Into Space Without a Rocket (and Not Much Money, Either)

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Abstract

This paper describes high altitude balloons as an affordable alternative for providing flight test opportunities for student built satellite systems. Traditional approaches to gain access to space include sounding rockets, Get Away Specials on the Space Shuttle and secondary payloads on expendable boosters. Each of these is time consuming and expensive. High altitude balloons provide a means to fly student payloads in a "near space" environment relatively easily. As a case in point, the Air Force Academy's recent flight of a small satellite under a 250,000 cubic foot balloon to 110,000 feet is summarized briefly.

Introduction

Engineering educators are always looking for ways to involve their students in real-world design projects that move beyond paper solutions to actual hardware. In the best of all worlds, students get to apply theory from the classroom and experience all the joys and frustrations associated with the design, fabrication, and testing of working systems. Innovative programs in all the traditional engineering disciplines are being developed and reported regularly. For example, at the Air Force Academy alone, the Civil Engineering Department has built a full scale construction laboratory where cadets experience building design and construction methods by doing it themselves. The Aeronautical Engineering Department teaches flight test by putting cadets in Cessnas and having them do flight test. Those of us teaching Astronautical Engineering, here and at other schools around the country, face an especially difficult challenge in this regard. We can't put our students in space and it is very difficult and expensive to put their projects there.

Space educators and experimenters are nothing if not innovative. They've used a variety of methods to get student projects into space, close to space, at least, into a regime that's a lot like space. Sounding rockets in a variety of sizes are used to carry student experiments to a range of altitudes from several thousand to several hundreds of thousands of feet. Small scale rockets are built and flown every semester at the Air Force Academy[1]. Larger student payloads are boosted from the NASA facility at Wallops Island and the Air Force's 45th Space Wing is working with Florida schools to provide sub-orbital rides from Cape Canaveral. Experiments on these vehicles typically involve environmental study, zero-G effects or imagery. Aside from the expense, obvious limitations are short time of flight and difficult recovery.

If the goal really is to put space engineering students' projects into space, then some kind of hitchhiking arrangement is required. Get-Away-Specials (GAS Cans) and mid-deck lockers on the Space Shuttle have hosted student projects for years[2]. Our experience is that flying on the Shuttle is feasible, even for undergraduate students, but these projects require years of planning, coordination and review. Mission durations are short and experimenters have little control over when their payload gets manifested on a flight.

A ride as a secondary payload on an expendable booster is another route to space for university projects. Utah State, Weber State and the University of Surrey in England have all put satellites into orbit this way. A number of other schools, including the Air Force Academy, Stanford, and Arizona State are actively pursuing this path[5,6]. Even with all the new commercial boosters on the horizon, the cost of buying a ride as a secondary payloads is daunting. It remains to be seen if any of these schools can be successful in buying, begging or borrowing a ride to orbit on an expendable.

There is another way to flight test space vehicles. A number of schools, most recently the Academy, have flown and operated real space hardware in a near-space environment using high altitude, helium filled balloons. The following sections will briefly discuss what balloons can offer to a space engineering curriculum and describe some of the organizations and bureaucracies with which the hopeful ballooner may want to or may have to coordinate. Finally, the Academy's recent experience and future plans are presented as an example of one school's first ever ballooning adventure.

Whv Balloons for a Space Experiment?

Clearly, a balloon payload at 100,000 feet isn't "in space" but it is in a harsh environment that challenges the student designers to toughen or protect the equipment they plan to send aloft. Atmospheric pressure is reduced by a factor of 75 and the craft is cold soaked for hours at -50 to -70 degrees Fahrenheit[b]. Due to the thin atmosphere, convection is greatly reduced and radiation becomes the dominant means of heat dissipation.

As a result, students building a balloon payload are faced with many of the same challenges as they would be if their experiment were truly going into space. Missions can last from hours to days so power generation, storage and management are key problems. Thermal control systems are required to keep batteries, computers, radios and experiments all within temperature limits. Tracking, telemetry and communications (TT&C) requirements for a balloon payload at 100,000 feet are, conceptually, no different than for a satellite in low earth orbit. The issues of antenna gains, frequency selections, transmitter power, bit rates and telemetry streams are all the same. Finally, students learn all the same lessons from building, integrating, and testing real hardware.

In addition, balloon flights offer a number of advantages over other ways to flight test space systems. Most obvious is flexibility in choosing launch sites and setting schedules. Any large, open field becomes a launch pad and any day that the weather cooperates and the hardware is working can be launch time. Best of all, high altitude ballooning is cheap. Less than $5,000 is needed to pay for the balloon, helium, and electronics required for tracking and terminating the mission.

What Can Be Done Uncler a Balloon?

It only makes sense for space engineering students to fly balloon payloads if their experience and accomplishments are relevant to true space operations. The hardware must be able to do things that an orbiting spacecraft might do. Successful, two-way communication with a payload flying out of sight in a harsh environment is worthy goal all by itself. Ground station operations during a balloon mission are really no different than the satellite operations conducted at Weber State or the University of Surrey.

Attitude determination and control can be done under a balloon using many of the same techniques used on orbit. Sun sensors, horizon sensors and Global Positioning System (GPS) receivers all work in both environments and are within reach of upper level undergraduate and graduate engineering students. Single axis attitude control can be done with simple cold gas thrusters if the payload is hung on a low friction swivel below the balloon. A set of gimbals can be used to allow rotational freedom about three axis.

Beyond testing normal satellite bus functions, useful research can be accomplished during a balloon flight. In fact, high altitude balloon research is being conducted by scientists around the world. Environmental study, aerosol sampling, imagery, and radiation measurement experiments are all candidates for a student built “balloon satellite”. Integrating experiments and working with experts from other disciplines are invaluable though frequently frustrating experiences for space engineering students and faculty alike.

The Air Force Academy’s Experience

For years, the Astronautics Department at the Air Force Academy has had an aggressive program for teaching the principles of space system engineering and design. Prior to 1993, opportunities for students to build and fly space hardware were limited to two GAS can experiments and regular flights on small sounding rockets. That year, however, the department started its Small Satellite Program with the goal of having cadets design construct, launch and operate small satellites. As a first step in that direction cadets began designing, building and testing satellite subsystems (communications, data handling and power) during the Spring of 1994. These formed the foundation for a small satellite, dubbed USAFASAT-1, that was built and flown under high altitude balloon in the Spring of 1995.

USAFASAT-1 was a 20 Kg vehicle that looked like a box mounted under a pyramid (Fig. 1). The box housed all the electronics and power while the pyramid provided a flat surface for the solar array and volume needed by the control system’s compressed nitrogen bottles. USAFASAT-1 required the integration of subsystems including power, communications, data handling, structure, and software. Its primary missions was to evaluate a single axis attitude determination and control system made up of a cadet built sun sensor and cold gas thrusters. This control system was to rotate the spacecraft about its vertical axis to keep the solar array aligned with the sun throughout the one day mission. Subsystem characteristics are summarized in Figure 2)[6].

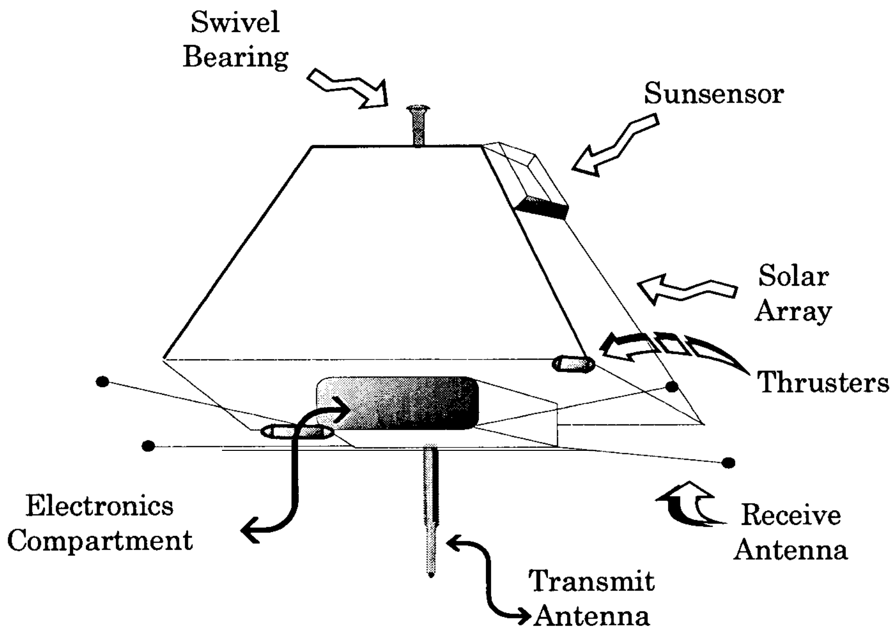

Figure 1 USAFASAT -1 External Arrangement

Power	**Solar arrav:120 silicon cells, 15 watts max.** **Batteries: 40 Nickel Metal Hydride cells** **DC to DC conversion to 5 volts**
Communications	**Transmit: 2w FM UHF at 437 MHz** **Receive: FM VHF at 145.9 MHz** **AFSK modulation 300/1200 baud**
Data Handling	**Computer: Single board NEC V40 @ 8.5 MHz with 512k RAM** **c oremands: 16 bilevels** **Telemetry: 16 analog, 16 bilevels and 17 computer variables**
Structure	**Aluminum sheet metal, partially insulated for thermal control**
Software	**500 lines of assembly language under DOS 3.3 in ROM**

Figure 2: Subsystem Characteristics

Communications, command and control were run from a ground station fixed at the Academy. It consisted of a HAM radio station with directional antennas on the roof of the academic building. Software for monitoring telemetry and commanding the satellite was written in-house and installed on a PC that was part of that ground station.

USAFASAT-l was launched at dawn on 22 May, 1995 on a 250,000 cubit foot balloon from the Academy's parade field. The spacecraft was powered up prior to launch and two-way communications were verified before the balloon was released. All subsystems were operating before launch but the attitude control system was not switched on until more than an hour later as USAFASAT-1 neared its target altitude. Telemetry was received throughout most of the flight though frame synchronization problems prevented all of it from being recorded.

Analysis of the telemetry shows USAFASAT-1 was rotating at between 6 and 12 degrees per second when the attitude control system was turned on. It appears the vehicle acquired and tracked the sun for 40 minutes, expending 1000 pulses before running out of compressed gas. It swiveled slowly after that and the batteries were soon depleted. Communications were lost whenever the solar array was not illuminated but were reestablished each time it swung back into the sunlight.

USAFASAT-1 spent 7 hours at altitude between 100,000 and 110,000 feet. At that time, the spacecraft was separated from the balloon and successfully recovered by parachute. It landed about 60 miles southeast of the Academy.

Although USAFASAT-l was designed and built entirely in-house at the Academy, the actual balloon launch required coordination and assistance from several other organizations. First and foremost, close coordination with the Federal Aviation Administration (FAA) was mandatory. The Academy kept the FAA fully informed of our plans and then reported balloon position to them at regular intervals throughout the mission. Dr. Norm Kjome at the University of Wyoming is one of the world's leading experts in high altitude ballooning. He supervised launch operations and loaned key pieces of equipment including a radio beacon, GPS receiver, radar reflector and flight termination device. Finally, a group of dedicated volunteers called the Edge of Space Science provided an independent HAM link and assisted with tracking and recovery.

Conclusions and Lessons Learned

The Academy's first experience with high altitude ballooning for its space engineering students was an enormous educational success. Course critiques were uniformly enthusiastic with comments like "learned more here than all my other courses", "rewarding and motivational", and "fitting capstone for aerospace engineering students". Cadets did spend a tremendous amount of time on the project and many recommended that final spacecraft integration and testing be spread over an additional semester. (Several times students were ordered to leave the lab and get some sleep).

The learning that accompanied this heavy work was also high. Each of the cadets had been exposed to spacecraft design in other, traditional, academic courses. To build USAFASAT-1 they had to apply that textbook knowledge. They also had to learn a whole new set of practical skills including soldering, wire-wrap, printed circuit board fabrication and vacuum testing. Communication skills were also honed during frequent formal and informal design reviews.

In summary, the Academy's USAFASAT-l project gave our students every educational benefit of building real hardware and putting it into space. They learned much from the pain and satisfaction that comes with building and operating complex systems. They experienced the thrill of launching their prized project, seeing it disappear from sight, operating the payloads from a ground station and recovering useful data. Without the capabilities of a high altitude balloon, none of that would have been possible.

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