THE PARASAT SPACE FLIGHT PROGRAM

Christopher A. Kitts and Jeffrey M. Ota
ckitts@scudc.scu.edu and jota@scu.edu
kitts@leland.stanford.edu and jota@stanford.edu

Santa Clara Remote Extreme Environment Mechanisms Laboratory, Santa Clara University
Space Systems Development Laboratory, Stanford University

Abstract: The ParaSat program, a new university-based satellite development initiative, is described. The goal of this program is to produce student managed and engineered satellites capable of supporting both education and research. Educationally, these projects expose students to the following: 1) a range of subsystem technologies necessary to develop such a spacecraft, 2) a range of lifecycle phases including conception, fabrication, and test, and 3) a realistic design team environment that includes the satisfaction of a principal investigator, the rational defense of design choices, and involvement in a team enterprise. From a research perspective, the resulting spacecraft provide inexpensive and rapidly developed platforms for space based research and/or technology demonstration; these platforms, however, are limited in capability and have a lower than normal reliability. Compared to existing academic satellite development programs, the ParaSat program has been designed to operate with minimal resources: less than $5,000 cash, less than one year development time, undergraduate students with no formal space technology background, and little to no laboratory space. The design of this program and results from past and current projects are presented.

1. INTRODUCTION

Within the past five years, several universities throughout the world have initiated hands-on educational programs relating to spacecraft design, fabrication, test, and operation. The centerpiece of these programs is often the full-scale development of a low-cost small satellite. Excellent examples of such programs exist at Stanford University, Arizona State University, the University of Colorado, and Boston University..

As an educational project, the simplicity of these satellites affords students a unique opportunity to understand the operation of a complete system; furthermore, the pace of these projects allows students to experience a several phases of a complete mission lifecycle. From the research and development perspective, the developed spacecraft can be used to support a variety of low power, mass, and volume payloads in a low-cost albeit high risk space mission.

This approach to engineering education has generated widespread interest in universities throughout the world. Unfortunately, many of the advantages enjoyed by the leaders in this field are not available to other schools interested in implementing their own satellite engineering program. This is especially true at the undergraduate level. In addition, the programmatic challenges, which exist and must be managed during all phases of such a program, are especially daunting during the start-up phase of such an effort.

As a result of these challenges, Santa Clara University has initiated the ParaSat Space Flight program as a means of extending the benefits of hands-on spacecraft design projects to institutions with limited resources.

2. THE PARASAT PROGRAM

The Santa Clara Remote Extreme Environment Mechanisms (SCREEM) Laboratory has initiated the ParaSat Space Flight program in order to guide the scope and strategies of new university satellite programs with limited resources and capabilities. Like many of the university programs that currently exist, the ParaSat program has the goal of producing student managed and engineered spacecraft that contribute to the educational experience while also providing a platform capable of supporting inexpensive albeit risky space experiments. But because of limited resources, the ParaSat program has simplified the scope of adopted missions and designs while still attempting to provide a comprehensive educational experience.

The general design guidelines for ParaSat-class vehicles are similar to those of the SQUIRT program with the following exceptions: orbital lifetimes may be on the order of days or weeks, cash equipment budgets are limited to about $5,000, limited or no functionality for several subsystems is permitted, and permanent attachment to spacecraft and/or rocket stages is considered acceptable. ParaSats rely heavily on the use of corporate donations, reengineered COTS equipment, HAM radio communications, battery power, and simple operational strategies. The configuration guideline is to be on the order of one cubic foot and to weigh less than 15 kilograms. The development time for these systems is less than one year, and the orbital lifetime is on the order of days or weeks.

The name “ParaSat” was derived from two particular features of the program. First, because a ParaSat-class spacecraft does not need to provide all subsystem functions provided by conventional spacecraft, the “para-“ prefix was used to denote a mechanism that “closely resembled” a typical satellite. Second, because a ParaSat-class vehicle may be permanently attached to another vehicle and may even consume some of its resources, the humorous resemblance of “ParaSat” to “parasite” was considered appropriate.

For comparison, it is instructive to compare the scope of typical ParaSat missions with more complex university programs that currently exist. Given the author’s affiliation with Stanford University’s Space Systems Development Laboratory (SSDL), this comparison can easily be done with SSDL’s primary microsatellite program, the Satellite Quick Research Testbed (SQUIRT) program [1]. The general design guidelines for SQUIRT-class vehicles include a 25 pound bus mass, a 12 inch tall by 18 inch diameter modular hexagonal structure, a cash equipment budget of $50,000, heavy reliance on re-engineered commercial equipment, a 12 month limit on orbital life, and the use of amateur radio communications. SSDL's eventual goal is to establish an educational and laboratory infrastructure to support the production of a fully capable SQUIRT satellite on a yearly basis.

SSDL's SQUIRT program is specifically designed to capitalize on the resources available to the laboratory. It's students are Masters, Engineers, and Ph.D. candidates with graduate level backgrounds in engineering fundamentals, formal coursework in space system development, multi-year availability, and a deep commitments to engaging in concentrated developmental projects. In addition, the SSDL laboratory is adequately furnished with design, analysis, development, and test equipment. Furthermore, SSDL's location and firmly established contacts with the aerospace industry in Silicon Valley permit it to take advantage of invaluable partnerships with both commercial companies and government institutions; these contacts provide crucial design advice, equipment donations, and assistance with costly environmental testing. Finally, SSDL's reputation and past achievements allow it to raise substantial money in order to cover its developmental costs. These advantages enable SSDL to adequately meet the challenges inherent in offering a real-world satellite engineering program.

Table 1 shows a comparison between the programmatic attributes of the SQUIRT and ParaSat programs.

Table 1. Programmatic Comparison of SQUIRT and ParaSat Programs . Adapted from [2]

	SQUIRT	**ParaSat**
Mission Life	Months-Years	Days-Months
Development Time	12-48 Months	9-18 Months
Team Effort	8000-12,000 Hours	1000-5000 Hours
Student Level	Graduate	Undergraduate
Student Experience	Satellite Design Course	None
Number of Students/Team	25-100	5-10
Material Cost	$1,000-$10,000	$25,000-$100,000
Facility Grade	Simple to Extensive Laboratory	Garage to Simple Laboratory
Subsystems	All	Most

3. PARASAT MISSIONS

Several ParaSat class missions have already been accomplished or are in development. These include two 10-15 kilogram microspacecraft as well as several subkilogram “picosatellites”.

3.1 The Barnacle Project

Barnacle, the first ParaSat spacecraft, is the first microsatellite built by Santa Clara University [3]. Its missions include characterizing experimental sensors and validating the space operation of a new low cost spacecraft computer. This project was completed in one year, involved seven senior undergraduate engineering students with no previous space technology experience, and required a cash budget of less than $5,000. The Barnacle project set an impressive precedent as being the first undergraduate managed and engineered satellite completed in less than 1 year; it also laid the foundation for the SCREEM laboratory. Barnacle's processor subsystem consists of an experimental Motorola 68HC11 microprocessor, an eight channel data acquisition board, 16 Kb of ROM, 48 Kb of RAM, and backup digital spacecraft control circuit. This is a student developed, radiation tolerant design that includes error detection and correction logic as well as latch-up protection circuitry. The communications subsystem is composed of a modified commercial transceiver and software based 1200 baud data packetization. A power control unit provides 5 and 12 volt regulated power to components.

Figure 1. The Barnacle Microsatellite: Sounding Rocket Configuration

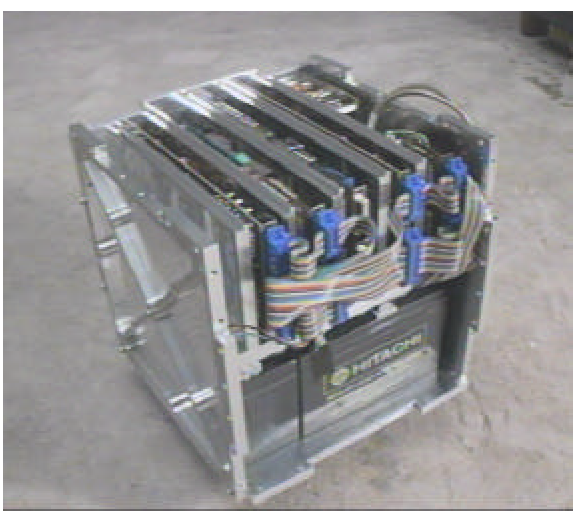

Figure 2. The Barnacle Microsatellite: Orbital Configuration

Based on student interest and launch opportunities, two flight versions of Barnacle have been developed. The first is packaged in an 18 inch long, 6 inch diameter aluminum tubular structure as shown in Figure 1. This version is testing a set of commercial accelerometers and is powered by a multi-cell primary battery. This configuration is manifested for launch in June 1999 on an experimental sounding rocket as part of the CATS (Cheap Access To Space) prize competition. The second version of the Barnacle spacecraft, shown in Figure 2, is packaged in a 9 inch cube machined aluminum structure that houses components in an internal tray system. This vehicle is testing a set of micro-machined radio frequency switches and is powered by a simple solar panel and a secondary lithium ion battery. This platform is designed to be permanently affixed to a launch vehicle upper stage and is being considered for launch in late 1999.

3.2 The Artemis Project

The Artemis Project is Santa Clara University's second microsatellite endeavour and involves the development of several sub-kilogram picosatellites [4]. These picosatellites are being produced by a team of seven undergraduates, fabricated for under $2,500 apiece, and developed on in several iterative design phases. Together, these three spacecraft will be ejected by the SSDL Opal microsatellite which is currently manifested for launch in September 1999.

The first Artemis picosatellite, shown in Figure 3, is a 200 gram device housed in a 3 by 4 by 1 inch aluminum housing. Its mission is to periodically broadcast a simple Morse Code greeting to groundstations throughout the world. In addition to providing an appealing capability for the students, this limited functionality supports the Opal requirement of demonstrating the survivability and the deployment capability of the Opal picosatellite storage and ejection system. The satellite electronics include a Basic Stamp processor, an amateur radio transmitter, and a primary battery which will provide a lifetime of a few days.

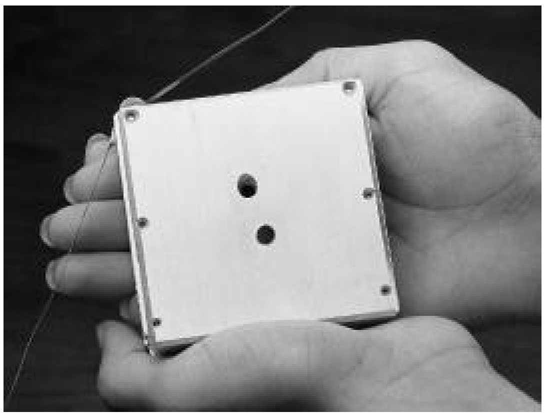

Figure 3. The First Artemis Picosatellite: Exterior Structure

The second and third Artemis picosatellites are designed to operate in a joint mission for sensing Very Low Frequency (VLF) waves generated by Earth lightning. The simultaneous sampling of VLF wave data from different points in space leads to the generation of novel scientific data concerning the Earth's ionosphere. This mission is intended to be an experimental demonstration of more advanced distributed spacecraft missions that are likely to occur in the future. To accommodate the additional electronic circuitry required for this experiment, each of these picosatellites are housed in a 8 by 3 by 1 inch aluminum structure, twice the size of the first picosatellite. Circuitry includes a VLF receiver, a Motorola 68HC11-based controller with 48K of memory, an array of light sensors, and an amateur radio receiver and transmitter. The power system consists of 8 solar cells on both primary faces of the craft as well as a lithium ion battery.

3.3 The Emerald Subsatellite

A third ParaSat project is being formulated at this time as part of the joint Stanford University – Santa Clara University Emerald mission. Emerald is a two satellite mission supported through the AFOSR/DARPA University Nanosatellite Program [5]. The two Emerald spacecraft will attempt to demonstrate basic satellite formation flying technologies such as GPS-based relative position determination and course position control. This mission is being targeted for a 2001 Space Shuttle launch.

As part of this mission, a dedicated ParaSat system on the order of 1-2 kilograms is being planned. One possible configuration, shown in Figure 4, is to have this device be a subsatellite attached to the tether or flexible boom that will adjoin the two Emerald satellites. This subsatellite will be required to support the Emerald mission by severing the tether upon reception of a ground command, thereby allowing the Emerald vehicles to free fly. The ParaSat team will be free to add additional functionality to the sub-satellite given their interests and the availability of mass, power, and volume.

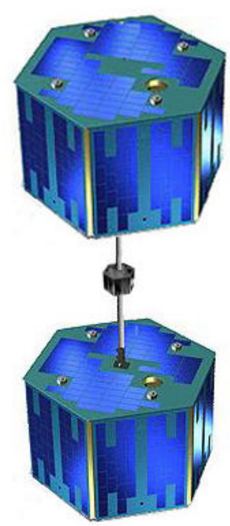

Figure 4. The Two Emerald Microsatellites with a ParaSat at the Tether Midpoint

4. FUTURE MISSIONS

In addition to past and current ParaSat missions, several missions are being conceived for future student teams. These missions include designing a series of Space Shuttle missions as well as developing a satellite as part of the established yearly Starshine project.

4.1 Shuttle Payloads

The Space Shuttle's Student Experiment Module (SEM) is a particularly promising launch opportunity being targeted by the ParaSat Program. Displayed in Figure 5, the SEM houses a rack of student experiments packaged in 300 cubic inch trays and with a mass of up to 2.7 kilograms. The SEM provides experiments with power, thermal control, and a pressurized environment. Housed in Space Shuttle Get Away Special (GAS) cans, SEMs fly on a periodic basis given student demand and Shuttle resources.

Several ParaSat missions are currently being conceptualized for flight on the SEM. The first is a simple testbed capable of testing component tolerance to launch loads, microgravity, and the radiation environment. This will contribute to ongoing, sponsored programs for evaluating both commercial components as well as newly developed micro-electromechanical systems (MEMS). A second class of experiments includes a host of magnetometer and accelerometer sensor systems for simple dynamics experiments. A variety of other possible missions are also under consideration; several of these may include the participation of students in several local high schools.

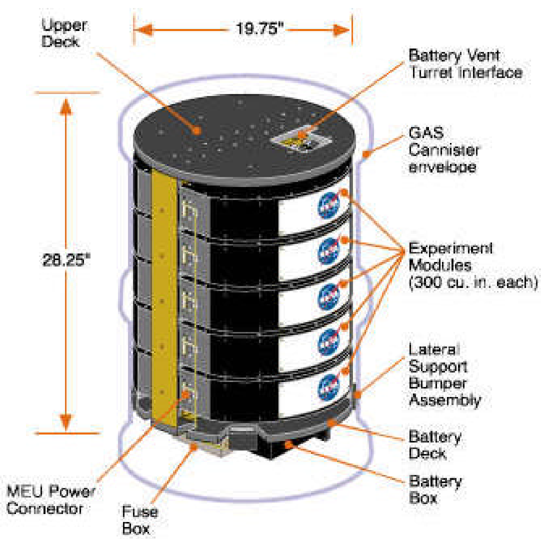

Figure 5. The NASA Space Shuttle Student Experiment Module

4.2 Amateur Rocket Payloads

The Santa Clara area has a very active group of amateur rocket developers. In fact, it is this group that is designing the CATS competition rocket, shown in Figure 6, upon which the Barnacle microsatellite is manifested for a June 1999 launch.

This group has a very keen interest in student education and hopes to expand its offering of launch opportunities for student developed payloads. Current planning is ongoing for future missions with an assortment of sub-orbital payloads to be provided by Santa Clara University, Stanford University, and a variety of secondary schools in the Silicon Valley area.

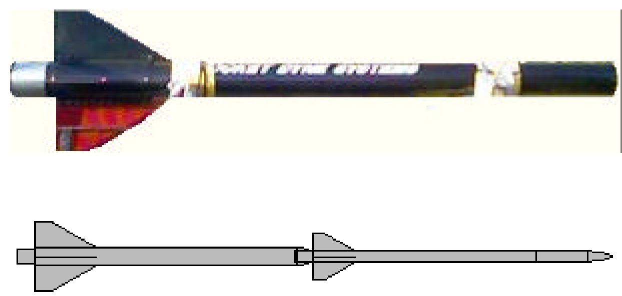

Figure 6. The ICANO Mission Amateur Rocket that will launch the Barnacle Microsatellite: Photo of the 15 ft long Booster Stage (top), Drawing of the complete 32 ft long, two-stage solid rocket (bottom).

4.3 The Starshine Program

Starshine is an educational program with an objective of launching a simple passive satellite every year in order to study the effects of solar activity on atmospheric drag [6]. Each Starshine satellite, shown in Figure 7, is a 19 inch diameter sphere with 877 highly polished one inch diameter mirrors attached to its exterior. Launched by the Space Shuttle from a GAS can, these vehicles can be visually tracked by students who will send their observations to a central processing group for determining the spacecraft's orbit over time. In addition, students will conduct observations of solar activity for correlation with the spacecraft's computed drag profile.

The Starshine program relies on a sponsoring organization, such as a national laboratory or a university, to coordinate mirror polishing by hundreds of high schools throughout the world and to administer the data processing during and after each flight. The SCREEM laboratory has initiated its involvement in the Starshine program with the hope of becoming a sponsoring organization within the next few years.

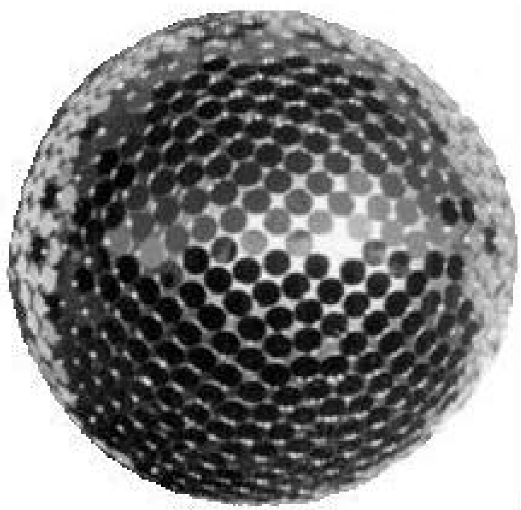

Figure 7. The First Starshine Satellite to be launched from the Space Shuttle in Spring 1999. The sphere is 19 inches in diameter.

5. RESULTS AND CONCLUSIONS

The ParaSat space flight program has been specifically designed to allow resource constrained universities to participate in real-world satellite development activity. The enabling strategies for this program include the following: 1) limiting the scope of project goals and design features in order to accomplish these projects within severe resource constraints, 2) capitalizing upon excess resource and launch capacity of host vehicles, 3) relying on industrial and governmental partnerships for mission sponsorship, design advice, and in-kind donations, and 4) strong leadership that enforces rational decision-making and appropriate verification requirements. These approaches have allowed student teams to manage and develop flight systems for as little as $2,000 cash, in under a year, and with undergraduate teams with no formal background in satellite technology.

From a research perspective, the spacecraft provide a simple, low cost, rapidly developed platform capable of supporting a narrow but plentiful niche of technology demonstration and science experiments. Although the student-designed nature of these spacecraft significantly increases the risk, the low costs and related educational benefits have attracted enough industrial and governmental interest to support parallel programs at several institutions. As a result, ParaSat vehicles are beginning to make small but meaningful contributions to space science and technology; perhaps more importantly, the program is being institutionalized as a means by which to rapidly test advanced technologies in an unobtrusive manner.

Educationally, participation in these projects has several distinct benefits. The simplicity of the system allows all students to completely understand the designs and technologies employed. Project speed allows students to witness all phases of a mission lifecycle. Finally, the real-world nature of the projects holds students accountable for the impact of their decisions, requires the team to satisfy an external customer, and necessitates the cooperation of a mission team with varying backgrounds and expertise.

These characteristics have prompted the ParaSat program to be declared “a model for engineering education” by a panel of chief executives from several major Silicon Valley technology firms [7]. In addition, a recent editorial in the trade newspaper Space News cited this program as an excellent example of “a meaningful aerospace education” [8]. Ultimately, it is exciting, hands-on educational opportunities of this nature that will best prepare the future generation of engineers.

6. ACKNOWLEDGEMENTS

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