AC 2007-1817: PACE GLOBAL VEHICLE COLLABORATION

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PACE Global Vehicle Collaboration

Introduction

Capstone design teams have become an integral part of undergraduate engineering education. Through these programs, students have the opportunity to apply what they have learned in the classroom to actual design projects. Capstone classes provide distinct benefits to students who participate in them. Students are able to put to use their newly acquired "text-book" design experience in real engineering applications. Also, students are able to participate in professional activities such as writing technical papers, submitting patents, and holding design reviews. All these activities occur in a classroom atmosphere under instructor supervision. The companies that are able to collaborate with these students on these projects also enjoy the ability to observe potential employees prior to actually hiring them. They typically also retain the rights to any intellectual property produced by these students during the duration of their capstone courses.

Traditional Capstone Design Course Limitations

Capstone design courses are not without their limitations, however. Typically, small businesses are most interested in participating in capstone design projects. Because of their substantial financial resources, larger businesses are typically able to provide their own internal training procedures; therefore, they are less interested in becoming involved in school instituted projects. Since many of the companies that sponsor these projects are smaller, they often lack the resources to provide a consummate design experience for these students. Some of the aspects current capstone design teams lack are: cutting-edge software integration, international collaboration, and experience with a large corporative structure.

Large corporations are using computers to solve engineering problems more now than ever. A vast myriad of engineering software is available to provide accurate and comprehensive solutions to many of the problems engineers face today. Albeit these solutions will always need to be verified either by empirical results or analytical methods, computer software continues to make engineering analysis more complex and more thorough. Capstone projects should strive to incorporate these software tools to more fully simulate an actual work experience. Recent research indicates that a lack of authenticity is one of the current drawbacks to capstone design experiences. [1] The use of real industry software tools and analysis packages offers students a more authentic experience than would otherwise be available.

Since the inception of advanced communication devices and transportation equipment, the world has, in a sense, become smaller. The world has become a global marketplace, in which companies must understand a large global picture to remain competitive. Without a global perspective, large corporations soon become outdated and unprofitable. More and more engineers are being called upon to assist in technology transfers, international design collaborations, and global manufacturing issues. In a survey of students that participated in a recent global product development course, German researchers Dutta and Weilbut reported that over 80 percent of those that participated felt that the global team approach added "tremendous value to the course".[2] Students also seemed to indicate that they would like to participate in similar projects again given the chance.

In the same vein, many reports have been done identifying the needs and crucial details necessary for successful engineering projects. In their discussion of such traditional projects, Todd and Magelby state that successful capstone courses identify and meet the requirements of all stakeholders in the development. This is true, however, articles such as this make no mention of the ever increasing impact globalization has on the engineering world. This makes international capstone projects not only relevant, but also ground-breaking.[3]

Indeed, large corporations face many issues that small companies do not have to worry about. From global politics to logistical issues, many areas affect whether a large corporation can execute and remain profitable or not. As the world continues to change, the skills requisite to solve certain engineering problems are often scattered across the globe. Global collaborations have become necessary to solve such problems.[4] Large corporations might also be less inclined to work with capstone design teams because they struggle to find meaningful projects that can be contained within the constraints of a one to two semester design experience.[5]

International collaborations allow for companies or other organizations to draw upon the combined strength of many different cultures and backgrounds. Properly utilized, these differences can be harnessed to exploit technical, analytical, or managerial prowess from all over the globe.

Modern engineers must be aware of the laws of land as well as the laws of nature. A polished graduate will be aware of political and social interactions and their affect on the engineering forum. Independent learning, critical thinking, and the development of excellent communication skills must be developed to produce a skillful professional.[6]

The merits of capstone courses have been proven over and over again. Since the functionality and success of these programs is becoming more and more apparent, it is requisite for the academic community to challenge these design teams with new and more rigorous goals. As the engineering world continues to become a part of a vast global environment, engineering capstone design teams must prepare students for the transition to an international design forum.

Therefore, leading universities should provide students that exhibit a drive to be a part of the international community with an opportunity to participate in global design projects as part of their capstone experience. Participating students should exhibit superb leadership and teamwork qualities. Language training is also necessary. Because English is widely recognized as the modern international language, students from non-English speaking countries should strive to develop proficiency in English. Students in English speaking countries should in turn develop skills in a different foreign language so as to act as a liaison to other countries. Finally, a lead school should be selected that has many students with the above characteristics. This school is responsible for not only coordinating efforts between schools but for the overall project integration as well.

Project Definition and Scope

In conjunction with General Motors, Sun Microsystems, UGS, Electronic Data Systems (EDS), and a total of twenty-nine teams from around the globe, one university led an effort unprecedented in size and scope for collaborative capstone design projects. Table 1 indicates the number of schools and students participating from each of the countries involved in the project giving an idea of the sheer size of the undertaking. Drawing on talent and skill from countries and cultures all over the planet, the PACE (Partners for the Advancement of Collaborative Education) Global Vehicle collaboration was not only a design project; it typified the meaning of the phrase "multi-national collaboration".

Table 1

Continent	Country	Number of Universities	Number of Students
North America	**United States**	**6**	**51**
	Canada	**3**	**25**
	Mexico	**3**	**27**
South America	**Brazil**	**1**	**3**
Europe	**Germany**	**1**	**5**
	Sweden	**1**	**5**
Asia	**India**	**1**	**14**
	China	**1**	**2**
	South Korea	**2**	**54**
Oceania	**Australia**	**1**	**8**

Table 1: Global participation shown by continent, number of universities, and number of participating students. Since the PACE partners are US based companies, the strongest showing is from North America for now.

Students participating in this project hail from ten different countries on five continents. Some schools have more than one team as they draw upon talent from the whole gamut of their various engineering programs. Participating students have majors in Mechanical Engineering, Industrial Design, and Manufacturing Engineering. Because of the recent radical changes in the global economy and marketplace, students around the globe from various disciplines have begun to see the value of collaboration. Traits such as co-operation, teamwork skills, communication flexibility, and language fluency are developed through projects such as this.[7]

The basic organization of the project is as follows: an overall project integrator is in charge of integration between three different sub-assembly leads. These leads are responsible for communication, design review, and integration between all the schools under his/her jurisdiction. Each team is given a specific component within a sub-assembly to design, manufacture or modify, and analyze. This year was the first of a three-year effort to push students to stretch the boundaries of the traditional capstone experience. This year's project will be repeated for the next two years, each time increasing in scope and complexity.

The goal of the collaboration was to build a next generation Formula race car. In choosing this project, the instructors of participating schools wanted to work on something that they viewed as worthwhile while staying within the bounds of his/her expertise. These are both important elements in a successful capstone course.[8]

Typically, when the words “capstone engineering project” and “formula race car” are heard together, images of a pint-size Formula SAE car are brought to mind. This race car is completely different. Although not quite as long as a true F1 race car, this car has a comparable track width and a wheelbase that is approximately two-thirds as long as a true Formula one car.

The power train used is a 2.0 Liter GM Ecotec engine that is both turbocharged and supercharged. This year’s vehicle will run off of gasoline. Approximate engine brake horsepower is estimated at 500 HP. Future projects could include the exploration of an ethanol-powered engine as well as the use of composite materials in the chassis design.

Finally, four different industrial design schools have designed bodies for the car. One of these bodies was selected for manufacture on a 5-axis mill. In the future, hopefully all four bodies will be able to be manufactured. This will give the effect that the chassis can have four completely different totally interchangeable exteriors.

In choosing the scope of this project, the goal was to find a challenge that would not only be an interesting project for the students, but also interesting to the PACE partners as well. By stretching the limits of their experience and training, the students were able to develop their engineering skills faster and work on a project that more closely resembles a true industry problem.

Corporate sponsors including General Motors were interested in backing this kind of project because it allowed students to participate in a design situation that closely imitated a contemporary design experience. Also, GM was interested in developing good leaders that have hands on experience in solving more realistic problems. This project also helped students become more excited about working in the automotive design sector and to become passionate about the work they had done. Talents developed by this project including critical thinking skills, leadership experience, and creativity are highly valued in new hires at GM. They felt that this project was an excellent way to foster these talents and to generate an environment conducive to the development of future GM engineers.

In itself, this task for a single school to complete is no doubt a formidable one. However, after extending the objective to include cooperation from twenty different schools heralding from five continents, ten countries, and speaking seven different languages, the task quickly becomes much more than a mere design project; indeed, it becomes almost Herculean in scale. The students did not view this as a hindrance, however. Instead, participants viewed the challenge to work together as an opportunity to become more than any one school alone could achieve.

Organization and Leadership

Because of the difficulty involved in the successful completion of this project, a clear organizational structure and a variety of communications methods were required. Not only did the communication methods need to be clear, they also needed to be inexpensive. Figure 1 below shows the overall structure of the student organization for the project.

The PACE program was initially designed to encourage university students to become exposed to advanced software packages used in industry and to utilize these tools in collaborative design projects. These companies saw the benefits this kind of collaborative experience could afford students while still in the undergraduate setting.

PACE touts its program as giving students the skills they need to succeed in the future. PACE also proclaims that the traditional role of an engineer has changed dramatically in the past few decades and will continue to change.

Because the companies comprising the PACE partnership are international corporations, they have a vested interest in establishing partner schools world-wide so as to foster the development of future leaders and talent around the world. The idea of a global collaboration occurred a few years ago after some initial collaborations between US schools were begun. After the success of each previous project, the goal has grown in ambition and scope. Last year, the lead university ran a smaller global collaboration which was a virtual design exercise only. This year, students not only designed and analyzed a car; they manufactured and tested the car as well.

The organization of this project also solves the problem of time constraints that have caused large corporations to shy away from becoming involved in capstone design projects in the past. This project will not end with the current group of students; students in year's following will be challenged to improve and modify the design until a truly innovative, "next-generation" model is produced.

Figure 1: Each branch below a colored block represents one team. The three main integrators are shown in yellow, bright green, and red. Dark blue denotes the overall student lead.

As the chart shows, underneath the overall project lead, there were three sub-groups: power train, chassis, and body design. Each group had an integration leader. As the logistics of designing a twin-charger system are quite involved, there was also a separate induction team integrator who functions within the power train team as a whole. Each sub-group leader was in charge of coordinating the efforts of eight to eleven separate teams. Each team also had a faculty advisor that assisted the students in their design and analysis. These faculty members were indispensable in providing necessary experience and coaching to the students.

Each team within a school also had a leader. To reduce confusion, this person functioned as the main liaison to other schools. He or she was also the major speaker in design reviews held between sub-groups and the overall project integrator. Team members as well as team leaders shared the responsibility of design and analysis of each component. Team leads, sub-group integrators, and the overall student lead were chosen based on experience, leadership qualities, and academic excellence. Team lead nominations were ratified through common consent by team members in most cases.

In addition to the engineering students, the lead university also recruited several business students to assist the project with necessary tasks which are unrelated to the capstone design project per se.

These students comprised an "advisory board" that worked with the overall design integrator and the advising professors to make financial decisions regarding the project, solicit funding, and publicize the project. These business students helped maintain rapport with General Motors, our corporate sponsor and elicit other funds from private donors. Through these two sources, the students were able to pull together enough funds to conduct the project.

Tools of Collaboration

Because the schools were spread all over the world, it became requisite that the teams become proficient in using collaboration software to discuss design intent. Issues such as component size, placement, and interfacing had to be worked out via teleconferencing, VoIP (Voice over Internet Protocol) tools, or other traditional methods such as email. Clear communication was essential to the project early on because it allowed for ample refinement and analysis time later on in the project.

The participating schools have utilized many web-based technologies to maintain constant communication within the different groups around the world. The main collaborative tool has been Teamcenter Community (TcC), a tool developed by UGS to allow uploading and downloading of different revisions of parts and documents associated with the project. TcC also has an application sharing feature that allows for remote PC control. About half way through the project, students were able to start using Teamcenter Engineering (TcE), another collaborative tool. This software was especially useful in dealing with version control of parts.

Other collaborative tools the students have used include various instant messaging devices such as MSN messenger, Google Talk, and Skype. Skype and another VoIP device called Gizmo Project also provided the students with a feasible way of placing a large amount of long distance phone calls. The lead school was also equipped with a phone conference number that allowed an unlimited number of participants. As can be expected, email played a vital role in communication between schools. An effort was made to standardize email addresses by providing each team member with a Gmail account that was specified by project name, school name, and team member name. Each project member's personal information was posted to Teamcenter Community for reference and convenience sake. These communication methods of networked computers, video and telephone conferencing, and application sharing software such as Teamcenter Community have proven to be effective collaboration tools.[4]

The students used the web-based Google calendar to ameliorate the problems associated with time zone differences. This calendar allowed the students to post meeting times and deadlines in their own time, and simultaneously displayed the event in the correct time all around the world. This eliminated the human error factor of trying to calculate meeting times and confusion caused by such events such as daylight savings time.

Video conferences were also held using Tandberg and other videoconferencing software. Although initially expensive to purchase, this tool allowed for the quick communication of a tremendous amount of information. Video conferencing devices can be linked to computers to show models and analyses, as well as communicating intangible factors such as body language that are sometimes lost in a simple telephone conversation.

Design and analysis tools that were used came exclusively from the UGS, Altair, and MSC corporations. To model the components for the vehicle, the students used UGS's NX 4. There were many advantages to using a premier CAE package. Not only did it allow students to make complex models, but it also allowed for a wide variety of analyses which can be performed within the package itself. Also, if a student familiarizes himself/herself with an upper-end CAE package and later is required to learn a different package in the workplace, it is much easier to learn new software if the student has already been exposed to an advanced package. Also, UGS has worked with numerous analysis packages to allow models that are created within an NX 4 environment to be imported into other software. These PACE tools allowed the students to perform nearly every step of the design process virtually. Analysis software such as Fluent, LS Dyna, and Optistruct were used to analyze and optimize the design. Meshing tools such as Hypermesh, T-Grid, and Gambit were used to allow these finite element analyses to proceed. The flexibility and power provided by this software was a great aide to the students.

Design and Manufacturing Processes

Brainstorming was the first step during the design process. Since the goal was to produce an innovative, next-generation design, creative brainstorming sessions were a must. The design experience was a very visually based process, and brainstorming was no exception. The industrial design students created many sketches giving the engineers "vision". Industrial designers have sometimes complained that by the time they are brought onto a design project, the engineers have already completed most of the design. In these instances, their somewhat menial function is to be responsible for making the engineer's design "look nice". Being aware of this situation, the participants in this project wanted to avoid this problem. As such, the industrial design students were involved in the project every step of the way. A few of the many initial concept sketches produced by the ID students can be seen in Figure 2 below.

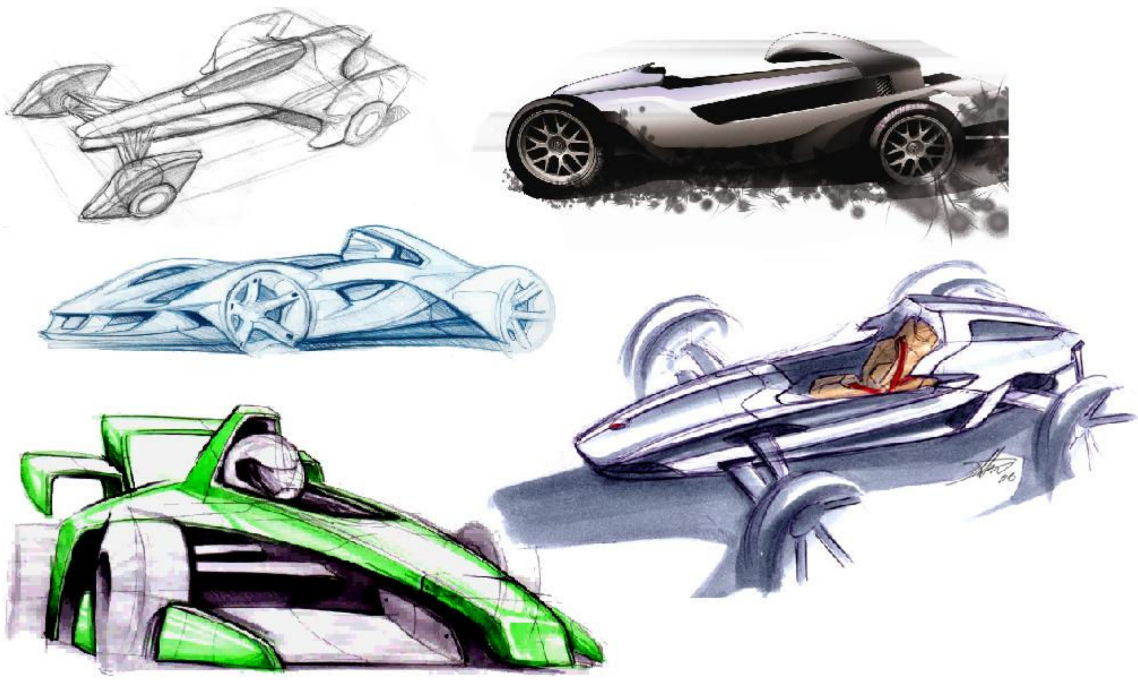

Figure 2: The brainstorming phase is crucial to developing innovative designs. The above sketches were early models of what the Industrial Design students imagined the car looking like.

A typical component design proceeded as follows:

1. Project scope defined, statement of work completed and submitted to the advisory board/overall student lead.
2. Brainstorming and divergent thinking exercises.
3. Research of existing technology.
4. Initial concepts generated, posted to Teamcenter Community for commentary/discussion.
5. Initial analysis of models started. Problem areas sent back to design stage.
6. Advanced models created
7. Preliminary Design Review held.
8. More analysis performed. Advanced models are given go/no go status for Critical Design Review.
9. Critical Design Review held. Design frozen.
10. Analysis is continued, manufacturing/modifying of components begins.
11. Manufacturing of components complete. Parts sent to lead school for assembly.
12. Assembly and testing of finished vehicle.

A flow chart is included below in Figure 3 to illustrate the iterative loops in the design process described above:

Figure 3

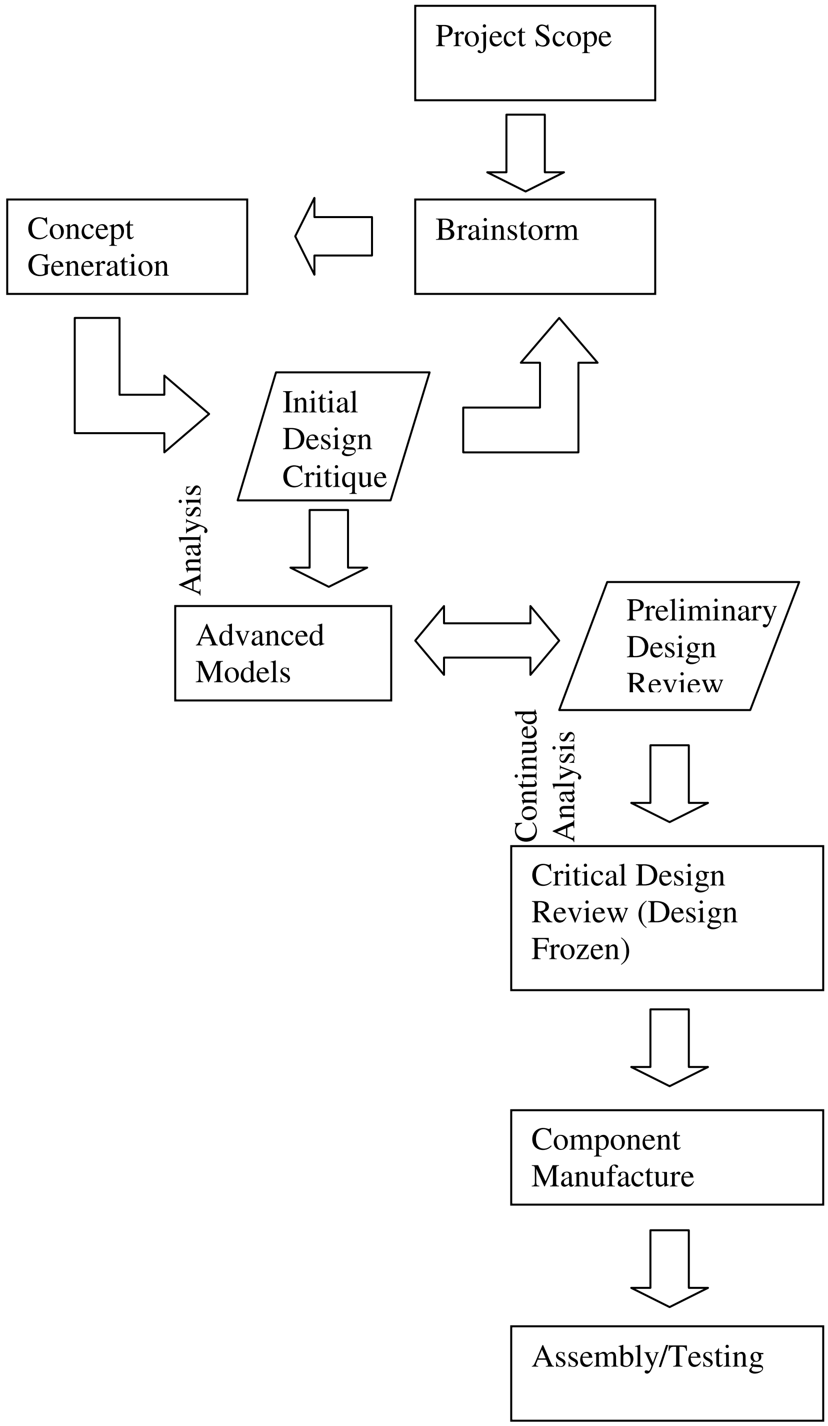

Figure 3: This diagram shows the design iteration loops between: first, the brainstorm, concept generation and initial design critique stages and second, the advanced model and preliminary design review stages.

Some have suggested that linear design methods in collaborative groups are an oversimplification of the engineering process. To a certain extent, they are right that collaborations of this sort sometimes lead to unclear alternatives and solutions that create problems rather than the other way around.[9] Students found that this was sometimes true, but they felt that the benefits of teamwork and collaboration outweighed the detriments. Eventually, the participants in this project developed an iterative process in which they faced challenges by stepping back and approaching the problem from a different viewpoint. New solutions were then able to be formed and the design continued. Figure 4 gives examples of some of the components designed by students for this year's project.

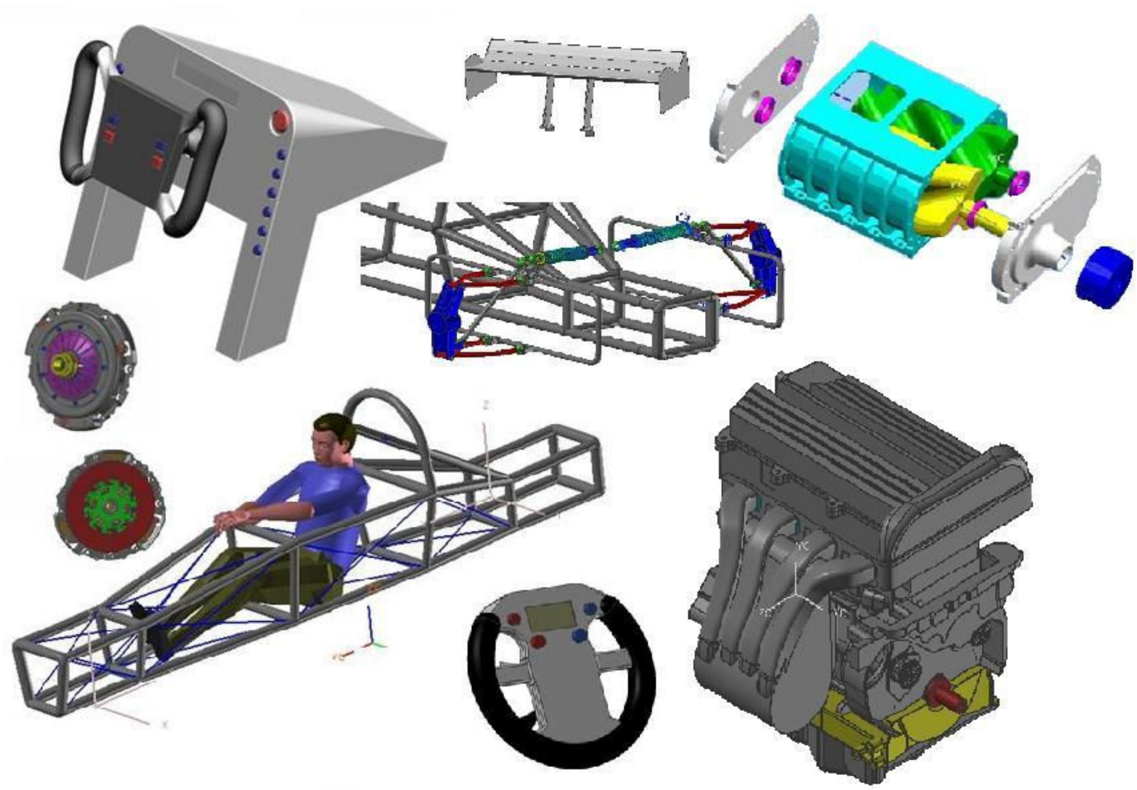

Figure 4: This project helped students develop advanced modeling skills. All the above parts were created using NX 4.

Analysis was perhaps the most crucial step in the design process. Not only did a thorough analysis allow sponsors to trust the design the students created enough to build and manufacture the vehicle, analyses also helped the students know what elements of their design needed improvement. Through this iterative process, the students were able to obtain a robust, safe design. Figure 5 gives examples of just a few of the many analyses performed throughout the project.

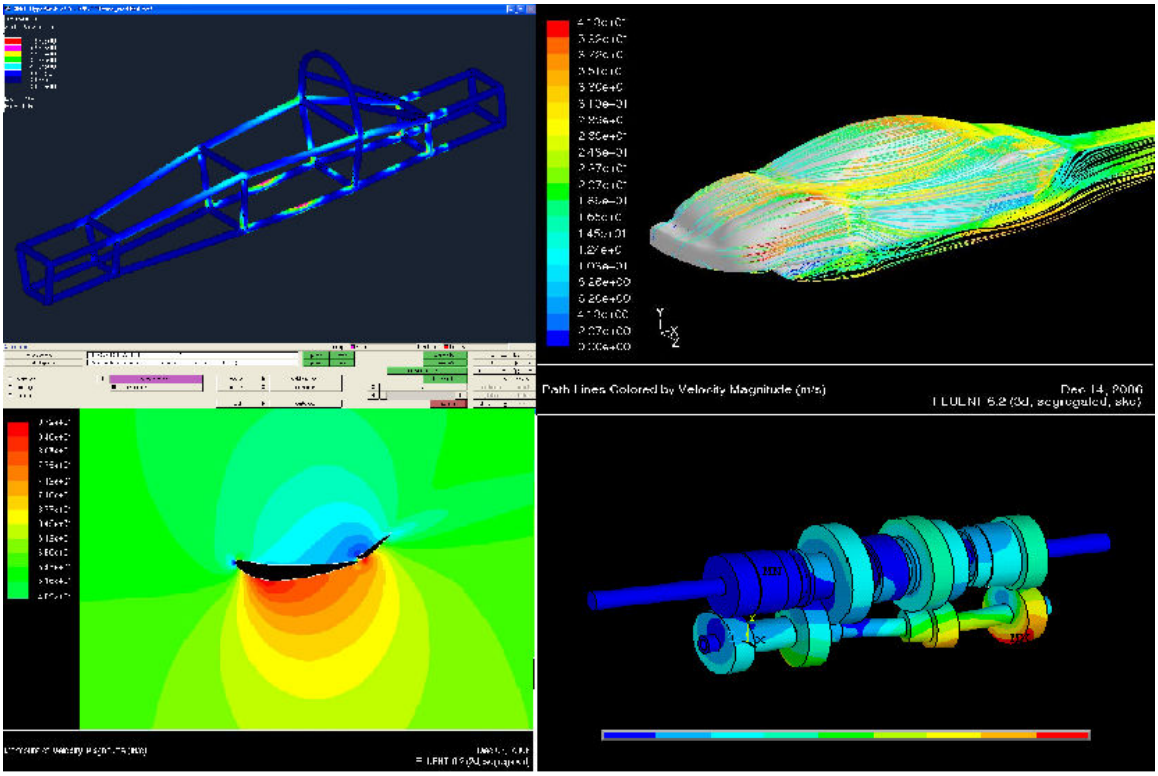

Figure 5: Analyses were performed using UGS and MSC software. The above show the results from both structural and fluid analyses.

This year's project is only the beginning. As previously mentioned, the formula racer project will be continued both next year and the year following. Future teams will improve on this design and continue to push the limits of creativity and innovation. After the formula project, a new challenge will emerge. Currently, the project review board is analyzing the viability of designing a next-generation concept vehicle for General Motors.

This is the first project of this magnitude to be undertaken by a group of undergraduate students as part of a global collaborative team. The lead school has for the past few years been preparing for the challenge of designing, analyzing, and manufacturing a working race car in a single academic year through international cooperation. This year, the goal was finally accomplished as twenty schools from around the globe combined their efforts to not only produce an amazing piece of engineering, but they did so in a collaborative fashion that was truly unparalleled in undergraduate education.

Although an American university has been the lead school for this project this year, the eventual goal is to allow other universities to share the spotlight and notoriety as leaders in the global engineering design forum. This will become more and more necessary as business and engineering stretches beyond cultural and ethnic barriers. The academic community must lead this effort in global cooperation. As this project indicates, capstone design teams are the perfect venue for such collaboration.

Examples of Global Collaboration

This project allowed for many examples of collaboration using the design process detailed above. Some examples of this collaboration are listed below:

Example One: Body Design

Each of the four body designs went through a rigorous design and analysis procedure before being selected as the final model from each industrial design school. First, each of the four ID schools created brainstorm sketches based on the provided project scope. These students not only researched traditional body designs, but also derived inspiration from non-automotive sources to add flair and creativity to their drawings. For example, some students drew sketches based on animals, such as eagles and dragons, while others were motivated by aircraft design. One Korean student used the current trend of “destroyed” blue jeans to create a design that exposed the chassis in a way similar to the way these popular jeans expose the wearer’s leg. These sketches were then posted on TcC for others to review. Critiques of these sketches including initial 2D flow analysis using Fluent were sent back to the ID schools. The students then produced new sketches reflecting changes induced by their peers’ evaluations. After these later sketches were generally approved by the flow and substructure analysis teams, the industrial design students began to create 3D models of their designs using Alias. They again posted their models to TcC for peer scrutiny. The frame team used Teamcenter Visualization to check for frame-body interference points. Likewise, the wing teams were able to clearly see the ID students overall intent so they could try to match the appearance of their wings to the look and feel of the bodies. The analysis teams used the Alias models to perform the 3D flow analysis. Also, optimization software was used to increase the lift-to-drag ratio and the down force of these bodies. After this work was complete and manufacturability of the design was deemed viable, preliminary and critical design reviews were held. Students relied heavily on email as well as VoIP tools to facilitate daily correspondence. Some of the challenges encountered during this process were language differences, frame-body interference issues, and wing placement adjustment. Language barriers were overcome through language liaisons at the lead university as well as each school having at least one member proficient in at least rudimentary English. Design issues were overcome primarily using email and TcC, including the application sharing function which allows for remote workstation control.

Example Two: Wing Mounts

The race car was designed to utilize two different front wings: one designed for high-down force and the other designed for low-down force. These two different wings were designed at two different schools, one Swedish, the other Australian. A potential conflict arose about how to mount the two wings to the frame. The debate came down to whether the same mounting device would be used for both wings or whether each wing team would be required to create their own bracket structure. Initially, there was no way to match both of the two wing designs to the frame, as the required bracket structures were completely different. The chassis integrator held weekly meetings via teleconferencing with the wing teams to discuss their status. Through these meetings and the models posted on TcC, it was decided that the wings would be made the same length with mounting points that could be used with a single bracket design. The Australian school was asked to build the bracket, and the Swedish school had to modify their parametric model of their wing design to match the Australians' bracket. The use of SI units allowed for the clear communication of sizes and dimensions. Language could have been a difficulty in this situation had it not been for the excellent English skills of the Swedish team. Design iteration was facilitated as mentioned mostly through TcC and the Tandberg videoconferencing device. This problem was generally solved in the advanced model to preliminary design review stage. As advanced models of the bracket device were generated by the Australians, the Swedes were able to modify their preliminary models to the given constraints before moving into the design review phase.

Example Three: Frame-Engine Interference

The lead school also made an effort to visit the campuses of every participating school around the world. This was in part to train these schools in using the collaborative software as well as to foster a spirit of friendship and cooperation among the participants. During one of these visits to a Canadian school, the visiting professor from the lead school wanted to show the power of the Teamcenter visualization tool in an application share with a student back at his own university. The professor asked his student to show the Canadian students an interference problem between the frame and the engine exhaust manifold. The student was able through a quick application share to open the part using the Teamcenter visualization software, show the interference—which he circled in red, and finally illustrate how the geometry of the frame was changed to avoid the interference. Solving this problem involved iteration in the early critique stage. This problem was avoided before either the frame or the engine made it to the preliminary design review stage. The use of collaboration tools allowed the students to easily avoid a potentially egregious mistake. Language problems were also potentially an issue with this problem as well, but because the lead university had a student liaison that was fluent in Portuguese, the frame team was able to communicate with the engine team. This was a good example of how the collaboration software was used to its fullest potential: collaboration on how to utilize the software in a problem-solving event. This kind of a situation could easily occur in some of the larger international corporations in the world today. If two components were designed in two different locations in the world, collaboration similar to this would be required to work out interference issues. In this way, the global collaboration was able to closely mimic current industry developments.

Example Four: Seat Placement

A final example of the use of collaborative tools in successful design iteration was the seat placement in the frame. Rider ergonomics and safety were assigned to a Korean school. As such, they were in charge of the seat design. The Korean school needed to discuss with the American frame team placement issues of their seat. They had created preliminary models and placed them in the latest version of the frame which was downloaded from the Teamcenter site. Initially, the Korean school did not have a good idea of what a Formula style seat should look like. Instead, they first tried to use a NASCAR type racing seat. This seat was too large for the frame; also, it was not in an aggressive, reclined position suitable to a Formula style racer. Also, this seat posed safety problems because if used, this seat would cause the driver's head to break the roll-bar plane. This became very apparent in the initial design critique phase. The chassis lead was able to communicate to them some of the problems with their design and help guide them toward a more suitable alternative. Later, they were able to model a more suitable seat that could then be attached to the frame. Through an application share and a VoIP meeting, the Korean school was able to communicate what changes needed to be made to the frame to accommodate their new design. Through simple English and the intermittent translation provided by the fluent Korean speaking American student liaison, language barriers were able to be overcome. The success of the resolution of these conflicts shows not only the viability of these collaboration tools, but also that they can be used across borders and cultures to elicit effective cooperation from teams all around the globe.

Overall, participating students found that identifying project goals and milestones helped keep the project on track. It was also necessary to keep the sponsor, General Motors, well-informed during the process so that they could provide useful insight and monitor safety issues. Finally, identifying the specific strengths of different schools and assigning tasks accordingly was of utmost importance. This allowed for the optimal utilization of the varied resources, strengths, and skills within the group. Figure 6 shows some of the parts described in the above examples.

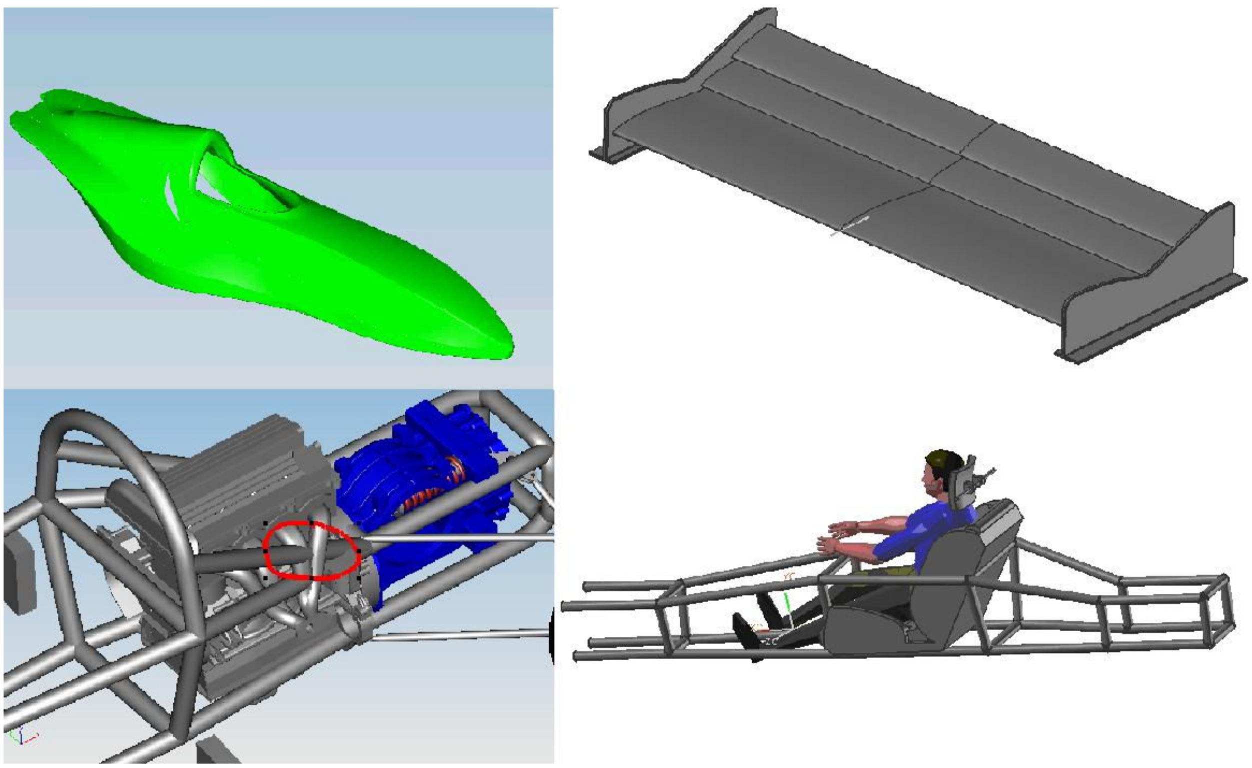

Figure 6: Pictures such as these were used to quickly and effectively communicate design intent to solve problems and continue on with design iteration. From the top left: 1) the Korean university's finished body model, 2) the Swedish university's wing mounted in the Australian university's mounting bracket, 3) the frame-engine interference issue high-lighted in Teamcenter visualization, and 4) the Korean university's original seat in the American university's frame.

Hopefully, the race car will ultimately be used as a pace car in a professional race. Although this is merely a cosmetic role, it would promote positive attention to the project. Also, this car will be displayed for a period of time in the General Motors main campus display room. This is partially to publicize the work done by the students on this project, and to show those at GM the capabilities and successes of the students involved with the PACE project.

Conclusion

This document has detailed the organization, leadership, and tools used in the completion of the multi-national project. Global collaborations provide invaluable lessons in teamwork, patience, and cultural understanding that can be found nowhere else. Large companies are more willing to fund capstone projects of this nature because they get more back from projects that last more than a few semesters and are willing to feature software used in their specific industries. Global collaborations more fully imitate industry experience because of current globalization trends in the world today. This project was a successful cooperation between many different nations, cultures, and backgrounds. Ideally, this experience will become a model for international capstone design teams in the future.

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