Creating Real-World Experiences for Space Systems Students

Darren McKague and Thomas H. Zurbuchen
College of Engineering, University of Michigan

The Masters of Engineering in Space Engineering Program at the University of Michigan focuses on developing systems engineering skills for future space systems engineers. The program centers on three courses - two courses taken in the students' final two terms, focusing 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 hands-on, flight program emphasis is made possible by using resources from the university as well as external sources to integrate flight opportunities into the program. This paper describes the program and gives specific examples and lessons learned from past coursework to demonstrate the integration of real-world experiences into the curriculum.

Corresponding Author: Darren McKague, dmckague@umich.edu

Introduction

The Masters of Engineering in Space Engineering program at the University of Michigan (UM) in its current form 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 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.

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

All of the students in the program are required to take AOSS 582 and 583, which form an integrated capstone series, and AOSS 590, a project course. All three of these courses are focused on getting students hands-on experience in the design of space missions and systems.

The primary goals of AOSS 582 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, often 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, and scientific payloads/sensors
- Hands-on tutorials on tools for the design of space missions, such as computer aided design (CAD), the Satellite Tool Kit (STK), radiation analysis, thermal analysis, and 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.

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, working 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. For this, graduate students run tutorials on key space mission design tools covered in 582 as well as participating in design reviews for the undergraduate design courses.

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 "real-world" 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 flight opportunities is facilitated by direct involvement from numerous faculty and staff at the university as well as partners from outside the university who are actively engaged in the space flight industry.

Implementing "Real-World" Projects

Implementing these types of "real-world" projects requires substantial advance planning. In addition to formal lesson planning, the instructors must come up with projects as well as customers to give focus to the students' hands-on experiences. This is often done several months in advance to make sure expectations and outcomes are formulated clearly and are adequate for the class.

The process of finding suitable projects is primarily tied to the search for the right customers. As stated above, the idea is to have projects with real-world applicability outside of the academic environment. To that end projects are sought from customers with a vested interest the outcome, hence an interest in taking part in the process – in mentoring students on specific technologies and system engineering processes, taking part in project reviews, and in funding hardware development. These customers are often either technology specialists who want effort put into developing space mission concepts, or potential employers of our students. The former often have scientific expertise and are in need of engineering support to bring a mission together. The later are not only interested in the projects themselves, but are also interested in interacting with the students to find and advertise to future employees. Thus quite a bit of the work in finding customers is spent speaking with colleagues searching for missions in need of systems engineering as well as canvassing managers at the various NASA centers and private aerospace contractors who typically hire our students.

While the projects need to be applicable to the goals of the customer, they must also be sufficiently focused and of appropriate scope to be completed within two terms. The complexity, cost, and timescale of typical space-borne missions often limits our students' work on traditional missions to up-front, high level mission architecture development or the prototyping of low technology maturity mission enabling components. We try to couple these two aspects of large mission development whenever possible to give the students experience with mission architecture development as well as some hardware experience. Meanwhile, the development of a University class of small satellites has made possible the end-to-end development of satellite missions designed, built, and operated by students[4]. This has become an integral part of our program, opening up opportunities for our students to get their hands on space-flight hardware.

An important part of this process is defining high level requirements up front with the customers for each project. This helps define the scope of the project as well as giving the customer an idea of what to expect from the students. Once requirements are set, schedules with specific milestones and well defined outcomes are developed to ensure that steady progress is made by the students and to keep the customers involved in the process. The NASA life-cycle model with its associated design processes and reviews is used (e.g., formal requirements management, risk analysis, formal reports, design reviews with customer feedback, etc.), once again giving the work relevance to the "real-world."

Another important consideration is the number of projects to run through the program each year. For this, a balance must be struck between having enough students on each project to make sufficient progress while providing enough work for each student to ensure that they are fully engaged. With our program, we have found that this means between 5 and 10 students per project, which translates into typically 3 to 5 projects each year. Finding projects well in advance through colleagues and industry contacts helps to ensure the right number of interesting experiences for the students year after year.

Example Projects

In this section, we describe a few projects from our program to give an idea of the type and scope of project that has worked for us in the past, as well as showing how project work can evolve in to opportunities beyond the classroom.

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[5]. With funds from Google and the UM College of Engineering, a prototype solar powered satellite based internet station was designed, built, and tested, and three follow-on units were built and deployed in rural Kenya, Africa by the students in the program with local assistance[6] (Figure 2). 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 ground station antenna deployed by our students in Nguruman, Kenya. Two other units like this one were deployed in November of 2008 to provide internet access to rural Kenyan villages.

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 2) 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.

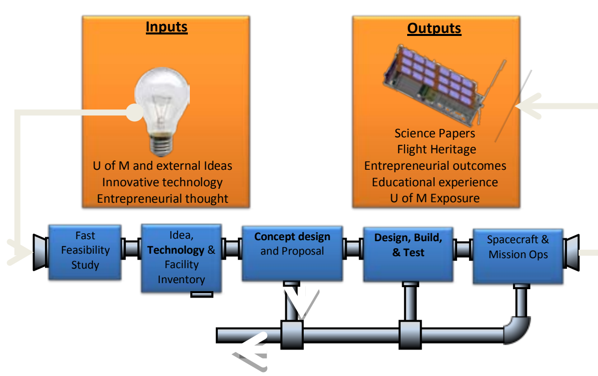

Figure 2. The Michigan Nanosatellite Pipeline (MNP) concept. Ideas from inside and outside UM are integrated into the pipeline for further development, leading to flight missions, new science, and new technologies that can be used in future MNP missions.

In addition to developing nanosatellite concepts for external customers, the students have developed a number of concepts of their own within the MNP. 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 3 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.

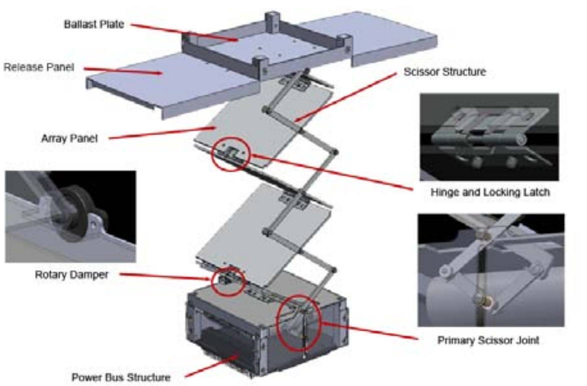

Figure 3. The eXtendable Solar Array System (XSAS). XSAS increases available nanosatellite power by a factor of 5. XSAS will fly on the NASA C-9 aircraft as students continue to refine the design.

A group of students is also looking into developing a business when they graduate based on concepts developed in the MNP. Specifically, they are investigating the creation of a business based on low cost imagery 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 combining engineering and business school students to develop business strategies around technologies developed at the University.

Conclusions

In its 7 year history, the program has graduated over 80 students with a nearly 100% placement record. Comments from former students now working in the field include: "I couldn't imagine a better preparation for this type of job," and "I feel surprisingly equipped for the position I was hired for and know that the foundation I gained in Michigan will only better facilitate my progress into the future." One manager at a major aerospace company said of our program: "If you do not like this program – don't come to Aerospace industry!" 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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