3U, 6U and 12U CSDs. 6U shown with access panels removed. Dimensions in inches [mm].

Feature	Benefit
Preloaded Payload Tabs	Preload means the **payload can't jiggle and damage itself**. Creates a modelable load path to the payload so strength at critical locations like reaction wheel bearings can be accurately calculated.
Low Tip-Off	**Payloads stabilize rapidly**. Precision tabs, roller bearings and a linear way combine to minimize disturbance torques.
Six Mountable Sides	Greatly **reduces the cost, complexity and mass** of adjoining structures and interface plates to the launch vehicle.
Motor Driven Initiator	Creates the **lowest cost, most reliable** dispensing mechanism that **resets in seconds** without consumables.
Robust Structural Design	**Withstands**

TABLE OF CONTENTS

1. FLIGHT HERITAGE

The CSD is at Technology Readiness Level (TRL) 9. A 3U CSD flew aboard the inaugural Falcon 9 v1.1 flight on September 2013 and released the 7-piece POPACS payload in orbit. See ref. 6. Also see www.planetarysys.com for up to date flight heritage.

Figure 1-1: Integration of POPACS mission (Ref. 2, 6)

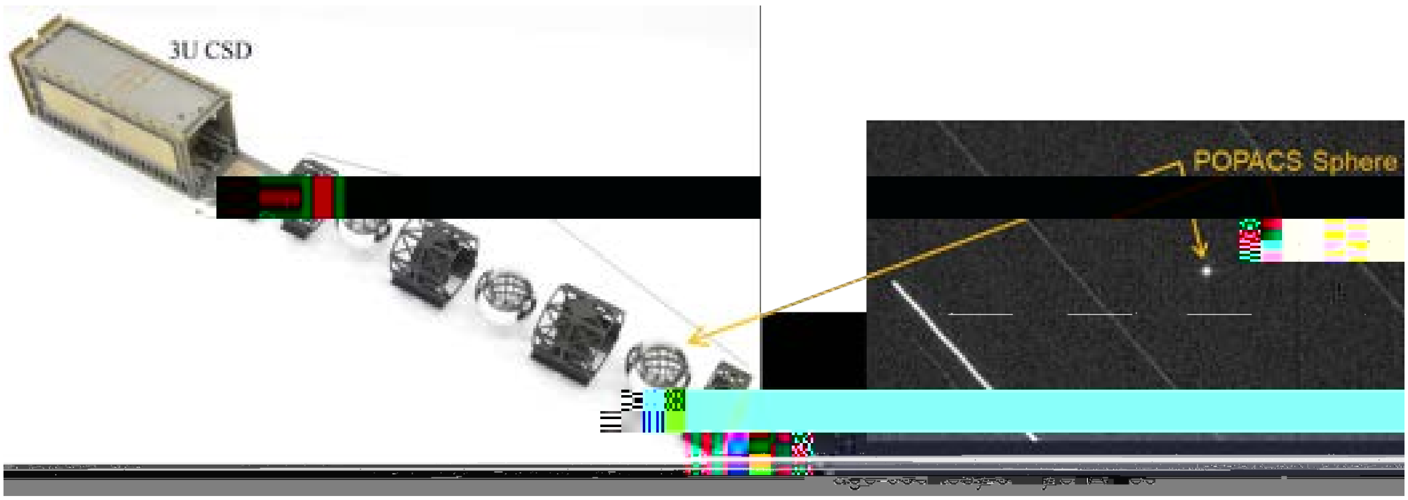

Figure 1-2: POPACS satellite and on-orbit image

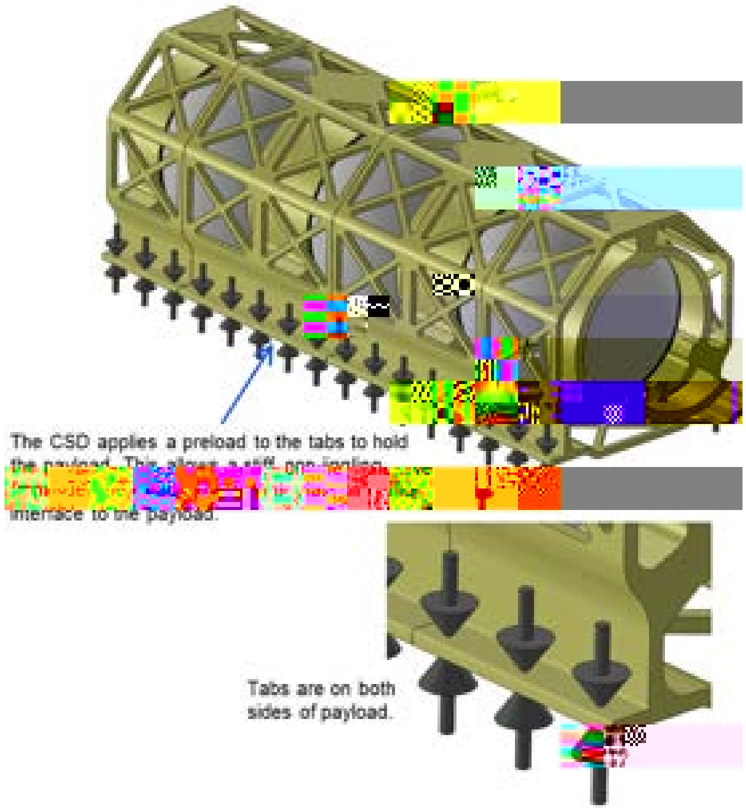

Figure 3-3: Preloaded tabs of a 3U payload (ref. 2)

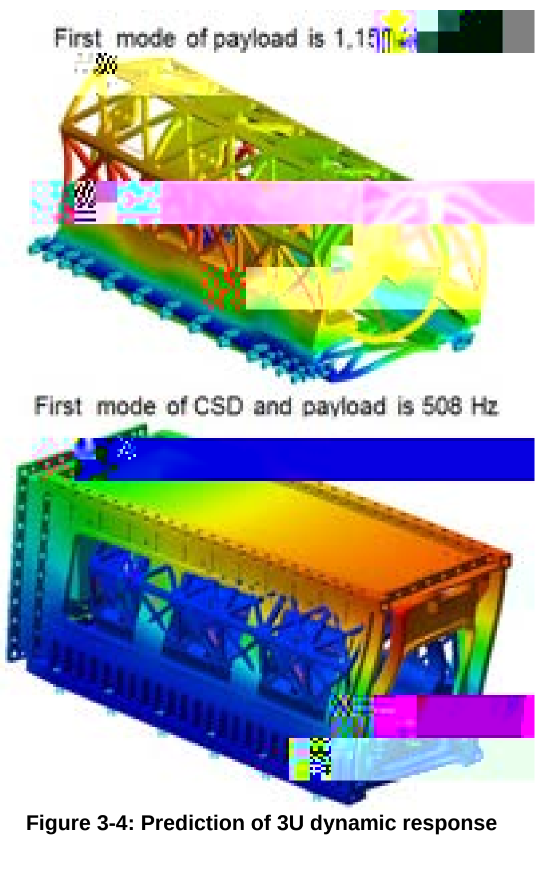

Figure 3-4: Prediction of 3U dynamic response

Preloaded tabs allow for accurate dynamic modeling that can be used to predict fatigue of structures, mechanisms, electronics, PCBs, solder junctions, etc.

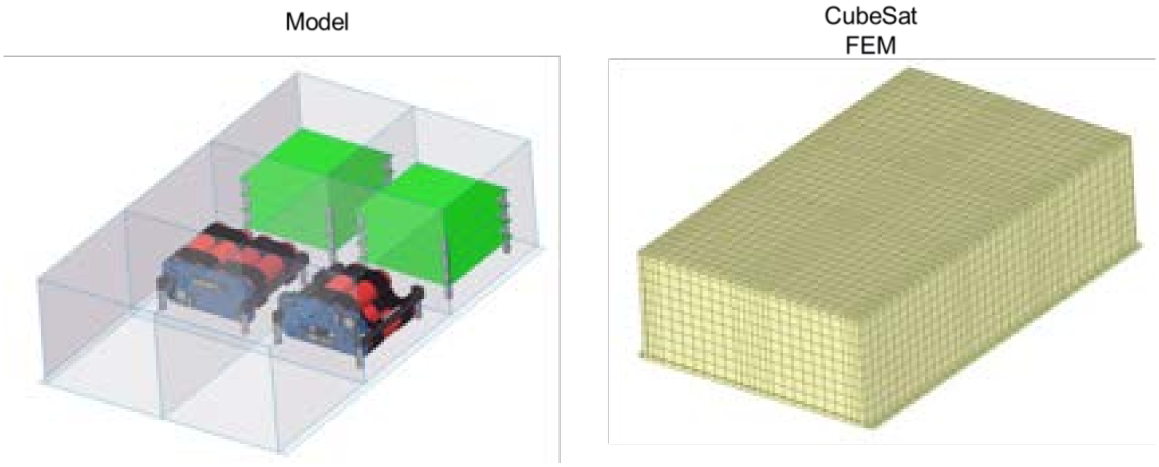

Figure 3-5: Satellite model and FEM

Figure 3-6: Normal modes analysis of satellite elements

Figure 3-7: Identifying components with high strain

The CSD's unique ability to preload tabs attached to the payload guarantees a stiff, invariant load path from launch vehicle to payload. In the sine burst profile below, the input to the CSD is transferred through the tabs to the payload, verifying that there is no slipping or jiggling within the system.

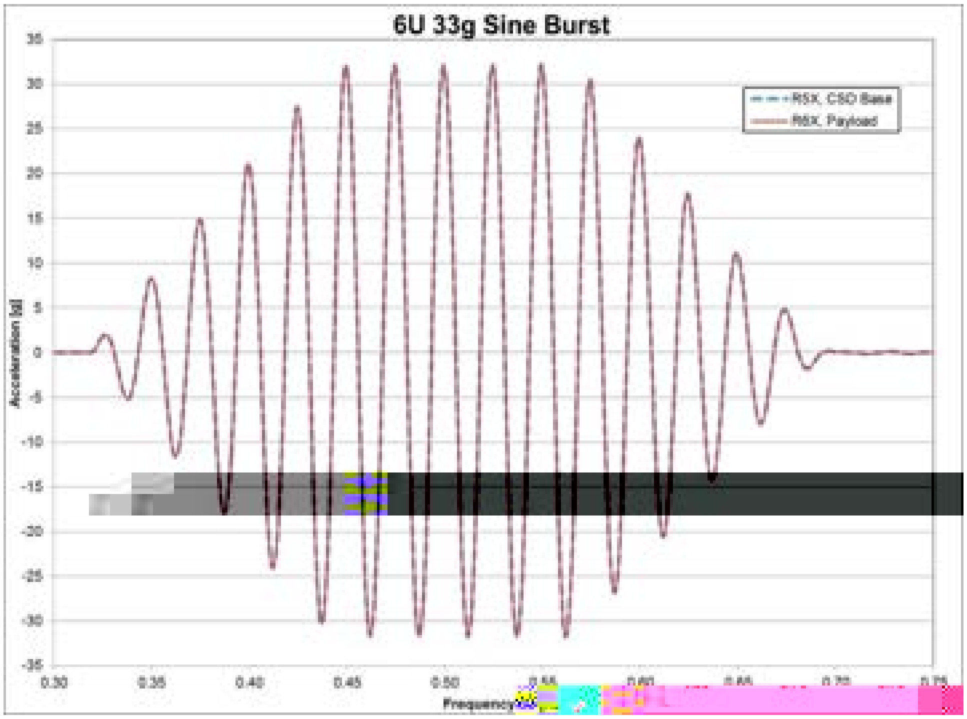

Figure 3-8: Actual payload and CSD response during a sine burst test

Preloaded tabs allow designers to accurately model and predict their payload response with high confidence. The sine sweep profiles below demonstrate no change in load path (slipping) from the CSD to the payload after sine burst and random vibration exposure.

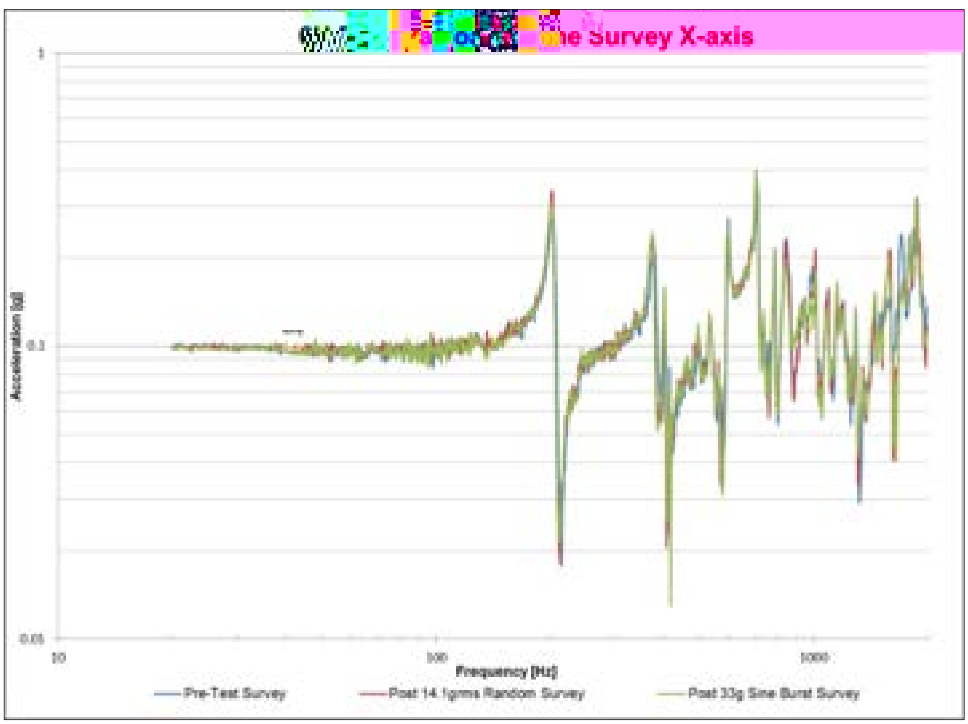

Figure 3-9: Actual payload sine sweeps

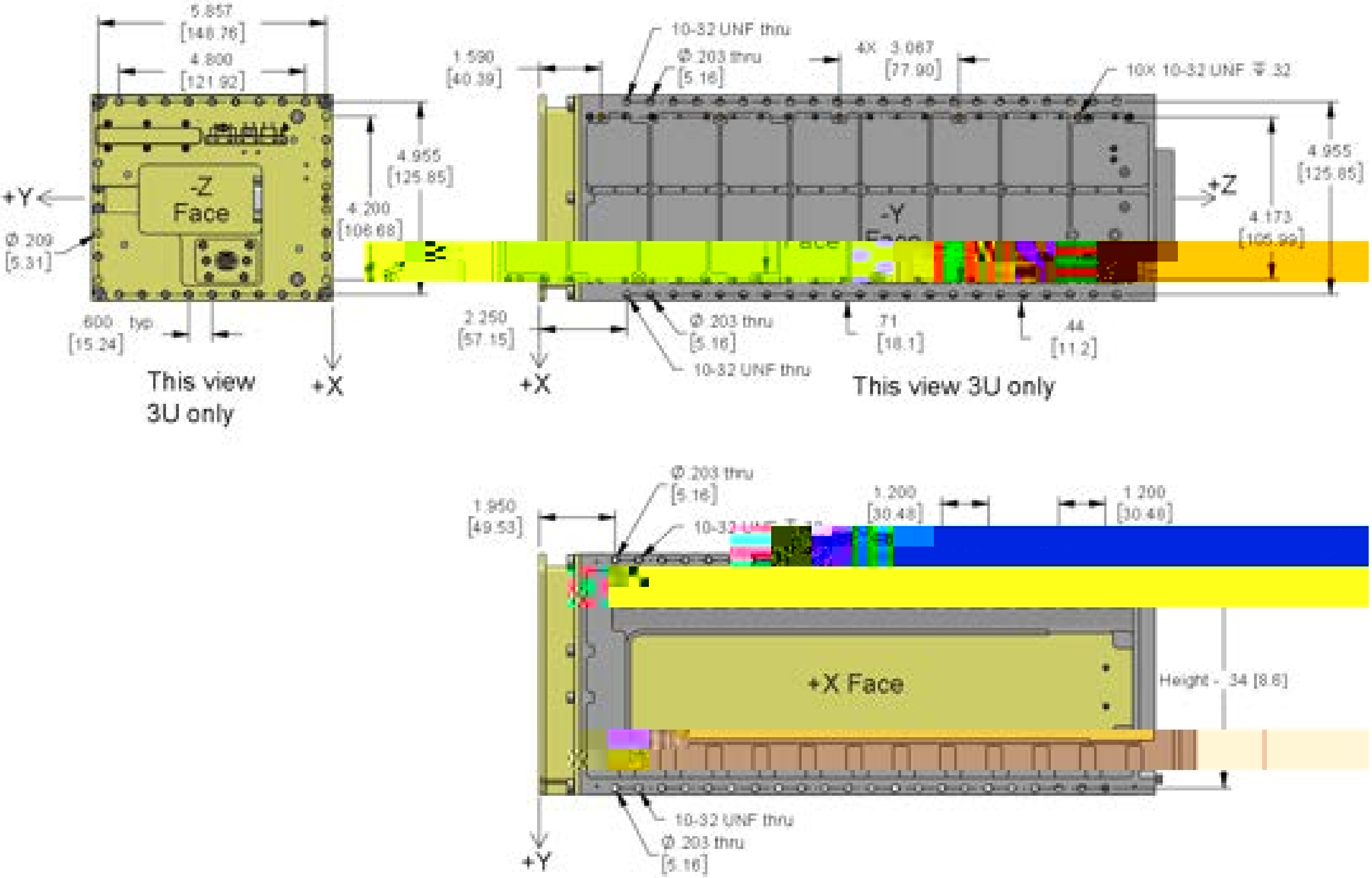

Figure 5-2: Mechanical interface dimensions (cont.). Some views unique to 3U.

6. ELECTRICAL INTERFACE

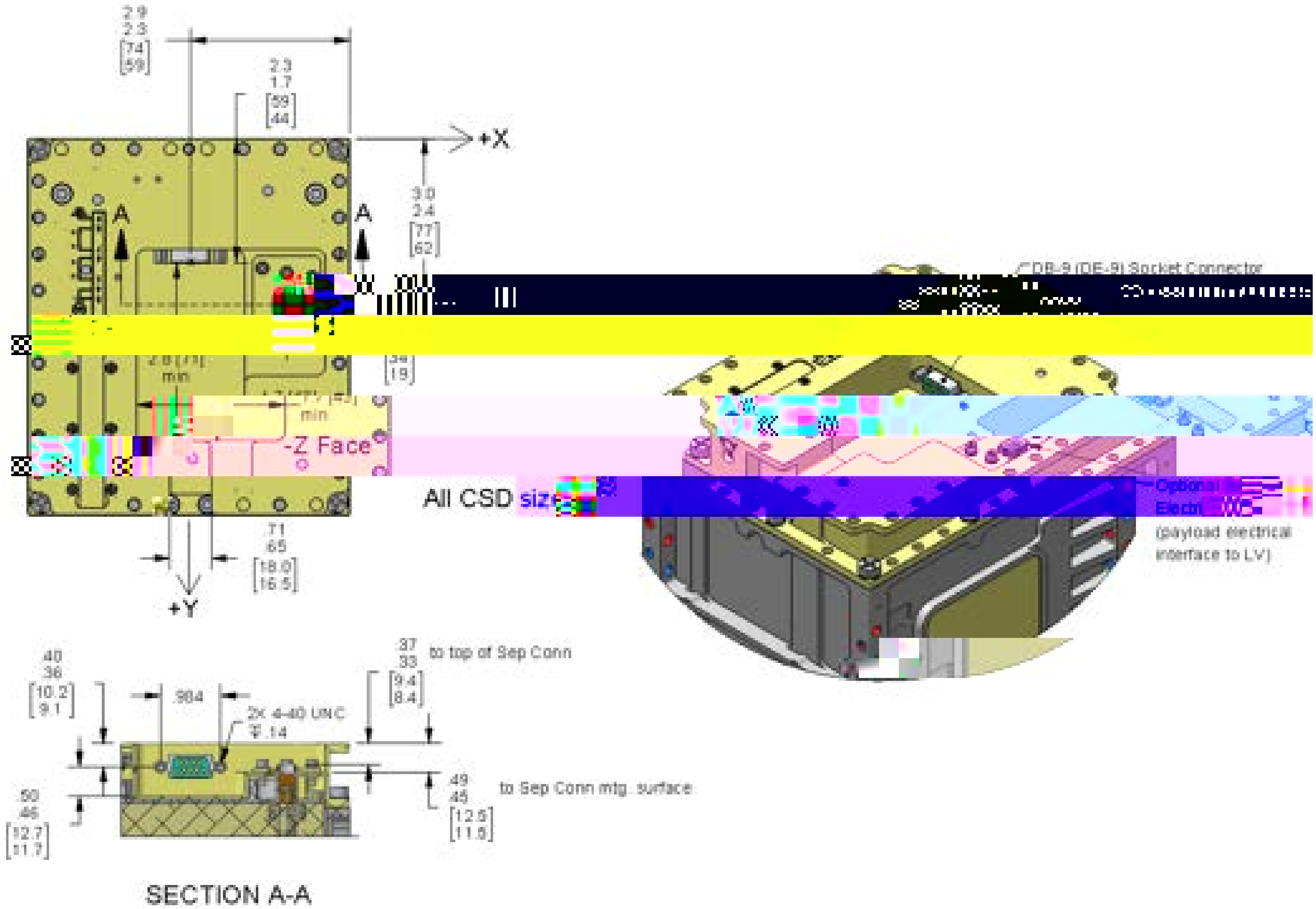

Figure 6-1: Launch vehicle electrical interface

7. ELECTRICAL SCHEMATIC

Figure 7-1: CSD electrical s

During qualification testing, PSC monitored the electrical continuity of the Separation Connector, Door Switch and Occupancy Switch. See Figure 7-3 for the circuit. The Separation Connector had 14 of its 15 pins wired in series through loopbacks.

In thermal vacuum testing all circuits remained electrically closed across all temperatures.

During shock and random vibration testing the components were monitored at 10 kHz per channel to detect intermittencies. All three items exhibit some intermittencies. The frequency and duration of the intermittencies varies with CSD size, excitation axis, mounting face and payload dynamic response. Electrical designers should be aware of these potential intermittencies to design their hardware and software accordingly. Figure 7-4 and Figure 7-5 show example intermittency during 14.1 grms random vibration. The units of time are seconds in the figures below.

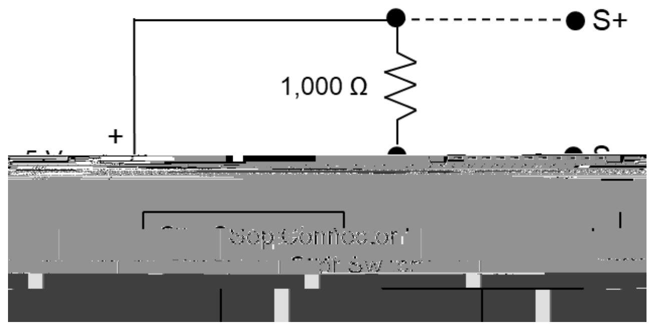

Figure 7-3: Measurement circuit

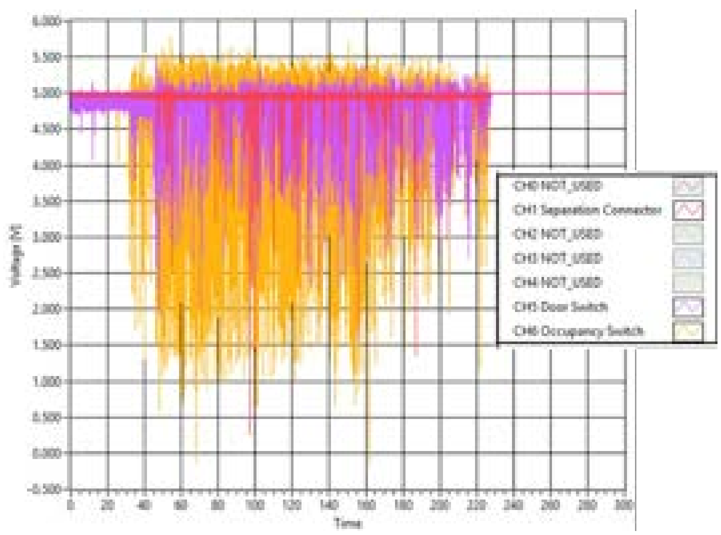

Figure 7-4: Example random vibration intermittency

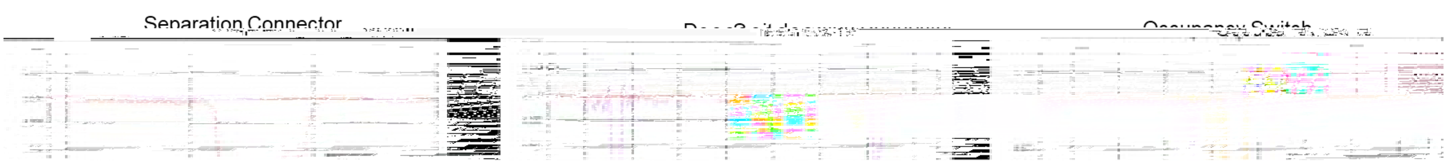

Figure 7-5: Typical duration of discrete intermittencies

9 MAXIMIZE TELEMETRY

It is crucial the launch vehicle (LV) utilizes all CSD switches to maximize flight telemetry and inform anomalies. Both limit switches can be monitored on a single channel by wiring as shown below.

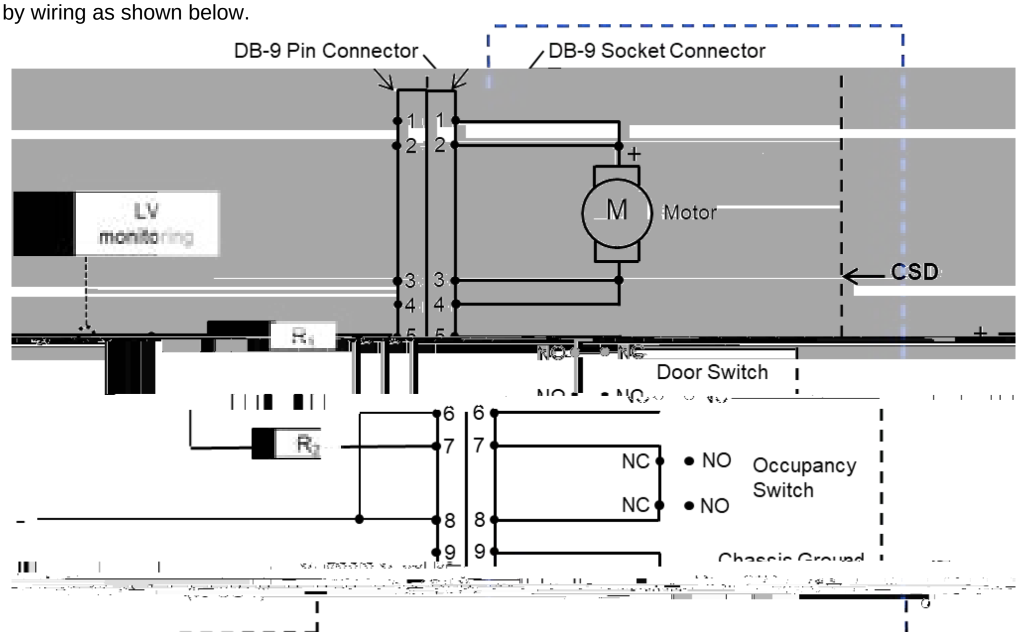

Figure 9-1: Door and Occupancy Switch monitoring

The current flowing through 'LV monitoring' will vary depending on Door Switch and Occupancy Switch state. Thus the state of both switches can be determined from one channel. See Figure 9-2 for example.

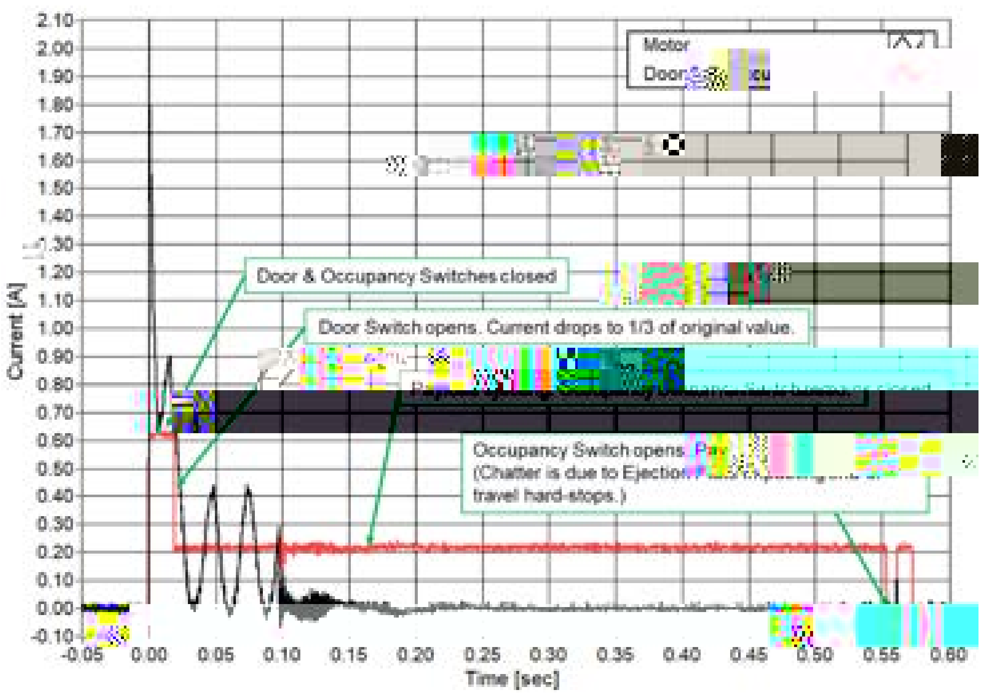

Figure 9-2: Monitoring door and occupancy switch on a single channel

Also, the payload's ejection velocity can be approximated using the timing of the two limit switch activations.

$$\frac{2}{-}$$

V is ejection velocity [length/time]
D is distance between Ejection Plate's stowed and deployed positions [length] see Figure 15-3
T_O is the Occupancy Switch opening time [time]
T_D is the Door Switch opening time [time]

11. PAYLOAD IN CSD

The figure below shows the size and location of CSD access zones relative to the payload origin. Dimensions apply to all CSD sizes.

Figure 11-1

12. ENVIRONMENTAL TESTING

All flight CSDs undergo environmental tests to verify workmanship. CSDs that have been qualified for a specific mounting face undergo acceptance testing on all flight units. If a specific size and mounting face has not yet been qualified, the flight unit receives proto-flight testing. Mounting the CSD via the -Y or -Z face is considered standard. If planning to mount the CSD via any other face contaacentalED v actandarontaacafyifi(fi)-3.5(a)-7.9 (ti)-3.6. (l)-3.5 (

12.2 Thermal Vacuum

Testing is conducted in PSC's thermal vacuum chamber. The CSD is fastened via the -Y face to aluminum interface plates which are in turn fastened to a copper plate. A heat exchanger pumps refrigerant through tubing on the underside of the plate to conductively heat and cool the CSD.

Location: PSC
Objective: Verify separation at temperature and pressure extremes
Test Description: During this test, the CSD will be thermally cycled in a chamber that maintains vacuum. The payload in the CSD will be separated while still under vacuum at the conclusion of thermal cycling. Upon test completion, the CSD and payload are removed from the chamber and formally inspected.
Test Parameters:

Temperature Range [°C]: -24 to +61 (Values may be exceeded at PSC's discretion).
Thermal Cycles [-
Separation Temperature [-]: hot or cold extreme at PSC's discretion
Pressure at Separation [Torr]: <1E-4

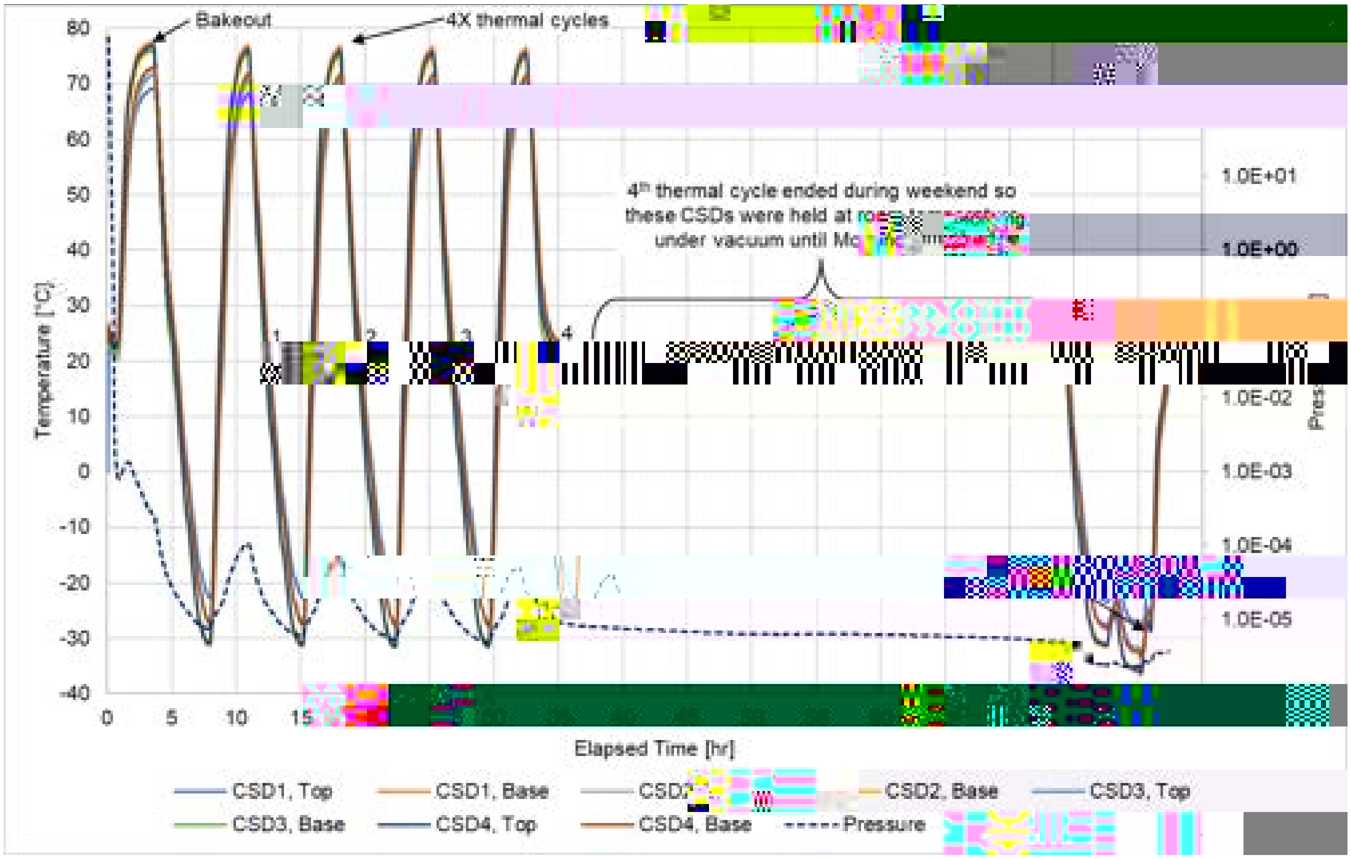

Figure 12-1: Sample thermal vacuum environmental data, 4 CSDs tested concurrently

Figure 12-2: Thermal vacuum testing 4 CSDs in PSC's chamber. Conveyors allow complete payload dispensing (see Section 25).

12.4 Applied Shock (not a standard test)

Shock testing is only performed on qualification and proto-flight units. Figure 12-5 shows the qualification applied shock SRS specification for the CSD. For each impact and axis >50% of the curve is above the specification. Both the positive and negative SRSs meet the tolerance. This is measured at the CSD interface surface, <2 in from the CSD. Figure 12-6 shows a respresentative time domain impact. Figure 12-7 shows a representative test setup.

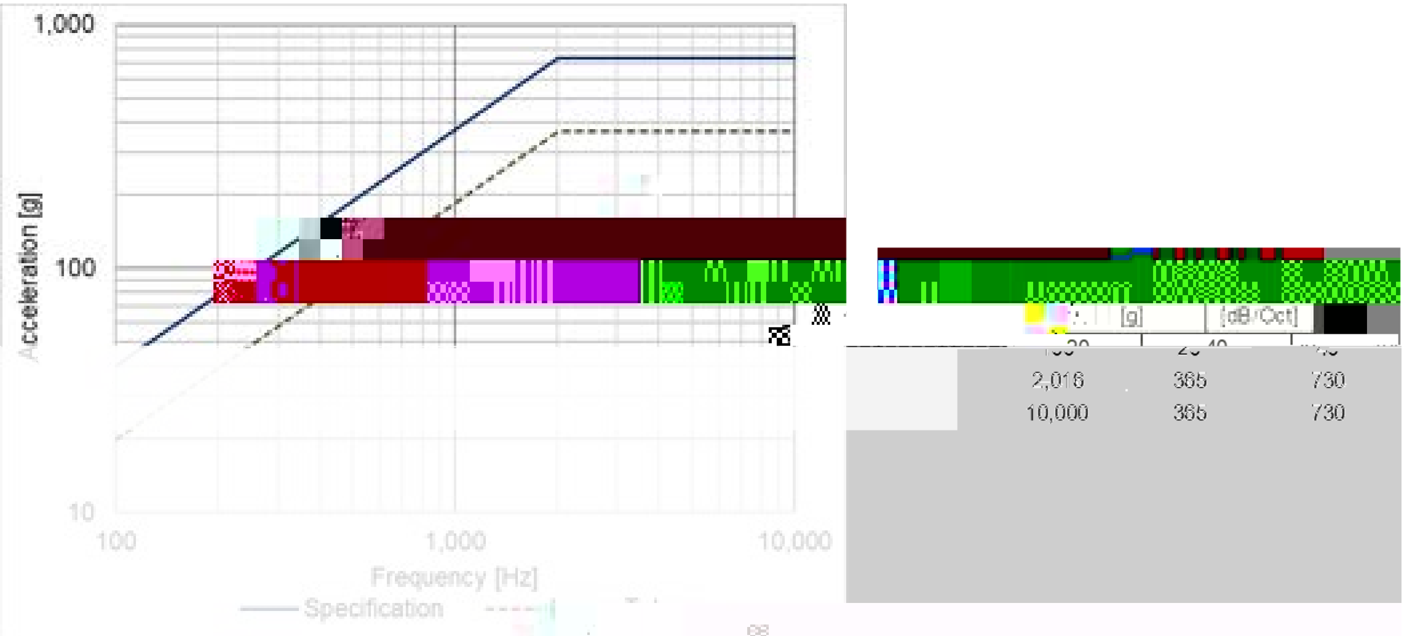

Figure 12-5: CSD applied shock specification

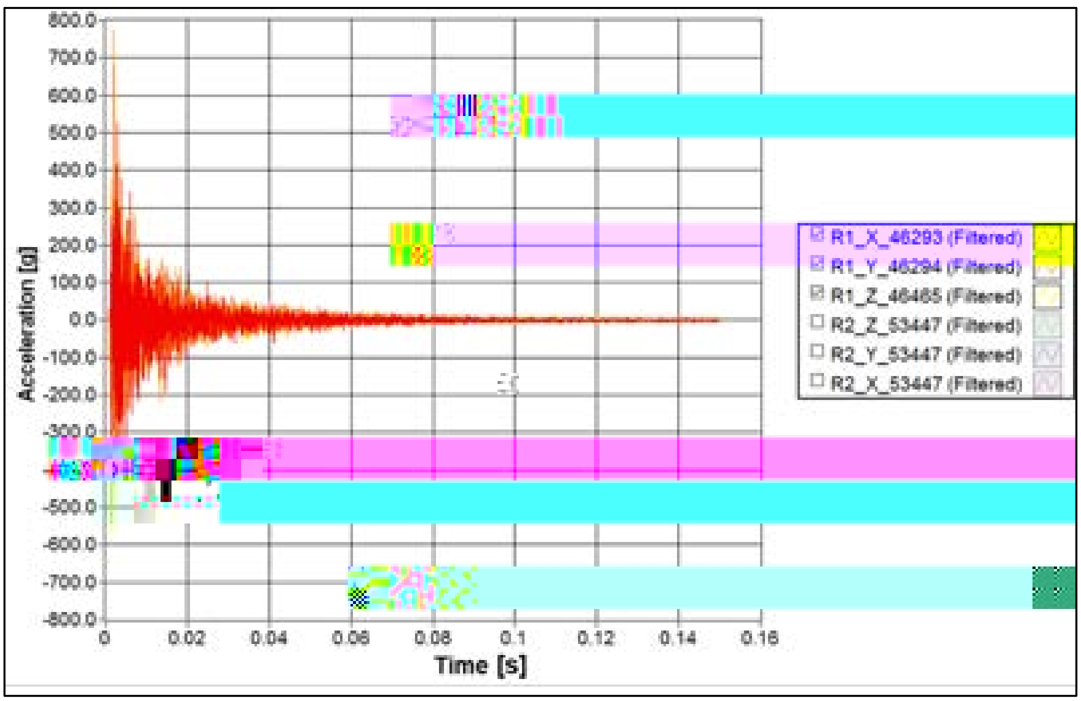

Figure 12-6: Representative time domain shock impact

Figure 12-7: Qualification applied shock test setup, 6U, -Z mtg face

12. CSD-GENERATED SHOCK

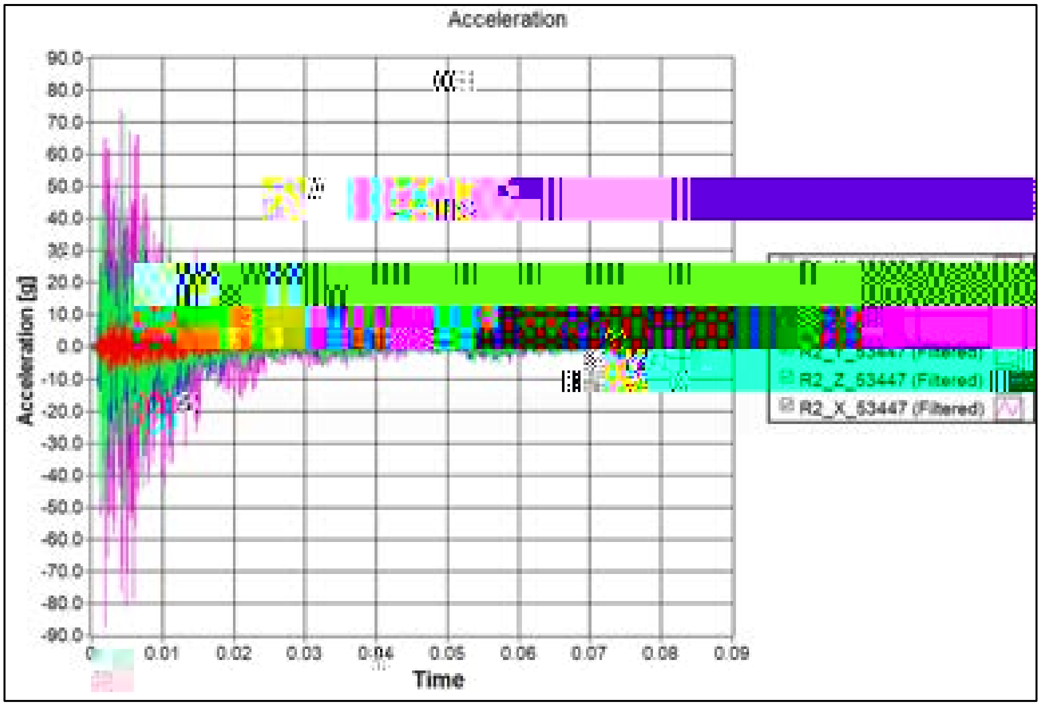

Figure 13-3: Representative time domain CSD generated shock, initial impact (R1 LV, R2 payload)

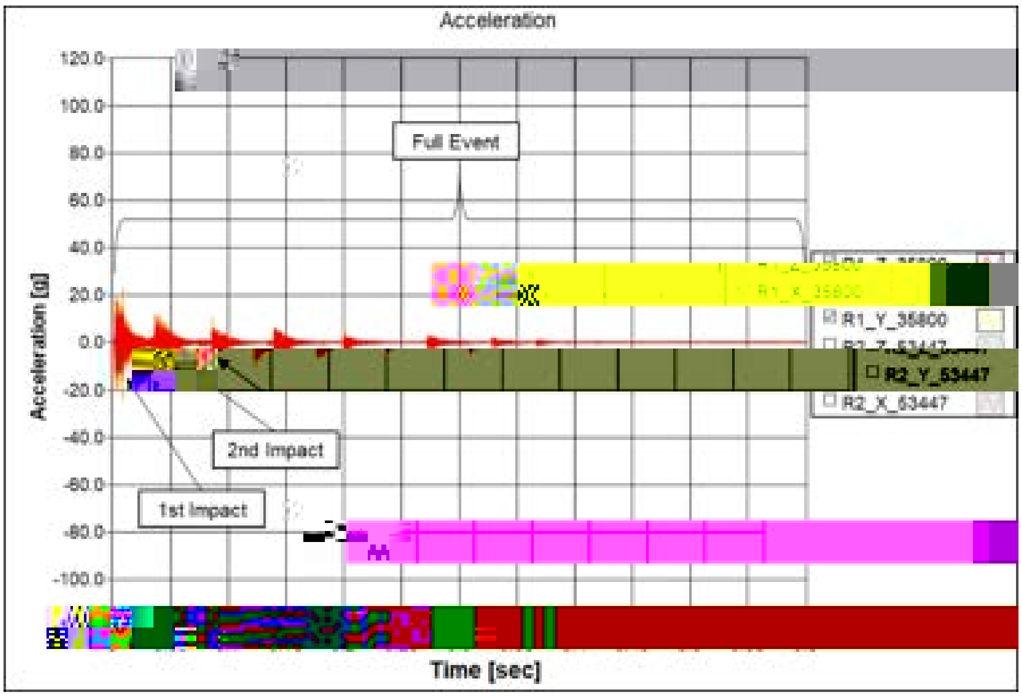

Figure 13-4: Representative time domain CSD generated shock, full event

14. MICRO-GRAVITY FLIGHT

In August 2014, PSC conducted micro-gravity flight testing of the 3U and 6U CSDs aboard NASA's Weightless Wonder aircraft. The testing took place over 4 flights with about 40 parabolas per flight. The 3U CSD was operated 52 times in micro-gravity and the 6U CSD was operated 84 times in microgravity. The separation velocity and tip-off rates of the payload were measured during each operation. Videos and papers of CSD operations during the micro-gravity testing can be found at www.planetarysys.com. These papers explain the scatter in the rotation and velocity measurement which are expected to be lower on orbit (ref. 11).

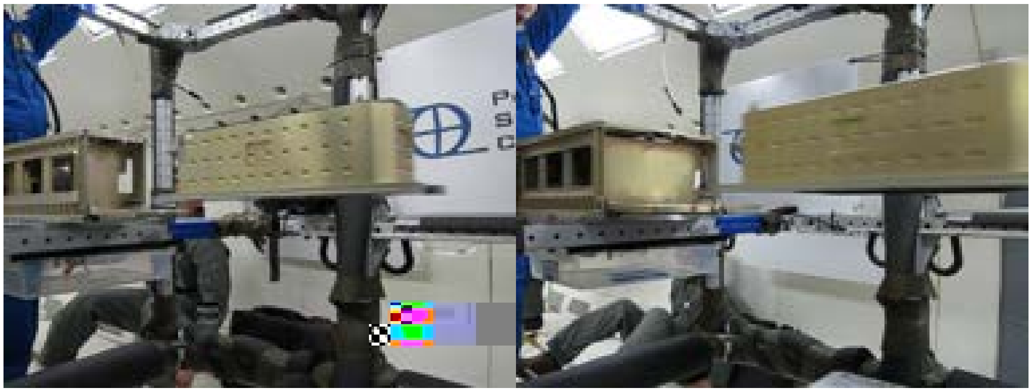

Figure 14-1: 3U and 6U deployment in micro-gravity

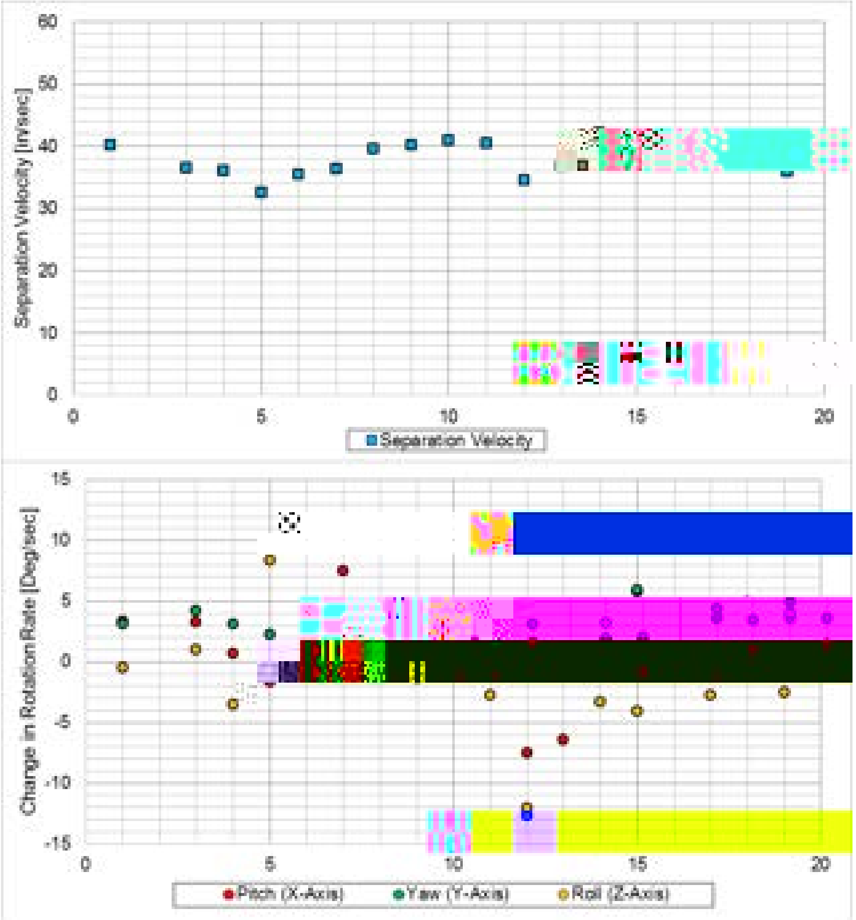

Figure 14-2: Flight 3, 3U CSD (1 spring, 9.94 lbm payload)

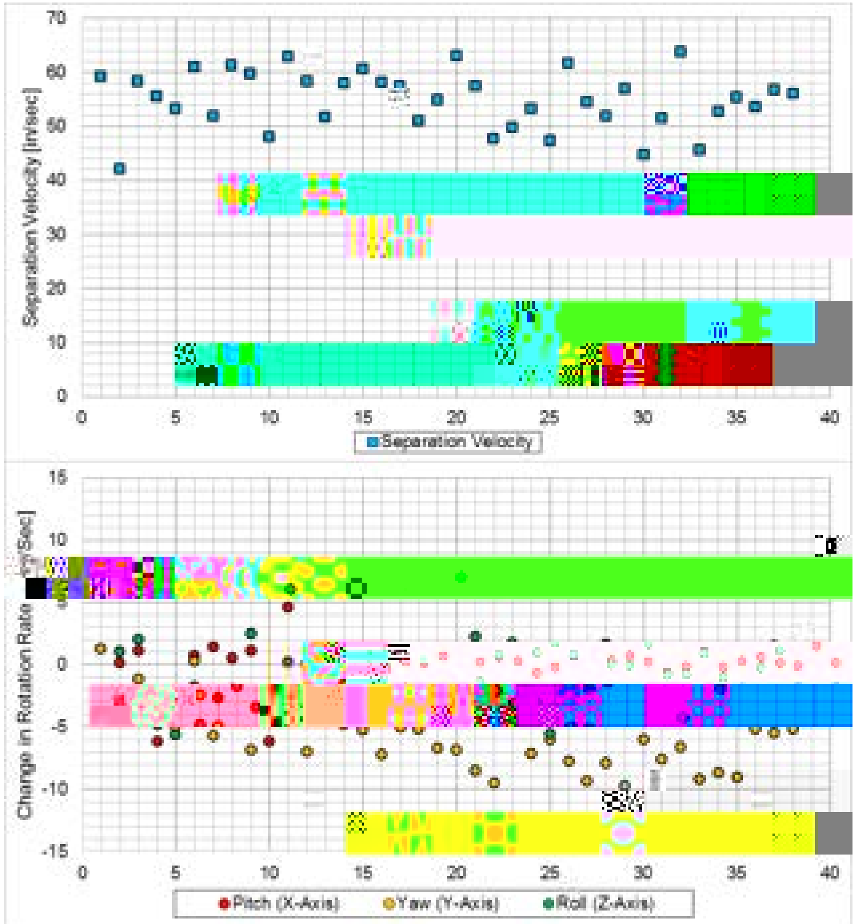

Figure 14-3: Flight 4, 6U CSD (4 springs, 19.85 lbm payload)

Figure 14-4: Test structure floating during micro-gravity test

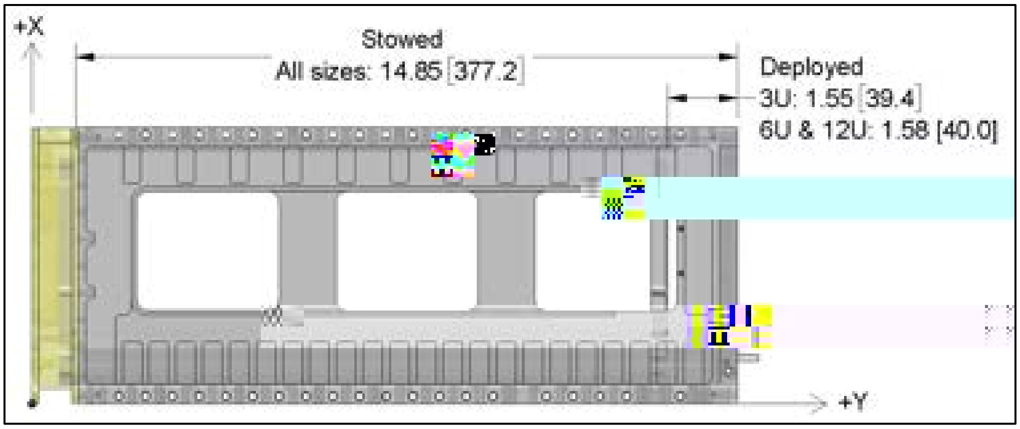

Figure 15-3: Ejection Plate travel

Figure 15-4 shows the Separation Time for the 6U qualification benchtop test. Operations 1, 81 & 91 were the initial use of new payload tabs. Notice the 'work-in' period associated. The specific reasoning is unknown but likely related to slight polishing of surface imperfections and thus a reduction in friction. Also note that operations 81 to 120 were with payload tabs outside of the allowable thickness tolerance per *Payload Specification 2002367*. PSC tests with tabs that envelope the allowable tolerance to ensure reliability. Source is PSC document 2003030.

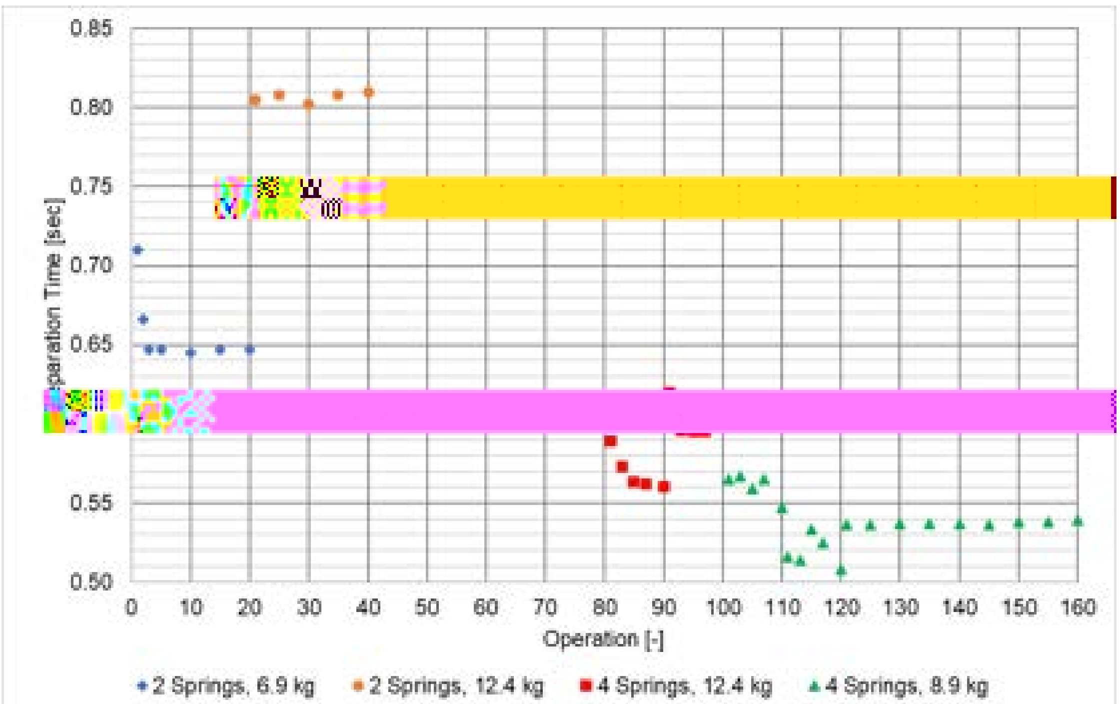

Figure 15-4: 6U qualification benchtop separation summary

Figure 16-3 shows example door angle vs. time during payload ejection. T = 0 s corresponds to power on to the CSD initiator (motor). Impact frequency and decay rate are dependent on both payload mass and ejection spring quantity, both of which are unknown for the data presented. Source is PSC document 2003130. See Table 4-1 for the door's mass moment of inertia.

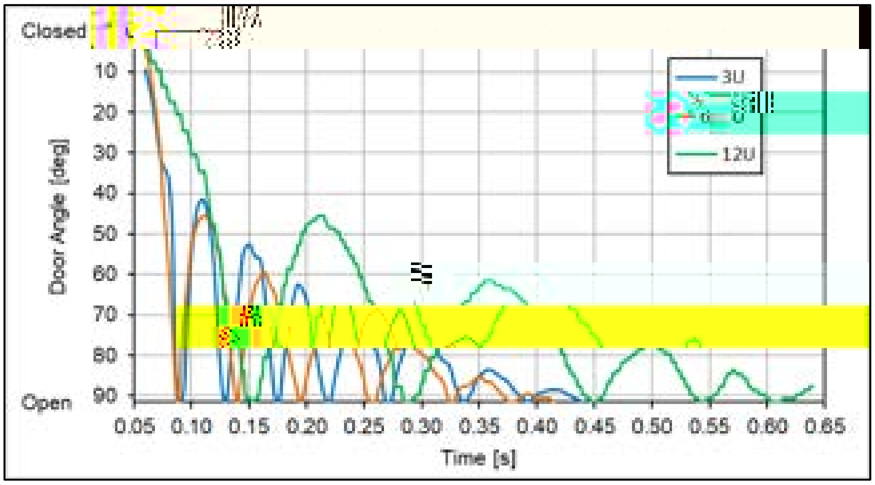

Figure 16-3: Example door bounce during ejection

The torque on the CSD's door during both opening and closing was measured for all three sizes. It was first measured with a payload installed and then repeated without a payload. See Figure 16-4 and Figure 16-5. The hysteresis is due to friction. With the payload installed, all three sizes are very similar because the majority of the torque results from the tab preload system which is identical for all CSDs. Without the payload, the 3U experiences less torque because it has fewer internal springs than the 6U and 12U. The CSD was oriented with gravity in +X to minimize gravity induced torques. See Figure 16-6. Source is PSC document 2003108.

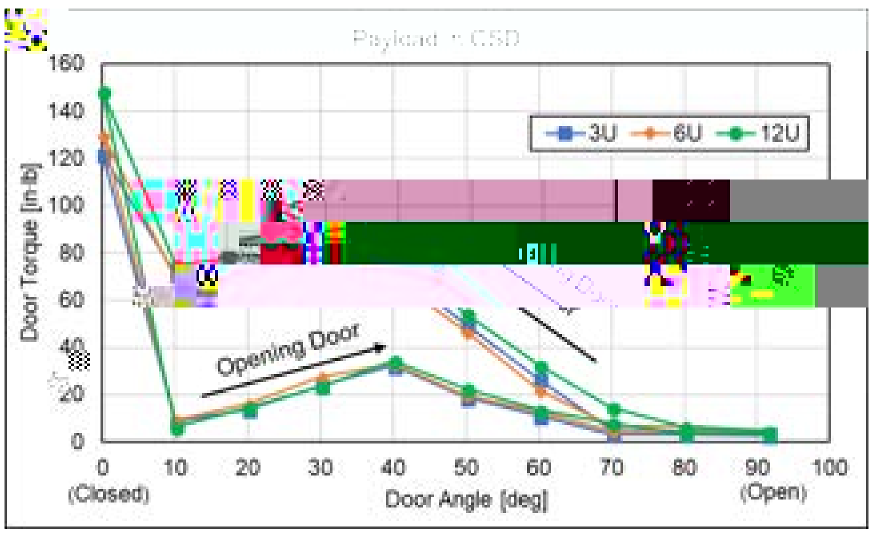

Figure 16-4: CSD door torque with payload installed

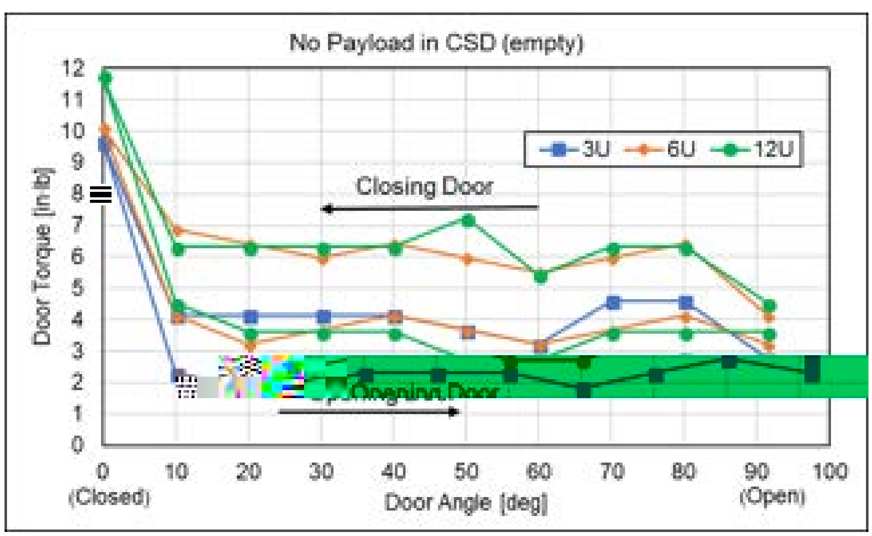

Figure 16-5: CSD door torque without payload (empty)

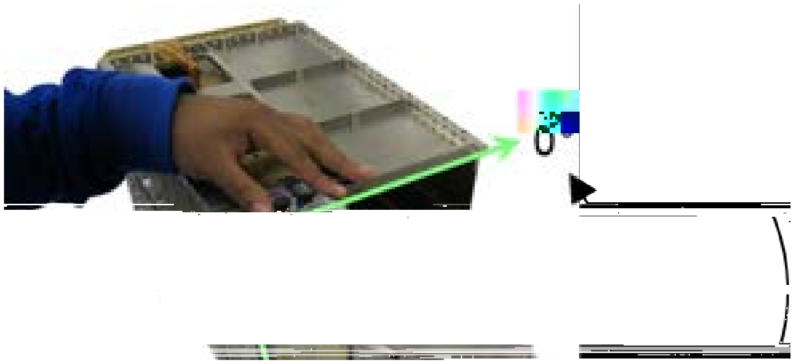

Figure 16-6: Door torque test setup

17. ALLOWABLE PAYLOAD RESPONSE

The 3 RSS payload response due to all loading shall not exceed a total of 800 lbf (3,560 N) on both tabs. This capability is verified with margin on qualification and proto-flight CSDs.

Simply claiming a dispenser can accommodate a certain payload mass is not productive because every payload has a unique dynamic response. The loading on the CSD is affected by the variable stiffness, damping, and effective mass of each payload. Figure 17-1 illustrates the extreme difference in response of two payloads of the same mass. Higher damping within the payload and/or isolation between the CSD and launch vehicle greatly increases the mass capability.

Figure 17-1: Payload response comparison

As a further example a 12 kg 6U payload exhibited a lower total response than a 9 kg payload despite being 33% heavier. Both were tested in the same CSD with the same 14.1 g_{rms} input.

It is important to note that the total 800 lbf response limit does not typically result from the quasi-static launch acceleration multiplied by payload mass. For example if the launch vehicle provides an 8g launch load, the payload cannot be 100 lb. Resonances and low damping can create higher effective responses than 8 g. Isolation systems can increase damping and move the resonant frequency. This is what larger vehicles do: coupled loads analysis, then if the response is too high, isolate or strengthen. If encapsulation is not absolutely necessary use a Lightband instead. It is lighter, supports much larger loads, allows larger volumes and has lower tip-off.

Contact PSC if the 800 lbf response requie re ane (i)--l d.8(av)--l d.8(a8 (e ane ()-3.-l)-3.5 u-l)-onan

TAB GAPS & DISCONTINUITIES

The CSD can accommodate payloads with tab gaps greater than those listed in the Payload Specification 2002367 (ref. 3). **However this may result in a customized CSD and increase cost and/or delivery time.**

19. PAYLOAD VOLUME

The CSDs external volume is equivalent or smaller than other dispensers while simultaneously allowing the largest payload volume.

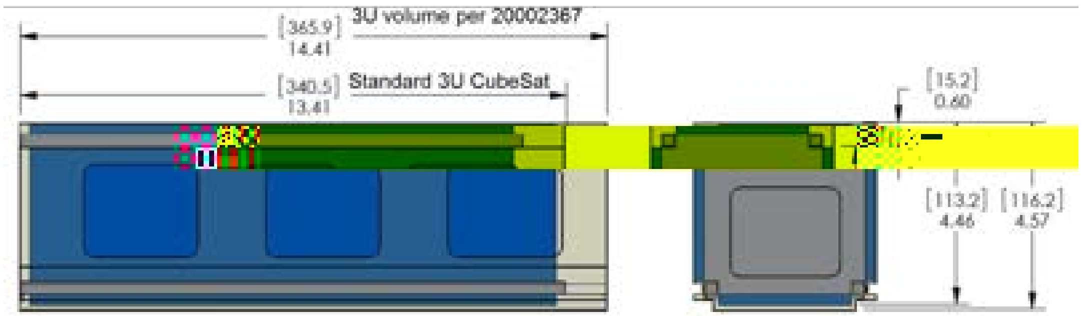

Figure 19-1: Comparison of 3U Payload Volumes. The CSD allows 15% more payload volume.

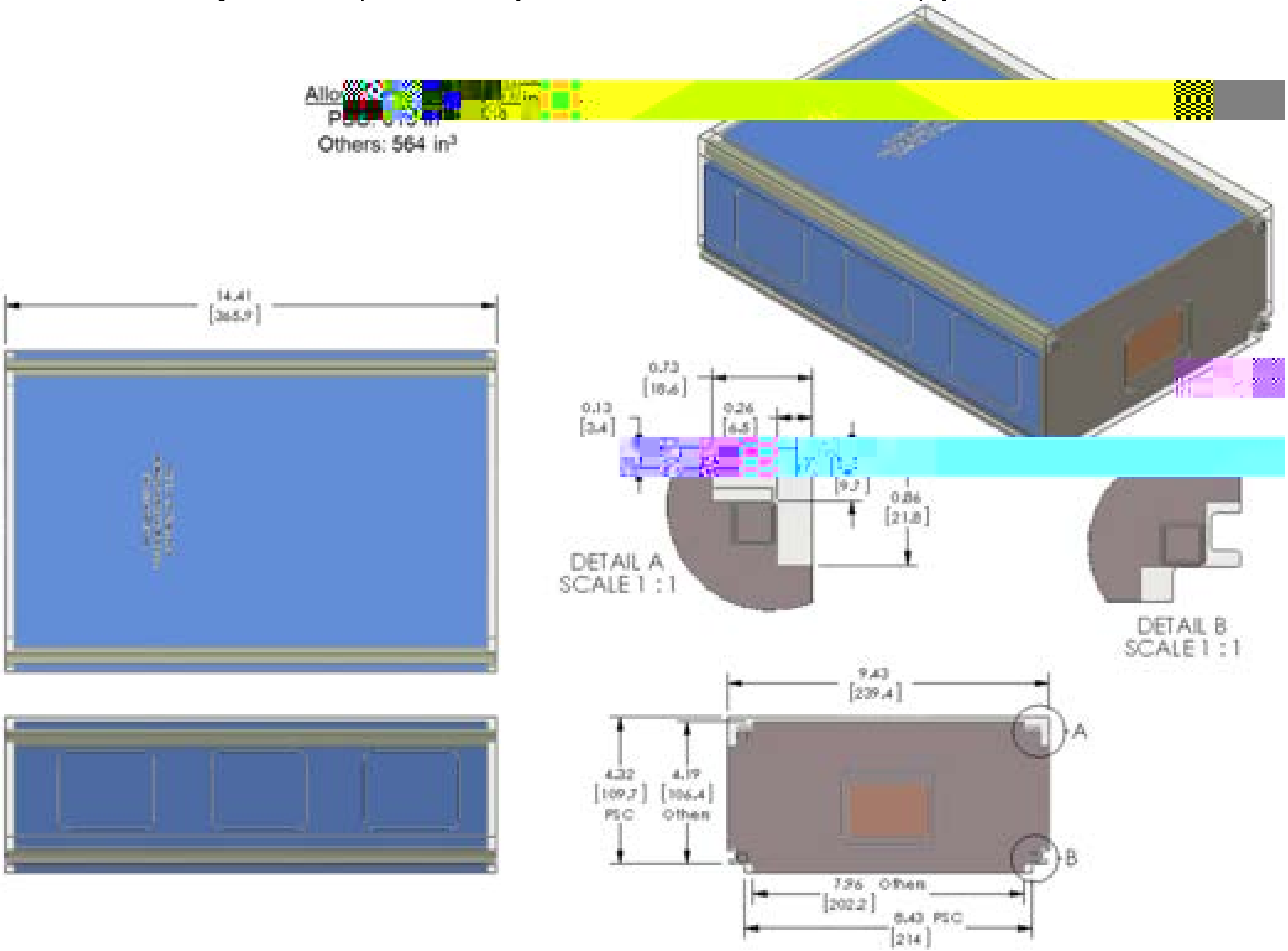

Figure 19-2: Comparison of 6U Payload Volumes. The CSD allows 9% more payload volume.

OPERATION AND INTEGRATION

Payload installation and integration is quick and straightforward. The figures below demonstrate the ease of attaching the CSD to a launch vehicle. The numerous mounting surfaces with threaded and through holes eliminate the need for additional interfacing structures. Use a minimum of 4 fasteners, one at each corner, when attaching the CSD to adjoining structures. The exact fastener qty. required shall be determined to ensure no gapping or slipping between the CSD and LV interface. The payload may be installed either before or after the CSD has been attached to the LV interface. Operating the door (either electrical or manually) after installation and verifying reliable dispensing of the payload is essential to ensure proper operation in the final flight configuration. PSC document 3000257 *CSD Operating and Integration Procedure* (ref. 13) shall be used for all payload installations, CSD operations, and launch vehicle integration. Further, only trained personnel shall use the CSD. See section 29 for details.

Figure 20-1: Installing 6U payload in CSD

Figure 20-2: Using thru holes to mount CSD via –Y face

Figure 20-3ucN7.6 (i)-32 hucN7.6 0 Td P6i]f47741.15 Td1Td 8V-2./P eprh(he) (s)-2.4 rc 0 T5–

Figure 20-4: Installing CSD initiator electrical harness

Figure 20-5

21 CSD CONSTRAINED DEPLOYABLES

The CSD is capable of constraining deployables. Document 2002367 Payload Specification (ref. 3) provides details on allowable contact locations of deployables to the inside of the CSD. The distance from the payload maximum envelope to the walls can vary between .03 to .07 inches for the +/-X faces depending on the width of the payload tab. This is due to the necessary gaps in the X-axis between the tabs and the CSD. If a deployable is located on the –Y payload face, a small rotation rate will be imparted on the payload during ejection as the deployable contacts the door.

Figure 21-1: A 6U payload ejecting from the CSD

22. FASTENING PAYLOAD TO EJECTION PLATE

To facilitate hosted payloads, the payload can be permanently bolted to the CSD's Ejection Plate in the 6U or 12U. In addition, the Ejection Plate and payload can be fastened to the rear of the CSD. When the CSD initiates, the door opens and the payload either remains in the CSD or fully deploys but remains attached to the CSD. The latter is beneficial to increase aperture or field of view or deploy antennas or solar arrays. The payload can remain electrically connected to the host via a flexible harness.

The simplified CAD models of the CSD show the location of these attachment holes on the Ejection Plate.

Figure 22-1: Payload remains attached to CSD to facilitate hosted payload usage

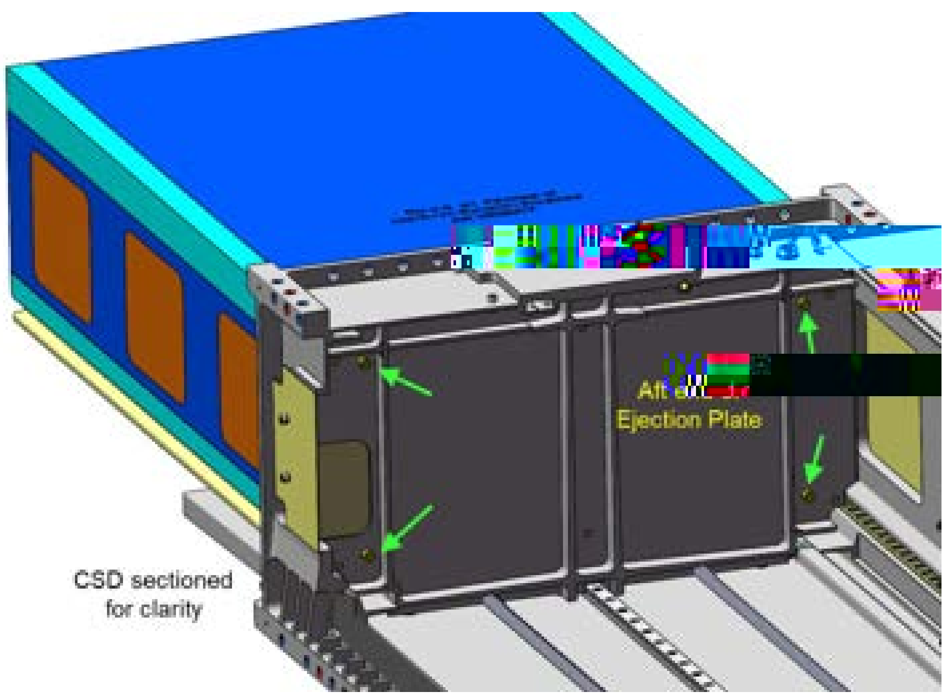

Figure 22-2: Payload permanently fastened to CSD's Ejection Plate via 4X .112-40 SHC screws

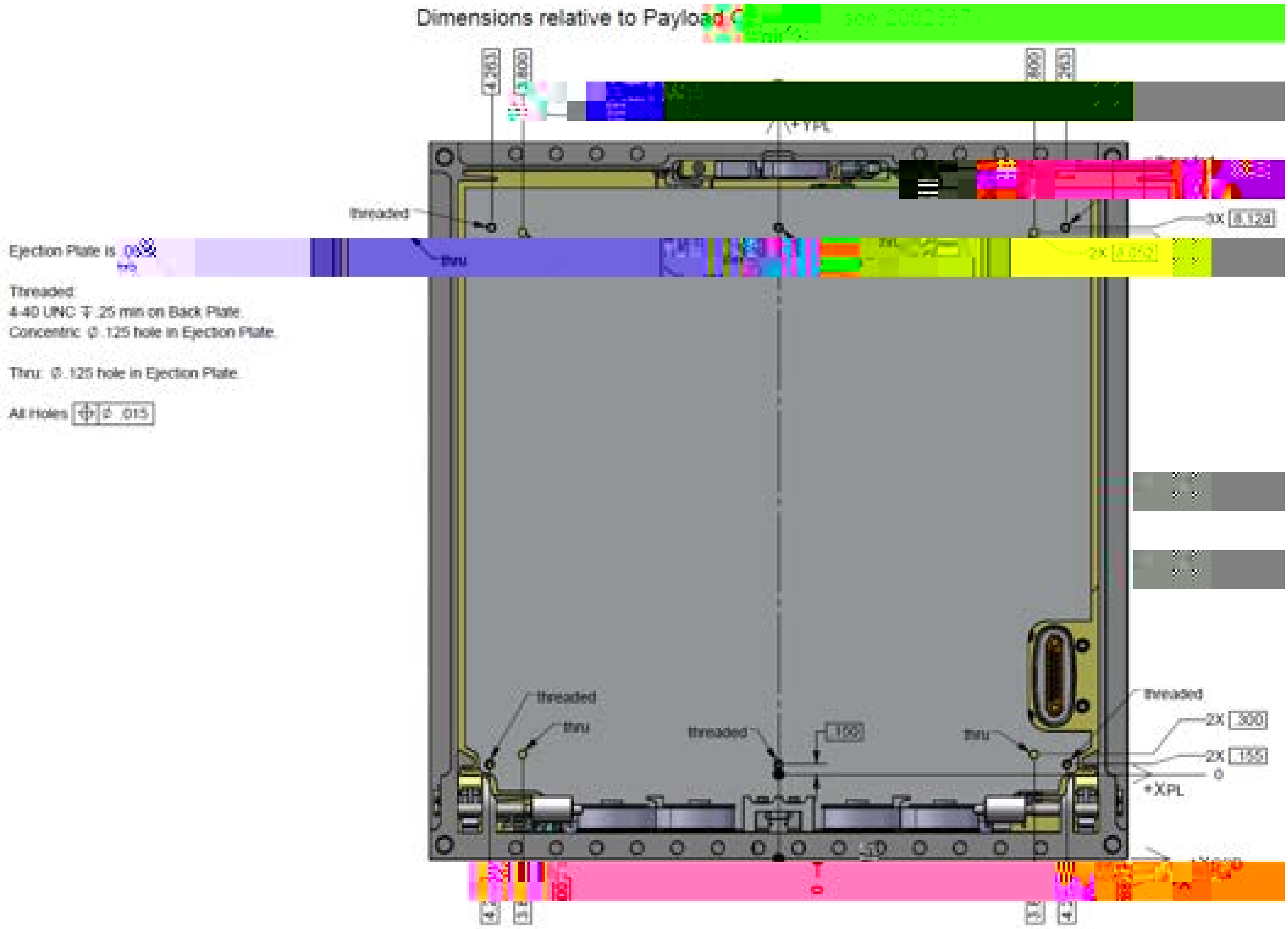

Figure 22-4: Payload mounting holes to CSD Ejection Plate or Back Plate, 12U

23. REDUCING DYNAMIC LOADING ON PAYLOAD

The CSD rigidly grips the payload’s tabs, creating a direct load path from the launch vehicle to the payload. To reduce these potentially harmful LV induced vibratory and shock loads the use of an isolation system is strongly recommended. PSC has tested several isolation systems. These include commercial isolators as well as spaceflight specific isolators from MOOG CSA Engineering. All isolators tested to date drastically reduced the random vibration response and shock acceleration. The substantial benefits to the payload include increased allowable payload mass and reduced fatigue loading of sensitive components. PSC does not offer an isolation system as a product. The figures below show the significant reduction in loading during random vibration and shock testing.

Figure 23-1: Isolation system benefits during random vibration testing

Figure 23-2: 6U CSD vibration test with Moog CSA ShockWave isolators

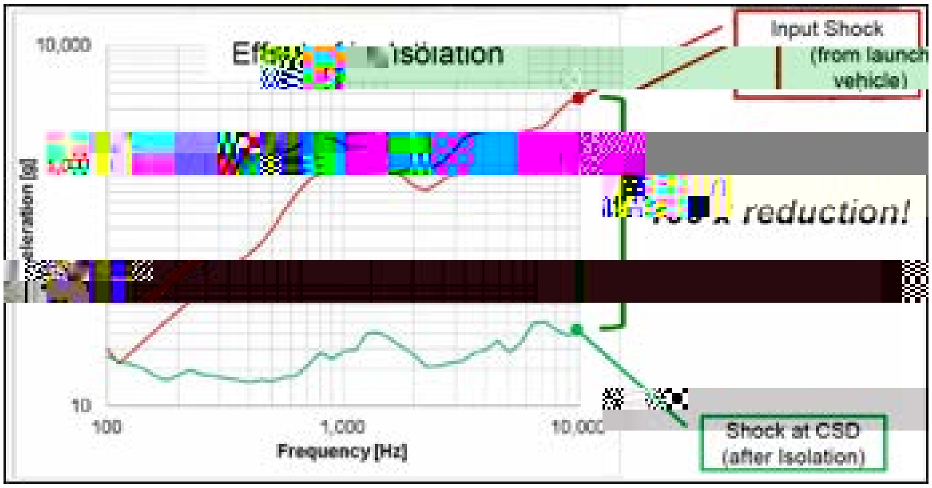

Figure 23-3: Isolation benefits during shock testing

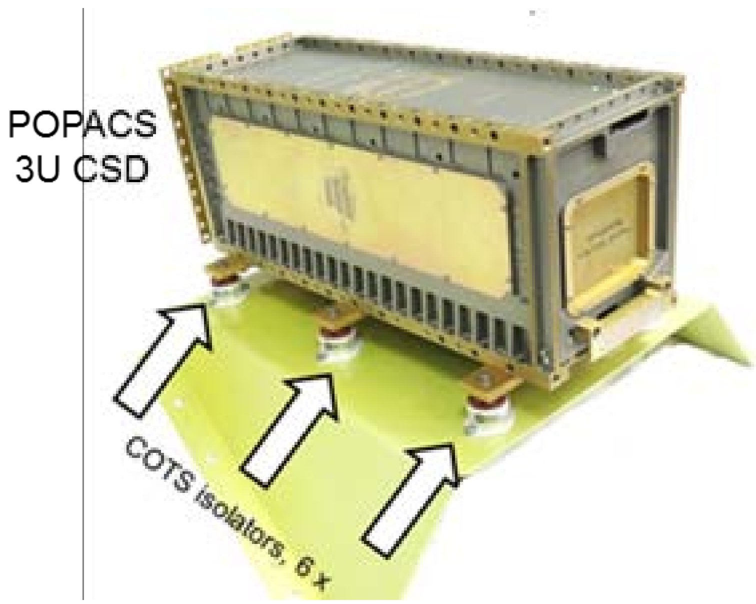

Figure 23-4: COTS isolators used on POPACS mission

24. CSD APPLICATIONS

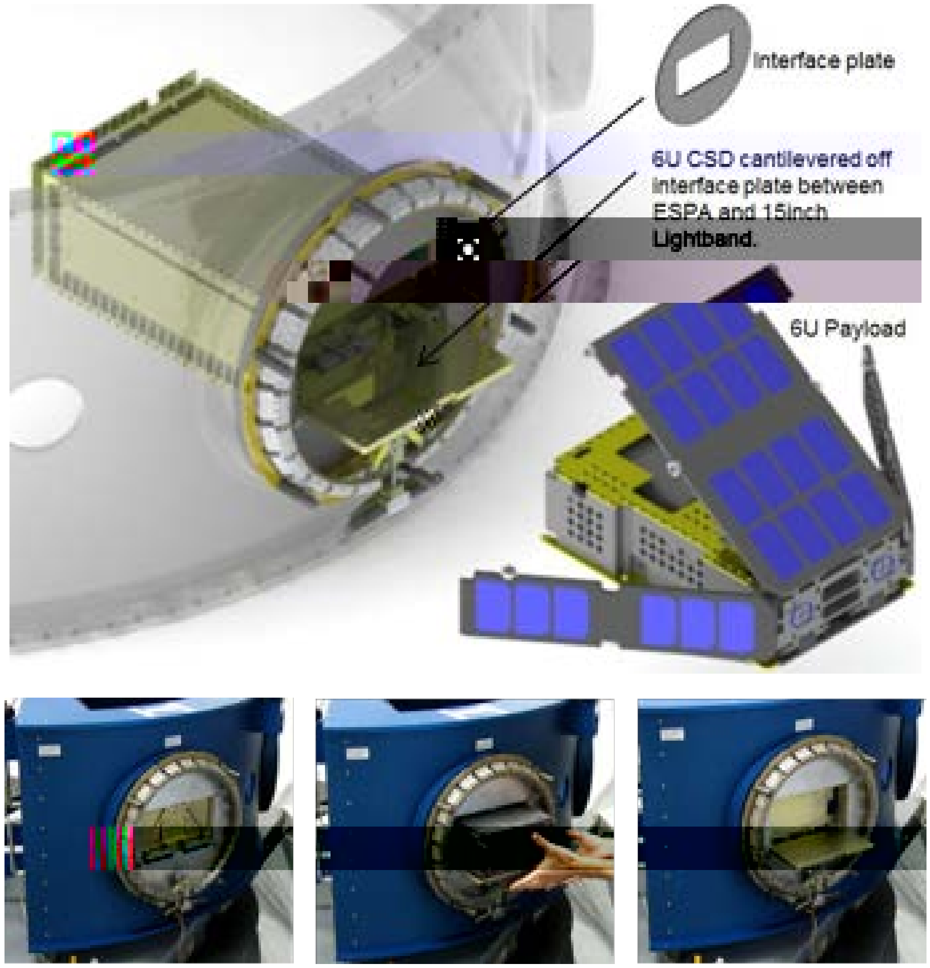

Figure 24-1: 6U payload deploying through ESPA port. CSD mounted directly via +Z face.

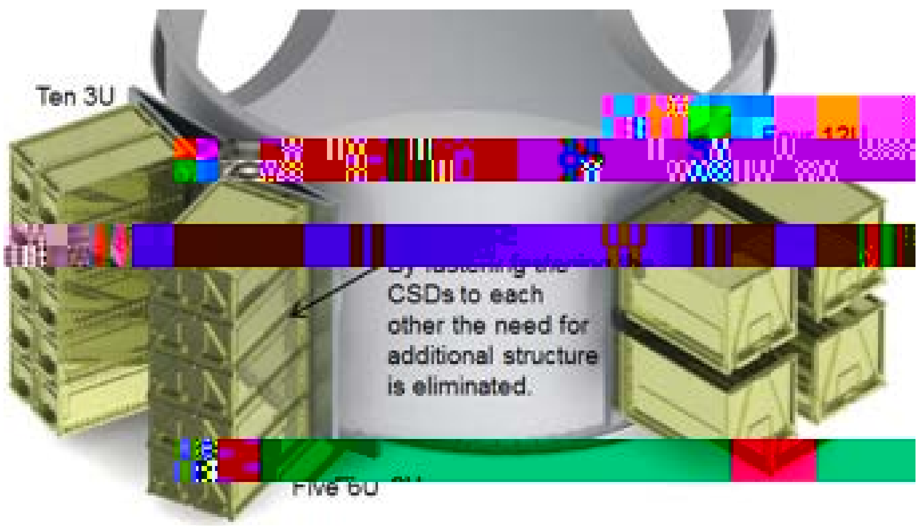

Figure 24-2: CSDs mounted to ESPA Grande

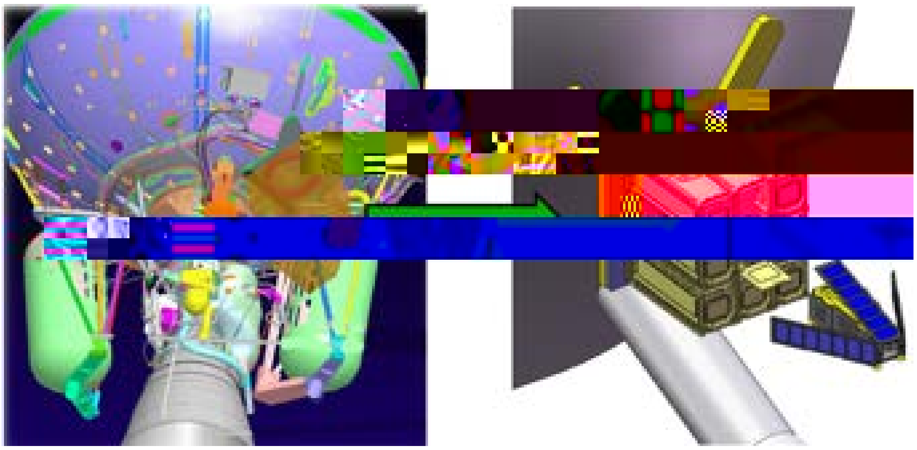

Figure 24-3: Nine 3U CSDs mounted to Atlas V Aft Bulkhead Carrier (ABC) via simple lightweight and low cost isogrid plate

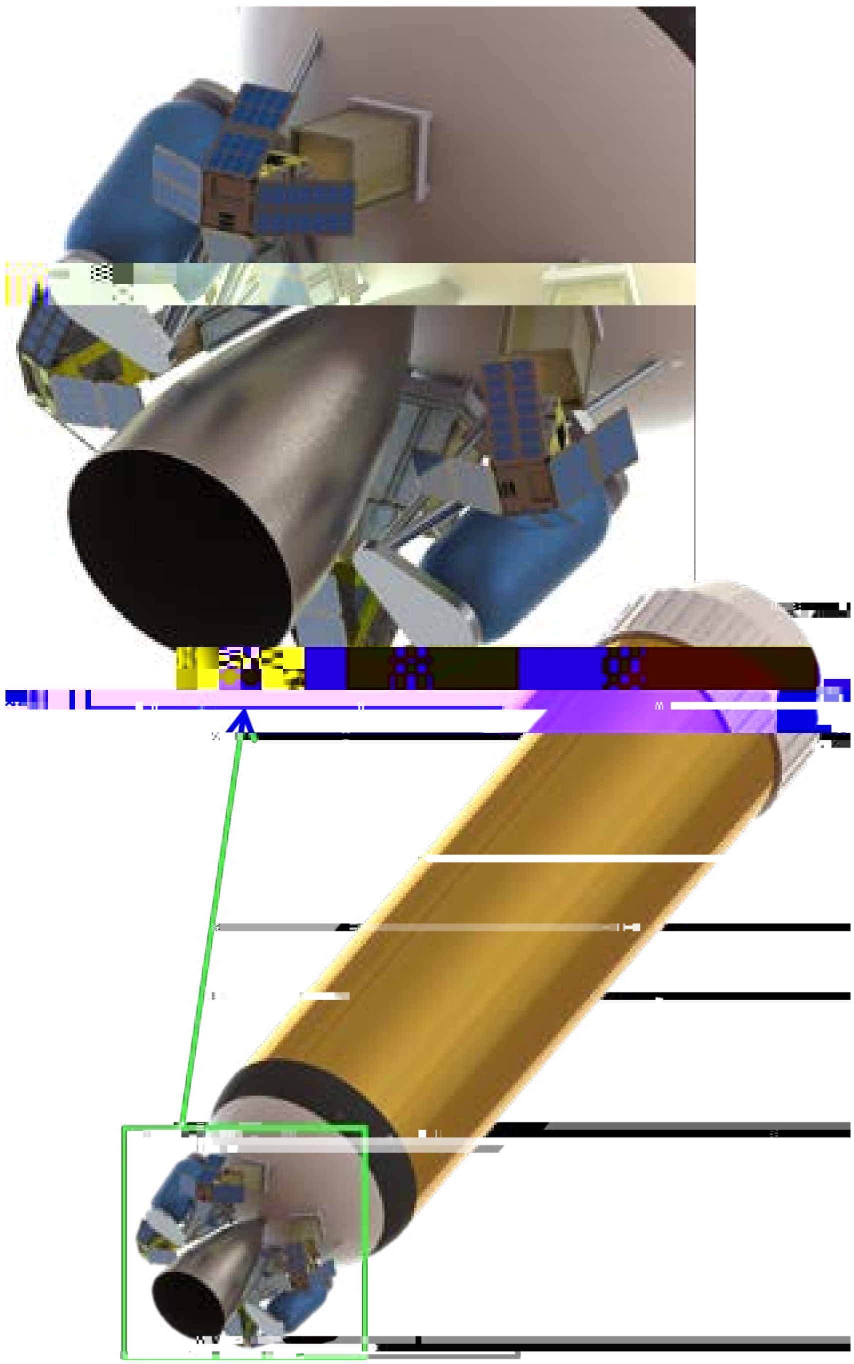

Figure 24-4: Four 12U CSDs on aft of stage

CSDs can dispense hosted payloads from large spacecraft. The separation connector enables trickle charging, thermal control and state-of-health telemetry for days, months, or years.

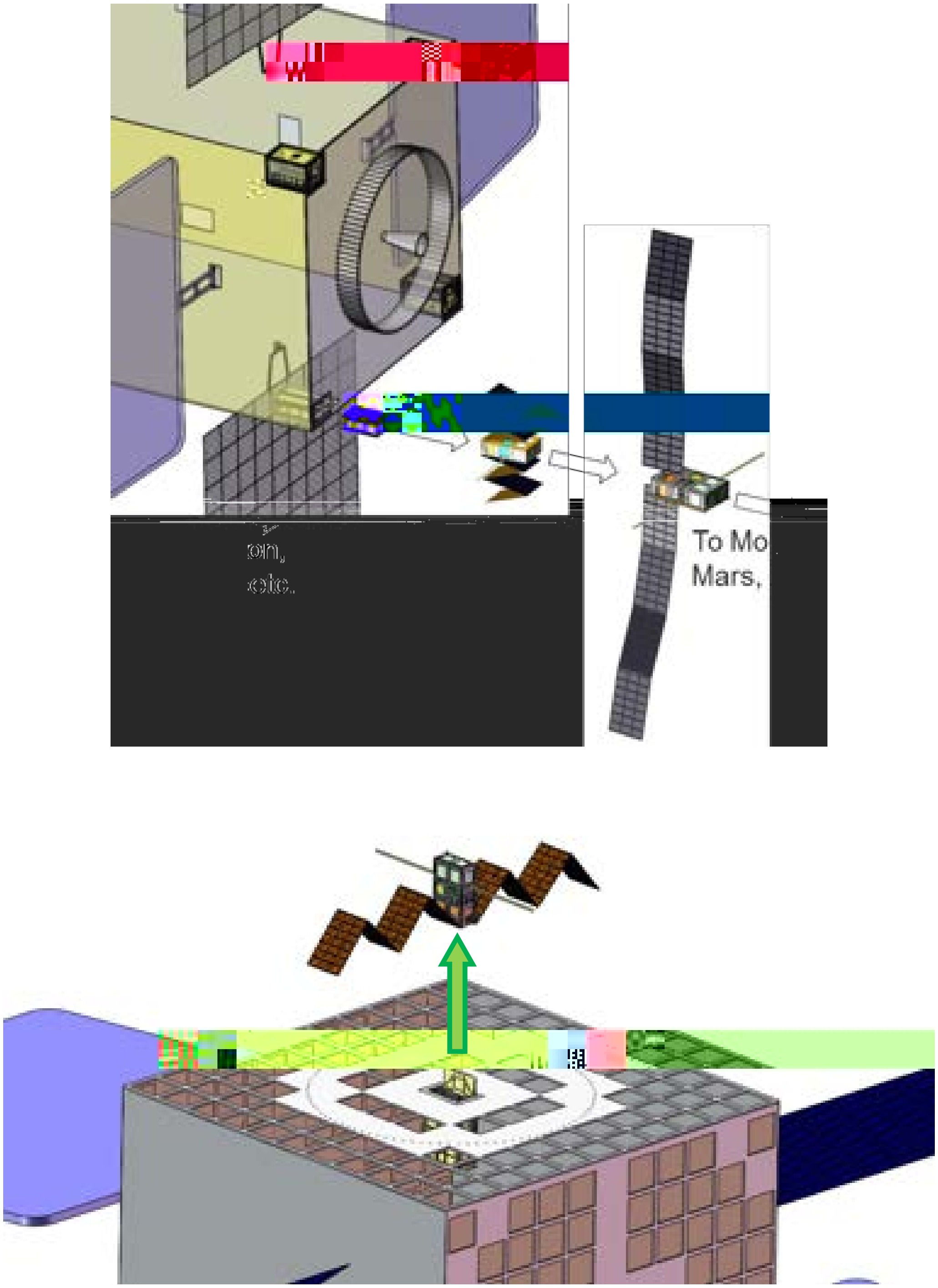

Figure 24-5: CSDs as hosted payloads

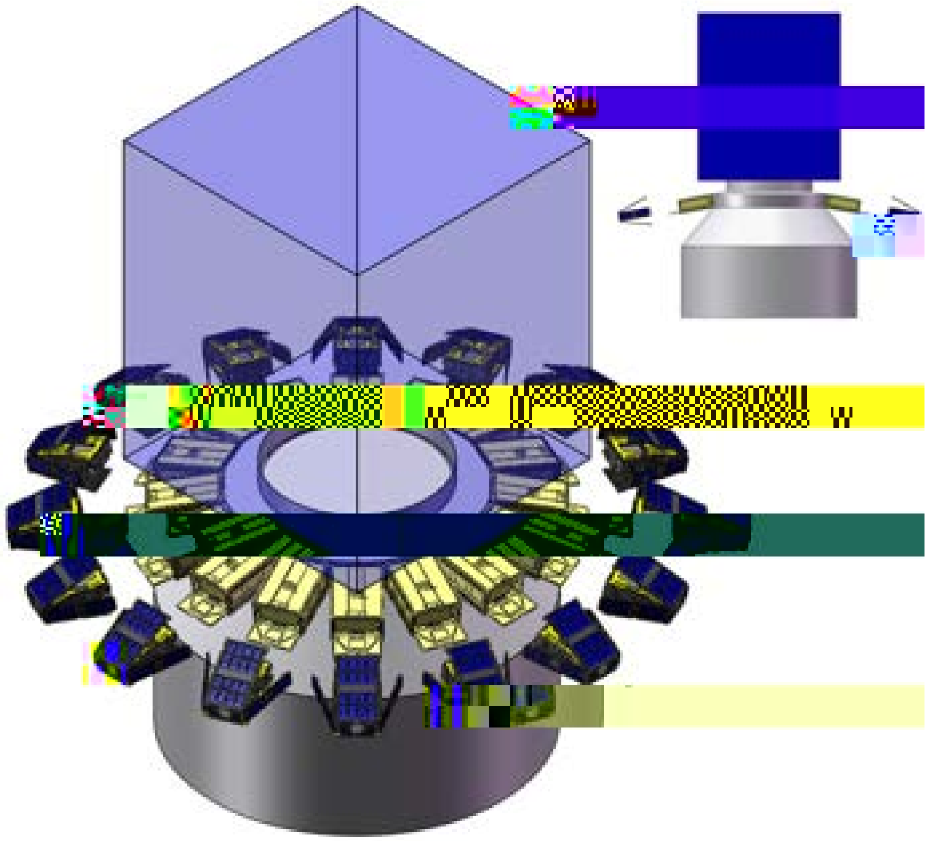

Figure 24-6: Sixteen 6U CSDs mounted underneath primary payload

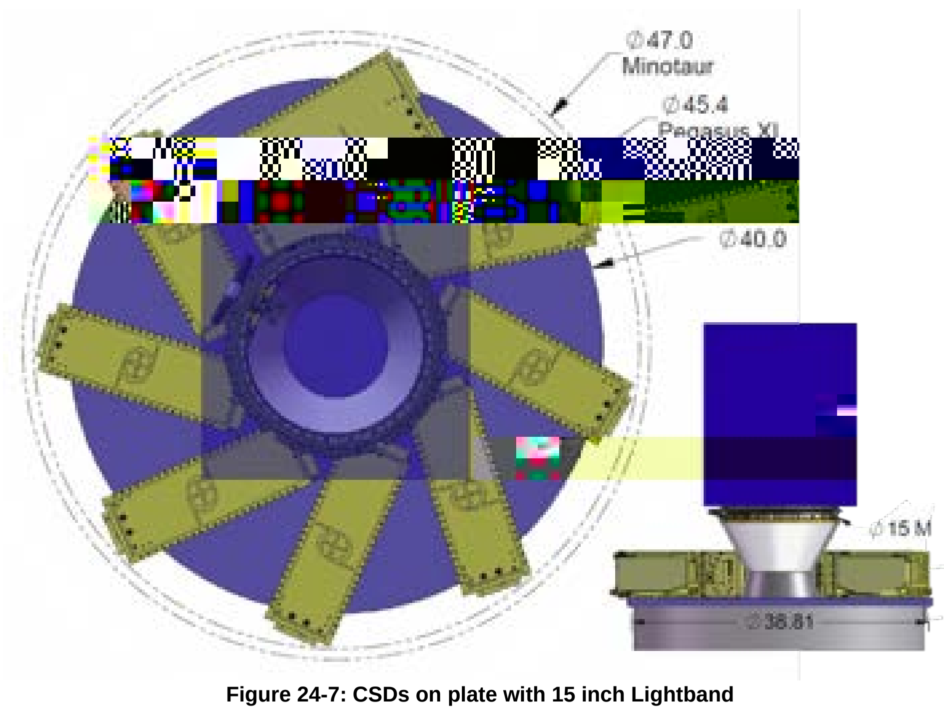

Figure 24-7: CSDs on plate with 15 inch Lightband

The CSD can accommodate multi-piece payloads. Each discrete payload remains rigidly clamped via the tabs. The payloads need not occupy the entire length of the CSD (requires a custom matched CSD).R

The ability to mount CSDs to any face maximizes launch opportunities and simplifies integration. Figure 24-13 demonstrates the ability to mount CSD's to each other to maximize LV packaging density. Notice the open doors do not interfere with adjacent CSDs ability to deploy.

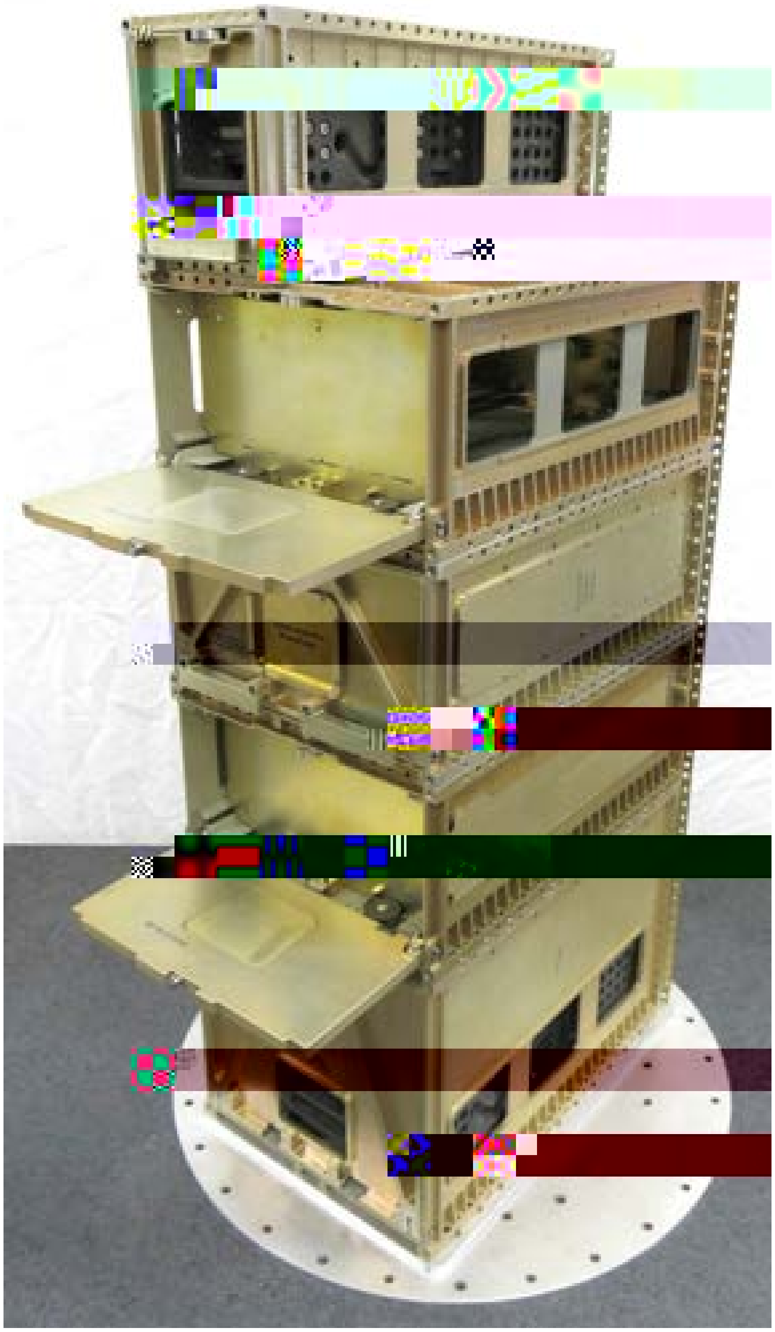

Figure 24-13: Five CSDs stacked on a single mounting plate

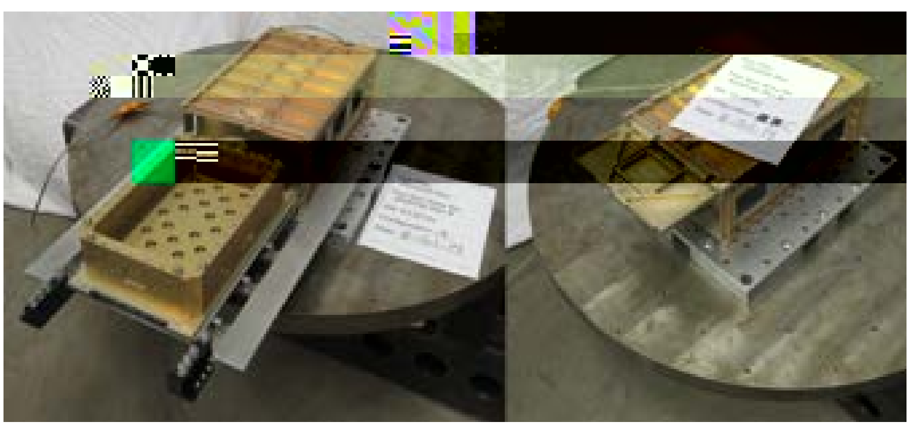

Figure 24-14: CSD mounted via –Y and +Y faces

(CS(f4 1mMD)-9.4 ())]TJ0 Tc 0 Tw 2277.6 0 TdSf

The CSD can accommodate existing CubeSats. Fastening custom tabs to an existing CubeSat allows for seamless integration into the CSD (see Figure 24-18). PSC does not sell these custom tabs.

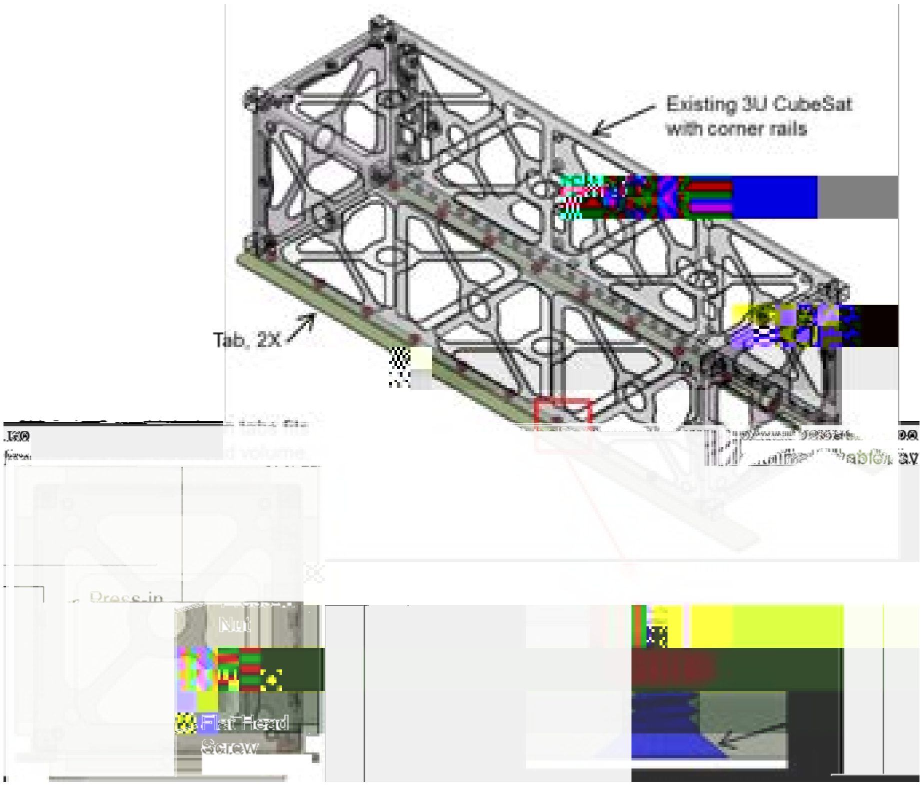

Figure 24-18: 3U CubeSat with bolt-on tabs

A Lightband separation system can be used in lieu of a CSD when the size of the payload renders canisterization impractical or the payload exceeds the allowable CSD volume.

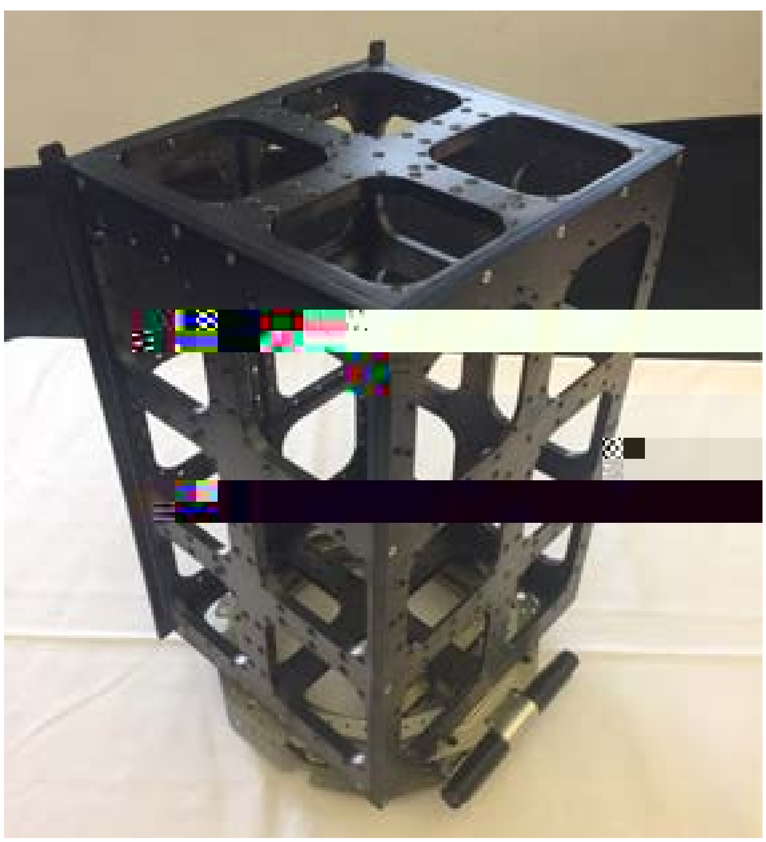

Figure 24-19: An 8 inch diameter Lightband used to separate a 12U payload

25. TEST SUPPORT

The top and bottom clamps should be aluminum alloy 6061-T6 with surface finish electroless nickel per ASTM B733-15, type IV. The preload (clamping normal force) shall be approximately 4,000 lbf per tab (8,000 lbf total).

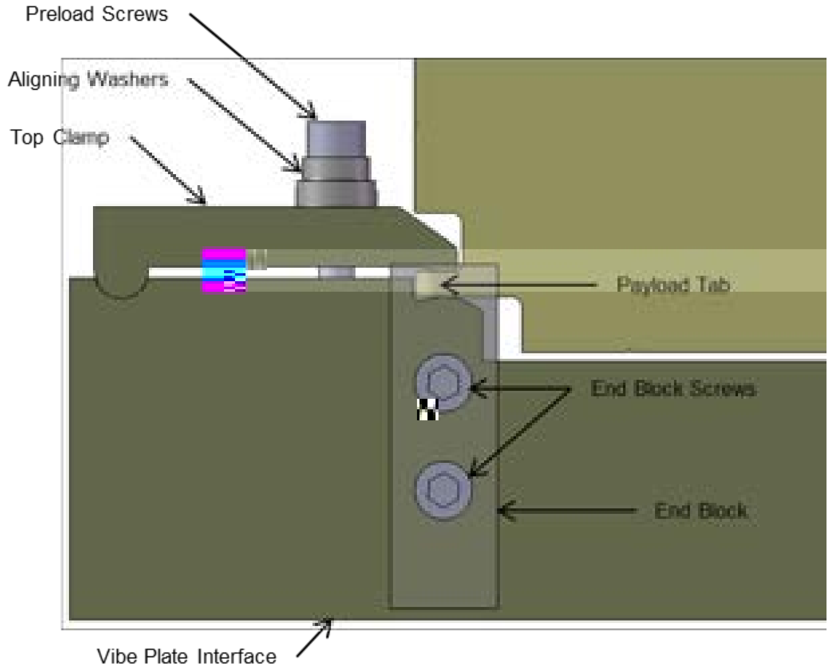

Figure 25-3: Clamp section view

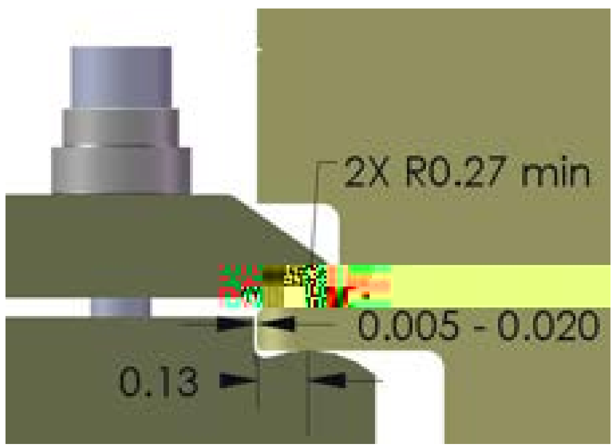

Figure 25-4: Contact details (dimensions in inches)

26. SPECIFYING AND ORDERING

When ordering a CSD specify the exact configuration using the following system. Mounting the CSD via the -Y face is standard. Mounting via the -Z face is also common but may increase cost. Mounting via any other face is considered custom and may incur additional cost and lead time.

30. RELIABILITY

Probability of Success	Confidence Level [%]
>0.999	60
>0.998	85
>0.997	95
>0.996	97.5

Table 30-1: Minimum reliability and corresponding confidence level

Table 30-1 was calculated using Table 22.4 of *Space Vehicle Mechanisms* by Peter L. Conley given approximately 1,000 no failure tests. CSDs have cumulatively been operated more than 3,000 times during production, testing and flight operations. There have been no failures to operate in testing at published environments.

Prior to spaceflight, each CSD is separated numerous times to verify operability. These include operations conducted during acceptance testing by PSC and additional operations performed by the customer. As shown in Table 30-2, the CSD allows the user to verify operation multiple times before flight. Further, the CSD is the only dispenser that enables complete separation of the payload during ground testing. This is essential for verifying total functionality. Only allowing the door to open does not fully verify the dispenser.

	Competing Dispensers	CSD
Typical quantity of operations on non-refurbished flight unit	1	7

Table 30-2: Comparison of dispenser operations before launch

PSC tests development and qualification units to examine reliability limits and inform the allowable limits of CSDs in ground test and space flight. A typical qualification campaign will result in more than 100 separation tests on a single CSD. In fact the three current qualification CSDs each have over 300 operations. The initiation electrical telemetry for every operation is recorded on PSC's data acquisition systems.

Because of the reusability of the CSD and the high production rate, it has been inexpensive to amass test data that is several orders of magnitude larger than cso6 w(DC 0of the r)-5.3 (ede)-1.6 (as)-3.8te cas. T (of the Cw)-3.5 (t hde)-3.7 (pens2.1 (agn.2 v)-b (D and t(s)-3.8 r)-5.3 (eso6 w(D)-3.6 (owab)-3.6

31. FAILURE MODES AND EFFECTS ANALYSIS

A detailed failure modes and effects analysis (FMEA) has been performed for the CSD in PSC document 2003138. Contact PSC for more info. The CSD's reusability enables significant testing and the accumulation of thousands of operations to expose design weaknesses which can then be corrected. These operations are several orders of magnitude greater than competing dispensers. Obtaining this amount of knowledge with other technologies would be prohibitively expensive and time consuming.

Further, PSC has simulated failures by purposely removing or damaging components and operating to examine the affect. Table 31-1 summarizes the failures simulated in a 12U CSD (PSC test 2003198-). All operations were performed in PSC's thermal vacuum chamber at pressure <1.0E-4 Torr.

Table 31-1: 12U CSD failure simulations

1) Shims (used to seize the Preload Stick bearings) loosened and stopped the payload midway through ejection.

32. STORAGE REQUIREMENTS

Store the CSD in a sealed enclosure in relative humidity of less than 95% (non-condensing) at temperatures from 0 to 50°C. PSC should be contacted prior to operation if any of the maximum allowable storage durations are exceeded.

Table 32-1: CSD allowable storage duration

CSD State	Max. Allowable Storage Duration [yrs]
No Payload	5

REFERENCES

1 Hevner, Ryan; Holemans, Walter, "An Advanced Standard for CubeSats", Paper SSC11-II-3, *25th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, August 2011.

2 Holemans, Walter; Moore, Gilbert; Kang, Jin, "Counting Down to the Launch of POPACS", Paper SSC12-X-3, *26th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, August 2012.

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