Recent CubeSat Launch Experiences on U.S. Launch Vehicles

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ABSTRACT

CubeSats are currently required to follow the traditional secondary payload model. In this model, secondary payloads must identify a particular launch opportunity with a primary. The secondary payloads must commit to the launch and are subjected to any delays solely due to the primary. Additionally, this secondary payload paradigm is forcing suboptimal use of excess launch capacity since it complicates the process to add additional secondary payloads close to the launch date. This situation does not scale to support the growing demand for CubeSat launches that could potentially reach 100s of CubeSats per year within the next few years. A more flexible secondary launch model is required to support the CubeSat community and provide the fast access to space made possible by the CubeSat standard. This flexible model will allow developers to focus on the development of their spacecraft. Several key developments are necessary to reach a truly flexible secondary launch capability including technical, political, and regulatory issues. Some of the most critical are currently being addressed by work being performed by Cal Poly and their industrial and government partners.

INTRODUCTION

The CubeSat small satellite standard was jointly created by Stanford University and Cal Poly State University 11 years ago in 1999. The initial goal was to enable university students to gain hands-on education with satellites from conception to operations within 1-2 years (see Figure 1). A unique feature of the CubeSat Program is the use of a standard deployment system, the Poly Picosatellite Orbital Deployer or P-POD. The functions of the P-POD are to provide a standard interface between the CubeSats and the launch vehicle, protect the launch vehicle (LV) and primary payload, and to provide a safe and reliable deployment system for the CubeSats [1].

The first few years of CubeSat development were largely dominated by universities. A grass-roots CubeSat community grew quickly to dozens of CubeSat developers. In 2004 the first annual CubeSat Developer's Workshop was held at Cal Poly to help facilitate this newly formed university based community. However, due to the lack of interest from the US launch provider community, the first few launches were on Russian vehicles [2]. Far from ideal, use of Russian launch vehicles both required ITAR compliance and prevented US government developers from participating.

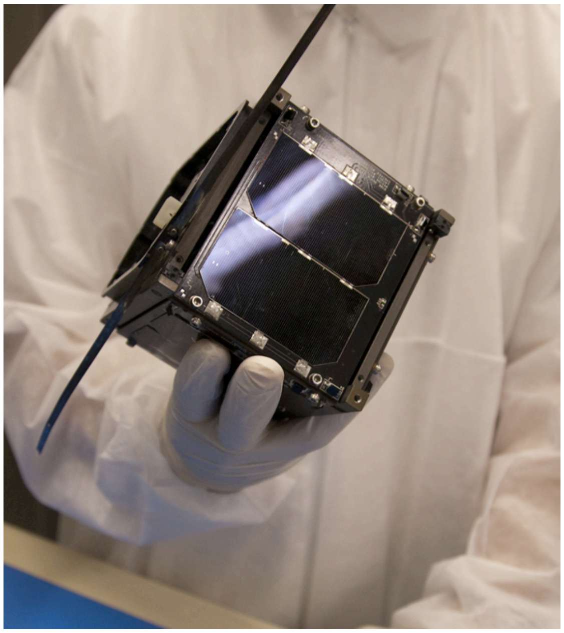

Figure 1: Cal Poly's CP 6, a typical CubeSat Class Spacecraft

In late 2006 the first CubeSat launched on a US launch vehicle - NASA's GeneSat (see Figure 2) - successfully made it to orbit aboard a Mintaur-1 [3]. In the years since that launch, interest by US government and industry groups has grown exponentially and the number of U.S. based launch opportunities has increased accordingly. Overall, more than 60 CubeSats have been launched. These launches have used 10 different launch vehicles in Russia, India and the U.S. However, this paper will focus primarily on the experiences working with U.S.

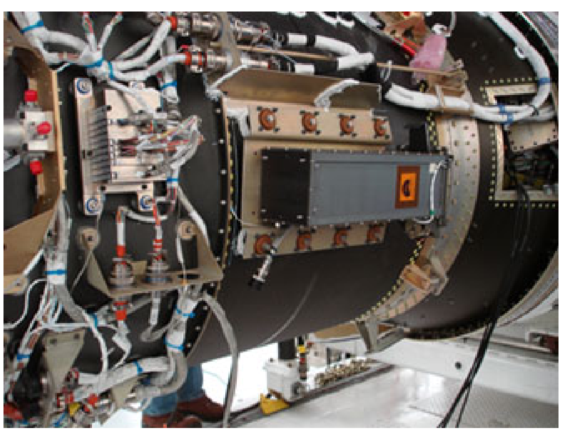

Figure 2: GeneSat integrated in a P-POD and ready for launch

launch vehicles.

Table 1: Cal Poly / SRI launch involvement

Year	Launch Vehicle	# of CubeSats
2003	Rockot (Russia)	6
2006	Dnepr (Russia)	14
2006	Minotaur I (U.S.)	1
2007	Dnepr (Russia)	7
2009	Falcon I (U.S.)	2
2009	Minotaur I (U.S.)	4
2010	Minotaur IV (U.S.)	3
2010	Falcon 9 (U.S.)	8
2011	Taurus XL (U.S.)	3

The Cal Poly / SRI team has been working to provide CubeSat launch opportunities for many years. Table 1 shows all CubeSat launches with Cal Poly / SRI involvement. The table shows some trends:

- After some involvement with Russian vehicles, the Cal Poly / SRI team has focused its efforts on U.S. launch vehicles.
- The number of launch opportunities per year is increasing. This trend is expected to continue in the next few years.
- Launch opportunities are becoming available in many launch vehicle types. Again, this trend will continue with additional vehicles developing CubeSat capability.

The experience gained from these launch campaigns provides insight into the evolution of CubeSat launch opportunities throughout the years as well as the differences between different types of launch opportunities.

RUSSIAN VS. U.S. LAUNCH OPORTUNITIES

The primary difference between the initial CubeSat launches in Russia and later U.S. opportunities is the presence of a primary payload. The Russian launch opportunities were cluster launches with a number of secondary payloads sharing a vehicle (see Fig. 3). This type of launch provided a number of benefits to the CubeSat developers:

Figure 3: Integrated Payloads being loaded into the Dnepr 2007 cluster launch

- Space on the vehicle was available to all payloads and allocated by the launch provider to payloads as they committed to fly.
- While different size payloads were involved in the launch, all developers expected a shared ride with a number of other spacecraft.
- Payload interfaces were custom developed by the launch provider to accommodate each payload.
- Cluster payloads utilize the traditional payload accommodation. As a result, environments were benign and testing requirements were well understood and available to all developers
- Launch cost was low and based on total system mass.

As a result, in cluster launches CubeSats were treated as just another payload and allocated space and interfaces as needed. In addition, these open low-cost launch opportunities were ideal during the early years of the CubeSat standard when universities dominated the development and no major government sponsors were available.

On the other hand, Russian launches had some major disadvantages:

- Access was not available to U.S. government customers.
- U.S. Satellites needed to follow ITAR rules and obtain appropriate export licenses.

Opportunities for cluster launches are traditionally not available on U.S. launch vehicles, therefore sponsorship or support from a primary payload organization is required to gain access to a vehicle. As a result, initial CubeSat access to U.S. launch vehicles was closely tied to the development of CubeSat class spacecraft by U.S. government organizations. Fortunately, NASA Ames was an early adopter of the CubeSat standard and as a result the first U.S. CubeSat launch, in 2006, involved a NASA Ames spacecraft (GeneSat) flying on a Minotaur I vehicle. The primary payload for this launch was TacSat2 from the Air Force's Space Test Program (STP). So far, all CubeSats launched in the U.S. have involved some sort of government sponsorship or support.

In addition to the need for primary payload sponsorship, a few other trends have emerged in the U.S. launch opportunities:

- U.S. CubeSat launch opportunities include non-standard payload accommodations for CubeSat class payloads. Some examples include the solid motor casing on the Upper stage of Minotaur vehicles (see Fig. 2) or the P-POD near the upper stage nozzle of the Taurus XL launch vehicle (see Fig. 4). As a result, testing requirements are extreme due to increased margin to account for uncertainty.

- High-value primary payloads demand increased quality control testing and verification from the secondary payload developers.
- Launch cost is based on the development of CubeSat specific accommodations and the quality assurance required to satisfy the primary payload. These costs may be high and include significant NRE investment.

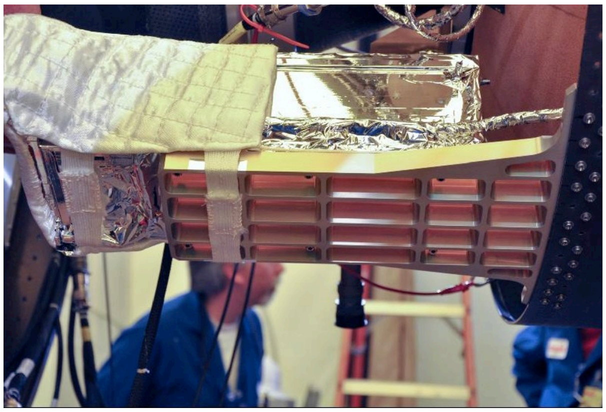

Figure 4: ELaNa 1 P-POD on Taurus XL Upper Stage Motor (credit: NASA/ R. Beaudoin)

Even with cost and sponsorship challenges, the CubeSat standard has succeeded in the U.S. and the number spacecraft being developed is increasing exponentially. Growth is occurring for all developer types: university, industry and government.

STATUS OF U.S. LAUNCH OPORTUNITIES

The increase in CubeSat development activity has been a catalyst for a similar increase in the development of CubeSat launch capability. Specific CubeSat launch opportunities are currently being manifested for ULA's Delta II and Atlas V launch vehicles and SpaceX Falcon 9 launch vehicles. As a result many of the initial objectives of the CubeSat program are becoming a reality:

- U.S. government organizations with interest in CubeSat development, including NASA and the DoD, are sponsoring the development of CubeSat accommodations on U.S. launch vehicles. In addition to the vehicles that have already demonstrated CubeSat capability, accommodations are being developed or studied for Delta II, Delta IV, Atlas V, Athena, and Taurus II.
- U.S. launch providers are planning CubeSat accommodations as part of their launches. These accommodations are included even before specific CubeSats have been selected for flight.
- Universities are gaining access to low-cost or government-funded launch opportunities through programs like NASA's ELaNa Program and the NSF space weather program.
- Launch capacity is being shared between U.S. government organizations. This increases the number of launch opportunities for individual CubeSats while minimizing the chances of wasted launch capability.

These results bring the CubeSat standard close to achieving the flexible secondary launch model where standardized spacecraft have access to any compatible launch vehicle (see Fig. 5).

LEASSONS LEARNED AND FUTURE DEVELOPMENT

While the increase in CubeSat launch opportunities is a very positive development, a number of challenges are emerging as the launch volume increases.

Standardization 'the next step": The CubeSat standard

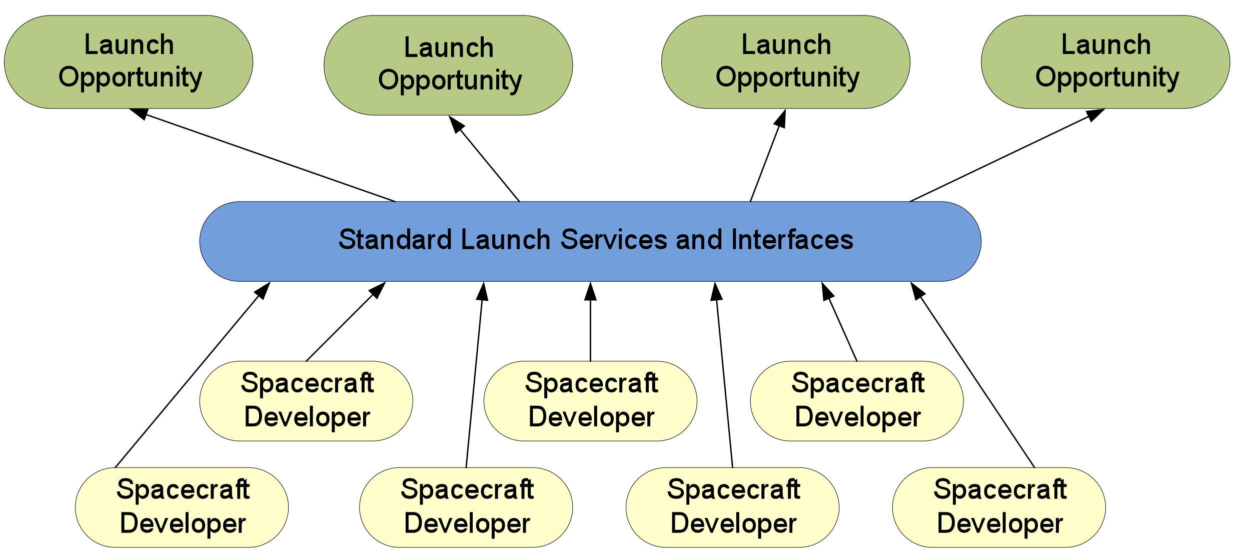

Figure 5: Flexible Secondary Payload Model – All Opportunities are filled with Spacecraft Developers that are ready to fly; Optimized over the current secondary launch paradigm

has succeeded in providing satellite developers with a simple specification that can be followed to achieve compatibility with a number of launch vehicles. However, the same level of standardization is not available when considering the requirements for the entire CubeSat launch package that includes the P-POD as well as the qualification plan:

- Current launch vehicle CubeSat interfaces are specific to a single launch vehicle with specific mounting patterns and electrical connector types. This makes CubeSat deployers incompatible between launch vehicles. When launch opportunities were infrequent, this was not a problem since usually only one launch was being considered at any given time. With the current increase in launch tempo, several launches are being processed in parallel, usually on different vehicles. The ability to transfer payloads and provide backups between vehicles is reduced when deployers cannot be transferred between vehicles.
- Qualification requirements are very different between launch vehicles and this makes it difficult for developers to qualify their systems for several vehicles. In addition, the testing profiles are very conservative given the lack of solid environmental data for many of the CubeSat mounting locations. Therefore an encompassing profile is difficult to justify since it would produce extreme testing requirements.

The next level of standardization must address these shortcomings. An attempt must be made to standardize mechanical and electrical interfaces. Even if a single interface is not feasible, reducing the number of different systems should be an objective of the CubeSat community. Similarly, the environmental testing requirements must be simplified and ideally a standard testing profile that qualifies systems for a large range of vehicles should be developed. This is not feasible given the current highly conservative test profiles. However, if more realistic profiles become available a unified test specification could be acceptable. More accurate profiles can be obtained through flight instrumentation.

Centralized CubeSat manifest: Even with standardized interfaces and secondary launch availability, manifesting a payload still presents significant challenges for both the launch providers and the payload developers. Launch providers must be familiar with the satellite developer community and understand the readiness levels of numerous developers. At the same time payload developers must monitor launch availability on a number of launch vehicles for compatible flight opportunities. In addition, once a secondary opportunity is manifested, a number of payload developers may be interested and a mechanism must be available to fairly select flight payloads as well as back-ups. Finally once payloads are selected, contracts must be negotiated between the developers and the launch providers. Contract development may have a significant impact on the schedule, especially if the parties are not familiar with each other and terms and conditions must be negotiated. These challenges grow exponentially as the number of satellite developers and launch opportunities increase. In addition, the increase launch tempo may result in shorter manifesting schedules further increasing contracting complexity. Finally, coordination must take place across government agencies and launch providers.

An independent centralized payload manifesting entity can more efficiently manage the connection between launch providers and spacecraft developers. This entity would be tasked with the establishment of contractual relationships with the launch providers, monitoring of the spacecraft developer community for compatible payloads, and selection of secondary payloads once launch opportunities are identified. Payloads would be required to show an appropriate readiness level before being considered for manifest.

CubeSat Standard Evolution: The availability of launch opportunities and a large developer community on CubeSat class spacecraft has played a significant role in the improvement of the technology available for small satellites. As a result future CubeSats have amazing performance potential and many new missions are being proposed for such systems. However, the current state of the CubeSat standard places some significant limitations on future CubeSat systems. The biggest limitation is the lack of propulsion systems. While the technology already exists and high-end propulsion subsystems for CubeSat are currently in development, propulsion systems are not allowed to fly in most CubeSat missions due to the perceived risk to the primary mission. This limitation must be addressed and procedures must be established to qualify CubeSat propulsion systems for launch. This will require a collaborative effort between CubeSat spacecraft developers, launch vehicle providers, primary payload teams, and range safety officials to define a new set of qualification and safety standards.

CONCLUSION

The CubeSat standard has become a highly successful example of secondary payload standardization. Launch opportunities for developers of CubeSat class spacecraft are materializing on a fairly regular basis and as a result a large developer community has materialized.

However, CubeSats are mostly using a traditional secondary model to get launch opportunities. The CubeSat standard is currently evolving toward a truly flexible secondary launch model. Technical and programmatic challenges lie ahead for the CubeSat community to implement the flexible secondary launch model, however many of these challenges are currently being worked. Funding must be allocated to increase the number of launch vehicles with compatible accommodations. In addition, some logistical and process improvements are required to make secondary launch manifesting compatible with the fast spacecraft development currently being implemented by the CubeSat developer community. Once flexible secondary launches are available they will revolutionize the secondary payload market and will have a significant positive impact on the space industry as a whole.

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