Enabling Flexible Secondary Launches with the CubeSat Standard

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ABSTRACT

CubeSats are currently forced 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 University about 10 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.

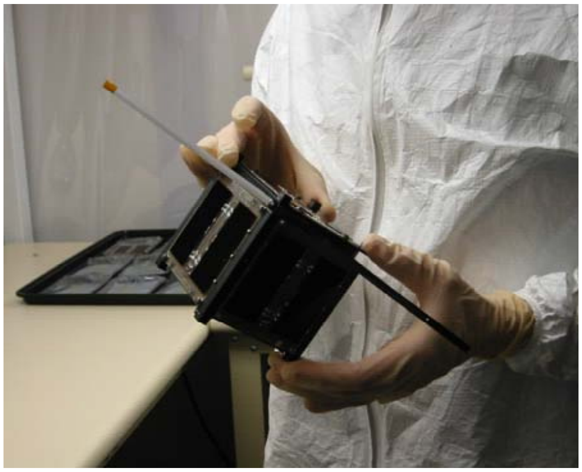

Figure 1: Cal Poly's CP 1, a typical CubeSat Class Spacecraft

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 2 years since that launch, interest by US government and industry groups has grown exponentially. Cal Poly University with government and industry partners is currently working towards providing CubeSat accommodations on every US launch vehicle in the near future.

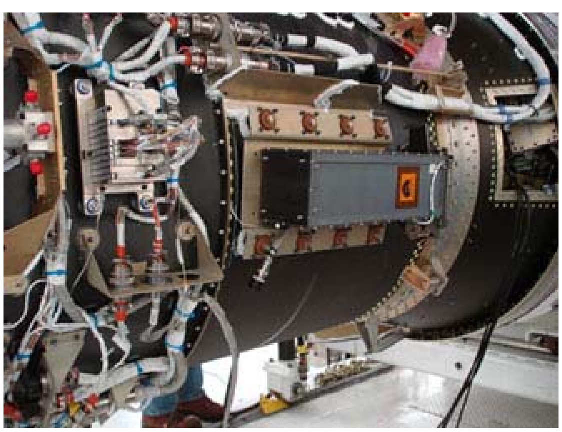

Figure 2: GeneSat integrated in a P-POD and ready for launch

Overall in the past 6 years more than 40 CubeSats have been launched with over 20 currently in orbit [4]. Many more are scheduled for launch in the next few years. However, CubeSats are currently forced to follow the traditional secondary payload paradigm. In this paradigm 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 associated with the primary. CubeSat developers typically have to secure a slot 1-3 years ahead of the actual launch and commit to that particular launch opportunity. This coupled with the rapidly growing interest by government and industry has limited University access. In effect launch slots are bought up before a university CubeSat project that could occupy that spot has even started. 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 paradigm is required to support the CubeSat community and provide the fast access to space that can be made possible by the CubeSat standard [5]. This secondary launch paradigm will allow CubeSat developers to focus on the development of their spacecraft. Once the developer is ready, has fully tested spacecraft functionality, and passed all environmental and safety tests, they will be delivered to a central facility for integration into the next available launch opportunity. If the current US launch excess capacity was properly utilized -- a CubeSat should be able to get a launch no more than 3-4 months after delivery. This kind of launch responsiveness would enable CubeSat experiments, educational projects, and operational missions to move at their desired pace and be decoupled from launch issues. Most importantly, issues with schedule overrun on the CubeSat development will not result in either a lost flight opportunity or being forced to fly when not fully prepared.

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. These include:

- Prequalification of CubeSat launch systems in all launch vehicles: This will reduce the time to launch once mass margin is identified for a particular launch.

- Validation of the P-POD's ™ capability to protect the launch vehicle and primary payload in case of a satellite structural or electrical malfunction: This will streamline the satellite qualification and approval process, especially for universities and first time developers with limited experience.
- Development of standardized CubeSat processing and testing flows for all launch vehicles: This will facilitate the development of CubeSats even before a launch opportunity is identified and provide launch heritage to the community on every launch.

The vision of enabling flexible secondary launches is achievable in the very near term and the rewards and impacts of enabling 100s of educational and experimental CubeSats to launch every year is unknown but extremely exciting.

SECONDARY PAYLOAD LIMITATIONS

The successful CubeSat launch vision described above represent a significantly increase in the number of secondary payloads being launched. This is a particularly significant shift in the secondary payload availability on US launch vehicles. While this is a welcome development, CubeSats are still being treated as traditional secondary payloads required to work with a payload manifest limited in its flexibility to accommodate new or alternative secondaries and focused on custom secondary payload arrangements.

Fixed Secondary Payload Manifest

Secondary payloads must be manifested on a specific launch opportunity with an agreeable primary payload early in the launch process. This requires the secondary payload to commit to a launch opportunity 1 to 3 years before launch. This timeline is incompatible with the short development times envisioned by a truly responsive spacecraft development process. CubeSat development times are as short as one year. Therefore, the current schedule forces satellites developers to make difficult choices:

1) Commit to a particular launch in the very early stages of the CubeSat design

2) Select a launch later in the CubeSat development process

Option 1 is difficult since many of the spacecraft requirements and schedule are unknown and might become incompatible with the Launch Vehicle. Additionally, CubeSat schedule over-runs (due to unpredicted requirements) may result in the need to launch a satellite completed with little time for testing or even to the loss of the launch opportunity. Option 2 may result in a launch years after the satellite is completed. Additional launch delays can accumulate due to issues with the primary payload.

This early secondary payload manifest also presents a problem for launch providers since the availability of mass margin may not be identified in the early stages of the launch process. Primary payloads cannot release mass margin until their vehicle has reached a significant level of maturity and this usually occurs well beyond the point on the primary's schedule when secondary payloads can be manifested. The result is that large amounts of lift capacity going unused every year.

Custom Secondary Payload Arrangements

Traditional secondary payloads are seen as one-of-a-kind payloads. While this may seem to be a positive development for secondary payloads allowing for highly customized satellites, the resulting launch cost increase puts secondary launches out of the reach of most space experimenters and small satellite development programs. These cost increases result from a number of contractual and technical issues including contracting arrangements between the secondary and primary payload suppliers, development of customized accommodations and interface documents for the secondary payload, extra structural and coupled loads analysis, verification of secondary payload requirements. In addition to the cost increase, the need for development of custom secondary payload interfaces creates a significant risk to the secondary payload. First, a significant investment is required before the primary payload is in a position to accept the secondary payload as a sufficiently low risk item. Second, environmental and test requirements will not be available to the secondary payload developer until the launch provider has performed a significant amount of analytical work. As a result, a significant investment is required to determine the compatibility of a secondary payload on a particular launch opportunity. Most secondary payloads cannot risk the funds required for this a priory analysis without a guarantee that a launch opportunity will materialize. This traditional secondary payload approach and its limitations are described graphically in Figure 3.

ENABLING FLEXIBLE SECONDARY LAUNCH OPPORTUNITIES.

Given the limitations described above, flexible launch opportunities cannot materialize using the traditional secondary payload model. In order to transform secondary launch logistics some radical changes are required:

- *Payload independent secondary manifest*: Launch vehicles should manifest secondary launch interfaces whenever the payload mass margin is available and a willing primary has been identified. Initial manifest does not require the identification of a specific payload just an announcement of availability. In a truly flexible secondary model, this announcement could occur very late in the launch opportunity is identified. In a flexible secondary launch model secondary payload developers must be prepared to complete their spacecraft before a specific launch becomes available. This represents a significant investment for the developers and can only be successful if

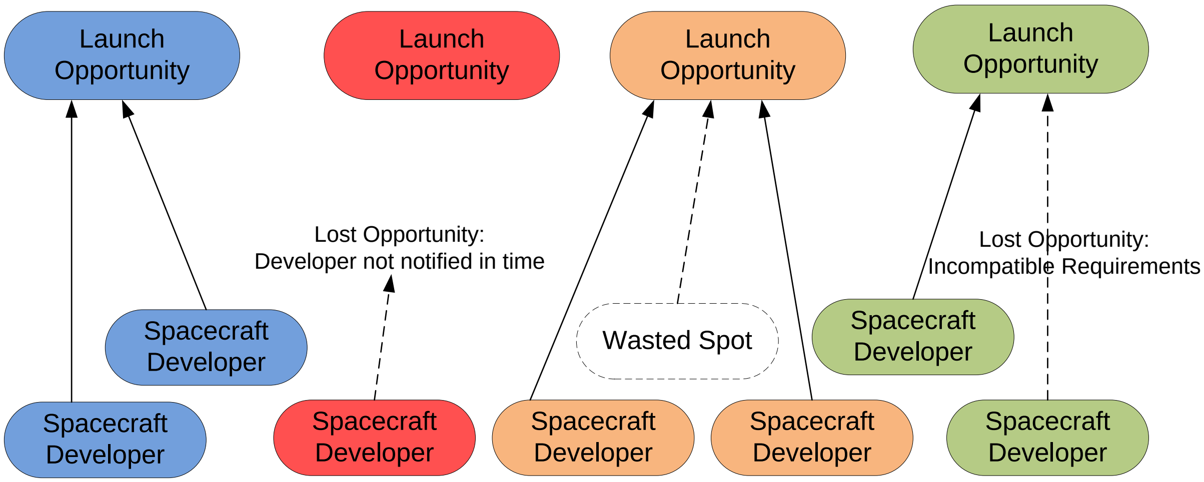

Figure 3: Traditional Secondary Payload Model -- Suboptimal allocation of payloads results in missed opportunities

launch schedule. However, for this model to be successful it is imperative that secondary payloads are available when launch providers identify opportunities. This requires additional logistical changes.

- *Standardized secondary payloads*: In order for the secondary manifest to be payload independent, interfaces and mass properties for the secondary payload must be defined a priori. This definition requires standard accommodations to be analyzed and qualified as an independent up-front effort. Clearly, identifying a funding source for these efforts can be a challenge and in many cases secondary payloads utilizing the traditional model will provide the initial funding and will develop the interface. Once a standard interfaces and payload properties are defined, mass margin can be made available to secondary payload developers without custom interface work. Ideally, standard interfaces can be shared across multiple launch vehicles thus maximizing launch opportunities for secondary payload developers.

- *Secondary payload developer community*: If secondary launch opportunities are made available shortly before launch, the schedule does not allow developers to start spacecraft construction once a there are guarantees of compatibility with upcoming launch opportunities. A clear and stable secondary payload standard as well as the potential for frequent launch opportunities is critical to the emergence of a vibrant developer community. On the other hand, without this developer community launch providers will not have the incentive to incorporate secondary payload accommodations.

- *Centralized secondary payload contracting*: Even with standardized interfaces and secondary launch availability, manifesting a payload still presents significant challenges for both the launch providers and the payload developers. Short schedule manifesting requires launch providers to be familiar with the satellite developer community and to understand the readiness levels of numerous developers. At the same time payload developers must continuously monitor launch availability on a number of launch vehicles for compatible flight opportunities. This constant monitoring represents a significant overhead with associated cost increases. 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.

A 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.

These changes would revolutionize the secondary payload market, and this flexible secondary payload model is illustrated graphically in Figure 4. In this new model, secondary payload developers would be isolated from most of the logistics involved in the launch process since the connection between the payload and the launch vehicle would be addressed by the secondary payload standard interfaces. In addition, once standardized interfaces are developed, the launch providers would require minimum effort to incorporate secondary payloads onto their vehicles. The ultimate results would be a significant reduction in the cost and schedule to launch secondary payloads along with a dramatic increase in the number of launch opportunities available to secondary payload developers.

It should be noted, however, that the standardization required to obtain truly flexible secondary payload launches would present some challenges to the spacecraft developers, including the following:

- *Increased qualification test levels*: In order for secondary payloads to be compatible with a large number of launch vehicles the standard qualification profiles for shock and vibration must include the worst-case loads for all vehicles. These testing levels would be higher than those required for payloads dealing with a single launch vehicle.
- *Secondary payload constraints*: The standardized accommodations on the launch vehicles place limits on the mass properties and dimensions of secondary payloads. These constraints are especially stringent if the standard is designed to eliminate the need for customized analysis to verify compatibility with the launch vehicle.
- *Limited orbit options*: As with all secondary payloads, standardized secondaries would be limited to popular orbit types with significant launch opportunities or they would require their own additional propulsion to reach their target orbit. Missions with rigid and unusual orbit requirements could however still benefit from the flexible secondary launch model since it would be more likely that secondary accommodations would be available on any launch vehicles targeting their required orbit. Such secondary payloads would require a manifesting process more closely tied to a

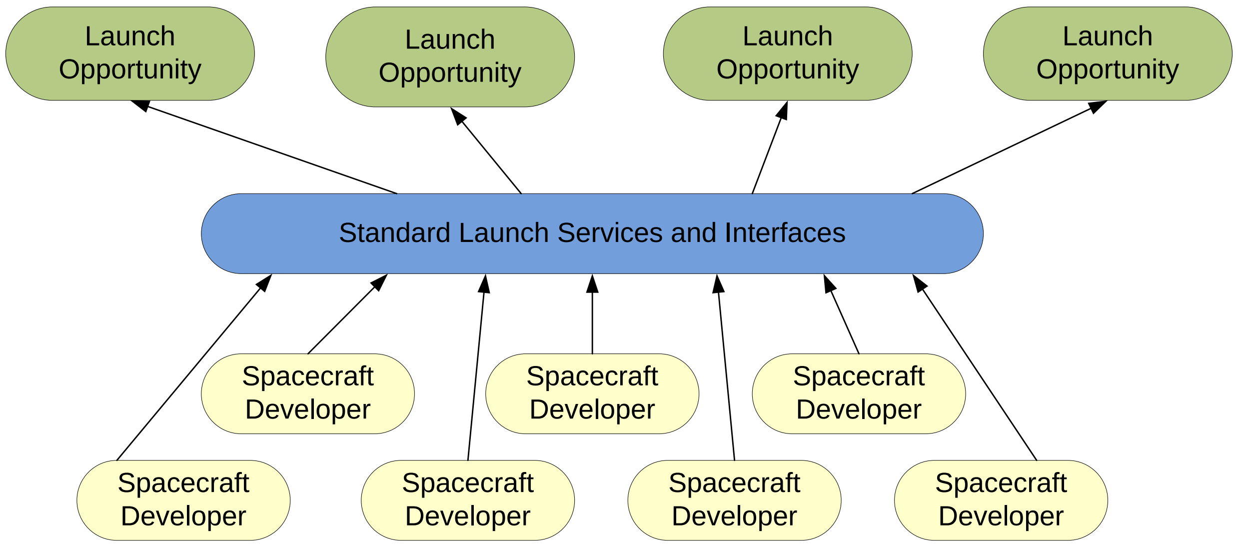

Figure 4: Flexible Secondary Payload Model – All Opportunities are filled with Spacecraft Developers that are ready to fly; Optimized over the current secondary launch paradigm

primary with similar orbit requirements–this would more closely resemble the traditional secondary manifest model.

BENEFITS OF FLEXIBLE SECONDARY LAUNCHES

Reaching the level of standardization required to enable a flexible secondary payload model requires a significant investment: appropriate standards must be defined, launch vehicle accommodations must be identified and qualified and compatible spacecraft must be developed. These up front costs can only be justified if the resulting change in secondary payload availability can provide significant industry-wide benefits. The initial and more direct effects would be felt by the secondary payload community.

First, the flexible model would produce a large number of low-cost launch opportunities taking advantage of existing under-utilized launch capacity. This increase in secondary launches would make secondaries a more credible option for a large number of space missions including science, technology demonstrators and education. However, the new launch model not only changes the total number of secondary launches but equally important it increases the launch frequency, with opportunities many times a year. These opportunities would utilize a variety of vehicles launching into many different orbits. The increased number of opportunities makes it easier for developers to find launches compatible with their schedule and orbit requirements.

Second, the flexible model decouples the launch and spacecraft development schedules. Spacecraft developer's systems can reach a high maturity level before committing to a launch. This would reduce the need to launch spacecraft under schedule pressures and increase the mission success rates for secondary payloads. In addition, the large developer community allows for the designation of back-ups in case last minute problems force a manifested payload to pull out from a launch. Furthermore, the negative consequences of a missed launch are minimized since the launch capacity is utilized by the back-up and the high launch frequency guaranties the de-manifested payload a timely re-fly opportunity.

Third, lower launch cost and increased launch opportunities would change the risk posture of the secondary payload developers. As a result, lower cost spacecraft could be developed since the mass, cost and complexity associated with highly redundant systems would frequently exceed the cost of a second flight. In effect, the lower cost redundant system would be a second copy of a minimally redundant spacecraft. In addition to lowering spacecraft cost, minimal redundancy increases the performance capability of smaller secondary payloads and reduces system development time.

Finally, given the previous effects, the secondary payload community would be in a position to accelerate the development of new science and technology with frequent low-cost missions supplementing and, in some cases, replacing larger more complex spacecraft that take many years to develop and fly infrequently. Spacecraft could be developed quickly and launched a few months after they are completed. Therefore, secondary payloads would always fly with current state-of-the-art technology. In addition, the lessons learned from a mission could be incorporated into new missions very quickly resulting in a very fast learning curve.

While these changes are centered on the secondary payload community, a vibrant secondary payload community would have positive effects on the entire space industry. The following are just some of the areas that would see revolutionary improvements from flexible secondary payload community:

- *Space Science*: Constellations of small satellites can perform missions requiring multiple simultaneous measurements that are not feasible with single spacecraft. Such missions would benefit from improvements in small spacecraft capability and increased secondary launches.
- *New Technology Injection*: Primary payloads are reluctant to incorporate "unproven" technologies into their vehicles. As a result, on orbit technology demonstration missions are critical to qualifying the latest technology for flight. This is a mission perfectly suited to secondary payloads with their low cost and higher risk tolerance.
- *Workforce Development*: The U.S. aerospace industry is facing critical staffing needs due to an aging workforce and a reduced number of science and engineering graduates with an interest in pursuing space careers. University and government small satellite programs are a great training and motivation tool and can play a key role in the development of the next generation of space professionals. However, these work force development activities have limited budgets and can not compete with industry and government in securing launch opportunities. Only, frequent, low cost launch opportunities will make regular access to space for workforce development a reality.

THE CUBESAT STANDARD AS A SECONDARY PAYLOAD ENABLER

Even though most CubeSat launches to date have followed the traditional secondary launch model, the CubeSat standard has already developed some of the infrastructure required to implement a flexible secondary launch model:

- A well-defined standard is available to both developers and launch vehicle providers. This includes a qualified standard launch vehicle interface (the P-POD) that has already been integrated on a number of launch vehicles.
- A large CubeSat developer community has emerged with worldwide participation from industry, government agencies and academic institutions.
- The launch manifesting process has experienced a substantial centralization with a few organizations supporting integration and contracting efforts for the larger developer community. These organizations include Cal Poly in the U.S., ISIS in the Netherlands [6] and the University of Toronto in Canada [7].

While the developments listed above are far from a complete implementation of the flexible secondary model, the results from these small steps have been very impressive and parallel the developments that are expected from a more flexible secondary payload model. Some of the more significant results include:

- *Development of spacecraft without a launch manifest*: CubeSat developers have achieved sufficient confidence in the maturity and stability of the CubeSat standard to largely decouple the development of their spacecraft from the availability of a launch opportunity. CubeSats are routinely taken to very high levels of completion before searching for a launch opportunity. This approach was pioneered by academic institutions to train students in the integration and testing of space systems even when a launch opportunity was not available but it is now being adopted by developers in government and industry as well.
- *Generic secondary manifesting*: Launch providers are proposing CubeSats as secondary payloads without selecting specific spacecraft for flight. This is a direct result of the availability of significant number of CubeSats awaiting launch. This significant step in the development of the flexible launch model can be directly traced to the existence of a standardized launch vehicle interface with a proven flight record.
- *Incremental technology development*: Given the increased availability of launch opportunities afforded by the CubeSat standard, developers are implementing a multi-launch approach to technology development with series of demonstration missions of increased complexity and performance. Examples of this strategy include The Aerospace Corporation's AeroCube series of spacecraft and NASA's GeneSat, PreSat, and PharmaSat missions.
- *Redundant spacecraft development*: A number of CubeSat developers are implementing redundancy by developing multiple copies of simple low-cost vehicles. This trend is again a result of the confidence that launches at a relatively low cost will be available on a regular basis. Some examples of this approach include NASA's NanoSail program, and Cal Poly's CP series of spacecraft. In Cal Poly's case the availability of back-up spacecraft was critical to the program's recovery from the 2006 Dnepr launch failure.
- *Increased small satellite capability*: 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. This includes improvements to basic bus technologies with the availability of components from a number of dedicated industrial sources (Pumpkin [8], Clyde Space [9], Astronautical Development [10], etc.) as well as the development of innovative scientific payloads such as those being developed for the space weather community through the NSF CubeSat program [11].

Clearly, the CubeSat standard has improved the launch potential for small secondary payloads. However, CubeSat's most important contribution is the development of a stable secondary payload standard on which to base the implementation of a flexible secondary launch model. As described above, CubeSats have already completed some of the initial steps in the implementation of a flexible model. In addition the CubeSat small size and low cost make it the ideal standard to develop the logistics and processes for a truly flexible secondary launch model. Some critical next steps must be implemented at this time in order to move CubeSats towards the truly flexible model.

First, CubeSat accommodations must be implemented on additional launch vehicles. This process is currently ongoing with a number of launch providers in the US and abroad. It is critical that these accommodations are implemented in a way that maximizes the number of launch opportunities. Ideally, accommodations should be available on every flight with mass margin being the only restriction. Funding requirements for initial implementation may be significant in some cases but long term non-recurring investment should be small. Recurring costs will further decline as the specific configurations are flown multiple times and launch providers gain experience and confidence. Along with the launch vehicle accommodations, standardized test and integration flows must be developed that maximize the number of compatible launch vehicles. This is the next level of standardization and is critical to the decoupling of spacecraft development from launch opportunities.

Second, logistics plans must be developed to accommodate very large numbers of CubeSats. To reach the full benefits of a flexible secondary launch model requires a significant increase in the number of launch opportunities available to developers. Ideally launch opportunities several times a quarter with up to 100 CubeSats a year should be available. This increase cannot be achieved with launch integration and testing processes that mimic those required for large primary payloads. A new approach must be developed that streamlines the process while maintaining appropriate quality control levels to guarantee safety and mission success. These new processes may benefit from a centralized servicing entity acting as a single point of contact between launch providers and CubeSat developers. This centralization would follow the model already established on the launch contracting and manifesting process that has already proved its benefits to the CubeSat developer community.

Third, operational concepts must be developed to respond to the increased numbers of secondaries as well as the new fast paced development schedules. Of particular concern is the need to deorbit CubeSats quickly to ease debris concerns. Currently a number of technologies such as drag systems and electrodynamic tethers are being proposed that could accelerate Cubesat decay rates. Launch plans could also be implemented to place secondary payloads in lower orbits to speed up reentry without the need for deorbiting systems [12]. Some additional key operational areas deal with the communication needs of large numbers of CubeSat launches including frequency allocation and coordination, as well as ground station availability [13, 14].

Finally, the stability of the CubeSat standard must be maintained. This is necessary to continue to grow both the developer community and the compatible launch accommodations. In addition, the experience necessary to develop new standardized logistics flows requires a long-term commitment and repeatable processes. Eventually the experiences from the CubeSat standard will be available to the space community as a whole and may pave the way for different and more capable 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. Funding must be allocated to increase the number of launch vehicles with compatible accommodations. This would put the CubeSat standard in a position to serve as the basis for the implementation of truly flexible secondary launches. In addition, some logistical 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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