



The Capstone Marketplace: An Online Tool for Matching Capstone Design Students to Sponsors with Challenging Problems

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“Work-in-Progress:”

The Capstone Marketplace: An Online Tool for Matching Capstone Design Students to Sponsors with Challenging Problems

The Capstone Marketplace is an online tool developed and maintained to match multi-disciplinary student teams with challenging engineering projects. While web based tools exist for matching students to projects at individual institutions, the Capstone Marketplace is intended to enable broader participation and as such is open to all institutions with the capability of participating in undergraduate level capstone projects. The marketplace project sponsors provide domain expertise and advice, students research the project details and work towards solutions, while faculty supervisors help guide the teams and grade their work. The Capstone Marketplace makes it easier for sponsors to reach out to a broad pool of students and provide them with the added benefit of an engaged and knowledgeable mentor. Students can more easily find projects best matched to their interests and needs and faculty have an open source for student projects that can lead to new research partners and collaboration.

Rationale

The Capstone Marketplace was created by the Systems Engineering Research Center (SERC) to help address a critical challenge of developing the next generation of systems engineering (SE) talent for future US DoD and defense industry needs. Given the scope of engineering opportunities generated by the US DoD, and the increasing complexity of engineering projects in today’s world, it is clear that the emerging engineering workforce needs to have an understanding of systems engineering processes and tools. According to a 2010 National Defense Industry Association, Systems Engineering Division study “The quantity and quality of Systems Engineering expertise is insufficient to meet the demands of the government and defense industry”.¹ NDIA has identified this as the second highest priority in its 5 top SE issues up from the number 4 position in the previous study.

The Capstone Marketplace seeks to address this issue by providing an important opportunity for students to enhance their system engineering knowledge by:

- Working on real and complex problems with engaged mentors
- Working on multi-disciplinary teams
- Implementing and gaining experience with systems engineering approaches and processes.

Previous research has demonstrated that students who worked on multi-disciplinary capstone projects had increased interest and learning in basic systems engineering concepts. They also developed a better appreciation of the differences in methods and tools of different engineering disciplines.²

The Capstone Marketplace Concept

The Capstone Marketplace can most easily be described as an on-line dating service matching students working on capstone design to sponsors with challenging problems. However these “dates” are a bit different in that they involve not just the matched student team and sponsor, but a faculty advisor and mentor or subject matter expert.

Sponsors

The primary role of the sponsor is to provide a real world problem, challenge, or engineering need. This establishes them as a key stakeholder and allows for the student team to engage in a process that closely replicates that which they will experience in a career position in industry or government. We have actively encouraged sponsors to not pre-judge what undergraduate students are capable of and to provide problems that have truly been challenging to solve. This approach has been a success with respect to the students and the sponsors. The students gain motivation from the more challenging projects and the sponsors have benefited from real solutions with several capstone teams producing prototypes that have moved them closer to a solution. Of the 4 sponsor respondents to a survey from the 2013-14 academic year, 3 responded affirmatively to the survey question, “Do you feel that you have received, or are on track to receive, information or results from the student team that you would not have otherwise found?” Two of the 2013-14 teams developed functional prototypes. One team has filed a provisional patent application for a device that addressed a sponsor problem that had previously gone unsolved.

The sponsor is additionally requested to provide some level of funding to support the project. The typical level of funding is \$10,000 dollars but no upper or lower bounds have been established. In fact the project with the patent pending technology was funded at \$5,000. The funding is primarily intended to allow the teams to build working prototypes and/or support travel for testing or in person meeting with the stakeholders. The impact of developing a working prototype is significant and is strongly encouraged in Capstone Marketplace projects. This step moves the students beyond the design phase of the project and into prototype development where integration of components, testing and evaluation, redesign, and finally demonstration add significantly to the student’s experience.

Mentors/Subject Matter Experts

In addition to the funding and sponsor connection each capstone marketplace project is assigned a mentor or subject matter expert (SME). The project mentor has proven to be a critical component, providing insights and knowledge that lead to better outcomes for the students, sponsor, and faculty. While difficult to quantify, the anecdotal evidence from the Capstone Marketplace projects shows that an engaged and thoughtful SME or mentor can provide as much value to the project outcomes as the sponsor funding. The sponsor typically assigns the mentor but there have been cases where individuals not directly connected to the sponsor have served

successfully as SMEs on projects. Mentors not directly provided by sponsors have been identified by project participants at the faculty or sponsor level and have served on a voluntary basis. Given the positive impacts of these SMEs there is an effort to increase the level of mentor engagement with future projects. In the upcoming rollout of the next generation Capstone Marketplace website we are including the ability for mentors to apply directly to projects where sponsors, students, and faculty can choose to engage with an interested SME. A new searchable listing of key topics of interest or experience will better enable making these connections at the project start.

Students/Projects

The core of the Capstone Marketplace and the primary reason for its existence is centered on students. In its third year of existence the Capstone Marketplace now has engaged over 70 students at 6 institutions and 5 sponsors. There have not only been multi-disciplinary, but multi-institution and multi-sponsor projects. Currently there are ten active projects representing 48 students, from 10 majors at 4 institutions.

The 2012-13 academic year was the pilot year. For the pilot lessons learned from previous research were implemented and the Capstone Marketplace website was developed and launched creating an open source tool to better enable student participation and collaboration. The central marketplace concept enables not only collaboration within a single institution but across multiple institutions. In this initial year there was such a project that involved two institutions with 12 students representing 4 disciplines, two sponsors, and outside mentoring. The project evolved from two distinct projects. Initially one project tasked students with developing a humanitarian aid/disaster recovery (HADR) kit for deployment and distribution by the US Navy. This project was joined to a separate project that tasked students with the design of a safe and affordable ferry for Bangladesh where repurposed vessels and unsafe operation lead to upwards of 1000 fatalities a year. The synergies between these projects presented an opportunity to develop a broader combined project that led all involved to benefit. The ferry project was modified to enable its dual use as both a ferry and a key component in a HADR distribution system. The addition of the region and requirements associated with loading and unloading from a vessel added a component for a team of engineering management students and enhanced the project for the students working on the HADR kit. The end result was a success with the students gaining insights into a complex systems oriented problem with multiple stakeholders. The multi-institution arrangement enabled them to collaborate with students in disciplines not available at their respective institutions exposing them to a variety and diversity of teammates, skills, and abilities.³

The 2013-14 year saw a doubling of the CM from 3 projects to 6. The projects were provided by two DoD sponsors and involved 34 students from 5 schools representing 6 majors.

Table 1: 2013-14 Academic Year Capstone Marketplace Students

Institution	Student Disciplines/Majors	Number of Students
Georgia Institute of Technology	Electrical Engineering Mechanical Engineering Computer Science	8
Johns Hopkins University	Mechanical Engineering	4
Smith College	Engineering Science	3
Stevens Institute of Technology	Bio-medical Engineering Mechanical Engineering Naval Engineering	9
University of Alabama in Huntsville	Mechanical Engineering Aerospace Engineering	10

The 2013-14 year also saw a joint institution project involving the same institutions from the pilot year. This large single group was separated based on the suggestion of the sponsor appointed SME. Two distinct initial concepts were developed from the initial student concepts. These concepts were distinct to the separate institutions and were both deemed to have merit by the SME. These separated projects both went on to success with one leading to successful full-scale prototype testing at a US DoD facility and the provisional patent application mentioned previously. Table 2 below identifies the key systems engineering process stages this student team implemented in their project and indicates that they did gain insights and knowledge relevant to systems thinking and systems engineering processes. All of these students went on to jobs with either the DoD or defense industry.

Table 2: System Engineering Process for a 2013-14 Team

Phase	Description
1	Develop clear and concise mission needs, goals, and objectives to focus the project scope
2	Research, Concept Generation, and Concept Elimination

3	System Prototyping and Testing
4	System Verification and Validation “Build the right system and build the system right”
5	System Optimization
Repeat cycle from Phase 2 to final prototype	

The success of the 2013-14 projects led one of the project sponsors to propose 12 new projects and agree to double their level of financial support to 10 projects at \$10,000 each for the current 2014-15 year. An additional new sponsor was also added. These current projects again expanded the pool of students to ~50 representing 10 majors.

Table 3: 2014-15 Academic Year Capstone Marketplace Students

Institution	Student Disciplines/Majors	Number of Students
Georgia Institute of Technology	Electrical Engineering Mechanical Engineering Computer Science	4
North Carolina Agricultural and Technical State University	Industrial and Systems Engineering	3
Stevens Institute of Technology	Bio-medical Engineering Mechanical Engineering Civil Engineering Electrical Engineering Naval Engineering	27
University of Alabama in Huntsville	Mechanical Engineering Aerospace Engineering	12

The status of the ongoing projects thus far is good. The majority of the projects will be completed by the date of the conference and poster session and this information will be added.

Faculty

The role of the faculty should not be any greater than that associated with the typical capstone or senior design course. Based on discussions with potential faculty participants there is some

evidence of concern among faculty members that participation in a Capstone Marketplace project will be more burdensome due to the system engineering focus of the projects. A faculty retrospective review with project advisors indicated that this was not their experience. Results of this retrospective review did identify some administrative hurdles connected with contractual challenges associated with DoD sponsorship of some of the projects. Additional complications identified included the different perspective associated with the open nature of student research compared to the relative closed nature of some of the project sponsoring agencies. Communication challenges between the mentors and students was also identified as area that required improvement. Findings from this retrospective review enabled the marketplace administrators to identify areas of potential problems and proactively address them. Processes for establish subcontract and enabling purchases were developed to reduce the administrative burden on participating institutions. Faculty advisors were encouraged to establish and maintain contact with the sponsor and mentor and to inform the Capstone Marketplace of communication and coordination problems that were readily resolved. These steps have improved but not eliminated the problems identified in the faculty retrospective. The retrospective review will be a regular component of Capstone Marketplace projects and will be expanded to include a sponsor/mentor and student version.

Rather than add an additional faculty burden, the system engineering focus of the projects and the related resources can serve as a means to reduce the burden on the faculty by enabling the students to become more self-directed. An engaged mentor and/or sponsor can also tend to focus students with scheduling requirements and tasking, potentially reducing the need for faculty directives to stay on schedule. Beyond the student interactions the faculty participants benefit from the growing Capstone Marketplace network of sponsors, mentors, and colleagues at other participating institutions.

Participant feedback

Selected questions from 2013-14 surveys intended to assess ongoing projects are included in Table 4 below. While the numbers of respondents were limited they represent 80% of sponsors, 100% of faculty, and 32% of students. The student and faculty responses indicate that their participation in a Capstone Marketplace project was a positive experience that they would recommend to others students or faculty. The sponsor results indicate that the student teams exceeded their expectations and the sponsors continued and expanding participation indicate their satisfaction. Student survey responses indicate that the projects were viewed positively with 90% of survey responded indicated that they would recommend participation in a Capstone Marketplace project to a friend. The student response below to the survey question, “Would you recommend participating in this type of a project to your friends?” provides a general sense of the comments received, “Yes, it is very challenging, but helps you learn better time management and allows you to use the skills you have learned throughout your schooling.”

Table 4

Responses to General Faculty Satisfaction Survey Questions				
	Yes	No	Maybe	-
<i>Would you recommend participating in this type of a project to your colleagues?</i>	5	0	1	
<i>Would you recommend participating in this type of a project to future students?</i>	5	0	1	
Responses to General Satisfaction Student Survey Questions				
<i>Would you recommend participating in this type of a project to your friends?</i>	10	1	0	
Responses to General Satisfaction Sponsor Survey Questions				
	Exceeded all objectives	Exceeded some objectives	Met all objectives	Failed to meet some objectives
<i>In your opinion, how successful has the student team been in meeting project objectives?</i>	2	2	0	0

The Capstone Marketplace Website

The core of the Capstone Marketplace is the website which establishes the “market” where students, faculty, and mentors can view the potential projects. Key pages from the current Capstone Marketplace are included as Appendix A.

The vision for the Capstone Marketplace website is for it to become a broadly used tool for matching students to projects and enabling new system engineering learning in a group that would not otherwise have the opportunity. In order to achieve this, the Capstone Marketplace will need to move far beyond the current small base of schools and sponsors. Knowing that this is the desired future state the role of the present and future Capstone Marketplace administrator is purposefully limited. The basic administrative steps are as follows:

1. The site administrator posts the project descriptions to the marketplace after they are developed with support from the Capstone Marketplace researchers.

2. Applications submitted by both students or faculty go directly into a database, and the basic proposal information is provided to the Capstone Marketplace administrator as a simple email notification.
3. The Capstone Marketplace researchers assemble the proposals and provide them to the sponsor for review and selection.
4. The sponsor determines which proposals they feel can best achieve their project goals and notifies the Capstone Marketplace administrator.
5. The proposal teams are notified of acceptance or rejection.
6. The project proceeds

Once the Capstone Marketplace project is underway the role of the administrator is greatly reduced. Even these limited administrative tasks will prove onerous at large scale and while there will always need to be some advisory or administrative support a key goal is for minimal required administrative participation as the Capstone Marketplace scales up.

Currently there are tasks focused on ensuring that systems engineering processes are implemented and that the teams, sponsors, and mentors all get off to a successful start. In these initial years as we establish the Capstone Marketplace it is critical that the projects are successful from the perspective of all participants. Primary tools in this effort are surveys that are distributed at the middle, and end of the projects to ensure they are progressing properly. The timing of the first semester surveys enable course corrections to any project off track.

The current website has been successful and functional. However it is now undergoing a redesign to add functionalities intended to improve the user experience and better establish the website as a project resource. By improving the effectiveness of the website and establishing it as an open resource that will be used more frequently throughout the project we hope to create more awareness of the Capstone Marketplace itself, allowing for necessary growth in participation. The list below identifies the new capabilities which will be implemented:

- Team formation:
 - o Searchable key topics database that will tie together:
 - Project requirements as defined by the sponsor,
 - Areas of expertise or interest as defined by mentors and faculty,
 - Areas of interest, experience and academic disciplines as defined by the students.

- This will enable identification of synergies between all users with the goal of better enabling multiple institution collaboration and participation of non-sponsor mentors or SMEs.
 - o A message board to allow for communication at the preliminary team forming stages where potential students can establish a line of communication the same way students in a single institution may communicate amongst themselves to team form based on interest and capabilities.
- Project support:
 - o The resources section of the website will continue to be expanded
 - Findings from ongoing research into best practices for exposing undergraduates to system engineering and systems thinking will be used to provide tools and suggestions for students and faculty.
 - A tool for securely storing relevant project materials will be added to enable sharing across institutions, sponsors, mentors, and if applicable the public viewers of the website.
 - A shared project calendar permitting transition to popular web based calendar tools.
- Assessment:
 - o Core systems engineering principles are being established and a pre-project and post project assessment will be developed to better enable an assessment of student learning and the efficacy of the Capstone Marketplace.

Conclusion

The Capstone Marketplace has the potential to become a dynamic force in furthering student knowledge, enhancing engineering education, and helping to develop the quantity and quality of systems engineering expertise that NDIA and our DoD sponsor have identified as lacking. Additionally, with the enhanced emphasis on the ability to work on multi-disciplinary teams and systems development from ABET on student outcomes assessments, these type of projects offer a means to satisfy a critical educational and assessment need for participating faculty and institutions. Research has shown that experiential learning through participation in multi-disciplinary engineering projects with engaged stakeholders is an effective means to accomplish this.² The majority of the literature surveyed regarding such capstone project endeavors tends to focus on increasing the level of exposure to and use of systems engineering best practices.^{3,4,5} While this is, indeed, one of the foci of the Capstone Marketplace, the creation and refinement of

the marketplace itself and the process through which students, their advisors, and their sponsors are brought together into a collaborative group is of equal importance.

The Capstone Marketplace was established to better enable this collaboration by developing an open marketplace that will be broadly available to many engineering schools rather than rely on the initiatives of individual institutions to bring such stakeholders together. The Marketplace first provides a virtual environment within which stakeholders may be matched to one another and pre-engage around a particular challenge or problem set. Once the relationship has been solidified, interaction may continue within the virtual realm, as well as the physical. For those deliverables requiring the design and development of a tangible product, the Marketplace again will serve as a medium to arrange for in-person meetings and design/build sessions as needed. This problem-based learning approach has been a proven process with measurable impacts.⁶

Beyond the focused system engineering learning it is anticipated that the Capstone Marketplace will provide students with work experiences that enhance key engineering attributes and best practices, developing students' critical thinking capabilities, and improving their technical, organizational, and social skills. Taken together, this experience will serve to enhance student success in both the university setting and in their ensuing careers. This has been shown previously with measurable results such as higher student graduation rates, increased number of publications, and increased access to a wider sponsor network for potential funding.⁷

The Capstone Marketplace also offers a novel problem solving approach for sponsors. Giving them access to intelligent, capable, research oriented, technology savvy undergraduate students who approach the project or problem without preconceptions or institutional requirements that can all too frequently inhibit the ability to find solutions. Project mentors gain insights into new ways of solving problems and an opportunity to engage with future engineers giving extra motivation to continue on with the lifelong learning that is necessary to stay current in any engineering discipline. And students, faculty, sponsors, and mentors all gain from participation through an enhanced network of engineering colleagues, mentors, and friends that they can call on in their careers.

Acknowledgments

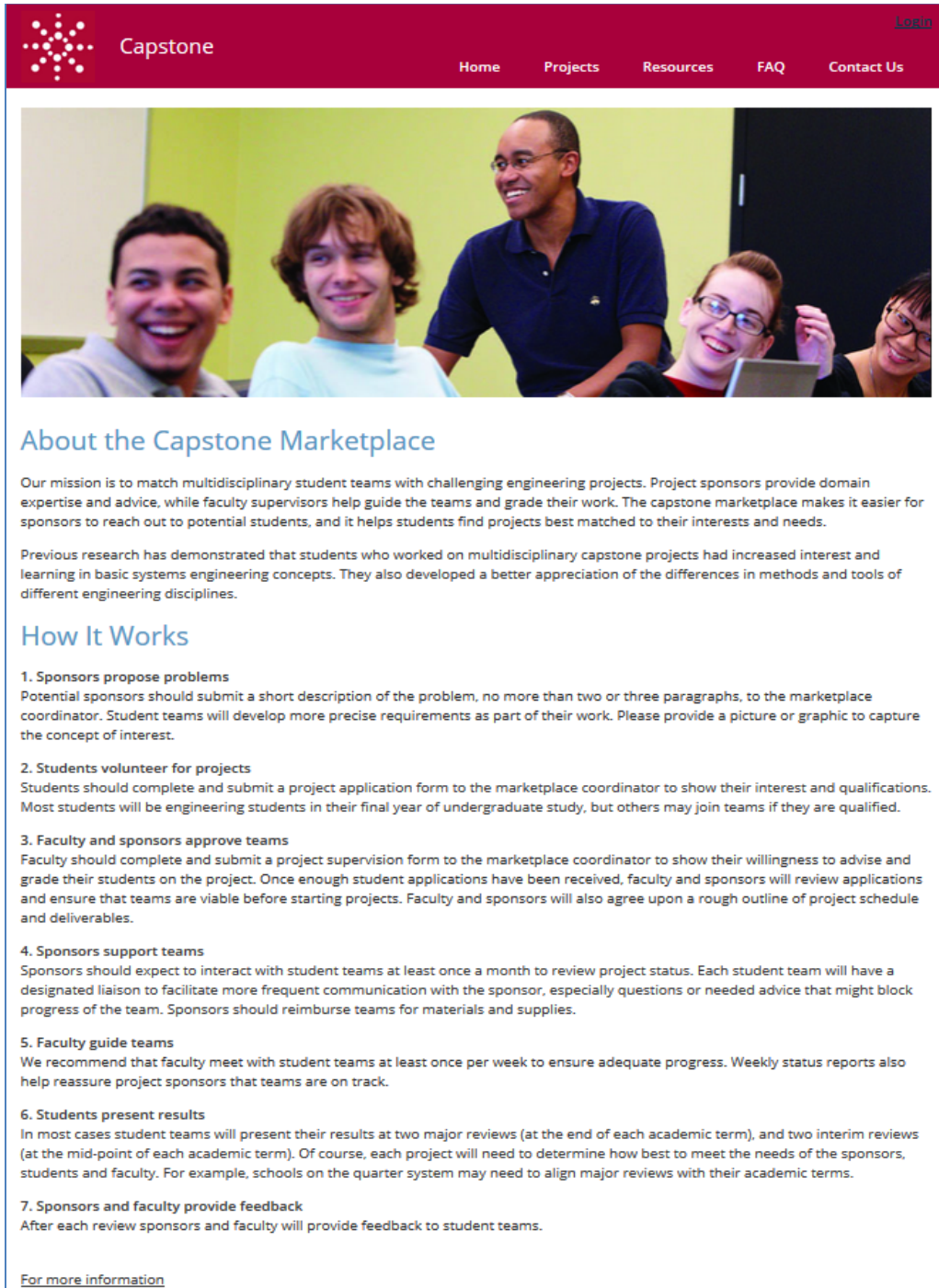
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Appendix A: The Capstone Marketplace Website www.capstone marketplace.org

The Capstone Marketplace front page is shown in *Figure 1*. From here users can access the catalog of projects, learn more about the Capstone Marketplace, and review supporting resources.



About the Capstone Marketplace

Our mission is to match multidisciplinary student teams with challenging engineering projects. Project sponsors provide domain expertise and advice, while faculty supervisors help guide the teams and grade their work. The capstone marketplace makes it easier for sponsors to reach out to potential students, and it helps students find projects best matched to their interests and needs.

Previous research has demonstrated that students who worked on multidisciplinary capstone projects had increased interest and learning in basic systems engineering concepts. They also developed a better appreciation of the differences in methods and tools of different engineering disciplines.

How It Works

- 1. Sponsors propose problems**
Potential sponsors should submit a short description of the problem, no more than two or three paragraphs, to the marketplace coordinator. Student teams will develop more precise requirements as part of their work. Please provide a picture or graphic to capture the concept of interest.
- 2. Students volunteer for projects**
Students should complete and submit a project application form to the marketplace coordinator to show their interest and qualifications. Most students will be engineering students in their final year of undergraduate study, but others may join teams if they are qualified.
- 3. Faculty and sponsors approve teams**
Faculty should complete and submit a project supervision form to the marketplace coordinator to show their willingness to advise and grade their students on the project. Once enough student applications have been received, faculty and sponsors will review applications and ensure that teams are viable before starting projects. Faculty and sponsors will also agree upon a rough outline of project schedule and deliverables.
- 4. Sponsors support teams**
Sponsors should expect to interact with student teams at least once a month to review project status. Each student team will have a designated liaison to facilitate more frequent communication with the sponsor, especially questions or needed advice that might block progress of the team. Sponsors should reimburse teams for materials and supplies.
- 5. Faculty guide teams**
We recommend that faculty meet with student teams at least once per week to ensure adequate progress. Weekly status reports also help reassure project sponsors that teams are on track.
- 6. Students present results**
In most cases student teams will present their results at two major reviews (at the end of each academic term), and two interim reviews (at the mid-point of each academic term). Of course, each project will need to determine how best to meet the needs of the sponsors, students and faculty. For example, schools on the quarter system may need to align major reviews with their academic terms.
- 7. Sponsors and faculty provide feedback**
After each review sponsors and faculty will provide feedback to student teams.

[For more information](#)

Figure 1

The projects sub-page shown in *Figure 2* provides a look at several available or underway for the current year.

The screenshot shows the Capstone website's 'Projects' page. The header includes the Capstone logo, navigation links (Home, Projects, Resources, FAQ, Contact Us), and a 'Login' link. Below the header, the 'Projects' section is introduced with a paragraph: 'The following projects are part of the Capstone Marketplace. Each proposed project is intended for a multidisciplinary team of advanced undergraduate engineering students.'

The page displays nine project cards, each with a title, a representative image, a description, and a 'Learn More' button. The projects are:

- Advanced Body Armor:** Design novel/innovative/advanced materials for body armor.
- Cyber Wireless I&W: Behavioral Models:** Investigate Behavioral Models in LTE/UMTS and the Emerging FirstNet Air Interface.
- Cyber Wireless I&W: Cognitive Radio Air Interface Experiment:** Investigate Threat Detection Methods in LTE/UMTS and the emerging FirstNet Air Interface. Includes a block diagram showing the flow from Internet to Ethernet, PC, LTE Base Station, Ethernet, and RF frontend.
- Advanced Power Technologies:** Design portable power systems with decreased size and weight. Includes an image of a soldier with various equipment.
- Avoiding Information Overload:** Provide only needed information to soldier. Includes an image of a person's head with floating letters.
- Body Worn Processor:** Design a body-worn processor.
- Enhanced Performance:** Enhance and monitor human performance. Includes an image of soldiers in various poses.
- Novel/innovative communications:** Provide novel/innovative communications mechanisms. Includes an image of a satellite in space.
- Armored Window Improvements:** Design an armored window that can be fully opened. Includes an image of a military vehicle.

Figure 2

Accessing the “Learn More” tool will provide detailed information on the individual projects as shown in Figure 3.

The screenshot shows a web page for a project titled "Austere Landing Zone Assessment" on the Capstone website. The page has a dark red header with the Capstone logo and navigation links: Home, Projects, Resources, FAQ, Contact Us, and a Login link. The main content area is white and contains the following sections:

- Project:** Austere Landing Zone Assessment
- Image:** A diagram of a Dynamic Cone Penetrometer (DCP) with labels: Hammer, Anvil, Rod, and Cone. Next to it is a photograph of two soldiers in camouflage uniforms using the DCP on a landing strip.
- Sponsor:** Special Operations Forces (SOF)
- Status:** Active: Stevens Institute of Technology
- Summary:** Assess a potential landing site under nighttime conditions
- Description:**
 - Current Capability:**
 - Dynamic Cone Penetrometer (DCP) is the only authorized device to measure weight bearing capacity for landing fixed wing aircraft on austere landing strips.
 - Current DCP method for measuring surface weight bearing capability is slow, cumbersome and manpower intensive making potential runway surface measurements difficult to perform in a timely manner in all weather conditions, day or night.
 - Issues:**
 - Current system:
 - not reliably operated by 1 person
 - requires min of 25 readings to complete airfield survey (~15 min per reading)
 - is not night readable (Night Vision Goggle capable)
 - System computer is not ruggedized and is subject to vibrations from the hammer
 - System is noisy for tactical operations
 - Desired Research / Capability:**
 - Hyperspectral imagery data is available from a U.S. Navy (Naval Research Laboratory - NRL) sensor installed on the International Space Station (ISS). Research recommendations from the Army Research laboratory will be utilized.
 - Research concept is to conduct analysis of ISS sensor hyperspectral imagery data from several (3-5) landing zone areas that have been measured using the DCP method to determine if a California Bearing Ratio (CBR) or equivalent rating type assessment is possible using remote, hyperspectral imaging techniques to a depth of 36 inches below the surface. Research goal is to determine how hyperspectral imagery data might be used to enable a remote sensing capability for future landing zone assessment requirements.
 - Capability Needs:**
 - Aircraft operations require airfield surveys to ensure safe operation. US military forces require the ability to quickly and accurately survey and assess a potential aircraft landing site in one period of darkness.
 - The improved capability must:
 - Be timely, silent, accurate, not dependent on GPS for high fidelity geo-coordinates, concealable, light-weight, easily transportable by one man or vehicle mountable and capable of remote operation.
 - Produce a product that measures CBR or equivalent rating of soil shear strength for aircraft landing operations.
- Buttons:** Student Application ►, Faculty Application ►

Figure 3

From this page the student (or faculty) can apply to participate in the projects using a simple online form (Figure 4).

Capstone Login

Home Projects Resources FAQ Contact Us

Student Application Form

Project Name:

1. Information about you

Name:*

Email Address:*

School or Organization

Expected Graduation Date:

2. Information about the faculty member who will give you a grade for this project at your school

Faculty Member Name:

Faculty Member Email:

Faculty Member Department:

3. Information about the project you want to join

Please specify the type of work you want to perform on the project, such as roles you will assume and tasks you will perform:

In one or two sentences, why do you want to work on this project:

Figure 4