AC 2012-3561: AN INTERNATIONAL MULTIYEAR MULTIDISCIPLINARY CAPSTONE DESIGN PROJECT

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An International Multiyear Multidisciplinary Capstone Design Project

The senior design capstone course(s) has been a major element of engineering education for many years, at least partially driven by the requirements of ABET for a capstone experience which states:

> "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints." [1]

Although there are no external requirements on the length of the experience, many programs now extend to two semesters and are increasingly including projects sponsored by area industrial companies. One objective of this is to make the experience as close to 'real world' as possible in an effort to help students prepare for what they will see in their careers. In addition, the senior design course is frequently used as a point of assessment for several of ABET's Outcomes a-k.

Description of Senior Design

At the University of St. Thomas (UST) located in St. Paul, MN, a two semester senior design project has been part of all engineering programs since their inception. Most projects are sponsored by industry and although the difficulty of the projects varies somewhat, it's usual that the companies consider these projects challenging. In fact, we attempt to screen the projects to select ones that are 'important but not critical' to the companies. Important so they provide the necessary resources and invest their time in participating in reviews with the students but not so critical that the company suffers if the project is less than totally successful. Although we recently introduced a modest fee of $2,500 per project, most companies fund the projects well beyond this fee with several companies investing over $10,000 in their project. In spite of this interest by industry, it is important that these remain the students' projects and not become faculty or company projects that the students merely participate in.

Another hallmark of our program is its interdisciplinary nature. We have one common course for all engineering students and strive to have Senior Design team sizes of four to five students with a mixture of electrical and mechanical engineering students on each team. This is of course tempered by faculty's assessment of the needs of the projects as well as the available student pool.

International Multiyear, Multidisciplinary Capstone Design

A search of the literature reveals a limited number of multinational capstone design programs and even fewer multiyear projects. This is due in part to the considerable logistical challenges inherent is such undertakings. Many of these very worthwhile programs involve service learning projects in the developing world, often partnering with Engineers Without Borders (EWB). As Jack Zable points out, these projects have their own challenges including funding, finding suitable mentors and absence of external pressure needed for completion. [2] The Department of Civil Engineering at Rose-Hulman Institute of Technology partnered with EWB and the Kwame Nkrumah University of Science and Technology (KNUST) in Ghana in 2006 and 2007.[3] The teams developed facilities to support education and research efforts in Ghana. Michigan Technological University's Civil and Environmental Engineering Department implemented their six credit International Senior Design course in 2000. [4] Students spend two weeks on site collecting data in either Bolivia or the Dominican Republic. Students then develop a final design and report.

The Mechanical Engineering Department at Michigan Tech recently developed an international capstone design course based on service learning, but the focus is on the design of assistive devices for people living with handicaps in India.[5] These projects launched in 2010 have the added benefit of appealing to students from underrepresented groups such as women who may be less interested in the traditional mechanical engineering challenges such as Formula SAE Car design. Wright et al followed up on their program with a post-graduation assessment. [6] Their preliminary results suggest international senior design has an even greater impact than traditional senior design.

One of the first multinational capstone design projects involved an aircraft design project at Virginia Polytechnic Institute and Ecole Des Mines De Nantes in France, as reported by Marchman et al. [7] The program involves all levels of students and several disciplines, although growing a project across departmental lines is not without challenges.

Description of Ocean Glider project

A project was proposed in 2010 by an industry sponsor who had a history of mostly successful projects with us that was different in several important aspects from our typical projects. First of all, he proposed a five year, 'spiral design' project in which the design would be refined each year until it was ready for production. This project also involved a major part of the project being designed under the responsibility of a team at the University of Beira Interior (UBI), a university in Portugal. The sponsor's technical goal is to develop an ocean research vehicle, such as one shown in Figure 1, which is low cost so that a large fleet could be deployed in the fertile regions of the ocean to monitor ocean health, principally algae concentrations. These regions of the ocean provide a large percentage of the protein needed to feed the equatorial areas of the world. The sponsor's other goal is to foster the development of the next generation of engineering expertise.

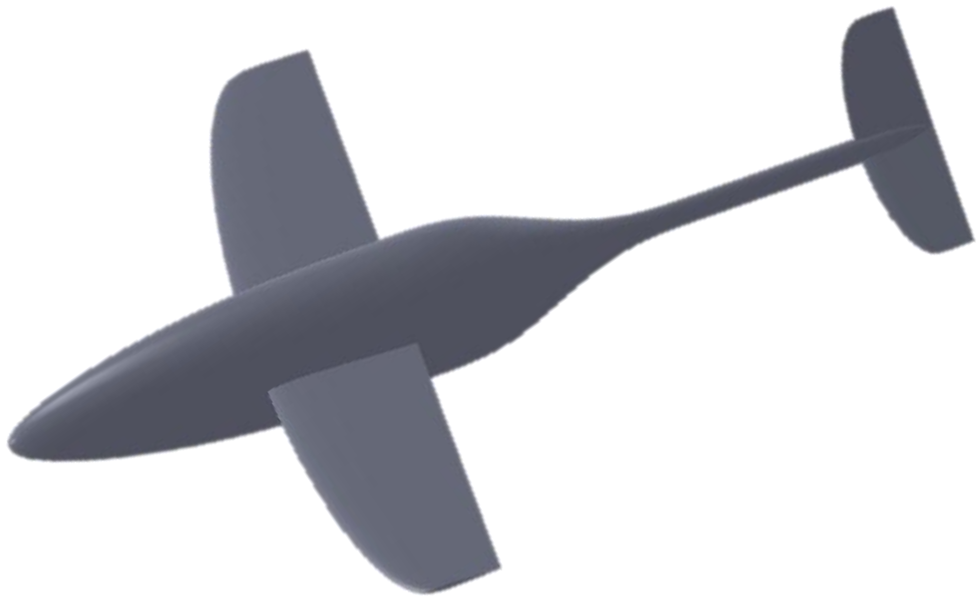

Figure 1. Preliminary model of the Ocean Glider.

The task was to design an autonomous underwater vehicle that utilizes changes of buoyancy and fixed wing hydrodynamics to provide the propulsive power. Major design requirements provided by the sponsor included:

- Able to transit from Boston to the Azores.
- Autonomous operations for a minimum of 4 continuous months before maintenance is required.
- Deployed useful life of 2 years.
- Launched and recovered from an ocean going ship or from a dock that has access to the world's oceans.
- Navigate to a minimum accuracy of 1000 meters left or right of the desired programmed course upon returning to the surface after a dive of 300 meters.
- The ocean glider shall be capable of powering all of the systems for at least 4 months.
- Any expendable fluid used in the Propulsion sub-system shall be bio-degradable.

The ocean glider should cost at most $25k to produce, a very aggressive target.

The ocean glider is similar to an aircraft glider except it travels below the water. It is propelled by changes in buoyancy that causes the glider to descend and ascend. Hydrodynamic forces on the wings convert the vertical motion into horizontal motion much like wings on an air glider. See Figure 2.

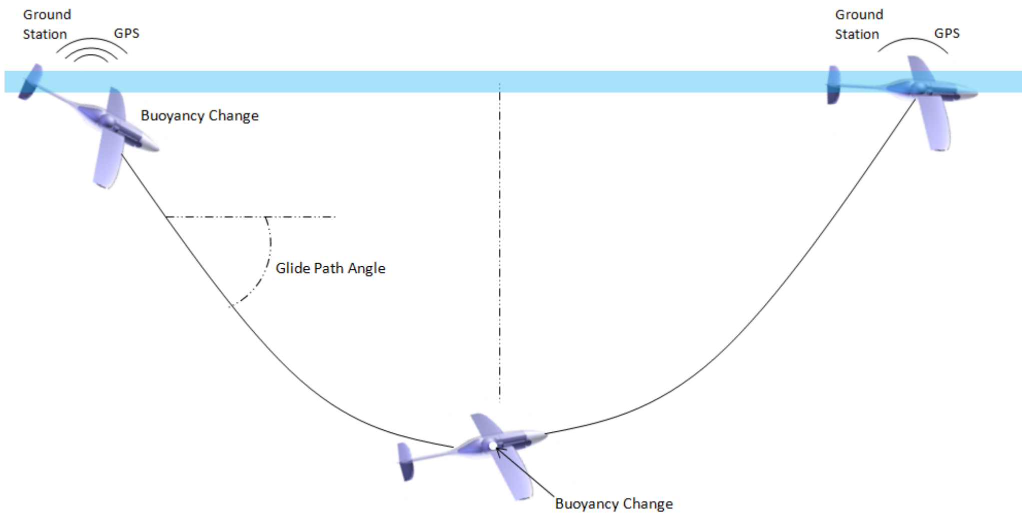

Figure 2 The Ocean Glider communicates via satellite at the beginning of each dive.

Figure 3 shows the UBI team with a one half scale model. Figure 4 shows the major subsystems planned for the ocean glider. Note that UBI is responsible for the water frame while UST is responsible for most of the internal systems. The customer at present is taking responsibility for the communications subsystem in addition to the scientific payload.

Figure 3. The 2012 UBI Team with a half scale model of the water frame.

Several other water vehicles that operate on buoyancy have been fielded. Several are compared in Figure 5. One major difference between our vehicle and those shown is the design glide path angle. Existing gliders have a relatively steep glide path compared to the ocean glider.

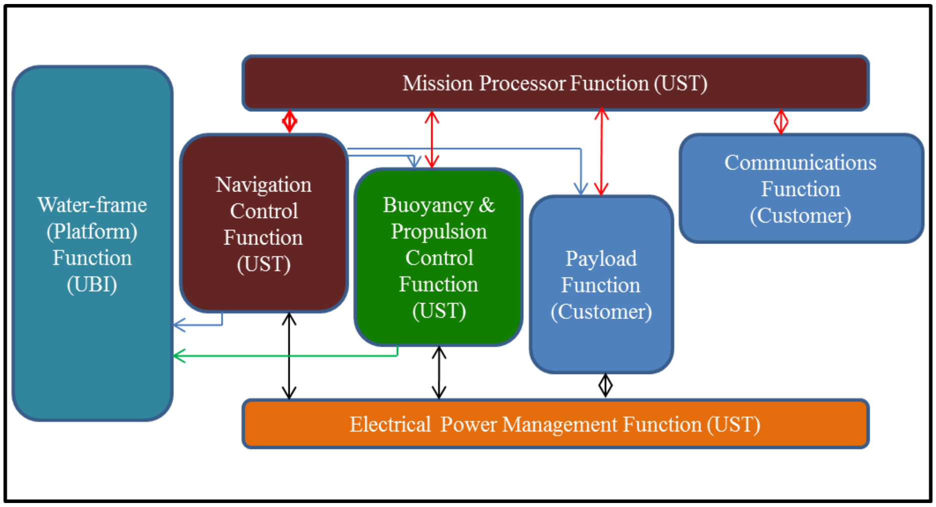

Figure 4 Functional Block Diagram including ownership.

Name	Seaglider	Slocum	Spray
Picture			
Energy	10 MJ	8 MJ	13 MJ
Pump Type	840cc Reciprocating	520cc Single-Stroke	900cc Reciprocating
Cost	$70,000	$70,000	$50,000
Duration	200 Days	20 Days	330 Days
Buoyancy Force	1.28 N	2.26 N	1.23 N

Figure 5 Brief survey of existing ocean gliders.

Operations are planned to be controlled from a ground station that receives periodic updates from the glider(s) including position, health and scientific data and sends routing commands back to the vehicle(s). Design of the ground station is planned for a future year of the spiral.

The preliminary layout of the five year plan is:

- Year 1 – Development of requirements and preliminary design of subsystems to meet requirements.

- Year 2 – Refine requirements and solutions. Detail and build proof of concept subsystems.
- Year 3 – Build and integrate prototype subsystems for vehicle level testing. Refine requirements and preliminary planning for base station.
- Year 4 – Test and refine design(s). Build prototype ground station.
- Year 5 – Refine design for volume manufacturing.

The sponsor is familiar with the work of UBI through previous work they had done together on air vehicles. Their expertise is in designing aerodynamically efficient airfoils and gliders and thus the sponsor selected them to design the shell (waterframe) of the vehicle.

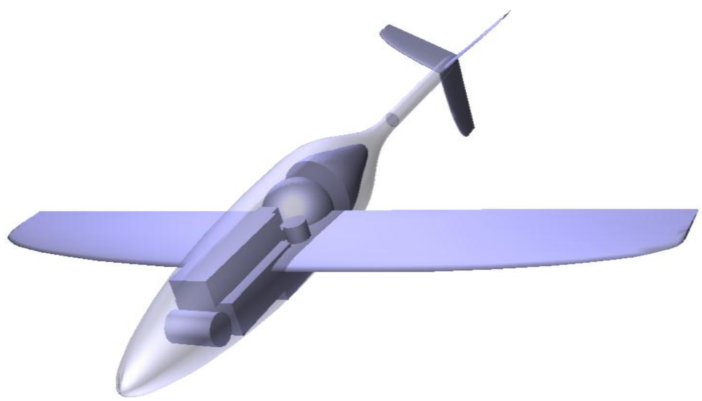

Figure 6 Preliminary design of the Ocean Glider Waterframe showing the flying tail and payload modules.

Multidisciplinary aspects – ME, EE and Aero

This project required inputs from electrical, mechanical and aeronautical engineering disciplines. With the European team providing the aeronautical expertise in the waterframe, the USA team provides the mechanical and electrical engineering students working together to design the navigation, control, power and propulsion subsystems and package them into the waterframe. Coordination was required at many of the interfaces. For example, the USA team had to estimate (and refine in each spiral of the design – see Figure 6) the size, weight, power and volume of the electronic subsystems so that the European team could design a hydrodynamically optimized vehicle that would carry the subsystems. And the stability derivatives of the waterframe were needed by the control team to develop the simulations necessary to prove out controls. And waterframe performance characteristics were needed by the power team to help them develop alternatives for recharging the batteries. Several examples of the trade-offs and exchanges common in engineering design were required as the shape of the waterframe and the details of the subsystems developed. The USA team in 2011-12 consists of 3 electrical engineering students and 4 mechanical engineering students. Currently the European team consists of two aeronautical engineering students.

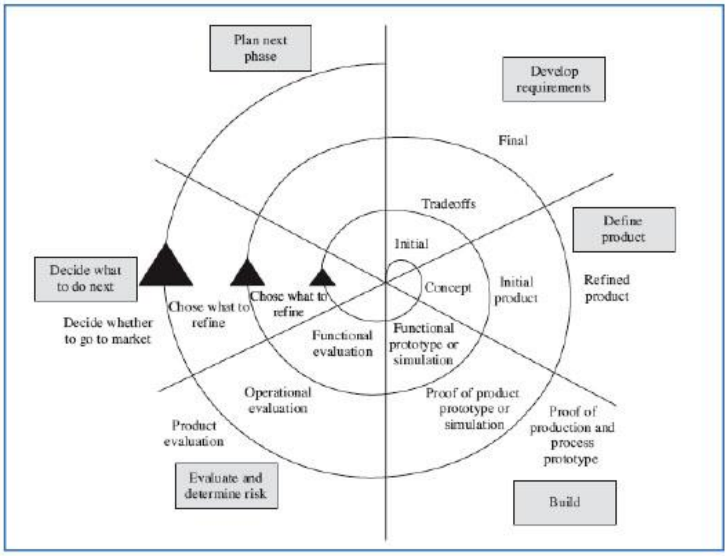

Figure 7 The Project employs a spiral design process similar to that proposed by Ullman[8].

The complexity of this project has resulted in several aspects that are not typical in our senior design projects. These have included:

<u>Biweekly video conferences via Skype</u>. Early in the first year we instituted approximately bi-weekly coordination meetings between UBI, the UST team and the sponsor. Every attempt is made to have the students organize and lead these meetings with the student leaders negotiating the day/time and agendas although the faculty sponsors at both locations typically participate along with the industrial sponsor. Skype video conferencing was used because it is economical and the internet is readily available at all locations.

<u>More formal requirements</u>. Because of the multiyear, multisite and evolutionary nature of the project, see figure 7, it has proven more important than ever to document requirements in a form that can be shared. We are now looking at a formal computerized requirements management tool to help with this process since we are finding that the evolution of the requirements through the various spirals and across locations has been difficult using word processing tools.

<u>More formal interface documentation.</u> Interfaces between subsystems, especially those affecting the mounting of components inside the waterframe, have also become more critical. The students are seeing first-hand the problems with incomplete interface definitions. In addition, they are seeing the type of documentation more normally associated with formal industrial

development projects. The buoyancy engine prototype, developed by the Summer Fall team and shown in Figure 8, will need to be integrated into the water frame and control systems.

Emphasis on final reports to provide connections to future years' designs. In more typical senior design projects we have done, final reports and related product design documentation were required and graded but since it was not really used, it was easy to overlook details. Even the students have seen the problems this creates when the next team of students picks up the evolutionary design and tries to understand what has been done. As a result, they are now seeing first-hand the importance of good documentation.

Periodic steering meetings of sponsor and faculty at both locations. We have found it useful to occasionally supplement the biweekly student meetings with meetings of just the faculty and sponsor, typically again using Skype video. These meetings are used to keep the big-picture, five year plan on track and to adjust the plan for problems discovered in each year's work.

Use of common database. The students quickly found the need to share information between teams and established a documentation bank on one of the servers a section of which all participants could access. This facilitated the controlled sharing of design documentation.

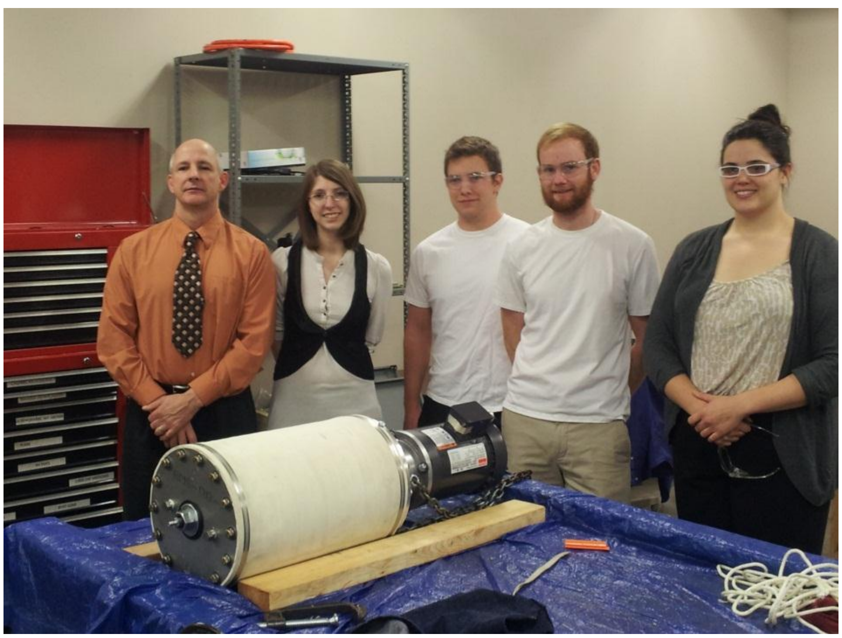

Figure 8 UST Team 2 with the buoyancy engine.

Assessment

Assessment of the project has so far not differed much from the assessment of our more traditional industry-sponsored senior design projects. In the first of the two semesters, assessment occurs using the following milestones:

- Problem and Requirements understanding
- Preliminary Design Review (Including inputs from sponsor)
- First Semester Final Report
- Peer assessments (currently done within the USA team only)

In the second semester, the typical (specifics differ slightly year to year) milestones are:

- Critical Design Review (including inputs from sponsor)
- Testing review (including inputs from sponsor)
- Final review (including inputs from sponsor)
- Second Semester Final Report
- Peer Assessments (currently done within the USA team only)

In addition, informal technical comments on the USA designs are solicited from the European team and vice versa based largely on the design review presentations.

We have identified several benefits from this project. First of all, the students have seen the cultural differences between the two locations. This has included finding good times to meet (the European team tends to be available later in their afternoon because of the traditionally late (by American standards) dinner hour. They also see first-hand the complications due to the 6 hour time difference between the USA and Europe. Just finding a time convenient to both teams can be a challenge. They have also seen language and school schedule differences as well as school requirements. Even daylight savings time differences have disrupted the process since the two countries change to and off of daylight savings time on different dates. In fact, this resulted in a missed meeting when neither team noticed that the USA had changed time but Europe had not. Some times in industry it's these 'little' differences that complicate efficient operations and our students have seen the effects already.

The students are also seeing first-hand the challenges of multi-location development as well as handoffs of designs from one part of a company to another. These operations, while uncommon in school or senior design settings, are increasingly common in industry and the more we can prepare our students for this 'real world', the better off the students will be. They have also learned more about using video conferencing to efficiently conduct business and the tools that can help, such as agendas and minutes. Connected to this is the principle that each year's student work is built on the work of earlier students and contributes to the work of future students. Thus, the students' work is seen in a much larger context than is common in most of our senior design projects.

Another benefit to the students and faculty is that they are seeing first-hand the contributions and capabilities that non-USA students have to engineering projects. This will hopefully help everyone to have a more realistic view of where USA education stands relative to the rest of the world.

The full assessment of these benefits is currently hard to quantify since our first group of USA students are just now getting jobs. Our plan is to survey these students to get at least a qualitative assessment in a few months.

There are several lessons learned that we have already identified however. Our program has had occasional two-year senior design or other student projects and so have seen the need to transition from one team to another. But we have found the transitions in this project to be harder than expected with new teams wanting to start from scratch rather than pick up where the previous team left off. In our previous experiences with this, it was either possible to manage the degree of duplication or the duplication was needed due to poor performance in the previous year. In this project, it has proven much harder to control and in future iterations we intend to focus the students' attention on reviewing and accepting prior years' work.

Finally, one additional challenge is from the interdependence of the two locations. Not unexpectedly, problems that come up in one program can affect the other. One example of this was when the European university failed to have a student working on the project for a semester. Since their work was slightly ahead of the USA team, the effect was minor but this lull in activity was very noticeable and served to reinforce the interdependency. If this situation had continued, it could have seriously impacted the USA students.

In conclusion, both universities and the sponsor are happy with this new approach to senior design. Although not all the teams have performed up to expectations, our expectations are high and most of the teams have risen to the challenge. More importantly, the students (and faculty) have learned a lot about successful international collaborations to design complicated machines.

Acknowledgements

UBI Students Joao Morgado, Francisco, etc.

Fall 2010 Spring 2011 UST Team 1 Josh Kleven, Matthew Deutsch, Sean Engen, Frances Van Sloun, Jim Giancola, and JB Korte

Summer Fall 2011 UST Team 2 Carol Comp, Colin Grist, Carly Olin, Dan Quinn, Richard Thompson

Fall 2011 Spring 2012 UST Team 3 Matthew Logue, Brian Dwyer, Tony Markert, John Albers, Taylor Kobayashi, Cooper Mazon and Hamza Jabri

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