# Lessons Learned Flight Validating an Innovative Canisterized Satellite Dispenser

**Ryan Hevner**
**Planetary Systems Corporation**
**2303 Kansas Ave.**
**Silver Spring, MD 20910**
**301-495-0737**
**ryanh@planetarysystemscorp.com**

*Abstract*—**This paper details the lessons learned during the testing and flight of a 3U modular payload in an innovative new dispenser. The Canisterized Satellite Dispenser (CSD) has many features beyond typical CubeSat dispensers. The primary benefit is the payloads are preloaded to the dispenser, creating a secure load path that is modelable and facilitates accurate prediction of the payload's flight environments. The Polar Orbiting Passive Atmospheric Calibration Spheres (POPACS) payload flew aboard the inaugural Falcon 9 v1.1 and were successfully placed into orbit.**

## TABLE OF CONTENTS

## 1. INTRODUCTION

The growth of CubeSats over the last decade has been exponential. As the sophistication of these satellites continually increases, the need to provide an equally refined dispenser is critical. With the help of the Air Force Research Laboratory (AFRL), Kirtland AFB and the department of Operationally Responsive Space (ORS) via a Small Business Innovative Research (SBIR) grant, the CSDs were designed and qualified. Both 3U and 6U sizes were developed. Both sizes accommodate payloads loosely based on the existing CubeSat standard where a "U" is a cube approximately 10cm per side. The 3U CSD is the primary scope of this paper. It is at Technology Readiness Level (TRL) 9 via the successful flight in September 2013.

To facilitate the adoption of this new technology independent specifications and data sheets were created [2] [3]. A payload specification defines the mechanical and electrical requirements necessary to ensure the satellite will properly interface with a CSD. It encompasses payload sizes of 3U, 6U, 12U and 27U. By making the payload a standalone specification, any organization may design a dispenser to accommodate these payloads.

A CSD Data Sheet serves as an ICD for both the launch vehicle provider and payload. It defines mechanical and electrical interfaces as well as test environments and predicted in-flight performances. It pertains only to Planetary Systems Corporation's (PSC) product.

The POPACS mission was the inaugural flight of a CSD. Many of the unique features of the CSD were essential to enabling the mission. The payload consisted of three aluminum spheres, each 10cm diameter with masses of 1.0 kg, 1.5 kg and 2.0 kg, sandwiched between aluminum spacers. The spheres were held in compression and had no mechanical attachment points. The innovative tabs required by the payload specification enabled the CSD to grab and preload the spacers, preventing jiggling and potential damage to the spheres.
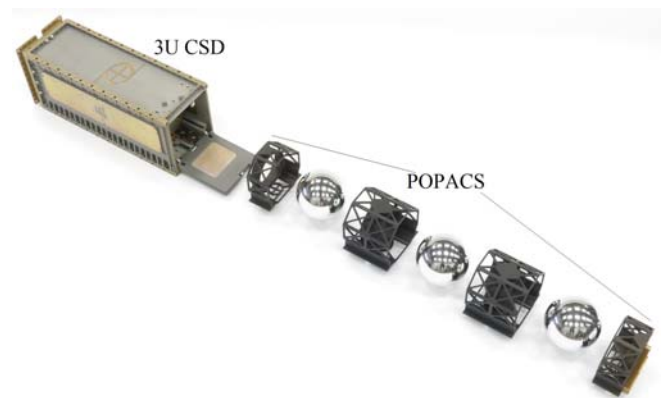


**Figure 1: POPACS Payload and 3U CSD**

The CSD contains several additional innovations that streamline testing, reduce cost, increase integration options and ease payload design.

The integration and launch revealed further lessons learned that, if implemented will assist future missions. These pertain to use of the CSD and the telemetry gathered by the launch vehicle.

## 2. POPACS PAYLOAD

POPACS serves to measure the change in density of the upper atmosphere as a result of Coronal Mass Ejections (CMEs) [4]. They are in a highly inclined and highly elliptic orbit. The varying ballistic coefficients of the spheres cause them to separate and decay at varying rates. The spheres can be optically and radar tracked. The mission was conceived and lead by principal investigator Gil Moore.
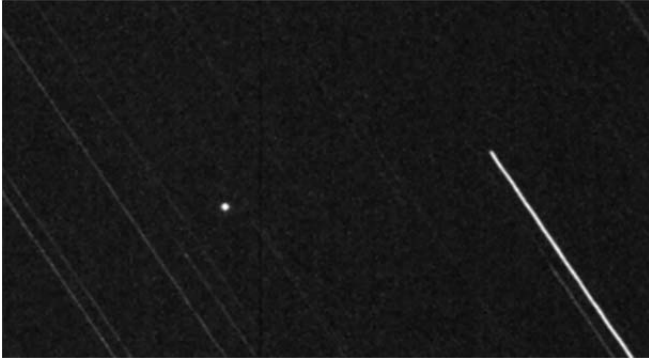


**Figure 2: Tracking a POPACS sphere on orbit [5]**

To maintain constant drag force regardless of orientation, the exterior surface of each sphere contains no mechanical attachment points, divots or protrusions. Further the spheres are highly polished bare aluminum which is relatively soft and susceptible to scratching. To prevent damage, each sphere was sandwiched between elastomer O-rings at +/- 45 deg. latitude in each spacer. Three acetal-tipped spring plungers provided relative separation of each spacer from the sphere upon ejection. The total mass of the payload was 5.7 kg.
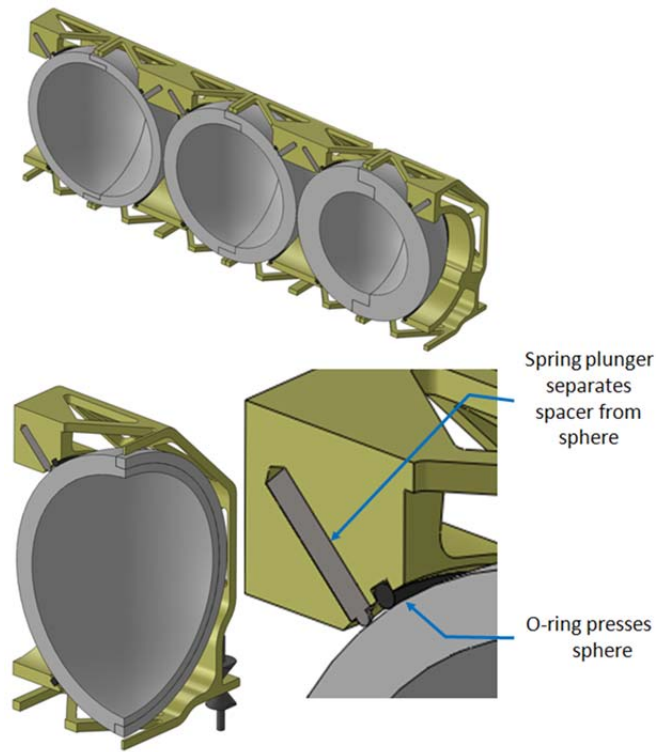


**Figure 3: POPACS payload detail**

## 3. CSD FEATURES

The CSD contains several unique features that differentiate them from typical CubeSat dispensers. These features, some of which are listed below, enable advancements in payload design and integration. More detail can be found in the CSD Data Sheet [2] and the Payload Specification [3].

1) A pair of aluminum tabs run along the ejection axis of the payload. These tabs are clamped by the CSD and create a rigid junction, similar to how a brake caliper grips the brake rotor on an automobile. This allows the dynamic and thermal environments to be accurately modeled and predicted. Also, because the payload structure need only contain the two tabs, as opposed to the four rails in a CubeSat, the shape is unrestricted.
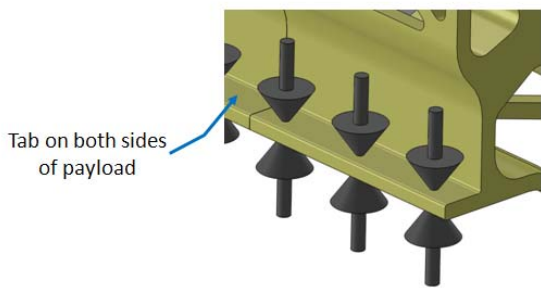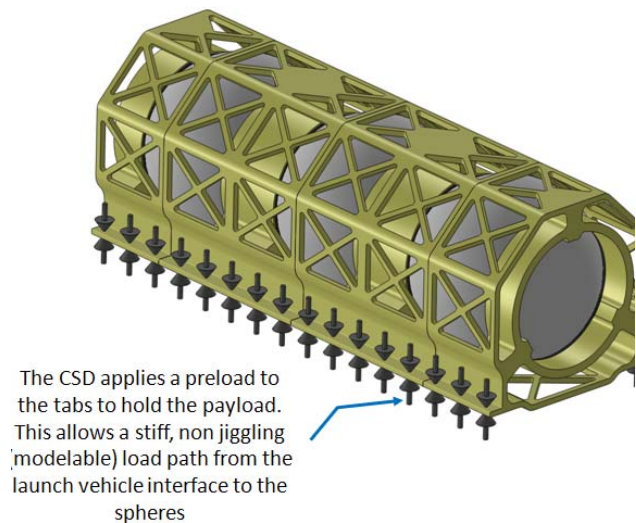
The CSD applies a preload to the tabs to hold the payload. This allows a stiff, non jiggling (modelable) load path from the launch vehicle interface to the spheres

Tab on both sides of payload

**Figure 4: Preloaded payload tabs**

First mode of payload is 1,155 Hz
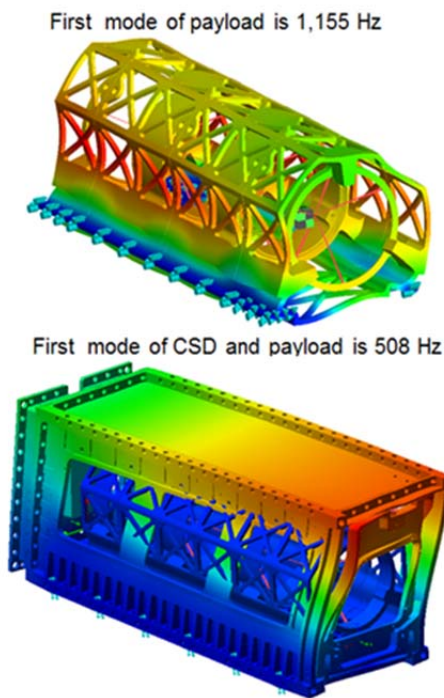
First mode of CSD and payload is 508 Hz

**Figure 5: Stiffness prediction of payload and CSD**

2)  The internal payload volume is larger while the external CSD volume is similar to existing dispensers. The

compact design of the CSD's ejection system and door initiator enables the payload to be approximately 2.5 cm longer than a 3U CubeSat. Further because the payload only requires the two tabs, the other two corners are free of the typical rails and indentations.

3)  The payload mass can be 2.0 kg per "U". A 3U payload may be 6.0 kg and a 6U may be 12.0 kg. This was essential for POPACS as the typical CubeSat mass allowance of 1.33 kg/U was insufficient.

4)  An available 15 pin separation electrical connector allows communication and charging between the payload and launch vehicle. This is important to assess the health of the payload after integration. It also permits trickle charging batteries, enabling the satellite to operate immediately upon ejection.

5)  A completely re-usable door release mechanism consists of a motor and latching system. There are no consumables and the system automatically resets. This permits extensive testing, reduces overall program cost and reduces schedule. The motor's characteristics can be monitored to provide insight into the performance and health of the mechanism.

6)  Defined areas of the CSD's interior may be used to restrain the payload's deployables. This reduces payload complexity by eliminating restraint/deployment mechanisms.

7)  Separate door and occupancy switches indicate when the CSD door has opened and when the payload has fully ejected. This is essential to knowing the state of the system on-orbit and the exact orbital injection time. The timing of both events can also be used to estimate ejection velocity.

8)  The CSD can be mounted via any of its six sides. There are no protrusions such as initiators, or torsion springs. The CSDS can also be bolted to each other. This streamlines integration and reduces the overall system mass by eliminating the need for additional support structures or adapters. It also facilities the use of CSDs as hosted payloads on larger satellites.

## 4. TESTING

Initial testing of the prototype CSD revealed several deficiencies that had to be corrected in order to pass qualification. Shock testing proved to be the most challenging environment. To qualify the CSD for use on many launch vehicles it must be capable of withstanding the shock resulting from fairing or stage separation. The shock environment creates significant loading across a wide frequency band. The low frequency loading excites a large percentage of the payload's mass. The CSD must generate sufficient preload to prevent slipping of the payload. The equivalent acceleration load on the payload is much higher than a typical quasi-static load. Further, at high frequencies

3

smaller items excite and very stiff or brittle items can sustain damage.

The two primary flaws related to these low and high frequencies. First the preload generated by the CSD clamping on the payload tabs was insufficient and the payload slipped in the CSD. Secondly, the door initiator auto-actuated allowing the door to open. Both of these issues were corrected and the CSD passed qualification testing, however it illustrates the importance of performing shock testing on space-flight hardware. Neither of these deficiencies arose during previous 14.1 grms random vibration testing.
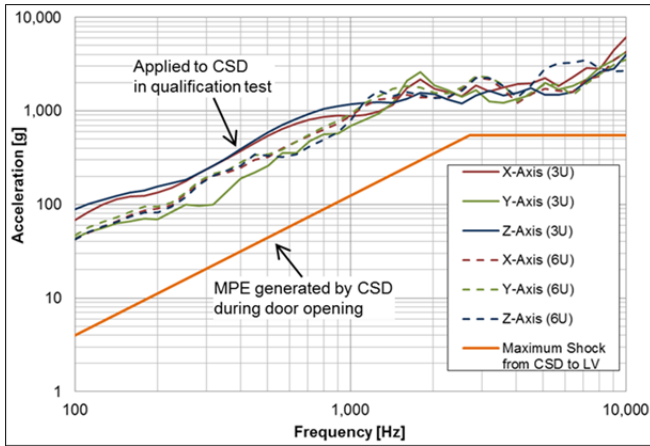


**Figure 6: Example CSD Shock Environment**

Verification that the payloads didn't slip was also verified during random vibration and sine burst testing. Both the payload and CSD base were instrumented with accelerometers to compare their responses. The image below shows the 3U CSD with a 6.0 kg payload excited at 50g during a sine burst test. The high correlation confirms the CSD's preload is sufficient to prevent slipping.
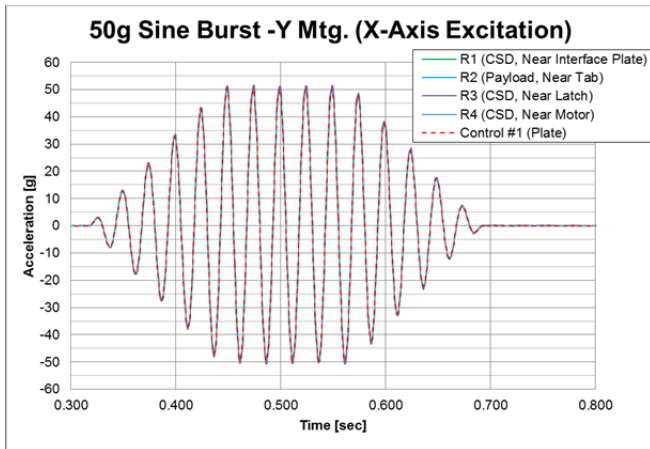


**Figure 7: 50g sine burst test of 3U CSD**

Further, low level sine sweeps were taken during vibration testing in each axis. The image below shows overlays of three runs: pre-test, after random vibration, and then after

sine burst. They overlay well, validating no significant changes in the stiffness of the structure or load path.
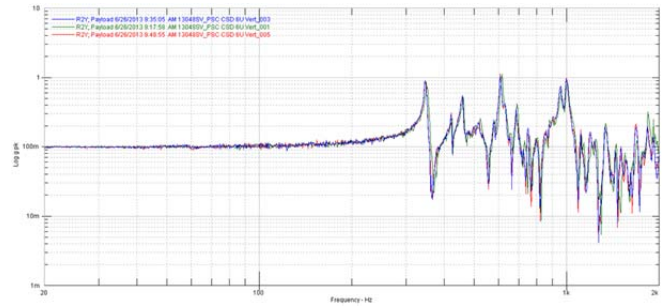


**Figure 8: Sine sweep overlays**

Isolation systems are extremely valuable at reducing the detrimental loading on the payload. This is especially important with tertiary payloads like CubeSats and CSDs as their location on the launch vehicle is often in a harsh and/or uninformed environment. They are typically located in previously unused and therefore lightly analyzed locations of the launch vehicle. They can be on adapter cones and plates with significant resonances, near high shock sources like stage separation systems, or near motors.

Fortunately, the low mass of these payloads enables the use of relatively simple isolation systems. They can reduce the high frequency environment substantially. This is especially useful for payloads consisting of sensitive optics, ceramics or other instruments. The POPACS mission used commercial off the shelf (COTS) isolators to successfully reduce the dynamic environment of the CSD. Also, different COTS isolators were demonstrated during qualification vibration and shock testing of the CSDs. The example image below shows the response above and below the isolation system during random vibration testing. Note the overall reduction from 14.1 grms to 4.1 grms and the substantial high frequency attenuation.
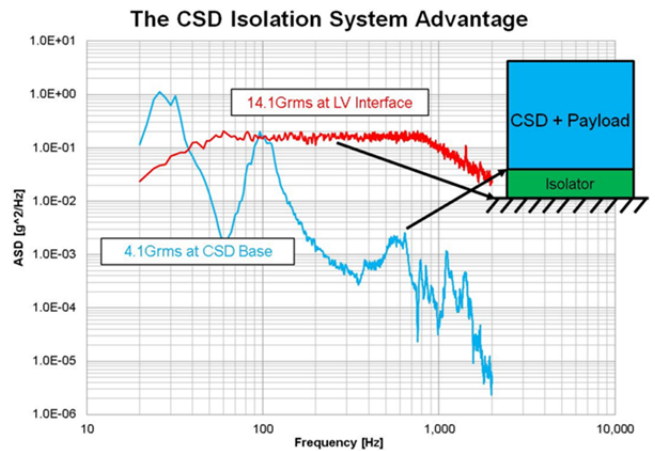


**Figure 9: Benefit of payload isolation**

**Figure 10: Using isolation systems on CSDs**

Because the CSD door initiator is a motor driven latching system there are no consumables. The CSD can be cycled in a matter of seconds. Performing several hundred operations on the initial CSD design revealed components that experienced premature wear and potential usability concerns. These issues were corrected resulting in a design that now withstands hundreds of separations.

One area that exhibited premature wear was the payload tab and CSD interface. Initially the tabs were designed as irridited aluminum to maintain electrical conductivity from the CSD to the payload. The surfaces displayed signs of galling. The interfaces were thus changed to hard anodized aluminum to increase abrasion resistance. This reduced the friction coefficient between the CSD and payload thus requiring an increase in clamping preload.

Being able to fully separate the payload from the CSD is the only way to truly verify performance. Merely allowing the door to open does not ensure the payload will eject. By creating a conveyor mechanism for testing, the payload is allowed to fully eject from the CSD. While this setup is not an exact representation of on-orbit performance it provides further assurance of mission success. It alleviates concerns of hang fires due to thermal induced interference, deployables snagging and ejection system anomalies.
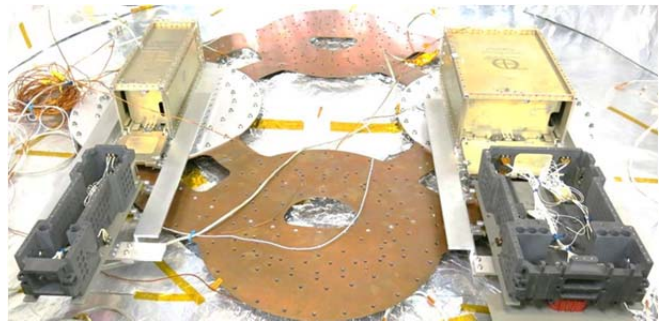


**Figure 11: Payload mockups deploying from CSDs during thermal vacuum testing**

The telemetry provided by monitoring current and voltage of the door initiator enables verification of torque margin and monitoring of the overall system health. A loss of preload or increase in mechanism friction can be deduced by examining the initiation profiles. This provides further mission assurance as the initiator is never replaced or refurbished and the entire system remains in a test-as-you-fly configuration.

By monitoring the door and occupancy switch states the performance of the ejection system can be verified. Also the payload's ejection velocity can be estimated. The figure below shows sample telemetry from the CSD's door initiator and switches.
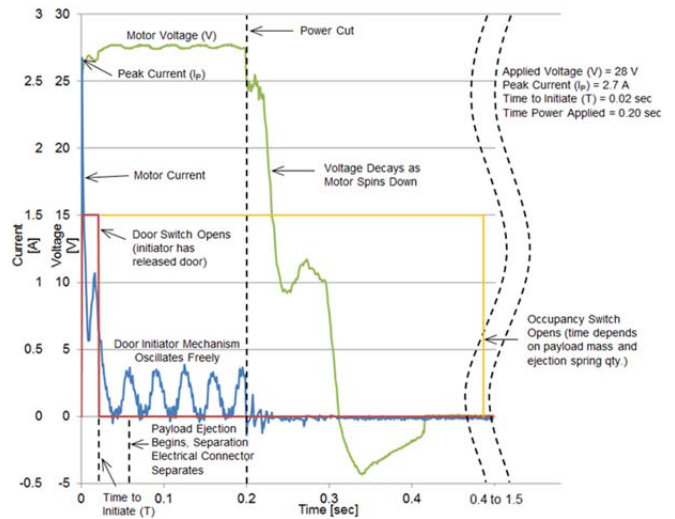


**Figure 12: Electrical profiles of CSD initiator and switches**

## 5. INTEGRATION AND LAUNCH

A fit check of the payload in the CSD shall be performed as early as program schedule permits. Because of the intimate relationship of the payload tabs to the CSD the fit shall be verified. Further, the payload can be integrated with the CSD and used together during environmental testing. Payload separations during thermal vacuum testing and after vibration testing will increase mission assurance.

It is essential for the launch vehicle to gather as much information from the CSD as possible. The door and occupancy switches should always be monitored. On POPACS, the occupancy switch was not used. Because the spheres were so small and difficult to locate it took several days to confirm proper ejection from the CSD. Also, sensing both signals enables prediction of the separation velocity through the relative timing of the two events, the distance traveled by the ejection system and the separation spring force. This further facilitates prediction of the orbit location and Two Line Element (TLE) sets for use in tracking the payload. Although much more resource intensive, video confirmation of the deployment shall always be considered and implemented as funding allows.



**Figure 14: Integration of POPACS 3U CSD on Falcon 9 v1.1**

## 6. CONCLUSIONS

The CSD has proven to be enabling technology through the demonstration of the POPACS mission. It permitted a multi-part payload to act as a single structure during launch yet safely release seven components in orbit. The rigid connection between the payload and the CSD also allowed accurate predictions of the payload's dynamic response and prevented damage to the payload. The reusable initiator permitted significant testing to verify reliability. The numerous mounting faces increase integration possibilities and reduce overall system mass.

Isolation systems are a simple and effective means of reducing the peak response of the payload which is especially crucial as tertiary payloads are often located in high response locations of the launch vehicle. Further as payloads become more sophisticated, isolating expensive and sensitive instruments from harmful environments is essential.

PSC is working to create correlated finite element models of the CSD for use by payload designers and launch vehicle providers. This will further facilitate the prediction of payload response. The payload designer can optimize the payload structure and component locations. They will also be able to decide if an isolation system is necessary.
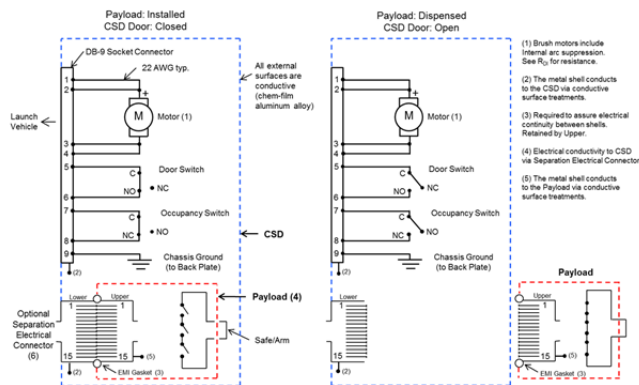


**Figure 13: CSD electrical schematic**

The CSD contains numerous through and tapped holes on every external face. When possible, mounting of the CSD should be performed using the through holes from above. This prevents the need to first mount the CSD to an adapter structure from the underside. The CSD can instead be mounted directly to the launch vehicle structure. It eases tool access and speeds integration time.

Wiring harnesses shall also be well thought out. Avoid unnecessarily thick cables with large bend radaii. This makes it difficult to route the harness and places undue strain on the mounting hardware. Also ensure there are provisions for strain relief. The CSD has numerous holes for cable tie attachment.

Performing a functional verification test with the CSD increases the probability of success. This is facilitated because the CSD has no consumables and the payload can be quickly re-installed.

## REFERENCES

[1] Munakata, Riki, *CubeSat Design Specification*, Rev 12, Cal Poly SLO, 1 Aug 2009.

[2] *Canisterized Satellite Dispenser (CSD) Data Sheet*, 2002337 Rev A, Planetary Systems Corp., 6 Aug 2013.

[3] *Payload Specification for 3U, 6U, 12U and 27U*, 2002367 Rev A, Planetary Systems Corp., 6 Aug 2013.

[4] Holemans, Walter and Moore, Gil, *Counting Down to the Launch of POPACS, SSC12-X-3 26th Annual AIAA/USU Conference on Small Satellites*, Aug 2012, Logan, UT.

[5] Allred, Tyler, www.allred-astro.com

## BIOGRAPHY

*Ryan Hevner received a B.S. in Engineering from Rensselaer Polytechnic Institute in 2002. He has been with Planetary Systems Corp. for 11 years. During that time he has enjoyed designing numerous Lightband separation systems, unique Space Shuttle payload deployment systems and the Canisterized Satellite Dispensers.*

## ACKNOWLEDGEMENTS