Introducing Space Exploration into Engineering Curricula

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Abstract – Opportunities to introduce space-related, experience-based projects and courses into the undergraduate engineering experience are explored. The University of Alabama's Alabama Space Exploration Program currently supports student groups in three space-related students programs: the BAMASAT program, the Student Launch Initiative, and the NASA Reduced Gravity Student Flight Opportunities Program. In addition to a brief outline of these activities, the undergraduate course *Introduction to Space* is outlined. The Anseri X-Prize, the nation's *Vision for Space Exploration*, and the renewed efforts around the globe to develop space systems have some calling this the new age of space exploration. By providing students with hands-on opportunities to design, build, and fly space hardware, we can better prepare the next generation of engineers to take us back to the Moon and ultimately to Mars. These activities can also be used to recruit the best and brightest students into both our undergraduate and graduate programs.

Keywords: Space Exploration, Rocket, Balloonsat, Near-space, Reduced Gravity, Space Systems.

INTRODUCTION

Recent reports indicate that the United State can expect to experience a critical shortage of qualified scientists and engineers in the near future. Stated reasons for this anticipated shortage include: a decreased number of international students due to stricter immigration laws, the aging of the U.S. population, and a culture in which the scientific and engineering fields are no longer valued as much as they once were. While the exact reasons for this complex problem can be debated, it is clear that something must be done to stimulate an interest in engineering and retain those students who have already chosen engineering as their field of study. In a recent article in *Mechanical Engineering* magazine, the early days of space exploration are credited with creating a time when engineers were "heroes" [1]. It is generally accepted that the launch of Sputnik and the Cold War between the United States and the former Soviet Union was at least partially responsible for the focus on science and engineering in the United States during the 1950s and 60s. While federal support for space exploration has decreased since the 1960s, the exploration and development of space continues to motivate students to choose engineering as a career. In fact, there are few things that inspire students like the prospect of traveling to and exploring space.

Today, we find ourselves at the beginning of what is being called the new age of space exploration. This paper will explore a few of the ways in which space exploration and astronautics can be incorporated into a typical mechanical engineering curriculum. The goal of such activities will be to keep those students already in engineering excited about their chosen field. To be more specific, the paper will examine how space-related, experience-based courses and projects can be used to challenge and inspire engineering students.

STUDENT SPACE HARDWARE PROJECTS

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Perhaps the best way to get undergraduate engineering students excited about space is to have them participate in hands-on student space hardware projects. The University of Alabama's Alabama Space Exploration Program (ALSEP) is a program aimed at doing just that. Currently, ALSEP has active balloonsat, experimental rocketry, and reduced gravity programs. Obviously, these are not the only possible student space programs available. A simple Internet search using the phrase "student space" resulted in 127,000 websites containing the phrase. Student space projects/programs range for relatively simple demonstration experiments for elementary school students to liquid fueled rockets for student research purposes. Because the topic of student space projects/programs is so broad, in this paper only those projects sponsored by ALSEP will be discussed.

BalloonSats

BalloonSats use lighter than air balloons to transport payloads to near-space. Near-space is defined as altitudes of 20 km (approximately 65,000 ft.) to 100 km (approximately 328,000 ft.) above the Earth, with the 100 km altitude being the Kármán line (the internationally defined edge of space). Most existing BalloonSat programs operate at altitudes of around 30 km (approximately 100,000 ft.). Figure 1 provides a typical image taken at altitude by The University of Alabama's BalloonSat, the BAMASAT [2]. Students participating in the BAMASAT program typically receive credit for the design/build/fly exercise via the capstone design course in the mechanical engineering program. An outstanding introduction to BalloonSats is the "Starting Student Space Hardware Programs" workshop sponsored by the Colorado and the Montana Space Grant Consortia [3]. Another good source for information on BalloonSats is a series of articles by L. Paul Verhage appearing in *Nuts & Volts* magazine. A collection of these articles can be found on the Parallax, Inc. website [4].

Student Launch Initiative (SLI)

The Student Launch Initiative is a student rocketry competition currently being developed by the Alabama Space Grant Consortium. While the exact details of the competition are still being determined, students from The University of Alabama (UA) are designing and building a rocket powered by an "M-Class" hybrid rocket motor that is expected to be similar to rockets suitable for the SLI competition. The UA rocket program, known as the Phoenix Program, has the goal of designing a rocket that can reach an altitude of approximately 3 km (10,000 ft), provide

Figure 1: An image from 26 km above the Earth
(December 2004/BAMASAT – 1).

real-time telemetry of the rocket's trajectory, and record still/video images during the flight. Students participating in the Phoenix Program typically receive credit for the design/build/fly exercise via the capstone design course in the mechanical engineering program.

NASA Reduced Gravity Student Flight Opportunities Program (RGSFOP)

The NASA Reduced Gravity Student Flight Opportunity Program allows undergraduate students to conduct research in a reduced gravity environment aboard NASA's C-9B aircraft. For the RGSFOP, the C-9B flies a series of parabolic maneuvers over the Gulf of Mexico to produce periods of hypergravity (approximately 30 s in duration) and microgravity (approximately 25 s in duration). Student teams are selected from across the country based upon proposals submitted by the students to the RGSFOP. After being selected and prior to the flight, students teams must still develop a Test Equipment Data Package (TEDP) to ensure their experiments meet NASA requirements, undergo physiological training at the NASA's Johnson Space Center, and have their experiment physically reviewed and approved by NASA personnel. Additional information about the RGSFOP can be found on the Microgravity University website [5]. The University of Alabama has a long-history of participating in the RGSFOP. Three mechanical engineering faculty members have, either while at UA or while serving as faculty members at other universities, participated in RGSFOP campaigns. The current UA RGSFOP project is focused on the development of a cold gas thruster system for a student-built satellite. This interdisciplinary project, schedule for submission to the RGSFOP in the Fall 2006 semester, will contain both propulsion systems design as well as guidance, navigation and control systems design components. Currently, students participating in the capstone engineering design course in the mechanical engineering program are designing the frame to house the experiment and students taking a mechanical engineering project elective course are performing the initial design calculations for the cold gas thruster system.

INTRODUCTION TO SPACE

The course "Introduction to Space" aims to provide a broad survey of topics relevant to space exploration and development. The course is an elective in the mechanical engineering program at The University of Alabama and is loosely based on the course "Gateway to Space", taught at the University of Colorado at Boulder [6]. While the course is lecture based, students taking the course are expected to participate in several design, build, and test activities. The required text is *Understanding Space: An Introduction to Astronautics* [7] by Sellers. As the author states in the Preface, the textbook is intended to provide the "big picture" of space. The textbook is written in a manner that allows most undergraduate students majoring in science or engineering related fields to easily grasp concepts ranging from rocket propulsion to basic orbital mechanics to space operations. This is an important point in that the ultimate goal is a course that is accessible to students from many disciplines, not just mechanical engineering students. The textbook is supplemented with: handouts to provide additional information on a number of the topics covered in class, Internet links to question banks on ham radio and amateur rocketry, and MathCAD worksheets. The specific graded components of the course may be classified as follows:

- Introduction to Ham Radio
- National Association of Rocketry (NAR) Certification
- Student Launch Competition
- Space Systems Project
- Outside Speaker Series
- Team Challenges
- Lectures on Topics Related to Space Systems and Astronautics

Introduction to Ham Radio

Amateur, or Ham, radio provides an ideal method for long-distance communication to and from student space systems. Amateur radio transmitters began to spring up across the United States shortly after Guglielmo Marconi transmitted the first wireless signal across the Atlantic Ocean in 1901. With the advent of commercial radio stations after World War I, the federal government began to regulate the transmission from amateur radio stations to certain frequencies. Today, the Federal Communications Commission (FCC) regulates amateur radio. To broadcast using amateur radio frequencies, an individual must obtain a license from the FCC. The most popular, and easiest to obtain, type of the amateur radio license is the Technician Class license. In the Introduction to Space course, students are given a brief history of amateur radio and the procedure for obtaining a Technician Class license from the FCC is explained in detail. The students are then provided with a link to a website containing the bank of questions from which the FCC examination for the Technician Class license is drawn [8]. During in the term, the students are given three opportunities to take a 35-question mock Technician Class license exam. They are graded based upon the best score they receive during these three opportunities. In addition to the mock FCC examinations, students are given extra credit in the course for actually taking and passing the FCC Technician Class license examination.

National Association of Rocketry (NAR) Certification

The NAR is one of the two self-regulating bodies for amateur rocketry (the other being the Tripoli Rocket Association). The rockets designed, built, and launched during the Introduction to Space course are considered experimental and contain propulsion systems that are not considered high power. As such, these rockets are not bound by the rules and regulations set forth by the NAR. Having said this, all rockets built and launched during the course are expected to meet and or exceed the safety standards set forth by the NAR. The reason for this is to instill in the student a strong appreciation for the dangers associated with rockets and rocket propulsion systems. NAR Level 2 Certification is the first level of certification the NAR provides that involves testing and is usually one of the first steps amateurs take when beginning to develop high powered rockets. After an introduction to amateur rocketry, the students are provided with a link to a website containing the bank of questions from which the NAR Level 2 Certification examination is drawn [9]. During the term, students are given three opportunities to take a 33-question mock NAS Level 2 Certification examination. They are graded based upon the best score they receive during these three opportunities. In addition to the mock NAR Level 2 Certification examination, students are given extra credit in the course for actually receiving an NAR Level 2 Certification.

Student Launch Competition (SLC)

In the SLC, student teams are expected to design, build, and launch a model rocket capable of achieving an altitude of 1,000 ft. The rockets are judged based upon the time to apogee, the gross lift off weight, the accuracy of the design with regard to achieving the 1,000 ft. design altitude, launch procedures, performance of the rocket, and cost of the rocket. Prior to the launch, the student teams must submit a report detailing the design of the rocket. The report contains a complete set of mechanical drawings, design calculations, and performance estimates. Prior to the actual launch, each rocket must undergo a Flight Readiness Review (FRR) to ensure the rocket can be safely launched. The review consists of a physical examination of the rocket, a comparison of the rocket with the design outlined in the design report, and a brief presentation by the respective student team regarding the design/fabrication experience. No student rocket is launched without first passing this review. After the launch, the student team with the best performance score (based upon the above-mentioned criteria) is declared the winner of the competition and receives bonus credit for the assignment. The winning student team is also awarded points toward the semester-long team challenge described below. While the 1,000 ft. design altitude is not impressive even by model rocketry standards, the SLC allows the student teams to undergo a complete design cycle. Unlike some student design efforts, the SLC is small enough in magnitude to allow student teams the time to perform detailed engineering calculations prior to the actual fabrication of the model rocket. The SLC is the major design activity for the first half of the semester.

Space Systems Project (SSP)

The SSP is the major design activity for the second half of the semester. For the SSP, student teams are expected to design, build, and fly a system capable of recording temperature both inside and outside the instrumentation module during a BAMASAT flight. As previously stated, the BAMASAT platform is The University of Alabama's near space platform and achieves altitudes on the order of 100,000 ft. The student team's SSP is evaluated based on the quality of the initial design predictions with respect to the data obtained during the flight as well as the overall quality of the design/fabrication effort. Prior to flight, each student team is required to undergo a Flight Readiness Review (FRR) of their SSP to ensure the safe operation of the SSP. This review consists of a physical examination of the SSP, a brief report detailing the design of the SSP, and a brief presentation by the respective student group describing their respective SSP. No SSP will be flown without first passing the FRR for the SSP. The team judged to have the superior system is awarded bonus credit for the assignments and is awarded points toward the semester-long team challenge described below.

Outside Speaker Series

Several times during the semester, invited speaker provide presentation on various space related topics. For the Spring 2006 semester, there are 5 invited speakers. The first speaker is from NASA and will outline space related scholarship/fellowship opportunities for the students. The second speaker is from the Air Force Space Command and will discuss US military space capabilities. The third and fourth speakers are from NASA will discuss both the past and the future *Vision for Space Exploration*. The fifth speaker will introduce the students to the concept of a business plan. The overall goal of this component is to give the students exposure to experts in the field of space operations and development. The goal of having the students introduced to the concept of developing a business plan is to reinforce the fact that as engineers they will have to operate in a market-driven economy.

Team Challenges

From above, it is clear to see that student teams play an important role in the Introduction to Space course. Teams are chosen at the beginning of the semester and the make-up of these teams does not change throughout the course. To strengthen the team concept, student teams participate in team building challenges throughout the semester. Points are awarded to the students teams based on their performance in these challenges. At the end of the semester, the student team with the most points is named the winner for the term and receives both an award and extra credit toward their final grade.

Lectures on Topics Related to Space Systems and Astronautics

Despite a strong emphasis on hands-on learning, the course also has a traditional lecture-based format component. The topics covered during the lecture portion of the course primarily follow the textbook and include:

- Philosophical Reasons for Space Exploration
- Elements of a Space Mission
- A Brief History of Space Exploration
- The Global Positioning System
- The Structure of the Atmosphere (textbook supplemented with handouts)
- Outer-Space: The Solar System and Interstellar Space
- Basics of Orbital Mechanics
- Rocketry (textbook supplemented with handouts and with MathCAD worksheets)
- Trajectories and Re-Entry Vehicles
- Experimental Rocketry (textbook supplemented with handouts)
- Propulsion Systems and Launch Vehicles
- Space Vehicle Control

- Space Power Systems (textbook supplemented with handouts)
- Thermal Management (textbook supplemented with handouts)
- Life-Support Systems
- Space Operations and the Space Industry

As with all classes, homework on the in-class lectures is regularly assigned and collected for grading. There are no examinations on the material covered in the lectures during the semester but there is a comprehensive final examination at the end of the semester.

RESULTS FROM INTRODUCTION TO SPACE

The Introduction to Space course was first taught in the Spring 2005 semester. During the initial offering, only eight students (7 undergraduate students and 1 graduate student) registered for the course. While this was initially viewed as unfortunate, the small class size allowed more individual attention to be given to each of the three student teams. During the Spring 2005 semester, the team challenge component was not implemented due to the small team sizes (two teams with three undergraduate students and one team with an undergraduate and a graduate student). Note that the graduate student taking the course was given additional, more theoretical assignments to ensure the quality of his experience the course. After this first offering, it was decided that the course would be strictly limited to undergraduate students.

The SLC component of the course was perhaps the most enjoyable (see Fig. 2) and, at times, the most frustrating for the students. As the student teams completed the initial design for their rockets, they quickly learned that they could not just submit orders and have the parts arrive in a day or two. Delays in receiving parts caused more than one design change. Even when the rockets were "ready" to be launched, problems with the quality of the fabrication led to numerous concerns over whether or not the rockets were truly ready. An example of this was the rocket produced by a group that focused almost exclusively on the weight of their rocket. Their rocket, while well designed otherwise, possessed fins that we exceptionally thin. The concern was that the fin structure was not adequate and, in fact, this turned out to be the case as the fins sheared off shortly after launch. The experience was not a complete loss however. While the student team responsible for the rocket did receive more than their share of good-natured criticism from the other student teams, the video of the unstable rocket has already been shown several times as an example of how a rocket behaves when the center of pressure is not adequately behind the center of gravity. A second lesson learned by the student teams was the necessity of following a launch procedure. As mentioned above, part of the grade for the SLC involved a reading of the altitude at apogee. This team's rocket

Figure 2: Student Launch Competition – Spring 2005

performed as expected but they did not turn on the altimeter prior to the launch. Given the time restraints associate with the launch event, they did not have a second opportunity to launch their rocket and thus they did not get the chance to record altitude data.

The SSP for the initial offering of the course consisted of the entire class acting as a group to design/build/launch a minimum diameter rocket that could achieve an altitude of 4,000 ft. While great care was taken by the students to ensure that the same mistakes made during the SLC would not be repeated for the SSP, there were many other lessons to be learned. Perhaps the most important lesson for the students in this activity was that just because parts (as described on the Internet) seem to meet the requirements of their design; it does not mean that these parts will be acceptable upon delivery. For example, a "sonic beacon" was chosen as a means of locating the rocket after it had landed. Upon receipt of the sonic beacon, the students quickly realized that the sound levels produced by this beacon would not be sufficient. The students spent a considerable amount of time modifying the sonic beacon to produce sound levels that would be acceptable but, in the end, settled for a beacon that transmitted a low-power radio signal on a predetermined frequency. The second lesson was that, at times, disaster strikes even if you take all the precautions you think are appropriate. On the day of the SSP launch, the weather was perfect, the launch was perfect, and the deployment of the parachute was perfect. The problem was the wind. Upon descent, the wind carried the rocket well outside the launch range into a swampy area that was not accessible. The entire class spent several hours searching for the rocket but the rocket was never recovered. To the students, it was a disaster but the experience was priceless. The primarily motivation for changing the SSP for the Spring 2006 offering of Introduction to Space was to have the students focus not only on the system itself but also on the recovery of the system, as recovery is a critical aspect of any BAMASAT campaign.

Finally, it must be noted that the Introduction to Space course has also proven to be an outstanding mechanism for recruiting graduate students. Of the 7 undergraduates in the Spring 2005 offering of the course, 3 have now gone on to graduate school at The University of Alabama. Of those three, 2 directly enrolled in the PhD program while one is working toward a Masters degree (with plans to pursue a PhD at another university). In addition, one of the 7 original undergraduate students is still an undergraduate and is currently working on the RGSFOP project. The enrollment for the Spring 2006 offering of the course was limited to 20 students. The course was completely full of mechanical engineering students almost immediately after registration began. This was somewhat unfortunate as the goal is to create a course that is truly interdisciplinary. One thing is clear; our best and brightest students have a strong interest in space related studies. It is imperative that we must provide them with opportunities that will strengthen this interest.

CONCLUSIONS

This paper has examined how student space hardware projects can be incorporated the undergraduate educational experience. The projects discussed are those currently sponsored by the Alabama Space Exploration Program (ALSEP) at The University of Alabama, i.e. the BAMASAT, Phoenix, and RGSFOP projects. These projects have attracted and continue to attract some of our best and brightest students. The reason for this is that our students are inspired by the dream of and the challenges associated with space exploration. The Introduction to Space class provides a way to incorporate space into a traditional mechanical engineering curriculum. It offers the students the opportunity to participate in hands-on design activities while still getting the "big picture" of space exploration and development.

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