Vulcan Centaur – Next Generation Multi-Manifesting for Low-Cost Access to Space

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This paper is an introduction to the next generation multi-manifesting capabilities of the Vulcan Centaur launch vehicle. Leveraging United Launch Alliance's (ULA) extensive history of successful multi-manifest missions with a focus on future market needs has resulted in a highly flexible and capable launch vehicle that offers greater access to space at lower cost. From Aft Bulkhead Carriers (ABC) to ESPA rings and multi-launch canisters to constellation dispenser concepts, Vulcan's suite of multi-manifest capabilities enables opportunities for greater utilization of its tremendous performance. We will also discuss the manifesting approaches and mission integration tools that allow us to unlock the potential of multi-manifesting on Vulcan for our customers.

I. Introduction

United Launch Alliance (ULA) continues to build upon an already extensive launch history of 145 missions with 100% mission success, delivering numerous high-value payloads on-orbit for the Department of Defense, the National Reconnaissance Office, NASA, and a variety of commercial customers. In order to transform our business model and provide all our customers with assured access at lower cost, ULA developed our next generation launch system—Vulcan Centaur. Vulcan Centaur offers shorter span times and faster satellite integration while providing the same outstanding mission assurance offered by our heritage launch vehicles. ULA's Vulcan Centaur will service the entire mission domain, currently requiring both the Atlas V and Delta IV Heavy for access, with a highly reliable, scalable, single core vehicle. In addition to delivering high value primary payloads, we will continue expanding the multi-manifest capabilities provided to the market by Vulcan Centaur.

ULA is broadening the host of access provisions developed for our Atlas V and Delta IV families of vehicles to provide even larger dual-manifest and multi-manifest mission opportunities on Vulcan Centaur. Operationally relevant small satellite technology enables proliferation of mission capability through mass production at vastly cheaper costs, while offering greater resiliency to space architectures and mission capability. Multi-manifest ability allows customers

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to achieve this resiliency at the incremental cost of scalable performance. Access for small satellite missions is frequently provided within the excess performance of a vehicle configured for the primary mission. For the relatively nominal cost of additional solids, much larger secondary missions are accommodated with very little impact to the primary mission.

ULA leads the industry in both upper stage performance and orbital insertion accuracy, enabling unmatched flexibility across a host of orbital insertions and mission designs. Vulcan Centaur's cost effective, easily scalable single core heavy lift capability enables new and unique multi-manifest mission opportunities, allowing for the rapid deployment of new technologies to an impressive range of separation orbits. We continue to hone our ability to accommodate increasingly complex and rapid integration of satellite payloads later in the mission readiness timeline.

More than 75% of ULA's contracted missions over the last few years have or are planned to host multiple satellites on a single launch vehicle. Our longer-term technical roadmap focuses on rapid re-manifesting and integration, longer mission durations and enabling accommodation of late payload volume and mass growth. This paper provides a foundation to build better strategies for affordable and reliable multi-manifest access to space, discusses strategies for fleet deployment, describes successful pairing methodologies and provides insights into our Do No Harm strategy for mission assurance and mission success.

II. Multi-Manifest History

ULA is an industry-leading multi-manifest launch service provider, with a 100% successful track record of integrating and flying multi-manifest missions on our Atlas V, Delta IV, and Delta II launch vehicles. These missions featured a wide range of capabilities, including both non-separating and propulsive EELV (Evolved Expendable Launch Vehicle) Secondary Payload Adapters (ESPAs), Aft Bulkhead Carriers (ABCs), and CubeSat/Poly Picosatellite Orbital Deployers (P-PODs). To date, ULA has flown six ESPA missions for the US Air Force and NASA, nine ABC missions that deployed 59 CubeSats, and four P-POD missions that deployed 18 CubeSats for numerous customers. Our extensive multi-manifest history includes successful multi-manifest spacecraft deployments to a variety of orbits and in all phases of flight. Highlights include flying multi-manifest missions to the Moon, the first interplanetary multi-manifest mission to Mars, as well as the successful deployments of rideshare spacecraft prior to primary spacecraft separation. A complete listing of our multi-manifest history can be found in Table 1.

Table 1 ULA Multi-Manifest History, 2000-2021.

Mission	Vehicle	Launch Date	Rideshare Type	Rideshare Hardware Used
Iridium 1-12 (Constellation)	Delta II 7920	Multi	Multi	Platform Dispenser
Globalstar 1-7 (Constellation)	Delta II 7420	Multi	Multi	Post Dispenser
EO-1/SAC-C/Munin	Delta II 7320	11/21/2000	Dual + Secondary	DPAF
Jason-1/TIMED	Delta II 7920	12/7/2001	Dual	DPAF
ICESat/CHIPSAT	Delta II 7320	1/12/2003	Dual	Reduced-Height DPAF
GPS IIR-8/XSS-10	Delta II 7925	1/29/2003	Secondary	Delta II Guidance Section
Delta IV Heavy Demo/Nanosat-2	Delta IV Heavy	12/20/2004	Piggyback	Mission-unique bracket
CALIPSO/CloudSat	Delta II 7420	4/28/2006	Dual	DPAF
STP-1	Atlas V 401	3/8/2007	Secondary	ESPA
LRO/LCROSS	Atlas V 401	6/18/2009	Secondary	ESPA
NPP/ELaNa III	Delta II 7920	10/28/2011	Secondary	Delta II P-POD
NROL-36/OUTSat	Atlas V 401	9/13/2012	Secondary	ABC
NROL-39/GEMSat	Atlas V 501	12/5/2013	Secondary	ABC
AFSPC-4/ANGELS	Delta IV M+(4,2)	7/28/2014	Secondary	ESPA
SMAP/ELaNa X	Delta II 7320	1/31/2015	Secondary	Delta II P-POD
AFSPC-5/ULTRASat	Atlas V 501	5/20/2015	Secondary	ABC
NROL-55/GRACE	Atlas V 401	10/8/2015	Secondary	ABC
AFSPC-6/ESPA	Delta IV M+(4,2)	8/19/2016	Dual	ESPA
WorldView 4/Enterprise	Atlas V 401	11/11/2016	Secondary	ABC

JPSS-1/ELaNa	Delta II 7920	11/18/2017	Secondary	Delta II P-POD
AFSPC-11	Atlas V 551	4/14/2018	Secondary	ESPA
InSight/MarCO	Atlas V 401	5/5/2018	Secondary	ABC
ICESat II/ELaNa	Delta II 7420	9/15/2018	Secondary	Delta II P-POD
AEHF-5/EZ-1	Atlas V 551	8/8/2019	Secondary	ABC
AEHF-6/EZ-2	Atlas V 551	3/28/2020	Secondary	ABC
SBIRS GEO 5	Atlas V 421	5/18/2021	Secondary	ABC
Landsat 9/L9 EFS	Atlas V 401	9/27/2021	Secondary	ESPA

Over these years, we have applied our multi-manifest experience to continuously improve our launch service offering, developing novel capabilities for previously flown multi-manifest missions and refining our integration processes. Examples include gaseous Nitrogen purges (demonstrated on GEMSat), multiple restarts of the Centaur upper stage to support the LRO/LCROSS mission to the Moon, first time deployment of a rideshare mission ahead of a primary spacecraft on AEHF-5, use of separation sequencers enabling greater flexibility and numerous deployments as demonstrated on Landsat-9, the deployment of the MarCO A and B CubeSats in a loose formation with the InSight spacecraft to Mars (first interplanetary CubeSats), and in-flight power capability for STP-3. Vulcan Centaur builds on this legacy, actively leveraging our expertise on multi-manifest integration work for numerous upcoming Vulcan missions.

III. Expanding Market Needs

The cislunar domain stands to benefit from the incredible proliferation of new technologies and the mission models that those new small satellite technologies enable. While many small satellite missions have flown to Earth orbits, the flight of the MarCO spacecraft to Mars and the anticipated launch of CAPSTONE to a lunar orbit, demonstrate the breadth of mission needs that can be fulfilled by small satellites. Furthermore, as we expand beyond Earth orbit, the need to observe and protect the broadened horizons of our expanding space environment will become increasingly important.

ULA developed concepts and performed studies to align the evolution of our Vulcan Centaur launch services to meet the emerging needs of this expanding small satellite community beyond Earth orbit. The baseline Vulcan Centaur supports ESPA secondary payloads, leveraging the success of this capability on Atlas Centaur and Delta IV. We couple this with our expertise in delivery across the cislunar space to create new ways of rapidly deploying capability across the domain. Our experience with high thrust maneuvering systems allows us to develop rapid delivery solutions to maximize the mass to orbit on every launch, enabling lower cost secondary missions, especially when compared to dedicated launch costs. Further, we recognize the business/mission benefit from rapid operational orbit deployment compared to the months required for low thrust, Solar Electric Propulsion delivery to a desired orbit regime. The evolution of our systems is shaped with this community in mind.

Vulcan Centaur was designed with mission flexibility in mind, taking advantage of multiple concepts developed by ULA's Advanced Programs team to support access to space for various multi-manifest configurations, from small to large masses and from LEO to Lunar orbit and beyond. These concepts range from payload accommodation enhancements (e.g. shrinking the integration timelines) to Centaur V enhancements (e.g. expanding our reach, duration and mission flexibility), and even to 3rd stages, creating additional multi-manifest maneuver capability by removing the limits of a single upper stage. Demonstration of ULA's next generation of capabilities will begin with the inaugural flight of Vulcan Centaur, delivering the Astrobotic Peregrine Lander to its Trans Lunar Orbit, and will continue to evolve. ULA implemented a block upgrade program to enable rapid advancement of capabilities for the small satellite market as well as the traditional National Security Space, NASA and commercial markets. We stand committed to accelerating the benefits of innovation and increasing the pace of operational capability that this segment provides the entire domain.

IV. Multi-Manifest Capabilities Overview

As discussed in Section 1, ULA successfully launched numerous multi-manifest missions, such as STP-1, AFSPC-4, AFSPC-11, and LRO-LCROSS. These missions featured our wide variety of multi-launch capabilities, including use of ESPA rings for larger satellites, the C-Adapter Platform (CAP), and ABC for smaller spacecraft, as well as other custom multi-manifest solutions. Our experience integrating unique, complex multi-manifest missions has resulted in a team highly skilled in multi-manifest integration, with the ability to provide both standard and creative custom solutions. With the introduction of Vulcan Centaur, we continue to offer these proven solutions while leveraging our team's experience to introduce new capabilities like the ABC Heavy and Multi-Launch Canister. These new capabilities further maximize payload manifesting flexibility and performance for our customers, opening the door for numerous multi-launch scenarios as illustrated in Fig. 1.

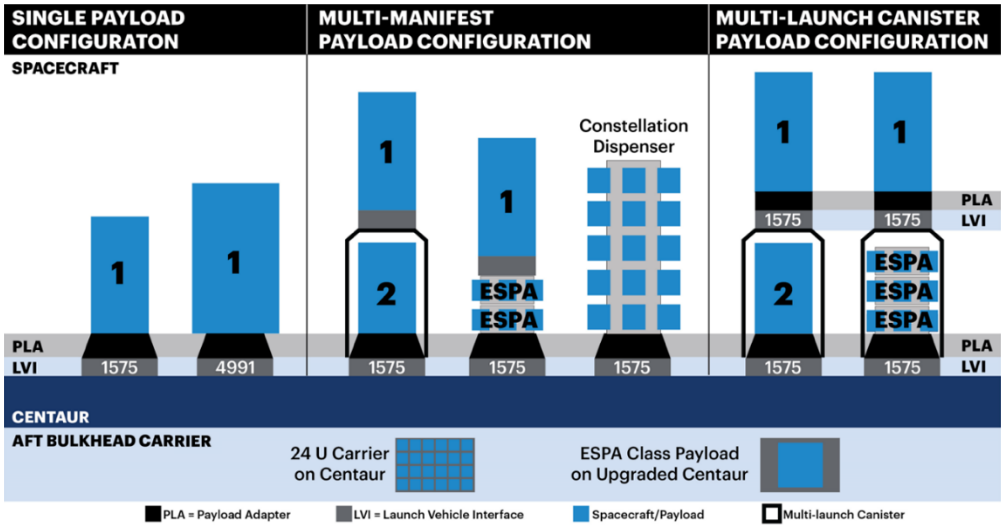

Fig. 1 Vulcan Centaur Enables Numerous Multi-Manifest Scenarios.

A. C-Adapter Platform (CAP)

The C-Adapter Platform (CAP) is located within the payload fairing and attached to the side of a C-Adapter. It can carry an auxiliary payload with a mass up to 45-kg (100-lbs). Figure 2 shows the usable volume dimension of the CAP and its location on the side of a typical C-Adapter. A C-29 Adapter can accommodate up to four CAPs on a single flight. The number of CAPs and the positioning of the CAPs around the circumference of the C-adapter are subject to available mission margins and mission requirements. The CAP can accommodate various deployment options and is large enough for an 8-in Motorized Lightband, which can be mounted on either the base of the CAP or on the back wall.

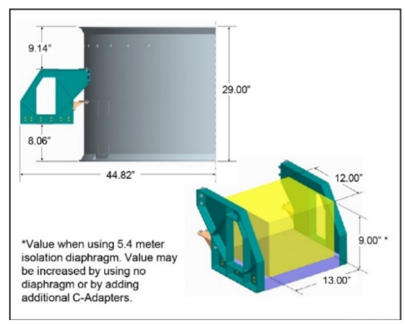

Fig. 2 CAP Location and Volume.

B. Aft Bulkhead Carrier (ABC)

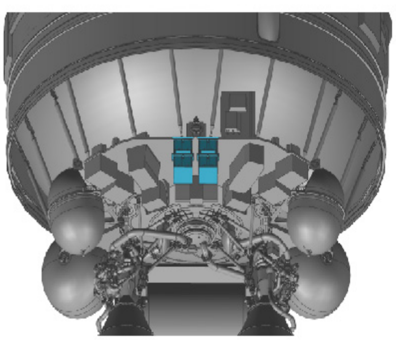
Fig. 3 ABC Mounting Location.

On Atlas V, the Aft Bulkhead Carrier utilizes volume on the Centaur aft bulkhead previously occupied by a helium bottle that is no longer required. Since its first flight in September 2013, the Atlas V ABC has flown on nine missions, releasing 59 CubeSats. On Vulcan, the ABC will be installed on the aft bulkhead's equipment shelf, as shown in Fig. 3. The ABC can carry up to 24U of CubeSats or up to 80-kg (176-lbs) of auxiliary payload mass and accommodates both separating and non-separating payloads, with a volume that is slightly larger for non-separating payloads. The ABC is large enough to accommodate a 15-in Motorized Lightband separation system.

Since the ABC is on the aft-end of the Centaur and outside of the primary load path, it has the advantage of not interfering with the primary payload environment. It also has the ability to be deployed into low-Earth orbit during the Centaur first coast portion of the mission. We demonstrated this capability on both the AEHF-5 and AEHF-6 missions where a secondary spacecraft was successfully deployed before the primary spacecraft with agreement from the USG customer. The separation plane of the ABC is oriented to provide clearance and prevent re-contact with the Centaur in coast. To avoid contamination or plume impingement, the Centaur inhibits the normal settling thrusters during the period of deployment.

C. ABC Heavy

The ABC Heavy on Vulcan Centaur is an adaptation of the original ABC developed for use on the Atlas V and features simple interfaces, low-cost attach hardware, and streamlined launch site integration. This capability expands Vulcan Centaur's multi-manifest capacity by utilizing interfaces previously reserved for one of Centaur V's Helium bottles. While it retains the key advantage of being outside of the primary load path, ABC Heavy is designed to carry an auxiliary payload of up to 125-kg (275-lbs) and a spacecraft volume envelope consistent with current ESPA payloads. This location is only used for missions requiring the highest performance from the upper stage with an extra Helium bottle, and is therefore available real estate on most mission designs. Further enhancements are possible with future configurations of the Centaur V. A view of the mounting location for ABC Heavy on the Centaur V aft bulkhead is provided in Fig. 4.

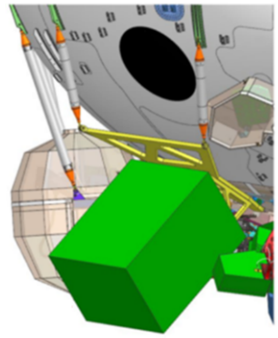

Fig. 4 ABC Heavy Mounting Location.

D. ESPA, ESPA Grande, & Separating ESPAs

Small satellites can be launched using the EELV Secondary Payload Adapter (ESPA), a 62-in diameter, 24-in-tall ring structure that can support up to six spacecraft around its circumference. For larger payloads, ULA also offers the ESPA Grande, a 62-in diameter, 42-in tall ring capable of supporting up to five spacecraft. The ring is mounted between the top of a C-Adapter and the bottom of the primary spacecraft payload adapter, as seen in Fig. 5, duplicating the EELV standard interface plane (SIP), and passing the electrical interfaces through to the primary payload.

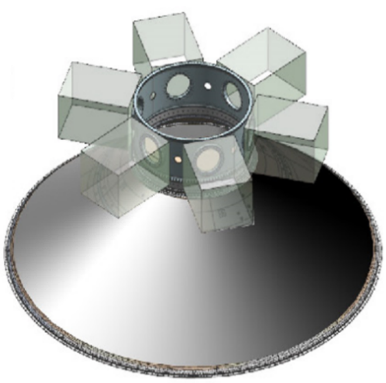

Fig. 5 Typical ESPA & C-Adapter Structural Stack.

The ESPA ring features 15-in diameter bolt circle interfaces, each able to accommodate a single spacecraft of up to 450-kg (991-lbs) in mass, and a volume of 24-in x 28-in x 38-in (61.0-cm x 71.1-cm x 96.5-cm). The ESPA Grande utilizes 24-in diameter bolt circle interfaces, each able to accommodate a single spacecraft of up to 700-kg (1543-lbs), and a volume of 42-in x 46-in x 56-in (106.7-cm x 116.8-cm x 142.2-cm). The spacecraft may be attached to the ESPA or ESPA Grande with a ULA-supplied separation system or directly through an auxiliary payload provided adapter.

ULA can also support missions with separating ESPAs that act as independent space vehicles. This capability was successfully demonstrated on the LRO/LCROSS mission and with EAGLE on the AFSPC-11 mission. Through our experience and established relationships with separating ESPA providers, we are also able to offer this capability to multi-manifest customers.

E. Multi-Launch System

The multi-launch system takes advantage of Vulcan Centaur's tremendous performance and very large payload fairing volume, enabling the launch of two or more primary payloads on a single core vehicle. The Vulcan Centaur multi-launch system is a baseline capability on Vulcan, consisting of an internal canister and two 1575-mm payload attach fittings (Fig. 6). Payload adapters are integrated as required. The forward and aft payload positions are structurally qualified to a 9-mT (20,000-lbs) payload, with a 3302-mm (130-in) vertical center of gravity (cg) offset and a 203-mm (8-in) lateral cg offset. The two compartments are designed to be independent, with separate environmental control systems and dual re-rad and Radio Frequency attenuation capability.

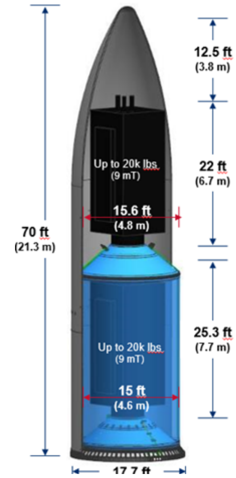

Fig. 6 Multi-Launch Canister.

F. Proliferated Constellation Dispenser Concepts

Heavy lift launch vehicles, like Vulcan Centaur, are ideally suited for the deployment of full segments or planes of a satellite constellations. This this type of mission takes full advantage of Vulcan's significant scalable performance and large payload fairing volume, which translates into greater affordability on a per spacecraft basis. Over the years, we developed multiple dispenser concepts for numerous scenarios, honing our overall experience with these systems and cultivating the ability to offer creative solutions optimized to bring the greatest value for our multi-manifest customers. Given the projected rate of access for constellation deployments, we also see opportunity for increased multi-manifested delivery for compatible/paired payloads.

V. Manifesting & Mission Integration

ULA flies missions for two primary customer markets: US government (USG) and commercial. The logistics and mechanics for manifesting multiple spacecraft on these two types of missions differ slightly. For USG missions, this customer typically controls the full performance of their launch vehicles. ULA can work with the USG customer on behalf of other multi-manifest customers or a potential multi-manifest payload can reach out directly to the applicable agency to apply for manifesting with a primary mission. For the US Space Force, the Multi-Manifest Office (MMO) is the primary point of contact. For NASA missions, it is the Launch Services Program (LSP). A key consideration for multi-manifest customers interested in manifesting on missions with these customers is their timeline. Advanced coordination for multi-manifest on these missions benefits all parties involved, with both customers typically requiring a multi-manifest payload to be identified and working with them 24 – 36 months in advance of the target launch date. This allows time for contracting and the performance of mandatory mission integration work, such as coupled loads analyses and Do No Harm (DNH) assessments.

For missions with commercial customers, ULA typically retains control of the launch vehicle performance not required to support the primary customer(s) mission objectives, which provides multi-manifest customers easier access to the remaining mass to orbit capacity. With its significant, scalable performance and large payload fairing volume, Vulcan Centaur is uniquely designed for multi-manifesting, enabling high performance utilization and greater affordability. The capabilities described in Section 3 highlight the versatility of the Vulcan vehicle. With regard to contract timing, commercial missions are typically on contract 24 months before launch, but can accommodate significantly shorter timelines with primary customer alignment.

With regard to identifying pairings for multi-launch missions, there are several key criteria we consider: required launch date, separation orbit, and DNH. The first criterion for pairing is alignment of launch dates. The more flexibility a multi-manifest customer can accommodate in their launch date, the more potential pairing options will be available and the greater the probability of finding a match. For the second criterion, ULA looks to match multi-manifest payloads with a co-passenger going to the same or similar orbits. Payloads designed to fly to standard orbits (e.g. LEO, GTO, and GEO) will have the greatest number of pairing opportunities, but given the tremendous performance of the Vulcan vehicle, spacecraft deployments to different orbits will be possible in some circumstances. We can also leverage our experience with long duration propulsive ESPAs and relationships with space-tug providers to create additional flexibility in pairings. Regarding the third criterion, ULA recommends multi-manifest payloads design to industry standards and minimize mission unique needs to ensure compatibility with potential co-passengers. While ULA is highly experienced working with customers to accommodate mission unique spacecraft and requirements, the more standard the spacecraft, the more likely it is to be compliant with DNH considerations and compatible with all co-passengers flying on the mission. Standardization is also a key enabler for accommodation of later payload swaps and integration work.

Integration flexibility is a key differentiator when it comes to successfully manifesting multiple spacecraft on the same mission. ULA's standard integration approach is to accommodate variations in multi-manifest properties that would cover all multi-manifest candidates. Applying the range of properties to key integration activities, such as trajectory, loads, safety and launch site processing, allows for potential late integration opportunities.

For a standard integration timeline, ULA requires the rideshare manifest to be determined at 12 months before launch (L-12 months). Rideshare manifests that are well understood and mature, may push the standard integration timeline to L-10 months, which is the typical start of our verification loads cycle. Constantly looking for ways to improve and streamline the integration process, ULA has developed a powerful Coupled Loads Analysis tool called RAPIDS (Fig. 7). This tool generates spacecraft and launch vehicle loads using a wide range of rideshare properties, including mass properties and location in the stack, and generates a bounding set of loads for use by the team for each configuration covered in the analysis. Using RAPIDS and other techniques currently in development, a future rideshare selection timeline approaching L-3 months may be possible, where ground operations becomes the limiting capability.

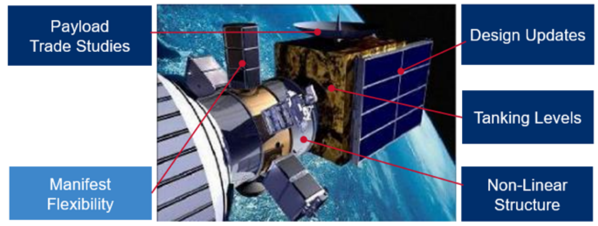

Fig. 7 RAPIDS Benefits.

As a standard practice, ULA performs a DNH assessment for every multi-manifest mission. Developed by ULA from our lessons learned on past missions, this process is a best practice that systematically evaluates potential risks presented by multi-manifest payloads to the primary spacecraft and overall mission and ensures that each potential risk category is adequately mitigated. The ULA DNH evaluation assesses potential risks in areas such as spacecraft mechanical and electrical design, mission requirements, qualification, and operations to ensure impacts to the mission are fully characterized and understood by the integrated mission team. The completed DNH assessment provides all parties confidence that the multi-manifest payload(s) are fully compatible with the primary spacecraft, each other and the launch vehicle.

VI. Conclusion

Throughout ULA's history, we have developed capabilities and pioneered processes that have enabled and expanded multi-manifesting, from the early days when rideshare was a novelty to the industry norm it has become today. ULA understands the benefits multi-manifesting brings to the entire space domain, which is why we invest in capabilities like the Centaur restartable upper stage, ABC, Multi-launch System, and large volume payload fairings, and develop processes like DNH, now an industry standard. We recognize multi-manifesting enables greater launch opportunity and affordability, which helps close business cases and accelerates demonstration, test and evaluation of new technologies and augmentation of operational capabilities. With Vulcan Centaur, we will serve the SmallSat market with both flight proven products and the introduction of new capabilities that offer even greater flexibility. And, given the ever-changing demands of the market, we will continue to work closely with our customers and industry partners, supporting studies and developing concepts, to ensure we can deliver the creative, cutting edge solutions our industry needs.