ABSTRACT

The University Nanosatellite Program (UNP) was founded in 1999 as the first government-funded program to mentor university students in the design, integration, and operations of small satellites. UNP Employees have assisted in the development of over 80 satellites from a number of universities across the country. This paper presents the lessons learned from UNP's 19-year history of mentoring students in small satellite systems engineering.

INTRODUCTION

The University Nanosatellite Program (UNP) is a university-outreach program run out of the Air Force Research Laboratories (AFRL) at Kirtland Air Force Base in Albuquerque, NM. The program was founded in 1999 in order to facilitate small-satellite development at universities across the United States and was one of the first government-funded small-satellite programs.

The UNP office is run by a program coordinator and a team of systems engineers that continually monitor the progress of, at times, more than 15 teams in various phases of the program. Over the years, differences in the office team infrastructure and policy have yielded varying results in terms of the process the students take to achieve the completion of their satellites. Roles and responsibilities of employees of the UNP office have changed over the years as well as the methods employed to teach systems engineering. Despite these variances in administration, a number of common themes have been observed. This paper aims to consolidate these commonalities into a fixed set of lessons learned for the benefit of the university small-satellite community.

The UNP has three main objectives, which are outlined in Figure 1. The primary objective is to educate students in best systems engineering practices in preparation for use in the workforce. Secondarily, the program aims to bolster small satellite technology development for industry and Department of Defense use. Lastly, the UNP program fosters the development of university satellite labs by giving them satellite-development resources and access to systems engineering training.

Figure 1: UNP Objectives

In order to accomplish these objectives, a rigorous four-phase program has been developed and refined. The current organization of the program, shown in Figure 2, is the result of iterative revisions over the course of 19 years. The four phases take the students through the complete satellite mission lifecycle, beginning with mission conception and requirements development, continuing through system design and implementation, and finishing with testing, launch, and operations. The phases themselves feature specific reviews that are administered by the program office and attended by a variety of industry partners.
that participated in the program themselves as students or are interested in recruiting.

**LESSONS LEARNED**

This paper itself was written using inputs solicited from a wide variety of resources spanning the entire history of the UNP. Sources include university principal investigators, past student participants, industry supporters, and former UNP systems engineers. These individuals were asked to think of lessons learned from participating or administering the program. Responses were collected and sorted into three categories:

1) Mission Management, i.e., dealing directly with systems engineering principles;

2) Personnel Management, i.e., dealing with student and staff support given the constraints of the university setting;

3) Project Management, i.e., dealing with timelines and university politics.

Based on the information obtained from this group of respondents, a common theme emerged: problems caused by the risk associated with a shortage of monetary, personnel, and schedule limitations. Some of this risk can be self-inflicted as a result of common difficulties associated with a workforce made largely of university students. Almost all of the lessons learned discussed in this paper can be traced back to causes and implications of one of these risks.

**Mission Management**

The first category of lessons learned is mission management. The application of systems engineering to a “real-word” application (i.e., a satellite mission) for the first time is challenging in any scenario, but the resource constraints in the university environment can introduce particular difficulties. By nature, universities tend to lack stable monetary and personnel resources because university research activities are generally funded on a project-by-project basis and are limited to a largely student workforce. When attempting to navigate a full space-mission lifecycle, this workforce is often overtasked as it consists entirely of part-time student engineers. Additionally, the student workforce is by definition not made up of “career” employees and is thus highly susceptible to turnover, sometimes as often as every semester. Such constant turnover creates an urgency in schedule as the full satellite must be completed before too much engineering knowledge is lost.

Difficulties caused by resource limitations manifest themselves throughout the project lifecycle, beginning with design tasks. In this phase (Phase A in Figure 2), university teams tend to struggle with a common set of issues. Firstly, lack of resources limits the scope of what a university satellite mission can accomplish. In some cases, the students cannot assess mission feasibility accurately until too far into the design process because of inexperience projecting resource needs. Often, university teams fail to appropriately take into account the resource requirements associated with both payload and spacecraft bus development. In the past, successful universities have found ways to make some aspect of spacecraft bus development a mission objective or levy the development of a main payload on another entity in order to divide the work and reduce resource strain. Others are able to design missions that do not require the development of overly complex systems in the spacecraft payload or bus. With simpler mission concepts, mission design and verification become more achievable in a resource-strained environment. Proper feasibility studies are also a key part in determining how much effort will be required to accomplish proposed mission concepts.

Validation of the mission concept both in terms of feasibility and design of an appropriate concept of operations (CONOPs) is another Phase A task in which problems have been found to arise, this time somewhat self-inflicted due to lack of experience. If the mission concept is not developed adequately during the creation of the mission proposal, mission success criteria tend to be ill-defined at conception and may change throughout the development process. Without firm mission success criteria, it becomes difficult to develop appropriate requirements. Teams with ill-defined requirements then struggle to finalize a mission design and are unable to create verification and validation plans that reinforce success criteria. University teams that have spent time developing the mission concept during the proposal and pre-proposal stage before the beginning of Phase A are more likely to be able to move forward in their development process without having to backtrack due to poor requirements. These teams have kept design and verification paths in mind during the development of the mission concept and CONOPs and do not encounter as many problems at implementation.

Software development -- from a design standpoint -- also leads to difficulties. When teams largely made of
systems, mechanical, and electrical engineers attempt to write spacecraft software, they tend to skip design and immediately try to implement solutions. The common theme in teams that are able to make it through both design and verification of their spacecraft is an understanding of the systems-engineering processes involved in software development. Proper configuration management, requirements definition, and verification planning is necessary for both hardware-related and software-related work. These concepts must be recognized and applied far before implementation as part of the definition process. In some cases, teams that do not complete these tasks early must pause their timelines in order to equalize progress on software and hardware. In others, teams attempt to move on to verification and validation and find that they are unable to finalize their software due to a continuous stream of bugs. In general, teams that make it through Phase B have spent time planning software infrastructure and design before attempting implementation.

All three of these risks can be mitigated by planning vigorously during the first half of spacecraft development. This requires a greater investment of time into the first half of the systems engineering process in order to avoid unnecessary slow-downs in the second half.

**Personnel Management**

The next major category that was called out in survey responses was personnel-related lessons learned. The primary link between all successful UNP teams is the right combination and management of personnel.

A number of responses called out common roles that need to be filled in order to complete a small-satellite mission. From an interpersonal standpoint, one reviewer divided the tasks into four major roles. The first of these roles is a motivating force behind the team. This individual is aware of the overall vision and mission scope and works to spread that vision across the team and to stakeholders. This role often delves into the political side of the project and is thus usually held by the principal investigator of the mission. The second role is the source of the team’s momentum. These individuals complete the bulk of the design and implementation. In order to function well, they enable each other and the rest of the team as they complete tasks. The third role is a verification role. These individuals handle verification of the implemented design created by others. The last role requires emotional intelligence and manages the meshing of the team. These individuals work to ensure that the team remains cohesive through day-to-day operations. These roles can overlap and can be carried out by almost any team member. If any of these roles is not filled, the teams are at risk of encountering problems that may prevent completion of the satellite. The best UNP teams are teams that feature all four types of team member.

From an engineering standpoint, there are also a wide variety of technical roles that need to be filled. Interdisciplinary teams that incorporate electrical, mechanical, and computer science disciplines in addition to the more obvious systems and aerospace disciplines are able to assign tasks to the most equipped individuals. Teams that feature individuals with such diverse background skillsets can thereby reduce the amount of time spent learning specialized topics during satellite development.

These aspects of personnel management can be applied to a team in any setting, but there are certain problems that universities face on larger scales by virtue of having a predominantly student workforce. First, recruiting is a large part of personnel management. Many university teams cannot pay the student population for their efforts, so many new recruits (as well as established team members) must have other motivations for working on the mission while also completing university coursework. If the student base is largely unmotivated, the team will suffer overall. Additionally, turnover is guaranteed in a university setting, sometimes as often as every semester. Turnover can significantly lengthen the timeline of satellite development unless managed actively and consistently. Teams that enforce a “deputy” role that shadows the primary lead for at least a semester for all student leadership positions are more likely to be able to keep development continuous and can avoid the re-completion of work.

**Project Management**

The third and final survey response category is project management. This section deals largely with alleviating the shortage of resources and common risks from which university teams suffer. Successful project management can manifest itself both in the systems engineering process and in the navigation of university politics.

By far the most important factor in the success of a university small satellite mission is schedule. Timeline can become a high-risk item in university settings because of issues like high and frequent turnover rates, and student obligations like class and internships. Successful student managers are able to use timelines as motivation for the team while avoiding both overstressing the team by pushing too hard and allowing the timeline to slip by becoming too lax. For example, successful managers have used the launch manifestation process as motivation. UNP finds launches on behalf of university teams and works with the launch provider and the university team to complete the launch integration process at a certain point in the program’s timeline. Manifesting too early causes overstrain, while manifesting too late...
perpetuates eternal hardware and software development. By recognizing these risks and aiming for an appropriate manifestation date, student managers are able to renew motivation at the right time during the verification and validation phases of the project.

Another example of timeline management is the use of student-enforced internal reviews. Because Phase B is progress based, teams can potentially go long durations (e.g., multiple years) without a formal UNP review. Student managers that enforce internal reviews are able to create intermediate milestones for their team to work toward during those periods of time. In this way, a university team is able to push its schedule forward and combat the risk of losing too much engineering knowledge by taking too long to finish the spacecraft.

Regarding resource shortage, the development of a university satellite lab requires the procurement of specialized equipment and software, for example ESD safe tools, thermal modelling software, and oscilloscopes and other test equipment. Additionally, a clean space is required in which to assemble a flight unit of a spacecraft. Predictably, schools that already have this type of lab infrastructure in place are generally able to move through the mission lifecycle more quickly than those that do not. New schools can build up spacecraft development infrastructure by varying sources of income while in the UNP program.

A final important factor related to project management is the support given by the university that houses a given small-satellite lab. Such support is crucial not only to an individual mission but to the long-term health of the lab itself. Primarily, lab space and overall support for the endeavor are required for the completion of the satellite and maintenance of the lab. Such support that can be helpful includes base funding, funding for the payment of students and staff, and promotional support for recruiting purposes. University labs that receive more support are able to focus more on the completion of the satellite and less on the sustainment of the base-level resources they need in order to operate.

CONCLUSION

This paper discusses a set of lessons learned from 19 years of the University Nanosatellite Program, drawn from the responses of surveys given to individuals with a variety of relationships with the UNP. These lessons are meant to inform university students, staff, and faculty of some common concepts to watch out for in their pursuit of completing a university small satellite. Though, by its nature, this paper focuses on traditional problem areas, the goal is not to discourage any university from participating in the UNP or similar programs. No school is able to avoid every pitfall and heed every piece of advice presented in this paper. However, awareness of these concepts can help a school successfully develop a satellite mission. Finally, it is emphasized that, regardless of the mission outcome of each university’s small-satellite program, the primary objective of the UNP is education. We believe that any attempt made to build a university small satellite imparts an invaluable amount of knowledge and experience to the students and should be supported and continued.

NOTES

1 – Quoted from the response of George Hunyadi of DigitalGlobe.

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