start and are then timed through a short speed trap. The goal is to measure the vehicle's top attainable speed. All teams are required to have at least one female rider, and the top male and female speeds for each team are averaged to obtain the team's score for the event. Figure 6 shows vehicles lined up to begin the sprint event. The utility endurance event is held on Saturday afternoon, where practical vehicles negotiate a road type course that includes speed bumps, potholes, parking spaces, and stop signs. As an added challenge, the practical vehicles must carry a small package, similar in size and weight to a bag of groceries.

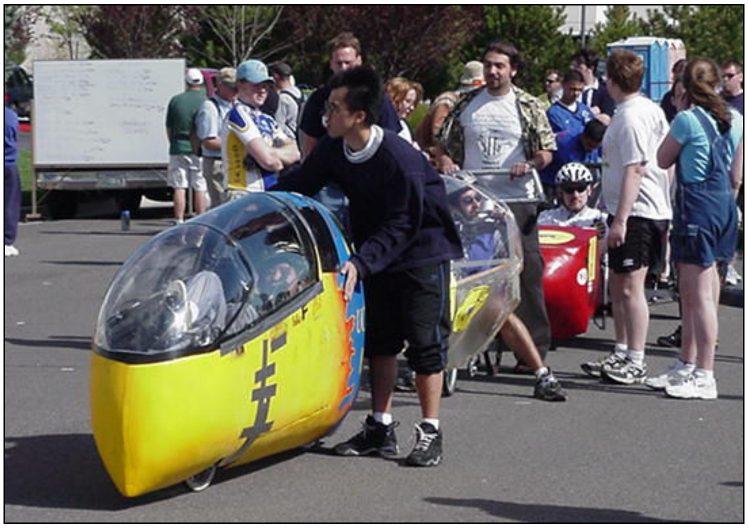

Figure 6 – HPVs (left to right) from University of California Davis, University at Buffalo, and Youngstown State line up for the Sprint Event

Sunday morning's endurance event sees all single and multi-rider vehicles on a road course at the same time. Vehicles are seeded based on the female rider's sprint time and complete a total distance of about 40 miles (64 km). Minimum distances are normally prescribed for a female rider, and maximums are established for all riders. Rider changes are made in a pit area, and reward the team that can get in and out of their vehicle quickly. Figure 7 shows vehicles racing in the endurance event.

A Sunday awards luncheon completes the competition weekend. Trophies are awarded for first through third place in each vehicle category (single-rider, multi-rider, and practical) and also for each event (design, sprint, endurance, and utility). Each competing team receives at a minimum a certificate of participation. In addition, judges awards are often given for spontaneously created categories, such as best demonstration of crash survivability or most creative use of duct tape.

ASME sponsored a single HPV Challenge each spring until 2001. Host institutions during this period were primarily in the western half of the United States. As the event gained popularity and participation, ASME began in 2002 offering two Challenges, with the second event designed to be more accessible to east coast schools. Over the past several years, some twenty to thirty schools have participated in each version of the Challenge, some with multiple vehicles entered in the competition.

Figure 7 – HPV's (left to right) from the South Dakota School of Mines and Technology, Sand Diego State University, and University of Nevada, Las Vegas racing the Endurance Event

A Framework for Senior Design

ASME's HPV challenge can provide an outstanding framework for students to satisfy the goals and objectives of a senior design project. Common elements of a senior design course, along with corresponding elements of the HPV Challenge, are presented in the following sections.

Schedule:	Many institutions require a year-long senior design sequence that begins in the fall term and finishes prior to spring commencement. Planning for the HPV Challenge typically begins in the fall, where early decisions are made with regard to vehicle type, configuration, and overall design goals. Detailed design continues through the fall, with construction and testing following in the spring. The competition itself normally occurs during late April or Early May, a few weeks before the end of most school's academic years.
A systems approach to problem solving:	A systems approach to problem solving is typically utilized in many aspects of the project, both major and minor. Major decisions, such as what type of vehicle, and minor ones, such as the required diameter of a drive axle, can both be solved using a systems approach.
Quantitative and measurable performance objectives:	The competition rules structure includes specific guidelines that provide quantitative and measurable performance objectives. Examples include roll-over protection, energy storage devices, criteria for stopping distance and turning radius, and the prescribed use of helmets and safety belts.

Project planning; use of a Gantt chart:	Many design courses require development of a Gantt chart for planning purposes. A detailed project such as this illustrates the true usefulness of such a tool, especially when hard deadlines for report submission and the competition itself are imposed.
Design decisions; use of the Pugh method	Many design courses also require use of the Pugh method for decision analysis. This project presents numerous options to students, such as such as what material(s) to use for the frame and fairing, what fabrication method(s) to employ and what drive system to utilize. The Pugh method of selection analysis can be an ideal tool for illustrating the importance of decision making early in the design process.
The role of analysis in design:	This project offers many opportunities for students to apply principles learned in the classroom. Examples may include a shear & moment diagram to fully understand a beam's loading, Mohr's circle to learn the combined affects of bending and shear in a drive axle, or the opportunity to apply finite element analysis or computational fluid dynamics to a real-world problem.
Engineering economy and tradeoffs:	This project provides many opportunities to apply economic principles and trade-offs. Project teams must budget limited funds, and must also consider fiscal constraints in their decision making. In addition, competition rules require teams generate an estimate of the manufacturing cost of the vehicle.
Case studies in engineering design:	The longevity of the HPV Challenge, along with many student teams developing websites that document their designs, provides numerous opportunities for students to review past designs. The commercial HPV industry also provides a significant body of technical knowledge for examination, along with the technical journal *Human Power*.
Design evaluation; comparing performance to objectives:	This project requires that students actually build what they design. Nowhere are lessons more thoroughly learned than by the first hand experience provided by this project. Typical "discoveries" include designed parts that cannot be made, under-designed (or mis-analyzed) parts that fail, or over-designed parts that produce a vehicle weighing much more than anticipated.
Oral and written communication skills:	Competition rules require that teams submit a written design report with specific evaluation criteria. In addition to the written report, teams are required to give a five to ten minute oral presentation to the competition judges. Teams are encouraged to use presentation aids, such as Microsoft® PowerPoint. These requirements are similar to that of most senior design courses, allowing students to satisfy both with minor modifications.

Lessons Learned

Student teams from UNC Charlotte have competed in several HPV Challenges over the years. The following lessons are offered to any student teams and/or faculty advisors that may be considering fielding a team in the future.

Continuity from year to year: Many schools that field entries in the HPV Challenge do so with a team composed predominately of senior students. It is recommended that project teams include junior, sophomore, and even freshmen engineering students, even if their participation is voluntary and not for academic credit. Many lessons are learned in the course of this project. Too many times, valuable experience gained during the year departs along with the graduating seniors, and next year's team is left to start from scratch.

Athletes: Sixty percent of a team's overall score is related to performance in either speed or endurance events. Regardless of a vehicle's weight, aerodynamics, or other design features, the simple fact remains that human power is a significant determinant of a team's success. Schools that perform well in the competition are successful at recruiting experienced cyclists to their teams (subject to competition rules that limit eligibility to engineering students).

Training: Even if a school is unable to locate or persuade gifted athletes to join its team, performance in the speed and endurance events can be greatly improved by training among the members that plan to ride in the competition. A key is beginning early in the process, as gains in fitness take many months to be fully realized.

Importance of the design report: In counter to the above, design counts forty percent of a team's score. The majority of that score is based on the contents of the design report, which must be submitted about a month prior to the competition. During this period, construction of the vehicle typically dominates the student's time, and many teams submit reports of lesser quality than they would if they devoted more time and effort in its development. A possible solution is to divide responsibilities among the team members, ensuring necessary emphasis on the report.

Innovation in design: Another important element of the design event is innovation, a basic tenet of the entire competition. Judges look for innovative ideas in the application of human power and typically reward those innovations in the team's design score.

Realistic goals:	Although this is one of the valuable lessons learned first hand by students, it cannot be emphasized enough that projects typically take longer and cost more than initially thought. Students begin in September imagining sleek, lightweight rockets crafted from carbon fiber and titanium. In reality, time and fiscal constraints often require more realistic choices.
Adhering to a schedule:	As teams form in September, students typically feel they have plenty of time to design and build a vehicle. Early months usually pass without significant progress. A common occurrence in early team meetings is for members to continue proposing unrealistic alternatives while not making concrete decisions, accomplishing little and wasting valuable time. A suggested approach is to require that detailed design be complete by the end of the fall term, with major decisions (vehicle type, drive system, fairing placement, etc.) being made much earlier. If construction does not begin in early January, teams inevitably have difficulty finishing their vehicles in time for the competition.
Testing:	A major element of the design report is testing. Since the design report must be submitted a month prior to the competition, results of vehicle testing must be available before that deadline. This obviously requires the vehicle to be somewhat complete and rideable many weeks in advance. Student teams typically do not complete the vehicle until a few days (or in some cases hours) before the competition. This leaves little time for any testing at all, and of course results in no test results being included in the design report, lowering a team's score in that area.
Break-in period:	As mentioned above, vehicles are often not completed until just before the competition. In addition to testing, this also prohibits any significant break-in period, and the valuable opportunity it provides to learn about the vehicle and any needed modifications. In addition, even experienced cyclists may not be familiar with a recumbent riding position, and can benefit greatly from getting in some miles before the competition.
The fairing:	Competition rules require all vehicles to be equipped with a full or partial aerodynamic fairing. The fairing must cover at a minimum 1/3 of the frontal area of the vehicle. Of course, a greater aerodynamic benefit is realized by a full fairing. As important as the fairing is, it is often the most neglected element in the design. Important considerations, such as material, method of construction, opacity, shape, etc., are often left to the last minute, and are not given due consideration. The vehicles that place highly in the performance events give a great deal of attention to this important area of vehicle design.

Conclusion

ASME's HPV challenge provides an outstanding framework for students to satisfy the goals and objectives of a senior design project. The various vehicle types and competition events provide multiple avenues of project focus to pursue. The design process enlists multiple disciplines within engineering, including strength of materials, structures, aerodynamics, machine design, and engineering economics. The competition's rules structure provides necessary constraints, and the competition dates, typically late in the spring semester, necessitate adherence to a strict timeline. Participants must prepare and submit a comprehensive design report that is reviewed by the competition judges, typically experienced design engineers. They must also make a formal presentation to the judges as part of the competition weekend. In short, the HPV Challenge provides students a detailed, real-world, hands on engineering design project that is also an excellent framework for a senior design project

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