SSC20-VIII-06

Leveraging the Success of the CubeSat Standard to Create a SmallSat Standard for ESPA Spacecraft

Dave Pignatelli, Ryan Nugent, Alicia Johnstone, Pauline Faure and John Bellardo
California Polytechnic State University
1 Grand Ave, San Luis Obispo, CA 93407; (805) 756-5074
dpignate@calpoly.edu

ABSTRACT

The space industry has found significant utility in short turn-around, small satellite missions. There has also been a significant increase in both rideshare and dedicated launch opportunities for small satellites around the world. Small satellites can be developed in much shorter timelines than the traditional, large spacecraft missions. In order to fully leverage the short-development time of small satellites, a standardized design approach is required. Following the success of the CubeSat Design Specification (CDS), it is clear that a standard set of specifications in a concise document allows developers to design their spacecraft without knowledge of their specific launch opportunity. A publicly available standard provides developers and launch vehicles with a set of common parameters for initial design and analyses. CubeSats have shown that a standardization approach is effective at getting missions to space quickly and inexpensively. As the small satellite industry continues to flourish, adapting to the new paradigm is crucial to widespread success.

INTRODUCTION

Over the past decade, the space industry has become increasingly aware of the significant benefits in utilizing small satellites, and in the past couple of years the small satellite industry has increasing interest in spacecraft that are between 50-300kg. There has been a steady increase worldwide in both rideshare and dedicated launch opportunities for the small satellite market which has been one of the main drivers for the increased interest in larger small satellites.

With so many small satellites being developed every year, an approach to launch them that will effectively take advantage of the short development will aid greatly in the success of the industry. A recent study conducted by Bryce Space and Technology indicated that all 1,078 small satellites on commercial launches in the last 5 years experienced delays, and the median delay was 128 days[1]. Furthermore, the same study indicated that 40% of these delay days were caused by the primary payload and 20% of these delay days were caused by launch vehicle development. Significant launch delays can be detrimental to small businesses and startup ventures and thus need to be minimized. Launch delays caused by vehicle development can be reduced by reducing the amount of engineering applied to integrating each small spacecraft. This can be accomplished by a standardized specification for small satellites. The proposed standard, the Small Satellite Design Standard (SSDS), would cultivate a broad base of standardized satellites that can be easily and quickly integrated to launch vehicles with minimal non-recurring engineering and analysis.

The role of the SSDS to the spacecraft developer and launch provider mirror those of the CubeSat Design Specification (CDS). After seeing the effect that standardization has had on the inception to launch time, it is clear that there are significant gains to be had by adopting a similar model for larger spacecraft. By agreeing to a set of specifications, the small satellite developer and the launch vehicle provider can begin their designs well before the spacecraft is manifested. This will reduce development cost for all parties. Additionally, having known physical properties allows the launch vehicle provider to perform initial analyses prior to knowing the specific spacecraft(s) manifested on a launch, which will reduce time to launch. This feature of the standardized specifications also allows the manifested small satellites to be treated as Line Replaceable Units (LRU), meaning that a manifested spacecraft can be replaced by another spacecraft that adheres to the SSDS without significantly revisiting analyses and interface considerations. A LRU allows for quick replacement of a payload without greatly affecting the overall cost and launch timeline. This is key, as larger spacecraft have an impact on launch vehicle dynamics that cannot be ignored or approximated like the smaller spacecraft. It turns out that there are several key differences between CubeSats and larger small satellites that present new challenges when it comes to creating a standard set of specifications. One of the primary goals of the proposed SSDS is to effectively navigate through the applicable specifications to standardize without unnecessarily hindering function or innovation.

In addition to the above benefits, the standard specifications that are laid out by the SSDS encompass requirements from a broad range of launch configurations. The goal is to prepare a spacecraft to fly on as many launch opportunities as possible, including vertical and horizontal launch configurations in addition to dedicated and rideshare opportunities. Ideally, a spacecraft that is designed to the SSDS can be slotted on any launch that also complies with the SSDS, and within a truncated timeframe. All of this together results in lower costs for both the spacecraft and the launch providers and rapid launch time frames.

CUBESAT VS SMALLSAT RIDESHARE

As the size of the spacecraft increases, a number of differences drive a different approach to the launch process. The most obvious difference is the lack of a closed container around a spacecraft larger than a 12U CubeSat. Due to the lack of a container, the larger small satellites have no concrete volume requirements and therefore come in many different shapes and sizes. This, combined with the increased mass, causes each small satellite to have different structural properties that the launch vehicle must take in to account. In the large spacecraft world, this is nothing new. Mass and dynamic properties of big spacecraft are typically provided to launch vehicles 2 or more years before launch, which would completely encompass the development cycle of most, if not all, small satellites.

When it comes to CubeSats, due to the containerization, low mass, and high first fundamental frequency, launch vehicles are able to assume that each CubeSat payload is very similar to the next, and therefore do not require detailed information so far in advance. This is one of the primary factors that makes the rapid mission inception to launch time of CubeSats feasible, as well as making launch manifesting for CubeSats on rideshare missions more flexible. The flexibility comes in to play when it is relatively simple and easy to replace one CubeSat with another if necessary.

As one might expect, larger small satellites have similarities with both the CubeSat model, as well as, the large spacecraft model. Like CubeSats, small satellites have lower inception to launch times, which is an advantage that must be leveraged to fully realize the benefits that small satellites have to offer. In contrast, small satellites can be dramatically different from each another, which means their effect on launch vehicle dynamics cannot be neglected and due to different masses, volumes, and interfaces, cannot always replace one another. Therefore, both spacecraft developers and launch vehicle providers must have knowledge of each other early in the development cycle. This becomes a hindrance because spacecraft developers cannot develop a spacecraft confidently until they have a confirmed launch, and launch vehicle providers cannot manifest general spacecraft slots without knowing they will have a spacecraft for that slot. In order to fully leverage the cost and schedule benefits of small satellites, there must be something to bridge the gap.

APPLICATION OF STANDARDIZATION TO SMALL SATELLITES

The goal of the SSDS is to provide a common target for both launch vehicles and spacecraft, analogous to what the CDS has done for CubeSats. For instance, a launch vehicle might provide accommodations for six 3U CubeSats, and then sell those accommodations to auxiliary payload integrator. The auxiliary payload integrators will buy these slots with confidence that six 3U CubeSats will be available, because any 3U CubeSat designed to the CDS will be compatible. This also makes swapping payloads feasible with minimal non-recurring engineering (NRE) efforts. In order for this to work, the spacecraft must adhere to a prescribed range of properties that is practical for both the spacecraft design as well as the launch vehicle analysis requirements. The goal is to standardize the bare minimum to have the desired effect for the launch vehicle, while maintaining enough room for creativity and innovation on the spacecraft side.

Additionally, in order to avoid dictating specific interface adapters and separation systems, it is important that these items are taken in to consideration when evaluating the adherence of a spacecraft to this specification. For example, the goal is not to specify a specific separation system manufacturer, but the 15" separation rings made by 3 different manufactures may not have the exact same mass properties or volume. The dividing line between what is part of the spacecraft being specified by the SSDS and the launch vehicle is illustrated below along with the reference coordinate system in Figure 1.

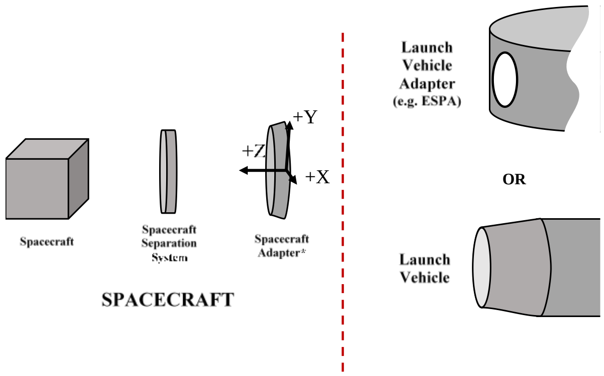

Figure 1: Spacecraft vs Launch Vehicle Disambiguation and Coordinate System[2] (*Spacecraft Adapter only if needed)

To prevent a too much restriction, three classes of spacecraft are proposed, with overall mass being the distinctive factor. These classes have many similarities, but differ primarily in mass properties and standard interfaces. The notional mass ranges for these classes are shown in the Mass Properties section below.

STANDARDIZED PARAMETERS

Based on research by Cal Poly and other collaborators, it is clear that it is essential to standardize mass properties, structural dynamics, mechanical interfaces, and electrical interfaces to achieve the goals outlined in this paper. If launch vehicles are prepared to carry spacecraft that fall in to the allowable range of these parameters, then spacecraft developers can be confident that designing to most or all of these parameters will meet the requirements to fly on a wide selection of launch vehicles.

Mass Properties

It is important to specify a range of mass properties to give launch vehicles bounding cases to prepare for. These mass properties include overall mass and center of gravity (CG). These values play a large role in ascent analysis and interface strength. Overall mass is also a factor in determining orbital insertion performance. As mentioned previously, three classes of small satellites are proposed. The notional values for these classes are shown below in Table 1.

Table 1: SSDS Mass Properties[2]

Class	Mass (kg)	Center of Gravity (cm)	
1	70 +/- 10	X	0 +/- 2
		Y	0 +/- 2
		Z	30 +/- 5
2	140 +/- 10	X	0 +/- 4
		Y	0 +/- 4
		Z	36 +/- 6
3	200 +/- 20	X	0 +/- 5
		Y	0 +/- 4
		Z	48 +/- 10

A tolerance is added to each value in order to give spacecraft developers a range to work with while providing launch vehicles a bounding case for analysis. Spacecraft developers desiring maximum possible launch opportunities with no added costs should attempt to stay within these values.

Structural Dynamics

Perhaps the largest divergence from the successful standardization models like the CDS, is the interaction of the structural dynamics of a larger small satellite with the structural dynamics of the launch vehicle. As spacecraft mass increases, stiffness has a tendency to decrease. Both of these trends result in much higher importance on understanding the dynamics of each system.

The simplest method of avoiding recurring coupled loads analyses, is to increase the stiffness of the spacecraft structure enough to mitigate the effects of the dynamic interaction between the spacecraft and the launch vehicle. This minimizes the amount of recurring analyses burden on the launch vehicle, and also provides a clear and concise target for spacecraft developers to aim for. The notional minimum frequency range for the SSDS is shown below in Table 2. Notional minimum frequency range below was taken from the NASA's ESPA Rideshare Users Guide in order to use a value that will be effective for the maximum number of launch vehicles, as other reference indicated lower values.

Table 2: SSDS Minimum Fundamental Frequency[3]

	Class 1	Class 2	Class 3
Min. Fundamental Frequency (Hz)	75	75	75

Volume

Guidelines for payload volume are also necessary in order to account for various launch vehicle fairing sizes and auxiliary payload accommodation configurations.

The SSDS only provides guidance for small satellite volumes as the myriad of different launch configurations could allow for many unique spacecraft shapes which could exceed the provided volumes, but not adversely affect launch opportunities. The selected volume guidelines were derived from currently available launch accommodations and previous studies, such as the Launch Unit and Moog's ESPA User Guide. Volume upper limits are shown below in Table 3.

Table 3: SSDS Volume Size Limits[4,5]

Class	Volume Size Limit (cm)	
1	X	45
	Y	45
	Z	60
2	X	61
	Y	61
	Z	72
3	X	71
	Y	61
	Z	96

Interfaces

Lastly, in order to have a uniform class of spacecraft, they all must support the specified interfaces to the launch vehicle, or be easily adapted to do so. This is critical so the launch vehicle does not have to redesign an interface, whether mechanical or electrical, for each individual payload.

Electrical interface specifications consist of pin counts and circuits. A minimum of 3 circuits is specified, with the notion that a slightly oversized connector is specified for flexibility in the event that the spacecraft desires more pins and the launch vehicle is able to provide them. The three circuits are used for primary and redundant separation actuation, and a separation telemetry indication. An example circuit diagram is shown below in Figure 2.

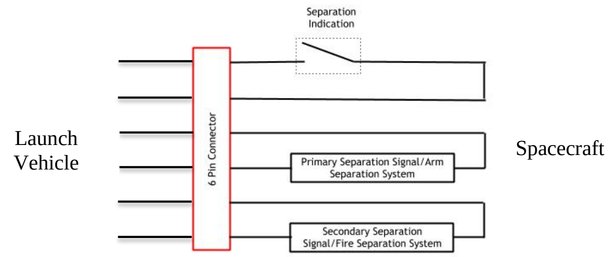

Figure 2: SSDS Electrical Interface Circuit Diagram[2]

In addition to the electrical interface itself, it is also necessary for spacecraft to design their mission around what electrical accommodations can be provided by the launch vehicle. The SSDS strives to minimize the amount of electrical interface functions in an effort to reduce complexity and maximize the number of launch opportunities for spacecraft adhering to its specification. Spacecraft requiring additional functions such as battery charging or launch vehicle telemetry may design with these functions in mind, but that may lower the amount of eligible launch opportunities.

Mechanical interface specifications consist of options consistent with available separation systems that would be practical choices for spacecraft of this size. For example, an 11.732" diameter separation ring was one of the proposed standard interfaces for the Launch Unit,[3] which is similar in mass and size to the "Class 1V" unit. The mounting pattern for this separation ring as shown below in Figure 3 would be included in the SSDS. The additional standard mounting interfaces are shown in Figure 4, Figure 5, and Figure 6.

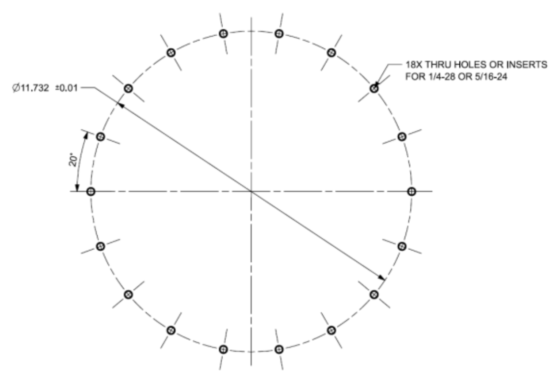

Figure 3: Standard Class 1 Mechanical Interface[2]

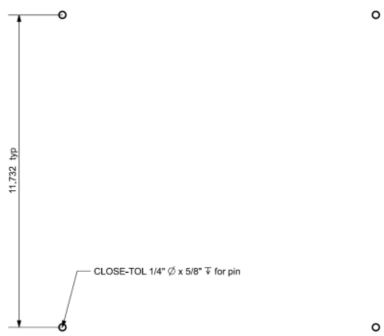

Figure 4: Standard Class 1 4-Point Mechanical Interface[2]

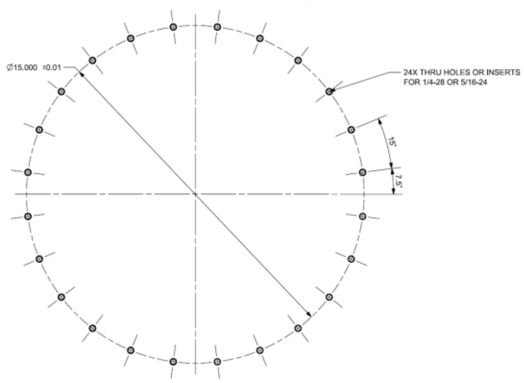

Figure 5: Standard Class 2 and 3 Mechanical Interface[2]

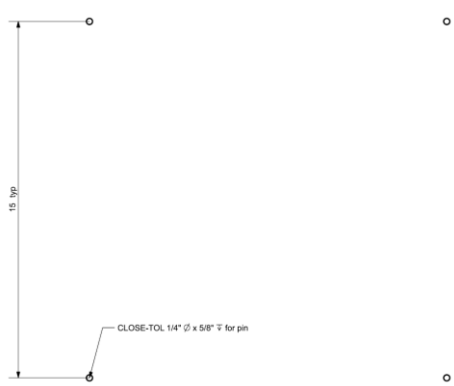

Figure 6: Standard Class 2 and 3 4-Point Mechanical Interface[2]

CONCLUSION

Rideshare missions involving high numbers of diverse small satellites can quickly turn in to long drawn out exercises in interface engineering, which is costly to both launch vehicles as well as spacecraft companies. Dedicated launches for small satellites could potentially face delays if a spacecraft is behind schedule which could affect following missions as well. A standard is needed to give spacecraft developers and launch vehicle providers a mutually agreed upon target to design and analyze to and provide flexibility with the manifesting process. Assuming the spacecraft developer is successful in adhering to the SSDS, launch providers would be prepared for the interfaces and structural properties of the spacecraft, requiring no design, analysis, or manufacturing and allow the launch vehicle provide maximum flexibility when manifesting payloads.

The CubeSat industry has seen the benefits of standardization, as CubeSats continue to launch rapidly with low costs. Applying a similar model to larger small satellites will lower launch costs and decrease time to launch, which will allow the small satellite industry to flourish, and launch vehicle providers to more effectively integrate their array of spacecraft. The end result is a plethora of viable launch opportunities with rapid launch times and decreased costs for small satellites.

References

1. "SmallSat Launch Delays Report 2020". Bryce Space and Technology. April 22, 2020. Accessed June 06, 2020. brycetech.com/reports/report-documents/Bryce_Metrics_Smallsat_Launch_Delays_2020.pdf
2. *Small Satellite Design Standard.* Draft, June 16, 2020. Cal Poly CubeSat Lab.
3. *NASA's Evolved Expendable Launch Vehicle Secondary Payload Adapter (ESPA) Rideshare Users Guide, and Do-No-Harm Requirements Document for 2019 Astrophysics Small Explorer and Missions of Opportunity Call (2019 Astro ESPA RUG).* Rev 0, April 1, 2019. Accessed June 16, 2020. explorers.larc.nasa.gov/2019APSMEX/SMEX/pdf_files/2019-04-01%202019%20Astro%20ESPA%20RUG.pdf
4. O'Quinn, Carrie. Braun, Barbara. Taylor, Allison. Piskorz, Danielle. Loghry, Chris. Kwong, Jeffrey. "Setting the Standard: Recommendations on 'Launch Unit' Standard SmallSat Sizes between CubeSats and ESPA-Class," Proceedings from 32nd Annual AIAA/USU Conference on Small Satellites, Logan, Utah, August 2018.
5. *ESPA User Guide.* November 2018. Accessed June 16, 2020. Moog Space and Defense Group. www.moog.com/content/dam/moog/literature/Space_Defense/spaceliterature/structures/moog-espa-users-guide-datasheet.pdf