

Development of a Flying Eye: A Project-Based Learning Experience

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Abstract

The paper describes the design for manufacturability of a prototype product as part of a manufacturing engineering capstone course. The product chosen was a vertically launched unmanned aerial vehicle (UAV)—the “Flying Eye.” The Flying Eye is an autonomous parafoil surveillance platform quipped with sensors, controllers, mechanical components, and software. Once the autonomous UAV is deployed, it is designed to follow a predetermined flight path down to the ground. The design effort of the prototype device took place over a three-year period as a collaborative effort between the Aerospace Engineering and Industrial and Manufacturing Engineering departments at California Polytechnic State University. This project proved to be an excellent tool for the “project-based learning environment,” which is the focus of Cal Poly’s hands-on engineering programs. Details of the Flying Eye project and lessons learned during the course of this educational experience are provided.

Keywords: *Project-Based Learning, Capstone Course, Manufacturing Engineering Education*

Introduction

This paper describes the design for manufacturability of a product as part of a capstone manufacturing engineering course at California Polytechnic State University (Cal Poly). The IME 455 Manufacturing Design and Implementation course is the second in a series of capstone courses that prepare seniors in the manufacturing engineering program to work in teams to solve real-world problems. In this upper-level course, students apply knowledge gained from prior coursework to develop the manufacturing processes needed for a specific product.

Project-based learning is becoming the favored pedagogical model for teaching engineering design (Dym et al. 2005; Shooter and McNeill 2000; Carroll and Hirtz 2002). In this approach to project-based learning at Cal Poly, students are required to work in groups to solve open-ended engineering problems. Every attempt is made to bring industry projects to the classroom to provide as authentic an experience

to the students as possible. The trend is also toward making these projects more interdisciplinary by collaborating with other engineering departments within the college.

The project chosen for the spring 2005 class was a vertically launched unmanned aerial vehicle (UAV)—the “Flying Eye.” The Flying Eye is an autonomous parafoil surveillance platform equipped with sensors, controllers, mechanical components, and software encased within a protective aerodynamic housing. It is launched to low altitude (typically less than 350 m) using either a rocket motor or a compressed air gun. Once the autonomous UAV is deployed, it follows a predetermined flight pattern down to the ground.

The next section provides an overview of the Flying Eye product, followed by a description of this capstone class. The results of the students’ efforts are discussed, followed by lessons learned and conclusions.

Flying Eye Design

The design for the prototype device was performed over a three-year period in a collaborative effort between the Aerospace Engineering and Industrial and Manufacturing Engineering departments at Cal Poly. Funding for this project was provided under a grant from the Office of Naval Research (ONR). The first proposal submitted to the ONR had the following as its main goal: “The proposed research project will lead to the development of a novel method for obtaining remote sensing data using an inexpensive, man-portable, expendable device.” Artist renderings and a simulation model were used to help convey the idea to the grant reviewers (*Figure 1*).

The electronics payload using a microcontroller board, compass, GPS, servos, and a camera was developed during the research phase. Several different



Figure 1
Artist Renderings of Flying Eye Concept

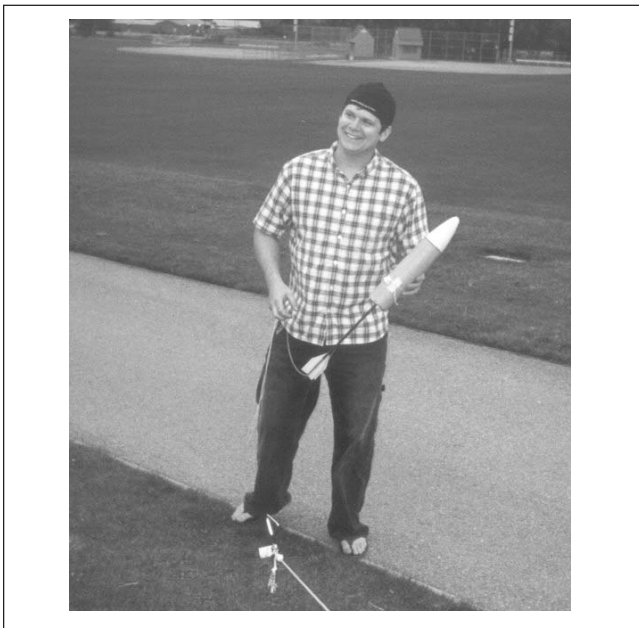


Figure 2
Prototype Test Projectile

projectiles were developed to provide a protective aerodynamic housing for the electronics payload and parafoil. The control software was built around a fuzzy logic algorithm. Tests on prototype projectiles, such as the one in *Figure 2*, have shown that the compressed air gun is capable of delivering a payload to altitudes well in excess of 500 ft (152 m). The gun launch mechanism pictured in *Figure 3*, was developed to allow for cheaper and more frequent flight tests.

Once it reaches the apogee, the Flying Eye separates into two components using a gunpowder deploy charge: the nose cone with the camera, navigation electronics, and parafoil; and a reusable



Figure 3
Compressed Air Launch Mechanism

rear section with a conventional parachute recovery system. The parafoil is inherently a very simple and stable flight vehicle. Directional control is provided by pulling on one of two control lines with connections to points on either side of the parafoil wing.

The parafoil with the nose electronics is shown in the descent phase in *Figure 4*, and a picture from the onboard video camera is shown in *Figure 5*.

The early versions of the electronics package made use of a Handy Board microcontroller developed at MIT (Martin 2000). This device provided excellent service during initial bench and prototype flight testing. The electronics package was later improved by replacing the Handy Board with a Rabbit 3000 microprocessor embedded in a Rabbit Model RCM3400 core module. The RCM3400 has 16 times the memory storage than was available in the prototype Handy Board device. This unit has more than adequate numbers of input and output ports for interfacing with the variety of sensors that have been incorporated into the advanced electronics suite. Details of the prototype work can be found in previous publications (DeTurrís, Ervin, and Alptekin 2003, 2005; Ervin, Alptekin, and DeTurrís 2005).

The manufacturing processes used for this research prototype were not appropriate for produc-



Figure 4
Parafoil with Nose Electronics in Descent Phase



Figure 5
Picture of Cal Poly Campus Taken from Onboard Video Camera

tion in high volumes and at low cost. Therefore, the prototype design was introduced to senior-level manufacturing engineering students as part of their capstone course requirement.

Capstone Course

The IME 455 Manufacturing Design and Implementation course is the second in a series of capstone courses that prepare seniors in the manufacturing engineering program to work in multidisciplinary teams to solve real-world problems. IME 455 is a continuation of the IME 418 Product-Process Design course, and typically the production of the design created in IME 418 would be carried out in IME 455. As an upper-level manufacturing engineering class, students apply their manufacturing knowledge

gained from prior coursework at Cal Poly to produce a marketable product. Required for manufacturing engineers, both courses are also available for students in the industrial engineering (IE) program as technical electives. The courses are offered once a year, with typically a much higher enrollment in IME 418 than in IME 455. IE students will often take IME 418 to satisfy a technical elective requirement but do not take IME 455. In spring 2005, there was only one IE student, with the 11 manufacturing engineering students taking the class as part of their graduation requirement.

Breaking with the traditional approach to this course, a single product was chosen for the entire class to work on as a team. The Flying Eye product was introduced to the class in the first meeting of the quarter. The Flying Eye, designed in a separate research project, was shown to students along with video clippings of initial test launches. The students were tasked with improving the design for ease of manufacture, making a prototype, and determining what processes would be most appropriate to mass produce it. They were to come up with the cost of the product if it was manufactured in quantities of 1,000.

The approach taken for this class was meant to address the ABET general engineering Criterion 3 (a-k) targeting design, teamwork, and communication. After the initial weeks of brainstorming, the class split into two groups: mechanical and systems integration, to maximize each person's capabilities. One class session per week was devoted to reporting on the progress of each individual as well as on group performance. Students were also asked to submit weekly progress reports. These reports were first submitted as hard copy and to the instructor only. Later, it was suggested that these reports should be saved in a shared folder, taking advantage of the department's Intranet.

Within the two main groups, each student was assigned to a subteam with a specific task to complete and present to the class at the end of the quarter for final product assembly. Each student team had ownership of an individual part. Ensuring that their parts would all fit together was facilitated by using the department's server to share design files. In this way, students were able to review each other's designs and verify design parameters. Despite a concerted effort to ensure that all parts fit together, one student found that his part needed to be re-machined due to a change of inner diameter in the body tube. This

error provided an excellent opportunity for the instructor to highlight the importance of a high degree of communication among team members. Team members were also asked to come up with cost estimates for mass production and to contribute to the class project final report. A Web page was developed as part of the reporting mechanism to pass information to future students (<http://www.ime.calpoly.edu/salpteki/IME455/455.htm>).

A professor from the aeronautical engineering (AE) department and an aeronautics consultant posed as customers and attended class meetings to help with design specifications. A student from the electronics engineering (EE) department worked as a supplier developing the electronics board. This created a realistic learning environment for the students as this supplier was late delivering his board to the “system’s integration” team, much to the chagrin of several students in the group. A mechanical engineering professor was invited to evaluate the final mechanical design, while several other colleagues contributed to the overall project success. A number of interesting issues and observations were made throughout the course of this project, as discussed in the following sections.

Design Thinking as a Team

The first three weeks consisted of brainstorming sessions as the whole class came up with new ideas to improve the existing design for manufacturability. The group tried to come up with “out-of-the-box” ideas to completely redesign the product to meet the vision of the aeronautics consultant. They did not restrict themselves to even the most basic elements of the prototype design during the brainstorming period. Options such as glider planes or small remote control airplanes were considered as substitutes for the parafoil-based design. Methods for extending flight time, such as incorporating a motor and propeller with the parafoil, were also considered (*Figure 6*).

Large Post-its® were used during design sessions to capture ideas. In prior studies, the process of sketching has been shown to enhance the construction of a mental representation (Römer, Leinert, and Sachse 2000).

There was much excitement and creativity exhibited by a number of the students, in contrast to what the instructor experienced nine years ago when she started teaching this capstone class for the first time.

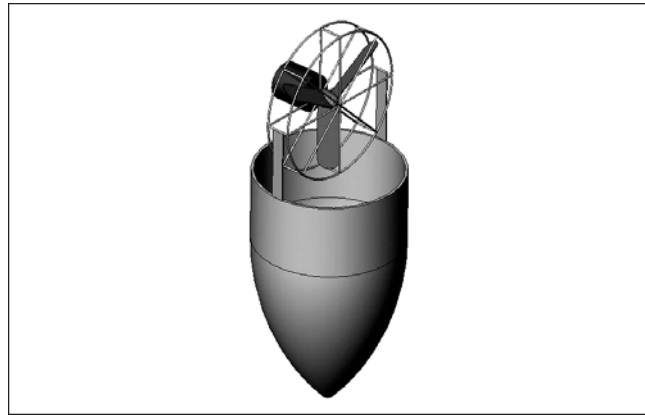


Figure 6
Design Alternatives for Extended Flight Time

At that time, students were complaining about being asked to “design,” rather than simply “machine” what had already been designed by others. This is a clear indication of positive results in continuous improvement efforts to increase students’ appreciation of “design.” In spring 2005, only one student wrote:

“I think that the interdisciplinary team project worked, but it would have been more efficient if our class was solely assigned to manufacture the parts rather than design and manufacture. As Manufacturing Engineers it is our job to come up with feasible solutions to manufacture products/parts, and although we have some background on design, it is not very comprehensive.”

As the weeks passed, many students tired of long hours spent in meetings. They were ready to go and machine their ideas rather than sit in a classroom environment. Although these design meetings were very enjoyable for the instructor and some of the students, other students worried that the design would become overly complicated. One student wrote in his progress report:

“It seems to me that many of the team members in this class want to completely redesign the rocket and make it more complicated than necessary. I have worked in groups many times in the past and I try to avoid working in groups with members that try to overcomplicate things. What usually happens is that a complicated design that cannot actually be made is created, and the rest of the group is stuck with the burden of how to fix the mess. In the end, the rest of the group is stuck with damage control.”

Eventually one student took the initiative to use a 3-D modeling program to capture the improved de-

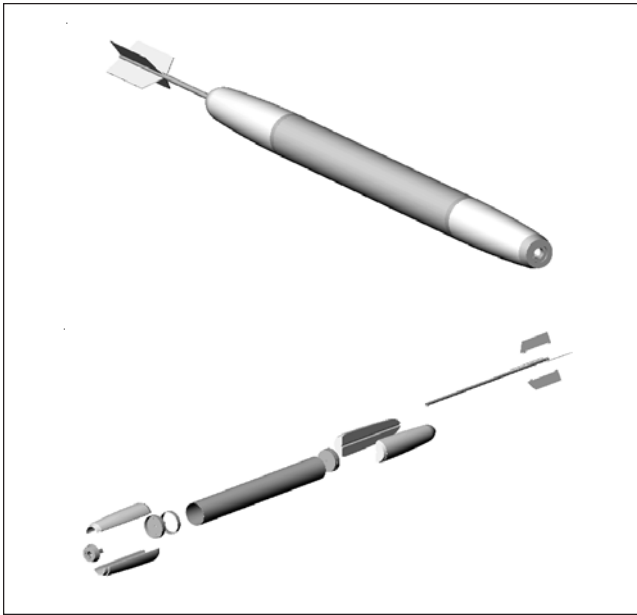


Figure 7
Improved Design

sign (Figure 7). Three-dimensional modeling was used to help visualize the final product and to see how it would all fit together. The same student also machined the mold to be used for the manufacture of both the nose cone and the aft body section. At this point, the students not only seemed to be more satisfied with the class project, and they also gained recognition from the aero professor and the consultant. What was accomplished during the first four weeks of the class was quite impressive.

Leadership and Project Management

Each of the main two groups had a group manager who was assigned by the instructor based on her assessment of students' group dynamics during brainstorming sessions. Two students appeared to be recognized by others as leaders. The rest deferred to these students when reporting on their progress. However, the choice of leaders was not universally accepted by all of the students. One student wrote:

"I think there was a lack of leadership. Maybe in the future, someone can be elected from the students as a leader who worked with different teams and coordinated with the professor."

This observation can also be viewed as a learning experience. It is likely that this student will find in the future that in industry one rarely gets to choose his/her own boss. A student who had prior project management background was assigned to be the project

manager, whose role included sharing management advice, setting a general timeline, proposing deadlines, and assisting the systems integration group.

Project Results

After performing a number of trade studies, students settled on a final product design. The team split into the various subgroups of: Body Tube, Nose Cone, Front Nose Cone Coupling System, Rear Bulkhead, End Cone and Fins, Cost Analysis and Mass Production, Electronics Board Layout, Servo Plates, Webpage and Report, and Project Management. The various component parts are shown in Figures 8 and 9.

Ultimately, the product matured into a single design for every component part except for the tail section. Two candidates in this part were radically different with the possibility that one would prove far superior to the other. However, it proved to be necessary to build prototypes of each to make an informed decision as to which candidate would best satisfy all of the pertinent criteria.

The two candidate designs were designated as the "arrow style" and "integral" fin assemblies. The advantage of the arrow-style tail section was that it used some of the same mold assembly as was used in the construction of the nose section. It was expected that this feature would save on mold fabrication costs in full-scale production and increase interchangeability of parts. The advantage of the integral tail section was that it would be much stronger than the arrow style. The final design selection would ultimately be dependent on factors such as the number of orders received and performance of the product in flight tests. These two questions could not be answered within the framework of the project time period. Figure 8 shows drawings for the integral fin assembly and its associated mold.

The critical design tradeoff for the rear bulkhead was between weight and strength. All components including the rear bulkhead needed to be as light as possible. However, the rear bulkhead needed to be strong enough to withstand the direct blast from the deploy charge. A clever design feature of this component was to make the side facing the blast concave. This feature spread the blast energy over a larger surface area and reduced the required thickness of material and hence the weight of the part. The drawing in Figure 9 shows the final design of the rear bulkhead component.

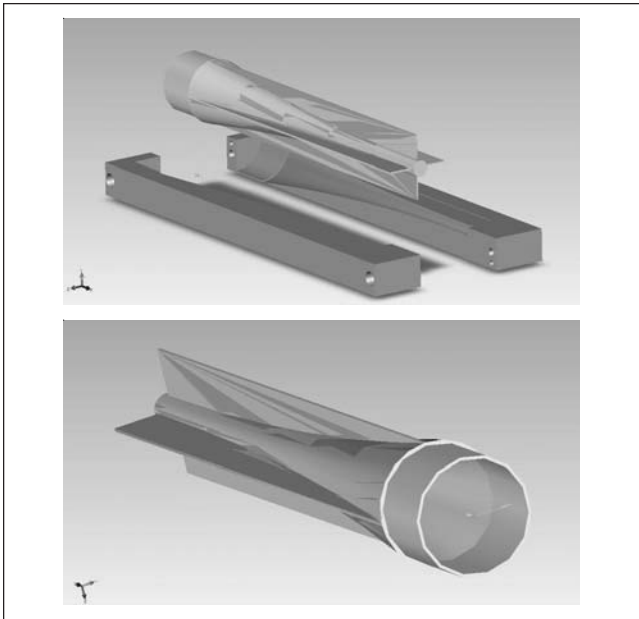


Figure 8
Integral Fin Assembly and Mold

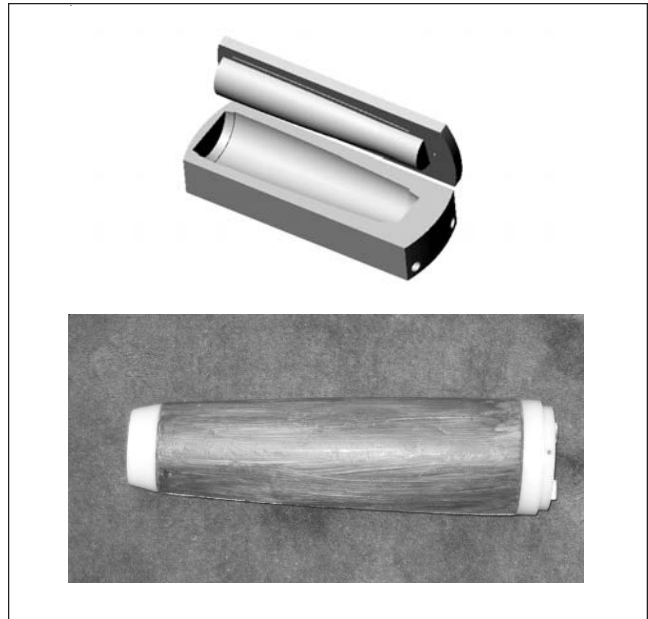


Figure 10
Nose Cone and Mold

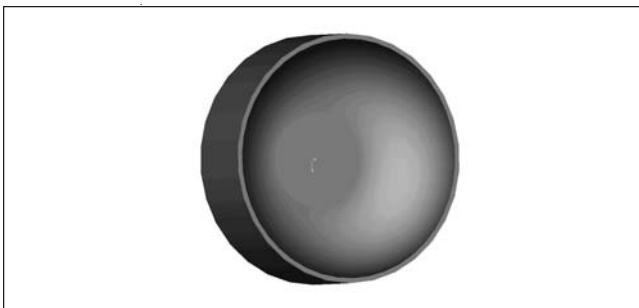


Figure 9
Rear Bulkhead



Figure 11
Disassembled Nose Cone

The nose cone houses the electronics for autonomous navigation and camera surveillance systems. Structural loads on this section are relatively light because most of the forces of launch and landing are absorbed by the electronics board layout. The main design trades for this part were cost, weight, and ease of access to internal electronics. This part was cast as two halves that were secured by the camera-mounting fixture at the front and by the nose cone coupling system at the rear. The material used for this part is a 4 lb/cubic foot density expanding urethane foam. *Figure 10* shows a drawing of the mold and a picture of the assembled nose section. *Figure 11* shows the nose section prior to assembly (note the camera mounting fixture with the camera in place at the front and the coupling system at the rear).

The electronic board layout provides the mounting surface for the electronic components and is the main structural member in the nose section. Strength, weight, thickness, and cost were the main areas for trade-offs in the design of this part. The student designer settled on sheet phenolic as the material from which the part would be cut. This part was designed to be fabricated using the Haas computer numerically controlled (CNC) machine, and the necessary fixtures were produced for this purpose. The student was eventually forced to produce the part by hand for the manufacturing prototype due to high demand for time on the CNC machine. The electronic board layout is shown in the nose cone in the top half of *Figure 11*.

Figure 12 shows a close-up view of the actual camera mounting fixture and the drawing created



Figure 12
Detail of Camera Fixture in NoseCone

by the student designer. This part needed to be light-weight yet strong enough to withstand impact with the ground and protect the camera electronics. It also serves to anchor the two halves of the nose cone at the front end of the vehicle.

This part was fabricated in a rapid prototyping machine. Not seen in the figure is a flexible mounting mechanism to further absorb shock loads that would be encountered in landing. In a full-scale production run, this part would be fabricated using plastic injection molding technique. Due to cost constraints, a mold was not fabricated for this part.

The finished and assembled product versions are shown in *Figure 13*.

Manufacturing Cost

Students calculated the cost of manufacturing a single unit at \$4,428. In a mass production run of 1,000 projectiles, the cost of the initial molds would be much greater. However, the cost of these more expensive molds would be amortized over the entire production run, resulting in a per unit cost of \$1,157. The technology employed for essentially every part of the final product would be different for a single-unit build versus a mass production run. A detailed final report, including cost figures prepared by the students is available at http://www.ime.calpoly.edu/salpteki/IME455/documents/455_report.pdf.

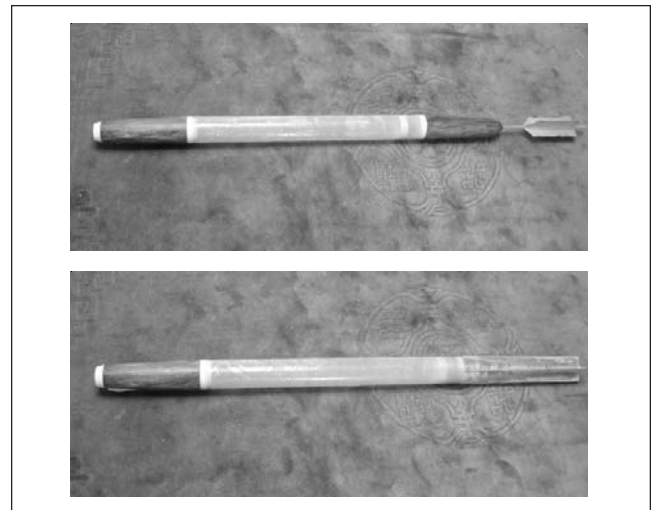


Figure 13
Design with Arrow-Style Fins and Integral Fins

Lessons Learned

Group Size

In many prior courses, students divided up into separate small teams to essentially compete against each other on similar or the same project for their grade in the class. In contrast, in this course the whole class worked as a group on the same product. One concern to this approach was that a lack of competition among the class would result in less motivation on the part of the students. However, structuring the entire class to work as one group was seen as more reflective of the situation that most students will find in industry. This class was designed by the instructor to demonstrate an environment where self motivation is required and to encourage teamwork among the class members.

The students were steered toward working on the instructor's "pet project" rather than their own projects that they carried from IME 418 (the first class of the series of capstone courses). They were given a chance to make a presentation to class during the first week of the quarter if they wished to work on their own projects that they designed in IME 418. The instructor presented her proposal to the class, and the product choice was the Flying Eye. It later became clear that this situation created some resentment. One student wrote:

"For next year, the biggest recommendation I can make is to let the students pick their own project. This will allow them to express their own creativity and it will insure their motivation to be at an ac-

ceptable level. It was hard for me to find the motivation for this project, because I had no previous involvement and I won't have any future involvement after this quarter."

Another said:

"In the end, I did like the class and it was good because I've never had an opportunity to work in that type of environment. In regular classes, teams usually consisted of two or three, but in 455, the entire class was a team. That was definitely interesting. I'm also torn on whether or not this 'one project per class' idea should be carried over though. I do like it as it gets the entire class involved but it also limits motivation as some students had the intention of doing their own project coming into IME 455. So I recommend in the future, the opportunity of doing a class-wide project, but also giving students the chance to do their own projects."

Other comments included:

"The rocket finally came together at the end, but this was a very difficult team project because of time conflicts, the size of the team, and trying to exchange information. It would work better if it were in smaller groups and we could choose what we wanted to produce. Meeting fewer times to discuss progress and spending the time to work would also be helpful."

And:

"It was difficult having so many people working on the same project. We had too many different ideas and opinions and there wasn't strong enough leadership to filter all the ideas and opinions. Most of our meetings were inefficient. So, for next year, make sure the group sizes are smaller."

There is a delicate balance to strike in this area, we want students to be highly motivated and to enjoy the learning experience. However, we also want them to have a realistic experience of the environment most of them will be going into in industry. Much of their educational careers have been focused on individual achievement and for many students the notion of the rugged individualist is accorded high esteem. The norm in modern industry, however, is to work as a team, where a focus on individual achievement often can be counter productive to the goals of the group.

Although most of the students expressed a preference for working in smaller groups, at least one student actually favored increasing the group size to include specialists in several other disciplines:

"I think it would have been better if we had brought in other engineering disciplines to help with each part of the rocket, i.e. – EE's for the electronics, AeroE's for the design of the rocket, MATE's for the materials, etc."

Students found it easier to make progress once the team had been divided up into smaller groups to work on component parts of the project. Working in smaller subgroups gave each member a better opportunity to express their own creativity; however, they were still constrained by requirements imposed by the schedule and needs of other groups. This environment provided a fairly realistic preview of what they can expect to experience in industry.

Several students regarded the compromise and consensus that are often necessary in group projects as being highly undesirable aspects that need to be avoided.

"In terms of interdisciplinary teamwork, breaking up into smaller groups yielded better results because decisions were less about consensus and compromise. Consensus usually requires more trust, project buy-in, and complete understanding of the project by all parties involved, while compromise hardly pleases everyone and often comes up with a lackluster solution. Furthermore, delegation allowed us to tackle a variety of smaller problems simultaneously rather than slowly moving through issues individually."

And:

"...Finally, breaking into smaller groups and giving students more responsibility over final design and implementation issues would cut down on compromise, facilitate learning, and improve group progress."

Compromise and obtaining consensus can often be a frustrating experience when working in groups. However, as businesses continue to expand into global markets with input coming from people of diverse backgrounds, the need for engineers to learn compromise in project decisions is likely to increase in the future. Jokes that refer to the poor result of projects designed by committee aside, it is often found that compromise and consensus among a group will result in a product superior to that which can be designed by any single individual. The approach taken by the class was to initially hold large brainstorming sessions to steer in the desired direction and then break into smaller teams to ad-

vance the project in parallel lines. This approach proved to be quite effective.

Bottlenecks

Several constraints slowed progress. Most of the team members were graduating seniors and were more concerned about finishing their own individual senior projects. Scheduling this upper-level class in the same quarter with senior project deadlines often took the focus away from progress in this class behind priorities in meeting individual graduation requirements. Furthermore, not everyone was available at the same time. Outside of class, most people did not have much extra time to meet or devote toward the class. Students often had to wait for others to finish their products, creating slips in scheduled milestones.

“Overall, this complex mechatronics project was difficult enough to provide a learning experience, but some changes might improve the process. ... Taking into account people’s daunting senior projects requirements, sensitivity to student schedules would yield better management of time and in our case less meeting and more machining.”

Available machine time was also limited due to high demand and long processing times during the school quarter. When groups finally had their solid model designs completed, long machine queues and early machine shop closures put a brake on progress. Ultimately, competing for limited campus resources and insufficient time were great obstacles. Some students worked into the early morning hours to get enough machine time to finish their component parts.

“It takes a long time to machine a part. Setup time is the true time killer. Don’t sleep. We will be in the lab every open hour.”

Pressure to Perform

Several students felt a heightened sense of urgency to perform well with literally the entire class dependent on them for success. Although they were working in subgroups in the final weeks, students had to have output from other groups to complete their own part of the project. When students work in small competing groups, a failure of a single individual or group does not affect the performance of the entire class. Some students in IME 455 performed heroic efforts to not let down the group.

“The Quarter before last, I took process design II. The class assignment for the entire quarter... was

to create a mold. It took the whole quarter to complete the project, literally working night and day. I hope that my second attempt to make a mold (in this class) will be twice as fast.”

And:

“Calculating the feeds and speeds for the main cavity has been complex since, the main cavity is a three-axis feature. ... The code for that is just under 40,000 lines of code or over 600 pages. WOW!”

And:

“This project has taken a lot more time than I anticipated. I really enjoyed making this mold, I just did not have the time. Unfortunately my other classes suffered from this project. On the bright side, I have learned a ton of things. I am completely confident with operating the Haas machines and generating G-codes.”

Students will find that it is often the case in industry that they will have less control than they desire over the design of a project, but will have enormous pressure to deliver their portion on time and within budget. The consequences of failure are likely to be much more severe than enduring the displeasure of a few colleagues. Hopefully, students in this class learned that their actions could have a far reaching impact on many others in the project.

Scale of the Project

Some student comments expressed concern about the scope and size of the project:

“The project next year can be improved by involving a smaller scale project.”

And:

“The attempt to introduce an interdisciplinary team project was a good learning experience. The backgrounds of the members of the group were not diverse enough for a more successful project. The design of the product was not finalized prior to the start of the project to develop mass production, and time was wasted in developing the design of the product and not designing the methods of manufacturing and mass production.”

At least one student found fault with the brainstorming sessions and would have preferred to dive into building a prototype as early as possible.

“Overall each team worked well together but I think that it would have been better if we went with our designs from the beginning of the quarter and

started building prototypes immediately. Instead we tried to come up with the perfect solution and only then did we start manufacturing the prototype. Once we started manufacturing the prototype it seemed to go quickly and if we made multiple designs I think that that would have been optimal.”

In industry, a balance often has to be found between perfecting the design and forging ahead into the next task. Discipline is usually enforced through strictly enforced schedules and milestones. Occasionally, extraordinary efforts must be called on to avoid major schedule slippage. Presumably those students that spent their early morning hours machining parts would testify to the truth of this assertion.

Lack of Crisp Requirements

Students found the open-ended nature of the project unsettling. Many expressed dismay in having to interpret and balance divergent and sometimes conflicting design requirements. In addition, they had to contend with areas where requirements were inadequate or missing altogether. This environment was a sharp departure from previous classes where a solution is known to exist and the steps to that solution can be studied and applied to obtain the correct result. All that is required of the student is to learn the steps to the solution to ensure success. The frustration felt by the students in the much more chaotic setting presented by this project is understandable and more reflective of the real-world environment that they can expect to experience in industry. Comments addressing this issue went along the lines of:

“First and foremost, a clear consistent goal with a customer in mind would focus our manufacturing decisions. While flexibility is important, directional leadership ought to precede good management.”

And:

- “[In the] interdisciplinary team project:
- Meeting with one another was a little difficult
 - Unsure of parts worked on by others
 - Waiting around for others to finish.”

Conclusions

A lot of administrative work goes into providing the project-based learning experience for students, but the result is a stimulating exercise. The approach of having the entire class work as a team with outside input provided aspects of realism they had not encountered in other courses. Despite the unfamiliar

environment, the students should be congratulated on the exemplary job on this project, and it is hoped that it was a meaningful educational experience for them.

There were a number of suggestions for improvement brought out by the students. All of their input was welcome, and many of these suggestions will be incorporated into the next offering of this course. However, some of the aspects that made the students most uncomfortable (working as a single team, open-ended project, tight deadlines) were important learning experiences. They are likely to face many similar discomforts in industry, and it is important that they learn to deal with these aspects as part of their education in college.

In future offerings of this course, it is recommended that some additional definition of the project be provided early in the design phase. However, a certain amount of the open-endedness that made students most uncomfortable should be maintained. It would also be desirable to expand the course to include a more global experience for the students. This could perhaps be achieved through collaboration with a foreign educational institution or perhaps through some device internal to the college.

There are more and more papers and publications that provide resources for educators on project-based learning. Those who are looking into offering project-based learning experiences are encouraged to review these reports. One such report, “Project Based Learning in Engineering: A Guide to Learning Engineering Through Projects” (2003), includes examples and assessment methods for group work that proved to be particularly useful in developing this class. The report can be accessed at <http://www.pble.ac.uk>.

Acknowledgments

“Engineering design is a journey” (Dym, Wesner, and Winner 2003). This journey was enjoyable. The support of the Cal Poly Research Dean’s office is acknowledged. All of the students in the spring 2005 IME 455 class contributed to this project’s success. Special thanks to Joshua Bram Nudelman for his excellent performance on this class project.

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