Design Experiences with a Student Satellite Program

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Abstract

The NevadaSat program began in 2002, and is an ongoing, multi-faceted program, providing students with high-impact exposure to the aerospace fields. The program includes activities in scientific ballooning, rocketry, and robotics. These are conducted for their own merits, but each program also moves us closer to our long-range goal of producing and operating a student satellite in Earth orbit, for the purpose of preparing students for the aerospace-industry workforce.

The student experience is largely based in design projects, and design competitions. In some cases, activities are coupled with "special topics" courses, and in others, as extracurricular projects. We have found that these interdisciplinary experiences provide a high-impact design experience that augments the more traditional design activities in the various engineering curricula. These activities are conducted statewide in Nevada, with participation of students and faculty from University of Nevada, Reno, University of Nevada, Las Vegas, Truckee Meadows Community College, and Western Nevada Community College.

Background & Introduction

The National Space Grant Student Satellite Program was created to address NASA's future workforce development needs. NASA has a strong need for engineers, scientists, and managers who have experience working in interdisciplinary teams. Similarly, NASA is a leader in the use of remote operations in the form of telescience or telecontrol of robots because of the numerous spaceflight missions conducted each year. The Nevada Space Grant Consortium's (NvSGC) student satellite program, NevadaSat, is one of the many national and international programs with student satellite programs [1]. Students participating in these types of programs typically study and develop complex systems that span a range of tasks, with Earth-orbiting satellites typically at the pinnacle. The approach taken typically uses a process of graduated steps in program complexity—the formula followed by other successful Space Grant Consortia such as the University of Colorado, is to use less complex design projects, such as high-altitude ballooning (BalloonSats) as introductory steps for students desiring to become involved in their larger-scale satellite (CubeSat) program.

In Nevada, we are using this approach of growing complexity, while maximizing the student design experiences at each level, rather than focusing only on the end-goal of creating an Earth-orbiting satellite. In recent years, we have conducted the following student design programs in Nevada.

1) BalloonSats: The BalloonSat program is aimed at introductory-level engineering and science students and it allows students to conduct near-space experiments in a cost-effective manner. Students design and construct payload packages typically including a camera, temperature sensors, pressure sensors, solar cells, etc. (Figure 1) and these are attached to high-altitude weather balloons, with tracking and communications equipment developed previously by NevadaSat. The balloon is released and rises until the balloon bursts (typically at ~25 km altitude). At this point, the payloads return to the surface via parachute, transmitting position data via radio.

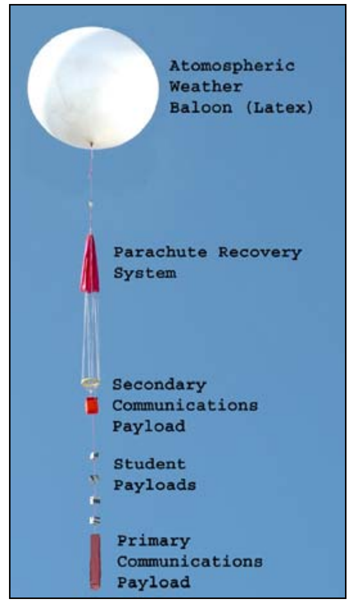

Figure 1: Student-built balloonsat system.

2) CanSats: CanSats represent the next level of complexity in the student satellite program. In this case, the payloads fit inside a standard soda can (hence CanSat) and are launched to an altitude of approximately 2 miles via a high power rocket. The Annual CanSat Competition is organized and sponsored by various groups each year. Student teams form each autumn, and work throughout the spring to prepare for the competition in the spring. Participants tend to be upper-division science and engineering students, as well as graduate students. Teams produce and present engineering documents describing their approach and the competition is run. The competition involves launching a CanSat (Figure 2) via rocket, and during parachute descent, the CanSat performs an aerial photo-survey of the ground, which is evaluated afterwards for accuracy. The performance and overall design, including engineering documents, is evaluated by judges.

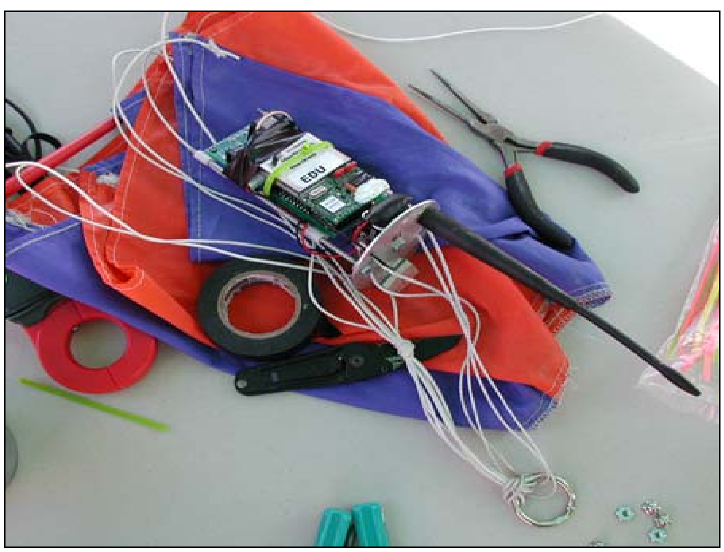

Figure 2: CanSat design entered in the 2005 competition (interior components).

3) ARLISS: The ARLISS (A Rocket Launch for International Student Satellites) competition is an international student competition conducted each fall, when universities from around the world meet in the Black Rock Desert in Northern Nevada for the competition. CanSat payloads (soda-can sized instrument packages) are launched via rocket to approximately 2 miles in altitude, where the payloads are ejected, and return to the surface via parachute. The goal of the competition is for the payload to return back to the launch site (which may be miles away) autonomously. The NevadaSat student participants are responsible for the design, construction, and operation of the CanSats, and a robotic vehicle (Figure 3) that finds its own way to the payload and brings it back to the goal.

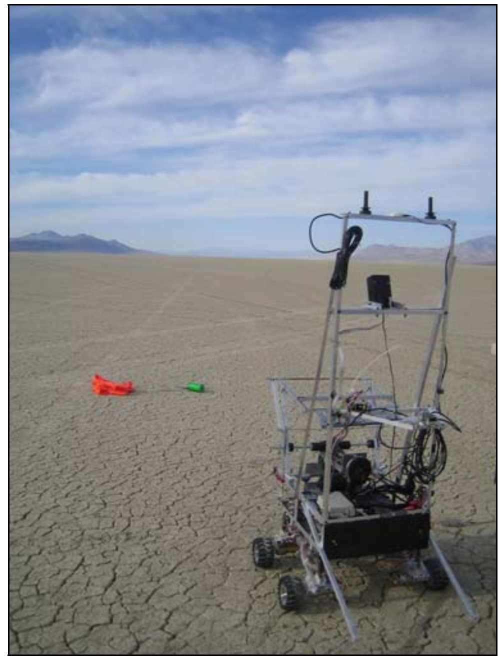

Figure 3: Autonomous robotic rover designed and built for the 2005 ARLISS competition.

4) University Rover Challenge (URC): The University Rover Competition (URC) is sponsored by the Mars Society. Student teams develop an untethered, off-grid rover that must complete both an engineering task and a scientific task. The engineering task involves navigating to a remote site and deploying a simulated radio repeater. The scientific task involves performing a site characterization to determine as much information as possible about both the site geology and paleontology.

Program Goals

The goals of the NevadaSat project have evolved over the first 5 years of the program. In an effort to coordinate our goals with our sponsor's goals, we are currently working towards the following general program goals.

1) Provide students with experience in working on interdisciplinary technical project teams.
2) Provide students with hands-on design experiences.
3) Prepare engineering students for aerospace careers.
4) Present students with both collaborative and competitive experiences with students from other institutions.

Description of Student Design Activities

Each of the four above-described projects works towards selected, overall program goals. All of the projects (BalloonSats, CanSats, ARLISS, and the URC) are design activities, and except for the BalloonSats, all take the form of student competitions (national and international). In 2005, we undertook our most ambitious agenda, when E. L. Wang and J.C. LaCombe co-taught a special topics course, with 12 students from 4 engineering disciplines enrolled. These students worked for credit, in three teams, on entries in the CanSat competition, the ARLISS competition, and development of a rocketry system, and an instrumented rocket engine test stand. In other program years, efforts have typically focused more acutely on two projects. Generally, project teams are assembled for extracurricular student involvement, and in some cases, students are employed over the summer to help advance some projects (such as designing and building control electronics for ballooning telemetry systems).

As introduced above, each of these project efforts focuses on design, and hands-on activities. These are described more comprehensively below.

BalloonSat

BalloonSat programs can be found in educational institutions in many states throughout the U.S., including (but not limited to) Nevada, Montana, California, and Colorado. However, only one article has been found on the subject of student ballooning programs [2]. There are, however, many reports on NASA ballooning programs [e.g., 3-13], which use balloons as low cost, low orbit research platforms. Several projects involve either developing less expensive or longer lasting high altitude balloons. Some of the articles point out the benefits of using balloons to carry payloads up to 30 km altitude for weather monitoring and other forms of data collection. For the education-based programs, a fairly comprehensive list of other university-based BalloonSat efforts can be found online [1]. The list continues to grow, however, as the University of Colorado, Boulder has been conducting workshops since 2002 [14], training faculty on how to start their own programs. This workshop was the original inspiration for us to begin the NevadaSat program.

A typical ballooning "mission" will begin with preparation of the infrastructure hardware (Figures 1,4), including the filling supplies (helium, etc.), and configuration of the tracking systems (typically GPS units attached to ham radio transmitters). These are re-used each mission. The main purpose of the mission, though, is for student teams to design and construct payload packages (Figure 5) that perform various scientific or engineering tasks. With their payload packages prepared, the students then participate in the actual mission by helping during the launch, chase, and recovery phases. Launches begin with careful weather forecasting and flight-path predictions. Approximately 6-12 people prepare the balloon by filling with helium (usually before dawn, while surface winds are low). The balloon, with a string of payloads below (Figure 1) is usually

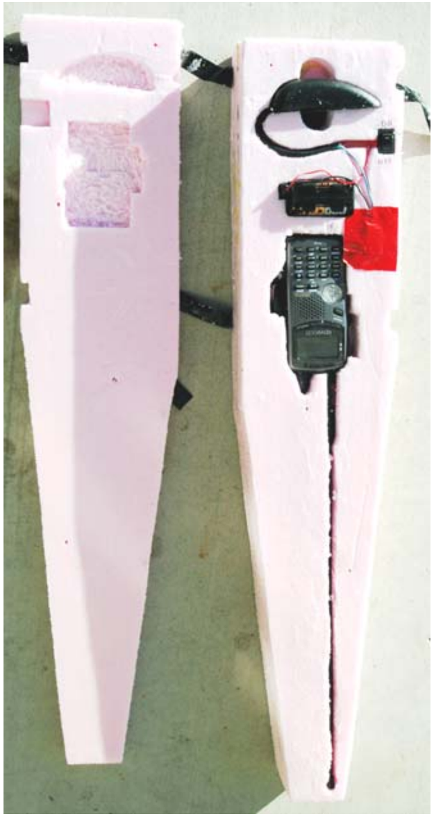

Figure 4: **Figure 3.** Typical tracking system consisting of a HAM radio and GPS.

Figure 5: Left: BalloonSat Payload being prepared by student participants. Right: Student teams inspecting their recovered payloads after a 150+ km chase.

released after dawn. It takes approximately 1-2 hours to rise to a maximum altitude (usually around 20 - 30 km above sea level). At this altitude, the ambient pressure is so low, that the balloon expands to the bursting point. After this, the payloads descend under parachute for approximately 1-2 hours. All the while, the system is flowing with the winds. The landing point can easily be over 150 km away from the launch location, although 30 – 80 km is more typical (depending on wind conditions). The extensive range necessitates several chase teams, equipped with radios to receive balloon coordinates and altitude. The chase phase is typically very exciting for students, and culminates with a hike to the last known radio coordinates, from where a standard ground search (pattern) ensues. After recovery, students extract their desired data, which typically includes electronic images (Figure 6), photographs (film), temperature, and air pressure data, all which can be correlated with balloon altitude and location. Additionally, some projects involve other more complex experiments, with their own data.

Figure 6: Student payload photo taken from 12 km. The lack of easily accessible recovery zones can be seen.

Ballooning is the easiest program to start from an administrative perspective, as its costs are fairly low, and the requisite technical expertise of the faculty and participating students are fairly minimal, provided they have participated in the Univ. of Colorado workshops (or have other similar training). Student participants usually focus on constructing the balloon payloads, rather than the infrastructure hardware. Balloon payload designs are fairly flexible, as size and mass constraints (specified by the FAA) are liberal. One key requirement though, is that the radio equipment used typically requires amateur radio licenses (Ham). Some programs take advantage of local amateur radio clubs in this regard, who help monitor the balloon's position with radios from the chase cars. In Nevada, though, we incorporate students earning Ham licenses into the program.

Most balloon flights contain simple experiments, which record changes undergone by the payload during its ascent and descent. However, BalloonSats are also used as low-cost testbeds for CubeSat hardware [2].

ARLISS & CanSats

CanSats derive their name based on the size and weight constraints of the device: all components must fit inside and have a mass no greater than a standard soda can (350 ml and 350g respectively). CanSats are launched via amateur rockets to altitudes upwards of 4 km. Figure 2 shows a typical CanSat.

To date, the two major CanSat competitions include A Rocket Launch for International Student Satellites (ARLISS) and the CanSat Competition [15, 16]. For the past few years, ARLISS has held an annual event at Nevada's Black Rock desert where the objective is to have students complete a satellite development-launch-recovery lifecycle in a single year. ARLISS has several forms of participation, including a general CanSat program [17, 18] (non-competitive) and an "Open Class" where schools compete against each other to build payloads that can find their own way back to the launch site (the distance traveled varies, but can exceed 15 km).

The rockets used at ARLISS require special certifications and (in some cases) even require federal licensing to purchase and use. They typically reach altitudes in excess of 4 km and speeds approaching Mach 1 (Figure 7). The CanSat program uses such rockets but the students do not perform the actual rocket vehicle design and launching. Instead, the certified amateur rocketeers do the rocketry part, working closely with the student groups who make the payloads (i.e., the CanSats). This operational paradigm is analogous to the mode in which NASA operates with other commercial lift services to provide launch services to a customer who provides the payload.

Figure 7: Typical ARLISS Rocket.

The Annual CanSat Competition is a more formal endeavor, and includes all aspects of the design process. Geared towards aerospace systems, these aspects of satellite development range from mission proposals, to design reviews, all the way through payload recovery and data reduction and interpretation. Like ARLISS, the overall objective of the CanSat Competition is to provide students with a realistic low-cost experience in space systems.

University Rover Challenge (URC)

The URC is a new design competition in 2007, which UNR is participating in. Its requirements are somewhat less rigorous than the CanSat competition, but the problem complexity is fairly extensive. Student design teams are tasked with solving both engineering and science problems, necessitating the assembly of an interdisciplinary group of students, who must work together to develop the design, and then build, test, and operate it. The format of the competition emulates a hypothetical robotic Mars mission, where astronauts on the Mars surface control the rover from a nearby location (i.e., no communications delay). UNR is presently preparing its entry for this, with the competition in late May of 2007.

Evolution of our Student Satellite Programs

From an institutional standpoint, student satellite programs generally require funds to implement. The National Space Grant College and Fellowship Program is a good source of funds in most U.S. states, and currently sponsors most of our peers' programs. Additionally, a core group of enthusiastic faculty is also very helpful to start a student satellite program.

Whereas high altitude ballooning is traditionally touted as the easiest student satellite program to start, in Nevada, recovery of balloons has proved difficult on occasion, due to the rugged terrain and lack of roads. Conversely, CanSats are traditionally considered a more advanced student satellite activity than BalloonSats but has turned out to be an easier program for us to start in many ways. While CanSats are more technically complex, the program is logistically easier to start because the ARLISS competition is held in Nevada each year (the Black Rock Desert is one of the premier launch sites in the world and is only 2 hours from Reno) [15].

The development of an engineering course dealing specifically with student satellites was viewed as an important approach to try to introduce students to aerospace issues at UNR. To this end, a curriculum for a new interdisciplinary *Student Satellite* course to support NevadaSat activities has been developed. The course was offered for the first time in the spring of 2005. This project-based learning environment was used for formal student involvement in two national design competitions (ARLISS, CanSat). Skills-based lectures were provided throughout the semester to augment the student design projects with the fundamentals of project planning, autonomous and teleoperated systems and satellite systems design. The course was successful in gaining participation and meeting program goals, but placed an extra burden on the teaching loads of the faculty. We are seeking effective approaches to offer this elective course on a regular basis at UNR.

Outside of the university classroom, we have also attempted to develop outreach activities. We have designed a CanSat workshop, which incorporates hands-on activities, including building, programming, and launching CanSats. An expandable "CanSat Kit" was developed, consisting of a GPS sensor, temperature sensor, a HAM radio, and a micro-processor. In the summer of 2004, 12 complete CanSat kits were assembled and a pilot version of the workshop was offered to students from local secondary schools and colleges. Eight students participated, including attending a trip to the Black Rock Desert to launch and operate their CanSats. This workshop provided valuable feedback to further refine the activity.

Evaluation

The evaluation of the NevadaSat activities has taken the form of informal feedback from students and formal assessment of desired project outcomes. Qualitatively, the feedback received from students who have participated in various NevadaSat efforts strongly indicates that student satellites have proved to be a very effective medium for providing both undergraduate and graduate students with "real" multidisciplinary engineering project experience. The attitude of most students can be summed up with the following quote from a student on an anonymous feedback form:

> "I've realized that my classes haven't taught me much about *real* engineering."

More formally, the desired outcomes of the NevadaSat project were evaluated in the context of the stated goals of the effort. These included the following:

	Desired Outcome	**Measured Outcome**
1	Students will be able to demonstrate an understanding of aerospace engineering project lifecycle and system management approaches (including teamwork).	Students volunteered for and were assigned project assignments. Students acquired numerous new skills, varying from individual to individual. In the second year, students (generally) played a more significant role in making their own "big picture" decisions.
2	Provide students with an understanding of satellites and balloon systems.	Students received broad exposure to all aspects of the program through regular group meetings attended by everyone (BalloonSats, CanSats, CubeSats). Nearly all systems and subsystems created by the students functioned properly Students regularly shared their knowledge with other students to increase team efficiency and flexibility.
3	Provide students with a project-based learning environment.	The students participated in various hands-on projects, acquiring numerous new skills necessary for project success. Delegation and specialization was critical. Each project area had a primary and secondary person responsible for it. Students did develop more advanced experience in their project areas, making each an integral member of the team.
4	To provide students with experience working on interdisciplinary teams.	Students from numerous disciplines worked together on projects. These included Mechanical, Electrical, Computer, and Materials Engineering.
5	Students should participate in the design, fabrication, operation, and evaluation of their overall effort.	Students were very hands-on and learned many skills not normally associated with their "home" disciplines. The team performed individual and group assessments of performance.
6	The student researcher(s) will obtain experience in communicating the results of their design efforts.	Students prepared a poster and made a technical presentation at the ARLISS competition. Students assisted in preparing a paper to be submitted for presentation at the 2005 ASEE conference. One graduate student defended a thesis on the subject of BalloonSat.
7	The CanSat program will formulate a plan (in coordination with other NV participants) addressing how the CanSat activities (and course) can be extended towards a CubeSat program.	The investigator team has met with representatives from other universities and formulated a plan for getting started. We have begun implementing this advice with the start of our ground station setup.

Conclusions

Many institutions have developed successful student satellite design programs. This paper has described our experiences, modeled on existing programs at other Space Grant Consortia. However, even when building upon the experience of others, starting a student satellite program has proved a challenging, but rewarding undertaking. From both the students' and institution's points of view, the outcomes are worth the effort. In addition to meeting the aerospace industries workforce development needs, a student satellite program provides students with an opportunity to complete exciting "real" engineering projects while working on multidisciplinary teams.

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