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Internally Isolated 12U Rail CubeSat Dispenser with Analyzable Boundary Conditions

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ABSTRACT

CubeSats are growing in size, capability, and complexity. Along with these increases comes decreased acceptance of risk. Tyvak Nano-Satellite Systems' 12U Dispenser incorporates significant upgrades to our flight-proven designs that mitigate the two key concerns for the developer designing a rail-type CubeSat.

First, the dynamic environments experienced by rideshare payloads can be extreme. The Tyvak 12U dispenser incorporates a first-of-its-kind internal isolation system that reduces the CubeSat environment by 70-90% compared to the external launch vehicle environment. The CubeSat developer can therefore maximize the design for the space mission rather than to survive excessive launch loads.

Secondly, developers have faced the challenge of modeling the dynamic response of their satellite due to the "floating" nonlinear boundary condition between it and the dispenser. The Tyvak 12U Dispenser solves this problem by incorporating movable rails that cradle the payload on all four corners. This mechanized rail interface provides an analyzable boundary condition and allows the developer to accurately predict isolated loads transmitted to the spacecraft. The design also provides a straightforward approach to structural design, analysis, manufacturing, test, and integration. The developer can then produce a satellite that is neither over-built nor over-tested.

INTRODUCTION

The need for more on-orbit power and capability is driving larger CubeSat form factors. The number of 6U and 12U CubeSats in the launch queue is likely to soon match or surpass that of the popular 3U form factor.

Today's CubeSat developer has two dispenser interface designs to choose from: the "rail" design and the "tab" design. A majority of the smaller form-factor CubeSats have used a rail design dispenser in the past. Many U.S. developers, as well as some foreign, have used the California Polytechnic State University ("Cal Poly") Poly Pico Orbital Deployer, or PPOD, for 3U and smaller form factor CubeSats. However, as CubeSats have grown in size, complexity, and cost, developers are looking for a more sophisticated approach to analyzing the loads than can be achieved in the "floating" rail design dispenser. The "tab" design helped resolve the modeling and analysis challenge. However, although the tab design provides an analyzable boundary condition to model the dynamic system, it results in direct transmissibility and amplification of the launch vehicle environment. The result is that an external isolation system is required to attenuate launch vehicle generated vibration and shock loads. These systems can be expensive and consume valuable volume on the launch system.

THE TYVAK 12U DISPENSER SOLUTION

Figure 1 Tyvak 12U Dispenser

Tyvak's design, Figure 1, addresses the two challenges of a rail-type dispenser head on. The design (1) includes an internal isolation system that reduces launch vehicle input vibration levels by 70-90% and (2) provides a defined mechanical interface between the dispenser and the CubeSat giving the developer an analyzable boundary condition to model for loads analysis. A test unit has completed extensive vibration testing and the first flight unit has been delivered for a launch in late 2018.

Additional features of the unit include: the door is non-load bearing and is optional providing additonal payload volume pending the launch vehicle mounting configuration; the dispenser can be mounted to the

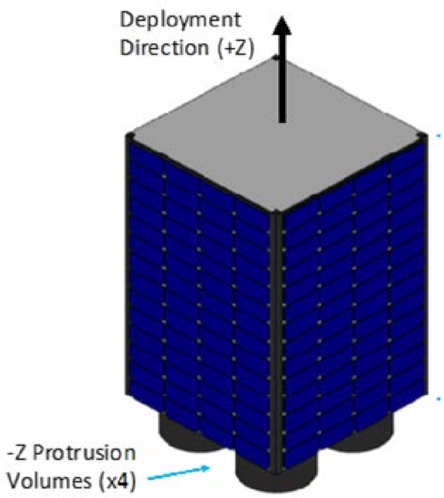

Figure 2 12U CubeSat Allowed Protrusions

launch vehicle using five of the six sides; and the Dispenser can accommodate four "-Z protrusions" up to 88mm in diamter and a height up to 50mm beyond the CubeSat feet as illustrated in Figure 2.

Tyvak's solution not only includes the Dispenser, but analytical tools to assist the developer with initial design solutions as well as detailed loads analysis. And finally, Tyvak has produced a test fixture for standalone testing of the satellite at the developer's facility eliminating the need to procure additional dispensers or travel to other locations to conduct testing.

DISPENSER OVERVIEW

The Tyvak 12U Dispenser is a rail type satellite dispenser capable of carrying a single 12U CubeSat payload. Unlike other rail designed dispensers, the CubeSat is not restrained by the door nor is the satellite free to "float" within the dispenser rails. The Tyvak dispenser has a unique design that "cradles" all four CubeSat rails. The dispenser rails and swivel clamps restrain the satellite in all three axes and the door is not a structural component. As a result, the door is optional, providing additional volume available to the satellite in the +Z axis.

The dispenser design incorporates a "box-in-a-box" approach as shown in Figure 3. The internal box, or structure, is composed of four dispenser rails that run the length of the CubeSat, an ejection spring mechanism (pusher plate), and swivel clamps near the top of each rail. The external structure is a high-strength aluminum frame, optional two-piece door, and either aluminum or carbon fiber panels, depending on mission requirements. Each panel doubles as an access port and can be removed to allow access to the satellite after integration into the dispenser. Each inner structure rail is isolated from the external structure via commercial-off-the-shelf, low-outgassing, aerospace qualified isolators.

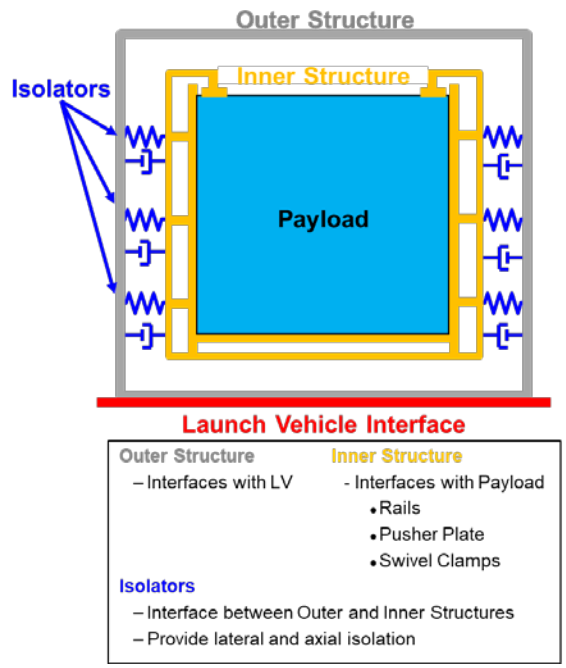

Figure 3 Tyvak 12U Configuration

MECHICAL INTERFACE

The 12U dispenser includes four rails that cradle the satellite on all four corners. Dispenser rails extend the entire length of the satellite, however, CubeSat rails may be discontinuous between the CubeSat standoffs, with at least 75% of aggregated rail length being preserved on each rail. This configuration provides a mechanical interface and analyzable boundary condition in all three axes that can be modeled for dynamic analysis. This approach gives the developer the tools needed to accurately predict the effects of transmitted launch loads.

The dispenser rails extend inward once the CubeSat has been installed and the pusher plate is depressed. The rails and swivel clamps securely hold the satellite in place during launch. The rails are hard anodized to prevent cold welding and assure a smooth payload release. The door is not required to restrain the satellite. Once the separation command has been sent to a non-explosive release mechanism, the pusher plate begins its forward motion and the rails retract outward allowing the satellite to smoothly exit the dispenser as illustrated in Figure 4.

Analysis predicts CubeSat tip-off rates to be 2-7 deg/axis/sec depending on satellite mass properties, separation velocity, and whether or not deployable appendages/surfaces are constrained.

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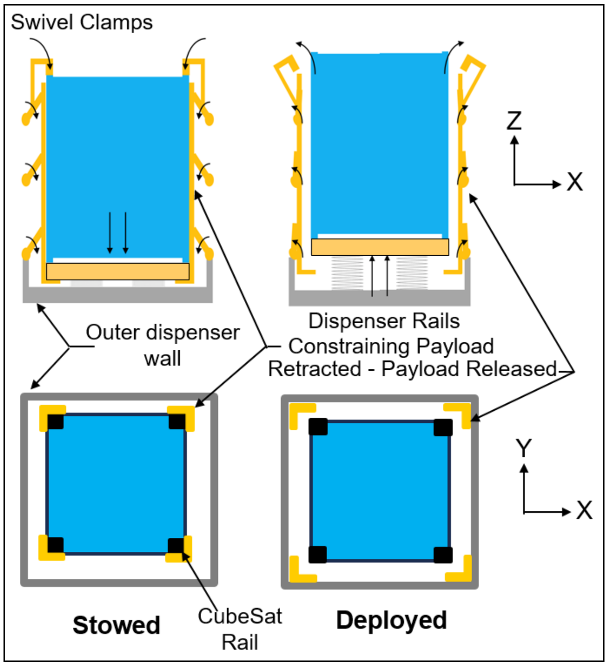

Figure 4 Mechanical Interface

PAYLOAD ISOLATION

The Dispenser incorporates a first-of-its-kind full 3-axis internal isolation, reducing vibration and shock environments for payloads that eliminates the need for costly and volume-consuming external isolation. The internal isolation is placed between inner and outer structures as shown in Figure 3.

The inner structure rides on these isolators, providing a damped environment for payloads. The outer structure remains a more rigid interface for launch vehicles. Lower launch loads allow the developer to focus on the space application versus surviving the launch environment. A more benign launch environment also results in an increased likelihood of passing environmental testing and improved on-orbit performance.

Recent testing of the dispenser used both 20 kg and 25 kg mass models to bound typical 12U satellite configurations. Both configurations were tested to NASA's General Environmental Verification Standard (GEVS) Max Predicted Environment (MPE) and the Atlas Aft Bulkhead Carrier (ABC) MPE+3dB levels. Testing was conducted from 20-2,000 Hz and the test setup is shown in Figure 5. One door was removed to install instrumentation cables on the mass model. This configuration verified the satellite is constrained by the internal structure and the two-piece door is not required for flight. It also demonstrated the door is restrained during launch and deflections are acceptable for flight. Results showed payload overall root-mean-square g's (Grms) levels were reduced by 70-90% depending on the configuration and the frequency content of the input environment.

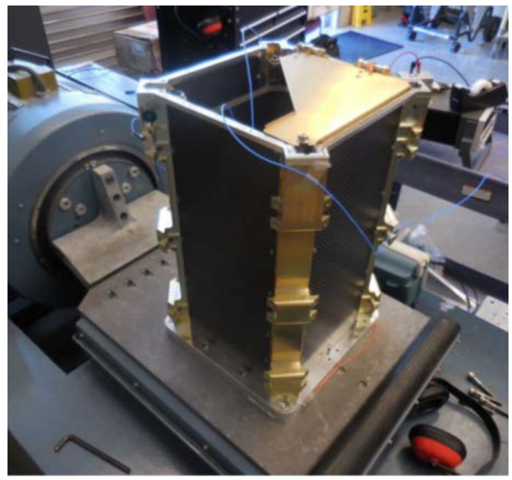

Figure 5 Dispenser Test Setup

Figure 6 shows the reduction of levels for testing to the GEVS MPE environment for a 25kg mass model. Overall levels were reduced from 10 Grms to 1.11 and 1.46 Grms in the X (lateral) and Z axes, respectively. Since the unit is symmetrical, results for X and Y axes were similar.

Attenuation begins at about 30 Hz with inputs reduced by 10-100 times starting at 60-100 Hz. There is some amplification below 30 Hz, but discussions with CubeSat developers indicate the increased levels at such frequencies do not present additional design challenges. Some amplification at low frequencies is required in order to achieve isolation at higher frequencies where levels are higher and sensitivities are more critical. Figure 7 shows a comparison of the results of the 20 and 25 kg models tested to the ABC+3dB levels. As can be seen, the isolation system's effectiveness was not significantly mass-dependent and was consistent for both configurations. This allows the user to accurately bound predicted loads early in the design phase, before an accurate mass can be calculated.

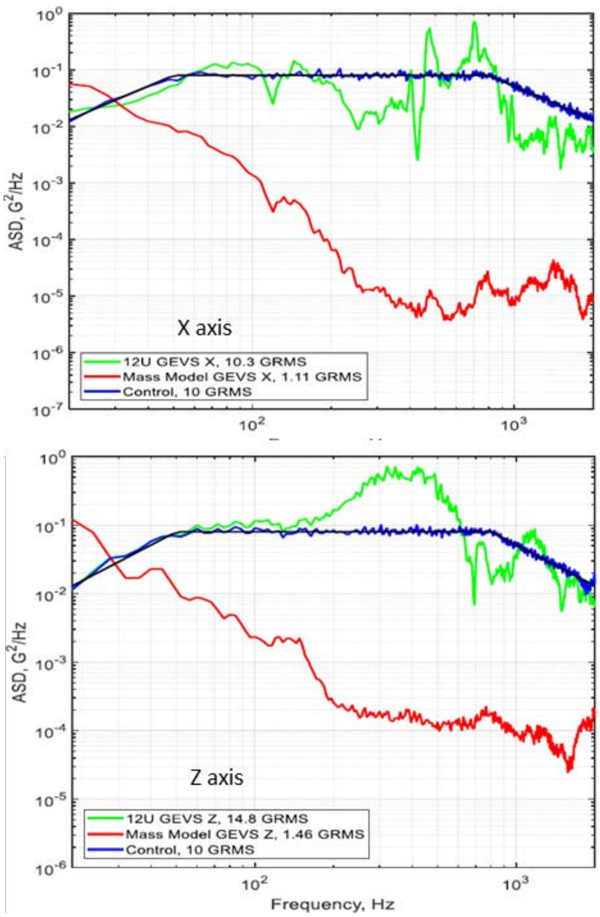

Figure 6 12U Vibration Reduction

CUBESAT LOADS PREDICTION

To be of real value, the CubeSat developer must be able to design to the reduced environment the satellite will experience. This requires the ability to predict the CubeSat environment inside the Dispenser given a launch vehicle input. Based on analysis of test results, Tyvak has developed a transfer function that can be applied to a launch vehicle input to provide a conservative prediction of the resultant payload environment. Figure 8 shows the resultant predicted Atlas ABC MPE+3dB environment using the transfer function and plotted against the actual test data.

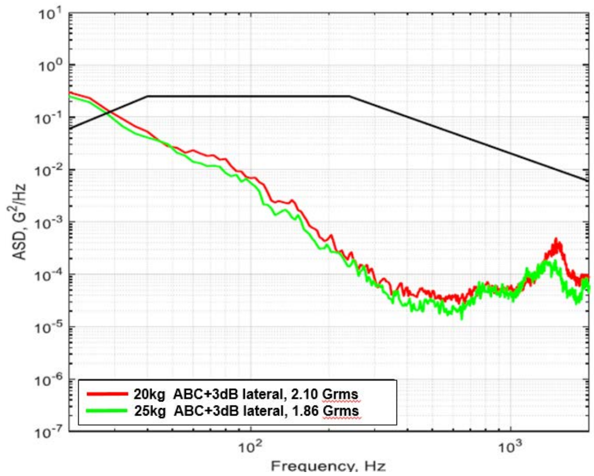

Figure 7 20kg and 25kg Test Results

Using the dispenser transfer function, the CubeSat developer assigned a launch on the Atlas ABC platform and planning to test to protoqual levels, can design to a vibration spectrum with an overall level of 3.5 Grms versus the launch vehicle input of 10.78. The predicted value is validated by the measured test data. The transfer function was developed to encompass results in all axes from both the GEVS and Atlas ABC levels since their frequency content is significantly different. The ABC level contains rather significant low frequency energy while GEVS contains more high frequency content. The result is a transfer function that provides a "top level" reduced design target for the developer, yet ensures they will not under-design the spacecraft. Tyvak has been able to separately validate the transfer function prediction approach with a flight CubeSat tested to real-world environments.

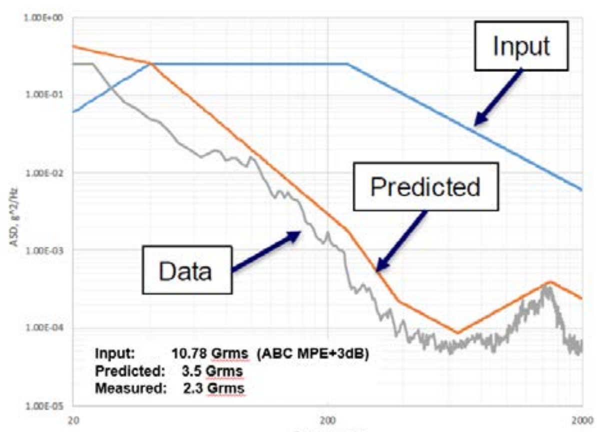

Figure 8 Predicted Vibe Level vs Measured

Figure 9 shows predictions for two test environments likely to be required for future 12U CubeSats. Similar reductions are predicted for other launch vehicle environments as well.

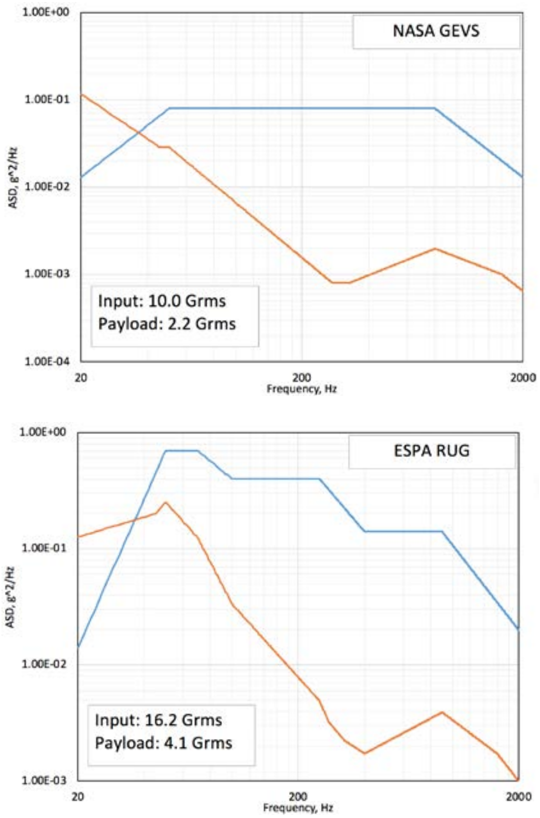

Figure 9 Predicted Vibration Environments

Although actual levels will be less than the prediction, it is clear that even the conservative prediction approach provides the developer significant relief and/or eliminates the need for a costly, uniquely-tuned, and volume consuming external isolation system.

Many CubeSat developers are not assigned a launch at program inception. They are forced to either guess at possible launch opportunities, or for maximum flexibility, design to levels that envelope all possible launch options. Since auxiliary payloads can be placed in a variety of configurations for rideshare missions, it is impossible to predict what a worst-case environment might be. However, in an effort to provide developers a conservative design target, Tyvak enveloped known environments based on launch vehicle user guides, previous launch integration efforts, and additional information provided by launch vehicle providers. Figure 10 illustrates this envelope for the US vehicles and environments specified on the graph. The black-dotted line is the resultant envelope with an overall level of 22.7 Grms.

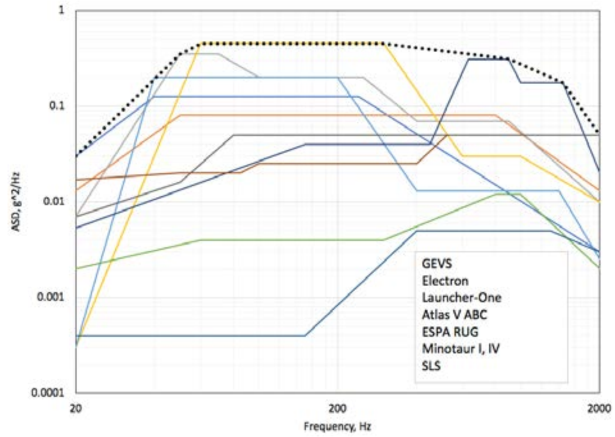

Figure 10 Enveloped Vibration Spectrum

Applying the Tyvak 12U Dispenser transfer function to the 22.7 Grms envelope results in a CubeSat level of 4.7 Grms as shown in Figure 11.

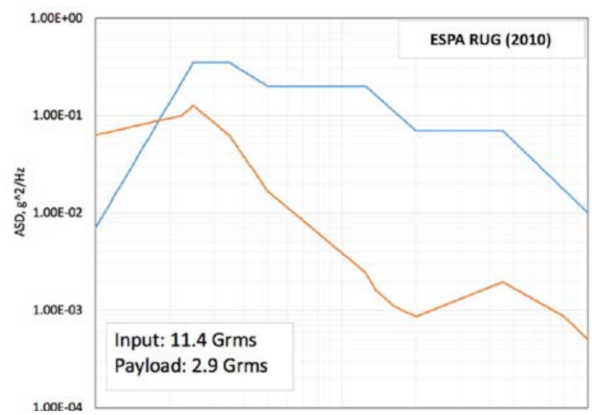

Figure 11 Prediction for Bounding Envelope

Therefore, a 12U CubeSat developer can design their satellite to the MPE spectrum defined above, 4.7 Grms overall, and be confident the satellite can fly on all of the vehicles/configurations listed in Figure 10, and likely. This allows the developer to focus on the space mission and not simply surviving launch. It also provides the developer and customer added flexibility in manifesting and launch scheduling.

DETAILED LOADS ANALYSIS

Today's sophisticated 12U satellite is likely being built to perform an important mission, and is more expensive and risk-adverse compared to previous-generation CubeSats. As a result, the developer – and customer – will want to perform a detailed loads analysis. This typically requires the development of a system Finite Element Model (FEM) that is used by the launch provider in their Coupled Loads Analysis (CLA). The results of this analysis are provided to the CubeSat developer to evaluate the structural integrity of their satellite. In order to provide an auxiliary payload FEM, a validated dispenser model is required.

Tyvak has produced a FEM that was validated by the recent testing. Correlation over a wide range of the test spectrum was excellent, with some departures in very high frequency due to the simplicity of the satellite model and the inherently low levels transmitted to the CubeSat. Details of the model will be provided to the appropriate organizations as required on a mission-by-mission basis.

Given the analyzable boundary condition, the system FEM can be produced and the developer is able to perform detailed loads analysis on the spacecraft prior to entering the test phase of the program. This provides the developer with a high level of confidence that the satellite will survive testing and the subsequent launch environment.

OPTIONAL DOOR

As described earlier, the Tyvak 12U dispenser utilizes an optional door designed to enclose payloads, which locks open upon deployment to ensure that there is no re-contact with the exiting payload. If desired, the door may be removed without affecting dispenser function or payload deployment dynamics. With the door removed, payloads have additional volume as shown in Figure 12 to use on a mission specific basis. This option may be limited by launch configuration and available volume surrounding the 12U dispenser.

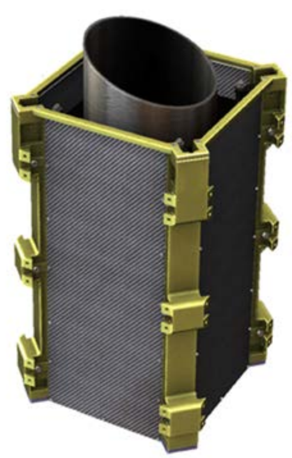

Figure 12 Dispenser Without Optional Door Providing Additional Payload Volume

TEST FIXTURE

For developers that require satellite-level testing prior to integration into the Dispenser, Tyvak has developed a test fixture, Figure 13, that simulates mechanical interfaces without requiring a full dispenser. This is a cost-effective way to facilitate the CubeSat test program that also provides schedule flexibility if multiple customers are testing at the same time.

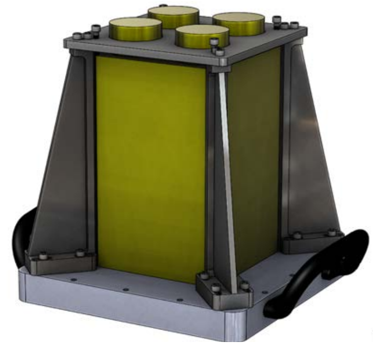

Figure 13 Payload Test Fixture

CONCLUSION

The Tyvak 12U Dispenser provides a unique launch interface that both reduces program risk and complexity by offering a first-of-its-kind internal isolation system and movable rails that cradle the payload on all four corners. The internal isolation system was test verified to reduce launch environments by 70-90% at the spacecraft interface. The system maintained a stable and predictable response across varying payload mass and launch environments. With the moveable rails and analyzable boundary condition at the satellite interface, the Tyvak 12U dispenser eliminates the need for complicated analysis to predict spacecraft loads. The optional door configuration enables larger payloads which traditionally would not be accommodated by a 12U dispenser. The Tyvak Dispenser solves the problems facing CubeSat developers and provides options not found in other dispensers.

ACKNOWLEDGEMENTS

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References

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2. Aft Bulkhead Carrier Auxiliary Payload User's Guide, May 2014