UASat: A STUDENT SATELLITE PROJECT

Christopher A. Lewicki
Masters Student, Aerospace Engineering
NASA Space Grant Graduate Fellow
UASat Program Manager

K.C. Hsieh
Professor of Physics
UASat Project Mentor

University of Arizona
Tucson, Arizona

ABSTRACT

This paper introduces UASat, of the Student Satellite Project at the University of Arizona in Tucson, Arizona. UASat is a small satellite that is being designed to launch from the Space Shuttle Hitchhiker Ejection System. Its unique inception history will be described, and student-proposed mission reviewed. Its broad-based participation and cross-disciplinary involvement will be presented. Its current progress and future schedule will be detailed.

1. INTRODUCTION

The Student Satellite Project (SSP) at the University of Arizona was initiated on November 7, 1996, by Department of Physics Professor K.C. Hsieh and Aerospace and Mechanical Engineering Professors Wayne Chen and Ernie Fasse. The initiators felt that the University of Arizona had all the right ingredients to support such an endeavor including a strong research program in space-related sciences and the engineering resources to make it happen.

Shortly after this genesis, a group of faculty met to discuss how to cradle the development of a satellite project, which would quickly become student-driven and designed. It was decided that an announcement of opportunity (AO) similar to an AO in a traditional spacecraft mission would be issued on February 5, 1997, and students would be invited to propose how they would utilize such an opportunity.

In order to provide some design constraint for this process, and also to ensure the best possibility of success for the eventual mission, the launch opportunity of the Small Shuttle Payloads Project Office Hitchhiker Ejection System (HES)[1] was chosen from the outset. The HES is an emerging capability on the Space Shuttle for ejecting a payload from a Get Away Special (GAS) canister, placing it into an orbit similar to the Space Shuttle's. Utilization of the HES has several advantages. One of the primary reasons for choosing it was for its resultant "standard" orbit of 28.5° to 57° inclination and an orbital altitude ranging from 185km to 400km.[2] Also, with the upcoming construction of the International Space Station (ISS), there are currently 34 Shuttle missions between December 1998 and January 2004[3] to the ISS orbit of 407km and 51.6° inclination[4]. The availability of launch opportunities coupled with the given HES constraints in Table 1 provide for a nice set of constraints for designing a spacecraft mission. Some might be quick to point out the disadvantages of HES, however, which include the 1-year orbital lifetime, and the requirement to design for launch from a man-rated vehicle.

Table 1: Hitchhiker Ejection System Characteristics

Maximum spacecraft weight	68 Kg (150 lb)
Maximum spacecraft height re separation plane	52 cm (20.5 in)
Maximum spacecraft diameter	50 cm (20 in)
Maximum CG location re canister centerline	1.27 cm (0.5 in)
Maximum CG location re separation plane	26 cm (10.25 in)
Ejection Velocity (at 68 Kg)	0.6 – 1.2 m/s (2 – 4 ft/s)

With these constraints in mind, over 80 volunteer student respondents were assembled into 17 teams, comprising 6 design subsystems: Science, Mechanical Structures and Analysis (MSA), Power Generation and Distribution (PGD), Data and Command Handling (DCH), Guidance Navigation and Control (GNC) and Tracking Telemetry and Command (TTC). The student teams were tasked with finding a faculty advisor and submitting a "Letter of Intent to Propose" one month later. Full proposals would follow on April 14, 1997.

An Evaluation and Selection Panel (ESP) was assembled from distinguished individuals of the University and local industry[5] to evaluate the proposals. They announced the selected proposal ideas on April 28, and the Student Satellite Project was formally organized on May 8, 1997. The current project organization, including the addition of a Strategic Technology Initiatives (STI) team, is shown in Figure 1.

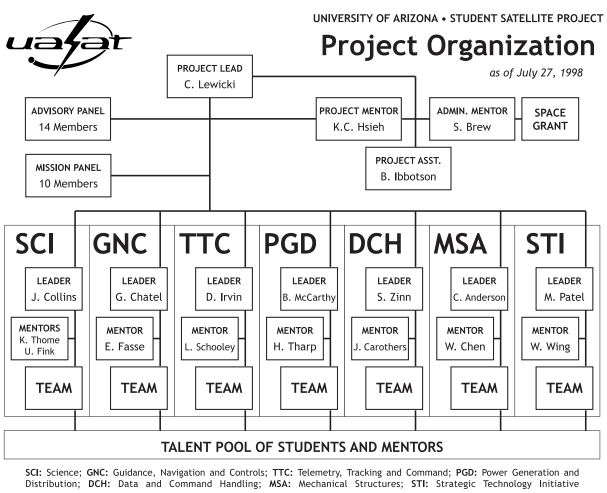

Figure 1: UASat Organization Chart

What follows is a description of the current preliminary design for UASat* and its science mission.

* From this point on, SSP and UASat are used interchangeably to describe the satellite project currently underway at the University of Arizona. UASat was formally adopted in February of 1998, when a student vote selected it as the name of the satellite described herein.

2. SCIENCE

The student-proposed science mission selected by the ESP was three-fold:

- Lightning Experiment
- Sprite Experiment
- Stellar Photometry Experiment

In order for these three experiments to be carried out on the same orbital platform, the design goal is to integrate them into a single optical system. A block diagram of the science instrument[6] is shown in Figure 2.

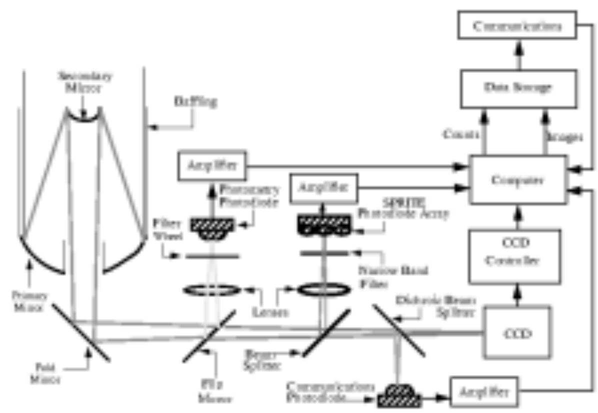

Figure 2: Science Instrument Block Diagram

2.1 Lightning Experiment

The goals of the lightning experiment are to improve the understanding of

- Thunderstorm Distributions
- Cloud Processes
- Storm Variability

To achieve this mission, UASat will need to detect and locate large areas of lightning activity over the Earth's surface. This includes cloud-to-ground, cloud-to-cloud, and intra-cloud lightning. An orbital platform for these observations represents a significant advantage since ground-based methods can only detect cloud-to-ground lightning strikes.[7]

The data obtained will help constrain global climate and global warming models. They will also help to develop theoretical algorithms that describe the electrical, microphysical and kinematic properties of tropical thunderstorms. Lastly, the data will help locate areas of deep atmospheric convection.

2.2 Sprite Experiment

Sprites are a phenomenon discovered in the summer of 1989. To date there has been little space-borne observation of them, limited initially to the Space Shuttle's payload bay cameras (which helped verify their discovery)[8], air-craft and ground observations over the continental United States, and possible indirect observation from the Gamma Ray Observatory (GRO).[9]

UASat hopes to make a significant contribution to the knowledge base on sprites by observing and imaging sprites and investigating correlations between:

- Sprite Production over Land vs. Ocean
- Frequency of Sprites (Relative to Cloud Flashes) vs. Latitude, Season, Storm Intensity
- Frequency of Sprites vs. Cloud-to-Ground Strikes

UASat also hopes to use the sprite data to help constrain atmospheric chemistry and space physics models, and to determine if sprites can occur over single thunderstorm cells as opposed to mesoscale convective systems.

2.3 Lightning and Sprite Experiment Approach

As shown in Figure 2, the lightning detector shares the same optics, and hence the same field of view (FOV). Lightning has a primary spectral peak at 777.4 nm, with observable spectra between 660 and 700 nm. The brightest spectral range of sprites occurs between 670 and 700 nm. In this range, sprites are as bright as lightning, while outside this region lightning is as much as 500 times brighter than sprites. To distinguish lightning from sprites, we take advantage of the geometry of the phenomena in order to distinguish them from each other. Lightning typically occurs below 15 km while sprite heads occur between 66 and 72 km. Using this information, the science team is proposing a limb-looking instrument for which the boresight will be at a 40 km tangent height to the Earth's limb. For the detection of sprites vs. lightning, use of a cylindrical lens is currently under study. Light from the FOV would be focused on a linear photodiode array, and spatial location of peaks could be used to differentiate sprites from lightning. This approach is shown in Figure 3. The experiment will operate continuously while the spacecraft is in eclipse and as resources permit in sunlight.

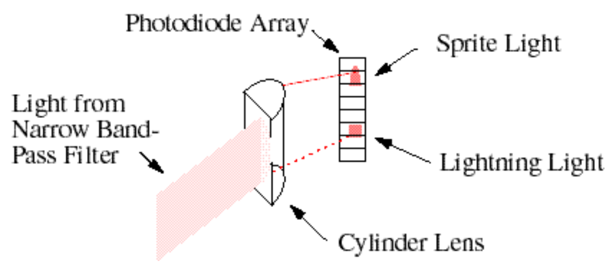

Figure 3: Cylindrical Sprite Detection Lens

2.4 Stellar Photometry Experiment

Also utilizing the optical system shown in Figure 2 is UASat's stellar photometry experiment. This experiment aims to make observations that will improve the accuracy of ground-based measurements of UBVRI colors for a selected set of standard stars. The primary goal is to obtain and publish an internally consistent data set spanning a range of magnitudes in the northern and southern hemispheres. The current set of standard stars is the 25 brightest stars in the sky which do not have close proximity to other stars. Observations are presently expected to last only one second, although there will be a considerable amount of setup time to ensure that the proper target star is in the FOV and the spacecraft platform is stable.

3. SPACECRAFT SYSTEM DESIGN

3.1 Mechanical Structures and Analysis Subsystem

The Mechanical Structures and Analysis (MSA) team is tasked with designing the structure which all other subsystems and experiments mount to. This team is also responsible for routing of subsystem interconnect cables throughout the spacecraft. The MSA team's current preliminary design is a 12-sided satellite that fills most of the volume and mass outlined in Table 1. The basic design includes body-mounted solar panels, a 15 cm aperture opening at the “top” face of the satellite and extending through the body, primary downlink antennae on the top face, and the marmon plate interface to the HES on the bottom face of the satellite. Positions of other components are described in following subsystem descriptions. The basic layout for the design is illustrated in Figure 4 and Figure 5.

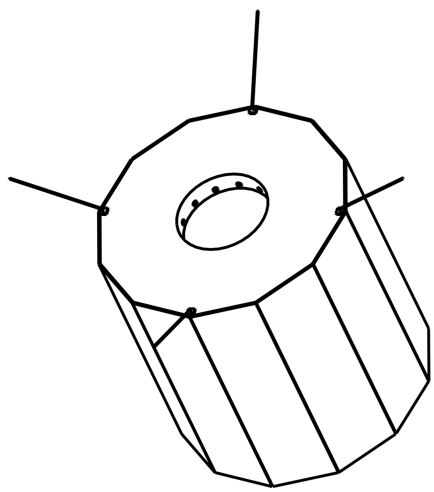

Figure 4: UASat Preliminary Structure Design

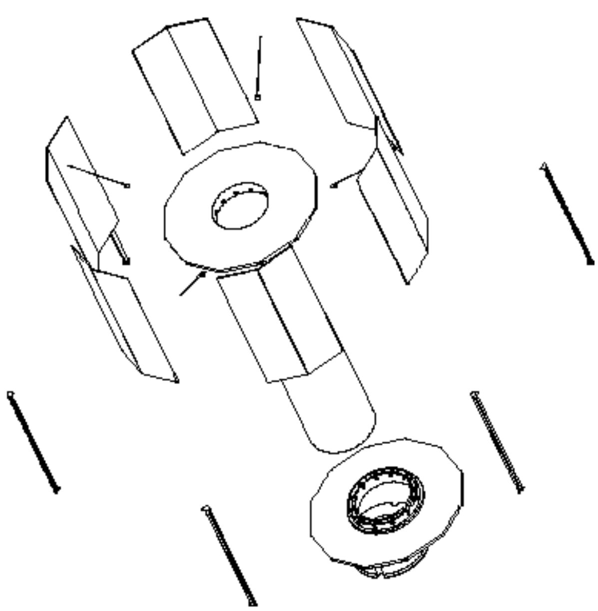

Figure 5: UASat Preliminary Structure Design (Exploded View)

The MSA team is utilizing the parametric design capabilities of Pro-Engineer (ProE) in the design of UASat. ProE allows concepts to be rapidly visualized and quick design studies to be performed on these components.

3.2 Data and Command Handling

The DCH team is tasked with command detection, verification, distribution and execution. They must interpret, store and carry out all commands uplinked, as well as perform general internal housekeeping functions. Typical processes will include executing attitude determination and control algorithms, interacting with the science instrument computer to pass data and commands, and relaying commands and data to and from the TTC subsystem. Essentially, they are the spacecraft computer. Presently, the DCH team is studying the utilization of an Intel 386EX class processor. Whether a system using this processor is built from the ground up, or a commercial single-board-computer is used remains to be determined. The group is internally organized to include a software and a hardware team.

Also under investigation is the choice of approach for the spacecraft operating system (OS). Due to the nature of the computing tasks aboard the satellite, the following traits are desirable for the eventual OS, whether it is coded in-house, or adapted from commercially or publicly available sources:

- Multitasking
- Real time (as schedule and budget permit)
- Priority oriented
- Runs on a simulator

UASat has selected the ORCAD suite of design, layout and simulation tools for its design of the DCH system and other circuit design tasks. ORCAD was chosen as it allows us to seamlessly interface with our AMSAT advisors Lyle Johnson and Chuck Green, who are located in Tucson.

3.3 Power Generation and Distribution

The PGD team is tasked with selecting, designing and integrating components for the solar arrays, battery subsystem, and distribution of power throughout the satellite on standard regulated buses. Silicon or Gallium Arsenide (GaAs) solar cells will be body-mounted circumferentially on the facets of the satellite, potentially leaving radiating surfaces if the design requires it. Isolation diodes will be utilized in the solar cell strings to protect against cell shadowing and failure. A peak power tracker approach is also under study to maximize power obtained from the solar cells. The current power storage approach utilizes 72 NiCad D-Cells, with 24 batteries in series, comprised of 3 D-Cells connected in parallel for redundancy. The batteries will be mounted in a pressure vessel near the marmon plate at the bottom of the satellite. While in sunlight, the satellite's activities and positioning will be optimized for maximum power generation, and other activities (science and telemetry) will be carried out as power permits.

3.4 Strategic Technology Initiatives

The STI team is primarily tasked with the design of a Laser Communications experiment. This experiment was originally included as one of the proposals for the TTC system, and the ESP elected to keep it on the satellite as an engineering experiment. The baseline for the experiment is for a laser uplink, where it will be integrated with the science experiment as depicted in Figure 2. The STI team has already prototyped both ends of a communications link using a Manchester encoding technique, and has tested it successfully with a direct serial link as the transmission medium. Currently the team is ready to begin testing with optics and lasers.[10]

3.5 Tracking Telemetry and Command

The TTC team is tasked with providing the communications link between the spacecraft and the ground. They must provide both the spacecraft and ground station radios, modems, and antennae. The TTC team is pursing the utilization of amateur radio bands for communications for several reasons, including: availability of inexpensive commercial hardware, existing equipment, local expertise, and the opportunity to providing a service to the amateur radio community.

Current plans are for communication on three radio bands. The primary high-speed data downlink will be on S-band (2.4 Ghz), and command uplink will be on 70 cm (428 Mhz). As a service to the amateur radio community, UASat will offer a PACSAT-style store-and-forward system with an uplink on 2 m (145 Mhz) and downlink on 70 cm. Base communications will be at 9600 baud , and the primary downlink will use quadrature-phase-shift-keying (QPSK) modulation in hopes of obtaining data rates in upwards of 2 Mbps. An illustration of the proposed antenna locations on the satellite is shown in Figure 6. The 70 cm and 2.4 Ghz antennae are fixed, and the 2 m antenna would be a deployable "carpenter tape" antenna released on orbit.

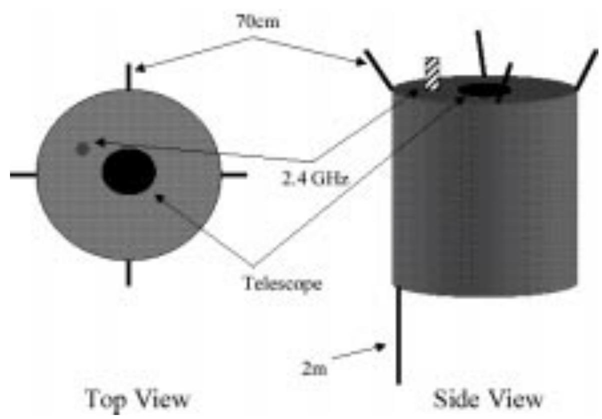

Figure 6: UASat Antenna Locations

The ground station for UASat had already been under construction for some time at the inception of the Student Satellite Project. The author is shown in Figure 7 assembling the ground station tower. Members of the University of Arizona Students for the Exploration and Development of Space (SEDS) and Amateur Radio Club (ARC) are collaborators on a project to provide SEDSAT-1[11] with a ground station and an Internet data center.[12] UASat plans to use a ground station approaching currently under development for SEDSAT-1, which utilizes the Internet and distributed amateur radio ground stations interacting with a relational database at the University of Arizona for increased downlink capability, and worldwide near-real-time coverage. Users worldwide can use a world-wide-web interface to retrieve data from the database, as well as place requests for data to be retrieved at the next uplink opportunity. All of the ground station software is currently being developed in Java with some C for the best portability and upgrade capability.

Figure 7: The author assembling UASat/SEDSAT-1 ground station

3.6 Guidance Navigation and Control

The GNC team is tasked with determining the absolute position and orientation of the spacecraft, and controlling the orientation to point the satellite at specified targets. This is perhaps one of the most ambitious and technically challenging design aspects of UASat. Due to the pointing requirements (Table 2) of the high-speed telemetry downlink, laser uplink experiment, and stellar photometry experiment, a passively stabilized platform will not suffice. Therefore, the GNC team is pursing the design of a three-axis stabilized platform utilizing reaction wheels for attitude control; coarse sun sensors, horizon sensors, global positioning system (GPS), micro-mechanical gyros, and a magnetometer for attitude determination; and magnetorquer coils for momentum dumping. This is summarized in Figure 8. Except for the GPS and magnetometer, all of the GNC components will be built in-house, as it is economically infeasible to purchase the components commercially.

Table 2: GNC specifications

Pointing Accuracy (Earth based)	1°
Pointing Accuracy (inertial)	0.1°
Slew rate	1°/sec.

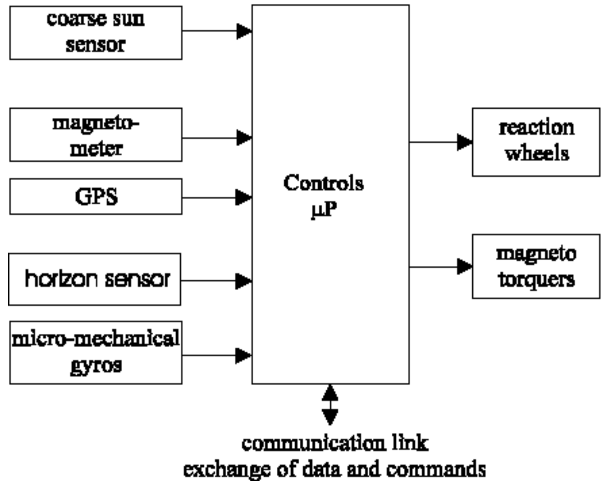

Figure 8: GNC block diagram

3.6.1 Reaction Wheels

A major design focus of the GNC team is that of the reaction wheels. Since satellites of this size typically do not utilize three-axis stabilization, there currently are no reaction wheels on the market that are small enough for UASat's needs. Design of such reaction wheels has been undertaken by small projects before, and we are utilizing as much of that experience as possible, as well as working with Honeywell's reaction wheel assembly group. The ground rules for design of the reaction wheels are that they be low cost, utilize standard components and common materials, be small in size in order to fit 4 of them in the satellite, have low power consumption to allow their operation, and be reliable enough to last the 1 year planned mission lifetime. On the advice of Honeywell, the GNC team is continuing the design of the assembly and the flywheel itself, while outsourcing the design and fabrication of the brush-less DC motor. Much more design details are available in the UASat Technical Notes.[13]

3.6.2 Sun Sensors

A concept for the UASat sun sensors is currently in the prototyping stages by the GNC team.[14] The design utilizes a Texas Instruments TSL230B programmable light intensity to frequency converter. The TSL230B digital output is easily interfaced to a microcontroller, and several of these placed strategically around the spacecraft can provide the two angles necessary to locate the Sun with respect to the spacecraft. Presently, the design for the sensor block is a 4x3 cm parallelpiped with two TSL230Bs mounted normal to each other. Up to six sensor blocks can be mounted in the six directions of the coordinate system for greatest redundancy. This concept is illustrated in Figure 9.

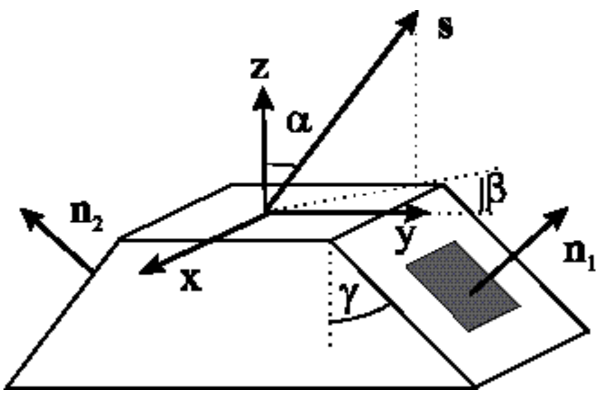

Figure 9: GNC Sun Sensor Concept

4. UASAT DESIGN TEAM OVERVIEW

Now that the design details have been presented, it is appropriate to review the organization of the student group that produced them. Since its inception, SSP has attracted a diverse group of students, including several different departments and colleges across campus, spanning from freshmen to PhD. Candidates. A distribution chart of students currently participating in the design of UASat is shown in Figure 10. The students are organized into the structure presented in Figure 1. Each design team is led by a student team leader who organizes the activities of the design team, along with the advice of a faculty advisor. These design teams each meet at least once week (many meet more often to work on projects), and the team leaders themselves meet on a weekly basis with the project manager to go over systems-level and administrative issues. The students who are participating in SSP are largely volunteers, pursuing the improvement of their technical skills and knowledge. Additionally there are an increasing amount of students who are taking advantage of independent study credit available from the project, as well as those who use it to satisfy their senior design projects. A few are fortunate to be supported by stipends, scholarships, internships, and fellowships, including the author, who is the recipient of a two-year NASA Space Grant Graduate Fellowship.

Major	Fresh	Soph	Junior	Senior	Grad	Totals
Aerospace Engineering	1.0	1.5	1.0	[illegible]	1.0	[illegible]
Astronomy	1.5	0.5	1.5	0.5	0.5	[illegible]
Biology				0.5		0.5
Chemistry				0.5		0.5
Computer Engineering		0.5	3.0	7.0		10.5
Computer Science		1.0	1.0	0.5		2.5
Creative Writing				0.5		0.5
Electrical Engineering	1.5	1.0	6.5	6.5	0.5	16.0
Engineering Mathematics			1.0			1.0
Engineering Physics		2.0		1.0		3.0
Management					1.0	1.0
Materials Science and Engineering		0.5	1.0			1.5
Mathematics				0.5		0.5
Mechanical Engineering		0.5	5.0	4.0	2.0	11.5
Microelectronic Engineering					0.5	0.5
Nondegree			1.0			1.0
Optical Engineering		1.0	1.5			2.5
Optical Sciences					2.0	2.0
Physics			1.5	1.5	1.0	4.0
Pre-Med				0.5		0.5
	4.0	6.0	26.0	25.0	8.0	69.0

Figure 10: Distribution of Student Participation in UASat (0.5 represents a double major)

4.1 Reviews

Since its formal organization, UASat has undergone two reviews. A Conceptual Design Review[6] (CoDR) was conducted on November 22, 1997 in the presence of the ESP, and a semester review[7] was conducted at the conclusion of the spring 1998 semester in the presence of members of the MAP. UASat is scheduled to undergo a formal System-Level Requirements Review in July 1998, and several more design, safety and progress reviews exist in the future. Figure 11 shows the tentative schedule for various milestones and goals in the design of UASat.

4.2 Communications and Documentation

A considerable effort is being made to make UASat information as accessible as possible. As a result, almost all information ever generated regarding SSP and UASat is available in electronic format over the world-wide-web. For standard communications outside of meetings, each team has its own “listserv” email list which students can add and remove themselves from.[15] These lists are automatically archived by the listserv software, and its contents and history are available for browsing and searching. This is especially useful in answering those questions regarding sources of information, and also for new students coming on to the project.

Each team also has its own web site which they can use to disseminate information within the team, post notes, archive information, or advertise to new students for recruitment.

Lastly, all public documents produced by UASat are made available online in the documents archive accessible off the project website.

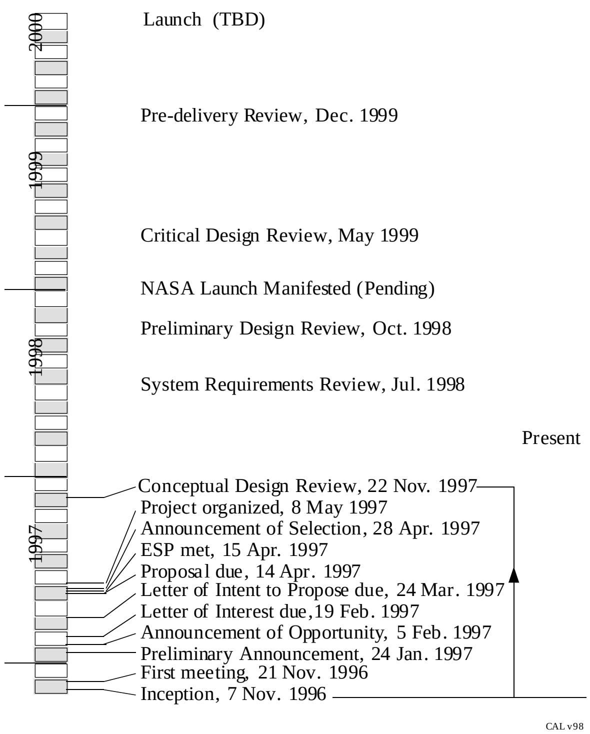

Figure 11: UASat Milestones and Goals

4.3 Documentation

UASat has recently adopted a technical documentation standard that is based upon a system in use by the CATSAT program at the University of New Hampshire. UASat's "Tech Notes" are a standard format in which all technical issues can be documented as work is in progress, for the benefit of other students who need the information for design purposes. The Tech Notes serve three primary purposes, and it will be left to the reader to decide which is the most important:

- To document detailed design work on systems pertaining to SSP
- To provide for transmission of design knowledge during student turnover
- To help focus teams' efforts when working on SSP

The Tech Notes are divided into 9 standard sections summarized in Table 3. A summary of current Tech Notes and their revision status is maintained by the project, and all Tech Notes are available online for easy access to the information. A complete description of the Tech Note system is itself available as a Tech Note.[16]

Table 3: Tech Note Sections

Section 1	Document Overview
Section 2	Requirements
Section 3	Design Discussion
Section 4	Various Lists
Section 5	Interface Requirements and Specifications
Section 6	Current Status
Section 7	Test Plan
Section 8	Concerns and Open Issues
Section 9	References

4.4 FUNDING

As with any project, funding is an all-important issue. SSP has progressed thus far on funds obtained primarily from within the University of Arizona. The participating departments and campus units have been generous in supporting the development of SSP, and technical advising from units both on and off-campus has been of considerable value. Student satellite projects fall within funding gaps in formal grant systems in that they are often too small to compete for formal space-research funds, yet too big to attract small donations. It is our intent to raise funds for this project in a manner similar to other projects of its kind: taking advantage of in-kind donations at every opportunity, and utilizing cash donations as wisely as possible. At this point we are waiting until our satellite is manifested for launch with the HES before aggressively pursuing the funding and support needed to bring this project to fruition.

5. CONCLUSION

One year into this Student Satellite Project, it can easily be said that it is a most educational, rewarding, and frustrating experience! The University of Arizona has been a center of activity in space science and engineering research since the beginning of the space program, and now the students have the opportunity to utilize these resources to realize a goal of their own. It is very satisfying to see students join the Student Satellite Project and watch their development as they learn the ropes, and have the opportunity to apply their classroom theory to real-life applications. This type hands-on education will certainly be a significant component in the education of all who have the opportunity to participate in it.

6. ACKNOWLEDGEMENTS

UASat would not be possible without the volunteering of time and effort from all of its student participants, past, present and future. In addition, the advisorship of the team mentors: Dr. Kathleen Virga, Dr. Hal Tharp, Dr. William Wing, Dr. Kurt Thome, Dr. Ernie Fasse, and Dr. Wayne Chen is most appreciated. We would also like to thank the members of the Evaluation and Selection Panel and the Mission Advisory group, whose members are too numerous to list. UASat thanks the following organizations for their monetary and in-kind support: Arizona Space Grant Consortium, University of Arizona Departments of Physics, Aerospace and Mechanical Engineering, Electrical and Computer Engineering, Astronomy, Optical Sciences, Planetary Sciences; College of Science, College of Engineering and Mines, Vice Presidents Office; and the following companies: Motorola, Honeywell, Burr-Brown, Research Corporation, and Raytheon. Lastly, the author would like to thank the Arizona Space Grant Consortium for their funding of his NASA Space Grant Graduate Fellowship, which allows him to pursue such interests as a project like UASat.

7. REFERENCES

[1] Hitchhiker Customer Accommodations and Requirements Specification, Goddard Space Flight Center, 1994

[2] NSTS 1988 News Reference Manual

[3] International Space Station Assembly Sequence (5/31/98: Revision D)

[4] International Space Station Fact Book

[5] A Student Satellite Project, K. C. Hsieh, C. A. Lewicki, COSPAR Colloquia series Microsatellites as Research Tools, Elsevier Science 1998.

[6] Student Satellite Project Conceptual Design Review Document, November 22, 1997.

[7] UASat Spring 1998 Semester Review Book

[8] The Role of Space Shuttle Videotapes in the Discovery of Sprites, Jets, and Elves; W. Boeck, et al.

[9] Fishman, G.J., Bhat, P.N., Mallozzi, R., Horack, J.M., Koshut, T., Kouveliotou, C., Pendleton, G.N., Meegan, C.A., Wilson, R.B., Paciesas, W.S., Goodman, S.J. and Christian, H.J., Discovery of intense gamma-ray flashes of atmospheric origin, Science, 264, 1313-1316, 1994.

[10] STI-002 Laser Uplink Experiment Overview, UASat Technical Note online at http://www.physics.arizona.edu/ssp/documents/technotes/

[11] Read more about SEDSAT-1 at http://www.seds.org/sedsat/

[12] Students for the Exploration and Development of Space Satellite 1 (SEDSAT-1): A Student Designed and Built Satellite and Ground Data System, C. Lewicki, A. Tubbiolo, H. Knoepfle, T. Bressi, G. McArthur, American Astronomical Society, Division of Planetary Sciences Conference Poster, 1996.

[13] GNC-005 Reaction Wheel Overview, UASat Technical Note

[14] GNC-006 Coarse Sun Sensor Overview, UASat Technical Note

[15] SSP Listservs online at: http://www.physics.arizona.edu/email/

[16] SYS-001 Technical Note Overview, UASat Technical Note