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University Nanosatellite Program - 20 Years of Education

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ABSTRACT

In 1999, the Air Force Research Laboratory's Space Vehicles Directorate (AFRL/RV) and Air Force Office of Scientific Research (AFOSR) began a unique program with the goal of educating future small satellite systems engineers – the University Nanosatellite Program (UNP). In the ensuing 20 years, 38 universities, and over 5,000 students, have participated in UNP, developing nearly 100 unique mission concepts and resulting in 11 flights to-date. Through UNP, full-time systems engineers are dedicated to guiding student teams through the development process, utilizing a small satellite specific user's guide, systems engineering classes and presentations, formal reviews, access to government and industry subject matter expertise, environmental testing, and launch. Each UNP cycle lasts 2-3 years and funds 10 proposals for development and possible flight selection. The UNP curriculum is updated each cycle in pursuit of continuous process improvement, striving to develop experienced and effective engineers for our nation's small satellite enterprise. This paper will discuss the history of UNP, its unique approach to educating small satellite systems engineers, and the impact the program has had on the small satellite enterprise over the last two decades.

UNP HISTORY

In 1999, the University Nanosatellite Program (UNP) was founded by various organizations, with the purpose to fly university-built satellites on the Space Shuttle. The first UNP cycle, NS-1, was co-sponsored by the Air Force Research Laboratory Space Vehicles Directorate (AFRL/RV), and the Air Force Office of Scientific Research (AFOSR), with help from the Jet Propulsion Laboratory (JPL), American Institute of Astronautics and Aeronautics (AIAA), Defense Advanced Research Projects Agency (DARPA) and NASA, with launch provided by the Space Test Program (STP). The program began with bold ambitions but meager success, with 14 universities provided funding to develop and fly small satellites.

Since this humble start, UNP has matured into a structured program with the goal of producing experienced small satellite systems engineers. Currently, UNP is on track to launch one to two satellites every two years, and has helped teach thousands of aspiring engineers the fundamentals of systems engineering and small satellite development. UNP alumni have spread throughout our country's small satellite enterprise – academia, industry, and government – helping lead the way as they graduate with a wealth of experience already in hand.[1]

The Small Satellite Revolution of the last two decades has prompted many organizations to develop educational programs for small satellites. For example, NASA has created multiple programs and publications, such as Educational Launch of Nanosatellites (ELaNa), the University Student Instrumentation Project (USIP), and the CubeSat 101 Guide. ELaNa has been instrumental in providing launches for educational programs, including UNP teams, while USIP provides funding to university teams building small satellites. Other educational initiatives, such as the Academy of Aerospace Quality (a database of online courses) are new but appear highly promising.

Figure 1: Inspection of the Prox-1 Satellite Structure

Process Improvement

UNP began during the very early days of the Small Satellite Revolution, learning in parallel with the students and folding those lessons into future cycles. Initially, funding was provided to 14 university teams with the intent to rapidly and cheaply create satellites from which the DoD could benefit. As these satellites were developed, they were split into multiple launches which created the distinction between the NS (Nanosatellite)-1 and NS-2 cycles. However, most of the

satellites were never completed, with only a single satellite being launched for NS-2. The program structure began to take shape with only one winner being selected for launch in cycles NS-3 and NS-4. After this, a more robust, phased development schedule was implemented, leading to the flight selection review. The final major change came during NS-8, removing the competition and allowing teams showing adequate development in the first phase to advance. Although no major changes have occurred since, the UNP team continues to learn new lessons, and feeds those lessons forward to future cycles.

UNP DEVELOPMENT PROCESS

Currently, the UNP office releases a request for proposals every three years, with the next release scheduled to occur late summer 2021. Up to ten proposals are selected, and funding is provided for two years of development (Table 1). During these two years, known as Phase A, teams are expected to meet an aggressive schedule of reviews from system concept through critical design review, culminating in the flight selection review. During this final review, teams are expected to demonstrate functional satellite electronics and software in a flat-satellite configuration.

Based on development progress, between two and four teams are selected to move into Phase B. Phase B includes a second round of funding, as well as the pre-integration and pre-ship reviews. Universities are expected to take no more than two years to finish development, testing, and integration in this phase.

To leave Phase B and be provided a launch, UNP sets a final bar that satellites must pass. This consists of five tests which must be completed successfully: 1) long range communications, 2) electrical power system functionality and complete charge cycle, 3) command execution, 4) simulated day-in-the-life, and 5) basic attitude determination and control system functionality. Many satellites don't make it to launch because of these minimum standards of functionality, however, the goal of UNP is education. The small satellite enterprise is very accepting of failure, which enables educational small satellites to exist. To adequately prepare young engineers for a career in industry, meeting a minimum bar of functionality is necessary, since many projects outside of academia are not research-based.

Upon completion of the five tests, the finished satellite is shipped to AFRL/RV at Kirtland Air Force Base for environmental testing, including thermal-vacuum and vibration (Phase C). Finally, after passing all tests, the satellite is provided a launch, typically by the Space Test Program, though sometimes through ELaNa. The satellite then transitions into Phase D, where the student team operates the satellite on-orbit.

Table 1: UNP Phases

Phase Name	Phase Details
A. Design and Development	• Select up to 10 programs • Fund universities through AFOSR • Emphasize design process from system concept to critical design review maturity • conduct 6 design reviews • Facilitate satellite development workshops and telecons • Select missions for phase B
B. Assembly, Integration and Test	• Support satellite assembly, integration, and testing • Meet regularly with university teams • Facilitate hands-on satellite fabrication workshops • Conduct three testing and integration reviews • Support final testing of integrated satellite and completion of UNP test metrics
C. Environmental Test	• Provide environmental testing capabilities including bake out, thermal cycling, vacuum, and vibration testing • Enable student participation during test campaign via the AFRL Space Scholars Program • Finalize launch preparation with STP and Launch Vehicle
D. Mission Operations	• University teams operate spacecraft • AFRL serves and advises in operations and data transfer

UNP Engineering Guidance

The UNP process is unique from other small satellite educational programs. In addition to providing funding and a small satellite specific user's guide, UNP provides courses, presentations, and environmental testing facilities, and employs multiple full-time systems engineers (typically alumni of the program). These engineers are available to answer questions and provide guidance, and also hold formal reviews throughout the satellite development process, ensuring the teams stay on track and gain real-world experience. The job of the engineers is not to hold the hands of the team, but to support the students in the process. They provide guidance when appropriate, but ultimately the student teams are responsible for all critical decisions. This is further emphasized in reviews, where praise is given for good work, but there is no shyness from constructive criticism.

In addition to the full-time engineers, UNP has a large network of alumni and supporters across the government, industry, and academia who assist in

advising, reviewing, and providing feedback to the schools. This ensures a variety of viewpoints are presented, allowing the schools to make informed decisions.

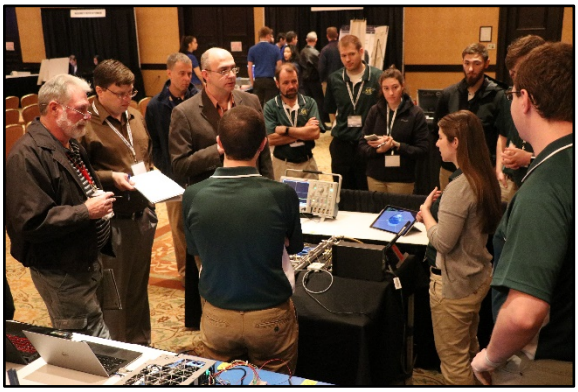

Figure 2: Students Present their Mission to a Judging Panel during the NS-9 Flight Selection Review

UNP also embraces constraint-based systems engineering. In any project, constraints such as schedule, cost, and technology development exist. While some systems must follow strict requirements-based engineering, the world of CubeSats is generally much more accepting of constraints. This applies even more so in the university environment, where knowledge loss from student turnover can kill a program as easily as running over budget. Generally, teams propose to build CubeSats with exquisite capabilities, and inexperienced students may not understand the technical difficulties associated with the mission scope. UNP would rather see a satellite make it to flight with reduced capabilities, than never see it fly, and experience has shown that university satellites taking more than four to five years to develop will likely never be completed due to student turnover.[2]

SURVEY OF UNP ALUMNI

The goal of UNP is to create capable small satellite systems engineers to support small satellite development across the government, industry, and academia. As UNP reaches 20 years of existence, many of the early UNP students now hold senior positions across the small satellite enterprise.

With such a broad reach, the impacts and benefits of UNP can be difficult to measure, so thousands of UNP alumni were asked to share the things they learned, the ways UNP has impacted their careers, or just fun memories they experienced along the way. Across the board, the respondents lauded UNP for the benefits to their careers.

UNP hopes to reach every alumnus of the program with the survey, so please reach out to the contact info on universitynanosat.org if you would like to respond. The survey sent to alumni included the following questions:

- What determined your decision to participate in UNP?
- What short-term and long-term benefits did you gain (personal, educational, professional) from your UNP experience?
- What would have made your UNP experience more valuable or successful?
- What is one situation you experienced while in UNP that you will never forget? For example, a memorable comment during a review, an event during a long night of testing, etc.
- What companies or organizations have you been employed by since you graduated?

Many alumni attributed their career development and success to the skills learned as a student in UNP. While there are many project-based experiences available at universities, very few have the scope of a UNP mission. The broad scope and open-ended problems presented are more equivalent to real-world problems, and include the opportunity to develop critical thinking and decision making skills required for success. Experience with the multi-year development cycle, formal reviews, and the engineering process rigor required is invaluable.

UNP alumni also shared the employers they have had, and the list is far too long to include – over 150 companies. Alumni are represented in every corner of the country's small and large satellite enterprises, and many companies, from startups to giants, maintain relationships with UNP to gain access to the pipeline of excellent systems engineers.

Figure 3: Students Participating in a Satellite Fabrication Course

Finally, the camaraderie created within UNP teams was mentioned in many survey responses. Most frequently mentioned was late night testing, struggling to achieve functionality with the occasional disheartening release of smoke. Some responses pushed into the ridiculous, such

as converting a hotel room into an assembly and testing space to frantically complete the satellite the night before an important review, or reenacting portions of the Lion King with satellites instead of Simba.

CONCLUSION

Since its inception, UNP has worked with 38 universities and over 5000 students, developing nearly 100 unique mission concepts and resulting in 11 flights to-date. Additionally, UNP has been recognized by Thomas Zurbuchen – Associate Administrator: NASA Science Mission Directorate, and has been listed in the Presidential STEM Portfolio.[3,4] This recognition along with the responses from our alumni continue to inspire us, and we hope this also inspires other small satellite education programs! Please reach out to us at the contact info on universitynanosat.org if you're interested in making a connection. We welcome experts with US citizenship interested in attending reviews and supporting students.

REFERENCES

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