Creating Real-World Experiences for Space Systems Students

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The Masters of Engineering in Space Engineering (Space Systems MEng) Program at the University of Michigan (UM) focuses on developing systems engineering skills for future space systems engineers. The program centers on three related courses - two courses taken back to back in the students' final two terms, both of which focus on core systems engineering skills, and an independent study course for further application of these skills. The focus of all three courses is experiential learning through the design of space missions. In an effort to make the learning experience as realistic as possible, missions are chosen that either directly involve flight missions, or that have a clear path to a flight mission, some of which have led to significant follow-on efforts outside the program. This hand-on, flight program emphasis is made possible by using resources from UM as well as external sources to integrate flight opportunities into the program. This paper describes the program and its three main design courses and gives specific examples from past coursework demonstrating the integration of real-world experiences into the curriculum.

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Introduction

The Masters of Engineering in Space Engineering (Space Systems MEng) Program, led by the Atmospheric, Oceanic and Space Sciences (AOSS) Department of UM, began in 2003 as an effort increase the breadth and depth engineers and scientists with a bachelor's degree working on space mission development. The program was developed based upon input from employers in the aerospace industry and the extensive space mission heritage at UM[1].

Specific objectives of the program are:

- To provide a comprehensive knowledge of space science and engineering and their interrelationship
- To increase depth beyond the baccalaureate level in a space-related discipline
- To teach the systems approach to conceiving, designing, manufacturing, managing, and operating complex space systems
- To provide practical experience in space system design, project development and management

These objectives are accomplished through six core courses taken by all of the Space Systems MEng students, covering key topics in space system technology, systems engineering, the space environment, space system management, and space policy, as well as four elective courses chosen by the student to give breadth across a range of topics and depth in a particular space system related discipline. The capstone courses described in the following section are part core courses required of all students.

In addition to a strong, hands-on curriculum, the space flight heritage at UM adds significantly to the strength of the program. For example, the Space Physics Research Lab (SPRL) at the University of Michigan has flown over 30 space instruments with NASA and the European Space Agency (ESA) and includes both personnel and facilities for "end-to-end" space mission design, build, test, and operation.

Capstone and Design, Build, Test Courses

There are several design, build, test courses within the UM College of Engineering from which the Space Systems MEng student can choose. Of theses, all of the students in the program are required to take AOSS 582 and 583, which form an integrated capstone series, and AOSS 590. All three of these courses are focused on getting students hands-on experience in the design of space missions and systems.

AOSS 582, Spacecraft Technology, focuses on an overview of space mission design processes and of the design of subsystems that make-up a typical space mission. The primary goals are an understanding of the processes by which the key components of space missions are systematically analyzed and developed, and a basic understanding of the key technologies typically needed to execute these missions. The first half of the course consists of a combination of lectures and tutorials, typically run by subject matter experts. These give the students a foundation on which to design specific missions in the second half of the course. Topics include:

- The typical space mission life-cycle
- Space mission analysis and design (SMAD)[2]
- Major spacecraft subsystems and their relevant technologies, including:
    - command and data handling
    - attitude determination and control

- power management
- ground systems
- thermal control
- scientific payloads - sensors
- Hands-on tutorials on the basic tools for the design of space missions such as:
  - computer aided design (CAD) tools
  - the Satellite Tool Kit (STK)
  - radiation analysis
  - thermal analysis
  - communication link budgets

This first phase of the course ends with the students working in teams, each covering one of the above spacecraft subsystems, to develop an oral presentation and written report covering the relevant basic principles, related technologies, and the application space for each technology. This helps to reinforce the material and to develop expertise in at least one subsystem for every student. The second half of the course is hands-on application of the above skills to specific projects run by the students in teams, often based upon mission requirements supplied by external participants who act as customers for the students.

The follow-on course, AOSS 583, Space System Design, focuses on formal systems engineering skills and management of space missions. Topics covered include:

- basic systems engineering functions and processes
- requirements writing and management
- technical performance metric development and monitoring
- technology readiness
- risk management including formal risk analysis and tracking
- formal trade analysis
- scheduling and work breakdown structures
- cost estimating
- proposal writing

These topics are covered in the first 8 weeks of class through a combination of lectures and hands-on tutorials. The students get experience with these concepts by working in teams on specific space system projects that are follow-on work from AOSS 582. Work on these projects begins in the third week of class, applying systems engineering concepts in parallel with the lecture and tutorial material. A hardware and software element is included in each project whenever possible, such as the prototyping of a mission enabling technology as part of the risk reduction process, or the development of software for mission analysis or test operation. AOSS 583 also includes a mentoring component for senior-level Aerospace engineering students.

Students are also required to take AOSS 590, Space Systems Projects. Students get experience using their systems engineering skills on a specific space project in an independent study environment in this course. Projects come from both within the university and outside from private industry and NASA.

In all of the above courses, the emphasis is on making the learning experience as hands-on and as realistic as possible. To that end, the students are expected to run their projects as if they were working in a professional organization for space mission development, with all of the typical customer interactions, formal reviews and documentation, and formal systems engineering process applied as they learn them in the courses. The projects on which the students work are chosen either because they are part of an existing flight mission, or they have a legitimate chance of leading to a flight mission. This emphasis on actual flight opportunities is facilitated by direct involvement from numerous faculty and staff at the university who are actively engaged in the space flight industry. Several examples of how this is accomplished are given in the next section.

Additional courses outside the core curriculum focus on giving engineering students breadth beyond their specific engineering discipline. This includes design, build, and test courses that emphasize the integration of students from multiple engineering disciplines, and courses that integrate engineering students with business and law school students who learn how to develop strategies for creating their own businesses. Once again, the goal is to give the students experience with how projects are actually run beyond a simple academic exercise, and the emphasis is on the generation of real opportunities in the form of new, marketable technologies and new start-up businesses. Examples of these broader efforts will be given in the next section as well.

Example Course Projects

IMAGINE

IMAGINE (IMplementing A Global Internet Network) is a system of ground and space assets designed by the students in the program to provide internet access to unconnected areas anywhere on the planet based upon requirements provided by the students' customers from Google[3]. Working with their customers, the students were able to identify a way to make immediate impact providing access to the least connected continent, Africa, where as of 2008 only 5 percent of the population has access to the internet[4]. With funds from Google and the UM College of Engineering, a prototype solar powered satellite based internet station (Figure 1) was designed, built, and tested, and three follow-on units were built and deployed in rural Kenya, Africa[5].

These field units in Kenya have been in operation since November, 2008, providing locals access to a variety of resources including information on agriculture, online training courses, job applications, scholarship applications, and professional research including teacher education and civil engineering for public projects.

Figure 1. IMAGINE prototype ground station being tested in Ann Arbor, MI. This prototype was used to develop and solicit funds for the field units shown in Figure 2.

Figure 2. IMAGINE ground station antenna deployed in Nguruman, Kenya. Two other units like this one were deployed in November of 2008 to provide internet access to rural Kenyan villages.

The students who developed IMAGINE have since graduated and moved on to jobs in the aerospace industry, but the project continues to evolve. A student group has formed outside of the academic setting for developing the next generation system to bring the internet to more unconnected users. The project has also been incorporated into a course on social ventures that involves students from several engineering disciplines as well as the business school. The goal of the course is to develop business plans around social entrepreneurship with the hopes of kicking off businesses based on ideas like IMAGINE.

Michigan Nanosatellite Pipeline

The Michigan Nanosatellite Pipeline (MNP) was developed by the Space Systems MEng students to further develop Michigan's ability to design, build, and operate nanosatellites. Nanosatellites are small satellites less than 10 kg that are often used to provide a rapid development, low cost platforms for high risk missions requiring inexpensive access to space. As such, they are often developed by universities giving students to get hands-on experience in the entire space mission life-cycle on actual flight hardware. The idea behind the MNP (Figure 3) is to provide a framework in which researchers both internal and external to the University of Michigan can test new technologies and explore new science in space while also providing the students hands-on experience with flight hardware and software.

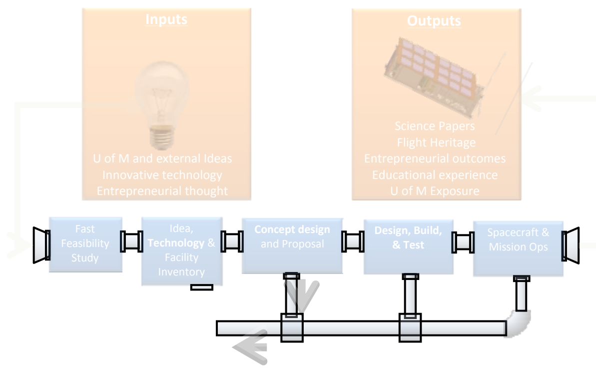

Figure 3. The Michigan Nanosatellite Pipeline (MNP) concept. Ideas from inside and outside UM are integrated into the pipeline for further development, leading to flight missions, new science, and new technologies that can be used in future MNP missions.

The students of the program have developed a number of mission concepts for both UM internal and external customers looking for low cost access to space. These missions include a low cost constellation of nanosatellites for in situ measurements of upper atmospheric density, a low cost, high accuracy magnetometer mission for measuring Auroral and equatorial field-aligned currents, a unified architecture for nanosatellite communications to provide easy access to data for a variety of satellite users, and a number of missions intended to raise the technology readiness level (TRL) of technologies for use on future space-borne missions. The MNP has also helped to develop facilities and flight hardware and software for the Radio Aurora Experiment (RAX), a nanosatellite flight mission schedule to launch in May of 2010[6].

The students have developed a number of concepts of their own within the MNP as well. Some of these have led to follow-on efforts to further develop them in to flight hardware. For example, the eXtendable Solar Array System (XSAS) shown in Figure 4 was developed by students to provide extend the available power for nanosatellites from the current orbital average of 5 W to around 25 W[7]. As part of the coursework, a prototype of the system was designed, built and tested. A group of students are now developing a second prototype for testing on board a flight NASA's C-9 Microgravity program. The students hope to develop the technology for flight on future nanosatellite missions using funding from a variety of sources including the Michigan Space Grant Consortium and the UM College of Engineering.

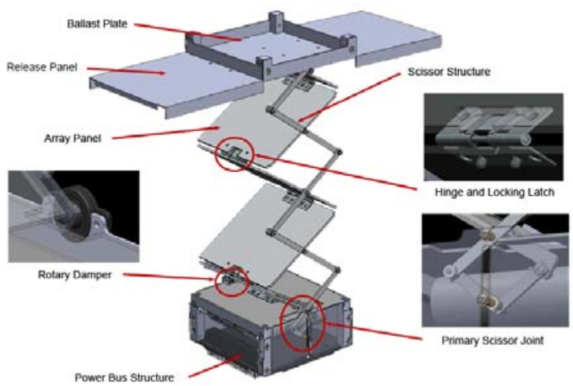

Figure 4. The eXtendable Solar Array System (XSAS). XSAS increases available nanosatellite power by a factor of 5.

As with IMAGINE, a group of students are also looking at developing a business around concepts developed in the MNP. Specifically, a number of students from the program are creating a business based on low cost imagery for generated from a constellation of nanosatellites. The business would be a disruptive influence in the geographical information system (GIS) industry currently dominated by comparatively high cost, long development time technologies. This effort began with a combination of the design courses in the program together with a research commercialization course, once again combining engineering and business school students to develop business strategies around technologies developed at the University.

Additional Flight Opportunities

As mentioned above, UM has extensive space flight heritage. In-house missions provide opportunities for Space System MEng students to get hands-on systems engineering experience on flight missions while also helping to advance the missions themselves. In addition to these in-house efforts, students are strongly encouraged to work with outside institutions, e.g. NASA and private industry, to work on flight missions at internships and as part of their formal course work (primarily through AOSS 590). This external interaction is enhanced by UM's involvement in current and future space missions.

Conclusions

In its 7 year history, the program has graduated over 80 students with a nearly 100% placement record. A large part of the program's success can be attributed to getting students as much real, hands-on experience as possible while in the program. This is accomplished by having the students work on actual space flight missions whenever possible, and when not possible by having students work on projects with a legitimate shot at developing into a flight mission. This enhances the education experience as well as motivating the students to develop their concepts beyond the classroom setting and helping to recruit new students. The focus on flight opportunities is made possible by actively engaging the numerous space flight resources available through the university in the form of faculty, staff, facilities, and external contacts to improve both the education of the students in the program and the standing of the university as a leading institution for space flight and space related research.

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