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Design and Development of a Dual-Use Satellite Deployer

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ABSTRACT

The CubeSat standard has led to the widespread implementation of repeatable design, integration, and operations processes.[1] Following launch, the deployment of a satellite is one of the most critical aspects of any mission. Satellite deployers, also known as dispensers, are used to release satellites from on-orbit launchers and platforms. Dispensers have evolved into two competing, but not interchangeable, configurations using either rails or tabs on the CubeSat structure to guide the satellite smoothly out of the deployer. Rail deployment aligns CubeSats along a set of four rails, one in each corner of the dispenser. The satellite is then pushed along the rails by an ejection plate at the rear of the deployer. Alternatively, tab-based dispensers align CubeSats along flanges which are gripped by the deployer. Both methods have seen extensive use and have proven to be reliable. The challenge discussed in this paper is the incompatibility of rail and tab systems. A satellite with a rail configuration cannot be deployed with a tab-configured deployer and vice versa. To address this issue, Rogue Space Systems has partnered with the Laboratory for Advanced Space Systems at Illinois (LASSI) to develop a "Dual-Purpose CubeSat Deployer" that can accommodate either satellite configuration. A technical solution for this challenge is presented with a description of the specific mechanisms and interfaces that allow the CubeSat developer freedom to choose between rails and tabs. Potential use cases are considered, illustrating the benefits of the Dual-Purpose CubeSat Deployer. Verification of the deployer design is being performed with a prototype unit in the Summer of 2024.

INTRODUCTION

With the standardization of CubeSat configurations, deployment options have also been limited to control cost of deployment. Nanoracks, Planetary Systems Corporation, and Exolaunch are just a few of the commercially available deployer options. But one factor remains for a CubeSat developer to consider: rail or tab dispenser?

Both dispenser styles are widely used. A CubeSat built with the rail configuration is characterized by the inclusion of four long rails along the length of the CubeSat. Reciprocal interfacing rails on the inside of the deployer restrain the CubeSat, preventing it from moving laterally during the deployment. The tab configuration utilizes two long flanges rather than the four rails.[2] These flanges, or "tabs," are located planar to one another and are gripped by reciprocating interfaces within the deployer. The tabs can, in special circumstances, be broken up to accommodate CubeSat design.

Unfortunately, a rail configured CubeSat cannot be deployed by a tab deployer and vice versa. Once a configuration is chosen, the developer is constrained to launch service providers that offer the matching style of CubeSat deployer. Rogue Space Systems Corporation (Rogue) and the Laboratory for Advanced Space Systems at Illinois (LASSI) seek to alleviate this constraint, opening more launch options for developers.

Rogue is a pioneering company at the forefront of the rapidly expanding space economy, specializing in providing cutting-edge and sustainable in-space servicing capabilities. LASSI is involved in several satellite and payload projects. Together, Rogue and LASSI are developing a Dual-Use Satellite Deployer providing this unique capability.

Development of the Dual-Use Satellite Deployer is in its final stages, with the manufacturing of a qualification test model nearing completion and verification testing to follow. A milestone schedule (Table 1) has been followed to rapidly develop and qualify the dispenser.

Table 1: Milestone Schedule

TASK	EXPECTED DELIVERY
Milestone 01: Kickoff Meeting and Solidify Design Concept	Award + 1 month
Milestone 02: Analyze test plan requirements + define Phase II requirements	Award + 3 months
Milestone 03: Preliminary Design Review Conducted	Award + 6 months
Milestone 04: Critical Design Review Conducted	Award + 9 months
Milestone 05: Part drawings completed; test demonstrations scheduled	Award + 10 months
Milestone 06: Complete testing demonstrations	Award + 13 months
Milestone 07: Complete additional testing or design adjustments and verify analysis results	Award + 14 months
Milestone 08: Deliver Final Reporting	Award + 15 months

SYSTEMS ENGINEERING AND MANAGEMENT

Development of the Dual-Use Satellite Deployer has followed a standard systems engineering process with appropriate verification procedures. The small geographically distributed development team has successfully used several virtual collaboration and management tools, along with regular coordination meetings, including Microsoft SharePoint, Teams, and Miro. These assets were used to store and archive each revision of the design to keep the team up to date and scheduling on track. Technical programs used by the project engineers include Solidworks and NX for design, and Ansys and Simcenter 3D for analysis. Neutral file formats allowed for the collaboration of designers and integration of sub-assemblies into top level models to ensure compatibility and fitment. The bulk of the design work was cordoned off into the sub-assemblies to limit the need for intense collaboration outside of major interface designs that were simple and straightforward. This allowed engineers to focus and develop their own designs without distraction.

A Systems Requirements Review (SRR) was completed in September of 2023 in which the top-level requirements of the system were defined and captured in a Requirements Traceability and Verification Matrix (RTVM). These requirements were categorized following a functional and physical decomposition process as follows:

1. Primary objective requirements
2. Deployment requirements
    a. Interface
    b. Mechanical
    c. Reliability
3. Structure requirements
    a. Compatibility
    b. Environment
    c. Payload
    d. Material
    e. Mechanical loading

Altogether, these requirements captured the scope of the project capable of deploying rail or tabbed CubeSats into orbit. Top level mission requirements are listed in Table 2. The top level mission requirements are broken up into three separate categories: Main Objectives, Primary Objectives, and Secondary Objectives. The Main Objectives listed in the RTVM stem directly from the STTR proposal and are directly tied to the project success. These are the most important and critical to tackle in this iteration of the design cycle. The objectives listed in the Primary and Secondary sections are considered potentially achievable or stretch goals for this phase of the project. Retrospectively, a sizeable portion of these goals were met or at least partially met to set the teams up for further success in developing a fully functional flight model.

Technical, cost, and programmatic risks have been anticipated and mitigation plans enacted to eliminate or reduce their impact if realized. The team identified a set of risks along with their likelihood of occurrence and the consequential severity of impact. Four principal risks are enumerated in Table 3.

A Preliminary Design Review (PDR) was completed in February of 2024. Within the PDR, subsystem design specifications for each configuration item were supported by trade analysis. The risks mitigations identified during SRR were tracked by the management team. The preliminary design of the system was completed, including the structure and layout of the subsystems, interfaces definitions and relevant control documents, safety analysis and plans, engineering drawing trees, verification and validation plans, and an assembly/integration plan. This proved that the system was ready to move forward toward the Critical Design Review (CDR).

The CDR was completed in April of 2024. At this point, all open items from the PDR were resolved and the RTVM was updated. The detailed design of the system was reviewed and found ready for fabrication and assembly of the qualification test product.

Table 2: Mission Objectives

MAIN OBJECTIVES	
MO-0000	Develop a viable deployer design for AFWERX that has been analyzed and tested according to industry standards and is compatible with both tab and rail CubeSat structures.
MO-0100	Develop the deployer design with the intent to modularize and scale to offer more than one CubeSat size.
PRIMARY OBJECTIVES	
MO-1100	Develop a deployment mechanism that safely deploys the CubeSat away from the LV
MO-1150	Develop a deployer design with comparable volume specifications to other CubeSat dispensers currently on the market.
MO-1200	Develop a mounting design (Dispenser to Launch Vehicle) that is compatible with across multiple launch vehicle (LV) platforms.
MO-1250	Develop a deployer design that reduces the load transfer from LV to Deployer that is comparable to other deployers currently on the market.
MO-1300	Develop a deployer design to ensure minimal satellite spin and oscillations upon release regardless of the deployment method used.
MO-1350	Develop an interface with the launch vehicle that supports mechanism feedback control
SECONDARY OBJECTIVES	
MO-2100	Develop a deployer that can hold various CubeSat sizes (3U, 6U, 12U, etc.)
MO-2150	Develop an interface with the LV that supports telemetry feedback

A key element of the CDR was a review of the available launch vehicles, their interfaces, and any outlier requirements that could impact the dispenser design. The SpaceX Falcon 9 launch vehicle was selected as a baseline for the initial verification test procedure definitions. The Rideshare Payload User's Guide (RPUG) acquired from SpaceX provided information regarding the interface between deployer and launch vehicle, the potential launch and environmental loading, and other requirements for design qualification.[3]

Table 3: Risks and Mitigations at CDR

#	RISK	MITIGATION	Likelihood/ Consequence
1	Mishandling of parts, components, or finished products by manufacturers, shipping/transit, or end users.	Proper inspection to be completed on all parts prior to integration and final assembly. Exhaustive checkout of assembled deployer will be performed prior to delivery. Upon delivery of assembled deployer, inspections ensure no damages were incurred during transit.	2,5 → 1,5
2	Cold welding of materials.	Appropriate coatings and anodized materials will be applied to surfaces where there is contact.	5,2 → 5,1
3	Uncaptured environmental constraints for new LV providers/launch systems.	Thorough testing of the system using enveloped environmental conditions. Additional margin testing to be performed to find system limits.	5,2 → 5,1
4	Supply chain issues.	Multiple vendors have been identified that are within the budget of the project. Long lead time items have been ordered early.	3,3 → 2,3

TECHNICAL SOLUTION

The Dual-Use Satellite Deployer is shaped much like a standard deployer, meant to fit within the SpaceX rideshare allowable volume. It has a width of 322 mm, height of 322 mm, and length of 510 mm. The initial design accommodates a 12U CubeSat with stretch-goals for deploying multiple 6U CubeSats. The design features a standard CubeSat deployer mounting configuration as described by the SpaceX RPUG. A visualization of the full configuration is provided in Figure 1.

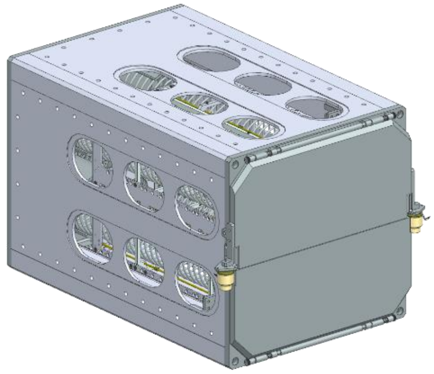

Figure 1. Dual-Use Satellite Deployer Configuration

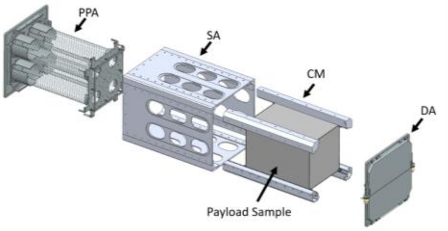

Figure 2: Exploded Assembly View

The deployer is comprised of three main sub-assemblies: the Shell Assembly (SA), the Door Assembly (DA), and the Pusher Plate Assembly (PPA). Figure 2 displays an exploded view of the full assembly in rail configuration.

The SA forms the main body of the deployer, including the primary support structures and exterior walls. This sub-assembly also includes the Clamping Mechanism (CM) assemblies which are the key feature for adapting the dispenser to tab or rail configurations.

The CM assemblies perform two functions. They provide two of the interfacing surfaces between the deployer and the encapsulated payload CubeSat. These surfaces are hard-coat anodized to reduce friction and prevent cold-welding between the deployer and the CubeSat. They also provide a clamping force on the payload prior to deployment to rigidize the structure and ensure a continuous load path throughout the entire system. The two configurations of the CM assemblies are designed to be easily swapped from the SA without disassembly of the full deployer. Bolts securing these assemblies are inserted and torqued from the exterior, making changing configurations easy and fast.

The rail configuration CM assembly is depicted in Figure 3. The shape of the rail adapter—the component interfacing with the CubeSat—matches the external faces of the standard CubeSat design with dimensions of 8.5 mm x 8.5 mm. The clamping mechanism provides a diagonal force from either side, centering the CubeSat laterally while also pushing it up into support structures forming the other two rail interfaces in the corners of the deployer. This provides the clamping force necessary to prevent movement during launch.

The CM utilizes a series of cams and rods to push the rail adapter into the CubeSat. A drive cam at one end of the CM assembly can be manually torqued to produce the clamping force (Figure 4), then locked into place with a pawl. This pawl disengages and removes the torque on the system upon opening of the deployer doors.

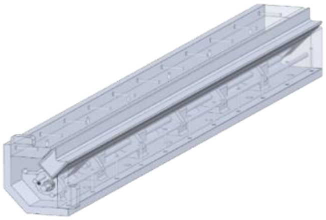

Figure 3: Rail Configured Clamping Mechanism Sub-Assembly

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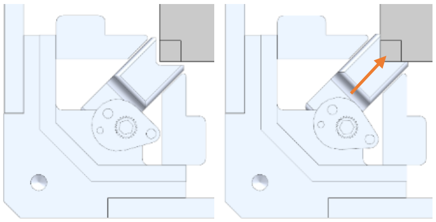

Figure 4: Clamping Mechanism Unactuated and Actuated

The tab configuration CM assembly works in a similar fashion. Cams and rods produce the clamping force, except the force is purely in one orthogonal direction. This provides an adjustable clamping force directly on the tabs of the CubeSat.

The clamping force on the encapsulated CubeSat keeps it from sliding along the rails/tabs during launch. The force is adjusted during assembly to specifications. The locking pawl is linked to the door assembly with a sliding linkage that disengages when the door opens, which requires a sufficient force initiated by the DA.

The DA is composed of a frame, two door structures that leaf together, and a latching mechanism, as seen in Figure 5. One door secures the other in place via an intersecting extrusion. Only the active leaf door is latched in place, to reduce complexity. The frame mounts to the front of the deployer with four M6 bolts and matches in outer dimensions with the SA. This provides a continuous structure for easy integration with the SA.

Both doors are hinged and include torsional springs that provide the moment to open the doors and release the clamping mechanisms. As the clamping mechanisms are on one side of the SA, only one of the doors requires attachment to the pawl-release linkages.

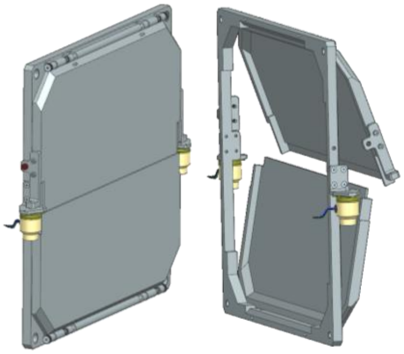

Figure 5: Door Sub-Assembly

To prevent overextension of the doors, a notch and wedge system is used. The hinge on the frame has a wedge into which a wedge on the doors can fit. When the doors are in a closed position, the notch and wedge are rotated ninety-degrees from each other, preventing insertion and locking. When the doors are fully open, the notch and wedge line up. Compression springs mounted on their hinges then shift the doors axially along the hinges to lock the notch into the wedge, thus preventing any further rotation away from the ninety-degree position while also preventing bounce-back of the door into the path of the deploying CubeSat.

The latching mechanism of the DA is a set of two EBAD TiNi Pin Pullers. These pin pullers mount to brackets attached to the DA frame. The pins lock a reciprocal set of brackets attached to the active door leaf when extended. The simple retraction of the pins is enough to unlatch the doors, allowing the torsional springs to apply the necessary torque to open fully. As a precaution during prelaunch handling, a set of bolts can also be used to lock the doors in place, attaching the active door directly to the frame. These bolts must be removed before flight to allow for the latching mechanism to work.

The rear section of the deployer is the PPA, serving as the mounting interface for the entire deployer to the launch vehicle and the means for applying the necessary impulse to the CubeSat to eject it from the deployer. The PPA is composed of a back plate, a set of springs, and the pusher/ejection plate. A set of guides can be added to reduce the chance of spring misalignment during PPA assembly.

The back plate of the PPA attaches to the SA with a series of M6 bolts and L-brackets. This provides a strong load path through the entire structure to the mounting interface. The back plate hosts the bolt pattern described earlier, standard to CubeSat dispensers. If needed, an adapter plate can be bolted onto the rear of the back plate to accommodate other bolt patterns.

Four stainless steel springs are used to store and provide the energy needed to launch the CubeSat. Requirements were laid out at the beginning of the system design necessitating that the CubeSat deploy at a rate within the range of 0.3 and 1.0 m/s. For a 12U CubeSat of approximately 24 kg, a low spring rate of 41.97 N/m per spring is needed. With a full compression of 300 mm, the springs store enough potential energy to deploy the CubeSat at an estimated velocity of 0.39 m/s. To enable quick changes of springs, circular plates are welded to the ends of each spring which are then bolted into the back plate and the pusher/ejection plate.

Figure 6 displays the PPA at nominal relaxed extension of the springs. The pusher/ejection plate is shaped to provide constant contact across the interface points of the CubeSat while being agnostic to the rail/tab configuration. This requires contact with the ends of the rails or the rear of a tab satellite frame. The plate also includes spaced holes, large enough to avoid interference with CubeSat external “tuna cans.” The springs are mounted around each of these holes, avoiding interference with the tuna cans.

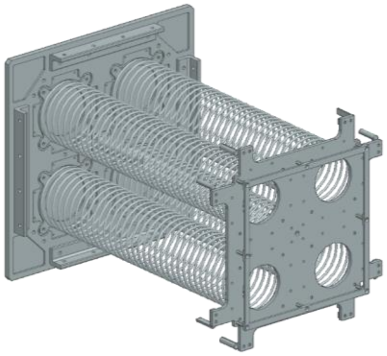

Figure 6: Pusher Plate Assembly

The pusher/ejection plate slides through the SA during deployment, pushed by the four springs and guided by the housing structures of the CM assemblies. Sets of "skis" are mounted to the corners of the pusher/ejection plate, providing a stable interface with these housing structures. The length of the skis is just enough to prevent rotation of the pusher/ejection plate during deployment, thus reducing the likelihood of jamming. The ends of the housing structures of the CM assemblies also include stops that are impacted by the skis at the end of deployment. This prevents the pusher/ejection plate from extending outside of the deployer. Hard anodizing on both the housing structures and the skis reduce friction and prevent cold welding between the surfaces.

The pusher/ejection plate can additionally mount a forward-facing buffer structure in the case of a shorter CubeSat. This structure is a square-shaped ring held forward by hex standoffs from the pusher/ejection plate. This allows the springs to be compressed without slack while the CubeSat is positioned within the deployer, thus retaining the nominal spring potential energy necessary for deployment. The standoff height can be adjusted as needed.

SYSTEM VERIFICATION

System verification follows system engineering principles, in which each requirement listed in the RTVM is subsequently verified for compliance. This is done through inspection, analysis, test, or demonstration of each requirement.

Many of the requirements regarding the system's structural integrity are being verified through analysis. A finite element linear analysis model of the structure was created in Simcenter 3D which utilizes NASTRAN for finite element analysis (FEA) solving (Figure 7). Each sub-assembly was meshed as an assembly FEM (AFEM) with most of the components meshed with 3D tetrahedral elements. Flat plates and noncritical components were reduced to 2D where possible. The pin pullers of the door latching mechanism were reduced to 0D point masses (CONM2) utilizing the masses, centers of gravity, and moments of inertia measured from the pin puller CAD. Beam (CBEAM) elements and rigid-link meshes (RBE2) were used model bolts throughout the structure.

Figure 7: Finite Element Analysis Model of the Full Configuration

The clamping mechanism was specifically simplified without the internal clamping components, only including the supporting structures, to reduce complexity. A breakout model of the CM was separately analyzed with representative constraints and loading.

Load factors were obtained from the SpaceX RPUG Table 4-1 CubeSat Dispenser (including CubeSats) Quasi-Static Load Factors. This table notes the expected axial and lateral load factors, placing them at 10 and 17 g's respectively. For this analysis, three subcases were created, one for each orthogonal direction. To capture worst-case loading scenarios, a 17 g load factor was also used in the axial direction. Fixed translation constraints were located at the mounting points on the back plate of the PPA.

All meshed structures are composed of aluminum 6061 with stainless steel fasteners. Material properties are listed in Table 4. The sustained acceleration simulations were solved without issue and displacement, von-Mises stress, and von-Mises strain results were extracted as listed in Table 5.

The maximum stress in all three load cases is significantly less than the aluminum 6061 yield strength (276 MPa), indicating a lack of plastic deformation. The low maximum strain further supports this conclusion. An example of the results, specifically depicting the load case in the local x-direction, is shown in Figure 8. The maximum stress is located at the latching mechanism where the leafed doors are pinned to the frame.

Table 4: Material Properties

Material	Aluminum 6061	Stainless Steel
Yield Strength [GPa]	276	215
UTS [GPa]	310	505
Density [kg/m^3]	2711	8000
Young's Modulus [GPa]	69	193
Poisson Ratio	0.33	0.29

Table 5: Displacement, Stress, and Strain Results of Full Configuration Analysis Model

Loading Direction	**Max Displacement [mm]**	**Max Stress [MPa]**	**Max Strain [mm/mm]**
X	0.394 at leafed door	75.83 at latch	2.077E-03 at hinge
Y	0.700 at latch	123 MPa at rear mount	2.751E-03 at rear mount
Z	0.675 at hinge	111 MPa at rear mount	2.677E-03 at rear mount

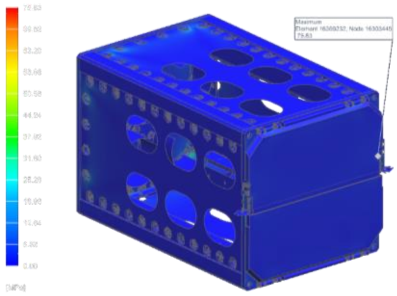

Figure 8: Linear Analysis Results for 17G Loading in X

A separate analysis of the clamping mechanism was also conducted in which the CM sub-assembly was fully meshed. Most components were meshed with 3D tetrahedral elements with only the rods and fasteners modeled as beam elements. The load factors were applied in an identical manner to the full model analysis. Translational constraints were located at the fastener points between the CM and the SA. Table 6 notes the displacements, stress, and strain seen in the CM sub-assembly breakout simulation.

The CM displays purely elastic deformation and its maximum von-Mises stress in all three load cases is far less than the yield strength of its material, aluminum 6061.

Table 6: Displacement, Stress, and Strain Results of Clamping Mechanism Breakout Model

Loading Direction	**Max Displacement [mm]**	**Max Stress [MPa]**	**Max Strain [mm/mm]**
X	0.0416 at end of clamping adapter	4.551 at geared cam	5.849E-05 at geared cam
Y	0.575 at end of clamping adapter	48.79 at geared cam	6.271E-04 at geared cam
Z	0.524 at end of clamping adapter	35.12 at geared cam	4.515E-04 at geared cam

The results of these initial linear simulations provided confidence in the design of the Dual-Use Deployer structures. As none of these structures exceed the yield strength of the material under expected loading conditions, let alone the ultimate tensile strength, there is a significant margin in the structure's capacity to handle launch loads.

The second phase of system verification involves a robust test campaign. Environmental tests at UIUC and Morehead University are expected to be completed in the Fall of 2024. These tests include:

1. A hardware fit check to determine the compatibility of commercial CubeSat structures within the deployer.
2. A vibration test at Morehead State University to determine responses to random and sine-sweep vibration according to standard test levels provided by the SpaceX RPUG or GSFC-STD-7000B.[4]
3. A full deployment test to determine shock response from a simulated deployment of a CubeSat.
4. A thermal-vacuum test in the UIUC LASSI Thermal-Vacuum Chamber (TVAC) to determine effects of vacuum and temperature on the deployer.
5. A deployment at temperature extremes in which CubeSat structures are deployed from the

deployer while at temperature extremes expected in accordance with the SpaceX RPUG.

The majority of these tests will be conducted at LASSI. These tests will include the use of two CubeSat structures: a rail structure acquired from GOMspace and a tab structure acquired from Exobotics. Simulated payload masses will be manufactured at UIUC machine shops and used to ballast the structures. Two prototypes of the deployer will be used, one for each configuration. A separate demonstration will be focused on obtaining subjective data on the ease of configuration changes.

CONCLUSION

A readily configurable CubeSat dispenser will provide additional flexibility for launch vehicle services providers, while reducing capital expenditures required to maintain a fleet of noninterchangeable deployment capabilities. Development of the dispenser is proceeding apace, system verification is underway, fulfilling the requirements tracked in the project's RTVM, and analytical verification results are promising. Several tests are set to be conducted over the summer of 2024 to complete the system verification process of this prototype model, including hardware fit checks, vibration tests, deployment tests, and TVAC tests.

Acknowledgments

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