THE STUDENT SPACE PROGRAMS LABORATORY: FOSTERING STUDENT SPACE SYSTEMS EDUCATION AND RESEARCH WITHIN A UNIVERSITY ENVIRONMENT

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ABSTRACT

In August of 2006, the Student Space Programs Laboratory (SSPL) was established at The Pennsylvania State University. The Lab emerged to cope with the challenges of increasing space mission scope and complexity; to formalize the processes and procedures of space systems engineering; to collaborate and share resources among projects; to connect better with University research; and to identify new opportunities for Penn State students to gain space-flight hardware development experience. In less than one year from its inception and building on past successes, the Lab has prospered in many ways that should serve to pave the way for increased student opportunities in the future.

1. HISTORY OF STUDENT SPACE PROJECTS AT PENN STATE

Student-oriented space projects at Penn State began with the NASA Get Away Special (GAS) payloads designed to fly in the payload bay of NASA's Space Shuttle. Penn State students produced three GAS payloads, which launched aboard the Shuttle in 1986, 1996, and 2001. These payloads focused on various objectives from recording orbital debris impacts to seed germination in space.

Beginning in 1997, Penn State students saw the addition of sounding rockets with the initiation of the SPIRIT (Student Projects Involving Rocket Investigation Techniques) sounding rocket program [1]. SPIRIT was designed to provide the opportunity for students from a wide range of educational backgrounds to gain hands-on experience in the design and fabrication of a research sounding rocket.

The last decade has seen a diverse set of student opportunities in space research. Following the third and last of the GAS payloads in 2001 (NASA canceled the program in 2004), the SPIRIT program completed three sounding rocket launches in 2000, 2003, and 2006. The Flyin' Lions team was formed in 2000 to pursue microgravity research using NASA's C-9B aircraft (formerly KC-135a) dubbed the "vomit comet." This program called the Reduced Gravity Student Flight Opportunities Program (RGSFOP) is run from NASA's Johnson Space Flight Center. The team's objective is to perform research requiring microgravity, and has included developing a device to aid astronauts' exercise in space and has performed research on dusty plasma.

In 2003, Penn State was awarded a contract with the United States Air Force Research Lab's third University Nanosat Competition. The Nanosat mission, dubbed LionSat (Local Ionospheric Measurements Satellite), was Penn State students' first foray into the area of orbital spacecraft design. With it came the complex challenges of meeting strict fabrication and documentation requirements for launch vehicle and space environments, as well as providing for command and control of the spacecraft on orbit.

2. MOTIVATION FOR A CENTRAL LAB

As the number of space projects and opportunities grew, so too did the complexity and aggressiveness of the missions. Penn State projects seemed to echo the trends in industry that, with increased mission complexity, a systems engineering mindset becomes critically important for success.

For example, the SPIRIT I mission produced five scientific instruments, including one from the State University of New York (SUNY) in Geneseo. SPIRIT II produced five scientific instruments as well, including two from Clemson University. In contrast, the ESPRIT (SPIRIT III) mission produced seven scientific instruments (including one instrument each from three partner Norwegian universities) in addition to three instruments for attitude determination, four demonstrations of new approaches in structures and mechanisms, and four electronics instruments to support the demonstrations. In addition to science and engineering instruments, each of the three rocket projects was based upon student-built mechanical and electrical support systems.

LionSat added another level of complexity. It was originally designed to fly on the Space Shuttle, similar to the previous GAS payloads, where the restrictions and requirements for a deploying spacecraft from the Shuttle are arguably the most rigorous in the industry. The challenges faced by the ESPRIT and LionSat missions indicated a need for formal education in

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systems engineering and project management. When faced with designing and integrating entire systems, students were not prepared by the typical classroom experience for the complexities and intricacies involved.

After the conclusion of launch operations for the ESPRIT mission, the participating students and faculty took the opportunity to review the strengths and weaknesses of past projects. The establishment of a central organization evolved as a logical solution to improve Penn State's capabilities. Student-oriented labs at other schools, such as the University of Michigan's Student Space Systems Fabrication Lab and Utah State's Small Satellite Program, have shown dramatic successes [2,3].

Students have commonly advocated for more formal recognition for their work, improved collaboration between projects, better resources, and opportunities for practice of systems engineering and project management. Faculty were interested in finding ways to provide real projects for science, engineering, and systems engineering that were an integral part of the educational process and a method to integrate their teaching, research, and service missions. Industry has been interested in programs that go beyond book learning and, in particular, those that are able to provide training grounds for systems engineering principles.

3. SSPL ORGANIZATION

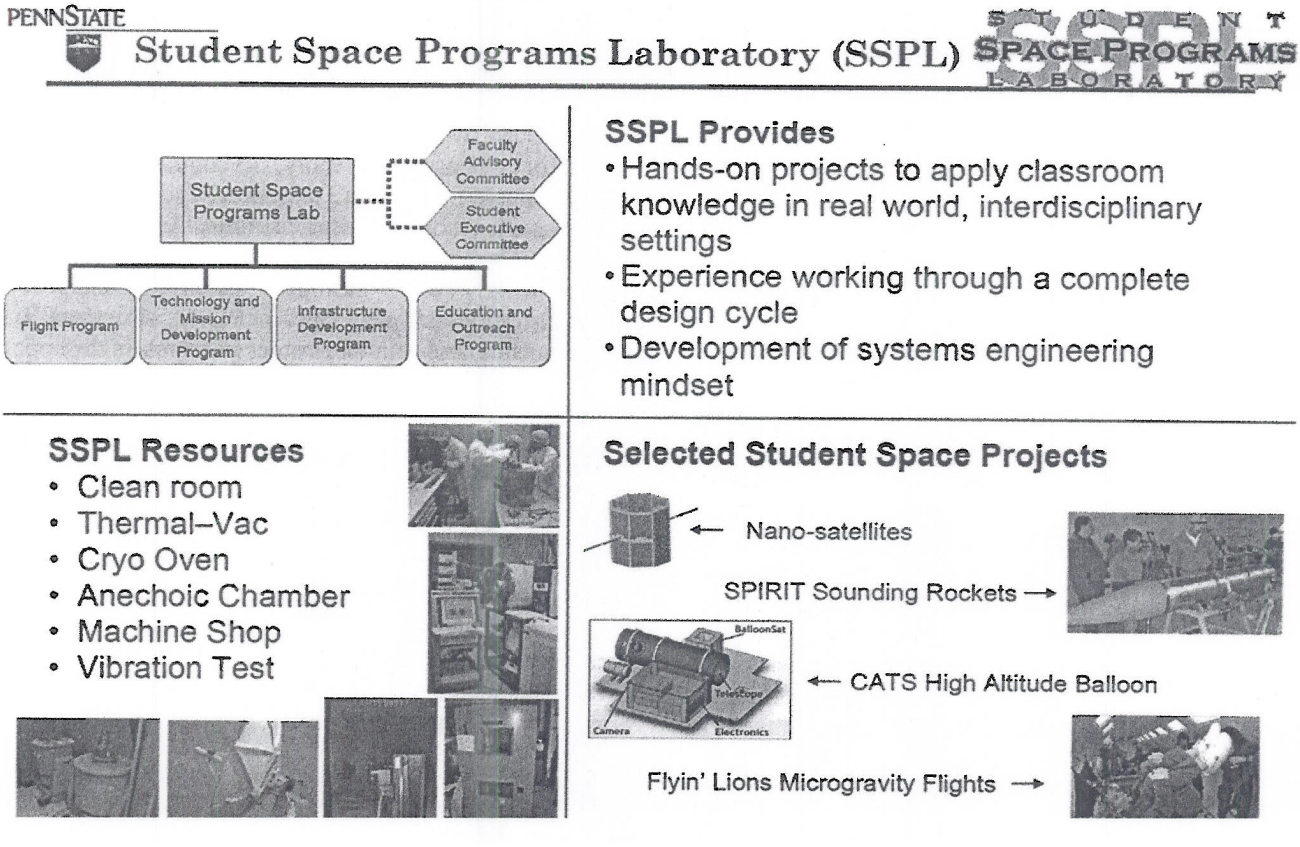
The primary focus of the Student Space Programs Lab is the integration of real-world space-systems project work with the traditional curriculum to better educate Penn State students and prepare them for careers in space science and engineering.

The overall structure of the SSPL is comprised of four interlinked programs: the Flight Program, Technology and Mission Development Program, Infrastructure Development Program, and the Education and Outreach Program (see Fig. 1). Each program was established with a specific purpose to facilitate student space research and projects at Penn State.

The lab is jointly managed two groups. The first is a Faculty Advisory Board comprised of faculty advisors from various disciplines and organized by the Director of the Lab. The second group is the Student Executive Committee comprised of the student project leaders and organized by the Student Programs Manager.

3.1. Flight Program

The Flight Program is the most visible and largest program. It includes all complete life-cycles of projects using platforms such as high altitude balloons, aircraft-based microgravity, sounding rockets, and satellites. Specifically, the program focuses on giving students the experience of working through a complete project life-cycle from concept through post-flight data analysis, as well as documenting and passing on the effort when graduation or other priorities intervene. The program's goal is to have multiple projects spanning various levels of complexity and in different phases of design.
Based on components found in various flight projects



and the research environment, the remaining three programs that develop the capabilities of the SSPL are focused on advancing capabilities in technology, infrastructure, and education to specifically address the recurring needs identified by students, faculty, and industry.

3.2. Technology and Mission Development Program

The Technology and Mission Development Program focuses on improving the capabilities of the Lab and ensuring new opportunities for its students. As the name implies, this program focuses on developing technology and planning future missions.

1. Technology Development

The technology development side of the program allows for the development of technology outside of a specific flight project. This typically occurs for one of two reasons: a technology addresses a specific student interest that may benefit future SSPL efforts, or the technology is identified as mission-enabling or mission-enhancing for future efforts.

First, as a student lab, it is important to allow students to explore their own interests. Often these interests can be recast in a way that also adds to the capability of SSPL. Similarly, this program allows for the integration of outside student groups, such as senior capstone projects or students pursing independent studies and theses.

Second, previous projects have occasionally struggled with pressures from students trying to prepare mission-critical components on the project timeline. With a dynamic student workforce, student-built mission-critical items present a high risk to the mission. When recurring critical components are identified, such as those in power, communications, or other standard subsystems, this program can support students developing these components in *anticipation* of future needs. Other components may be intended specifically for a future prospective project, but complex enough that SSPL must mature the technology before the mission begins or is proposed as a feasible project.

2. Mission Development

The mission development side of the program focuses on identifying and pursuing new projects and funding through proposals or other similar means. Also viewed as critical to the students' training, SSPL ensures that students are involved in the proposal process. Once an opportunity is identified, a small group of students (typically advanced students who have a firm grasp of systems engineering principles) will form a team to review the announcement of opportunity criteria, map the criteria to the Lab's interests and capabilities, and then perform the first-order feasibility study and mission design. Experienced faculty members provide oversight and guidance to the process. The students involved in this process gain valuable experience for later endeavors in academia or industry. Once the mission is accepted, students have the opportunity to see their proposal mature into a tangible flight project.

3.3. Infrastructure Development Program

In addition to component-level research and development, the Lab oversees the development of new facilities to enhance the development, testing, and integration of SSPL projects. One of the program's key objectives is to create a vertically integrated laboratory where the dependence on outside facilities or services is minimized. In the past year, the Lab has focused on improving such facilities as thermal–vacuum systems for component testing and calibration; adding capabilities for vibration testing; and preparing a satellite command and control station.

Beyond the development of facilities, the infrastructure development program is committed to developing the processes and procedures required for the verification and validation of spacecraft components. It is the program's goal not only to serve as an asset for SSPL projects, but also as a resource to other universities and outside organizations. For example, in the past year, the Lab has been helping a local company to do a portion of the qualification for an antenna to be flown on an upcoming orbital mission.

3.4. Education and Public Outreach

The faculty of the Penn State Electrical Engineering Department have a long history of ionospheric and atmospheric research, and in lecturing on courses in these areas. The educational program includes several courses at the graduate and undergraduate levels that are focused on space science education [4, 5].

SSPL is also focused on the education of the next generation of scientists and engineers. Every past student project has incorporated educational outreach as one of its priorities. Each project typically sponsors events such as classroom visits and demonstrations, open houses, or other functions to spread the excitement of science and engineering to students in grades K–12. The Education and Public Outreach (EPO) program is dedicated to continuing the rich relationship Penn State students have with other area schools and throughout the Commonwealth of Pennsylvania. Section 4.6 below describes some of the specific efforts SSPL has made in this area.

4. STRATEGIC PLAN

The four programs described above form the foundation of the Lab. For the Lab to mature and prosper, an adaptable strategic plan must identify priorities,

deficiencies, and methods to address them. To this end, the students and faculty identified several key priorities deemed necessary to achieve the desired resources and capabilities. With the SSPL in its infancy, the key priorities for the past year centered on

1. providing an on-ramp for new students in order to develop an experienced workforce,
2. diversifying flight projects,
3. integrating the lab with the Penn State curriculum,
4. interfacing with existing university research interests,
5. improving our domestic and international partnerships, and
6. developing a rich set of educational outreach activities and relationships.

These challenges are applicable to many student groups even outside of the space systems realm. The following sections describe the SSPL philosophy for meeting these challenges and the successes encountered.

4.1. Student On-Ramps: The CanSat Competition

One of the challenges observed throughout past projects has been the problems of recruiting new students in the later phases of the project lifecycle. Once the project reaches the advanced stages of design and fabrication, new students are often overwhelmed or intimidated by the difficult learning curve they need to overcome in order to contribute meaningfully to the team effort. This is not a result of any deficiencies on the students' part; rather, since they were not present during the early project development, they were not exposed to the project-specific details or the general tools and skills required. To compound the problem, these later-stage "crunch times" are exactly when new personnel are needed most and the fully engaged students rarely have the time required for intensive training efforts.

SSPL initiated the CanSat project as a training program for younger or inexperienced students. The CanSat Competition is an annual event open to North American high schools and universities and sponsored by several organizations including AIAA and NASA [6]. The project provides any interested student with an introduction to space systems and training for future projects within SSPL. Each year, first-year students led by experienced upper-class students will develop a miniaturized payload and will participate in its launch on a model rocket during the summer. CanSat provides new students a chance to learn the tools required for more complex projects and to network with faculty and upper-class students.

The overwhelming success of the CanSat program prompted the Lab to recast the project into one of the topics for a formal First-Year Seminar. At Penn State, each incoming student is required to take a one-credit first-year seminar in order to facilitate their transition into college and to engage them in the learning process. During the CanSat course, the students will perform the concept design and definition for the following year's CanSat entry. The students will be exposed to experienced students from other SSPL projects as well as to faculty members from several engineering disciplines and with extensive backgrounds in space science and engineering. Students will also be instructed in college survival skills such as time management and how to access university resources.

For students who want to get a more hands-on experience, the SSPL will sponsor optional training sessions to begin developing hardware prototypes for the rocket and satellite payloads. It is our hope that students will be motivated to form the core of the SSPL's future endeavors.

4.2. Diverse Project Portfolio

SSPL is focused on maintaining a diverse portfolio of active projects for several reasons. The first is to provide the Lab with funding support to continue the development of its facilities and capabilities for the benefit of the participating students. Secondly, a diverse project portfolio also brings with it better opportunities for student learning. Ultimately, the goal is to have concurrent projects in every phase from concept development through operational testing on various space flight programs.

In addition to the aforementioned CanSat project, during the past year, SSPL *students* proposed and were awarded missions with NASA's RGSFO and the US Air Force University Nanosat-5 Program (UNP). The RGSFO mission marked the first Penn State Flyin' Lions flight since the original teams flew in 2001 and 2002. The team completed the microgravity flight this past March and is currently finalizing the data analysis.

The UNP project, now referred to as SSPL's NittanySat project, is a two-year contract with the Air Force to deliver a functional satellite. NittanySat will have a similar to scope to LionSat [7] (which was part of the Nanosat-3 Program) but with a different mission. NittanySat will study the phenomenology of *D*-region radio wave absorption. The mission proposal was prepared by ten students in cooperation with faculty and, since its acceptance, has involved nearly 80 students.

4.3. Integration with the Curriculum: The Space Systems Engineering Certificate

In 2007, a Certificate in Space Systems Engineering was made available for students, primarily in the CoE, who wish to obtain recognition for completing a core set of

courses in Space Systems Engineering–related topics in addition to participating significantly in a space systems project [8]. As such, this certificate is intended to acknowledge those students who have gained a proficiency in space systems engineering through coursework and project work. The project work is to be documented through the submission of a report on their effort. This program, under the direction of and jointly administered by the Electrical Engineering Department, the Communications and Space Sciences Laboratory (CSSL), and the Aerospace Engineering Department, is designed to prepare students for careers in the space industry. It will also be of interest to students with a more general interest in systems engineering and interested in bolstering their credentials. It is intended that the Certificate will provide to potential employers a credential indicating that the student has achieved a level of competence in space systems.

Space-systems projects provide excellent design experiences that match well with the formal educational, rather than just the classroom, aspects of the design activity. Developing instruments and subsystems to meet the scientific objectives, given the constraints of economics, time, and other factors, provides real-world challenges for students. In order to address project requirements, students form into teams composed of a mix of academic backgrounds to focus on the range of problems presented by the design and construction of an instrumented rocket payload, satellite, or other space system. Additional benefits are derived from the experiences of integration, testing, sensor calibration, and participation in the flight operations associated with these projects.

The Certificate adds a degree of academic formalism to the student's project based work and recognizes a certain level of achievement. A student who completes this Space Systems Engineering Certificate will:

- be better prepared (in terms of breadth and depth of knowledge) to enter the space industry,
- have completed a hands-on project experience representing the application of principles learned,
- have a deeper understanding of the following:
  - systems approach to engineering;
  - several technical subjects related to space systems and physics;
  - processes and procedures for development of space hardware;
- be able to work in multifunctional teams.

4.4. Interfacing with External Research Interests

As the Lab matures, interfacing with researchers and organizations previously unaffiliated with SSPL will create additional opportunities for collaboration. This collaboration typically is in the form of relationships within Penn State, partnerships with other universities, and cooperation with industry sponsors. SSPL has made several significant efforts to maintain and improve these collaborative relationships.

The Center for Space Research Programs (CSRP) has been established in order to capitalize on the resident expertise and infrastructure developed from past projects and to attract new space research projects to Penn State [9]. Although housed in the CoE, the SSPL is viewed as a university-wide resource and accessible to students throughout the University. In a sense, it is the "student branch" of CSRP. Through its existing relationships, CSRP provides SSPL with connections to new research interests throughout the university and with external organizations. It also provides a valuable knowledge base in project management and engineering expertise that will benefit SSPL projects and their students.

4.5. International and Domestic Partnerships

External partnerships were an integral part of the previous SPIRIT missions. The SPIRIT program partnered with the State University of New York (SUNY) in Geneseo for SPIRIT I, Clemson University for SPIRIT II, and the Norwegian Universities of Bergen and Oslo and the Technical University of Narvik for ESPRIT. Because of the international collaboration, the ESPRIT partnerships were a particularly diverse and rewarding experience for all involved students.

Penn State is currently developing a memorandum of understanding between Penn State and Norwegian universities to continue the history of collaborative projects [10]. NittanySat builds on the collaborative heritage of the SPIRIT program by involving groups from the University of Graz in Austria and universities in Norway [11]. New partners, such as the Geophysics Institute at the University of Alaska will also support the mission.

Finally, student space projects often provide industry partners with a relatively low-cost—albeit high-risk—ride to space. By donating or discounting hardware for student rocket and satellite projects, industries can develop heritage for their technology. In exchange, the projects gain valuable resources that may normally exceed the resources of the university environment. For example, the ESPRIT mission successfully flight-qualified a company's embedded computer system for all NASA sounding rockets [12] in exchange for donations of significantly discounted hardware and engineering support. Both the SPIRIT Program and LionSat have developed relationships with several companies that have contributed to the projects' successes.

4.6. Education and Public Outreach

As education is a key priority for SSPL, the Lab has supported the re-establishment of the Penn State chapter of Students for the Exploration and Development of Space (SEDS). SEDS is an international student-led organization committed to furthering education and awareness of space. As part of SSPL, SEDS will form the cornerstone of a formal education and outreach program. As part of this mutual relationship, the two organizations will be able to share resources and knowledge in order to accomplish the common goal of providing educational opportunities for learners of all ages.

Other important educational resources is the Pennsylvania Space Grant Consortium, which is valuable partner in providing support for space research, and the Penn State College of Education.

5. RESULTS

The establishment of the Student Space Programs Laboratory at Penn State has resulted in a paradigm shift in how student projects are approached. The Lab is able to provide better opportunities for its students through more numerous and complex projects and can continually adapt to future challenges. It includes several laboratory rooms, including a clean room for instrument assembly and the other resources for space hardware development.

In less than one year, the Lab has made significant progress on the objectives it set out to address. Three new flight projects were added to provide new student opportunities. As a result, the number of active students has swelled to more than 100 in a given year. Students now receive formal recognition through the Space Systems Engineering Certificate and through the CanSat first-year seminar, which also provides an on-ramp into the program for younger students. Important new partnerships were established such as with CSRP and SEDS that will bring more capability to the Lab. Furthermore, existing international partnerships with Norway and Austria were renewed with the NittanySat project.

Through these efforts, the Lab already has become integrated into the Penn State curriculum, which will bring with it benefits for the students involved. Five senior design project teams completed projects for the lab in the spring 2007 semester, including students from the Electrical, Mechanical, or Aerospace Engineering Departments.

6. CONCLUSIONS

SSPL is a new organization, yet it has already demonstrated that it can significantly benefit the students of Penn State and the aerospace community at large. The past year has resulted in significant advances in student space research environment at Penn State. Continuing efforts will see greater improvements in the capabilities of the organization and consequently better opportunities for its students.

Most importantly, SSPL has demonstrated that it can provide students with the education and training necessary to make them valuable assets in today's space industry.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Mitchell, J.D., *et al.*, "SPIRIT: Student Projects Involving Rocket Investigation Techniques," *ESA SP-437*, 1999.
2. Liu, T. "The student space systems fabrication laboratory: an approach to space systems engineering education." *2006 ASEE Annual Conference & Exposition*, 2006.
3. Utah State University Small Satellite Program, http://userver.engr.usu.edu/smallsatprog.htm.
4. Bilén, S.G., C.R. Philbrick, T.F. Wheeler, J.D. Mathews, R.G. Melton, and D.B. Spencer, "An overview of space science and engineering education at Penn State," *IEEE Aerospace and Electronic Systems Magazine*, 21, no. 7, pp. S-23–S-27, 2006.
5. C.R. Philbrick, "Education in Space Sciences," *Proc. 17th ESA Sym*, ESA SP-590, pp. 25–32, 2005.
6. National CanSat Competition, http://www.cansatcompetition.com/
7. Bilén, Sven G., Charles L. Croskey, Robert Melton, David Spencer, Deborah Levin, and Michael M. Micci, "Students designing and building satellites: Penn State's LionSat and the University Nanosat Program," *2005 ASEE Annual Conference*, 2005.
8. Space Systems Engineering Certificate Program, http://www.engr.psu.edu/Departments/spacesys.asp
9. Center Space Research Programs, http://csrp.psu.edu
10. Wheeler, T., *et al.*, "A Broader Vision: Space Projects and International Collaboration," *Ibid.* 2007.
11. Bilén, S.G., *et al.*, "NittanySat—A Student Satellite Mission for *D*-Region Study and Calibration of Riometers," *Ibid.* 2007.
12. Real Time Devices, Inc., "RTD Investment in Future Pays Off," Spring 2007 PC/PCI-104 Product Guide. http://www.rtd.com.