# AC 2011-2186: SE CAPSTONE- INTRODUCING MULTIDISCIPLINARY DESIGN TO USCGA

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# SE CAPSTONE- Introducing Multidisciplinary Capstone Design to the United States Coast Guard Academy

The United States Coast Guard Academy (USCGA) is one of five Service Academies educating and training generations of Military Officers. USCGA offers eight majors including four engineering majors- Civil, Electrical and Computer, Mechanical and Naval Architectural and Marine Engineering. Each major has traditionally taught its own capstone design course, which ranged from a one-semester paper project to a two-semester project with a functional prototype. Multidisciplinary projects have been rare and collaboration on projects has usually been limited to having cadets from other majors working as part of design teams, but usually being enrolled in a separate independent study (directed study).

This paper will highlight changes brought to USCGA through the Department of Defense (DOD) Systems Engineering Grant. As part of the DOD Systems Engineering Grant, Civil, Mechanical and Electrical and Computer Engineering are collaborating on a project. The goal of this project is to design and build a bolt-on hybridization system for existing fleets of medium sized trucks. The system would capture & store energy during coasting and braking, and then turn that stored energy back into kinetic energy during acceleration. Increased fuel mileage would result in fewer refueling stops thus fewer refueling-related casualties, reduced reliance on foreign oil and reduced engine and brake maintenance. Other possible benefits include turning a 2-wheel drive vehicle into all wheel drive and silent (no engine) drivability. The current project plan is to design and build a full-scale prototype system. Major system components include energy capture, energy storage and energy delivery as well as braking and acceleration control systems and a rudimentary anti-lock brake system.

Cadets from Civil and Mechanical Engineering are collaborating as a capstone team with two Electrical Engineering cadets who are collaborating with them via a directed study. The amount of collaboration required for this grant is a major departure from past years. In this pilot, there are three Faculty Advisors, representing the three majors and a senior faculty member supervising the entire project. Issues that are being addressed include: differences in textbooks, grading schemes, course policies, assignments and schedules. The paper will discuss the rapid rate of change driven by the DOD grant and how these obstacles were overcome.

## Capstone Design and Research at USCGA

The United States Coast Guard Academy has grown from a Service Academy with four Majors, to one with eight majors (Civil Engineering, Electrical Engineering, Mechanical Engineering, Naval Architecture and Marine Engineering, Government, Management, Operations Research and Computer Analysis, and Marine and Environmental Sciences). Approximately one-third of

the CGA faculty is Permanent Commissioned Teaching Staff (Coast Guard Officers permanently assigned to teaching positions at CGA), another third is rotating Military Officers and the final third is tenure-track and temporary civilian educators. This mix of faculty is responsible for developing and delivering the academic content necessary to award Bachelor of Science Degrees in the eight majors. In addition to teaching and other collateral duties, the faculty also performs some basic research. Since military service Academies are undergraduate institutions, there are no Masters and PhD students available to help develop and maintain Research One or Research Two quality research programs.

In addition to a full academic load every semester, CGA Cadets participate in military training that prepares them to become officers in The United States Coast Guard (USCG). CGA Cadets also must participate in athletics. The combination of Academic, Military and Athletic commitments means CGA Cadets have very little time to work on research projects.

For CGA Cadets that either need the additional credits, or have the ability to take on additional work, faculty can use Directed Study Credits to give Cadets credit for working on research projects. All Cadets complete a Capstone project. Depending on the major, the Capstone course and project are either one or two semesters long. Currently, both Electrical and Mechanical Engineering have Capstone Design as two-semester course sequences that usually end with a prototype designed and built by the cadets. Both Civil and Naval Architecture and Marine Engineering have one semester Capstone Courses that require plan projects. The majority of Capstone Projects are restricted to a single discipline.

While many Capstone projects would benefit from outside assistance, making that outside assistance available is often not easy. CGA has some of the same barriers as other institutions when it comes to providing students with a multidisciplinary Capstone Design experience. Three barriers tend to appear- increased workload, project ownership and grading. Multidisciplinary projects are assumed to require more faculty time. For instance, a joint Civil and Mechanical Engineering project would require faculty from both Mechanical and Civil Engineering to advise the team. In addition to meeting with the students, the faculty would have to meet to discuss the project and team. What happens when the advisors do not agree project direction or course of action to solve a problem? At some point, one of the departments would have to own the project, and be responsible for providing project space, funds and administrative support (ordering supplies, etc). Grading can also become an issue. Does the Mechanical Engineering faculty grade the project, or does the Civil Engineering faculty? How the faculty handles the above concerns will affect the success of the project.

In addressing multidisciplinary capstone design, faculty at CGA, have addressed these concerns in different ways. In some cases, cadets on the same project have been graded separately. For example, Electrical Engineering sponsors SailBot, an autonomous Sailboat designed to participate in an annual international competition. Last year, cadets from electrical engineering were assigned the project as part of their capstone course. The naval architecture and marine

engineering cadets volunteered to work on the hull design for SailBot through a directed study through their major. This year, a group of electrical engineering cadets are working on SailBot through capstone, while three naval architecture and marine engineering cadets are volunteering their expertise for no credit.

Multidisciplinary Projects

There has been great interest in developing multidisciplinary projects. With an engineering faculty of less than forty, all faculty know each other and there is close support of each other's programs. Typically faculty may draw a student's support on a project from another major through the directed studies course.

Capstone projects are a significant effort for our seniors and their customers are often operational Coast Guard units. A significant number of important projects require a multidisciplinary team. Despite the desire to have students from different majors tackle these problems, there have been barriers to its implementation. Specifically, electrical and mechanical engineering students tackle their capstone projects over two semesters. The civil engineering students focus on their projects during the spring semester. Each major has its own lecture courses such as Design Project Management (mechanical engineering) and Construction Project Management (civil engineering). Mechanical engineering requires that all capstone projects include the design, fabrication and testing of a prototype. This is an option for Civil Engineering but not a requirement. Simpler barriers include scheduling and differing grading rubrics. There is also a desire to select projects requested by Coast Guard units that support a particular engineering major.

This academic year we are making a major effort to reduce these barriers by introducing a significant multidisciplinary project. This bolt-on hybridization project consists of a team of two civil engineers, two electrical engineers (as a directed studies project) and four mechanical engineers. There is at least one project advisor from each major and our dean of engineering serves as the overall project advisor. Each major also has a capstone coordinator. In addition to the three majors represented, the eight students form a larger team than the usual four. This introduces communications challenges. We will apply lessons learned from this project as we design next year's courses.

Systems Engineering

A systems engineering approach was already part of the capstone courses. In mechanical engineering, for example, the student team begins with interviewing customers to define the project, moves through the design process and prototype fabrication and eventually concludes with an operations and maintenance manual.

The major impact of this grant is the synergy with our efforts to work on green projects. In addition to the hybridization project, we are exploring projects from solar collectors to fuel cells.

There is an effort within the Coast Guard to reduce our use of non-renewable resources both on land and sea. We are also looking at developing opportunities for our students to have a greater experience with hybrid technologies that they may encounter in commercial shipping. This DOD System Engineering grant focuses on "portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources" which is an excellent fit. The Humanitarian Assistance and Disaster Response (HA/DR) Program resonates with the USCGA as it is a significant part of our mission.

Student/Faculty Interest

The faculty are selected as project advisors based on their interest and teaching loads. The interdisciplinary collaborations are based on interest in the project, trying a multidisciplinary approach and the intrinsic charm of an experienced project leader with four stripes on each shoulder board. There is strong interest to develop multidisciplinary projects for next year. We are working to develop a structure for multidisciplinary projects. If successful, this will make it more desirable for additional faculty to join in the future.

Systems Engineering Project

The current systems engineering project at the US Coast Guard Academy involves the design, construction, installation and testing of a bolt-on partial hybridization system for a small fleet vehicle such as a mail truck. DOD reports that significant numbers of casualties occur due to fleet refueling operations. The ultimate goal of this project is to provide DOD a bolt-on prototype that could increase fleet vehicle fuel efficiency and perhaps functionality, such as adding near silent electric-only creep mode. CGA purchased a used mail truck and the details of the project are evolving. As of this writing it looks like the plan is to parallel an electric motor/generator to the rear drive train, a combination battery/super capacitor will be used to store energy during braking and release energy during acceleration. The aim is to increase fuel efficiency of the mail truck during its start-stop mail delivery cycle by 20% or more.

The greatest challenges of the current project are administrative rather than technical – and the hackney phrase "herding cats" comes to mind. Four mechanical engineers have the project as their fall-spring capstone project, two civil engineers are assigned only for their one semester spring capstone, and two electrical engineers have joined in as a directed study for the spring semester. All three majors have different assigned faculty (and the mechanical engineering project advisor changed from fall to spring), all have different course structures and objectives, different assessment needs and different grading rubrics. Faculty and engineering departments at CGA work together exceptionally well, and we are optimistic of a highly successful outcome, not only for the project deliverables but for simplifying the administrative aspects of mixing different majors in a multi-disciplinary project.

Optimism from the mail truck project is so great that additional multi-disciplinary projects are already on the drawing board. A project is in planning to install a 5kW to 10kW solid oxide fuel cell. Generated electricity would be fed into the campus grid and the waste energy (heat) would be used through a variety of courses and projects. The end goal is to create a "green energy system in a box" that would accept a variety of input fuels, would output electricity, and with the flip of a switch, hot water, compressed air or rotary power – all in a field deployable package. Another project is to ruggedize various types of fuel cells for field deployment and possible shipboard use. CGA has a small diesel powered research vessel – one plan calls for replacing a diesel engine with a direct drive electric motor fed by a fuel cell. Another plan is to work to ruggedize and lighten a fuel cell for potential aircraft use – imagine a small fuel cell capable of burning jet fuel that produces electric power instead of the current turbine-generator auxiliary power units in use today.

Looking towards the future

As a military service Academy, many of our Capstone projects have a direct impact to resolving problems in our Coast Guard fleet. The direct tie to real world global problems makes this project not only challenging but also interesting to the cadets. The idea that this project could have global impact on future systems like mail trucks, refueling vehicles or any land vehicle that makes frequent stops has developed a deep seeded drive to figure out and overcome our obstacles on this Capstone project.

As past experience has shown, most procurements and engineering projects are multidiscipline – requiring not only an engineer but a team of engineers with many disciplines of engineering. As part of this team, academic majors from science, operations research and management need to be involved. The Academy is excited about continued development of a systems approach to Capstone problems – encompassing the entire process of procurement, engineering, testing, funding, training and fielding of new equipment.

The systems engineering approach also brings together cadets and faculty from cross disciplines. The interaction builds team work, opens lines of communication and continues to develop leadership in the cadets – realizing that one facet of engineering or section of the project is also linked to the timely development of other areas of the project.

Our cadet and faculty team are excited about the continued development of the hybrid mail truck. In the spring we will begin testing our design. Understanding that it is an iterative approach, the cadet team is currently developing metrics to determine the outcome and repeatability of standardized testing. We are eager to finish the design and begin testing the hybrid project.

Developing future multidisciplinary projects means addressing the concerns highlighted in this paper. When projects are advertised needs to change. Cadet schedules are finalized the week before classes start. Today, cadets register for a capstone lab. Each lab is tied to a specific major. By working with the Registrar and Curriculum Committee, the Engineering Department can

create common capstone lab times for all four majors, and eliminate the need to have cadets signed up for major-specific capstone lab. A related concern is the major-specific capstone lecture. There are common concepts taught in each capstone design lecture. The coordinators for each capstone course should meet and develop a common capstone course. A common capstone course would allow all cadets majoring in Engineering to learn the same concepts at the same time. There are some major-specific topics that could be addressed in major-specific modules that could be taught simultaneously. A common capstone design course would involve just as many faculty, but provide an opportunity to teach cadets about Systems Engineering in multidisciplinary classes. Mixed sections of cadets would give cadets an opportunity to comment on projects that might benefit from their engineering knowledge.

## Conclusions

CGA is currently only six months into the challenge of getting our collective arms around systems engineering and multi-disciplinary projects, and at this point there are still many challenges. Mixing majors requires more faculty involvement – the challenge is to ensure the individual faculty involvement is small so the total amount of faculty time remains reasonable. The good news is that thus far the rewards seem to outweigh the costs. Initial faculty and cadet reports are that the project experience thus far is realistic, relevant and exciting. Cadets are frustrated by the communication challenges but optimistic that this will be the best capstone experience in the building.

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