VULCAN LAUNCH SYSTEMS USER'S GUIDE

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ULA

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The Vulcan Centaur User's Guide will be revised periodically for incorporation of technical changes and updated capabilities. ULA welcomes and encourages comments and suggestions on information presented throughout the User's Guide. Please feel free to email your comments and suggestions to: contactus@ulalaunch.com.

FOREWORD

United Launch Alliance, LLC (ULA) is a complete launch services provider, offering standard and customized launch solutions to our commercial and government customers from the planning stages of a mission through launch and spacecraft separation. An evolution of the flight-proven, highly successful Atlas V and Delta IV vehicles, Vulcan Centaur is ULA's next generation launch vehicle solution designed specifically to meet our customer's needs.

FOCUS ON OUR CUSTOMER'S MISSION

At ULA, the success of our customer's mission is our number one priority. We see launch as a partnership, and we are committed to working with our customers to optimize their launch strategies. ULA designed Vulcan Centaur with greater capability and better value for the benefit of all our customers.

AFFORDABLE AND SIMPLE

With Vulcan Centaur, ULA will make access to space more affordable by taking advantage of new manufacturing technologies and streamlined processes. More affordable access to space means new opportunities in space and more capabilities on Earth.

Vulcan Centaur offers our customers unprecedented flexibility in a single system. From Low-Earth Orbit to Pluto and beyond, the single-core Vulcan Centaur does it all. This simple design is more cost-effective for all customers.

INNOVATIVE DESIGN FOUNDED ON PROVEN HERITAGE

Building on more than 120 years of combined Atlas and Delta launch experience, Vulcan Centaur introduces a balance of new technologies, flight-proven systems, and innovative features to ensure a reliable and affordable space launch service. Leveraging proven processes, technology and expertise, Vulcan Centaur provides the highest value launch service with optimal performance to meet the full range of requirements for all of our customers.

Vulcan Centaur leverages existing infrastructure, including manufacture and assembly at ULA's proven and sophisticated production facility in Decatur, Alabama, and launch facilities at Cape Canaveral Space Force Station, Florida, and Vandenberg Space Force Base, California.

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1. INTRODUCTION

1.1 Vulcan Centaur User's Guide Purpose

The Vulcan Centaur User's Guide provides customers with a planning document containing information about Vulcan Centaur and related launch services. It conveys information on Vulcan Centaur capabilities and payload interfaces as of the date of this publication. This user's guide includes the essential technical and programmatic data and requirements for preliminary mission planning and payload design.

Information within this user's guide is subject to adjustment as flight experience is gathered. Please contact ULA for coordination of preliminary mission planning and payload design compatibility.

The Vulcan Centaur User's Guide will be revised as necessary to update launch system capabilities and launch services information. ULA encourages and appreciates any recommendations that could improve the utility of this user's guide.

1.2 United Launch Alliance

ULA is a highly reliable space launch company with an unmatched record of experience, launch success, and mission capability. It is a joint venture between Lockheed Martin Corporation and The Boeing Company, which became operational on December 1, 2006. ULA consolidated the successful launch vehicle programs of these two companies and builds on five decades of prior experience including many hundreds of successful launches for commercial and government customers. The ULA team brings precision, passion, and purpose to the most technically complex, critical mission needs with affordable, reliable, on-time access to space.

This consolidation of launch systems allows ULA to best meet the demand for timely, reliable, and lower-cost launch services in support of commercial, national security, civil, and scientific missions. With a strong heritage of launching the most important space missions over five decades prior to its formation, ULA maintains an unwavering focus on delivering the highest quality and reliability. The result is an unrivaled launch success rate since the formation of the company. Vulcan Centaur leverages the experience and success of Atlas and Delta, expanding our capabilities while maintaining our unmatched record of mission success. The evolution of the Atlas and Delta vehicle families is shown in Figure 1.2-1.

1.2.1 Atlas

The Atlas family of launch vehicles began with the early development of spaceflight in the 1940s, culminating with the first test flight in 1957. Different versions of Atlas boosters were developed for crewed and un-crewed space missions, including the pioneering Project Mercury human launches that paved the way toward the Apollo lunar program. The addition of the Centaur upper stage in the early 1960s made lunar and planetary missions possible. In 1981, the Atlas G booster improved Atlas/Centaur performance by increasing propellant capacity and upgrading engine thrust. This baseline evolved into the successful Atlas I, II, IIA, IIAS, IIIA, and IIIB launch vehicles. The Atlas family of vehicles flew more than 600 times over the last six decades. Atlas V/Centaur, along with its predecessor Atlas II and III variants, all launched with 100% success, contributing to the unmatched reliability of the Atlas family of launch vehicles for the last 30 years.

1.2.2 Delta

The Delta family of launch vehicles began in the 1950s as a derivative of the Thor intermediate-range ballistic missile with its first successful satellite launch in 1960. Delta evolved into a larger, more advanced, and capable vehicle to deliver NASA, Telstar, and Intelsat satellites into orbit. Design changes included larger first-stage tanks, strap-on solid rocket boosters, increased propellant capacity, an improved main engine, advanced electronics and guidance systems, and development of upper stage and satellite payload systems. In the 1960s and 1970s, Delta served as NASA's primary launch vehicle for boosting communications, weather, science, and planetary exploration satellites into orbit. The Delta II family came into service in 1989 and had an impressive reliability record of 99% mission success over its long history of 155 launches. The Delta IV family came into service in 2002 and included a medium and a heavy variant. Delta IV maintains a remarkable reliability record of 100% mission success over more than 40 launches.

1.3 Vulcan Centaur Launch Services

Vulcan Centaur leverages the success, capabilities, and infrastructure achieved by ULA over the decades, including launch vehicle manufacture and assembly at our production facility in Decatur, Alabama, and launch capability from our facilities at Cape Canaveral Space Force Station (CCSFS), Florida, and Vandenberg Space Force Base (VSFB), California.

Vulcan Centaur provides customers the capability to launch any day of the year, any time of the day to a wide range of orbit inclinations and altitudes. Mission design options include low-Earth orbit (LEO), medium-Earth orbit (MEO), geosynchronous transfer orbit (GTO), geosynchronous orbit (GEO), trans-lunar injection (TLI) and high-energy Earth escape trajectories.

Vulcan Centaur's flexible launch manifest supports single payload and multi-manifest capabilities. Our multi-manifest capability enables optimal performance utilization, allowing launch of small and auxiliary payloads in conjunction with traditional large missions.

ULA typically offers a 12-month to 24-month mission integration process dependent on customer requirements and mission complexity. The overall mission integration timeline is tailored to the needs of each mission. The comprehensive standard services described herein accommodate the needs of most missions, and include mission-specific tailoring (for example, assignment of one of our standard payload adapters). For missions with requirements that go beyond our standard service, mission unique services are negotiated to supplement the standard service scope.

ULA can arrange commercial payload processing facilities at our East and West Coast launch sites for customer payload processing leading up to encapsulation in the Vulcan payload fairing. Our extensive experience with a wide range of payload adapters allows us to accommodate customer provided payload adapters or provide the payload adapter as part of Vulcan Centaur's mission-specific launch service.

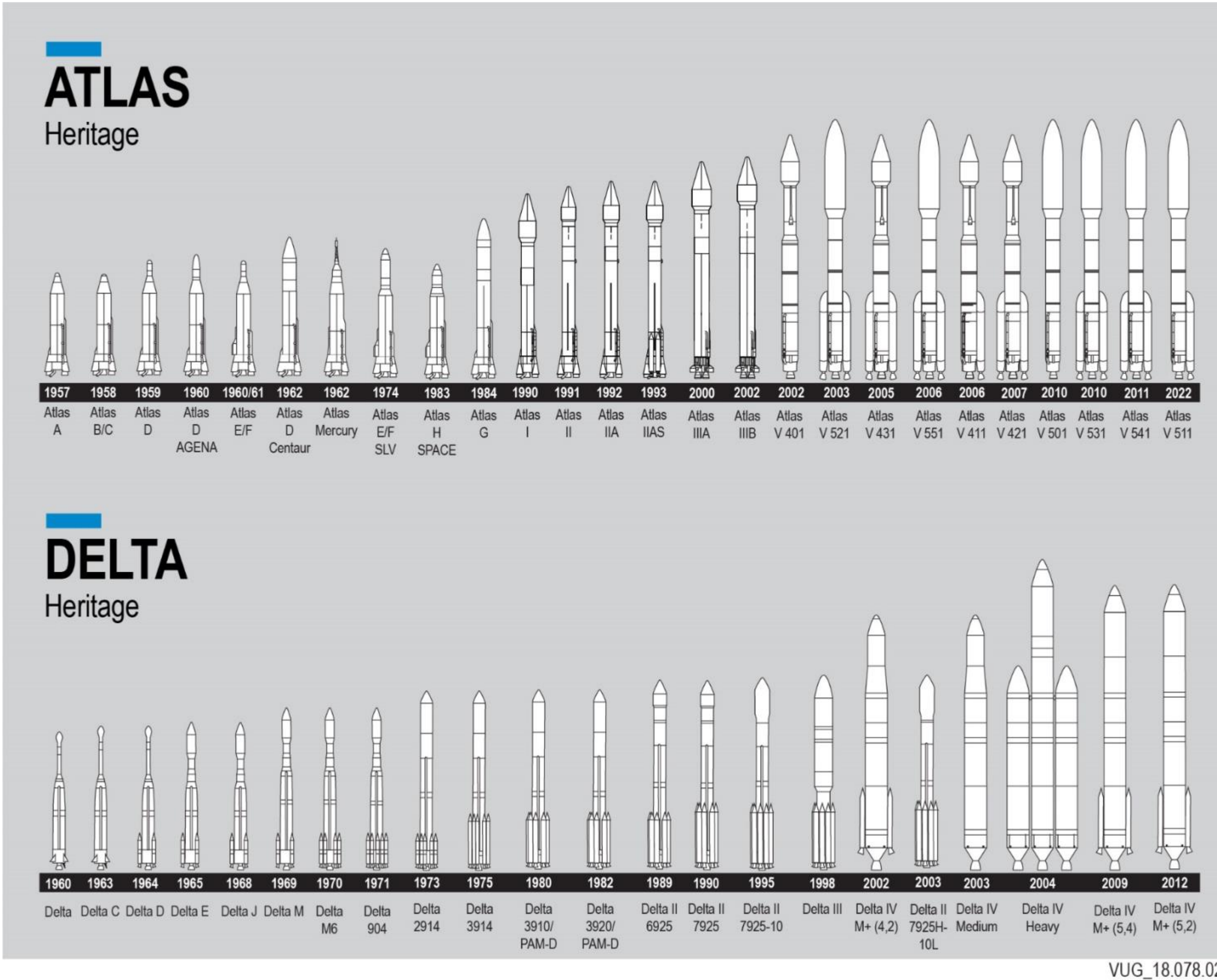

Figure 1.2-1 Atlas and Delta Evolution

1.4 Vulcan Centaur Overview

Vulcan Centaur is designed with a balanced combination of innovative new technologies and time tested best practices from the highly reliable Atlas V and Delta IV Launch Systems. Prominent features of Vulcan Centaur are identified in Table 1.4-1.

Table 1.4-1 Prominent Launch Vehicle Features

Features	Vehicle Characteristics
Booster Vehicle	• Flexible SRB configurations to meet mission performance needs • Brakepress-formed Orthogrid panels • Friction Stir Welded Tanks/Domes
Two BE-4 Main Engines	• 2446.5 kN (550k-lbf) thrust (Sea Level) each • LO_2/LNG
Centaur V	• Cryogenic second stage technology • Sophisticated trajectory optimization • Re-startable Dual RL10C engines
GEM 63XL SRBs	• Stretched version of Atlas V GEM 63 with 10% greater total impulse
Composite 5.4m Payload Fairing	• Standard and Long versions available • Significant volume accommodates large spacecraft and enables multi-manifesting

Vulcan Centaur is composed of a Vulcan first stage booster with zero, two, four, or six solid rocket boosters (SRBs), a Centaur V, and either a standard or a long payload fairing (PLF).

ULA's Vulcan Centaur design emphasizes flexibility, with configurations that provide a range of performance and payload accommodations. The Vulcan Centaur PLF comes in either a 15.5-m (51-ft.) standard PLF or a 21.3-m (70-ft.) long PLF as shown in Figure 1.4-1. The Vulcan Centaur launch system also offers multi-manifesting capability for two or more payloads, which further enhances Vulcan Centaur's affordability. For multi-manifest missions using the Multi-Launch Internal Canister, the long PLF is required.

The Vulcan Centaur launch vehicle naming convention is four characters with values shown below. For example, the naming convention VC2S represents a Vulcan Centaur launch vehicle with two SRBs and a Standard PLF.

Character Sequence	Value	Definition
1st & 2nd	VC	Vulcan Centaur V
3rd	0, 2, 4, 6	Number of SRBs
4th	S L	Standard PLF Long PLF

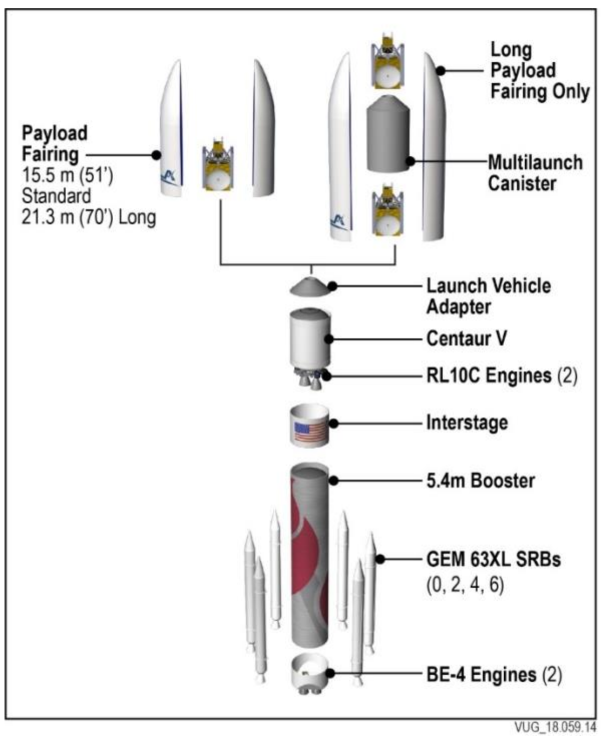

Figure 1.4-1 Vulcan Centaur Launch Vehicle Configurations

The Vulcan booster is made of aluminum orthogrid tanks that hold over a million pounds of liquid oxygen and liquid natural gas. The maximum launch vehicle thrust at liftoff is over 3.3M pounds, provided by a combination of Blue Origin BE-4 main engines, each delivering 2446.5-kN (550k-lbf) sea level thrust, and zero, two, four, or six Northrop Grumman Space Systems GEM 63XL Solid Rocket Boosters (SRBs).

The fully cryogenic Centaur V is an evolution of our high-performing hydrogen/oxygen, pressure-stabilized Centaur with flight heritage on the Titan and Atlas launch vehicles. Centaur V uses a pressure stabilized stainless steel tank, proven avionics, and two RL10 engines to maximize mass-to-orbit.

1.5 Vulcan Centaur Reliability

The Vulcan Centaur reliability model is directly derived from the Atlas and Delta reliability models and mission histories. Vulcan Centaur combines decades of engineering experience, proven design knowledge, manufacturing and launch efficiencies, and robust risk reduction methods to achieve the best value for your mission.

Vulcan Centaur is an evolution of the flight-proven, highly successful Atlas V and Delta IV launch vehicles as shown in Figure 1.5-1 and Table 1.5-1. The introduction of a careful balance of new technologies and innovative features (additive manufacturing, advanced welding and inspection processes, and many others) ensures a reliable and affordable space launch service.

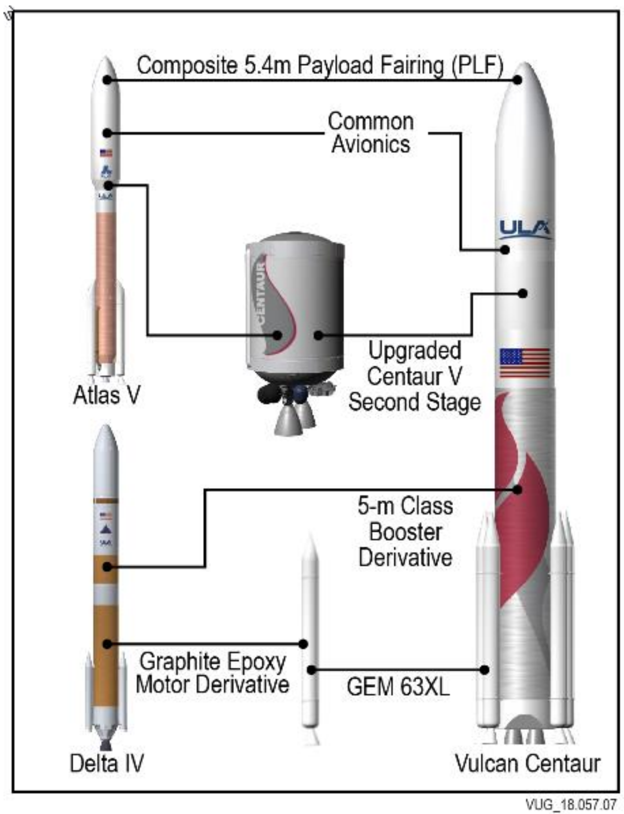

Figure 1.5-1 Vulcan Centaur Proven Technology

Table 1.5-1 Vulcan Centaur Proven Features.

Vulcan Solution/Feature	Benefit	Heritage
Composite 5.4-m Diameter Payload Fairing	Proven separation systems and payload protection	Atlas V and Delta IV
Common Avionics	Proven avionics minimize cost and risk	Atlas V and Delta IV
Centaur V	Proven second stage with added capability	Atlas V Centaur III and RL10 engines
5.4-m Diameter Booster	Optimized for performance and use of existing structure	Delta IV
GEM 63XL Solid Rocket Boosters	Proven SRBs with added performance	Delta IV GEM 60 and Atlas V GEM 63
Launch Sites	SLC-41 (CCSFS) and SLC-3E (VSFB) pads	Atlas V launch sites

1.6 Centaur Evolution

A key component of ULA's continued mission success is the evolution of the fully cryogenic Centaur second stage. Centaur's development began in 1958 to launch NASA payloads on lunar and planetary missions. Throughout the operational history of Centaur, systemic upgrades to avionics and engines continuously improved this highly capable and accurate second stage. Centaur's successful evolution, depicted in Figure 1.6-1, is proven over more than 260 missions, including over 150 missions featuring a dual-engine Centaur.

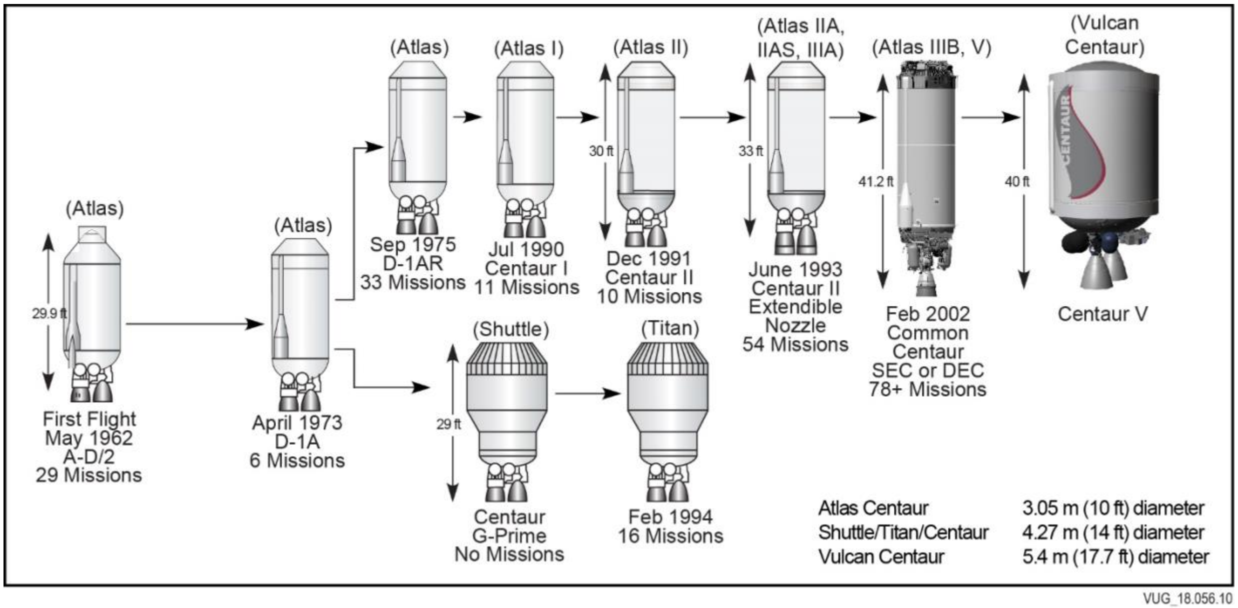

Figure 1.6-1 Vulcan Centaur Evolution

2. MISSION DESIGN AND PERFORMANCE

Vulcan Centaur is a versatile launch system capable of delivering payloads to a wide variety of orbits—from high inclination polar low Earth orbits and highly eccentric Molniya orbits out of Vandenberg Space Force Base (VSFB) to low and medium Earth orbits, geostationary transfer, geosynchronous orbits, trans-lunar injection, and high-energy Earth escape orbits out of Cape Canaveral Space Force Station (CCSFS). The Vulcan Centaur mission design can also be optimized to meet a broad range of customer mission-specific requirements.

Performance capabilities quoted in this document are presented in terms of payload systems weight (PSW). PSW is defined as the combined mass to orbit of the separated payload, the payload-to-Vulcan Centaur adapter, and other mission-specific hardware required on Vulcan Centaur to support the payload (e.g., RF reradiation system, payload instrument purge, mission-specific harnessing). Propellant reserves are held back to cover estimated 2.33-sigma Vulcan Centaur performance dispersions.

2.1 Typical Mission Profile

The booster phase begins with ignition of the two BE-4 engines. Avionics and Ground Systems perform a health check before the Solid Rocket Boosters (SRBs) are ignited and Vulcan Centaur lifts off. After a short vertical rise away from the pad, Vulcan Centaur begins pitchover, a coordinated maneuver to the prescribed ascent profile and flight azimuth. At a predetermined altitude, Vulcan Centaur transitions to a nominal zero angle-of-attack orientation to minimize aerodynamic loads and engine angles. Both of these maneuvers are implemented through the launch day wind steering system, which enhances launch availability by reducing wind-induced flight loads and engine deflections.

The SRBs are jettisoned after burnout is detected. This occurs roughly 100 seconds (sec) into flight. Once Vulcan Centaur reaches at least 24,384 m (80,000 ft.) and at least five seconds after the solids are jettisoned (if present), closed-loop guidance steering is enabled. Near the end of the booster phase, the BE-4 engines are throttled so that axial acceleration constraints are not exceeded. These g-levels typically do not exceed a 4.6-g steady state value.

A customer may request tailoring of the mission thrust profile to further limit loads per mission-specific payload requirements. Contact ULA for additional information regarding tailoring the mission profile to payload needs.

The BE-4 engine shutdown sequence is initiated when depletion of booster propellants is indicated by the propellant utilization system. After the BE-4 engines shut down at booster engine cut-off (BECO), the Vulcan booster separates from the Centaur V.

The PLF is jettisoned during the first main engine burn of the Centaur V after the payload-specific ascent heating constraint is satisfied.

The Centaur V engines are ignited at main engine start (MES) shortly after Vulcan booster separation and burn until the vehicle is placed into an initial parking orbit after main engine cutoff (MECO). The Centaur V engines can be ignited multiple times to meet mission-specific orbital requirements. One or two burns are typically used for LEO. Two or three burns are typically used for GTO, MEO, Molniya, and Earth escape orbits. GSO or near-GSO orbits utilize three burns to meet orbit requirements. Subsequent burns can be implemented for mission-specific requirements or Centaur V disposal.

Vulcan Centaur trajectory designs are developed using an integrated trajectory simulation tool and state-of-the-art optimization algorithms. ULA uses our vast knowledge of trajectory optimization techniques to maximize performance capabilities while considering specific Vulcan Centaur and/or payload constraints. A suite of mission-specific performance enhancement options such as inflight retargeting (IFR), or Polynomial Right Ascension of Ascending Node (RAAN) Targeting, also known as RAAN steering, increase launch window duration and improve launch schedule reliability. Contact ULA for details regarding how each option would address specific mission requirements.

Centaur V has the capability to meet orbital debris mitigation standard practices (ODMSP) for U.S. government missions after successfully separating the payload. If required by the customer, Centaur V disposal can be accomplished by reigniting the main engines to either place the Centaur V into a reentry orbit to burn up in the Earth's atmosphere; or to place it into a hyperbolic earth-escape orbit. Centaur V can also use its low thrust settling motors to place itself into a LEO, GTO, or GEO compliant disposal orbit.

2.1.1 Vulcan Centaur Ascent Profiles

Vulcan Centaur ascent profiles are developed using one or more Centaur V main engine burns suited for a particular type of mission. Figures 2.1.1-1 through 2.1.1-4 depict examples of single payload LEO, GTO, and GEO ascent profiles and ground traces showing sequences of events and timelines. For all missions after Centaur V/Payload separation, Centaur V conducts a Collision and Contamination Avoidance Maneuver (CCAM) to prevent payload recontact and to minimize contamination of the payload. Contact ULA for further details associated with mission design and launch vehicle performance capabilities.

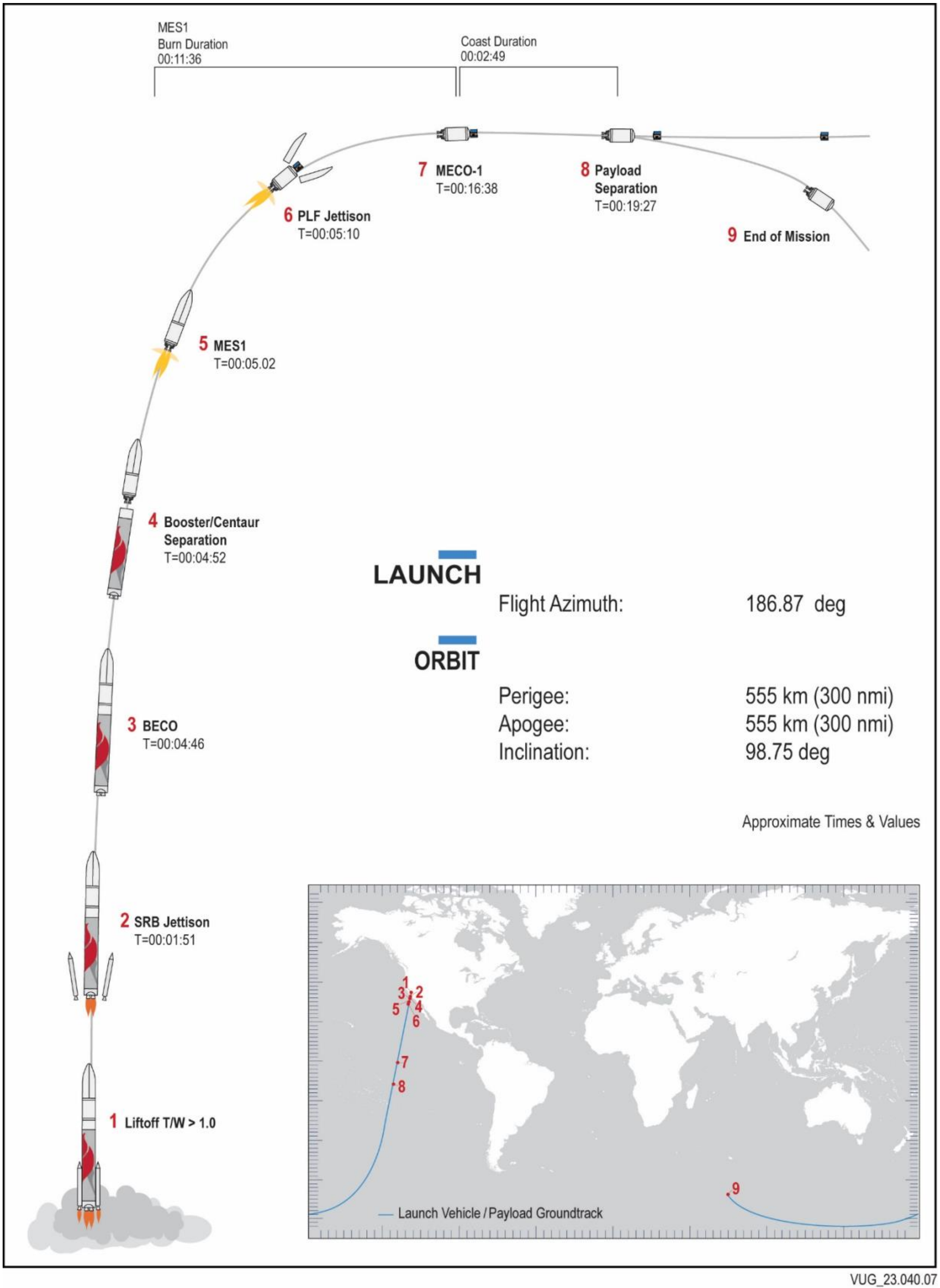

Figure 2.1.1-1 Single Burn Sun-Synchronous Ascent Profile and Ground Trace

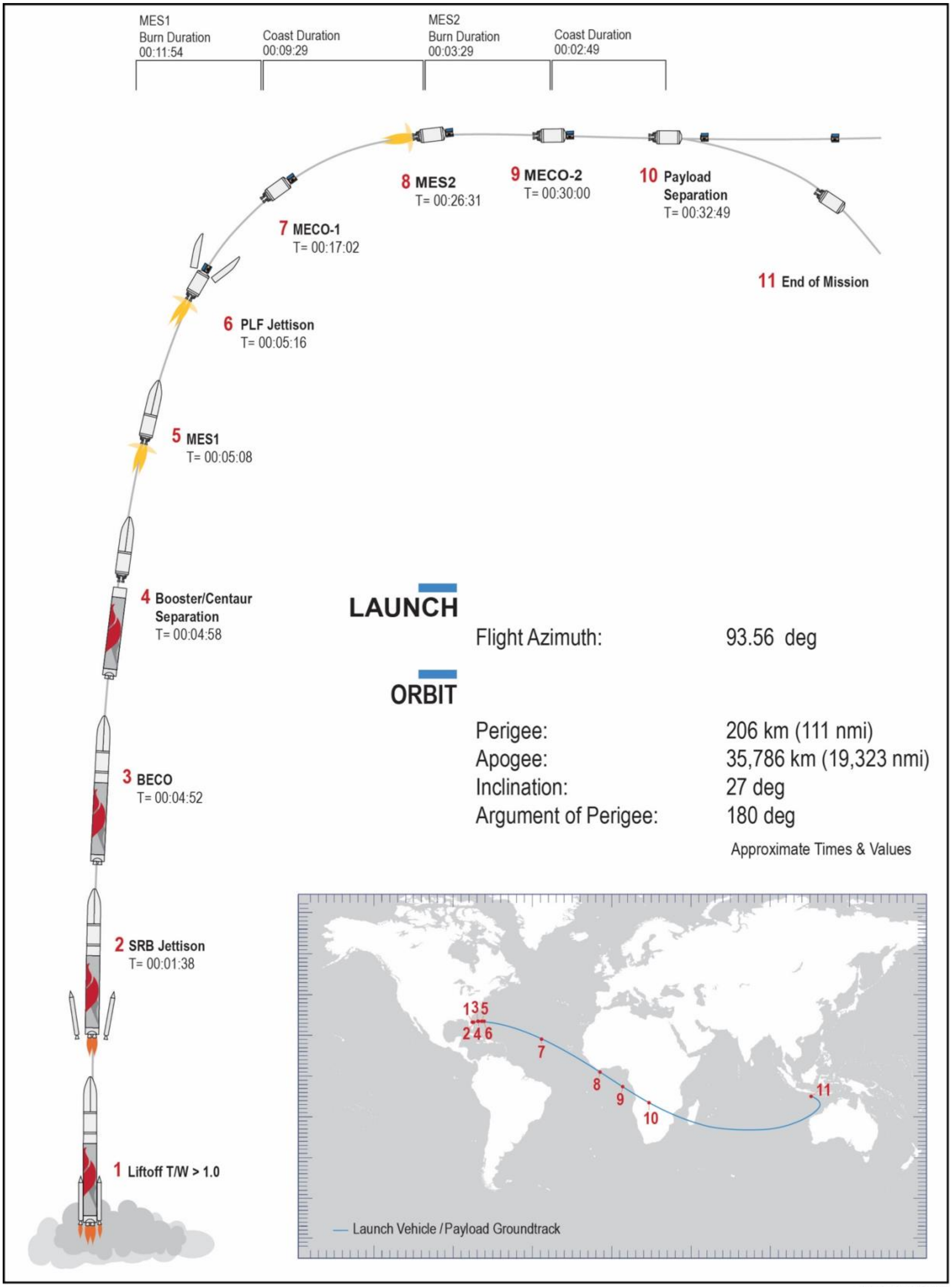

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Figure 2.1.1-2 Two Burn 1800 m/sec GTO Ascent Profile and Ground Trace

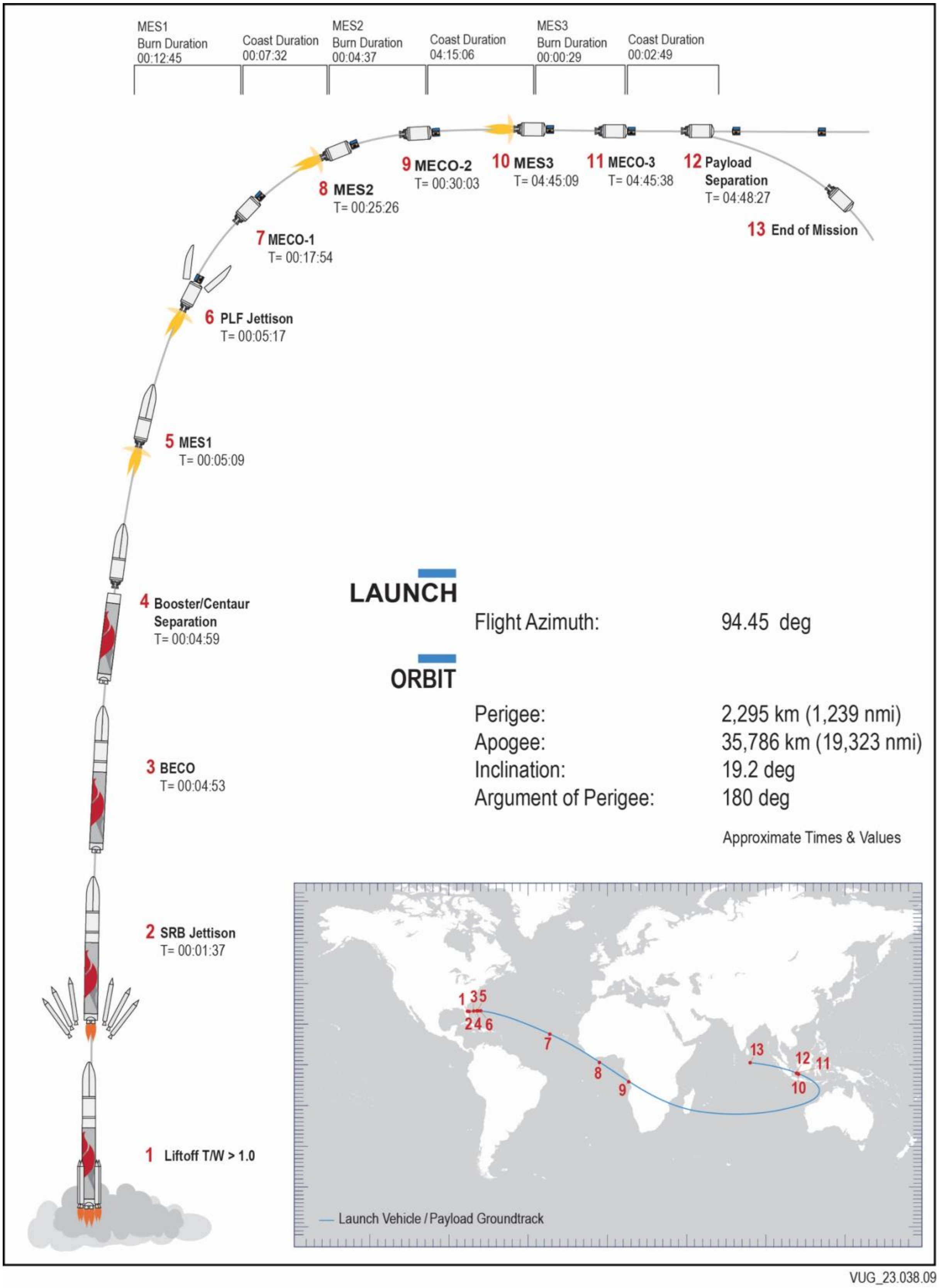


Figure 2.1.1-3 Three-Burn 1500 m/sec GTO Ground Trace and Ascent Profile

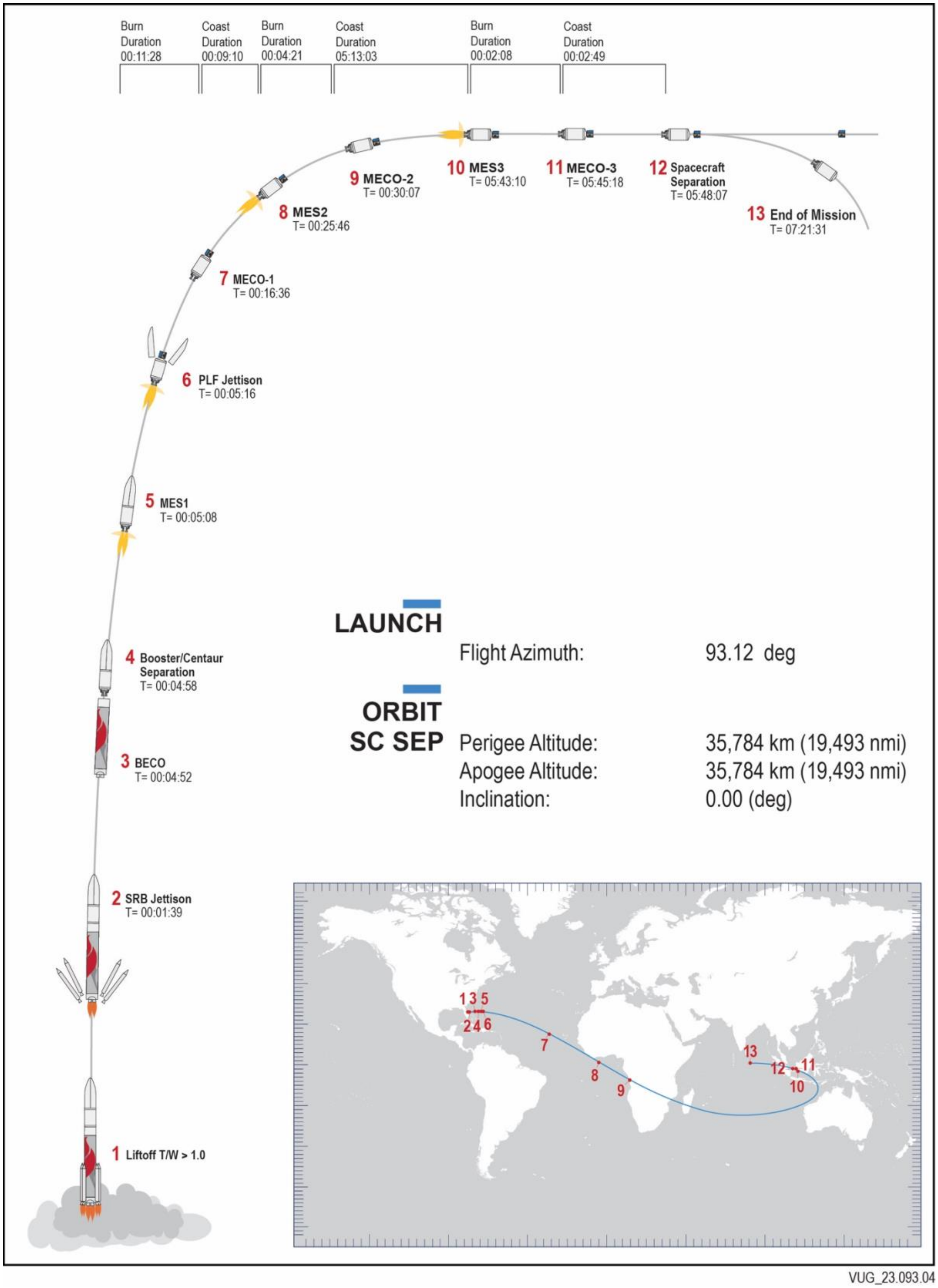


Figure 2.1.1-4 Three-Burn Direct Inject GEO Ground Trace and Ascent Profile

2.2 Vulcan Centaur Performance Capability

Vulcan Centaur performance capability for representative missions launched from CCSFS in Florida or VSFB in California is described in this section.

2.2.1 Low-Earth Orbit—International Space Station

Vulcan Centaur can launch payloads into Low-Earth Orbits that range in inclination from 28.5 degrees to 55 degrees from CCSFS with the International Space Station (ISS) orbit being a key destination at 51.6 degrees.

The simplest mission design to reach the ISS is a single Centaur V burn to payload separation with a near-instantaneous launch window. Performance is presented in Table 2.2.1-1 for a typical mission design. Missions with excess performance can use Vulcan Centaur's RAAN Steering capability to increase launch window duration as performance allows. The payload is injected into a representative orbit defined by:

- Perigee: 407 km (220 nmi)
- Apogee: 407 km (220 nmi)
- Inclination: 51.6 deg

Table 2.2.1-1 ISS Performance

Vulcan Centaur Configuration	ISS	
	kg	lb
VC0S	8,800	19,400
VC2S	16,300	35,900
VC4L	21,400	47,200
VC6L	25,600	56,400

2.2.2 Low Earth Orbit—Sun-Synchronous

LEOs with inclinations from 63.4 degrees through sun-synchronous inclinations to retrograde are launched from VSFB. Much like the ISS mission design, sun-synchronous missions can be either single or two burn, with the option of incorporating RAAN steering as performance allows to increase the launch window. Performance presented in Table 2.2.2-1 is typical for a single Centaur V burn to payload separation. The payload is injected into a representative orbit defined by:

- Perigee: 555 km (300 nmi)
- Apogee: 555 km (300 nmi)
- Inclination: 98.75 deg

Table 2.2.2-1 Sun-Synchronous Performance

Vulcan Centaur Configuration	Sun-Synchronous	
	kg	lb
VC0S	7,900	17,400
VC2S	14,400	31,700
VC4L	18,500	40,800
VC6L	22,300	49,200

2.2.3 Geostationary Transfer Orbit

Geostationary transfer orbits are reached by flying east out of CCSFS. The Centaur V first burn places the second stage into a parking orbit. The Centaur V second burn occurs near the first descending node of the parking orbit. Performance is presented in Table 2.2.3-1 for both the 1800 m/s GTO and 1500 m/s GTO orbits. The payload is injected into a representative orbit defined by:

1800 m/sec GTO

- Perigee: >185 km (100 nmi)
- Apogee: 35,786 km (19,323 nmi)
- Inclination: 27 deg

Table 2.2.3-1 GTO Performance

Vulcan Centaur Config.	GTO (1800 m/sec)		GTO (1500 m/sec)	
	kg	lb	kg	lb
VC0S	3,300	7,300	1,900	4,200
VC2S	8,300	18,300	6,400	14,100
VC4S	11,600	25,600	9,500	20,900
VC6S	14,400	31,700	12,000	26,500

- Argument of Perigee: 180 deg

1500 m/sec GTO

- Perigee: 2,295 km (1,239 nmi)
- Apogee: 35,786 km (19,323 nmi)
- Inclination: 19.2 deg
- Argument of Perigee: 180 deg

2.2.4 Geostationary Orbit

Geostationary orbits are reached by flying east out of CCSFS. The Centaur V has the ability to perform a direct injection into the Geostationary Orbit. Centaur V first burn places the second stage into a parking orbit. The Centaur V second burn occurs near the first descending node of the parking orbit and injects the payload into a transfer orbit. After an extended coast to the apogee altitude, the Centaur V performs a third burn to raise perigee to a disposal compliant Geostationary altitude. Performance is presented in Table 2.2.4-1. The payload is injected into a representative orbit defined by:

- Perigee: 36,101 km (19,493 nmi)
- Apogee: 36,101 km (19, 493 nmi)
- Inclination: 0 deg

Table 2.2.4-1 Geostationary Orbit

Vulcan Centaur Configuration	GEO	
	kg	lb
VC0S	--	--
VC2S	2,500	5,500
VC4S	4,800	10,600
VC6S	6,300	13,900

2.2.5 Transfer Lunar Insertion /Earth Escape/ Interplanetary

Centaur's heritage as a high-energy second stage makes it ideal for launching payloads into Earth escape and transfer lunar insertion (TLI) trajectories from CCSFS. Vulcan Centaur typically uses a two-burn mission profile to reach such high-energy orbits. Performance for a representative TLI and Earth escape (typical of reaching Mars) is presented in Table 2.2.5-1.

Vulcan Centaur Configuration	TLI		Interplanetary / Mars	
	kg	lb	kg	lb
VC0S	2,100	4,600	--	--
VC2S	6,200	13,700	3,600	7,900
VC4S	9,100	20,100	6,000	13,200
VC6S	11,300	24,900	7,600	16,800

- TLI Orbital Energy: -2 km^2/sec^2
- Interplanetary/Mars Orbital Energy: 20 km^2/sec^2

2.2.6 Medium Earth Orbit

Medium Earth Orbits are typically achieved with a Centaur V two-burn mission profile with an extended coast between the burns. Typical MEO inclinations range from 50 degrees to 55 degrees and are launched northeasterly out of CCSFS. The payload is injected into a representative orbit defined by:

- Perigee: 20,368 km (10,998 nmi)
- Apogee: 20,368 km (10,998 nmi)
- Inclination: 55 deg

Table 2.2.6-1 MEO Performance

Vulcan Centaur Configuration	MEO	
	kg	lb
VC0S	300	700
VC2S	3,800	8,400
VC4S	6,100	13,400
VC6S	7,900	17,400

Vulcan Centaur performance for a typical MEO mission is presented in Table 2.2.6-1.

2.2.7 Molniya

Vulcan Centaur can insert payloads into elliptical orbits with 12-hour or 24-hour periods at an inclination of 63.4 degrees by launching from VSFB with two Centaur V burns to payload separation. The 12-hour period performance is presented in Table 2.2.7-1. The payload is injected into a representative orbit defined by:

- Perigee: 1,203 km (650 nmi)
- Apogee: 39,170 km (21,150 nmi)
- Inclination: 63.4 deg
- Argument of Perigee: 270 deg

Table 2.2.7-1 Molniya Performance

Vulcan Centaur Configuration	Molniya	
	kg	lb
VC0S	2,500	5,500
VC2S	6,200	13,700
VC4S	8,900	19,600
VC6S	10,600	23,400

2.3 Vulcan Centaur Injection Accuracy

The Vulcan Centaur avionics suite provides certified injection accuracy to a variety of orbits as shown in Table 2.3-1. This exceptional accuracy translates into payload benefits such as extended spacecraft lifetimes.

Table 2.3-1 Predicted Vulcan Centaur Guidance Accuracy

Orbit	Perigee km (nmi)	Apogee km (nmi)	Inclination deg	AoP deg	RAAN deg
1,800 m/sec GTO	±1.9 (±1.0)	±67.2 (±36.3)	±0.01	±0.11	±0.12
1,500 m/sec GTO	±27.8 (±15.0)	±67.2 (±36.3)	±0.03	±0.25	±0.12
Lunar Transfer/Earth Escape	±1.9 (±1.0)	±4630 (±2500)	±0.01	±0.11	±0.12
MEO	±57.4 (±31.0)	±29.6 (±16.0)	±0.05	-	±0.05
ISS	±5.7 (±3.1)	±5.0 (±2.7)	±0.05	-	±0.04
Sun-Synchronous	±4.3 (±2.3)	±4.3 (±2.3)	±0.05	-	±0.04
Molniya	±3.7 (±2.0)	±55.6 (±30.0)	±0.05	±0.05	±0.05

2.4 Payload Separation Conditions

The Centaur V reaction control system (RCS) applies precision adjustments to achieve the proper attitude for payload separation. These corrections align Centaur's attitude to the inertial reference provided by the guidance system with a high degree of accuracy. Centaur V can provide a 3-axis stabilized attitude or a spin stabilized payload separation.

2.4.1 Pre-Separation Maneuvers

Centaur V can provide spin about any payload axis at payload separation. Longitudinal spin can be provided with an angular rate of up to 30-deg/sec (5 rpm). Transverse spin rates can be provided to spin stabilize the payload or to pre-compensate for expected tipoff rates. For missions using the Multi-Launch System, a spinning payload separation can be provided for one or both payloads, subject to mass property constraints.

2.4.2 Payload Attitude and Accuracy

The highly accurate Centaur V inertial measurement system in conjunction with advanced guidance and steering flight software can align the payload to virtually any payload separation attitude. The payload separation attitude can be defined relative to the fixed inertial frame, a sun-relative frame, or to a frame that rotates with the payload position and velocity. Table 2.4.2-1 summarizes the capabilities of the Centaur V for a 3-axis stabilized payload separation. Table 2.4.2-2 summarizes the capabilities of the Centaur V for a 30-deg/sec (5-rpm) spinning payload separation about the longitudinal axis.

Table 2.4.2-1 Centaur V 3-Axis Stabilized Payload Separation Capabilities

Attitude	Accuracy
Roll Axis Pointing Error	<1.4 deg
Pitch and Yaw Axis Pointing Error	<1.4 deg
Roll Body Rate	<0.25 deg/sec
Pitch and Yaw Body Rate	<0.1 deg/sec

Table 2.4.2-2 Centaur V 30-deg/sec (5-rpm) Spinning Payload Separation Capabilities

Attitude	Accuracy
Roll Axis Pointing Error	<1.75 deg
Roll Axis Angular Rate	30 deg/sec +/-3 deg/sec

2.4.3 Payload Separation Systems

The relative velocity and tipoff rates imparted by the payload separation system to the payload are strongly driven by payload mass properties and separation system type required to accommodate the payload interface (hard point or clampband interface). The payload separation system is designed to impart a relative velocity sufficient to avoid re-contact between the payload and the Centaur V and can typically be optimized to achieve a minimum of 0.3 m/sec (1 ft/sec). Angular rates at the separation command can typically be maintained to less than 0.1 deg/sec about the launch vehicle pitch and yaw axes and less than 0.25 deg/sec about the vehicle roll axis. Angular rates added by the function of the separation system (tipoff rates) are typically less than 1 deg/sec. ULA separation systems are designed to minimize tipoff with symmetrically oriented separation system components designed with small unit-to-unit variances. Tipoff stemming from large nominal space vehicle (SV) center of mass offsets can be compensated for as necessary on a mission specific basis.

3. ENVIRONMENTS

This section describes the Vulcan Centaur prelaunch and flight environments to which the payload is exposed during prelaunch and through launch.

3.1 Prelaunch Environments

3.1.1 Prelaunch Thermal Environments

The thermal environment around the encapsulated payload is maintained during ground transport from the Payload Processing Facility (PPF) through launch as described in the following paragraphs.

Ground Transport from PPF to Launch Site. An active payload air Environmental Control System (ECS) is utilized for temperature control, relative humidity control and to prevent condensation on the payload inside the payload fairing (PLF). A dry Gaseous Nitrogen (GN2) purge is utilized as backup to the active air ECS for relative humidity control and to prevent condensation on the payload inside the PLF. Payload gas conditioning is provided using analysis-derived temperature set points, flow rate set points, and dew point capability to maintain required environments around the payload. During ground transport from the PPF to the launch site, since payloads are usually not powered up, an acceptable temperature range around the payload inside the PLF is typically 3.9-30°C (39-86°F). If required, the active air ECS can control gas temperatures around the payload inside the PLF to maximum/minimum allowable temperature ranges as specified in Table 3.1.1-1. The maximum dew point temperature is typically 4.4°C (40°F) for active air ECS and -37.2°C (-35°F) for GN2 backup purge to provide relative humidity control and prevent condensation on the payload.

Table 3.1.1-1: Temperature Controllability Inside PLF Using Payload Active ECS Capability

PLF Length	Maximum & Minimum Allowable Gas Temperature Range Inside PLF	Smallest Span Between Maximum & Minimum Allowable Temperature Limits To Be Fully Compatible With ECS Capabilities Across 3σ Outside Ambient Temperatures
Standard	3.9-27.8°C (39-82°F)	13.9°C (25°F)
Long	2.8-32.2°C (37-90°F)	17.2°C (31°F)

Hoisting Operations. After the encapsulated payload arrives at the base of the Vertical Integration Facility (VIF) at SLC-41 or Mobile Service Tower (MST) at SLC-3E, the encapsulated assembly is hoisted atop the Vulcan Centaur upper stage. During hoisting operations at SLC-41 and SLC-3E, the encapsulated payload is purged with dry GN_2 with a maximum dew point of -37.2°C (-35°F). Gas temperatures around the payload inside the PLF do not change appreciably during this operation but over time will trend toward outside ambient temperature. The GN_2 purge is utilized to maintain a dry environment around the payload inside the PLF. Hoist is typically completed in less than one hour.

Post-Hoist through Launch. Following hoist, the payload ECS will provide actively controlled air or GN_2 into the PLF. Payload gas conditioning is provided using analysis-derived temperature, flow rate, and dew point ECS set points to maintain required environments around the payload external to the PLA stack inside the PLF. An active payload ECS can control gas temperatures around the payload to the maximum/minimum allowable temperature ranges specified in Table 3.1.1-2.

Table 3.1.1-2: Temperature Controllability Inside PLF Using Payload Active ECS Capability

PLF Length (Feet)	Maximum & Minimum Allowable Gas Temperature Range External To PLA Stack Inside PLF	Smallest Span Between Maximum & Minimum Allowable Temperature Limits To Be Fully Compatible With ECS Capabilities Across 3σ Outside Ambient Temperatures
Standard	4.4-19.4°C (40-67°F) (Inside VIF/MST) 3.3-22.2°C (38-72°F) (Outside VIF/MST)	10.6°C (19°F) (Inside VIF/MST) 13.3°C (24°F) (Outside VIF/MST)
Long	3.3-22.2°C (38-72°F) (Inside VIF/MST) 1.7-25.6°C (35-78°F) (Outside VIF/MST)	13.3°C (24°F) (Inside VIF/MST) 16.1°C (29°F) (Outside VIF/MST)

Air with a maximum dew point of -1.1°C (30°F) is used until just before the start of Vulcan Centaur upper stage cryogenic tanking after which GN2 with a maximum dew point of -37.2°C (-35 °F) is used**.** Dew point controllability is utilized to provide relative humidity control and prevent condensation on the payload.

Gas temperatures internal to the PLA stack can be calculated as part of the Payload Integrated Thermal Analysis since it would result from an energy balance between the payload, PLA, and PLA diaphragm prior to and following completion of Centaur V cryogenic tanking. Mission-unique arrangements for dedicated purges of specific payload components can be provided. The ECS flow to the payload compartment is supplied through a ground/airborne disconnect on the PLF and is controlled by primary and backup environmental control units.

3.1.2 Electromagnetic Compatibility

3.1.2.1 Launch Vehicle Radiated RF Emissions

Vulcan Centaur radiated emissions at the 1575-mm PAF interface plane are shown in Figure 3.1.2.1-1. These levels include Vulcan Centaur unintentional emissions from avionics boxes and intentional emissions from transmitters.

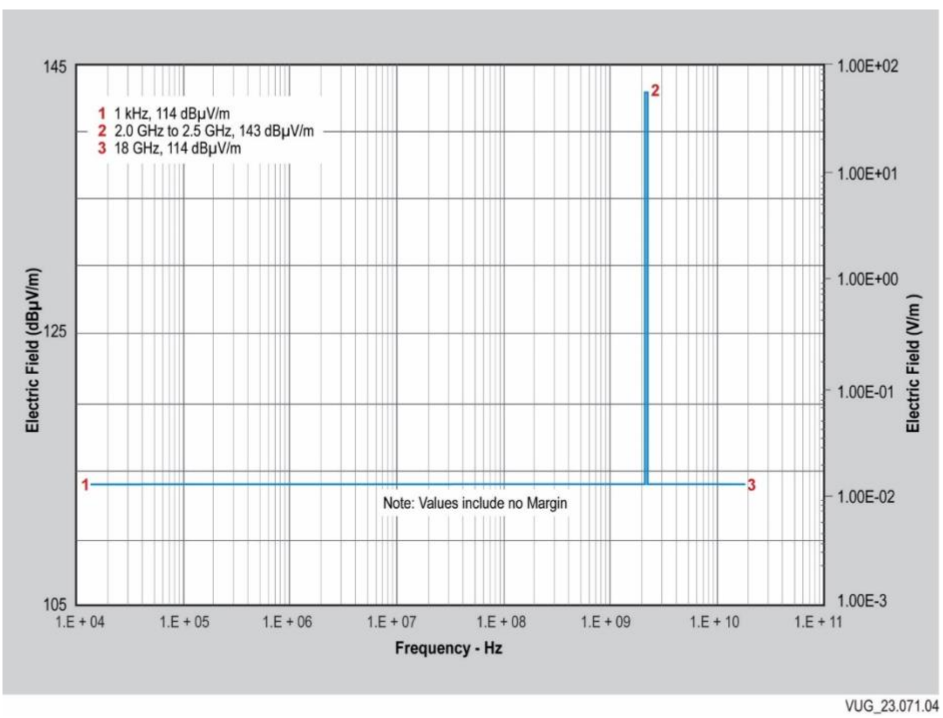


Figure 3.1.2.1-1 Maximum Launch Vehicle Radiated Emissions

3.1.2.2 Payload Radiated RF Emissions

The maximum allowable payload radiated emissions at the 1575-mm PAF interface plane are provided in Figure 3.1.2.2-1. As a mission specific service, a payload may be permitted to radiate inside the payload fairing provided that the payload emissions, including cavity effects, do not exceed the maximum level deemed safe for launch vehicle (LV) avionics and ordnance circuits. A mission-specific RF compatibility analysis will be performed to verify that the LV and payload transmitter frequencies do not have interfering intermodulation products or image rejection problems.

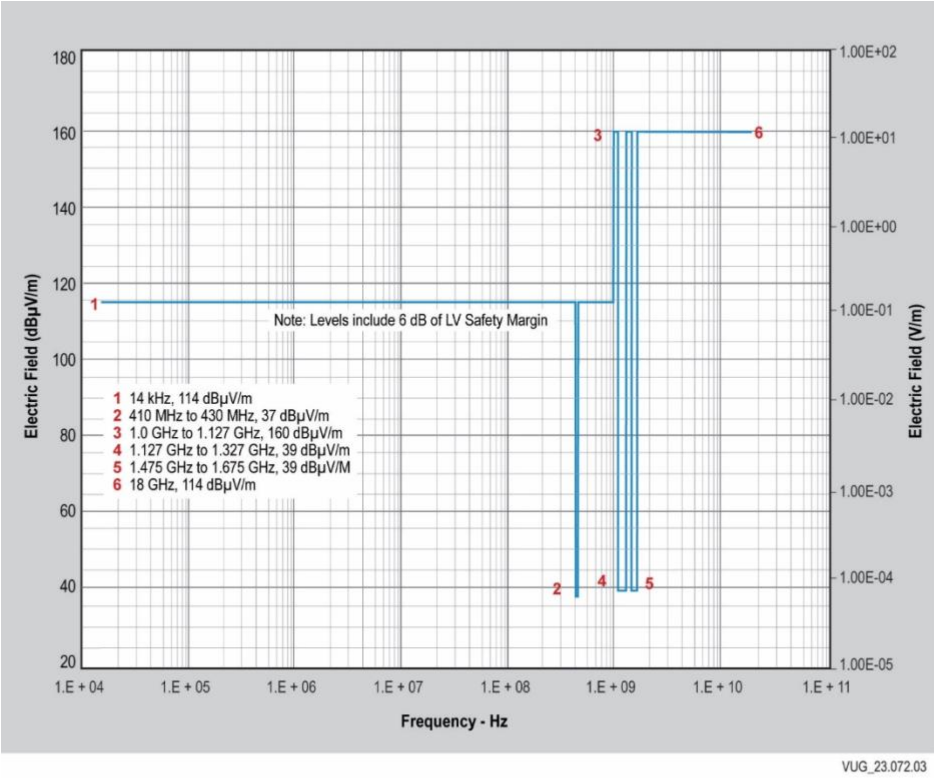


Figure 3.1.2.2-1 Maximum Payload Radiated Emissions

3.1.3 Prelaunch Contamination Control and Cleanliness

The Vulcan Centaur launch vehicle has been designed to comply with the strict limits on contaminant deposition on payload surfaces that have been developed for military and NASA payloads. Standard limits are a maximum of 150 Angstroms (A) of molecular (residue) deposition and 1% obscuration of surfaces from particles accumulated from the time of payload encapsulation through payload separation and completion of the CCAM. These standard limits are achieved through launch vehicle design features, and controls during manufacturing, processing, and verification by test and analysis. As a mission-unique service, stricter limits can be achieved by the use of additional measures.

The following measures are implemented during ground processing to protect the payload:

- Vulcan Centaur surfaces that form the payload compartment are cleaned and inspected to visibly clean when inspected from 15.2–45.7 cm (6–18 in.) with 100–125 ft. candles of light and nonvolatile residue less than 1 mg/ft^2.

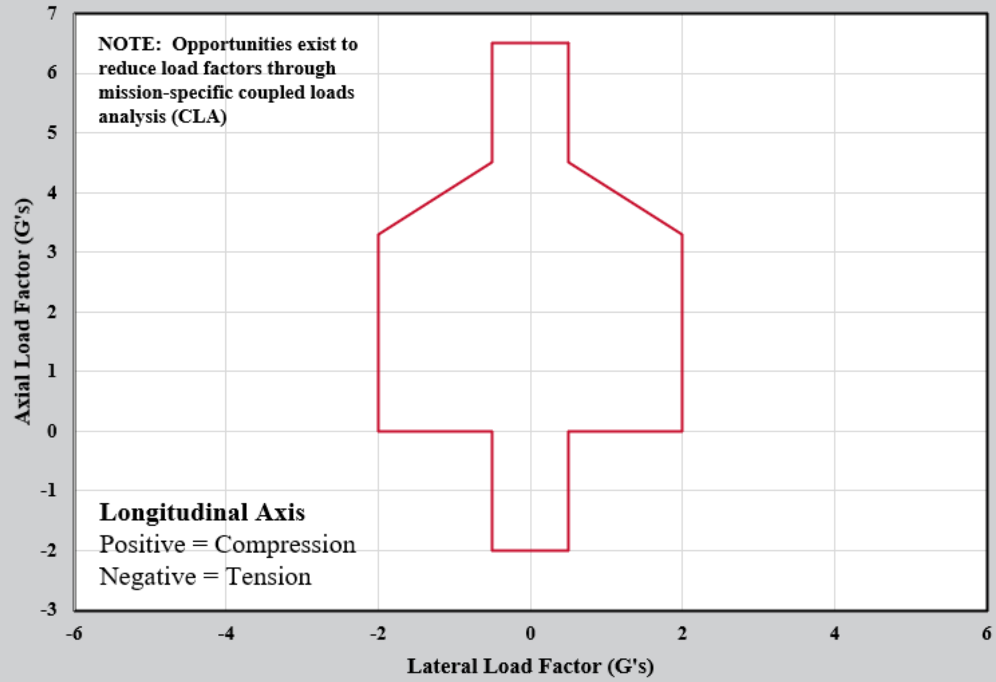
- Vulcan Centaur hardware cleaning and payload encapsulation are performed in Class 100K (ISO Class 8) environments.
- The payload is protected by purging the payload compartment with either Class 5000 or better air (ISO Class 6.7) or filtered Grade B GN_2 during transport to and while on the launch pad.
- Delivered air cleanliness is monitored by airborne particle counters and airborne hydrocarbon monitoring.
- Payload compartment hardware cleanliness is verified by inspection and surface sampling.

3.2 Launch and Flight Environments

This section describes general environmental conditions that may be encountered by a payload during launch and flight of the Vulcan Centaur Launch Vehicle. All flight environments defined in this section are maximum expected levels and do not include margins typically associated with qualification tests. Verification analysis necessary to assure payload compatibility with Vulcan Centaur launch vehicle environments is performed during the mission integration process.

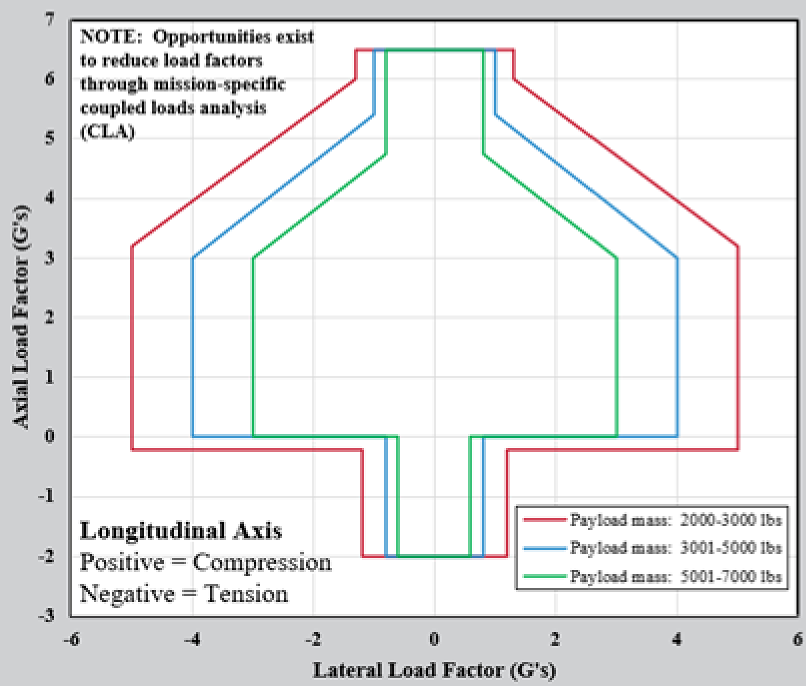
3.2.1 Payload Design Load Factors

The payload design load factors (DLF) depicted in Figure 3.2.1-1 and 3.2.1-2 are for use in preliminary design of the payload primary structure and/or compatibility evaluation of existing payloads with the Vulcan Centaur launch vehicle. The DLF definitions do not include uncertainty factors related to payload design maturity. The payload DLFs provide a conservative estimate of interface loading for the center of gravity of a rigid payload. The actual responses of a payload due to launch vehicle loading environments will depend on its specific static and structural dynamic characteristics. The payload cantilevered fundamental mode frequencies are assumed to be a minimum of 8 hertz (Hz) lateral and 15 Hz axial for all DLFs. Figure 3.2.1-1 is recommended for payloads whose masses are greater than 3,175 kg (7,000 lb). Figure 3.2.1-2 is recommended for payloads with lighter mass ranges. Preliminary design for those payloads can be determined by selecting the curve whose mass range the payload falls within. Payloads outside of these criteria require a mission-specific analysis for assessment of design load factors. Please contact ULA for additional information.



Payload Mass (>7000 lbs)	
Lateral (g)	Axial (g)
0.5	6.5
0.5	4.5
2.0	3.3
2.0	0.0
0.5	0.0
0.5	-2.0
-0.5	-2.0
-0.5	0.0
-2.0	0.0
-2.0	3.3
-0.5	4.5
-0.5	6.5
0.5	6.5

Figure 3.2.1-1 Payload Design Limit Load Factors (Payload Mass > 3175 kg or 7000 lb)



Payload Mass 2000-3000 lbs		Payload Mass 3001-5000 lbs		Payload Mass 5001-7000 lbs	
Lateral (g)	Axial (g)	Lateral (g)	Axial (g)	Lateral (g)	Axial (g)
1.3	6.5	1.0	6.5	0.8	6.5
1.3	6.0	1.0	5.4	0.8	4.8
5.0	3.2	4.0	3.0	3.0	3.0
5.0	-0.2	4.0	0.0	3.0	0.0
1.2	-0.2	0.8	0.0	0.6	0.0
1.2	-2.0	0.8	-2.0	0.6	-2.0
-1.2	-2.0	-0.8	-2.0	-0.6	-2.0
-1.2	-0.2	-0.8	0.0	-0.6	0.0
-5.0	-0.2	-4.0	0.0	-3.0	0.0
-5.0	3.2	-4.0	3.0	-3.0	3.0
-1.3	6.0	-1.0	5.4	-0.8	4.8
-1.3	6.5	-1.0	6.5	-0.8	6.5
1.3	6.5	1.0	6.5	0.8	6.5

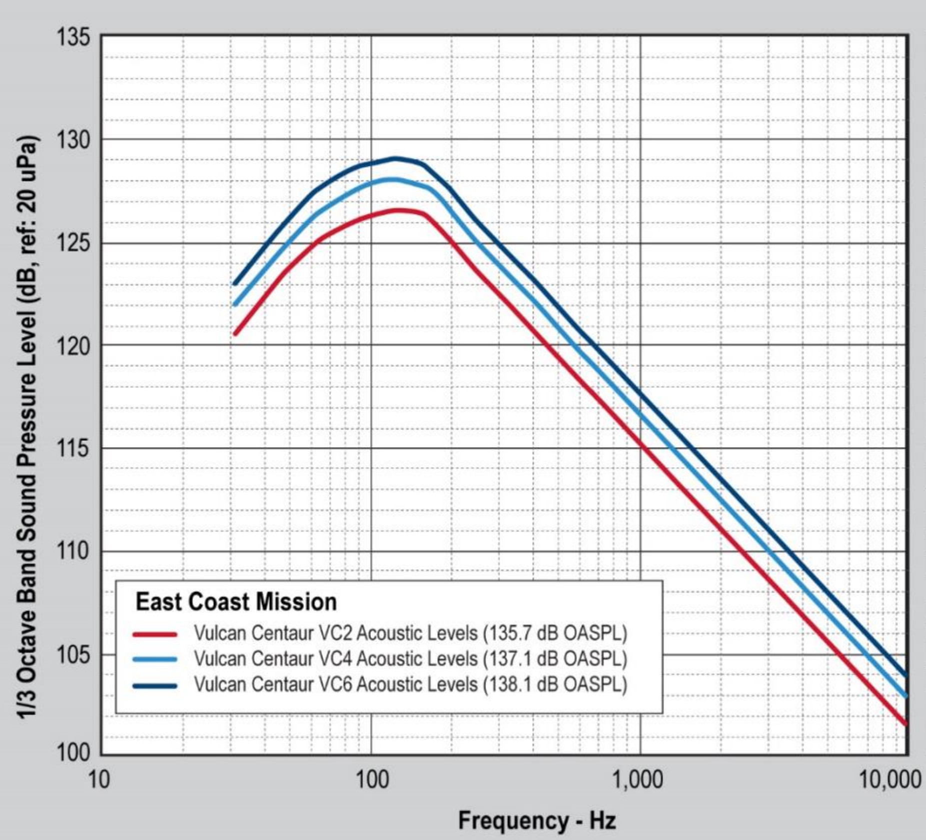
Figure 3.2.1-2 Payload Design Limit Load Factors (Payload Mass < 3175 kg or 7000 lb)

Payload design load factors are superseded by the mission specific coupled loads analyses (CLA). CLAs are dynamic analyses conducted as part of the mission integration activity to provide payload primary and secondary structure loads, accelerations, and deflections for use in design, test planning, and verification of minimum margins of safety.

3.2.2 Acoustics

The payload is exposed to an acoustic environment throughout the boost phase of the flight until the launch vehicle is out of the sensible atmosphere. Two portions of the flight have significantly higher acoustic levels than any other; the highest acoustic level occurring for approximately 10 seconds during liftoff and the other significant level occurring for approximately 20 seconds during the transonic/max-q portion of the flight. Acoustic levels inside the PLF are spatially averaged and will vary with different payloads due to acoustic absorption that varies with payload size, shape, and surface material properties. Acoustic sound pressure levels for the Vulcan Centaur Launch Vehicle for East Coast missions are presented in Figure 3.2.2-1. Acoustic sound pressure levels for the Vulcan Centaur launch vehicle for West Coast missions are presented in Figure 3.2.2-2. If necessary, a mission unique acoustic analysis can be performed for the specific mission configuration. Please contact ULA for more detailed information regarding mission unique acoustic environments.

These acoustic levels represent the maximum expected environment based on a 95% probability and 50% confidence (limit level). The levels presented are for payloads of square cross sectional shape with typical cross sectional fill ratios of up to 50%. A mission-specific acoustic analysis will be performed for payloads with other fill factors.

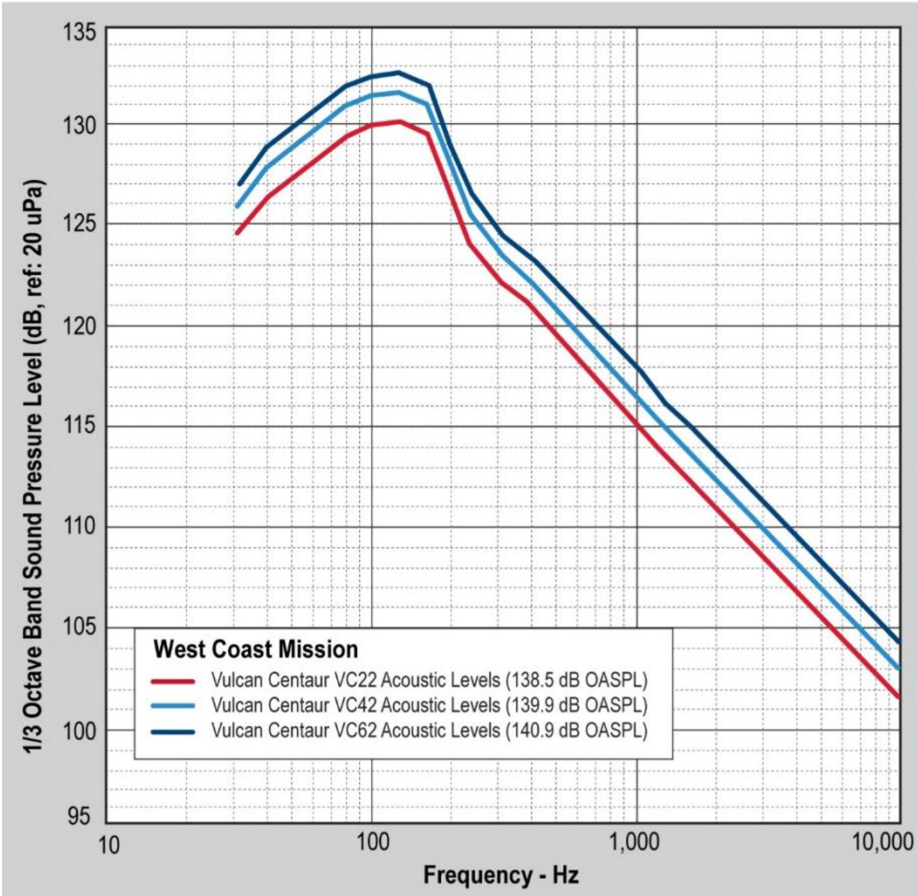


Frequency, Hz	1/3 Octave Band Sound Pressure, dB		
	VC6	VC4	VC2
31.5	123.0	122.0	120.6
40	124.8	123.8	122.4
50	126.2	125.2	123.8
63	127.5	126.5	125.1
80	128.3	127.3	125.9
100	128.8	127.8	126.4
125	129.0	128.0	126.6
160	128.7	127.7	126.3
200	127.5	126.5	125.1
250	126.0	125.0	123.6
315	124.6	123.6	122.2
400	123.3	122.3	120.9
500	121.9	120.9	119.5
630	120.5	119.5	118.1
800	119.1	118.1	116.7
1000	117.8	116.8	115.4
1250	116.4	115.4	114.0
1600	115.0	114.0	112.6
2000	113.6	112.6	111.2
2500	112.3	111.3	109.9
3150	110.9	109.9	108.5
4000	109.5	108.5	107.1
5000	108.1	107.1	105.7
6300	106.8	105.8	104.4
8000	105.4	104.4	103.0
10000	104.0	103.0	101.6
OASPL(dB)	138.1	137.1	135.7

Baseline: 95% probability and 50% confidence and assumes up to 50% fill by PLF cross-sectional area. dB ref: 20 micropascals

VUG_23.065.07

Figure 3.2.2-1 Vulcan Centaur East Coast Payload P95/50 Acoustic Levels (50% Fill Effect) – Standard & Long PLF Configurations



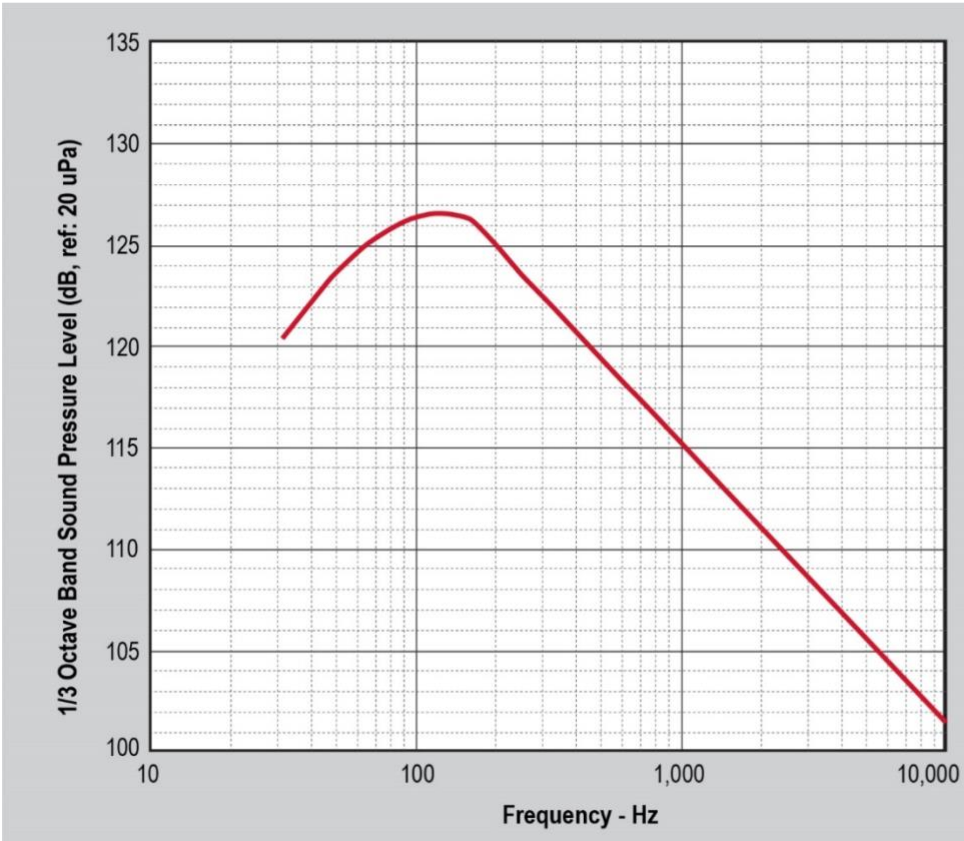
Frequency, Hz	1/3 Octave Band Sound Pressure, dB		
	VC62	VC42	VC22
31.5	127.0	126.0	124.6
40	128.8	127.8	126.4
50	129.8	128.8	127.4
63	130.8	129.8	128.4
80	131.8	130.8	129.4
100	132.3	131.3	130.1
125	132.5	131.5	129.6
160	132.0	131.0	126.6
200	129.0	128.0	124.1
250	126.5	125.0	122.2
315	124.6	123.6	122.2
400	123.3	122.3	120.9
500	121.9	120.9	119.5
630	120.5	119.5	118.1
800	119.1	118.1	116.7
1000	117.8	116.8	115.4
1250	116.4	115.4	114.0
1600	115.0	114.0	112.6
2000	113.6	112.6	111.2
2500	112.3	111.3	109.9
3150	110.9	109.9	108.5
4000	109.5	108.5	107.1
5000	108.1	107.1	105.7
6300	106.8	105.8	104.4
8000	105.4	104.4	103.0
10000	104.0	103.0	101.6
OASPL(dB)	140.9	139.9	138.5

Baseline: 95% probability and 50% confidence and assumes up to 50% fill by PLF cross-sectional area. dB ref: 20 micropascals

VUG_23.090.01

Figure 3.2.2-2 Vulcan Centaur West Coast Payload P95/50 Acoustic Levels (50% Fill Effect)

For the Vulcan Centaur Multi-Launch System for East Coast missions, the forward payload sound pressure levels are bounded by the Vulcan Centaur six solid acoustic levels as depicted in Figure 3.2.2-1. The Multi-Launch Internal Canister acoustic sound pressure levels seen by the aft payload are depicted in Figure 3.2.2-3. These acoustic levels represent the maximum expected environment based on a 95% probability and 50% confidence (limit level). The levels presented are for payloads of square cross-sectional shape with an equivalent canister cross-section area fill of up to 60%. A mission-specific acoustic analysis will be performed for payloads with higher fill factors.



Frequency, Hz	1/3 Octave Band Sound Pressure, dB
31.5	120.6
40	122.4
50	123.8
63	125.1
80	125.9
100	126.4
125	126.6
160	126.3
200	125.1
250	123.6
315	122.2
400	120.9
500	119.5
630	118.1
800	116.7
1000	115.4
1250	114.0
1600	112.6
2000	111.2
2500	109.9
3150	108.5
4000	107.1
5000	105.7
6300	104.4
8000	103.0
10000	101.6
OASPL (dB)	135.7

Baseline: 95% probability and 50% confidence, assumes 60% fill by PLF cross-sectional area. (dB ref: 20 micropascals)

VUG_18.082.01

Figure 3.2.2-3 Vulcan Centaur East Coast Multi-Launch Internal Canister Payload P95/50 Acoustic Levels (60% Fill Effect)

3.2.3 Vibration

The payload is subjected to a wide range of dynamic excitation during launch. For this reason, maximum expected flight dynamic environments are defined as low frequency and high frequency. The low-frequency vibration environment during Vulcan Centaur flight is characterized by a combination of the equivalent sinusoidal vibration specified at the payload interface and the results of the CLA. The maximum predicted sinusoidal vibration environment at the payload interface for all stages of flight with a resonant amplification factor (Q) of 20 is shown in Figure 3.2.3-1. If necessary, CLA will be used to modify the sinusoidal environment to incorporate any unique structural dynamic coupling between Vulcan Centaur and the payload.

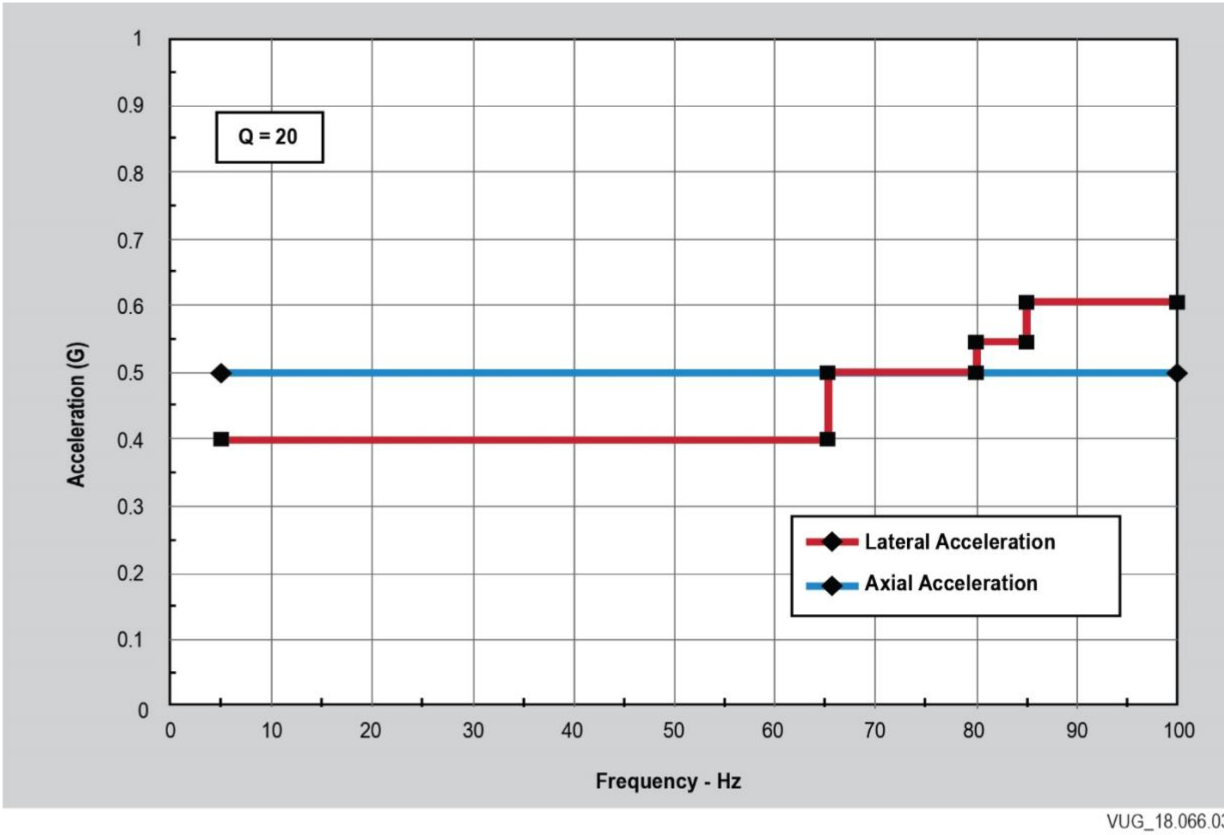


Figure 3.2.3-1 Vulcan Centaur Sinusoidal Vibration Levels Based On SRS

The high frequency vibration which the payload experiences is primarily due to the acoustic noise field, with a very small portion being mechanically transmitted through the payload interface.

The high frequency vibration level will vary from one location to another depending on the physical properties of each area of the payload. The interface levels depend on the structural characteristics of the lower portion of the payload, the particular payload adapter, and the influence of the acoustic field for the particular payload. The vibration level at the payload adapter interface depends on the adjacent structure above and below the interface. An acoustic test of the payload will therefore be the most accurate simulation of the high frequency environment experienced in flight and is preferable to a base input random vibration test. If the payload is mounted to a test fixture that has structural characteristics similar to the payload adapter, then vibration levels at the interface will be similar to flight levels. To accurately reflect the flight environment, it is not recommended to attach the payload to a rigid fixture during acoustic testing.

3.2.4 Shock

3.2.4.1 Launch Vehicle to Payload Interface Shock

For a payload dedicated launch configuration, the primary shock events occurring during flight that affect payload interface shock environments are launch vehicle induced PLF jettison and payload separation. For the Multi-Launch System, the primary shock events for payloads on the aft PAF are launch vehicle induced PLF jettison, launch vehicle induced canister separation, and payload separation while payload separation is the primary event for payloads on the forward PAF. While other events do produce shock, those events are enveloped by the primary shock events and not considered significant.

The maximum expected launch vehicle induced shock levels for the baseline configuration at the LV side of the 1575 PAF to payload interface plane is shown in Figure 3.2.4.1-1. This environment represents a circumferential maximum and is based on a statistical significance of 95 percent probability and 50 percent confidence, applicable in three mutually perpendicular axes, and a resonant amplification factor Q=10. A mission-unique shock analysis is required for other payload adapters that vary from the baseline 1575 PAF. A mission-unique shock analysis is also required for multi-manifest missions using the Multi-Launch System. Please contact ULA for more detailed information.

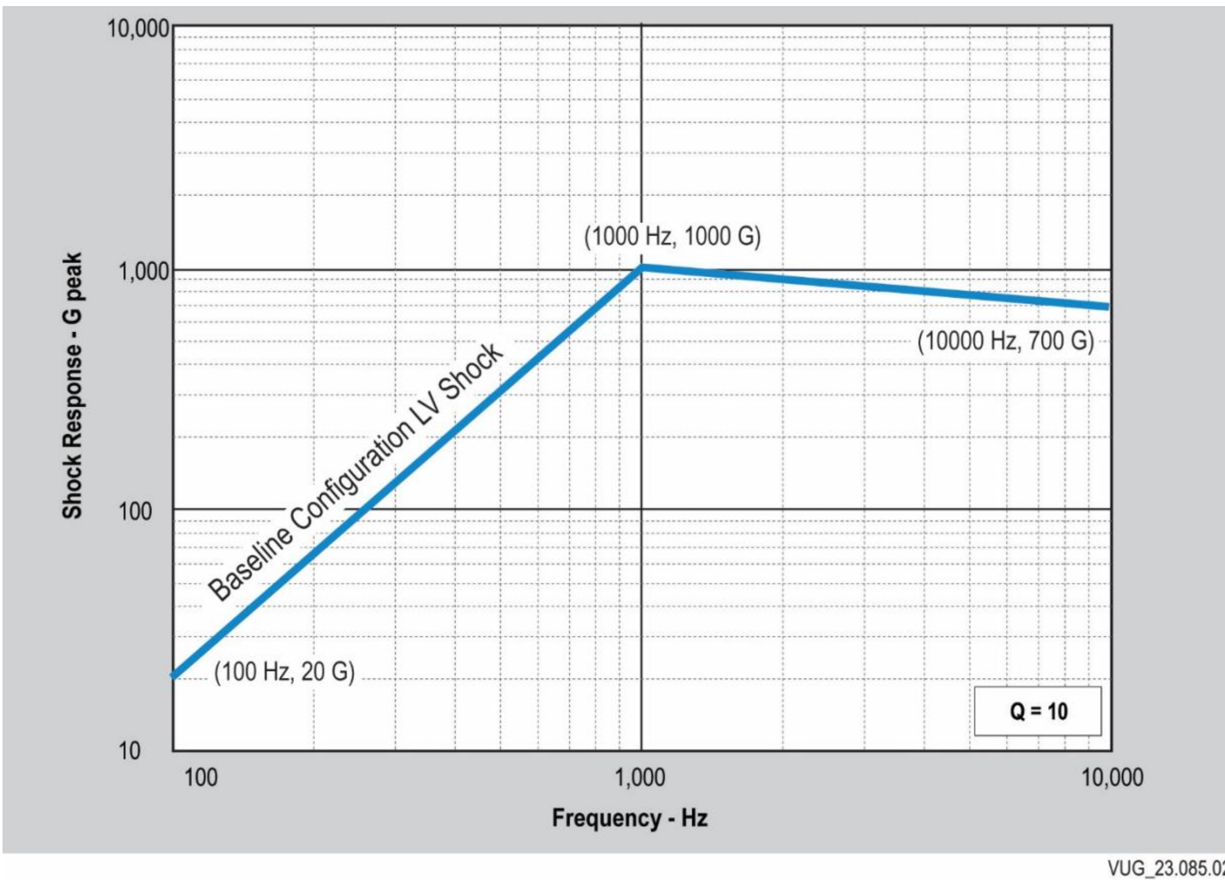


Figure 3.2.4.1-1 Vulcan Centaur Maximum Expected Shock Environments at the Payload Interface

The shock environment at the payload separation interface is typically a function of the mission specific payload adapter selected for the mission. Actual shock environments experienced by the payload at the top of the mission specific payload adapter will be determined following selection of the payload adapter and separation system. The shock response on the payload side of the interface depends on the unique characteristics of the payloads interface structure, mass, CG and stiffness in association with the selected payload adapter. ULA has experience with several industry standard payload adapters with low-shock separation systems shown in section 4.2.2, Payload Adapters and Separation Systems. Please contact ULA for additional information regarding the Vulcan Centaur payload separation shock environment.

3.2.4.2 Payload to LV Shock

The Centaur V has a robust capability of being compatible with low-shock payload separation systems. The Centaur V is relatively insensitive to the shock level induced by the payload low-shock separation system pyrotechnic event at the LV/payload interface. Additional analysis will be required for customers with unique payload separation systems not utilizing a low-shock (clampband) or separation nut system. Please contact ULA for more detailed information to ensure complete compatibility with payload interfaces.

3.2.5 Thermal

3.2.5.1 Launch and Flight Thermal Environments within PLF

The PLF protects the payload during ascent. Aerodynamic heating of the PLF results in a time-dependent radiant heating environment around the payload before PLF jettison. The total maximum integrated absorbed heat load radiated from the PLF inner surfaces to the payload is less than or equal to 38,224 BTU (11,203 W-Hr) during ascent up to PLF jettison for the Standard PLF. The total maximum integrated absorbed heat load radiated from the PLF inner surfaces to the payload is less than or equal to 54,790 BTU (16,058 W-Hr) during ascent up to PLF jettison for the Long PLF. PLF inner surface face sheet peak temperatures are less than or equal to 113.3°C (236°F) and PLF acoustic panel peak temperatures are less than or equal to 37.8°C (100°F) for both the Standard PLF and Long PLF. The inner surfaces of the PLF (inner face sheets and fairing acoustic panels) have an emittance less than or equal to 0.9. Absorbed heat flux to the payload is calculated using the following equation:

$$q = e*s*(T_{PLF}^4 - T_{Payload}^4) \text{ where } T_{Payload} = 7.2°C\ (45°F)$$

Please contact ULA for more detailed information regarding the payload fairing thermal environment.

After Payload Fairing Jettison: PLF jettison typically occurs when the 3-sigma maximum free molecular heat flux decreases to 1,135 W/m^2 (360 Btu/hr-ft^2). PLF jettison timing can be adjusted to meet specific mission requirements. Free molecular heating (FMH) profiles following PLF jettison are highly dependent on the trajectory flown and are provided on a mission-specific basis. Raising the parking orbit perigee altitude can reduce peak FMH levels, however, it will have a minor negative effect on delivered Vulcan Centaur performance.

The payload thermal environment following PLF jettison includes free molecular heating, solar heating, albedo heating, Earth thermal heating, and radiation to the Centaur V and to deep space. The payload also is conductively coupled to the forward end of the Centaur V through the payload adapter. Solar, albedo, and Earth thermal heating can be controlled as required by specification of launch times, vehicle orientation (including rolls), and proper mission design.

3.2.6 Static Pressure (PLF Venting) and ECS Impingement

The payload compartment is vented through dedicated vent ports near the base of the payload fairing to achieve depressurization through ascent. The vent ports are closed during launch and early ascent and open early in flight to protect against ingestion while on the pad and through early ascent. The compartment pressure and associated decay rate will vary by payload fill factor, solids configuration, and mission trajectory. Typical pressure profiles and decay rates for Vulcan Centaur two solids and six solids configurations are provided in Figures 3.2.6-1 and 3.2.6-2.

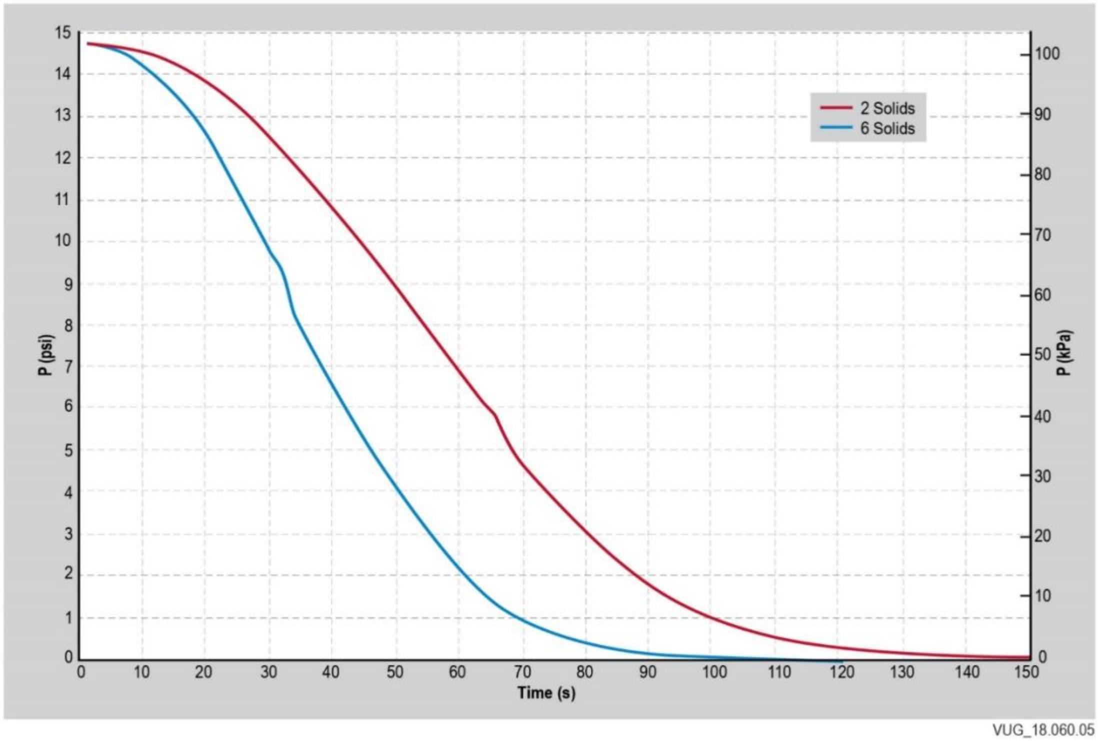


Figure 3.2.6-1 Typical PLF Compartment Static Pressure Profiles

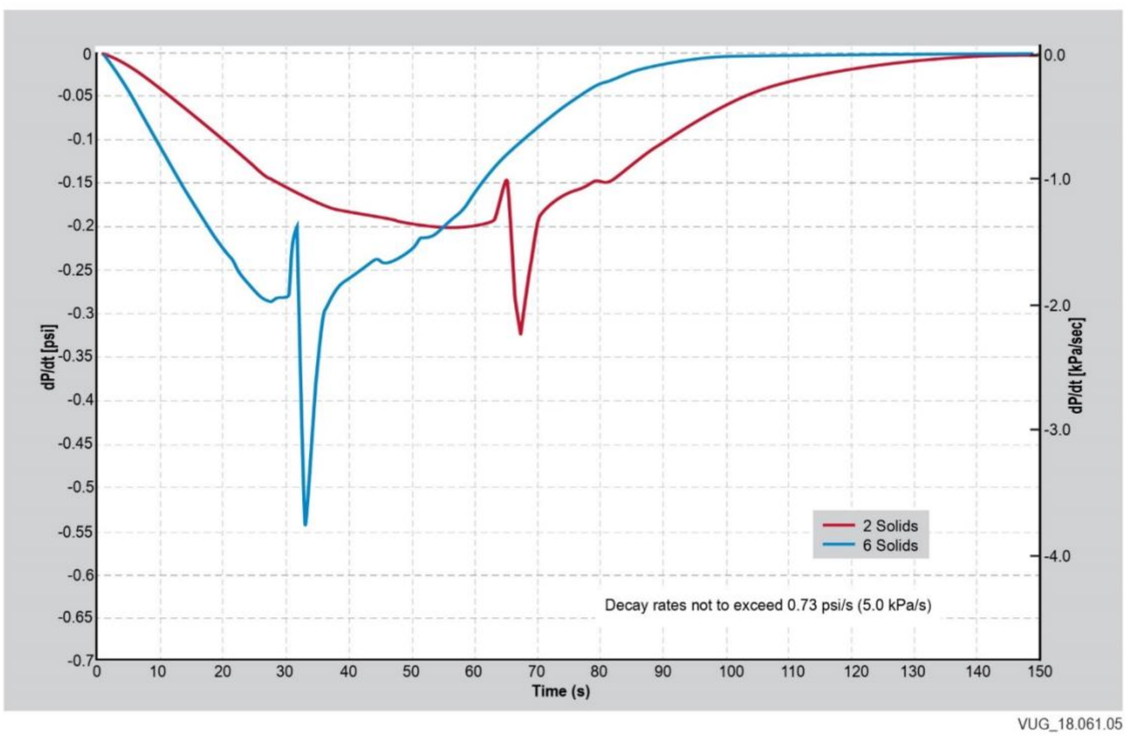


Figure 3.2.6-2 Typical PLF Compartment Pressure Decay Rate Profiles

The air velocity around the payload will be no greater than 9.8 m/sec (32 ft/sec) during ECS operation. Lower impingement velocities can be accommodated on a mission-unique basis by implementation of PLF ECS diffusers.

3.2.7 In-flight Contamination Control

Vulcan Centaur provides a payload compartment that complies with standard payload contamination control limits.

The following launch vehicle design features have been implemented to minimize payload contamination during flight.

- The payload is protected from exposure to unconditioned air on the ground and in flight by the use of a combination of tightly sealed PLF structural interfaces, vent blocking designs, and high flow rate ECS into the payload compartment while the launch vehicle is in the launch position.
- The payload compartment is comprised of high-quality, space-grade materials to prevent Vulcan Centaur from becoming a contamination source. Vulcan Centaur materials are chosen to minimize outgassing and avoid chipping, flaking, peeling, and other contaminant producing processes. The Vulcan Centaur program avoids materials that are cadmium or zinc-plated or made of unfused tin.
- Outgassing is further minimized during flight by temperature control achieved by the launch vehicle's thermal roll.
- Sealed pyrotechnic separation systems that capture pyrotechnic products are used throughout.
- Booster/Centaur V separation is accomplished using gas-driven actuators with negligible contaminant producing potential.
- Centaur V reaction control system thrusters consume low impurity hydrazine, which leaves negligible potential for contaminant accumulation on the payload.
- Rigorous testing has been performed of materials that are critical for outgassing potential.
- Rigorous testing of the payload fairing acoustic protection (FAP) system to simultaneous flight vibration and depressurization environments has been performed to determine the resulting contamination potential.
- Rigorous testing of pyrotechnic separation systems is performed as appropriate.
- Detailed analysis is performed of all ground and flight events as required to verify overall system deposition requirements.

As a mission-unique service, low deposition rates from the payload compartment environment can be characterized using witness plates inside the payload compartment during integrated processing. A historical database of particle and molecular witness plates inside the payload compartment during processing and residence on the pad confirms the effectiveness of ULA systems.

4. PAYLOAD INTERFACES

4.1 Vulcan Centaur Coordinate System

The Vulcan Centaur coordinate system, shown in Figure 4.1-1, uses a right handed X-Y-Z coordinate reference frame with the launch vehicle centerline as the longitudinal axis. The launch vehicle pitches about the Y-axis (nose up is positive), yaws about the Z-axis (nose right is positive), and rolls about the X-axis (clockwise is positive). The payload clocking on the launch vehicle will be defined within the *Mission Interface Control Document* to ensure best access to the payload needs and requirements. Coordinates shown within this *Vulcan User's Guide* are in the launch vehicle coordinate system frame, unless otherwise stated.

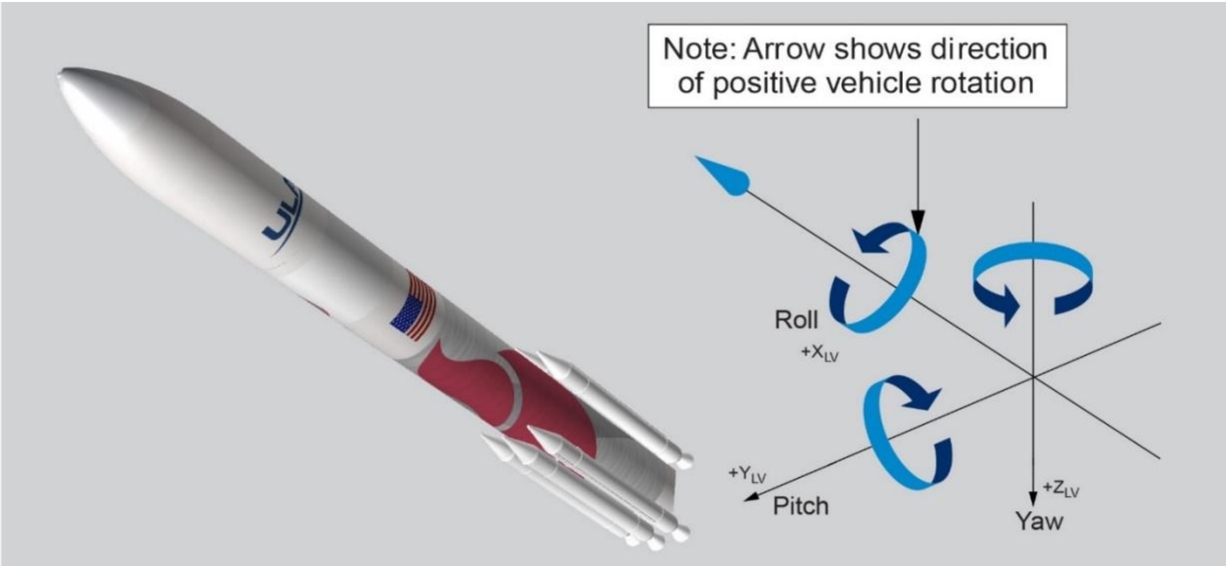


Figure 4.1-1 The Vulcan Centaur Coordinate System

4.2 Mechanical Interfaces

This section presents descriptions of the mechanical interfaces between the payload and launch vehicle family. The Vulcan Centaur payload mechanical interfaces are designed to meet present and future demands of the global payload market. The Vulcan Centaur program uses a heritage design approach for our standard payload adapter systems, which are used to adapt the Centaur V to the payload interface. Mission unique interface requirements can be accommodated by new or modified designs as required. Selection of an appropriate PLA should be coordinated with ULA as early as possible.

4.2.1 Vulcan Centaur Launch Vehicle to Payload Mechanical Interfaces

Vulcan Centaur leverages a multi-interface approach to provide flexibility for a large variety of payloads. The commercial standard launch vehicle to payload mechanical interface is available at the 1575-mm diameter, provided by the 1575 payload attach fitting (PAF).

Other ULA mechanical payload interfaces are available at 4991-mm diameter and 2624-mm diameter interfaces or at the top of a ULA-provided payload adapter (PLA) providing a bolted or separating payload interface at various diameters (ref Tables 4.2.2-1a-c). In addition, ULA has significant experience developing unique adapters and separation systems for specific customer needs.

4.2.1.1 1575-mm PAF Mechanical Interface

The 1575-mm launch vehicle mechanical interface is provided by the 1575 payload attach fitting (1575 PAF), which has a 120-bolt mating interface at a diameter of 1575-mm (62.01 in.), shown in Figure 4.2.1.1-1. The 1575 PAF interfaces to the LVFA at the aft interface and a ULA- or customer-provided payload adapter/payload separation system at the forward end.

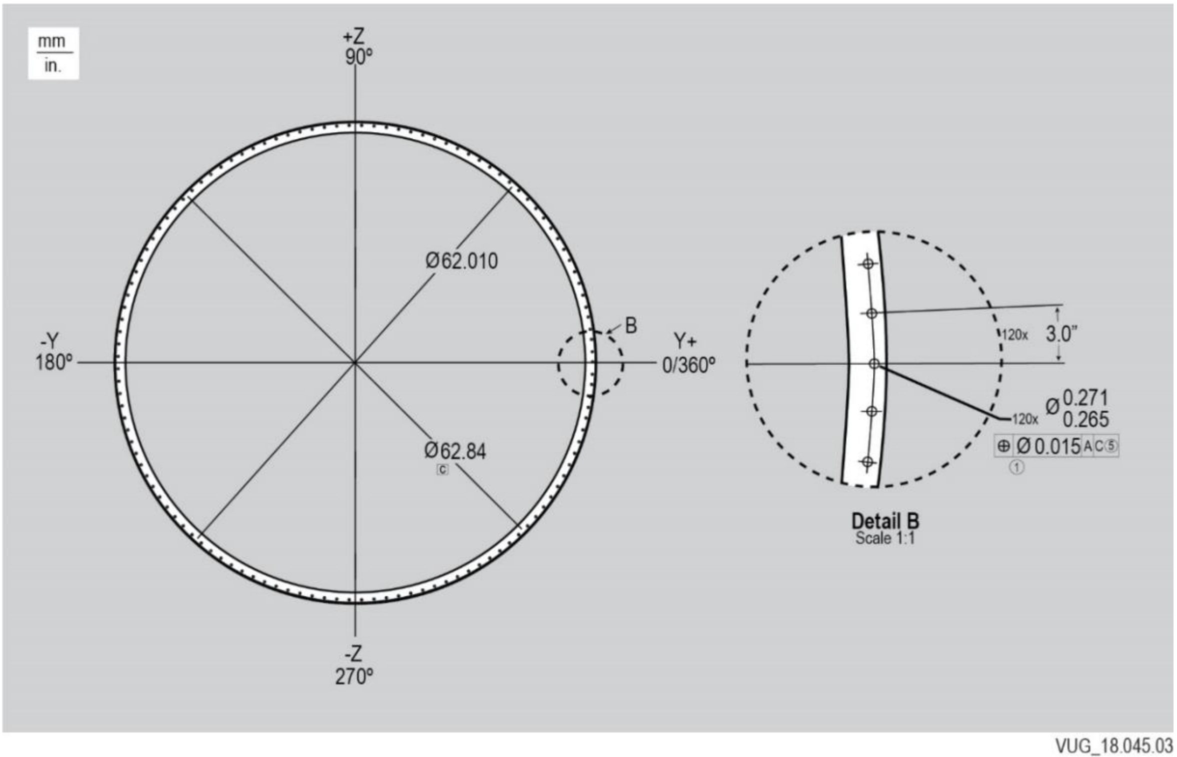


Figure 4.2.1.1-1 1575-mm PAF Interface Details

The 1575 PAF is a composite fiber reinforced polymer/aluminum honeycomb structure with metallic forward and aft interface rings, as shown in Figure 4.2.1.1-2. The 1575 PAF provides the mechanical interface for small and medium payloads. The structural capability of the 1575 PAF is shown in Figure 4.2.1.1-3.

Payload adapter interface options include a wide variety of bolted or separating interfaces, which are summarized in Section 4.2.2. Modifications to these systems or custom-designed systems may be accommodated on a mission unique basis.

Figure 4.2.1.1-2 1575 PAF

Static payload envelopes specific to each payload adapter and separation system are available. The static payload envelope defines the usable volume for the payload relative to the payload adapter. This envelope represents the maximum allowable payload static dimensions (including manufacturing tolerances) relative to the payload/payload adapter interface. This envelope design allows access to mating components and payload separation system for integration and installation operations, motion of the payload separation system during its operation, and movement of the payload and LV after separation of the payload. Clearance evaluation and separation analyses are performed for each payload configuration and, if necessary, critical clearance locations are measured during payload-to-payload adapter mate operations to ensure positive clearance during flight and separation.

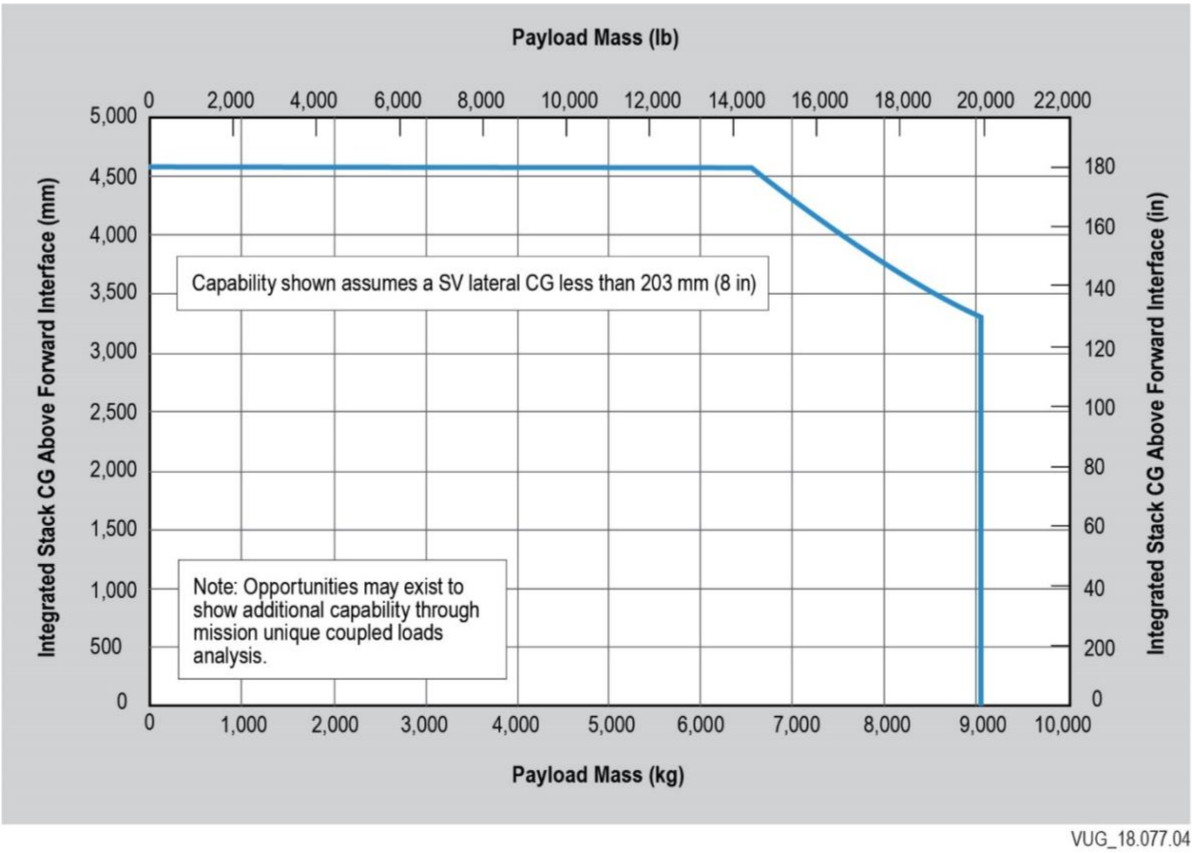


Figure 4.2.1.1-3 1575 PAF Structural Capability

4.2.1.2 4991-mm LVFA Mechanical Interface

The 4991-mm launch vehicle mechanical interface is provided by the Launch Vehicle Forward Adapter (LVFA), with a 216-bolt mating interface at a diameter of 4991.1 mm (196.5 in.). The LVFA interfaces with the Centaur V, 5.4-m payload fairing and either the 1575 PAF, a ULA-provided PLA or a customer-provided payload adapter/payload separation system. For customer-provided payload adapter/payload separation systems, coordination with ULA is required with regard to interface details and diaphragm compatibility (diaphragm which separates the Centaur V forward dome compartment from the payload compartment and provides a clean payload environment).

The LVFA is a metallic skin/stringer structure, utilizing machined forward and aft interface rings, shown in Figure 4.2.1.2-1. The LVFA provides the mechanical interface for medium and heavy payloads. The LVFA is designed to minimize mass and maximize lift and LV shock attenuation capabilities. Structural capability of the LVFA is shown in Figure 4.2.1.2-2.

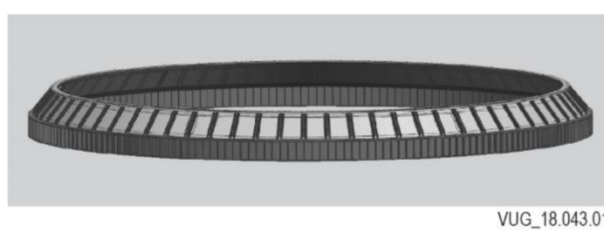


Figure 4.2.1.2-1 Launch Vehicle Forward Adapter

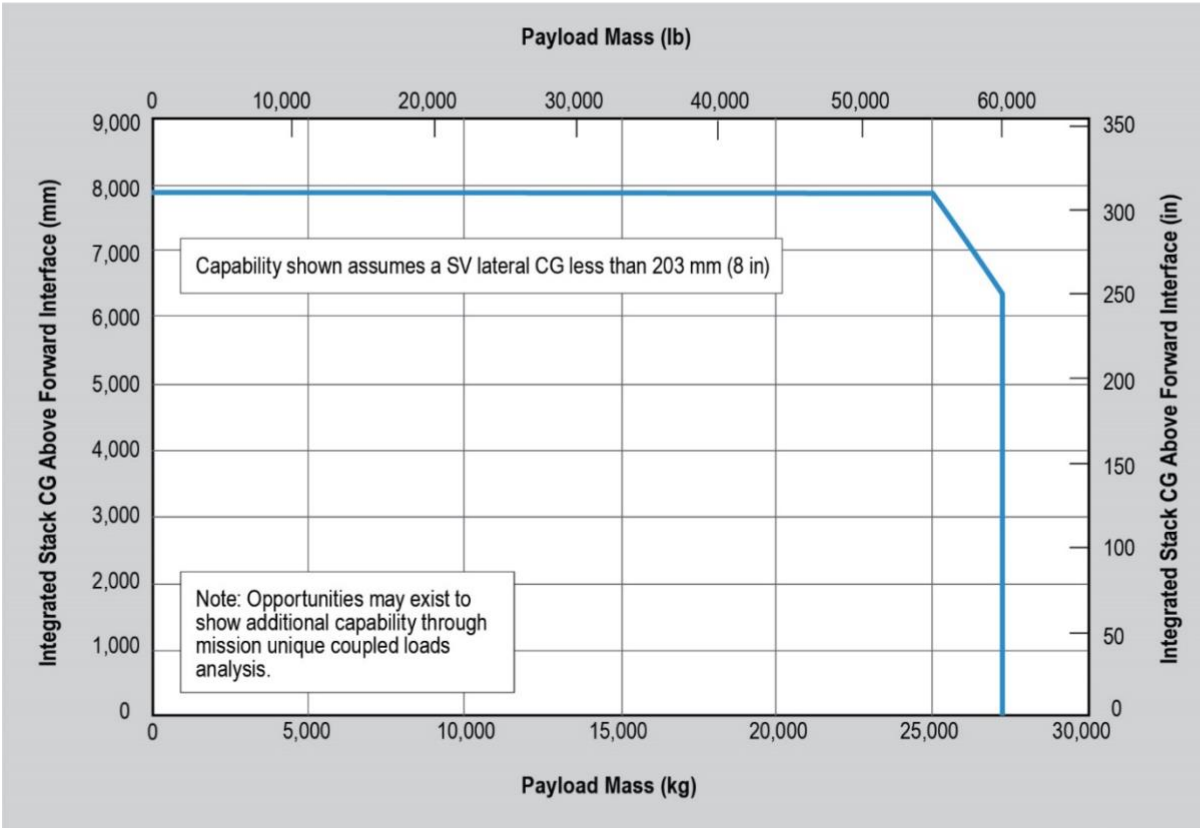


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Figure 4.2.1.2-2 LVFA Structural Capability

4.2.1.3 2624-mm Payload Mechanical Interface

The 2624-mm mechanical interface is provided by an integral payload adapter / LVFA combination with a 244-bolt mating interface at a diameter of 2624 mm (103.3 in.). The 2624 adapter interfaces with the Centaur V, the 5.4-m payload fairing and either a ULA-provided PLA/PSR or a customer-provided dispenser, payload adapter or payload separation system. For customer-provided payload adapter/payload separation systems, coordination with ULA is required with regard to interface details and diaphragm compatibility.

The 2624 adapter replaces the LVFA aft ring structure and interfaces directly to Centaur V with a metallic, rolled-ring forging structure. The 2624 adapter provides the mechanical interface for medium and heavy payloads and exceeds the structural capability of the LVFA 4991-mm interface listed above (and shown in Fig 4.2.1.1-2). Contact ULA for details on the structural capability and compatibility with the Vulcan Centaur vehicle.

4.2.2 Payload Adapters and Separation Systems

The ULA-provided payload adapter and separation system interface designs meet the requirements of currently defined payloads and offer the flexibility to adapt to mission unique needs. These components are designed to adapt to the 1575-mm, 2624-mm and 4991-mm interfaces defined in section 4.2.1 to the mechanical and electrical interfaces required by the payload and to provide a suitable environment during integration and launch activities. The interface information in Table 4.2.2-1 (Parts a, b, and c) should be used only as a guideline. Contact ULA to ensure complete compatibility with launch vehicle payload interfaces.

Table 4.2.2-1a Payload Adapters

Model/Mass	Note: All dimensions are in mm/in	Separation Mechanism	Used in Conjunction with	Features
937 mm Payload Adapter and Separation System 46.4 kg /100 lb		**Ø937 mm** (37 in.) Clampband	**1575-mm PAF**	Integrally machined aluminum forging with low-shock Marman-type clampband 3 or more matched spring actuators. Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Forward Interface: Ø945.3 (37.215) separation ring with shear lip Height: 406.4 mm (16.00 in.)
1194 mm Payload Adapter and Separation System 38.1 kg/ 84 lb		**Ø1194 mm** (47 in.) Clampband	**1575-mm PAF**	Integrally machined aluminum forging with low-shock Marman-type clampband 3 or more matched spring actuators. Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Forward Interface: Ø1215.0 mm (47.835 in.) separation ring with shear lip. Height: 254.0 mm (10.00 in.)
1575 mm Payload Adapter 10.5–79.6 kg/ 23.3–175.5 lb		Not applicable; non-separating; bolted interface	**1575-mm PAF**	Integrally machined cylindrical aluminum forging typically provided as a spacer between 1575-mm aft interface separation systems and/or SV-provided PLAs. Forward Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Height: 127 mm (5.00 in.) to 1117.6 mm (44.00 in.)
1575 mm Payload Adapter and Separation System 43 kg/ 95 lb		**Ø1575 mm** (62 in.) Clampband	**1575-mm PAF**	Machined aluminum rings with low-shock Marman-type clampband and up to eight matched spring actuators. Forward Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.86 mm (.270 in.) thru holes Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.86 mm (.270 in.) thru holes Height: 127 mm (5.00 in.)
1663 mm Payload Adapter and Separation System 89.6 kg/ 197.5 lb		Four Bolts and Springs	**1575-mm PAF**	Integrally machined aluminum forging. Separation bolts released by redundantly-initiated explosive nuts. Four matched spring actuators. Forward Interface: Ø1663.7 mm (65.50 in.) bolt circle with four shear cones Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Height: 562 mm (22.126 in)
1666 mm Payload Adapter and Separation System with Shear Lip 48.7 kg/ 107 lb		**Ø1666 mm** (66 in.) Clampband	**1575-mm PAF**	Integrally machined aluminum forging with low-shock Marman-type clampband and 3 or more matched spring actuators. Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Forward Interface: Ø1666.1 mm (65.594 in.) separation ring with shear lip. Height: 330.2 mm (13.00 in.)
1666 mm Payload Adapter and Separation System with Shear Pins 27.7 kg/ 61 lb		**Ø1666 mm** (66 in.) Clampband	**1575-mm PAF**	Integrally machined aluminum forging with low-shock Marman-type clampband with shear pins and 3 or more matched spring actuators. Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Forward Interface: Ø1666.1 mm (65.594 in.) separation ring with twenty-six equally spaced shear slots Height: 330.2 mm (13.00 in.)

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Table 4.2.2-1b Payload Adapters (continued)

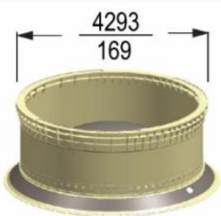
Model/Mass	Note: All dimensions are in mm/in	Separation Mechanism	Used in Conjunction with	Features
1742 mm Payload Adapter and Separation System 93.0 kg/ 205 lb		Four Bolts and Springs	**1575-mm PAF**	Integrally machined aluminum forging. Separation bolts released by redundantly-initiated explosive nuts. Four matched spring actuators. Forward Interface: Ø1742.2 mm (68.59 in.) bolt circle with four shear cones Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Height: 381 mm (15.00 in.)
2624 mm Payload Adapter and Separation System 91 kg/ 200 lb		**Ø2624 mm** (103 in.) Clampband	**2624-mm PLA**	Integrally machined aluminum forging with low-shock Marman-type clampband and up to twelve matched spring actuators. Aft Interface: Ø2624.0 mm (103.307 in.) bolt circle with 122X Ø8.84 mm (.348 in.) thru holes Forward Interface: Ø2634.0 mm (103.701 in.) separation ring with shear lip Height: 175.0 mm (6.89 in.)
2624 mm Payload Adapter		Not applicable; non-separating; bolted interface	**N/A (replaces 4991-mm LVFA)**	Five conic orthogrid panels welded to forward and aft interface rings. Aft ring replaces LVFA structure directly attaching to the LH2 skirt. Forward Interface: Ø2624.0 mm (103.307 in.) bolt circle with 244X Ø8.79 mm (.346 in.) thru holes Height: 1,837.7 mm (72.35 in.) [Note: Height includes replaced LVFA] Contact ULA for mass properties
3100 mm Payload Adapter and Separation System 159 kg/ 350 lb (1)		**Ø3100 mm** (122 in.) Clampband	**4991-mm LVFA**	Two integrally machined aluminum forgings with low-shock Marman-type clampband and up to twelve matched spring actuators. Forward Interface: Ø2933 mm (115.5 in.) bolt circle with 120X Ø8.60 mm (0.339 in.) thru holes Aft Interface: Ø3169 mm (124.8 in.) bolt circle with 120X Ø8.60 mm (0.339 in.) thru holes Height: 431.8 mm (17.00 in.)
3170 mm Payload Adapter 508 kg/ 1120 lb		Not applicable; non-separating; bolted interface	**4991-mm LVFA**	Six conic orthogrid panels with forward and aft interface rings. Composite dome diaphragm. Forward Interface: Ø3169 mm (124.8 in.) bolt circle with 120X Ø8.64 mm (.340 in.) thru holes Aft Interface: Ø4991.1 mm (196.500 in.) bolt circle Height: 1643.5 mm (64.705 in.)
4293 mm Payload Adapter 1327 kg/ 2925 lb		Not applicable; non-separating; bolted interface	**4991-mm LVFA**	Composite aft conical adapter, machined aluminum rings, composite dome diaphragm. Forward Interface: Ø4293 mm (169 in.) 3-point, 24-bolt interface. Aft Interface: Ø4991.1 mm (196.500 in.) bolt circle Height: 1975.87 mm (77.79 in.) System is in development. Contact ULA for current mass estimate.
4394 mm Payload Adapter 519 kg/ 1144 lb		Not applicable; non-separating; bolted interface	**4991-mm LVFA**	Composite strut tubes, machined aluminum forward and aft rings, composite dome diaphragm. Forward Interface: Ø4394 mm (173 in.) 18-point, 72-bolt interface pattern Aft Interface: Ø4991.1 mm (196.500 in.) bolt circle Height: 1090.0 mm (42.91 in.) System is in development. Contact ULA for current mass estimate.

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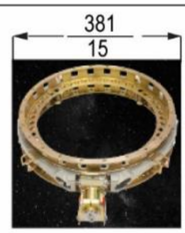
Table 4.2.2-1c Payload Adapters (conclusion)

Model/Mass	Note: All dimensions are in mm/in	Separation Mechanism	Used in Conjunction with	Features
1575 mm EELV Secondary Payload Adapter (ESPA) 136 kg/ 300 lb		Not applicable; non-separating; bolted interface	**1575-mm PAF**	Integrally machined cylindrical aluminum forging. Forward Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Payload Interface: Ø381 mm (15.00 in.) bolt circle with 24X 1/4" or 5/16" thru holes or threaded inserts at each of six ports. Height: 609.6 mm (24 in.)
1575 mm EELV Secondary Payload Adapter (ESPA) Grande 212 kg/ 467 lb		Not applicable; non-separating; bolted interface	**1575-mm PAF**	Integrally machined cylindrical aluminum forging. Forward Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Aft Interface: Ø1575.05 mm (62.01 in.) bolt circle with 120X Ø6.81 mm (.268 in.) thru holes Payload Interface: Ø609.6 mm (24.00 in.) bolt circle with 36X 1/4" or 5/16" thru holes or threaded inserts at each of 4 (or up to 5) ports. Height: 1066.8 mm (42 in.)
381 mm Separation System 6.8 kg/ 15.0 lb		**Ø381 mm** (15 in.) Clampband	**ESPA and 1575 PAF**	Low-shock Marmon-type clampband with 6 springs. Launch Vehicle Interface: Ø381 mm (15.00 in.) bolt circle with 24X 1/4" or 5/16" thru holes Payload Interface: Ø381 mm (15.00 in.) bolt circle with 24X 1/4" or 5/16" thru holes Height: 53.3 mm (2.10 in.) Photo Courtesy Sierra Nevada Corporation
381 mm Separation System 3.7 kg/ 8.2 lb		**Ø381 mm** (15 in.) Clampband	**ESPA and 1575 PAF**	Low-shock Marman-type clampband with 4-24 springs. Launch Vehicle Interface: Ø381 mm (15.00 in.) bolt circle with 24X 1/4" or 5/16" thru holes Payload Interface: Ø381 mm (15.00 in.) bolt circle with 24X 1/4" or 5/16" thru holes Height: 79 mm (3.11 in.) Photo Courtesy Beyond Gravity
610 mm Separation System 9.5 kg/ 21.0 lb		**Ø610 mm** (24 in.) Clampband	**ESPA Grande and 1575 PAF**	Low-shock Marman-type clampband with 6 springs. Launch Vehicle Interface: Ø609.6 mm (24.00 in.) bolt circle with 36X 1/4" or 5/16" thru holes Payload Interface: Ø609.6 mm (24.00 in.) bolt circle with 36X 1/4" or 5/16" thru holes Height: 53.3 mm (2.10 in.) Photo Courtesy Sierra Nevada Corporation
610 mm Separation System 5.8 kg/ 12.8 lb		**Ø610 mm** (24 in.) Clampband	**ESPA Grande and 1575 PAF**	Low-shock Marmon-type clampband with 4 - 10 springs. Launch Vehicle Interface: Ø609.6 mm (24.00 in.) bolt circle with 36X 1/4" or 5/16" thru holes Payload Interface: Ø609.6 mm (24.00 in.) bolt circle with 36X 1/4" or 5/16" thru holes. Height: 73 mm (2.87 in.) Photo Courtesy Beyond Gravity

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4.3 Payload Fairing Interfaces

The payload fairing (PLF) encloses and protects the payload during ground operations and launch vehicle ascent. The PLF incorporates hardware to control thermal, acoustic, electromagnetic, and cleanliness environments for the payload. The PLF has up to two standard access doors 180° apart and can be tailored on a mission unique basis to provide additional payload access to the encapsulated payload.

Two length variants of the PLF are available. The 15.5-m (51-ft.) long PLF is the standard offering for Vulcan Centaur and accommodates small to medium payloads. The 21.3-m (70-ft.) long PLF is available as a mission unique offering to accommodate large payloads and is also used with the Multi-Launch System.

4.3.1 Payload Fairing Envelopes

The Vulcan Centaur payload fairing envelopes are designed to maximize available volume to meet customer needs. The static payload envelope defines the usable volume for a payload. This envelope represents the maximum allowable payload static dimensions (including manufacturing tolerances) relative to the payload adapter interface. These envelopes were derived to ensure a 25.4-mm (1-in.) dynamic clearance to Vulcan Centaur hardware during all transport, flight, and PLF jettison events for payloads meeting stiffness and load requirements. Payload components extending below the 1575-mm PAF interface plane as defined in Section 4.2 can often be accommodated, but coordination with ULA is required for approval. Some increases in diameter may also be allowed on a mission unique basis, but must be analyzed. Figures 4.3.1-1 and 4.3.1-2 show the overall, simplified views of static payload envelopes for the 15.5-m (51-ft.) and 21.3-m (70-ft.) PLFs. Figure 4.3.1-3 shows the overall, simplified view of the Multi-Launch System static payload envelopes for the forward and aft payload compartments.

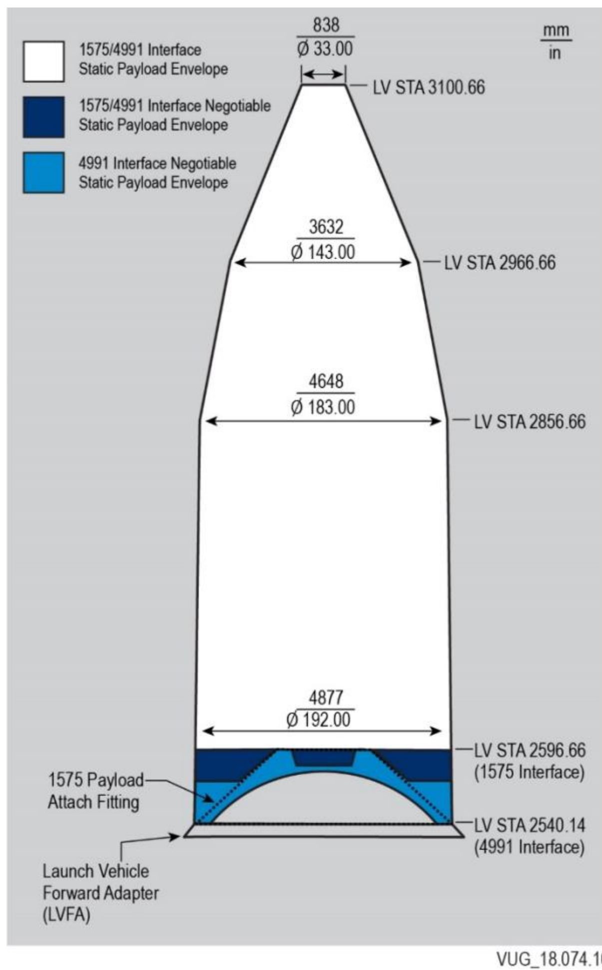

Figure 4.3.1-1 Vulcan Centaur 15.5-m (51-ft.) PLF Simplified Static Payload Envelope

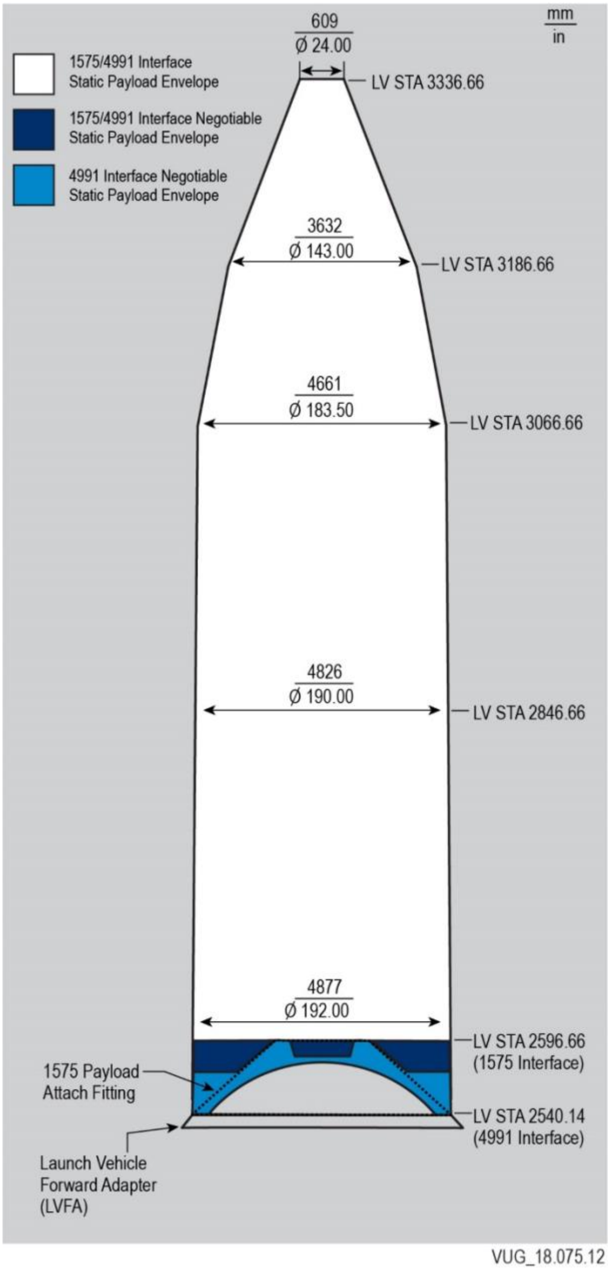

Figure 4.3.1-2 Vulcan Centaur 21.3-m (70-ft.) PLF Simplified Static Payload Envelope

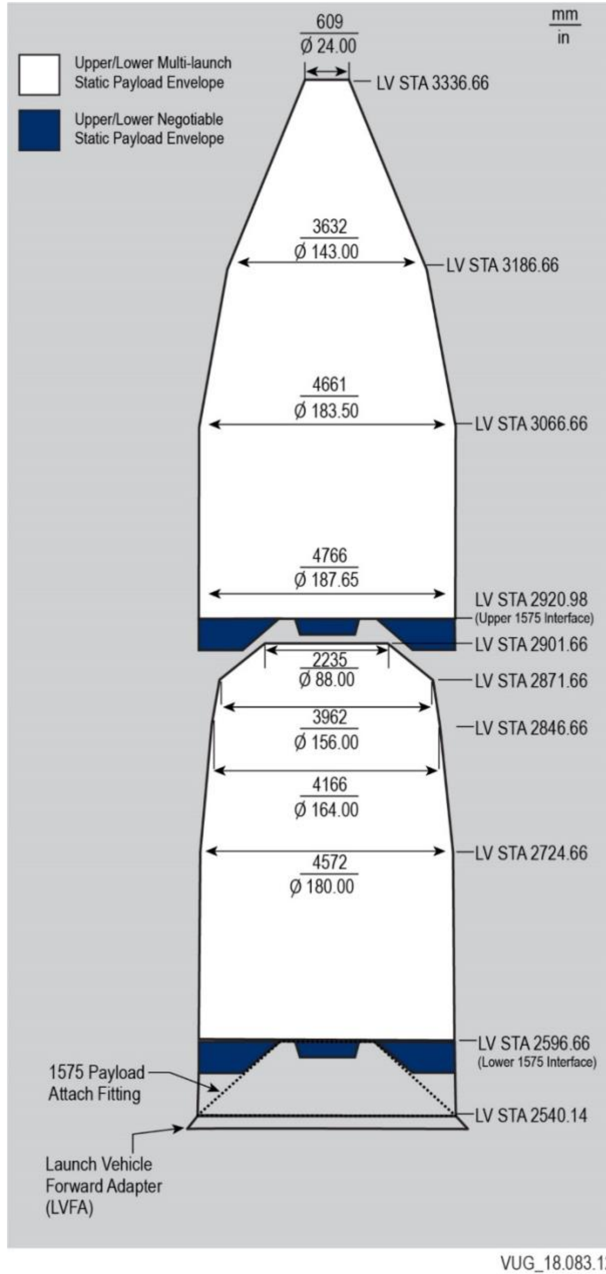

Figure 4.3.1-3 Vulcan Centaur 21.3-m (70-ft.) PLF Multi-Launch System Simplified Static Payload Envelopes

4.3.2 Payload Compartment Environmental Control

The Vulcan Centaur PLF geometry, material selection, manufacturing and processing procedures ensure a suitable acoustic, thermal, electromagnetic, and contamination-controlled environment for the payload. During prelaunch activities, conditioned air is provided through the ECS inlet located in the upper cylinder section of the PLF, providing thermal and humidity control for the payload compartment and preventing direct impingement of this flow on the payload. Mission unique ECS diffusers can be provided by ULA to reduce ECS impingement environment seen by the payload. Vent port assemblies are mounted in the lower cylinder section allowing air conditioning system air to exit the PLF and allow depressurization during ascent. A secondary ECS inlet may be added as a mission unique option to direct cooling air to specific points of the payload.

For the Multi-Launch System, the ECS provides conditioned air during prelaunch activities to each payload compartment through the PLF upper inlet for the forward payload and PLF lower inlet for extension to the aft payload enclosed within the Multi-Launch Internal Canister.

4.3.3 Payload Access

Both lengths of the PLF have two large doors centered below the payload envelope to provide access to the bottom of the encapsulated payload. The doors provide an opening of approximately 600 x 900 millimeters (24 x 36 inches). Diving board platforms can be inserted through these doors to enhance access to payload hardware near the door opening. Additional ground support equipment (GSE) can be developed as a mission unique service to expand access to the payload further from the door. If further access is required, additional 600 x 900-mm (24 x 36-in.) doors can be provided as a mission unique service in the PLF cylindrical section or lower ogive sections. The available sizes and allowable locations for these doors are shown in Figure 4.3.3-1. Mission unique access doors of a larger size or outside the noted areas can be coordinated with ULA. Post-encapsulation access is permitted from encapsulated assembly mate to the launch vehicle until PLF closeout operations before launch operations.

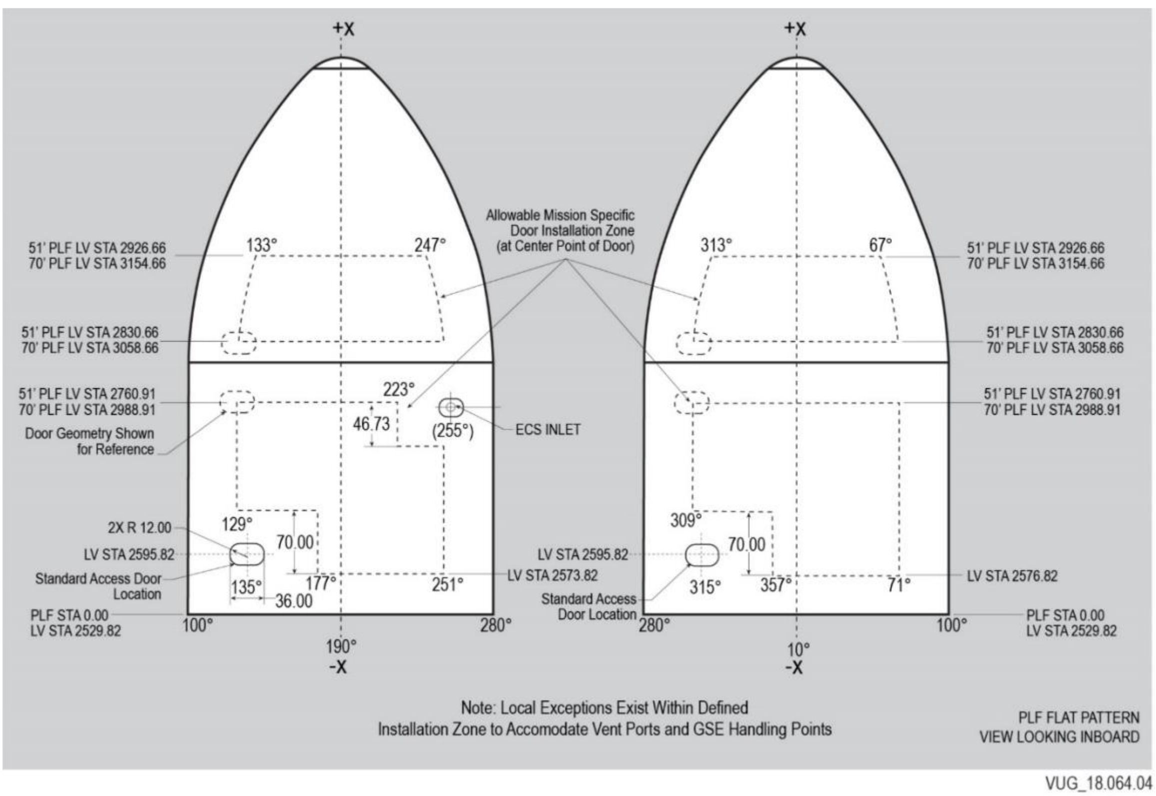

Figure 4.3.3-1 Vulcan Centaur Access Door Locations

For the Multi-Launch System, the PLF standard access doors allow access to the aft payload enclosed within the Multi-Launch Internal Canister. Additional mission unique PLF doors may be provided as required for access to the forward payload within the PLF.

4.3.4 Customer Logo

Customer-specified logos may be placed on the cylindrical section of the PLF. ULA provides logos up to 3.05 x 3.05 m (10 x 10 ft.) as a standard service. Figure 4.3.4-1 shows the area of the PLF reserved for customer logos. ULA works with customers to provide logo layouts on the launch vehicle to assist in determining proper size and location. For Multi-Launch System missions, the area of the PLF reserved for customer logos will be shared.

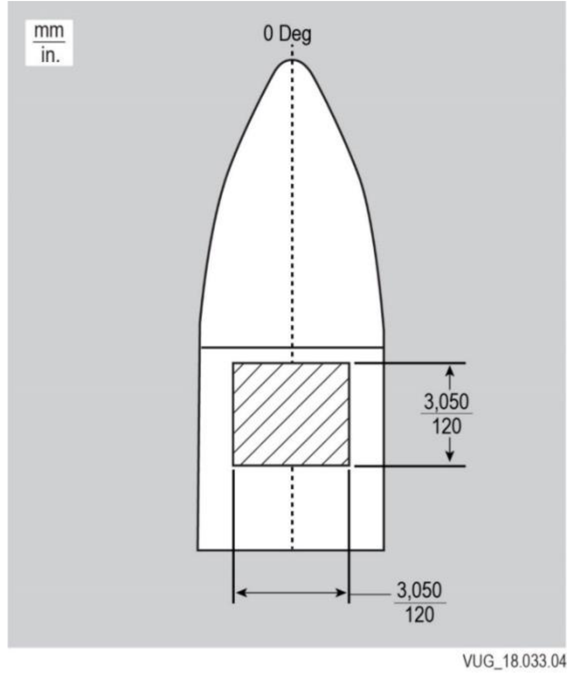

Figure 4.3.4-1 Customer Logo Location

4.4 Payload Electrical Interfaces

This section presents descriptions of the payload-to-Vulcan Centaur electrical interfaces. A dedicated payload umbilical provides payload circuits between the standard electrical interface panel (SEIP) and ground payload interface (GPI) for the payload electrical ground support equipment (EGSE).

The dedicated SEIP located on the PAF is comprised of multiple connectors to provide the payload with the necessary circuits from ground and airborne sources. Connectors at the SEIP are MIL-DTL-38999 Series III type and one set will be provided to the customer for integration based on circuit requirements. Table 4.4.1.1-1 provides circuit counts for the standard T-0 umbilical capability. Payloads requiring additional T-0 connectivity will be addressed on a mission unique basis.

Figures 4.4-1 and 4.4-2 provide an overall depiction of the dedicated payload interfaces and circuits provided by Vulcan Centaur for payload use.

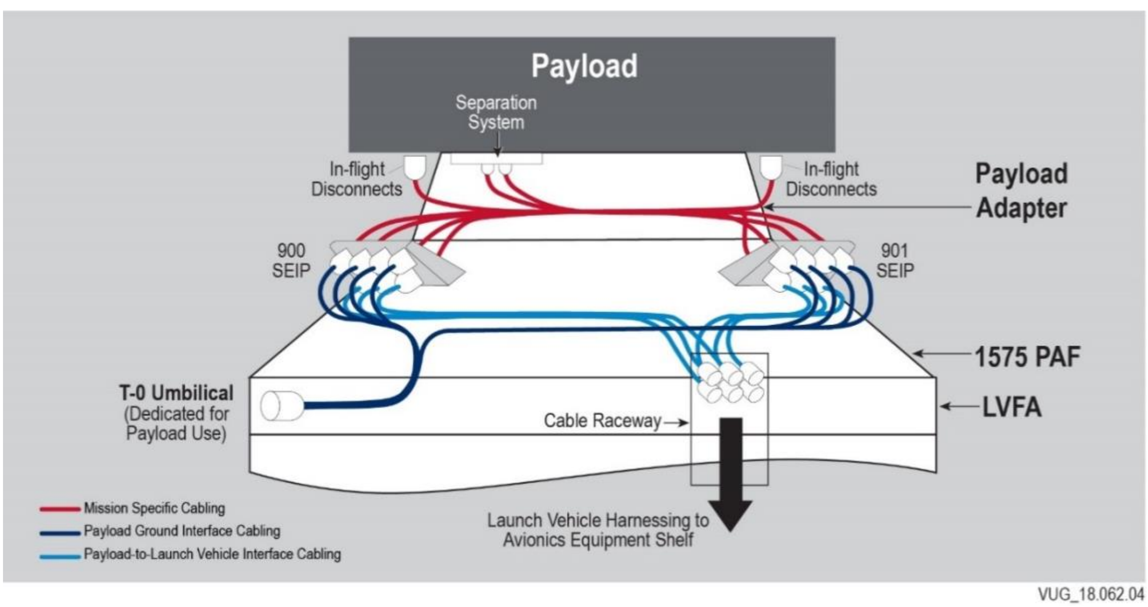

Figure 4.4-1 Payload-to-Launch Vehicle Electrical Interfaces Overview

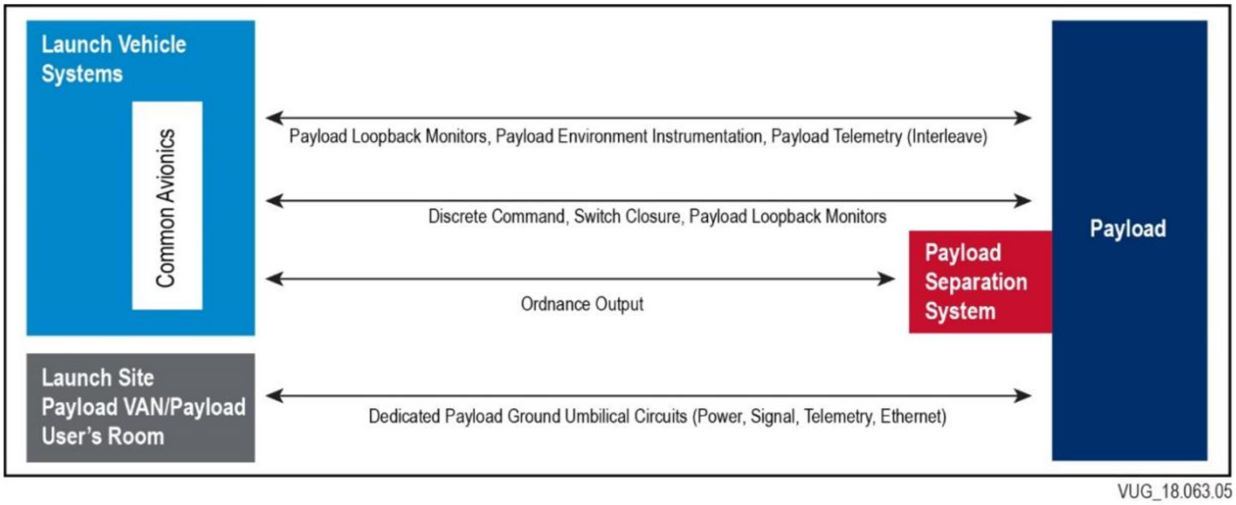

Figure 4.4-2 Payload Mission Interface Circuits

4.4.1 Umbilical Payload-to-Ground Support Equipment Interface

A payload-dedicated umbilical disconnect for on-pad operations is located on the launch vehicle forward adapter (LVFA). This umbilical interface provides circuits between the payload and ground support equipment (GSE) for payload system command, monitoring and power during prelaunch and launch countdown operations. The umbilical T-0 disconnect separates at liftoff from the receptacle mounted to the Vulcan Centaur.

4.4.1.1 Electrical Ground Support Equipment Interface Electrical Constraints

To prevent potential damage to Vulcan Centaur ground and airborne systems in case of a fault, the customer will be required to verify that the payload electrical ground support equipment interface design will provide current limiting protection in individual circuits for power, signals and data. Table 4.4.1.1-1 summarizes the current limits.

Table 4.4.1.1-1 Payload Circuit Current Limits

Signal Type	Gauge (AWG)	Number of Circuits	Conductor Limit	Multiple Wire Factor	Per Wire Limit (A) (4)
Power Circuit (1)	12	12 TP	60	.35	21
Signal Pair	20	60 TSP	15	.35	5
Data Circuit (2)	24	8 TSP 78 ohm	7.5	.35	2.5
Ethernet	24	2 TX/RX PAIRS	N/A	N/A	0.35

Notes:
(1) If power-bussing provisions are required, other mission specific gauge of wire may be required
(2) Limited by launch site existing wiring
(3) TP = twisted pair, TSP = twisted shielded pairs
(4) Per wire limit is based on existing wiring to the SEIP. Maximum allowable current may decrease with the addition of mission specific harnessing.

4.4.2 Payload Adapter Interface Wiring (Payload Provided)

For missions where the payload adapter is provided by the payload contractor, the payload contractor will supply the electrical interface harnessing forward of the Vulcan Centaur SEIP and routed on the payload provided payload adapter structure. This includes any inflight disconnect (IFD) connectors at the payload separation plane. The electrical interface harness is tested with the LV flight avionics to verify end-to-end functionality.

4.4.3 Payload Separation System Activation Circuit

The payload separation system activation circuit supports up to twelve pyrotechnic electro-explosive devices (EED) on a mission specific basis. The separation sequence is initiated by redundant commands from the Centaur V guidance system to the ordnance initiation components that provide power to the standard electrical interface panel (SEIP) interface at the payload prescribed separation time.

4.4.4 Control Command Interface

The Centaur V common control unit (CCU) can provide as many as 16 control commands (eight primary and eight secondary) to the payload at the SEIP. The CCU channelization architecture allows various configurations to meet a variety of payload needs for discrete command, switch closure, or similar signal activation.

Each individual circuit can be configured to provide a discrete command or a switch closure function. The nominal voltage, when configured as switch commands, is 22-32 Vdc for switching currents up to 1.0 amps each. Vulcan Centaur is capable of switching voltages as low as 3.05 Vdc, depending on mission specific requirements. The voltage range of switch closures is 22-32 Vdc at 0.5 amps each.

The Centaur V CCU can additionally provide up to 12 high current discrete commands (six primary and six secondary) at 22-32 Vdc and up to 3.0A each commonly used for secondary payload separation systems.

Mission specific compatibility analyses are performed for interfaces that use these commands to verify proper circuit interaction and appropriate circuit electrical deratings. Contact ULA for further details and capabilities not described herein for mission-unique needs.

4.4.5 Payload Instrumentation and Telemetry

Vulcan Centaur supports a mission-specific suite of instrumentation options to capture payload environments.

4.4.5.1 Payload Separation Monitor Circuit

Positive indication of payload separation is detected by continuity loops installed on each side of the payload IFDs that are wired to the SEIP and connected to the Centaur V instrumentation system. Indication of the payload separation event is telemetered to the ground. Centaur V can monitor up to 16 bi-level inputs (including breakwires) on a mission specific basis.

4.4.5.2 Payload Analog Voltage Monitors

Vulcan Centaur can provide up to eight analog voltage monitors as a mission unique launch service. Further coordination is required to understand SV circuitry, calibration curve, and determine sample rate. This data is telemetered to the ground and provided post-launch for review.

4.4.5.3 Payload Compartment Environment Instrumentation

Vulcan Centaur can provide a full suite of payload compartment environment instrumentation as a mission unique launch service in addition to the standard suite of launch vehicle environmental instrumentation. The full suite includes high frequency vibration, shock, and acoustic data in addition to the launch vehicle's standard low frequency acceleration, pressure, and temperature data. The data recorded from these measurements is provided post-launch for comparison to the payload interface control document (ICD) environmental requirements. Contact ULA for more information including mission-specific payload environment instrumentation.

4.4.5.4 Payload Telemetry (TLM) Options

Vulcan Centaur offers two options for transmission of payload data after encapsulated payload mate to the Vulcan Centaur launch vehicle.

4.4.5.4.1 Radio Frequency (RF) Reradiation GSE Interface

As a mission unique service, a RF reradiating system (S, C or Ku-band) can be installed in the PLF or Multi-Launch Internal Canister. The reradiation system provides the capability for payload RF telemetry transmission and command receipt communications after payload encapsulation through the time of launch. The pickup antenna is mounted on a bracket at a location appropriate for the payload configuration. This antenna acquires the payload RF signal and routes it via RF cabling to the PLF T-0 disconnect. A cable runs from the T-0 disconnect to a junction box that routes the signal to the EGSE location. It must be noted that radiating RF energy inside an enclosed PLF or Multi-Launch Internal Canister produces an enhanced resonant environment that may be in excess of payload or Vulcan Centaur limits. Early in the integration process, ULA will perform electromagnetic compatibility (EMC) analyses to evaluate this condition. For the Multi-Launch System, the mission unique reradiating system can be installed in the forward and/or aft payload positions to support payload RF telemetry transmission and command receipt communications after payload encapsulation through time of launch.

4.4.5.4.2 Payload Serial Data Interface

As a mission-specific service, the Centaur V common avionics will accept transmission of two payload serial data interfaces for interleaving into the Vulcan Centaur telemetry stream. For each data interface, the payload provides nonreturn-to-zero level (NRZ-L) coded data and a clock from dedicated drivers (as an input to Vulcan Centaur). The payload data and clock signals must be compliant with Electronics Industry Association RS-422, Electrical Characteristics of Balanced Voltage Digital Interface Circuits, with a maximum data bit rate of 2 kbps. The payload data is sampled by Vulcan Centaur on the leading edge of the payload clock signal. Cabling from the SEIP to Vulcan Centaur avionics has a nominal characteristic impedance of 78 ohms for these circuits. Data is presented as the original NRZ-L data stream in real time for those portions of prelaunch operations and flight for which Vulcan Centaur data is received. For postflight analysis, the payload data can be recorded to digital media.

4.4.6 Flight Termination Option

The Vulcan Centaur flight termination subsystem (FTS) provides the capability to destruct Vulcan Centaur and payload if required during non-nominal performance either by a secure radio link, autonomously after detecting an inadvertent vehicle break-up, or unintentional separation of Vulcan Centaur stages. If required for Range Safety considerations, Vulcan Centaur can provide payload destruct capability as a mission unique service.

4.5 Mission Options

4.5.1 Payload Compartment Shielding

For analysis purposes, the Vulcan Centaur PLF assumes 0 decibel (dB) of RF shielding. Higher levels can be provided through a mission unique kit that provides RF sealing features to the PLF, LVFA, and payload attach fitting or payload adapters as required. Contact ULA for more information on the RF attenuation capabilities.

4.5.2 Witness Plate Sampling

The PLF includes a mounting location for a witness-plate bracket next to each of the standard doors at the bottom of the payload volume. As a mission unique service, the bracket and witness plates can be installed at the launch site to collect information on contamination generation during processing activities from payload encapsulation through PLF closeout.

4.5.3 In-Flight Video

Vulcan Centaur can provide in-flight digital video as a mission-unique launch service. Vulcan Centaur can be custom outfitted with up to four cameras programmed to operate according to a custom sequence. Camera locations can be selected to view events such as launch vehicle ascent, staging, payload fairing separation, Centaur V operation, and primary/auxiliary payload separations. High definition (HD) video is an option with the custom sequence development. ULA can provide in-flight video to the customer in real-time or delayed viewing modes, depending on the mission-unique requirements. High-quality recordings generated from receiving assets are provided subsequently for post-flight use. Contact ULA for more information regarding custom video inquiries.

4.5.4 Payload Instrument Purge

As a mission-unique service, dedicated purges of specific payload components can be provided from encapsulated payload transport through T-0 disconnect. Grade B, Grade C, or ultra-high purity (UHP) GN_2 can be supplied at a flow rate up to 14.2 scmh (500 scfm) for the payload instrument purge. For the Multi-Launch System, a mission unique payload instrument purge can be supplied to the forward and aft payloads from encapsulated payload transport through T-0 disconnect.

4.6 Multi-Manifesting

Vulcan Centaur offers multi-manifesting launch solutions as described in Section 4.6. Centaur V has the capability for multiple engine starts to facilitate placement of multiple spacecraft into diverse mission specific orbits on a single launch. The trajectory design for each mission is specifically tailored to meet mission specific needs while satisfying payload and launch vehicle constraints.

4.6.1 Multi-Launch System Capability

The Vulcan Centaur Multi-Launch System provides a lower cost launch solution, launching two or more payloads on a single core vehicle. The Vulcan Centaur Multi-Launch System consists of the Multi-Launch Internal Canister and two 1575 payload attach fittings as shown in Figure 4.6.1-1 and can feature payload adapters as required. The forward and aft payload positions are structurally qualified to a 9-mT (20,000-lb) payload, with a 3302-mm (130-inch) vertical center of gravity (cg) offset, and a 203-mm (8-inch) lateral cg offset.

Vulcan Centaur is capable of inserting payloads into a variety of orbits and separating the forward and aft payloads into separate orbits. The trajectory design for a mission typically optimizes the mission's critical performance parameters (e.g., maximum payload lifetime, maximum weight to orbit) while satisfying payload and launch vehicle constraints. The Vulcan Centaur Common Avionics System's extensive capabilities allow the Centaur V to address and satisfy a variety of payload orbital requirements, including thermal control, sun-angle pointing constraints, and telemetry transmission maneuvers.

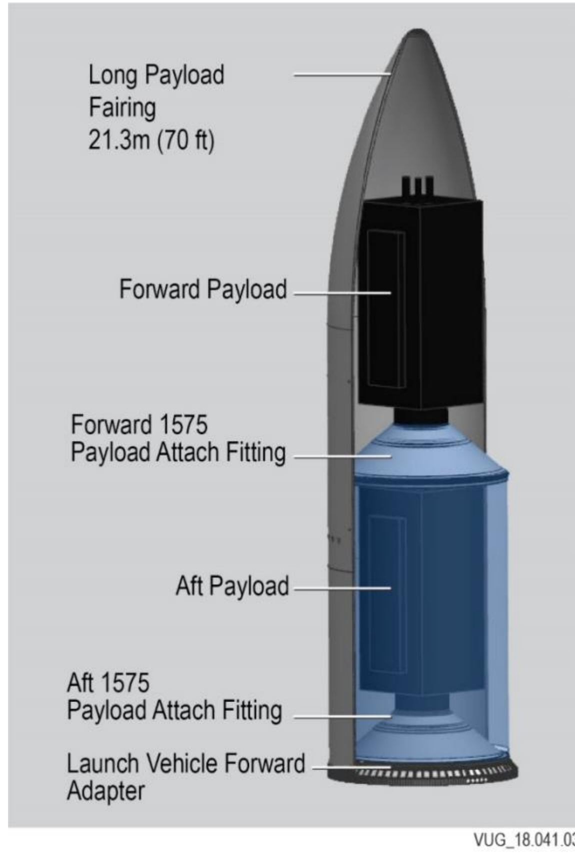

Figure 4.6.1-1 Multi-Launch System

In the case of a Vulcan Centaur Launch Service using the Multi-Launch System, ULA will identify a mission manager for each customer spacecraft. ULA's mission managers will work with each customer-appointed mission manager to ensure the timely, transparent, and accurate exchange of data in order to promote mission success. The Multi-Launch System provides independent compartments for each spacecraft so that, from a business and technical perspective, the Vulcan Centaur launch service customers receive as close to a dedicated launch service as possible.

4.6.2 Rideshare Mission Capabilities

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). Our extensive multi-manifest history includes successful multi-manifest spacecraft deployments to a variety of orbits and in all phases of flight, 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.

Vulcan Centaur offers a range of available small and large rideshare spacecraft integration capabilities from aft rideshare to ESPAs to large scale multi-manifest mission options. Our solutions include launch vehicle integration and are based on our flight-proven launch experience.

4.6.2.1 EELV Secondary Payload Adapters

Small satellites can be launched using the ESPA, a 1575-mm (62-in) diameter, 609.6-mm (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 1575-mm (62-in) diameter, 1066.8-mm (42-in) tall ring capable of supporting up to five spacecraft. The ESPA is mounted between the top of a C-

Adapter and the bottom of the primary spacecraft payload adapter or forward C-Adapter, as shown in Figure 4.6.2.1-1. The ESPA forward and aft interface duplicates the 1575-mm (62-in) standard interface plane (SIP) and passes the electrical interfaces through to the primary payload.

An ESPA ring features six 381-mm (15-in) diameter bolt circle interfaces, each able to accommodate a single payload 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 609.6-mm (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. Vulcan Centaur can also support missions with separating ESPAs that act as independent space vehicles.

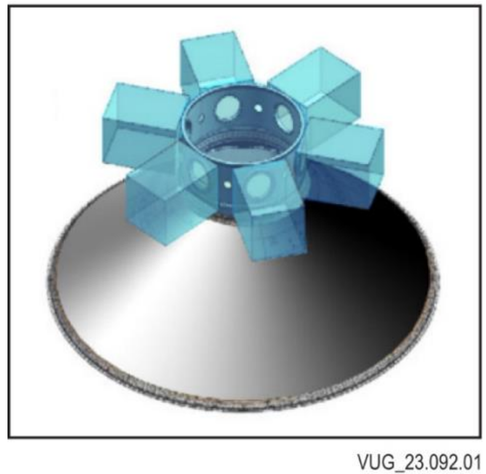

Figure 4.6.2.1-1 Standard ESPA Configuration

4.6.2.2 Aft Rideshare

The Vulcan Centaur aft rideshare capability uses available volume on the Centaur V aft bulkhead. A location on the equipment shelf, as shown in Figure 4.6.2.2-1, has been reserved for small payloads and is capable of carrying up to 95-kg (210-lbs). The allocated volume can accommodate CubeSat dispenser configurations providing an equivalent of up to 24U of capacity. Aft rideshares have the advantage of riding in a location separate and apart from the primary payload environment, enabling later integration and easier payload swaps.

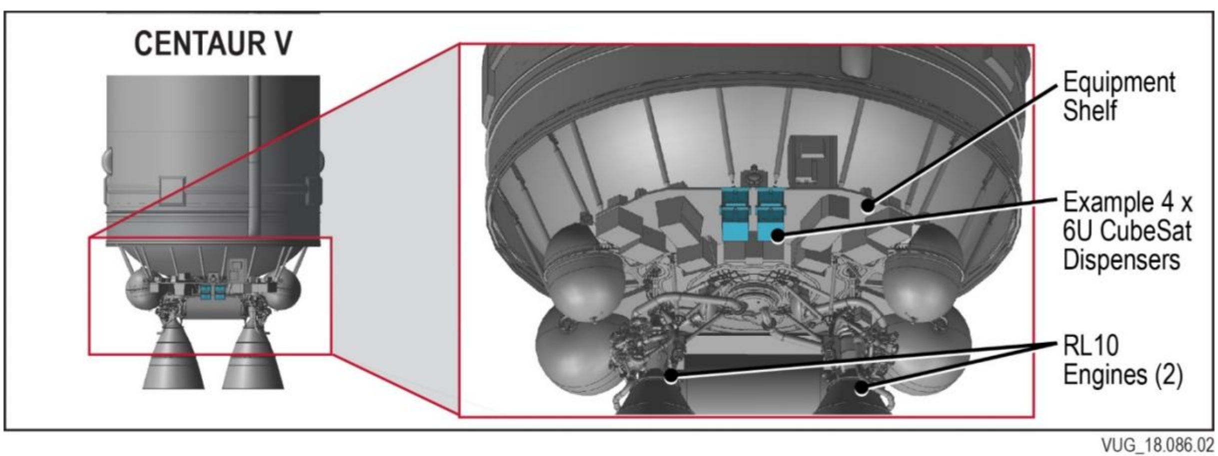

Figure 4.6.2.2-1 Centaur V CubeSat Aft Rideshare Capability

ULA is also developing a capability for manifesting ESPA class spacecraft on the aft bulkhead, an adaptation of the original aft bulkhead carrier developed for use on the Atlas V. This capability expands Vulcan Centaur's multi-manifest capacity by utilizing interfaces previously reserved for one of Centaur V's helium bottles. Like the capability on the equipment shelf, this system retains the key advantage of being outside of the primary load path. The system is designed to carry an auxiliary payload of up to 125-kg (275-lbs) and has a spacecraft volume envelope consistent with current ESPA payloads. A view of the mounting location on the Centaur V aft bulkhead is provided in Figure 4.6.2.2-2.

4.6.3 Dispenser Systems

Vulcan Centaur is a versatile launch system capable of accommodating and interfacing with a wide range of satellite dispensers, including those required to deploy large constellations comprised of many uniform small satellites. Contact ULA for additional information on Vulcan Centaur constellation capabilities.

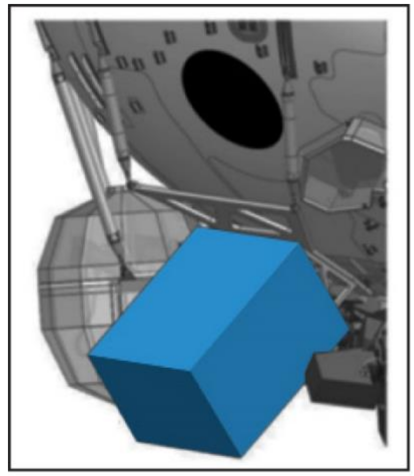

Figure 4.6.2.2-2 Centaur V Aft Rideshare ESPA Class Capability

5. PAYLOAD PROCESSING AND LAUNCH OPERATIONS

The Vulcan Centaur Launch System will use the vertical payload processing capabilities in place at the East and West Coast launch sites. Vulcan Centaur integrates the proven 5.4-m payload fairing encapsulation and encapsulated payload transport processes from Atlas V with the proven LV mate process from Delta IV, eliminating the more complex Atlas V suspended load and torus arm mate operations.

5.1 Cape Canaveral Space Force Station Launch Operations

Payloads requiring an equatorial or prograde orbit generally use the Eastern Range (ER) at Cape Canaveral Space Force Station (CCSFS), Florida (Figure 5.1-1).

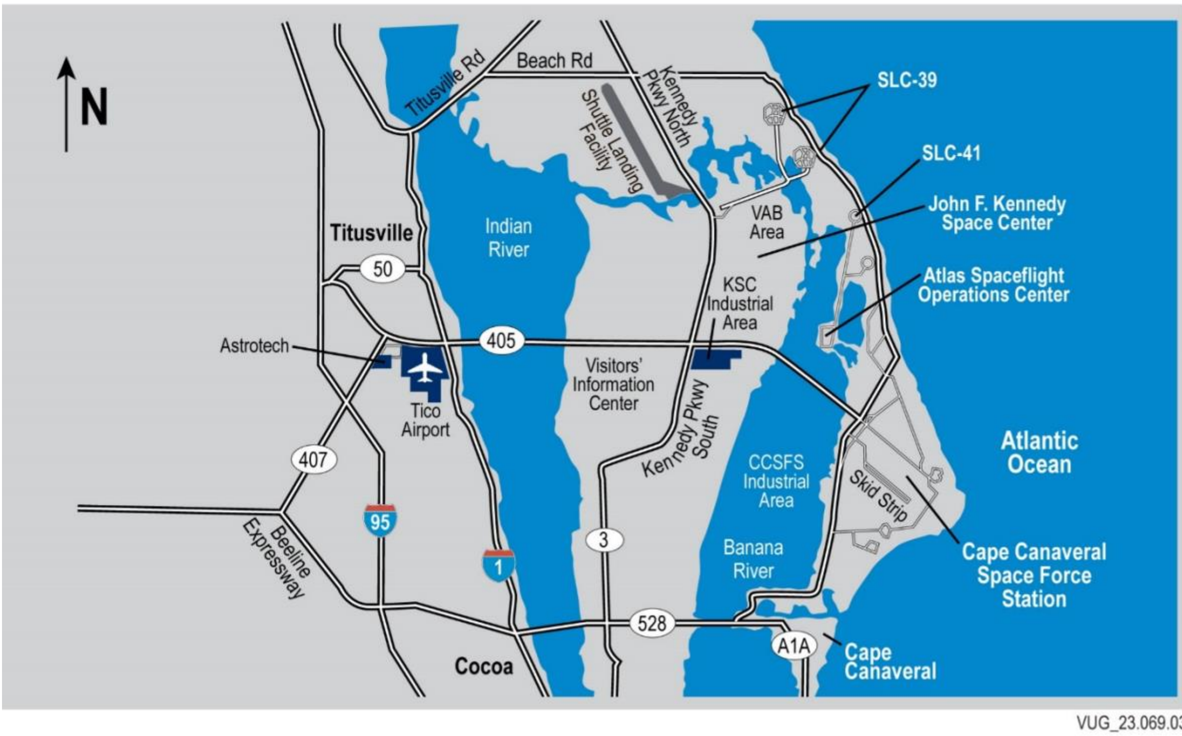

Figure 5.1-1 Cape Canaveral Space Force Station

5.1.1 CCSFS Payload Processing Facility

CCSFS facilities include payload processing facilities available to commercial and U.S. government customers. ULA has an established contractual and working relationship with Astrotech Space Operations (ASO), which owns and operates a payload processing facility (PPF) in Titusville, Florida. The Astrotech PPF is the primary facility for processing Vulcan Centaur class commercial, civil, and government payloads. ULA can arrange the use of the ASO PPF and services for the customer.

The payload fairing, adapters, and payload are delivered to the PPF and processed independently. Then, during integrated processing, the fueled payload is mated to the adapter, the PLF bisectors are moved into position, and the payload is encapsulated. The encapsulated payload is hoisted to the transporter and prepared for transport to the launch complex (LC). All integrated processing is accomplished vertically, enhancing payload safety and security while mitigating contamination concerns and reducing launch pad operations in the vicinity of the payload.

5.1.2 Encapsulated Payload Transport to Space Launch Complex 41

The encapsulated payload is transported from the PPF to Space Launch Complex 41 (SLC-41) on a Karlsdorfer Maschinenbaugesellschaft (KAMAG) transporter equipped with a portable ECS and a GN_2 supply. The ECS is the primary system and the convoy will not leave the PPF without a properly functioning ECS. The GN_2 supply is used as a backup in case of a failure of the ECS during transport and to provide mission unique payload instrument purges if required. The ECS system provides temperature and humidity control while the backup GN_2 system only maintains humidity control. The encapsulated payload is transported at night when temperatures are within payload parameters and there is no solar heating of the PLF. Instrumentation is used during encapsulated payload transport to monitor shock, temperature, and relative humidity within the PLF compartment.

5.1.3 Space Launch Complex 41

SLC-41, shown in Figure 5.1.3-1, is a dedicated area designed for Vulcan Centaur and Atlas V assembly, integration, checkout, encapsulated payload mate, integrated payload checkout, final preparations, and launch. SLC-41 consists of the Vertical Integration Facility (VIF), the Payload Van (PVan), the Vulcan launch platform (VLP), and the launch pad.


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Figure 5.1.3-1 Space Launch Complex 41

5.1.3.1 Vertical Integration Facility

The VIF is a weather enclosed steel structure approximately 22.9-m (75-ft.) square and 87.2-m (286-ft.) tall with metal doors, a hammerhead bridge crane, elevators, platforms, and servicing provisions required for Vulcan Centaur integration and checkout (Figure 5.1.3.1-1). Vulcan Centaur processing in the VIF includes stacking the Vulcan Centaur stages; performing Vulcan Centaur subsystem checks and system verification; installing the encapsulated payload; and performing integrated system verification, final installations, and Vulcan Centaur closeouts. Access to the payload can be provided in the VIF prior to PLF closeout.

Accommodations for payload personnel and test equipment are provided on VIF payload user levels. Access to the payload through the PLF access doors using portable access stands is dependent on the Vulcan Centaur and payload configurations.

Critical power (redundant facility power) and facility power (120 V) are provided to support necessary payload operations in the VIF. Communications on payload user levels in the VIF include an unsecure operational voice system, telephone and public address. Lighting of up to 50 foot candles (fc) is provided on payload access levels.

Figure 5.1.3.1-1 Vertical Integration Facility

The payload is fueled at the PPF before encapsulation. No provisions for payload propellant loading are available at the VIF or the pad. If required, emergency payload detanking at the launch complex will occur in the VIF. If it should be necessary to perform an emergency payload propellant detank, the VIF includes fuel and oxidizer drains and vent lines, emergency propellant catch tanks, hazardous vapor exhaust, and breathing air support.

5.1.3.2 Payload Support Van

The Vulcan Centaur dedicated payload support van (PVan) houses the payload mechanical and electrical ground support equipment and provides electrical, gas, and communication interfaces between the ground-support equipment and the payload. The PVan provides the payload GSE racks with an uninterruptible power source (UPS) at 60-Hz as a standard service and 50 Hz as a mission specific service. While at the VIF and or the pad, this communication system connects the payload GSE in the PVAN to the launch complex fiber optic network. This network interfaces with the payload remote command-and-control station located at the Advanced Spaceflight Operations Center (ASOC) or PPF. Additional remote payload processing sites may also access payload data by pre-coordinating with the Eastern Range for connectivity to the ASOC. As a mission-unique service, payload RF communications can be routed from the PLF reradiating antenna to the PVan and then through the fiber optic network. The communication system provides payload RF uplink and downlink capability at the VIF and at the pad.

The PVan, which is temperature and humidity controlled, travels with the Vulcan launch platform from the VIF to the pad. Dynamic loads are limited to 1.5 g during transit. When the PVan is housed within the Pad Equipment Building (PEB) at the pad, the payload GSE is protected from the launch-induced environment, including overpressure, acoustics, and thermal. The PVan can be staffed during operations at the VIF, during transit to the pad, and on pad until final pad clear operations. After launch, the customer's equipment is removed from the PVan, electrical checkout is performed and the new customer's equipment is installed.

5.1.3.3 Vulcan Launch Platform

The Vulcan Centaur dedicated Vulcan Launch Platform (VLP) supports final assembly of Vulcan Centaur, mating of the encapsulated payload in the VIF, transit to the launch pad, Vulcan Centaur fueling, final preparation for launch, thrust hold-down, and release of Vulcan Centaur at launch. All umbilicals connecting the VLP to the launch vehicle and payload include flyaway disconnects.

5.1.3.4 Launch Pad

Vulcan Centaur follows a clean-pad launch processing approach. The Vulcan Centaur is fully integrated off pad on the VLP in the VIF. The VLP transits to the pad the day before launch with the launch pad used only for launch day propellant loads and launch countdown. VLP and PVan interfaces are provided throughout launch pad operations.

5.1.3.5 Advanced Spaceflight Operations Center

The multi-functional Advanced Spaceflight Operations Center (ASOC) supports Vulcan Centaur launch control. The ASOC is located four miles from SLC-41. The launch operations center (LOC) in the ASOC provides customer interfaces for day-of-launch countdown participation and viewing. The main areas of the LOC include the Launch Control Center; the Mission Director's Center; the Spacecraft Operations Center; and mission support rooms.

- Launch Control Center (LCC). The LCC is the Vulcan Centaur command and control center for ULA to operate systems real-time, monitor critical data, and control the launch process.
- Mission Director's Center (MDC). The MDC provides customer management team positions integrated with the ULA launch management team. Each position includes access to Vulcan Centaur data, voice, and video. The stadium seating provides excellent viewing of the LCC video wall.
- Spacecraft Operations Center (SOC). The payload operations center provides four customer monitoring positions. Each position includes access to Vulcan Centaur and payload data, voice, and video. The stadium seating provides excellent viewing of the LCC video wall.
- Mission Support Rooms (MSR). The MSR provides space for customers' (if needed) and subcontractors' use. Accommodations include data, communications, and video display with easy access to the conference rooms.

5.2 Vandenberg Space Force Base Launch Operations

Payloads requiring polar and retrograde orbits use the Western Range (WR) at Vandenberg Space Force Base (VSFB) in California (Figure 5.2-1).

Figure 5.2-1 Vandenberg Space Force Base Facility Locations

5.2.1 VSFB Payload Processing Facility

VSFB facilities include payload processing facilities (PPFs) available to commercial and U.S. government customers. ULA has an established working relationship with commercial PPFs at VSFB and can arrange the use of these services for the customer.

The payload fairing, adapters, and payload are all delivered to the PPF and processed independently. Then, during integrated processing, the fueled payload is mated to the adapter, the PLF bisectors are moved into position, and the payload is encapsulated. The encapsulated payload is hoisted to the transporter and prepared for transport to the launch complex (LC). All integrated processing is accomplished vertically, enhancing payload safety and security while mitigating contamination concerns and reducing launch pad operations in the vicinity of the payload.

5.2.2 Encapsulated Payload Transport to Space Launch Complex-3E

The encapsulated payload is transported from the PPF to Space Launch Complex-3E (SLC-3E) on a transporter equipped with an ECS, redundant ECS and a gaseous nitrogen (GN_2) supply. The ECS is the primary system, providing temperature and humidity control, and the convoy will not leave the PPF without a properly functioning ECS. The GN_2 is used to provide mission unique payload instrument purges if required. The encapsulated payload is transported at night when temperatures are within payload parameters and there is no solar heating of the PLF. Instrumentation is used during encapsulated payload transport to monitor shock, temperature, and relative humidity within the PLF compartment.

5.2.3 Space Launch Complex-3E

SLC-3E is a dedicated area designed for Vulcan Centaur assembly, integration, checkout, encapsulated payload mate, integrated payload checkout, final preparations, and launch. SLC-3E consists of the Mobile Service Tower (MST), Umbilical Tower (UT), and the Launch Service Building (LSB) (Figure 5.2.3-1).

The Remote Launch Control Center is located in Building 8510 on North VSFB.

Figure 5.2.3-1 Space Launch Complex-3E

5.2.3.1 Mobile Service Tower

The Mobile Service Tower (MST) is a multi-level, movable, totally enclosed structure for servicing Vulcan Centaur and the encapsulated payload. A truck system on rails is used for transporting the MST from the park position to the service position over the launch vehicle. The MST is normally in place over the launch pad except during major systems tests and before cryogenic tanking during the launch countdown sequence.

Vulcan Centaur processing in the MST includes stacking the Vulcan Centaur stages; performing Vulcan Centaur subsystem checks and system verification; installing the encapsulated payload; and performing integrated system verification, final installations, and Vulcan Centaur closeouts. Access to the payload can be provided in the MST prior to PLF closeout.

The MST includes stairways and elevators for access to the payload user levels. Accommodations for payload personnel and test equipment are provided on MST payload user levels. Access to the payload through the PLF access doors using portable access stands is dependent on Vulcan Centaur and payload configurations.

Critical power (redundant facility power) and facility power (120 V) are provided to support necessary payload operations in the MST. Communications on payload user levels in the MST include an unsecure operational voice system, telephone and public address. Lighting of up to 50 foot candles (fc) is provided on payload access levels.

The payload is fueled at the PPF before encapsulation. No provisions for payload propellant loading are available at the launch complex. If required, emergency payload detanking at the launch complex will occur in the MST. If it should be necessary to perform an emergency payload propellant detank, the MST includes fuel and oxidizer drains and vent lines, emergency propellant catch tanks, hazardous vapor exhaust, and breathing air support.

5.2.3.2 Umbilical Tower

The Umbilical Tower is a steel structure that supports umbilical swing-arms. The umbilical tower supports power cables, command and control cables, propellant and gas lines, monitoring cables, and air-conditioning ducts to appropriate distribution points.

5.2.3.3 Launch Service Building

The Launch Service Building (LSB) provides a protective shelter for shop areas, storage, locker rooms, air-conditioning equipment, electrical switch-gear, instrumentation, fluid and gas transfer equipment, launch control equipment, and other launch-related service equipment. The LSB also contains the payload user room (Room 219) for supporting connectivity to the payload, payload testing, and payload-dedicated GSE. Capability also exists to connect the payload user room to the fiber optics transmission set/system (FOTS) for connectivity to offsite locations. The payload user room, which provides power, air conditioning, lighting and environmental protection, can be staffed during nominal on-pad operations until final pad clear operations. Facility, technical, and critical power circuits are available for customer use. Critical power is backed up by UPS.

5.2.3.4 Remote Launch Control Center

The Remote Launch Control Center (RLCC) is located in Building 8510 and houses the LCC, MDC, MDC annex and MSR.

- Launch Control Center (LCC). The LCC is the Vulcan Centaur command and control center for ULA to operate systems real-time, monitor critical data, and control the launch process.
- Mission Director's Center (MDC). The MDC provides customer management team positions integrated with the ULA launch management team. Each position includes access to Vulcan Centaur data, voice, and video.
- Mission Director's Center Annex (MDC Annex). The MDC annex provides customer monitoring positions. Each position includes access to Vulcan Centaur and payload data, voice, and video.

• Mission Support Rooms (MSR). The MSR provides space for customers' (if needed) and subcontractors' use. Accommodations include data, communications, and video display with easy access to the conference rooms.

5.3 Ground and Launch Operations

ULA provides complete launch vehicle integration and launch services for our customers. A system of facilities, equipment, and personnel trained in LV/payload integration and launch operations support payload and launch vehicle integrated operations. ULA's concept of operations supports a baseline 11-day single launch flow shown in Figure 5.3-1.

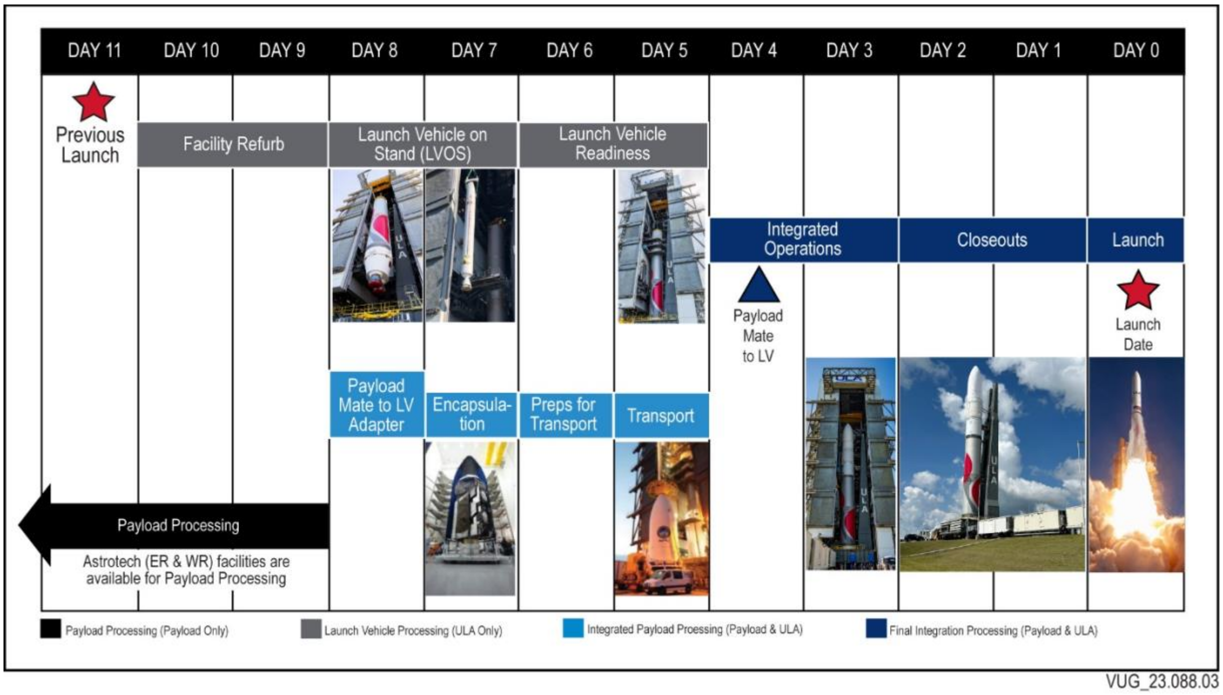

Figure 5.3-1 Baseline SLC-41 Single Launch Flow

5.3.1 Ground Operations

Payload processing and checkout is performed at the PPF. ULA encapsulation hardware and ground support equipment are staged at the PPF in advance of encapsulation operations. Payload encapsulation operations start after completion of standalone payload operations.

Payload encapsulation occurs in a vertical configuration at the PPF following completion of the customer's payload processing, checkout and propellant loading operations. The customer and ULA work together to mate the payload to the mission specific launch vehicle interface (LVI). Then, the payload is encapsulated by installing the PLF halves around the payload. The encapsulated payload is hoisted onto the transporter in the vertical configuration and prepared for transport to the VIF at CCSFS or the MST at VSFB.

The encapsulated payload is transported vertically on the transporter to minimize induced loads during transport from the PPF to the VIF or MST. The ECS remains active during the entire transport operation to maintain the required environment for the payload.

After arrival at the launch complex, the encapsulated payload assembly is hoisted into the VIF or MST and then mated mechanically and electrically to the Vulcan Centaur launch vehicle. The customer may perform limited payload functional tests shortly after the mate. These tests verify payload/LV/launch complex/RF interfaces before initiation of more extensive payload testing.

ULA performs the Integrated System Test (IST) with the payload before moving to launch configuration and launch countdown. The customer provides input to the test procedure and participates in the IST. This test exercises key elements of the countdown sequence arranged on an abbreviated timeline.

Activities to be performed during final closeouts consist of final preparations necessary to ready the LV, payload, and launch complex for start of launch day activities. Because many tasks are hazardous (e.g., limiting pad access, RF transmissions) and/or are prerequisites to others, they are organized on an integrated basis with their sequence and timelines controlled by launch pre-countdown operations procedures.

5.3.2 Launch Operations

For SLC-41 at CCSFS, the standard launch process transports the integrated LV and payload from the VIF to the launch pad the day before launch. For SLC-3E at VSFB, the countdown for a launch is a single day operation.

Launch window times and durations vary based on payload mission specific requirements and launch system constraints. Missions may have a small, instantaneous launch window that is only conducive to a very specific orbit, or may be several hours long.

In addition to mission-specific launch window restrictions, the decision to launch depends on weather launch constraints. Weather launch constraints include cloud conditions, lightning, thunderstorms, and ground and upper atmosphere winds. Excessive winds during launch may cause overloading of the vehicle structure and control system. Limiting conditions are well-defined and operational approaches have been developed to ensure launch within safe limits.

The launch day countdown consists of an integrated countdown that includes built-in holds to enhance the launch-on-time capability. ULA's launch conductor performs the overall launch countdown for the total integrated launch vehicle. Launch countdown management is designed for customers, ULA efficiencies, and control elements.

Should anything delay or interrupt a terminal count operation, standard procedure is to recycle operations and begin again at a predetermined step in the launch countdown. This recycle can occur as many times as necessary while the current launch window remains open. If delays occur that push the launch outside of the required launch window, the mission will scrub for the day and resume at the next available launch window opportunity, typically the following day. Launch vehicle systems and operations have been designed to enable recycle operations when appropriate. Although every recycle event and launch window requirement is unique, the launch system offers the general capability to perform multiple recycles within a given launch window, eliminating unnecessary launch delays.

6. MISSION INTEGRATION AND MANAGEMENT

6.1 Launch Service Management

The ULA mission integration and management process ensures successful execution of commercial and government missions. The typical mission integration timeline is a 12- to 24-month period depending on customer mission-unique requirements and complexity. The overall mission integration timeline can typically be reduced for repeat missions with similar payloads. Contact ULA for further information and to discuss your mission specific integration needs.

ULA encourages clear lines of communication with customers to discuss their particular mission requirements, tailor the integration process accordingly, and assess the latest launch manifest availability. ULA values our schedule reliability, and we strive to support every mission, on time, with 100% mission success.

6.1.1 Mission Management and Integration

The ULA customer-focused Mission Management Team facilitates all aspects of mission execution throughout the launch campaign. The Mission Management Team ensures on-time delivery of hardware and software, manages mission-specific and launch readiness reviews, and coordinates mission requirements with other areas of the broader ULA mission support team. The team supports customer needs and provides information on the status of mission-specific launch service implementations. The mission manager has full responsibility for the successful execution of launch services and programmatic activities associated with the mission. The mission manager coordinates and manages the mission integration activities, system analyses, integrated planning and schedules, technical meetings and reviews, integrated testing, Vulcan Centaur deliverables, and customer deliverables. The mission manager is the primary technical and programmatic point of contact for the customer.

The mission integration system engineer (MISE) is responsible for managing and integrating requirements across the SV/LV interface via the Interface Control Document (ICD). They also identify and manage any derived requirements and manage the definition, execution, and approval of all verifications. The MISE is also responsible for providing systems engineering information at Mission Integration Table-Top Reviews (MITTRs) and various other reviews and serves as a backup to the mission manager.

The spacecraft integrator (SI) is resident at the launch site to provide maximum efficiency in managing integrated launch-site operations. The SI is the primary launch operations point of contact and provides direct customer support following arrival of the payload at the launch site.

6.1.1.1 Integration Program Reviews

The mission readiness review process provides the visibility required to establish maximum confidence in mission success. Mission readiness reviews provide status on meeting customer requirements and focus attention on significant milestones during the payload integration process. ULA schedules mission integration meetings and reviews according to the mission integration schedule.

This incremental launch preparation review process provides an assessment of the readiness of the Vulcan Centaur systems to proceed with launch preparation, and assurances that all mission functional and support elements are ready to support Range Safety, countdown, and launch activities.

6.1.1.1.1 Mission Kickoff Meeting

The Mission Kickoff Meeting marks the start of the standard mission integration activity. The meeting's objective involves discussion of mission analyses to be conducted and interrelationships of space vehicle data inputs to ULA analysis schedules and launch vehicle products.

6.1.1.1.2 Verification Definition Review (VDR)

The VDR is a formal review of the mission requirements using the draft ICD to ensure the interface requirements are understood and to identify any integrated requirement risks early in the mission integration timeline. The mission team will review the ICD requirement verifications and methods and develop a Verification Closure plan.

6.1.1.1.3 Mission Integration Table-Top Review (MITTR)

For the typical 24-month integration period, ULA conducts two MITTRs to ensure compliance of the mission design to the payload mission requirements. At approximately launch minus 12-months, ULA conducts MITTR #1 to ensure the ULA mission integration team has a comprehensive understanding of all mission requirements that result in mission-unique/mission-specific hardware configurations, mission-specific ground rules, hardware analysis, and hardware modeling prior to start of final integration analyses. At approximately launch minus 4-months, ULA conducts MITTR #2 to verify that customer requirements have been correctly and completely addressed and to ensure integration analyses and designs meet these requirements. For shorter integration periods, these reviews are adjusted accordingly to ensure that requirements are executed within the allotted time.

6.1.1.1.4 Ground Operations Working Group (GOWG)

The GOWG meeting occurs at the launch site at approximately launch minus 8-months and includes representatives of the customer, contractors, and launch-site organizations involved in integrated payload operations. The GOWG provides a forum for coordinating launch-site activities and resolving operational issues and concerns. It is co-chaired by the launch site spacecraft integrator and the payload customer launch operations lead. The GOWG may be waived by customers that are launching nearly identical payloads as flown in the past (reflights) and that are familiar with Vulcan Centaur site processing.

6.1.1.1.5 Ground Operations Readiness Review (GORR)

The GORR occurs just before the arrival of the payload at the launch-site PPF. The meeting objectives are to formally kick-off the ground operations phase of the launch campaign, review the readiness of the facility to receive the payload, and ensure that processing plans, schedules, procedures, and support requirements are coordinated and understood. The launch site spacecraft integrator is the technical chairperson who is responsible for documenting meeting minutes and action items.

6.1.1.1.6 Launch Readiness Review (LRR)

The LRR occurs approximately two days before launch and provides a final prelaunch assessment of the integrated payload, launch vehicle, launch facility, Range and weather readiness. The purpose of the LRR is to ensure that payload systems, Vulcan Centaur systems, facilities equipment, Base and Range assets, and all supporting organizations are ready and committed to support the final launch preparations, countdown, and launch. The ULA Launch Director conducts the LRR. The Vice President of Government and Commercial Programs serves as the chair, with participation from the customer organizations, ULA management, and representatives from the launch site.

6.1.1.2 Integration Documentation

6.1.1.2.1 Mission Integration Schedule

ULA prepares a detailed mission integration schedule, which documents mission activities and provides a system for tracking and management. It provides visibility into and control of all major mission milestone events The mission integration schedule is used to track and monitor mission integration progress to avoid significant schedule or technical issues and possible financial impacts.

6.1.1.2.2 Mission Interface Control Document

ULA develops, coordinates, and maintains the mission ICD based on a payload Interface Requirements Document (IRD), Mission Requirements Annex or other customer-provided source interface requirements document. The mission ICD contains physical, functional, environmental, operational, and performance requirements for the payload interface and establishes how interface requirements are verified to ensure compliance of all interface details with ICD requirements. ULA prepares and coordinates the mission ICD with the customer and maintains configuration control after formal sign-off. The mission ICD is approved by the ULA mission manager and the customer and becomes a contractually binding document when signed. Subsequent changes to the mission ICD require formal agreement of all signing parties.

6.2 Mission Integration Analysis

ULA performs standard integration analyses to support first-of-a-kind commercial and government missions. ULA conducts a large number of analyses as part of the launch service, including coupled loads, critical clearance, Vulcan Centaur performance, mission trajectory, stability and control, mass properties, injection accuracy, launch window, EMI-EMC, RF compatibility, payload separation, and post-payload separation analyses.

For repeat missions where there are no changes to functional requirements or physical interfaces, previous analyses are reassessed to determine if the original analyses remain applicable.

The mission integration analyses are described in the sections below.

6.2.1 Coupled Loads Analysis

ULA uses a set of state-of-the-art, test-correlated, three-dimensional (3D) analytical finite element Vulcan Centaur models coupled with a customer-supplied dynamic math model of the payload for the mission-specific dynamic coupled loads analysis (CLA). Mission CLAs are run for all critical flight events for the mission configuration and exercise the unique coupling the payload has with the Vulcan Centaur, allowing for a mission-specific assessment of the loads and responses. CLA results supersede preliminary assessments such as those using Design Load Factors from Section 3.2.1.

6.2.1.1 Coupled Loads Analysis Model Requirements

The desired format for the customer-supplied dynamic mathematical model of the payload is Craig-Bampton, constrained at the Centaur V interface in terms of payload modal coordinates and discrete Centaur V interface points.

- The model should include Mass, Stiffness and Damping Matrices
  - Damping may be provided in tabular form, specifying modal damping values consistent with frequencies or mode numbers.
  - Multi-point interfaces are required, though single point interfaces may be accepted with prior coordination.
  - The payload dynamic model should have an upper frequency cutoff of 140 to 150 Hz, with at least enough modes to retain 95% of the modal mass.
- The output transformation matrices (OTM) should be in the form that, when multiplied by the payload modal and interface generalized coordinate responses, will recover the desired accelerations, displacements, or internal loads.
  - One of the OTMs should contain absolute displacement of points defined in 3 translational degrees of freedom (DOFs) to allow calculation of Loss of Clearance (LOC) between the payload fairing or other LV hardware and critical points on the payload, as described in Section 6.2.2.
  - Typical sizes of the OTMs are 200 to 500 rows for accelerations, 50 to 200 rows for displacements, and 1,000 to 3,000 rows for internal loads, though larger matrices can be accommodated.
- Documentation should be supplied with the model including: model unit definition, model checks including grounding, boundary and loss of clearance grid coordinates and coordinate systems, mode frequencies of the payload in its free-free condition and fixed at the payload/launch vehicle boundary, descriptions of the OTM rows and columns (if possible), OTM 1G acceleration and grounding checks, and documentation of recommended minimum uncertainty factors (SUFs/DUFs).

6.2.2 Loss of Clearance Analysis

The PLF or canister static payload envelope defines the usable volume for a payload and represents the maximum allowable payload static dimensions (including manufacturing tolerances) relative to the payload fairing or canister and payload adapter interface. Payload hardware with expected low clearance to Vulcan Centaur hardware (including the payload adapter and payload mounted hardware such as IFD towers) should be identified and included in the LOC OTM in the CLA analysis.

A loss of clearance analysis is performed to verify that dynamic deflections result in adequate clearance between the payload and Vulcan Centaur hardware. The analysis considers payload and Vulcan Centaur hardware (PLF, canister, payload adapter, or payload adapter mounted hardware) static tolerances and misalignments, dynamic deflections, and out-of-tolerance conditions. Dynamic deflections are calculated for ground handling, flight (using the coupled dynamic loads analysis), and PLF or canister jettison conditions. Any SV points that exceed the static payload envelope when accounting for static build tolerances will be deemed as critical clearance points by ULA during the LOC analysis. The Space Vehicle Contractor will be responsible for verifying the locations of the critical points when the SV fabrication is complete and reporting this data to ULA prior to SV shipment to the launch site. If necessary, critical clearance locations can be inspected as a mission unique service after the payload is encapsulated inside the PLF or the canister to ensure positive clearance during flight.

6.2.2.1 Computer-Aided Design Data Transfer Requirements

The Vulcan Centaur V program uses the Siemens NX CAD program. CAD data should be provided as solid (preferred) or surface model data of the SV outer mold line translated through the Standard for the Exchange of Product Model Data (STEP) converter. An alternative to this would be the equivalent in Parasolid file format or Initial Graphics Exchange Specification (IGES) format. Wireframe geometry may be included with the solid or surface model transfer.

6.2.2.1.1 Prerequisites to Data Transfer

The following criteria should be met by the customer before transferring CAD data:

- Verify that the data files contain the desired results by reading them back onto the originating CAD system from the source file before transmittal to ULA.
- Provide entire representation of all external payload components as seen during encapsulation for best integration to the Vulcan Centaur launch vehicle. All internal structures 12 inches forward of the LV interface ring are not necessary and should be removed from model transfer files. Do include any components internal to the aft interface ring or below the separation plane, as well as all in-flight disconnect hardware (GN2/electrical), omni & RF antennas, and any items requiring post-encapsulation access.
- Remove all non-essential geometry such as points, axis lines, and lines-of-action before creating the data.
- Generate shaded high-resolution CAD model images of the SV top, bottom and sides (denoting axis), and isometric views from the native CAD system prior to writing the output file for transmission.
- Write out the STEP, Parasolid and/or IGES model file ensuring all required SV assembly components are included. Ensure that the total payload model transfer does not exceed 200 MB in an uncompressed file size and that the file is output in the SV coordinate system.
- Ensure compliance with ITAR license agreements.
- If feasible, the file(s) to be transmitted should be compressed and transferred as a single compressed (.zip) file.

6.2.2.1.2 Data Transfer

A ULA-based electronic file server (i.e., iDM LiveLink or Airlock) is the preferred transfer method for all data files. An account can be established on a ULA firewall server for electronic data transfers. Alternative methods would be a compact disk, DVD media or the contractor providing similar access to one of their systems via a temporary account. Because of security concerns, email transfers are not recommended at this time. If electronic transfer methods, compact disk, or DVD are not feasible, contact ULA to provide a coordinated and acceptable method of data transfer.

The following information must be sent with the CAD data regardless of transfer method:

- Payload model security status must be clearly marked and communicated (Proprietary Data, Third-Party Proprietary, Non-public Space Vehicle Information [NPSVI], ITAR restricted, etc.).
- Name, email address and phone number of the contact person who is familiar with the model in case problems or questions arise.
- Payload axis and coordinate system.

- Payload access requirements for structure not defined on CAD model (i.e., fill and drain valve locations, battery enable connectors, safe/arms, equipment covers, etc.).
- Screenshots/CAD shaded images of the SV model top, bottom, isometric and sides from the native CAD system.

6.2.3 Vulcan Centaur Performance Analysis

ULA evaluates the capability of Vulcan Centaur to place the payload into the required orbit using trajectory simulation tools. Performance analysis results are provided through the trajectory report documenting LV propellant margin breakdown which includes the Flight Performance Reserve (FPR) for the given mission and SV mass.

6.2.4 Mission Trajectory Analysis and Design

The ULA mission trajectory-design process ensures that all trajectory-related payload, Vulcan Centaur, and Range-imposed environmental and operational constraints are met during flight while simultaneously providing performance-efficient flight designs. This process typically provides propellant margin (PM) above required performance reserves.

The ULA trajectory analysis tools provide output for the following areas when they are of interest: (1) detailed propulsion, mass properties, aerodynamic, and steering control modeling, (2) oblate Earth and gravity capability, (3) selectable atmospheric models, and (4) other selectable routines such as Sun position and tracker locations.

These simulation tools interface directly with actual flight computer software. This feature bypasses the need to have engineering equivalents of flight software. Another powerful feature is compatibility with 6-DOF modeling of Vulcan Centaur. Other features include significant flexibility in variables used for optimization, output, and simulation interrupts.

The trajectory design and simulation process determines the vehicle performance capability for the reference mission. It provides simulation of dispersed vehicle and environmental parameters for analyses of flight performance reserve and injection accuracy. Telemetry coverage assessment, RF link margins, PLF venting, and in-flight thermal analyses also rely on the reference mission design.

6.2.5 Stability and Control Analysis

ULA linear stability analysis is primarily a frequency response technique and is performed to determine Vulcan Centaur autopilot configurations; establish gain and filter requirements for satisfactory rigid body, slosh, and elastic mode stability margins, as well as demonstrating Centaur V maneuver and attitude hold capabilities. Uncertainties affecting control system stability and performance are evaluated through a rigorous stability dispersion analysis. Tolerances are applied to Vulcan Centaur, and environmental parameters are analyzed using frequency response to ensure that the Vulcan Centaur autopilot maintains robust stability throughout the defined mission.

6.2.6 Mass Properties Analysis

ULA performs mass properties analysis, reporting, and verification to support performance evaluation, structural loads analysis, payload/Vulcan separation analysis, ground operations planning, airborne shipping requirements, and customer reporting requirements.

6.2.7 Guidance Analysis

ULA performs guidance analyses to demonstrate that payload guidance and navigation requirements are satisfied. Analyses include targeting, standard and extreme Vulcan Centaur dispersions, and guidance accuracy. Guidance analysis verifies that the flight program achieves all mission requirements across launch windows throughout the launch opportunity. Standard Vulcan Centaur dispersion analysis demonstrates that guidance algorithms are insensitive to 3-sigma Vulcan Centaur dispersions by showing that the guidance program compensates for these dispersions while minimizing orbit insertion errors.

6.2.8 Injection Accuracy Analysis

The guidance accuracy analyses use a combination of Vulcan Centaur dispersions and guidance hardware and software error models to evaluate total guidance system injection accuracy. Hardware errors model off-nominal performance of guidance system gyros and accelerometers. Software errors include flight-computer computation errors and Vulcan Centaur dispersion effects. Positive and negative dispersions of independent Vulcan Centaur and atmospheric parameters that perturb Vulcan Centaur performance are simulated. The accuracy analysis includes sensor noise, effects of Vulcan Centaur prelaunch twist and sway on guidance system alignment during gyro compassing, and the covariance error analysis of the guidance hardware.

6.2.9 Launch Window Analysis

Launch window analyses are performed to define the open and close dates and times of mission-specific launch windows that satisfy mission-specific requirements on each launch day within the launch period. Vulcan Centaur can accommodate launch windows at any time of day and any day of the year within performance capability constraints for a given mission design. Customers are requested to provide opening and closing times for the maximum launch window the payload can support. If the launch windows are several hours long or there are multiple windows in a single day, then a span within the total launch opportunity will be jointly selected by ULA and the customer. This decision can be made as late as a few days before launch. The selected span is chosen based on operational considerations such as preferred time of day or predicted weather.

Some customer mission-specific requirements may involve more complex launch window constraints requiring further analysis by ULA. For example, launch system performance capability may influence a launch window for missions that require precise control of the RAAN due to additional propellant needed to accommodate out-of-plane steering required. Other constraints may include payload solar illumination considerations. ULA has successfully analyzed a variety of customer launch window constraints for past missions and is prepared to accommodate required launch window constraints for future missions.

6.2.10 Electromagnetic Interference (EMI)/Electromagnetic Compatibility (EMC) Analysis

ULA analyzes intentional and unintentional RF sources to confirm 6-dB margins with respect to all general EMI/EMC requirements. In addition, electro-explosive device (EED) RF susceptibility analyses are performed to range requirements for Vulcan Centaur and the payload.

The payload EED circuits analysis is performed by the customer and reviewed by ULA. The analysis confirms a minimum 20-dB margin with respect to the direct current (dc) EED no-fire power level. The EED susceptibility analysis verifies that safety margins of each EED are maintained when exposed to the flight vehicle and site source RF environments. An EMI/EMC

Control Plan is maintained to ensure compatibility between all avionics equipment. This plan covers requirements for bonding, lightning protection, wire routing and shielding, and procedures.

6.2.11 RF Link Compatibility Analysis (Airborne)

ULA conducts an RF compatibility analysis between an active payload and Vulcan Centaur airborne RF transmitters and receivers to ensure proper function of the integrated system. Transmit frequencies and their harmonics are analyzed for potential interference to each active receiver. The customer provides details of active transmitters and receivers for this analysis.

6.2.12 Payload Separation Analysis

Monte Carlo analysis of the pre-separation dynamics using a simulation of Vulcan Centaur and its attitude control system demonstrates compliance with all payload pre-separation attitude pointing, angular rate and spin rate requirements at a 3-sigma probability level. When the separation system is provided by ULA, the separation analysis also includes simulation of the separation event to determine conditions after functioning of the separation system (i.e., loss of contact) and to demonstrate compliance with all separation requirements. The analysis also includes verification of no re-contact during separation between hardware items on the payload and the launch vehicle.

6.2.13 Payload Post-Separation Clearance Analysis

After the payload has separated from the Centaur V, a collision and contamination avoidance maneuver (CCAM) is performed. The CCAM is designed to positively preclude physical recontact with the payload and eliminate the possibility of significant impingement of Centaur V effluents on the payload.

6.2.14 Wind Placard Analysis (Pre-launch, Flight)

Wind tunnel tests of the Vulcan Centaur configurations are performed to determine loading for ground and flight wind conditions. This information, combined with launch-site wind statistics, is used to determine the wind placards and subsequent launch availability for any given launch date.

6.2.15 End-to-End Electrical Compatibility Analysis

ULA conducts an independent, end-to-end electrical circuit interface compatibility analysis (ICA) to verify proper voltage, current parameters, and any required timing and sequencing interfaces between all payload and Vulcan Centaur airborne interfaces (through to the end function). The ICA verifies mission requirements against payload and Vulcan Centaur-released engineering to ensure electrical compatibility between the interfaces before the fabrication of flight hardware.

This analysis requires payload data from released electrical schematics and build/installation engineering such as contact assignments, wiring interfaces, and circuit detail of avionics (first level) to verify end-to-end (payload-to-Vulcan Centaur) compatibility. All in-between wiring and circuits are analyzed to verify proper routing, connections, and functionality of the entire system interface.

6.2.16 Post-flight Data Analysis

ULA uses proven analysis techniques to derive the individual stage performance information from available Vulcan Centaur telemetry data. In addition, the post-flight report presents historical data for past flights of similar family and statistics of the parameters of interest. The report provides a trajectory comparison of simulated flight that effectively matches observed data from the actual flight.

In addition to the performance evaluation of Vulcan Centaur, the post-flight report provides an assessment of injection conditions in terms of orbital parameters and deviations from target values and payload separation attitude and rates. The report also documents environments at the Vulcan Centaur/Payload interface to the extent that the Vulcan Centaur instrumentation permits. These environments could include interface loads, acoustics, vibration, and shock.

Finally, the report presents analyses of individual Vulcan Centaur system performance, and documents any anomalies noted during the mission. Vulcan Centaur and telemetry data provide the primary source of information for these analyses. Additionally, results of the review of optical data from both fixed cameras at the launch site and tracking cameras, and radar data are also presented in the report.

6.2.17 Destruct System Analysis

ULA develops a payload FTS configuration concurrence request for commercial missions (dedicated payload destruct capabilities are generally not required for communications payloads).

6.2.18 Mission Targeting

ULA conducts mission targeting to define target orbit parameters used to guide Vulcan Centaur into the desired orbit. This process requires a target specification from the customer and results in publication of flight parameter loads used for the flight computer and mission-specific software configuration drawing documentation.

6.2.19 Pre-flight and Flight Thermal Analyses

The mission-specific integrated Vulcan Centaur/payload thermal analysis provides the thermal environments imposed on the payload under prelaunch conditions following payload to launch vehicle mate and for flight mission phases up to payload separation. The integrated thermal analysis (ITA) is performed with customer-supplied payload geometric and thermal math models and a detailed payload power/heat-dissipation timeline. ULA provides the results to the customer for evaluation and determination of acceptability. The ITA data is used to assess thermal interfaces and mission operations to maintain predicted payload temperatures within customer-provided, allowable limits.

ULA performs a payload compartment gas conditioning thermal analysis and an ITA that ensure the purge environments around the payload during transport, hoist, and on-pad operations meet payload allowable ambient temperature, relative humidity, and no condensation requirements. These analyses determine launch site requirements and the allowable ECS gas temperature, flow rate and dew point set points required to meet payload allowable ambient temperature, relative humidity, and no-condensation requirements.

6.2.19.1 Payload Thermal Analysis Input Requirements

Payload geometric and thermal mathematical models are required to perform the ITA. These models should be delivered electronically. The Geometric Mathematical Model (GMM) and Thermal Mathematical Model (TMM) size should be less than 5,000 nodes/surfaces each. Larger payload GMMs or TMMs can be accommodated but should be coordinated early in the integration cycle, as the larger the payload model the longer it will take to process data and perform necessary analysis iterations or payload modeling updates as required.

The preferred GMM format is Thermal Desktop input format. Alternate formats are Thermal Radiation Analysis System (TRASYS), TSS, or NEVADA input formats. The GMM should include external surfaces only, should not include component trackers/tracers, and should minimize the use of embedded logic if possible. The documentation of the GMM should include illustrations of all surfaces at both the payload and component levels, descriptions of the surface optical properties (also identifying any logic that may be used), units used in the modeling (surfaces, formulas, etc.), and the correspondences between GMM and TMM nodes.

The preferred TMM format is Thermal Desktop. The alternate format is System-Improved Numerical Differencing Analyzer (SINDA) input format. The TMM should include payload internal convective and radiation modeling, component power/heat dissipations for prelaunch, ascent, and on-orbit mission phases (as required) and should minimize use of embedded logic if possible. The TMM documentation should include illustrations of all thermal modeling; units used in modeling, detailed listing of component power/heat dissipations to be applied for prelaunch, ascent, and on-orbit mission phases; steady state and transient test case boundary conditions with resulting analysis output to verify proper conversion of the payload input format to ULA analysis codes and maximum and minimum allowable component temperature limits.

For a 24-month integration span, payload GMM and TMM delivery is required no later than launch minus 12-months for the final mission analysis ITA. If there is a desire to have results during the preliminary phase of analyses, the payload GMM and TMM delivery is required no later than launch minus 18-months.

6.2.20 Mission-Specific PLF Venting Analysis (Ascent Phase) and Flow Impingement Velocities

A PLF venting analysis determines pressure profiles in the payload compartment during Vulcan Centaur ascent. The analysis incorporates the customer-provided payload venting configuration and any mission-specific PLF requirements. Analysis outputs provided to the customer include PLF pressure profiles and depressurization rates as a function of flight time.

The prelaunch payload gas-velocity analyses verifies that impingement velocities are compatible with the defined payload. ULA performs a worst-case analysis using the maximum air conditioning supply rate to determine flow conditions inside the PLF. The baseline analysis for Vulcan Centaur utilizes the standard diffuser which provides an impingement solution for most impingement requirements between 16 and 32 ft/sec. Because of the sensitivity of the analysis to payload geometry, a mission-unique diffuser can also be utilized in place of the standard diffuser. The mission-unique diffuser provides an impingement solution for requirements between 10 and 16 ft/sec.

6.2.21 Mission-Specific Payload Compartment Acoustic Analysis

An acoustic environment analysis of the payload compartment assesses effects of PLF noise reduction, mission-specific payload fill factors, and mission-specific trajectory design.

6.2.22 Mission-Specific Contamination Analysis

ULA will perform an assessment of contamination contributions from Vulcan Centaur sources to verify payload mission-specific contamination deposition requirements. ULA identifies and analyzes contamination sources starting from payload encapsulation through CCAM. This provides a quantitative assessment allowing the customer to approximate final on-orbit contamination budgets.

6.3 Payload Compatibility Test Requirements

6.3.1 Payload Testing

ULA requires that the payload withstand maximum expected flight environments multiplied by minimum factors of safety.

A payload environmental test report is required to summarize the testing performed and to document the compatibility of the payload with flight environments. Payload testing required for demonstration of compatibility is listed in Table 6.3-1. The minimum payload structural tests, margins, and durations to be achieved for the different possible approaches of payload program development are described in Table 6.3-2.

Table 6.3-1 Spacecraft Qualification and Acceptance Test Requirements

	Acoustic	Shock	LV IF Vibration	EMI/ EMC	Modal Survey	Static Loads	Flt Check
Qual	X	X	X	X	X	X	
Accept	X		X				X

The payload Structural Test Model (STM) is a test-dedicated qualification unit exposed to qualification levels and test durations with mass simulation of components which are tested in unit qualification programs. Data acquired during STM tests may be used to establish qualification levels for each component. The system-level vibration test shall include wet propellant tanks for new designs if not considered in subsequent payload acceptance testing.

Without a STM in the payload program development, the Protoflight Model (PFM) is the first payload flight article exposed to qualification levels and acceptance test durations.

Table 6.3-2 Payload Structural Tests, Margins, and Durations

Test	Qual	Protoflight	Flight
Static Level Analyses	1.25 x Limit (DLF or CLA)	1.25 x Limit (CLA)	1.1 x Limit (Proof Tests)
Sine Vib Level Sweep Rate	1.25 x Limit 2 Oct/Min	1.25 x Limit 4 Oct/Min	Limit Level 4 Oct/Min
Acoustic, Random Vibration, and Shock	ULA recommends payload test requirements follow industry standard: SMC-S-016, NASA-STD-7001A, NASA-STD-7003A. Payload testing that does not follow industry standard will require appropriate justification. Please contact ULA for additional information regarding payload test expectations.		
Note: Protoflight test levels are also used for validation of mission ICD dynamic environments when supplemental FM measurements are made for a specific mission.			

The Flight Model (FM) is defined as each flight article produced after the STM or PFM article. Tests required for each FM are intended as proof-of-manufacturing, workmanship, and verification of no impacts to the modal survey information from the qual model and are performed at maximum expected flight levels and acceptance test durations.

6.3.2 Flight Hardware Fit Check and Payload Separation Tests

Flight hardware fit checks verify mating of ground & airborne mechanical & electrical interfaces and envelopes. If a mission unique wire harness is provided by ULA from the Standard Electrical Interface Panel (SEIP) to the In-Flight Disconnects (IFDs) or a payload electrical interface panel, electrical mate scope is also included. Verification of payload compatibility to launch vehicle shock environments includes an assessment of all shock events defined in Section 3.2.4.1. If a ULA-provided separation system is fired to verify payload compatibility, a mapping of all shock sensitive components should be established during STM, PFM, or FM fit checks in order to assess component qualification to the maximum expected environment defined in Section 3.2.4.1. For customer supplied adapters and separation systems, a similar mapping process should be established, and ULA recommends firing the actual separation device on a representative payload adapter and payload to assess shock sensitive component qualification to the remaining maximum expected launch vehicle induced shock events defined in Section 3.2.4.1. Contact ULA for more detailed information regarding payload compatibility with flight environments.

6.3.3 Other Payload Testing

ULA recommends that the customer demonstrate the payload capability to withstand thermal and electromagnetic interference EMI/EMC environments.

6.4 Safety

Vulcan Centaur/payload design and ground operations must comply with applicable launch site Range Safety regulations, USSF requirements concerning explosives safety, and U.S. consensus safety standards to launch from either CCSFS, Florida, or VSFB, California. In addition, compliance with applicable facility safety policies is also required when using payload processing facilities.

CCSFS and VSFB Range Safety organizations have regularly updated their safety requirements documents. Effective 1 July 2004, Air Force Space Command Control Manual (AFSPCMAN) 91-710 is the single safety document for both CCSFS and VSFB, replacing Eastern/Western Range Regulation (EWR) 127-1.

ULA will facilitate interface activities with the launch-site Range Safety Office for all commercial launches. ULA System Safety engineers evaluate mission-specific payload designs and payload ground processing operations to provide guidance for successful completion of the Range review and approval process. ULA will evaluate each area and provide appropriate guidance for resolution of specific noncompliance items, while still meeting the intent of the applicable safety requirements. Applicable safety compliance documents are determined during negotiations with Range Safety, ULA, and payload at the outset of the mission integration process.

6.4.1 Safety Integration Process

The ULA process to facilitate Range and system safety coordination and receive Range Safety approval and permission to launch is shown in Figure 6.4.1.1-1. It identifies the respective responsibilities of the payload and/or launch services provider (Launch Services Integration Contractor (LSIC), NASA, and/or other government-contracting agency), ULA, and the Range. The timelines are indicative and typical and may vary to accommodate mission-specific requirements.

ULA also meets all Federal Aviation Administration (FAA) licensing and safety requirements for commercial customers and maintains valid launch licenses through the FAA for these missions.

For each mission integration effort, ULA assists the customer during the Range review and approval process. For commercial missions ULA, as required, obtains all Range Safety and system safety approvals. The following paragraphs summarize the safety integration process and define safety data to be developed by the customer during implementation of this process.

6.4.1.1 Payload and Vulcan Centaur Safety Assessments

Mission-specific payload designs and ground processing operations are documented in the Missile System Pre-launch Safety Package (MSPSP) or Safety Assessment Report (SAR) (Figure 6.4.1.1-1, Block A). The customer develops the payload MSPSP/SAR to describe the payload, document hazards, controls, and verifications associated with ground processing operations at the Range (e.g., pressure/propulsion systems, propellant systems, ordnance systems, toxic and hazardous materials, payload access, ionizing and nonionizing radiation, batteries, etc., and affiliated ground support equipment and operations). Range Safety regulations provide details on the MSPSP/SAR format and contents.

The initial or Phase 1 payload MSPSP/SAR is typically submitted to the Range and ULA thirteen months prior to launch. The final or Phase II payload MSPSP/SAR is typically submitted to ULA five months before scheduled launch. The Phase III payload MSPSP/SAR typically incorporates verification closeout data and the tracking log and is typically submitted one month before hardware arrival at the PPF. ULA requires a copy to review.

ULA combines data from the payload MSPSP/SAR with data from existing baseline Vulcan Centaur MSPSP (Ref. Figure 6.4.1.1-1, Block B) and the mission ICD to perform and document a safety assessment of the Vulcan Centaur-to-payload interface. Results of this assessment are delivered to Range Safety as the Mission-specific MSPSP (Figure 6.4.1.1-1, Block C).

For Western Range programs, the mission-unique (MU) MSPSP includes a seismic assessment for ULA hardware, operations, and integrated ULA-to-payload stack configurations. Some payloads may be required to perform a similar assessment or provide information for ULA assessment.

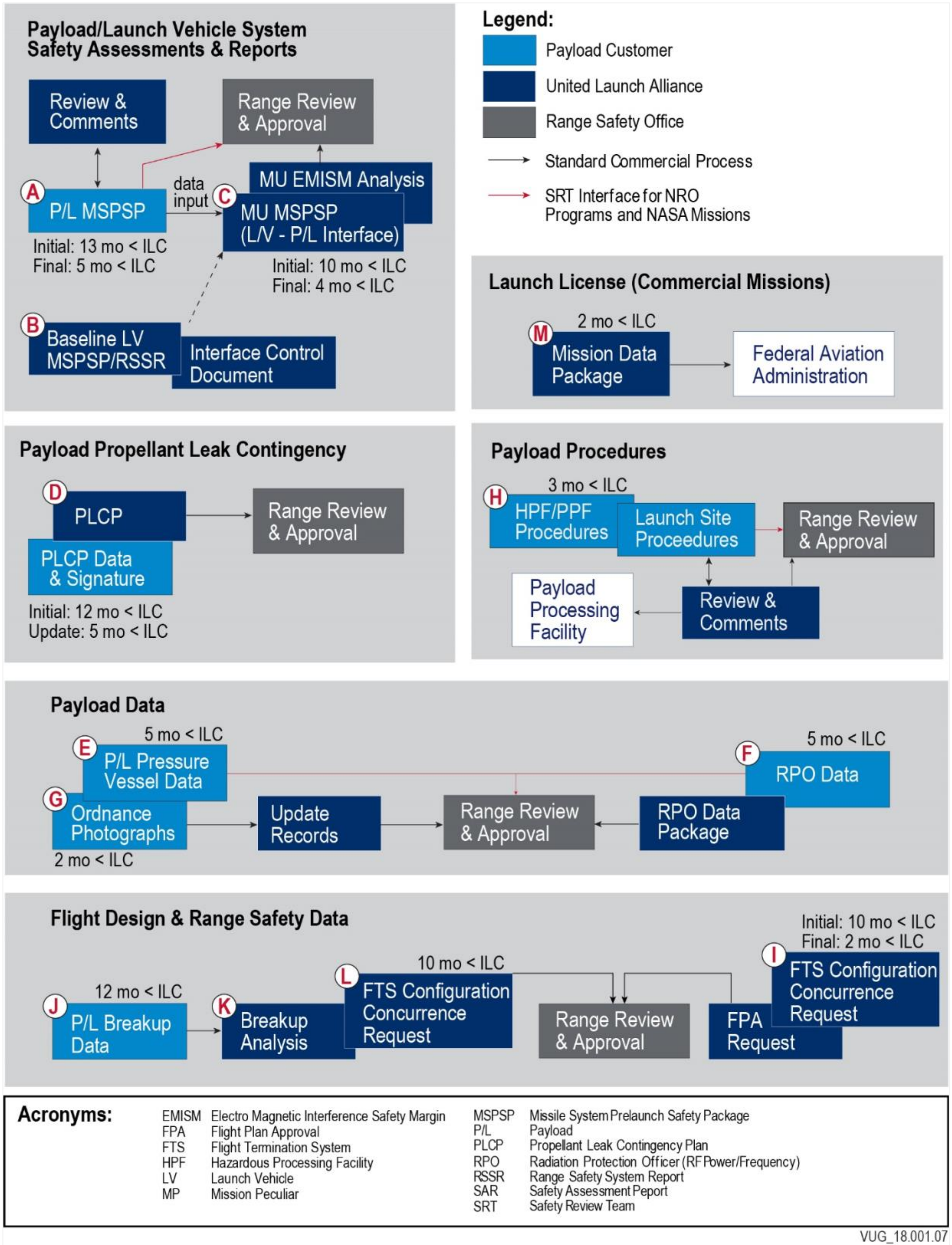

Figure 6.4.1.1-1 Safety Integration Process

6.4.1.2 Payload Propellant Leak Contingency Plan

ULA provides Range Safety with a Payload Propellant Leak Contingency Plan (PLCP) that is generic and applicable to all programs (Ref. Figure 6.4.1.1-1, Block D). The PLCP provides a top-level plan for depressurization and/or offload of payload propellants should leakage occur. The provisions of this plan become applicable during all integrated Vulcan Centaur/payload operations and remain in effect until completion of launch operations. The payload is required to develop detailed procedures to implement offload operations.

6.4.1.3 Additional Payload Data

The payload will provide pressure vessel qualification and acceptance test data to Range Safety for review and acceptance. These data appear in Figure 6.4.1.1-1, Block E and may be included in the payload MSPSP/SAR. For follow-on missions, if the previously submitted pressure vessel qualification data remains unchanged, only acceptance data are required. ULA requires a copy to review.

The customer will provide data specifying the type and intensity of RF radiation that the payload will transmit during ground testing, processing, and launch at the Range. For Eastern Range launches, this data needs to be submitted to the radiation protection officer (RPO) for review and approval. Eastern Range submittal requires the customer complete the appropriate RPO forms such as AFSC Form 2246 and 2257. At the Western Range, it is acceptable to provide this data to the RPO through the payload MSPSP/SAR. The process appears in Figure 6.4.1.1-1, Block F.

The Range requires photographs showing locations of ordnance items installed on the payload. This data appears in Figure 6.4.1-1, Block G. Payload ordnance photographs must be provided to Range Safety before encapsulated payload transport to the launch site from the PPF. If the payload selects the direct submittal option, ULA requires notification that photographs have been delivered. ULA can also submit these photos for the payload. A follow-up meeting between the Range and the customer is typically required to review ordnance data.

6.4.1.4 Payload Procedures

The customer submits payload processing procedures (on the Range), PPF procedures (on the Range), and launch pad procedures (SLC-41/VIF and/or SLC-3E/MST) (Figure 6.4.1.1-1, Block H) to the operator of the PPF and the Range for review and approval. Payload procedures to be implemented at either launch pad must comply with applicable Range Safety regulations and ULA policies. Procedures and operations that involve ULA personnel (e.g., payload mate, encapsulation) or that are performed at the launch site require ULA review. Customer PPF procedures must also comply with the applicable processing facility's safety policy. For first-time missions, the Range requires submittal of all payload procedures, hazardous and nonhazardous. For follow-on missions, only hazardous procedures may be required for submittal. For commercial missions, ULA, as required, obtains all Range Safety and system safety approvals.

6.4.1.5 Payload RF

Inadvertent payload RF transmitter/emitter "ON" status is considered to be a potentially catastrophic hazard. Inadvertent/unplanned payload RF transmissions could encroach upon Range Safety and ULA required EMI safety margins (EMISM) (20 dB for FTS and non-FTS ordnance and 6 dB for avionics). If inadvertent payload RF transmission is controlled by three independent inhibits, then the hazard is considered adequately controlled. If the payload has less than three independent inhibits, ULA may be able to perform a mission-specific RF reverberant field analysis that shows no EMISM margin encroachment. However, if that analysis shows encroachment, then the payload may be required to change the payload design or may be required to submit a Requirements Relief Request (i.e., a waiver) to Range Safety and ULA.

6.4.1.6 Payload Power-Off During Vulcan Centaur Ordnance Activity

During Vulcan Centaur ordnance connections at the launch site, the payload must be powered OFF (i.e., not just RF silence and no power switching). The schedule for payload power-off times and duration will be coordinated with the customer at the GOWG and daily schedule meetings at the PPF and launch site. However, if payload power OFF is not possible, then ULA will perform a mission-specific analysis of the payload power-on configuration (i.e., battery trickle charge, bimetallic thermostat controlled thermal conditioning heaters, telemetry, memory keep-alive) to determine if there is interference with Vulcan Centaur ordnance operations. If that analysis shows interference, then the customer may be required to change the payload design or operations or may be required to submit a Requirements Relief Request (i.e., a waiver) to Range Safety and ULA.

6.4.1.7 Flight Design and Range Safety Data

ULA develops Preliminary and Final Flight Data Packages for submittal to Range Safety. These Flight Data Packages enable the responsible Range Safety agency to evaluate whether the proposed mission is acceptable from the safety perspective via the issuance of a Flight Plan Approval (FPA). The Flight Data Packages also provide the data required by the responsible Range Safety agency to augment their launch operations support, if required. The Flight Data Packages describe the basic payload configuration, the preliminary flight profile, and the time of launch. Approximately 12 months before launch, ULA submits the preliminary Flight Data package to the Range. The Preliminary Flight Data Package includes a Preliminary Flight Plan Approval (PFPA) request to fly the mission on the Range. Approximately two months before launch, ULA will submit the Final Flight Data Package (FFDP) with a request for final FPA. Final FPA is typically received from the Range seven days before launch.

Documented separately but still considered a required component of the Flight Data Package is the payload intact impact analysis. This analysis provides payload debris characteristics resulting from both intact impact and vehicle destruct/reentry scenarios. ULA will work with the customer to develop payload inputs needed to support this analysis.

To support development of the Range Safety data package, the customer provides payload propellant quantities, propulsion system inhibit details, Isp, and breakup data to ULA (Figure 6.4.1.1-1, Block J). ULA uses the breakup data to perform an integrated Vulcan Centaur and payload debris and risk analysis (Figure 6.4.1.1-1, Block K).

Based on results of the breakup analysis and the payload propulsion system characteristics, ULA will submit an FTS configuration concurrence request to the Range (Figure 6.4.1.1-1, Block L). The purpose of this concurrence request is to obtain an agreement with the Range regarding requirements for a designated payload destruct capability. Because there are no appreciable and/or additional public safety hazards with typical missions, ULA typically pursues FTS concurrence without a separate payload destruct system.

6.4.1.8 Commercial Mission Launch License

For commercial missions, ULA obtains a launch license from the FAA. The Vulcan launch license requires mission-specific data to address each commercial mission. ULA develops a mission-specific data package for each commercial flight and submits it to the FAA (Figure 6.4.1.1-1, Block M). Payload information included in the FAA data package will include MSPSP approval status and overviews of hazardous payload commodities (e.g., propellants, pressure systems, batteries).

GLOSSARY

AFSPCMAN	Air Force Space Command Control Manual
AoP	Argument of Perigee
ASO	Astrotech Space Operations
ASOC	Advanced Spaceflight Operations Center
BECO	Booster Engine Cutoff
Btu	British Thermal Unit(s)
°C	Degrees Celsius/Centigrade
CCAFS	Cape Canaveral Air Force Station
CCAM	Collision and Contamination Avoidance Maneuver
CCSFS	Cape Canaveral Space Force Station
CCU	Common Control Unit
cg	Center Of Gravity
CLA	Coupled Loads Analysis
cm	Centimeter(s)
dB	Decibel(s)
dc	Direct Current
deg	Degree
deg/sec	Degrees per Second
DLF	Design Load Factor
DOF	Degrees of Freedom
ECS	Environmental Control System
EED	Electroexplosive Device
EELV	Evolved Expendable Launch Vehicle
e.g.	Exempli Gratia (Latin for "for example")
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMISM	Electro Magnetic Interference Safety Margin
ER	Eastern Range

ESPA	EELV Secondary Payload Adapter
EWR	Eastern/Western Range
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
FAP	Fairing Acoustic Protection
FFDP	Final Flight Data Package
FMH	Free Molecular Heating
FOTS	Fiber-optics Transmission System
FPA	Flight Plan Approval
ft	Foot (feet)
ft^2	Square Foot
FTS	Flight Termination System
GN_2	Gaseous Nitrogen
GORR	Ground Operations Readiness Review
GOWG	Ground Operations Working Group
GSE	Ground Support Equipment
GSO	Geosynchronous Orbit
GTO	Geosynchronous Transfer Orbit
hr	Hour(s)
Hz	Hertz
ICD	Interface Control Document
i.e.	Id Est (Latin for "that is")
IFD	In-Flight Disconnect
IFR	Inflight Retargeting
in.	Inch(es)
IRD	Interface Requirements Document
ISO	International Standards Organization
Isp	Specific Impulse
ISS	International Space Station
ITA	Integrated Thermal Analysis

KAMAG	Karlsdorfer Maschinenbaugesellschaft
kbps	Kilo (1000) Bits Per Second
kg	Kilogram(s)
km	Kilometer(s)
kN	Kilonewton(s)
lb	Pound(s)
lbf	Pounds-Force
LC	Launch Complex
LCC	Launch Control Center
LEO	Low Earth Orbit
LO_2	Liquid Oxygen
LOC	Launch Operations Center
LRR	Launch Readiness Review
LSB	Launch Service Building
LSIC	Launch System Integration Contractor
LV	Launch Vehicle
LVFA	Launch Vehicle Forward Adapter
m	Meter(s)
m2	Square Meter(s)
MDC	Mission Director's Center
MECO	Main Engine Cutoff
MEO	Medium-Earth Orbit
MES	Main Engine Start
MITTR	Mission Integration Table Top Review
m/sec	Meters Per Second
MSPSP	Missile System Prelaunch Safety Package
MSR	Mission Support Room
MST	Mobile Service Tower
mT	Metric Ton, 1000 kg
NASA	National Aeronautics and Space Administration

nmi	Nautical Mile(s)
NRZ-L	Nonreturn-to-Zero Level
ODMSP	Orbital Debris Mitigation Standard Practices
PAF	Payload Attach Fitting
PEB	Payload Equipment Building
PFPA	Preliminary Flight Plan Approval
PLA	Payload Adapter
PLCP	Propellant Leak Contingency Plan
PLF	Payload Fairing
PPF	Payload Processing Facility
PSR	Payload Separation Ring
PSW	Payload Systems Weight
PVan	Payload Van
RAAN	Right Ascension of Ascending Node
RCS	Reaction Control System
RF	Radio Frequency
RLCC	Remote Launch Control Center
RPO	Radiation Protection Officer
scmh	Standard Cubic Meters per Hour
scfm	Standard Cubic Feet per Minute
sec	Second
SEIP	Standard Electrical Interface Panel
SLC	Space Launch Complex
SOC	Spacecraft Operations Center
STM	Structural Test Model
TLM	Telemetry
TP	Twisted Pair
TSP	Twisted Shielded Pair

UHP	Ultra-High Purity
ULA	United Launch Alliance
UPS	Uninterruptible Power System
USSF	United States Space Force
UT	Umbilical Tower
V	Volt(s)
VSFB	Vandenberg Space Force Base
Vdc	Volt(s) Direct Current
VIF	Vertical Integration Facility
W	Watt(s)
WR	Western Range