2006-2472: HOW TO ENGINEER A WINNING COMPETITION PROJECT: LESSONS LEARNED FROM THE HUMAN POWERED VEHICLE CHALLENGE

John Gershenson, Michigan Technological University

Dr. Gershenson is an associate professor of Mechanical Engineering – Engineering Mechanics at Michigan Technological University in Houghton, Michigan and directs the Life-cycle Engineering Laboratory. Professor Gershenson performs research in the areas of life-cycle product architecture and lean and sustainable design and manufacturing. Specific research interests include: product and process architecture, product platforms, modular product design, lean manufacturing, lean engineering, life-cycle design, and design for the environment. Research sponsors include NSF, General Motors, Ford, Lucent Technologies, SME, and ALCOA. He has approximately 32 refereed publications and has been the PI on research projects with a total value of about $2.5 million.

How to Engineer a Winning Competition Project:
Lessons Learned from the Human Powered Vehicle Challenge

Abstract

Engineering society competitions, such as the ASME Human Powered Vehicle Challenge, are commonly used as projects in capstone engineering projects. At MTU, we have made use of this competition to give students and experience using a structured engineering design process and to help them become confident in their ability to bring a project from requirements to hardware delivery. These goals are realized in other capstone design projects as well at MTU and backed up by a set of corresponding lectures. MTU has had mixed results with competition projects in capstone design in the past. In the four years that we have participated the ASME Human Powered Vehicle Challenge, we have been able to overcome the usual issues that cause students to under utilize their engineering skills in competition projects.

The MTU Human Powered Vehicle team has been very successful in meeting their goals for the competition – engineering excellence. The keys to our success have been how we have solved the issues of team organization, advisor management, and sponsor support. Over a four-year period we have developed a system of organic leadership building and flexible staffing of engineering problems. The advisors have learned to both motivate and manage the team, while taking care of administrative roadblocks. We have also developed an extensive network of component and service sponsors; without whom, a project at this level is impossible. Of course, along with all of these important programmatic developments, it is still the engineering and a push to continually innovate with respect to the design, the engineering, and the fabrication process that has led to the success of the MTU Human Powered Vehicle program.

Background

As we discuss our use of a Human Powered Vehicle competition project to satisfy a capstone design requirement in MTU's Mechanical Engineering department, it is important to understand our unique capstone design program, ASME Human Powered Vehicle Challenge, our previous involvement in competition projects, and the history of our involvement in the ASME Human Powered Vehicle Challenge.

MTU capstone design

The MTU mechanical engineering capstone design, or senior design, program is in some way familiar, but perhaps unique in it size and funding. We have students take a two semester, six-credit sequence. During that sequence they work on a single, group-based senior design project as well as attend lectures on the engineering design process. During the first semester, there is a heavier lecture load and the students concentrate on requirements gathering, conceptualization, layout design, engineering analysis, and prototyping. During the second semester, the lecture load is light and the students concentrate on further engineering analysis, testing, fabrication, and delivery. We maintain a 75% level of industrially sponsored projects. Companies pay approximately $15,000 to have a group of four or five students and a faculty advisor solve an engineering problem that includes a fabricated deliverable and an engineering report. We have nearly 200 students per year in our senior design program working on roughly 40 projects. Advisors will typically advise four projects over the course of a year to receive the equivalent load of a one-semester course with 40 students. All groups have approximately $4,000 at their disposal for design and fabrication as well as the many fabrication resources on campus. It is not required that students do the fabrication themselves, as they have had previous experience in the curriculum. Many projects require outside manufacturing, often at an additional cost to the project sponsor. Several of the projects are not sponsored, by design. This allows freedom to develop equipment for the department laboratories and one competition project – the Human Powered Vehicle Challenge.

HPV competition

The ASME Human Powered Vehicle Challenge is ASME's main foray into large-scale student design competitions. The competition entails engineering and racing student designed vehicles that are entirely human powered. The competition includes single rider, multi-rider, and utility vehicle categories. Vehicles must be at least partially fared and even the single rider vehicles require an exchange of riders during the racing. Vehicles in the single rider race (the marquee event) must submit an engineering report that is judged on design and innovation, analysis, testing, safety, and aesthetics. Approximately 50 schools compete in the challenge in the east and west coast.

History of competition projects here and elsewhere

In the past, before our switch to primarily industry funded capstone design projects five years ago, our department had used competition projects for senior design occasionally and as extracurricular activities as well. As senior design experiences, the competition team projects ran into a common trap - the enticement to "just build" the product and then tinker with it until it is fast as opposed to taking the time to "engineer" the product. The unfortunate thing is that the tinkering had met with success in competition despite offering a poor learning experience in the engineering design process. This result is often due to the nature of the competition rules and the focus of the advisors on winning the "race."

Our involvement with HPV

For the last four years, MTU's department of mechanical engineering has been entered in the ASME Human Powered Vehicle Challenge. It started five years ago when we sent a faculty member to the competition to see if the project would be appropriate for our new senior design sequence. We were looking for the opportunity to engineer a product and show off the quality of our program to the country. We have made a point of going head to head with the best collegiate programs over these four years. As we state in this paper, we have found that it was necessary to develop an HPV "program" that is larger than just that year's students or advisor to maximize the learning potential in this project. It is not possible, as other schools in this and other competitions have learned, to compete on a one-year basis. One thing that we have done directly, and that the ASME HPV Challenge seems to support, is that we have emphasized vehicles that are radically different from one year to the next.

Motivation

As we stated our motivation has been to use HPV to expose students to a structured design process. We also have sought to give students the feeling of "winning" as an engineer. We were confident that our students were some of the best mechanical engineers in the country, it was clear that they did not know this. A national competition such as this, similar to an industrial project where students deliver to a customer for their approval, allows student to experience success as an engineer and gain confidence. Of course, it was also important in a national competition to show this quality and success to the rest of the country.

Team issues

One of the most important elements in the success of the MTU HPV program has been how the team itself has been formed, organized, and led. We have learned several lessons along the way as our team organization has improved.

How many students?

It takes more students than you would expect to have a successful competition team project. There are three issues at work here. The first issue is that if the vehicle is to be engineered, truly engineered from the ground up, there is a lot of work to be done in both the engineering and fabrication of the vehicle. The second issue is that there is a steep learning curve to learn the state of the art in HPV design, engineering, and fabrication both from our own past designs as well as the world of professional HPV design. The last issue is what I refer to as every students right to get a D. Students do not have to work hard and there will always be some that choose to get through the class with a minimum of work and the worst possible grade. These staffing issues can either extend the timeline for development or increase the number of students necessary.

At least one program has combated the time line by using what we call an "enterprise" approach. This is where students of varying graduating classes come together to form a team where the younger students are learning from and assisting the older students on the current vehicle. Some enterprises even have the younger students beginning development of the next year's vehicle in parallel with the production of the current vehicle. MTU has used this approach in their SAE competition vehicles with success. While it has the additional benefit of requiring that older students become teachers, it creates a wide variety in student capabilities and increases the difficulties in management and resources. This should be undertaken only if the resources exist.

The approach that the MTU HPV program has taken is to expand the staffing of this project to what we have found to be an ideal size – 16 students. We have tried staffing of between 12 and 20. We have found that it takes approximately 13 fully committed students to do a proper job on the vehicle. Having 16 allows a couple to "exercise their right to do nothing." Having a large number of students with a wide variety of abilities has been key to our success. We have ensured that success through word of mouth recruiting and by recruiting students from other departments, especially materials science and biomedical engineering. The way our capstone design program is set up in the college of engineering, several other departments can have their students take our senior design and receive full credit towards graduation as long as there is a sufficient major-specific content to the project. The tie in to materials and biomechanics are easy to justify on the HPV.

"Selecting" leaders

The HPV team does and must operate as a small development organization. The coordination and motivation of the entire group towards a single goal is necessary. We learned immediately that the project is too large and complex for the class grade to serve as a sufficient motivation to succeed. Neither can the best advisor motivate the students enough to succeed. The motivation must come from within and requires a good group with one or two great leaders. We have tried pre-selecting leaders, having leaders apply for the position, and appointing leaders halfway through the project. We have found that the best method for identifying leaders is to sit back and watch the leaders emerge over the first semester. At the end of the first semester, the advisor will approach those natural leaders – who set the example for quantity and quality of work and knowledge and also those whom the students naturally follow – to discuss their role as leaders on the team. Often it the leaders are two people – one is the technical leader the other is the management leader – and they must work in concert. When approaching the students, it is easy to convince them that the students are following their moves, although they usually do not realize this. However, we then offer them a deal – they will be treated as the leaders by the advisor, but they will be held to a higher level of accountability. I have never had a student refuse this deal. These students always rise to the challenge.

It is also important in this development organization model to give every student the experience of leadership. As we split into functional tasks and small groups, we make a point to give every student the opportunity to take on a leadership role. This is done to both spread the burden and to spread the experience. Students are not aware that this is going on. We have that formalizing this process, like formalizing the leadership selection process, gets in the way. Our attempts to pre-select leaders and to make the appointment of the leaders a public and formal affair usually backfires because the students are put under too much pressure to immediately act like a leader. Our more organic process allows the student leaders to slowly assume the role.

Organization

The lessons learned in how to organize the team as it undertakes the many different functional and component-based tasks of engineering and fabricating an HPV were significant. The first year we ran the HPV project we had four groups of five students that were split into two redundant teams based upon subsystem sets (two teams worked on the drive train and steering, two teams worked on the faring and frame). The teams worked in competition to develop the “winning” concepts during the first semester, and then were resorted to perform advanced analysis, testing, and fabrication in the second semester. While we did well, organizationally it was a failure. The competition bred groups that were engaged and those that were not in the second semester, plus we effectively lost the productivity of half our team in the first semester. Students were also so set on “winning” that many engineering issues were passed over in favor of innovation, making integration of the concepts difficult. One positive was that in the remix of the team made for a very critical eye during integration and the result was delayed, but well engineered.

In and effort to speed development and build team spirit, the second year we assigned students to groups to solve component-based problems (drive train, materials and fairing, structure, and steering) based upon their abilities and kept these groups intact throughout both semesters. The result was a significant increase in engineering capabilities and innovation, which effectively used up all of the development time saved (a near impossibility to avoid). However, having distinct subsystem “silos” led to significant integration issues at the end of the project and a noticeable “unevenness” in the level of engineering in each subsystem. It became obvious that we did not have the richness in engineering skills – particularly CAD and finite element skills – spread to each team. In the end, we were able to share some skills among the teams when absolutely necessary. This analysis typically was done after most of the significant engineering decisions were made.

In the third year, we moved to more of an engineering function-based organization. Because there were many engineering functions in the project, many students served on multiple teams. We had one team for CAD, one for finite elements, and one for engineering analysis, as well as a team to design the drivetrain, the steering, *etc*. There was a marked improvement in the level of engineering. We went from a team that had won the design and innovation for the last two years, to a team that once again repeated in design and innovation, but added to that the overall engineering crown. In addition, we moved towards a single group in the second semester for the purposes of fabrication. We began a serious undertaking on the production process side that required more hands. This is where the team leaders played a major role in coordinating these efforts. A significant role was also played by people who championed and led smaller fabrication elements for the drivetrain, steering, *etc*.

To build on the success of the previous year, the fourth year proceeded much the same. The only difference was that we did not initially limit the size of any of the functional or component groups and we allowed the students to associate themselves with these groups as they wanted. This was quite successful as the group size morphed as the needs of the groups changed.

Students were not left with nothing to do because the least capable or least involved student in a group would just move to another group where they were needed more. As we had in all previous years, the entire team met once per week to make sure progress, staffing, and integration was appropriate. In years three and four, we saw very few integration issues because of the overlap of the groups.

Advisor management

It seems that the level of involvement of the advisor makes a considerable difference in the success of such a large and complex project. The big issues that the advisor must be responsible for are getting the team up to speed quickly, managing the global schedule with an eye on the end, overseeing the financial and resource management, managing the leaders, and keeping an eye on motivation.

Because we are not an enterprise, but yet we expect each year to build on the design, engineering, and process successes of previous years, it is the advisor that must manage the lessons learned from year to year. We have been able to maintain an active group of HPV alumni, so the task is to know where the information is more than to remember each detail. We use these alumni, previous reports, and a significant amount of deadline pressure to get the groups up to speed very quickly.

The advisor is also the only one that has been through the entire development process of an HPV previously. As such, the advisor is the only one with a feeling for whether the schedule is on track or not. The students will learn to gauge where they sit by your level of comfort with the schedule.

As you will see later in this paper, the resources needed for running a successful HPV program are considerable. It is too much to ask the student leaders to manage all of these resources, especially dealing with administrative issues. That is a little too “real world.”

Managing the leaders is a daily job, accomplished by e-mail and passes in the hallway. They just need to know that it is okay to tell people what to do and that you trust their judgment. Showing your trust in them early and often is important, even if you risk some setbacks for that.

Motivating the students is the trickiest of all advisor tasks and involves a careful balance of involvement, becoming “one of them,” and maintaining distance. We have used a two-advisor system for this project in all four years. There has been one advisor that remained consistent with the second advisors coming and going. The one consistent advisor manages the project and puts in most of the time. The second advisor is brought on board for specific technical needs that year. The first two years, the technical advisor was the one that first went to see the race and had advance knowledge of what to expect. That advisor, Dr. Ghatu Subhash, also put in place the university resources to assist with the project financially. In the first year, Dr. Chris Passarello also helped to advise the team. The third year, we brought on an advisor to improve our engineering analysis capabilities. This advisor, Dr. Roshan D’Souza, guided the students in building parametric analytical tools. The last year, we brought in a composites expert, Dr. Ibrahim Miskioglu, as our emphasis was on the composite production process. These second advisor attends the two-hour weekly meetings (at night due to the size of the group and schedule conflicts) and is available for consultation on an open door basis. The primary advisor puts in considerably more time. With this large of a team, management by walking around is a necessity. The advisor needs to be where the students should be, when they are there and must be abreast of the daily achievements and set backs. The main reason for this significant advisor involvement is that the project requires more student involvement than just the class credit given. To achieve this commitment to the project from the students, the advisor must show their commitment first. I have achieved this by being there often and late. I have found it easiest to show up late at night while they are working (sometimes with food). This makes them feel that their advisor is with them. In addition, I make sure that they view me as someone that will defend them when there are issues with the administration. Occasionally, there will be a misuse of facilities, etc. It is best and easiest to put the entire blame on the advisor and gain the motivation of the students. Lastly, it is important to be a cheerleader, especially when things go wrong and to let them know that you are confident in them. Remember that they have never undertaken such a large project and they are scared by the shear complexity of it. You need to show confidence and appreciation. Sometimes it is an e-mail at 2am; sometimes it is just pulling individuals aside and congratulating them; always, it involves saying "thank you."

Resources

As stated previously, our senior design groups are given approximately $3,000 to fabricate their projects and $1,000 for travel. Theoretically, our HPV team is four groups. However, for resource purposes we are at about $8,000 total. Travel alone eats up a significant part of the budget, so maximizing resources through donations of cash and components and services is a must. Additionally, our senior design program has significant in-house fabrication resources and nearly any engineering resource imaginable. The HPV team has also built up its own cadre of fabrication resources and space specific to their needs.

Fabrication

In its first year, our project was given part of some available student workspace – just space. At the time, we were developing an aluminum frame with a carbon/Kevlar fairing. The space was used primarily for the fairing fabrication – molds and the final fairing – and for final assembly and testing of the vehicle. The split of fabrication (frame and drivetrain fabrication were elsewhere) coincided with the organizational split. It made for significant losses in communication. Much of our metal fabrication was also done out of house by local suppliers. This caused significant delays and rework. It also provided for a good educational experience for the students.

By the fourth year, we have moved to another space off campus that allows us the ability to gather resources that are more permanent. In addition, we have moved to an all composite monocoque so the entire vehicle is fabricated nearly as one with final assembly being a relatively minor affair. We still use the on campus machine shop for metal components, but there are not many components that are metal. The machine shop is a significant source for prototyping of functional elements however.

We have begun to rely nearly entirely on in-house fabrication resources to minimize the risk in production. As our composites manufacturing process (described later) becomes more complex, there are fewer suppliers that can help us. We now only use one outside manufacturing supplier for CNC machining our male plug for our monocoque on their 5-axis mill with a 10'x3'x3' bed and we use an outside supplier for the final paint job (for aesthetic and environmental reasons). We have gone so far as to build our own 192 cubic foot curing oven and we maintain and build our own vacuum pumps.

Sponsors

Nearly every single off the shelf component or service is now backed by a program sponsor. The students have put in a fantastic effort of making this part of their job. They see a component or service that will make the vehicle better, they know it is out of our budget, and they cold call the company to ask for their full or partial sponsorship of the vehicle. As you might expect, our vehicle looks like a NASCAR vehicle with the sponsor stickers all over. Sponsors are also helped by our corporate services department for tax deductions. The major reason we have been able to lock up such fantastic support for innovative components is our history of success. We have a letter that we send to or use as a script when speaking with potential sponsors. The script tells them of our successes, the press that we have received, and the other sponsors we have. They are then asked if they want to be associated with this group. It works. Sponsors are also kept informed of our progress throughout the year. At the end of the year they receive a CD with pictures and movies, a thank you letter, and a team t-shirt for the main contact. We have never had a sponsor not return the following year if asked.

Costs

As we stated previously, winning the HPV challenge (even the engineering portion) is expensive. Our fourth year vehicle program we estimate has a total value of $37,000 including travel, materials, components, and sponsored components and services. Obviously, we could not afford such costs out of the senior design budget. That is why the sponsorship is so important. Over 75% of that cost is sponsor donations of goods and services. This year was the first year that we did not solicit cash donations because they were not necessary. Travel costs have been perhaps the most significant recurring real cost for us. We are actually charged by the university for van rental and gas. These have been allayed by sponsorships of trailers, housing along the way, reduced hotel rates, and even a sponsorship by a fast food chain. We have saved money on material costs (very difficult to get sponsorships here) by ordering in bulk whenever possible. Many programs operate on much lower budgets. However, it is obvious that with the larger budget comes an exponential growth in educational opportunities. Our students are working with materials and production processes that they will see in industry, they are being forced by the investment to maintain a level of production quality, and these materials and processes require a significantly higher level of engineering and planning. By going with a larger budget, we actually have precluded most possibilities of designing on the fly.

Team Goals

Our team goals were to win the engineering portion of the competition, increase student confidence, and gain exposure for our program. We have done well on all three fronts.

Winning in engineering as a goal

The choice of a win in overall engineering rather than an overall performance win was very specific to the ASME HPV Challenge and its rules. Unlike other engineering competitions, the actual race or competition is ultimately driven by human physical power, not human brainpower nor by machine. If you put Lance Armstrong on a Huffy and give me his bike, he will still beat me in a race. We have no control over the engine, especially since MTU suffers from a "location deficit" (every year we have had snow when we left for the competition and nearly all of the testing and training must take place in a small gym on Sunday mornings). To leave our goal to something that is engineering-irrelevant and out of our hands does correspond with the purpose of our competition – to bolster the engineering skills and experiences of our students. Another reason for the goal is the nature of the competition scoring, which gives only 40% of the scoring for engineering and 60% for the racing. Again, with a focus on engineering, to make the overall win a goal would be impractical. I will admit that this year, for the first time, we were left with a bad taste in our mouths after winning the engineering as the engineering title was barely recognized by the event organizers. In the past, there has been a large trophy and a check associated with the engineering.

Motivating the goal

How do you maintain motivation for an engineering goal rather than a more common athletic goal? It is easy, because you are dealing with a group of engineers. Very few of our students have ever been state or national champions in any athletic endeavor. They are looking forward to the opportunity to have this same feeling from another source. This ties in very well with giving our students the confidence in their engineering skills. I will use two anecdotes to motive this point. In our third year, which was the first year that we won the overall engineering, the students submitted an excellent report. We then took the time to create and set up a fantastic display of the vehicle, its subsystems, and the design and fabrication processes at the event. All of the spectators and competitors were crowded around our display asking the students questions all day long. This continued as the students gave their oral presentation to the judges and the judges viewed this display set up on another part of campus. As we were walking back from the presentation, having cleaned up for the day, one student turned to me and said, "That was incredible. I have never had the experience where I was the one that everyone else wanted to be. I never thought that would happen in engineering or school." This past year, we had one student who had set plans to get an MBA and go into marketing after graduation, assuming that they were not a good engineer and they were therefore uninterested in doing it as a career. At our final lunch the team member said, "I never knew I was this good of an engineer. Now I have to rethink my whole career plan." Competition programs run well give these sorts of opportunities more readily than the typical industry sponsored programs. Competition programs run poorly give no such opportunities.

One other interesting point in motivating the goal of engineering has been naming the vehicle. Encouraging the students to pick names that emphasize the engineering of the vehicle and then continually referring to the vehicle by name, I believe, serves to remind the entire team of what is the goal of the project.

Career opportunities

One additional aspect that has helped to motivate the team is the career opportunities that the HPV has created. We have had success in creating an alumni job network, placing students in the composites industry, and placing students in the bike industry. This placement has helped motivate students to join the team, work hard while on the team, and to stay connected with the team after graduation.

We regularly get e-mails and calls from past alumni that are looking for new hires that know how to work hard and solve real engineering problems under pressure. They are confident that any student who survives our HPV program in style is appropriate. Alumni looking for a career change also keep in contact through our e-mail list.

We get many students that are interested in bikes that come to the HPV team. MTU is located among some of the best mountain biking in the Midwest. Many students view the HPV program as a way to get a job in the bike industry. The reality is that there are very few engineering jobs in the bike industry and even fewer in the frame and composites sections of the industry. In addition, these engineering jobs are rarely filled by people who have not had significant success outside of the bike industry first. As it turns out, the largest US bike manufacturer, TREK, has quite a few MTU graduates. Our HPV program has been able to place two students as fresh graduates as composites design or manufacturing engineers directly in the bike industry and two other students are beginning to start their own component company.

Our HPV program is unique in the country. Very few programs can claim to product a dozen undergraduate students with the knowledge and ability to conceptualize, design, analyze, fabricate, and test composite structures. We are supported by one course in the Material Science and Engineering department on campus that a few of the students will take. However, the bulk of their knowledge comes from their ramp up to, development of, and participation in our production process. Especially in the fourth year, we have developed in house process capabilities that are clearly better than anything we have seen on any student project in ASME or SAE.

How did we do it?

Because we are so proud of what we have accomplished in the MTU HPV program, I will use the last section of this paper to give readers a snapshot of the evolution

Designs

Following is a table that briefly highlights the design innovations and engineering feats in each of the four years of our program. Note that with the exception of the second year when our innovative drivetrain was never really race ready, the vehicle has been faster either in competition or in post-competition speed trials each year. This past year our top speed is approximately 45 mph.

Table 1: Design and engineering advances in the MTU HPV program.

	Design Innovations	Engineering Innovations
Year 1	• Convertible 2 wheel / 3 wheel design to run in utility and sprint (5 minute conversion) • Aluminum box tube frame • Full fairing • Extremely low recumbent • Sliding rear fairing half entry • Rear suspension • Multi-gear	• Frame FEA • FLUENT aerodynamics analysis • Recumbent drive train efficiency analysis • Tip over analysis
Year 2	• Carbon composite frame • Prone position • Helical gear linear drive train • Body harness with hanging body position	• Composite frame FEA • Mechanical efficiency analysis • VO2 testing
Year 3	• Full composite monocoque • Prone position • Crank-slider linear drive • Video-based vision system • Two wheel	• Composite monocoque FEA • Initial body position efficiency testing • Linear drivetrain efficiency • Parametric fairing analysis
Year 4	• Cable-based steering • Elliptical drivetrain • Molded-in video • Integrated, 360 degree roll bar • Front crash protection • 30% weight reduction	• Crash testing • Aerodynamic tuft testing • Complete body position optimization • Drivetrain comparison study • Composites layering analysis • Improved FEA accuracy • Improved FLUENT accuracy • Strain gauge *in-situ* material testing

Figures 1-4 show each of the MTU vehicles. The first two years' vehicles are shown in both two and three wheeled configurations. One thing to note is that as the engineering, materials, and integration became more complex, the vehicles have become simpler looking. This is only achieved through increased engineering upfront in the design process – the goal of teaching a structured design process.

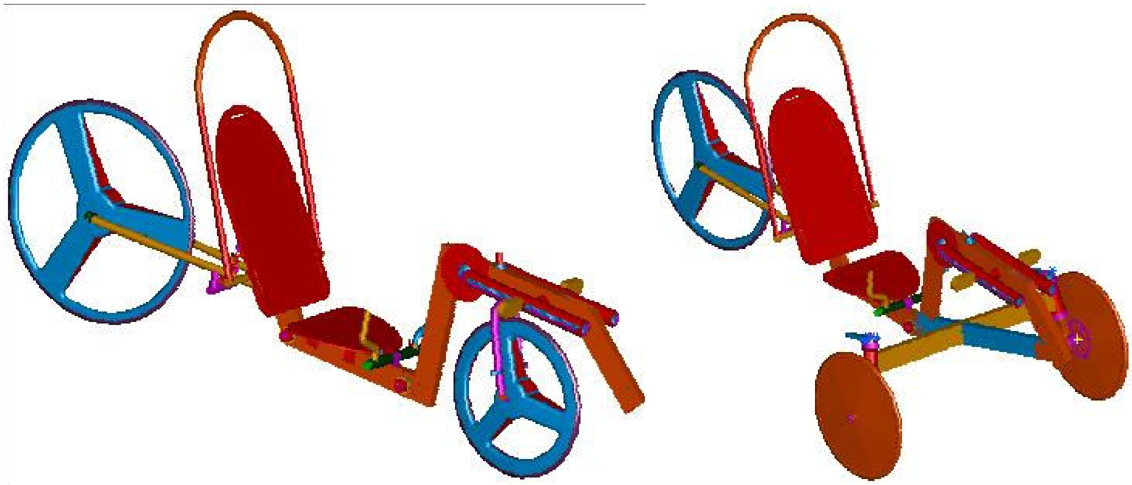

Figure 1: The Year 1 MTU HPV – The Sooper Yooper – in two-wheeled and three-wheeled configurations.

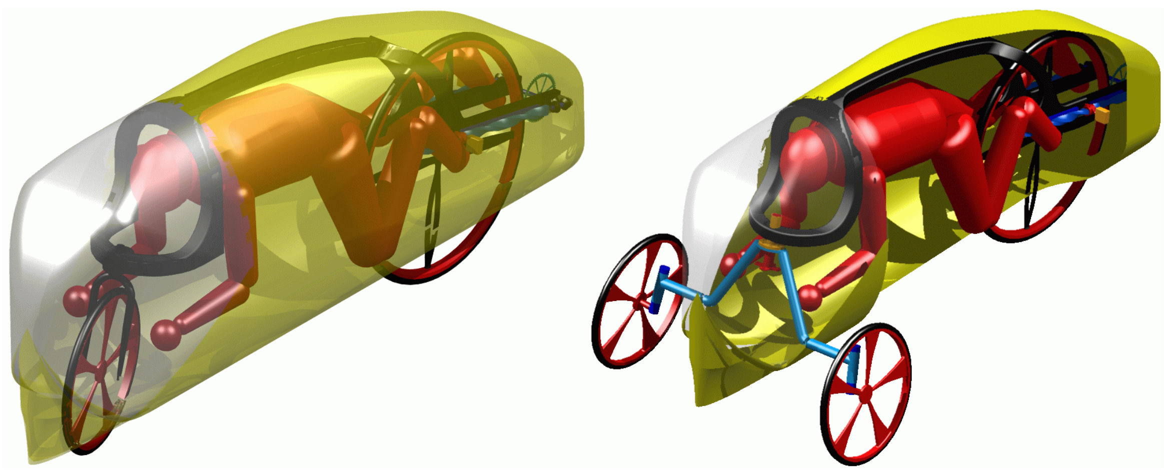

Figure 2: The Year 2 MTU HPV – The CT Cruiser – in two-wheeled and three-wheeled configurations.

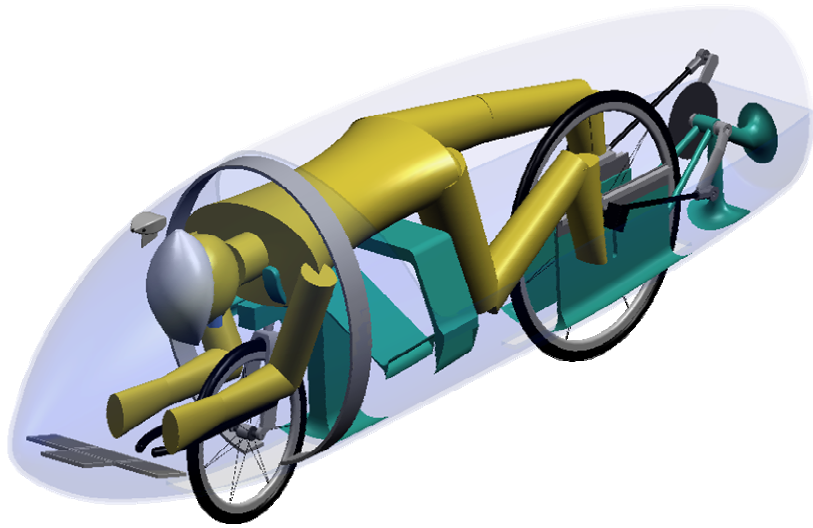

Figure 3: The Year 3 MTU HPV – The BIFOB – shown with its camera pod and video board.

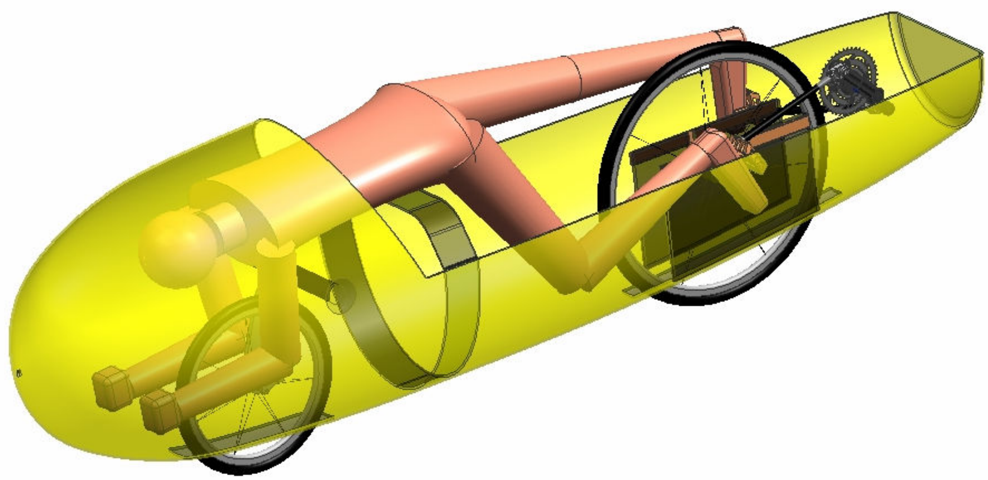

Figure 4: The Year 4 MTU HPV – Murphy – shown without the three molded in cameras and video board.

Processes

Following is a table that briefly highlights the fabrication process innovations in each of the four years of our program.

Table 2: Fabrication process advances in the MTU HPV program.

	Fabrication Process Innovations
Year 1	• Welding of aluminum box frame • CNC of female mold by supplier • Kevlar/Carbon lay up from a female mold
Year 2	• Lay-up of foam/carbon composite frame over water jet cut foam pieces • Ability to join composite elements • Molding in metal elements to the composites • Use of a male plug, to create a female mold for fairing lay-up • Female fiberglass mold made by supplier • CNC of plug by supplier • Fairing incorporates Nomex stiffeners • All machining done by students
Year 3	• Lay-up of monocoque composite in halves • Joining of monocoque halves • Joining of molded in components to the monocoque • All electronics wired by students • Fixturing for exact placement of components
Year 4	• Use of pre-impregnated carbon • Use of a progressive temperature/pressure lay-up and cure cycle • Building of 192 cubic foot curing oven with temperature control • Fabrication of fiberglass female mold in house • Use of a single mold for both halves • Production process test cycle

It may be difficult to tell, but as the vehicle has seemingly gotten simpler components and more complex in design so has the process. The number of major process steps decreases as everything becomes integrated, but the risk and necessary quality in each step increases significantly. The risk is again abated by engineering the product and the process together upfront.

Results

Following is a table that lists MTU's ASME HPV Challenge results in each of the four years of our program.

Table 3: ASME HPV Challenge results for the MTU HPV program.

	ASME HPV Challenge Results
Year 1	• 1st in Design and Innovation • 2nd in Utility Overall
Year 2	• 1st in Design and Innovation
Year 3	• 1st in Overall Engineering
Year 4	• 1st in Overall Engineering

Conclusions

The purpose of this paper is to show how MTU has been able to take advantage of a competition project to educate the students in the systematic design process and in the teamwork necessary to integrate the elements of that process and to instill in the students a confidence in their engineering capabilities. Over the last four years, we have competed in the ASME Human Powered Vehicle Challenge with considerable success on the engineering side. From this we have been able to improve our processes for team organization, advisor management, sponsor support, engineering design, and production. Perhaps the most important take away from our discussion is that it should not be assumed that achieving the educational goals of most capstone engineering design courses is easy within a competition framework. Careful planning and significant advisor involvement will be necessary.