



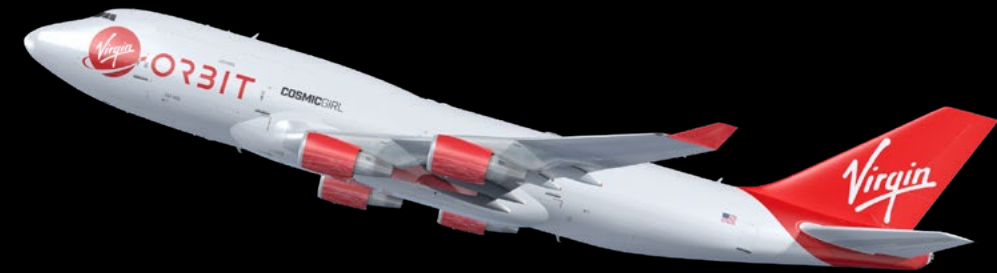
ORBIT



# LAUNCHERONE SERVICE GUIDE

Virgin Orbit, LLC / Version 1.2 / July 2019  
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# LAUNCHING THE SMALL SATELLITE REVOLUTION



Virgin Orbit is excited about the tremendous potential of small satellites to provide global connectivity, remote sensing, security, and visionary new capabilities that benefit our planet. Small satellites are doing more on shorter timelines, and at lower cost. We developed LauncherOne to complement this transformational movement; to get small satellites to orbit quickly, reliably, and affordably. Designed from scratch with these guiding principles, the LauncherOne air-launch system provides freedom from the constraints of fixed ground infrastructure and onerous pre-launch paperwork. We believe launching your small satellite should be hassle-free, and we are enabling this with streamlined processes and the superior customer service that distinguishes Virgin companies.

We invite you to contact us and share your mission needs. Together we open space to change the world for good!

**Dan Hart**  
President and CEO of Virgin Orbit



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# THE VIRGIN ORBIT EXPERIENCE

# 1 THE VIRGIN ORBIT EXPERIENCE

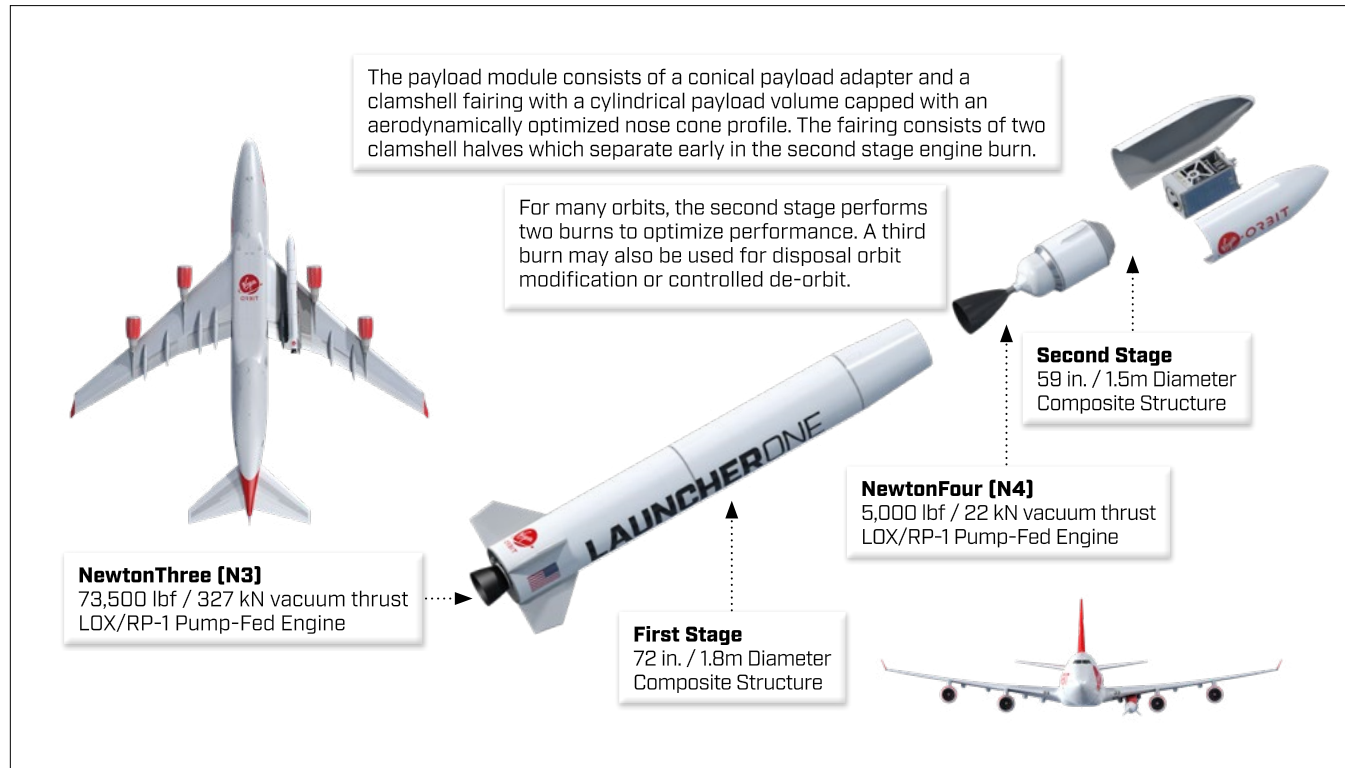
The rapidly growing small satellite industry requires a launch service that is equally agile, flexible, and affordable. Virgin Orbit's launch vehicle, LauncherOne, is the result of our investment in the team, technologies, and facilities required to build a customer-focused launch service.

## LauncherOne is Your Ride to Space

LauncherOne is a simple, expendable, launch vehicle designed to place small satellites of up to 500 kg / 1100 lbm into a wide range of Low Earth Orbits (LEO) at an affordable price. Rather than launching from the ground, LauncherOne is carried to an altitude of approximately 35,000 feet by the 747-400 carrier aircraft, Cosmic Girl, as depicted in **FIGURE 1**.

The simple design of LauncherOne increases reliability while keeping costs low. In order to balance performance with commercially-competitive pricing, LauncherOne was designed through a "clean-sheet" design process, in which all potential vehicle configurations were traded against each other (different numbers of stages, various propulsion types, etc.). Throughout LauncherOne's design, the Virgin Orbit team actively rejected complexity, favoring a straightforward and reliable design. This avoids the common trap of incurring significant cost increases for only a marginal increase in performance.

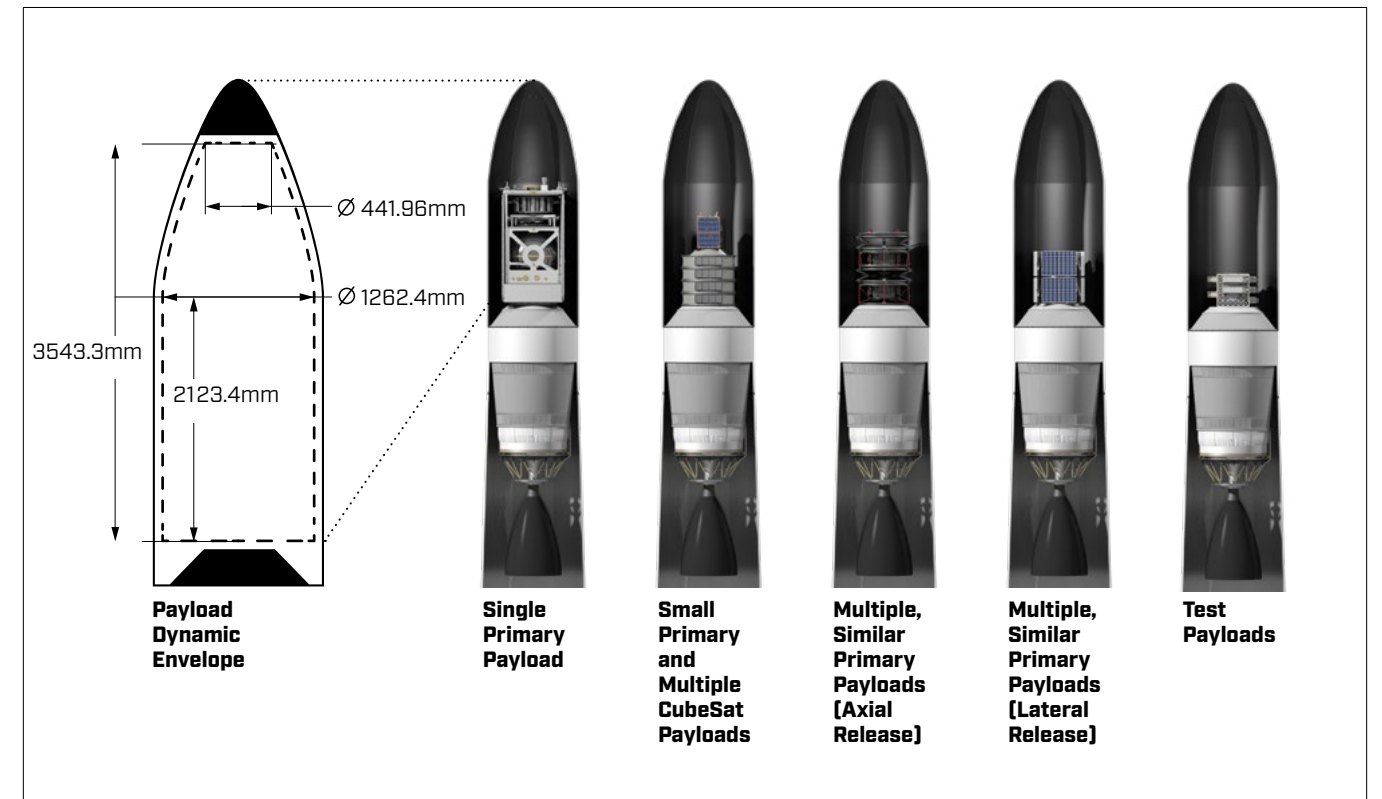
**FIGURE 1/**  
LAUNCHERONE SYSTEM  
EXPANDED VIEW



## Your Orbit on Your Schedule

Launches are available to any orbit inclination with as little as 6 months lead time. Air-launch eliminates much of the compulsory overhead of ground launched systems, and provides unprecedented flexibility in launch operations. By operating independently from national launch ranges, LauncherOne avoids common causes of launch delays such as manifest congestion in the launch queue, weather, unavailable radar tracking assets, and vehicles in the launch pad stay-out zone. The carrier aircraft serves as a mobile launch platform, offering custom launch solutions not traditionally available to small satellites, including tremendous flexibility in the spaceport of origin, orbital destination, and launch date.

**FIGURE 2/**  
LAUNCHERONE SAMPLE  
PAYLOAD CONFIGURATIONS



## Class Leading Payload Flexibility

The payload processing facility is located at an optimal location, close to major airports such as Los Angeles International (LAX) and Long Beach Airport (LGB), and both the ports of Long Beach and Los Angeles. The proximity to these international travel and shipping hubs enables seamless connectivity to all parts of the world.

The staffing and launch campaign logistics are simplified in comparison to many other launch systems. The site is secure but does not require clearances to work, featuring modern facilities and equipment. The facility is also close to local amenities such as hotels, restaurants, shopping, and fitness centers, making work shifting comfortable and convenient.

LauncherOne offers a large fairing for its class with a payload adapter capable of accommodating a variety of standards for one or multiple spacecraft.

Customers are welcomed at Virgin Orbit’s premier payload processing facility located in Long Beach, California. Payload teams can perform all final integration and testing in our state of the art cleanrooms, with features tailored to the small satellite customer and all the comforts and convenience of the lounge style office space our facility is well equipped to host your team.

### Bringing the Virgin Experience to Space Launch

As a member of the Virgin family, Virgin Orbit aims to extend the world renowned Virgin customer service to the space launch industry, placing particular emphasis on the value that our dedicated and spirited team of engineers can add to your launch experience. To accomplish this we are improving the overall experience of getting to orbit, by streamlining the processes leading up to launch and emphasizing customer satisfaction.

This document is intended as a launch planning resource, and more detailed, mission specific information is available upon request. After a Launch Services Agreement is executed, a Mission Manager is assigned to each customer to assist in all aspects of the mission. Please do not hesitate to contact us with questions or special accommodation requests.

## 1.1 CAPABILITIES AT A GLANCE

Key components of Virgin Orbit’s LauncherOne service are summarized in **TABLE 1**. The capabilities listed here are discussed in greater detail in the following sections of this Service Guide, and may be customized as needed to suit each customer’s mission-specific requirements.

**TABLE 1/  
LAUNCH SERVICES  
QUICK REFERENCE**

Service	Capability Summary
Payload Capability	<ul style="list-style-type: none"> <li>Up to 300 kg / 661 lbm to 500 km / 270 nmi Sun-Synchronous Orbit (SSO)</li> <li>Up to 500 kg / 1100 lbm to 230 km / 124 nmi circular 0 degree inclination Low Earth Orbit (LEO)</li> </ul>
Payload Dynamic Volume	<ul style="list-style-type: none"> <li>1262 mm / 49.7 inch constant cylindrical diameter</li> <li>2123 mm / 83.6 inch constant cylindrical length</li> <li>3543 mm / 139.5 inch overall payload fairing envelope length</li> </ul>
Launch Altitudes/ Inclinations	<ul style="list-style-type: none"> <li>Orbital inclinations from 0 to 180 degrees; subject to any launch-site specific population overflight constraints</li> <li>Flexibility to conduct launch from any licensed spaceport facility</li> </ul>
Launch Schedule	<ul style="list-style-type: none"> <li>Emphasis on reducing time-to-launch; 9 months for a typical primary payload</li> <li>Flexible launch windows to accommodate schedule changes/variation</li> </ul>
Payload Processing	<ul style="list-style-type: none"> <li>Independently-operated customer payload processing facility with ISO Level 8 (100k class) clean room in Long Beach, CA</li> <li>Additional Payload options include: <ul style="list-style-type: none"> <li>Receipt of cubesat loaded in dispenser</li> <li>Storage of loaded cubesat</li> <li>Encapsulation of payload at the customer site</li> </ul> </li> </ul>
Payload Integration	<ul style="list-style-type: none"> <li>Conical payload adapter with baseline interface diameter of 609.6 mm / 24.0 inches; other various diameters and bolt patterns available</li> <li>Compatible with ESPA and ESPA-Grande class configurations</li> <li>Support for commercially-available separation systems and CubeSat dispensers</li> <li>Secondary payloads manifested and managed directly by Virgin Orbit or via payload brokers or aggregators</li> </ul>
Regulatory Approach	<ul style="list-style-type: none"> <li>VO’s LauncherOne launch is licensed under the Federal Aviation Administration regulation 14 CFR 431, Launch and Reentry of a Reusable Launch Vehicle (RLV).</li> <li>Compliance with international orbital debris disposal guidelines</li> </ul>



DESIGN  
YOUR  
MISSION

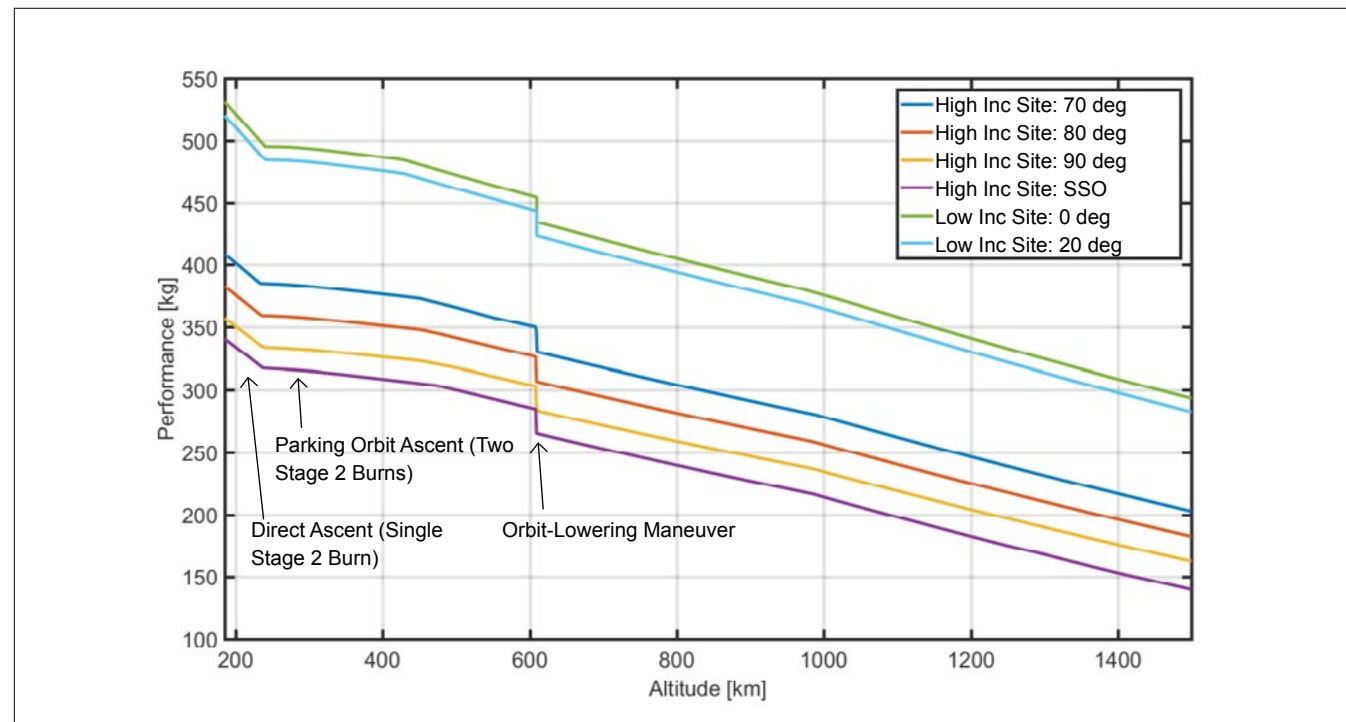
## 2 DESIGN YOUR MISSION

LauncherOne's air-launch architecture enables unparalleled flexibility in orbital destination to inclinations as low as 0-degree equatorial orbit.

### 2.1 PAYLOAD DELIVERY CAPABILITY

Performance curves for LauncherOne payload delivery to several reference orbits are provided in the figure below. Due to LauncherOne's high degree of customization, payload capabilities are best calculated for each customer based on their specific requirements. For more detailed payload capabilities, please contact Virgin Orbit.

**FIGURE 3/**  
ORBITAL PAYLOAD DELIVERY  
PERFORMANCE CURVES



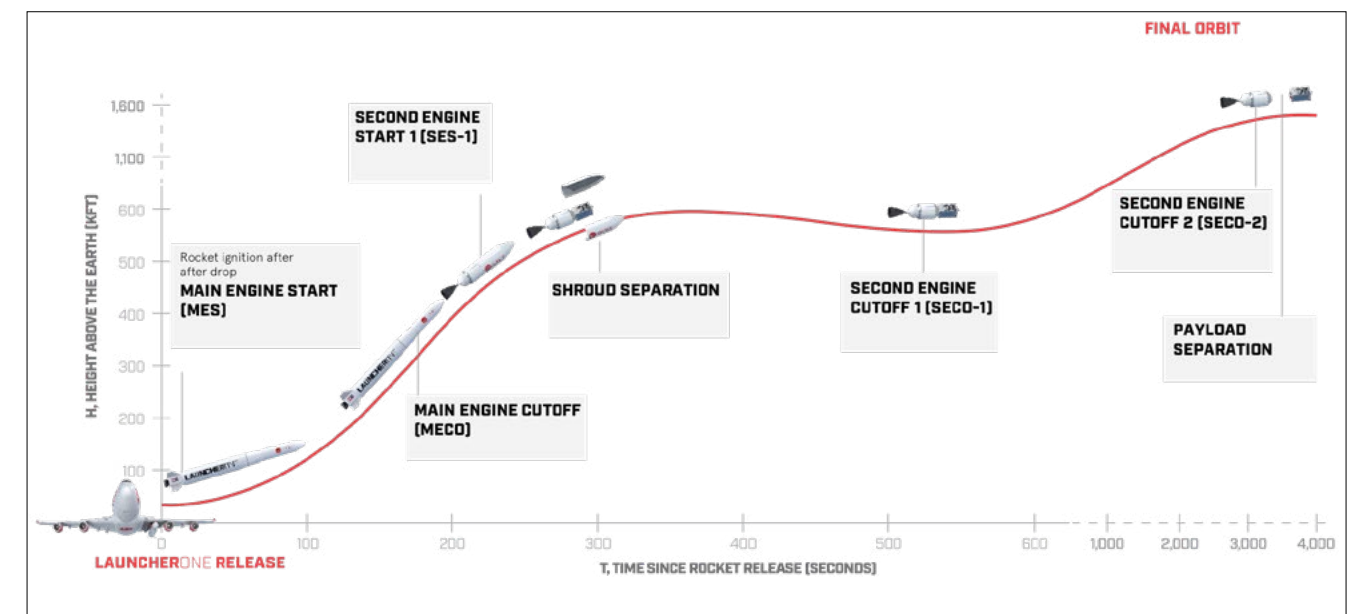
LauncherOne is designed to meet regulations that require a maximum orbit lifetime for an upper stage left above 625 km. Therefore, meeting this requirement necessitates a disposal burn for orbital altitudes above 625 km, consequently consuming a portion of total propellant. This is represented as the dip in the performance at 625 km in **FIGURE 3**. The increased performance below 230 km is for direct-inject orbits where a circularization burn is not required.

The performance curves in **FIGURE 3** provide the total spacecraft mass above the payload interface. Thus, the mass of any required separation system or dispenser must be included along with the payload in accounting for total mass. LauncherOne is compatible with a variety of small satellite separation systems and CubeSat dispensers. Please see Section 2.3 or contact a LauncherOne Mission Manager for more information.

## 2.2 MISSION PROFILE

The carrier aircraft, Cosmic Girl, takes off from the launch site with the fueled LauncherOne and payload. The plane flies out over an unpopulated flight corridor above the ocean to an altitude of 35,000 ft, and releases LauncherOne with a pitch angle of 27.5 degrees. Approximately 5 seconds later, vehicle ignition occurs and the vehicle ascends several hundred thousand feet before Stage 1 Main Engine Cutoff (MECO) occurs at approximately 3 minutes after drop. The second stage is then ignited following a short coast and carries the payload to a low parking orbit (for missions that are not direct-inject), shedding the payload fairing along the way early during Stage 2's burn. During a coast of approximately half an orbit, passive thermal control is performed with a nominal spin rate of 0.1 RPM. Once at target apogee, a circularization burn is performed to accurately deliver the payload into its target orbit. For missions above 625 km, the second stage performs an orbit lowering burn, and final verification of correct orbit insertion occurs within 90 minutes of final payload separation.

**FIGURE 4/**  
MISSION PROFILE



### 2.3 ORBIT INSERTION ACCURACY

We take our commitments seriously and that includes ensuring your payload is accurately deployed. LauncherOne employs a liquid propulsion system for its final stage, which allows for improved orbital insertion control, compared to solid propellant upper stages. Deployment of multiple payloads into orbits of different altitudes, eccentricities and slightly differentiated inclinations can also be accommodated. Orbit injection accuracy is dependent on payload mass, orbit altitude, and other mission-specific factors. Typical errors in injection accuracy for LauncherOne are provided in **TABLE 2** for a 500 km circular sun-synchronous orbit. Virgin Orbit's standard mission analysis includes refinement of these accuracy predictions based on customer-specified mission parameters.

**TABLE 2/**  
TYPICAL ORBITAL INJECTION  
ACCURACY (3 SIGMA)

Orbital Parameter	Accuracy
Altitude	± 15 km
Inclination	± 0.15°
Right Ascension of Ascending Node (RAAN)	± 0.2°
Eccentricity	0.0022

Prior to payload separation, the LauncherOne second stage can orient itself and the payload to the desired attitude. Typical accuracies for pointing and angular velocity are shown in **TABLE 3**. Missions with multiple payload deployments may select different separation attitudes.

**TABLE 3/**  
TYPICAL PRE-SEPARATION  
ATTITUDE AND SPIN-RATE  
ACCURACIES (3 SIGMA)

Altitude Type	Parameter	Angular Error	Rate Error
3-Axis	Roll	± 7.0°	± 2.0°/sec
	Pitch	± 6.0°	± 0.5°/sec
	Yaw	± 6.0°	± 0.5°/sec

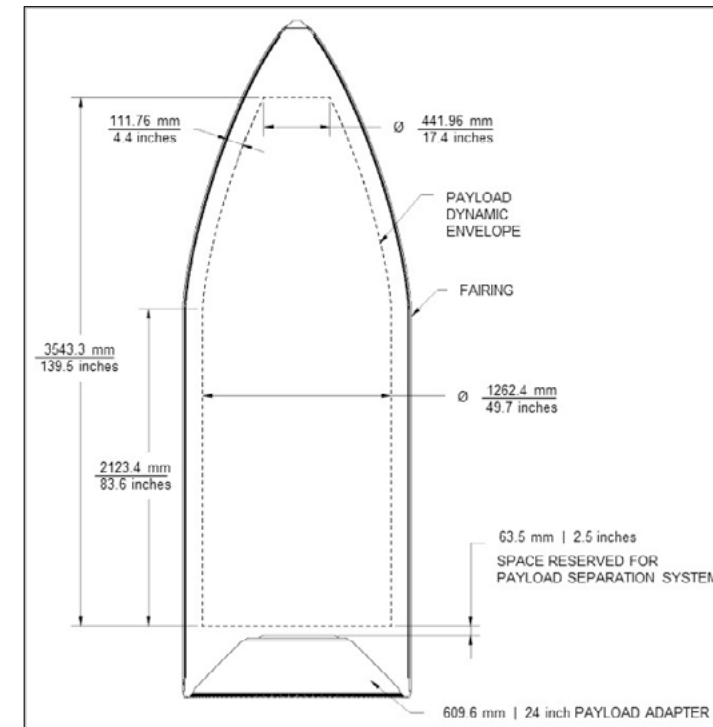
## 2.4 PAYLOAD ACCOMMODATIONS

LauncherOne offers one of the largest payload envelopes in the industry for its class. LauncherOne has the ability to multi-manifest satellites, employing the large fairing volume in a variety of ways to best meet customer requirements. For multi-satellite missions with primary and secondary payloads, typically a secondary payload adapter is attached to the standard payload adapter interface with the primary payload mounted on top. Side-by-side accommodation of two ESPA class payloads is possible as a custom configuration. The LauncherOne fairing can also accommodate a single ESPA-Grande class payload. Secondary payloads can be manifested and managed directly by Virgin Orbit, or via payload aggregators.

The LauncherOne fairing incorporates standard payload access doors near the base of the fairing composite structure. In the event of a contingency situation, the fairing access doors allow for late access to key portions of a customer spacecraft prior to launch vehicle propellant loading.

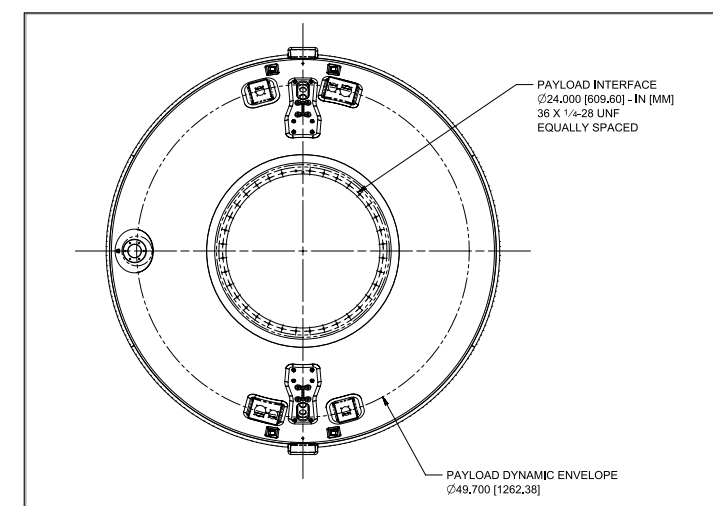
The available payload fairing dynamic envelope and spacecraft separation interface schematic for LauncherOne are illustrated in **FIGURE 5** and **FIGURE 6**, respectively. The dynamic envelope consists of a 1.22 m / 49.7 in diameter cylindrical section that is 2.12 m / 83.6 in long resulting in a 3.63 m / 139.5 in overall payload dynamic envelope length. The LauncherOne payload dynamic envelope is the net volume available for the payload after accounting for the axial height of a payload separation system and the thickness of acoustic blankets lining the conical and ogive sections of the fairing inner wall. These blankets may be reduced or removed to increase the available volume for spacecraft that exceed this dynamic envelope and are compatible with the changes to acoustic and thermal environments as a result of this removal. Virgin Orbit can perform mission specific analysis to

**FIGURE 5/**  
PAYLOAD FAIRING  
DYNAMIC ENVELOPE



evaluate your specific mission needs and discuss possible payload accommodations for specific requirements. LauncherOne's standard payload adapter consists of composite forward and aft rings with a composite conical section, providing the mechanical interface between the launch vehicle and the payload stack. The baseline payload adapter interface is a standard 609.6 mm / 24.00 inch bolt pattern. Various interface bolt patterns are available, including those compatible with the ESPA and ESPA-Grande class configurations. The dimensions of the standard interface are provided in **FIGURE 6**.

**FIGURE 6/**  
PAYLOAD SEPARATION INTERFACE



## 2.5 SUPPORTED SEPARATION SYSTEMS

Virgin Orbit will assist the customer in selecting an appropriate separation/deployer system. LauncherOne is compatible with multiple spacecraft separation systems and CubeSat dispensers in order to offer maximum mission flexibility to our customers. Primary spacecraft typically interface with the LauncherOne payload adapter, described above, via an annular or discrete point separation system. CubeSat payloads typically use dispensers designed to the CubeSat design specification.

Supported annular payload separation systems include, but are not limited to: Planetary Systems Corporation (PSC) Motorized Lightband, RUAG PAS separation systems, and Sierra Nevada Corporation QwkSep Low Profile Separation System.

CubeSat dispensers are commercially available in various sizes to accommodate the common 1U, 2U, 3U, 6U, 12U, 16U, and 27U CubeSat configurations. These dispensers are usually capable of simultaneous or independent deployment of multiple CubeSats. Cubesat dispensers supported by LauncherOne include, but are not limited to: Cal-Poly P-POD, Tyvak Rail-POD, Nanosatellite Launch Adapter System (NLAS), Innovative Solutions in Space (ISIS) DuoPack and QuadPack, PSC Containerized Spacecraft Deployer, Xtenti FANTM RAIL, XPOD Separation System, Astrofein GmbH Picosatellite Launcher, and D-Orbit's DPOD.

Virgin Orbit will conduct analysis of tip off and other payload separation dynamics as necessary to ensure safe separation from the launch vehicle and meets your mission requirements. For multi-payload missions, LauncherOne ensures that the deployment sequence allows for adequate separation between all deployed payloads. Following the separation event, the second stage of LauncherOne will perform a Collision/Contamination Avoidance Maneuver (C/CAM), if necessary, in order to minimize contamination and limit the potential for re-contact with the deployed payload.



THE  
VIRGIN  
ORBIT  
LAUNCH  
SERVICE  
PROCESS



### 3 THE VIRGIN LAUNCH SERVICE PROCESS

Virgin Orbit's launch service includes mission planning, accommodation for spacecraft processing, payload-to-launch vehicle integration, delivery of the spacecraft to orbit, and post flight analysis. Mission integration activities ensure that customer requirements are met or exceeded and the mission is conducted in a safe, expeditious, and reliable manner. Typical schedule, documentation, and safety considerations are described in the following sections.

#### 3.1 LAUNCH SERVICE ELEMENTS

All launches are given the high level of service and attention to detail that distinguishes the Virgin brand. To better serve our customers, we offer optional services to further enhance your launch experience and/or accommodate your unique needs.

##### Standard Services:

- **Virgin Orbit Mission Manager:** Your concierge for a smooth spacecraft integration and launch.
- **Virgin Orbit Interface Control Document:** Ensures all of your mission requirements are documented and the launch service complies with your spacecraft needs.
- **Trajectory and Performance Analysis:** Ensures your payload is delivered to your mission orbit.
- **Coupled Loads Analysis:** Confirms that your spacecraft is compatible with the launch environment.
- **Separation Analysis:** Verifies accurate and low risk payload deployment.
- **Post-Launch Status Quick-Look:** Spacecraft state vector will be made available within 90 minutes after separation based on the L1 navigation solution at separation. A Quick-Look assessment of post-launch status from launch vehicle telemetry data, as well as a preliminary evaluation of mission success, will occur no later than 180 minutes after separation.
- **Post-Launch Evaluation Report:** A full report will be delivered within 60 days after launch, containing details of launch trajectory, events, and environments.
- **Export Compliance:** In the case of a non-U.S. Customer and/or Spacecraft Manufacturer, Virgin Orbit will obtain and manage a Technical Assistance Agreement (TAA) from the U.S. State Department.

##### Optional Services:

- **Payload Separation System:** Focus on your payload and let us handle the acquisition, delivery, and processing of the separation system to ensure readiness for integration.
- **Thermal Analysis:** Ensure thermal compatibility with sensitive areas of your payload and the launch environment.
- **Licensing:** Assistance with various standard licensing processes is available for customers unfamiliar with spacecraft regulatory compliance.

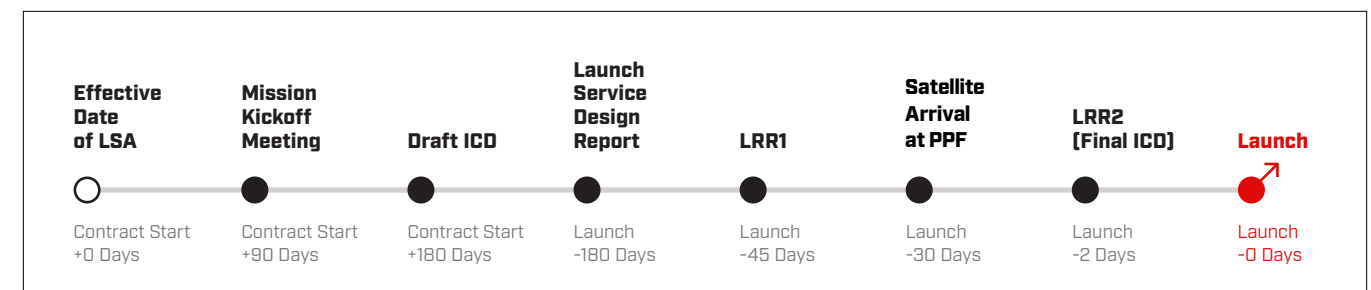
- **Spacecraft Review:** Peer review for spacecraft design, test, integration, and systems engineering is available from experts who have formerly worked on the relevant spacecraft systems.
- **Propellant Loading:** Assistance with logistics, processes, and procedures for on-site storage and handling is available for spacecraft propellant.
- **Security:** Localized and tailorable security is available, if desired.
- **Insurance:** Various pre-launch and launch insurance options are available through Virgin Orbit corporate partners.

#### 3.2 LAUNCH SERVICE SCHEDULE

Virgin Orbit's dedication to streamlining launch for small satellites includes emphasis on reducing time-to-launch. Virgin Orbit has instituted the corporate culture, processes, and supporting infrastructure to launch your payload as quickly and reliably as possible. For a standard engagement of a primary payload, payloads can launch in as little as 9 months from contract execution. Small secondary rideshare payloads can launch in 6 months or less from contract execution.

A top-level schedule for a complete launch service engagement is provided in **FIGURE 7**. The relative timing of milestones for each customer varies according to mission-specific requirements. Contractual launch service begins with signing a Launch Service Agreement and culminates in launch and delivery of a post-mission report. Each customer receives a Mission Manager as the primary point of contact and facilitator for all activities leading to launch. An Interface Control Document is jointly developed by Virgin Orbit and the customer to communicate requirements and ensure compatibility of the payload and the launch vehicle. Launch Readiness Reviews (LRR) are held to coordinate and assess overall readiness of the vehicle, payload, and facilities to provide a safe and successful launch. The outline schedule shown in **FIGURE 7** serves as the basis for a detailed schedule of all key technical milestones necessary for successful completion of the launch service.

**FIGURE 7/**  
NOMINAL SCHEDULE  
FOR LAUNCH SERVICE



#### 3.3 CUSTOMER RESPONSIBILITIES

As the spacecraft owner, the customer is responsible for providing documents to formally communicate the payload system description, mission requirements, safety data, and processing plans. This information facilitates coordination between the customer and Virgin Orbit ensuring smooth launch operations, and is used to satisfy FAA reporting requirements. Typical documentation requirements are as follows:

- **Responses to Payload Questionnaire:** Initial basic information about the payload and mission.
- **Inputs to the Launch Vehicle-to-Spacecraft ICD:** Spacecraft configuration, mission orbital parameters, mechanical and electrical interface definition, RF characteristics, ground operations needs, unique requirements, and other design considerations that encompass the overall mission.
- **Spacecraft mass properties and CAD model:** Mass, CG, and moments & products of inertia data, for Virgin Orbit to evaluate launch vehicle integration and flight dynamics.
- **ICD Verification Documentation:** Verification evidence indicating how each customer ICD requirement was verified (e.g. inspection, analysis, test, demonstration).
- **Finite Element Model:** Model to enable payload-to-launch vehicle Coupled Loads Analysis.
- **Payload Processing Plan:** Plan for payload processing and intended use of Virgin Orbit Payload Processing Facilities.
- **Safety Documentation:** Identification of hazardous materials and quantity of each; and identification of hazardous operations during payload processing.

The customer is ultimately responsible for obtaining licenses, permits, and approval from their national authority and any other necessary regulatory body (e.g. Federal Communications Commission, International Telecommunications Union, National Oceanic and Atmospheric Administration) prior to commencement of any launch integration activities. Virgin Orbit can provide assistance with regulatory needs, such as facilitating the submission of payload information to the FAA and providing information to the U.S. Government for space traffic management.

### 3.4 SAFETY AND MISSION ASSURANCE

Measures are in place to ensure safety of personnel and property throughout all aspects of payload processing, vehicle integration, and launch operations. Virgin Orbit strives to exceed the requirements of the Federal Aviation Administration (FAA), the Occupational Safety and Health Administration (OSHA), and other applicable regulatory agencies. Both a Safety Policy and formal Safety and Mission Assurance Process are in place to ensure risks and resulting hazards are methodically identified, and either eliminated or appropriately mitigated. Customer payloads and payload operations are responsible for compliance with these processes and requirements. Virgin Orbit can provide guidance regarding specific safety requirements. The entry point for communication of payload safety data is the payload questionnaire and it contains all questions needed for an FAA Launch License submittal. Virgin Orbit will review the payload documentation for compliance with applicable safety standards, and safety status is assessed during all readiness review meetings.



# PAYLOAD PROCESSING AND LAUNCH OPERATIONS

## 4 PAYLOAD PROCESSING AND LAUNCH OPERATIONS

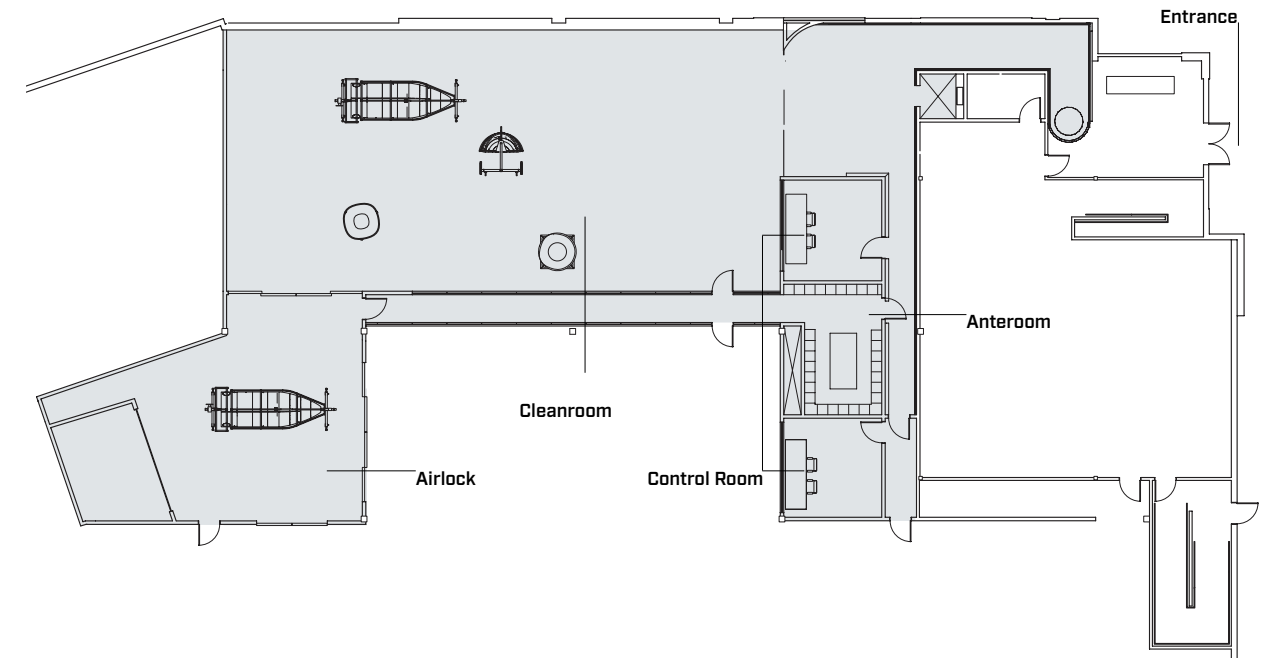
Payload integration and launch operations procedures are designed to minimize complexity, ensure system safety, and increase mission reliability. A typical processing flow is described in this section. Virgin Orbit is able to tailor standard payload processing and launch procedures to the customer's specific mission requirements.

### 4.1 PAYLOAD PROCESSING FACILITIES

Customers are welcome to test and process their satellite at Virgin Orbit's state of the art payload processing facility located in Long Beach, California. The facility includes an ISO 8 cleanroom, dedicated electrical control rooms, and conveniently located lounge style offices all under one roof. Baseline services and equipment available at the PPF include:

- Near LAX airport, a major hub serving worldwide destinations many with direct flights.
- Urban location provides simplified logistics for personnel and resource planning.
- The cleanroom is for customer spacecraft processing and fairing encapsulation and will be:
  - Certified ISO 8 cleanliness level (Class 100K)
  - Relative Humidity: 40-60%
  - Temperature: 63-77°F
- Electrical Control Room adjacent to the cleanroom for placing all electrical equipment for spacecraft testing or charging. There is a pass through between the control room and the cleanroom for electrical cables.
- Lounge style offices and conference rooms are provided with wi-fi, printer, copier, and fax machine.
- Power provided for customer electrical ground support equipment at 100V AC, 60 Hz and 230V AC, 50 Hz
- Uninterrupted Power Supplies (UPS), forklift, scissor lifts, rolling ladders, and small handheld tools
- Consumables including compressed air, helium, and nitrogen, isopropyl alcohol, lint free wipes, gloves.
- Virgin Orbit integration support personnel available up to six (6) days a week for twelve (12) hours a day, and optional 24/7 support
- Security is tailored for customer needs. Available security measures include electronic access IDs, 24-hour facility security guard, and closed circuit television.
- Accommodation for "green" propellant storage and loading. Possible propellant include cold gas, xenon/krypton, and various "green" propellants. Fully-fueled payload delivery will promote the most efficient integration process, but Virgin Orbit is able to address customer fueling requirements upon request. Fueling of hazardous propellants will occur at an external, Virgin Orbit procured processing facility.

**FIGURE 8/**  
LAYOUT OF PAYLOAD PROCESSING  
FACILITY IN LONG BEACH, CA



### 4.2 PAYLOAD TRANSPORT

After encapsulation the payload fairing module is secured within the Payload Transport and Integration Trailer. This purpose built mobile ISO Class 8 clean room is equipped to safely and efficiently transport the encapsulated payload to the spaceport site and integrate it to the launch vehicle. The internal environment is maintained at  $21 \pm 3.5$  °C (63-77°F) and humidity is controlled between 40% - 60% RH for the duration of the journey from Long Beach to the spaceport site and integration to the launch vehicle.

**FIGURE 9/**  
PAYLOAD TRANSPORT AND INTEGRATION TRAILER

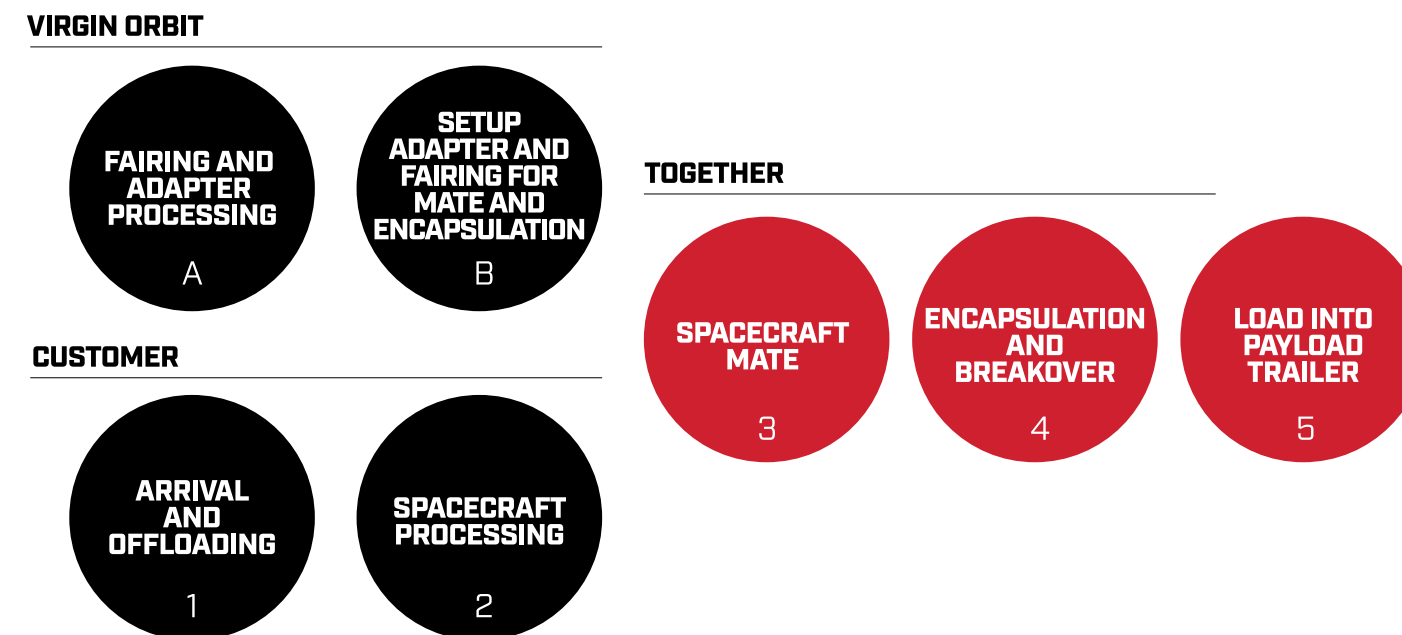


## 4.3 PAYLOAD PROCESSING FLOW

Virgin Orbit aims to make payload processing operations as smooth and efficient as possible for our customers by simplifying the integration process and offering as many essential resources as possible. Delivery of the payload is nominally planned for 30 days prior to launch, but this timeline can be reduced upon request. Additionally, options exist for encapsulation of the payload at customer facilities and storage in a flight-ready state for rapid “on-demand” launch. Typical procedural steps for payload processing for launches from Mojave Air and Spaceport or from any other CONUS (Contiguous United States) locations are as follows (for other spaceports, the payload processing facility remains the same but transportation from Long Beach to the spaceport will vary):

01. **Spacecraft Delivery to the PPF (Long Beach, California):** Virgin Orbit places the customer-crated hardware and associated ground checkout equipment into the designated work areas, and provides unpacking/packing support as needed.
02. **Spacecraft Standalone Processing and Final Preparation (Long Beach, California):** The customer completes independent verification of the spacecraft and makes final flight preparations such as solar panel cleaning and removal of covers/pins, supported as necessary by Virgin Orbit-supplied man lifts and other equipment in the PPF.
03. **Spacecraft Mate:** A joint operation to mate the customer spacecraft to the separation system and/or payload adapter.
04. **Fairing Encapsulation (vertical orientation) (Long Beach, California):** The integrated spacecraft and separation system on the payload attachment fitting is then encapsulated within the payload fairing. This encapsulated assembly is then reoriented to horizontal for transport.
05. **Transport to the Spaceport:** The encapsulated payload is transported in the Payload Transport and Integration Trailer to the spaceport. The trailer is equipped with an ISO 8 cleanroom with a climate controlled positive pressure environment during transport.
06. **Integration with the Launch Vehicle:** Virgin Orbit horizontally mates the encapsulated payload assembly to the launch vehicle.
07. **Late Payload Access:** While not part of the nominal launch process, it is possible to allow late access to the payload for mission-critical needs.

FIGURE 10/  
PAYLOAD PROCESSING FLOW



## 4.4 LAUNCH LOCATIONS

LauncherOne operates independently, and because we are not reliant on a government maintained launch range, we are unaffected by many of the external factors that can delay ground based launches from federal ranges such as weather, offline radar tracking assets, vehicles in the launch pad keep-out zone, and manifest jams on the increasingly crowded Eastern and Western ranges. The high-inclination launch site is the Mojave, California. The mid-inclination site is in Florida, and the low-inclination site is located in the Pacific Islands.

The baseline flight profile involves release of the LauncherOne launch vehicle over the Pacific Ocean, tens of kilometers from the California coastline, after a flight of approximately 30 minutes from Mojave. For low inclination launches, the drop point is optimally located based on the inclination desired for the mission. Due to the large range of the carrier aircraft and the flexible locations for spaceports, the drop point can be over 1000 km from the launch port.

## 4.5 LAUNCH OPERATIONS FLOW

For standard launch operations, launch occurs within three days after the delivery of the encapsulated payload to the spaceport. Key events in the launch schedule and typical timing relative to takeoff are as follows:

01. LauncherOne vehicle integration and checkout (L-4 days and earlier)
02. Payload mate to LauncherOne (L-3 days)
03. Launch Readiness Review (L-2 days)

04. Rollout and mate of LauncherOne with payload to carrier aircraft (L-2 days)
05. Propellant loading (T-6 hours to T-60 minutes)
06. 747 aircraft engine start and L1 GSE disconnect (T-30 minutes)
07. 747 aircraft take-off; LauncherOne purge provided to payload encapsulated environment by the carrier aircraft (T-30 minutes)
08. LauncherOne release and launch (T+0 minutes)
09. Second stage ignition (T+ 3 minutes)
10. Payload injection (Mission dependent, but approximately T+60 min)

# 5

## PAYLOAD ENVIRONMENTS

## 5 PAYLOAD ENVIRONMENTS

LauncherOne's payload environments are competitive with other similar launch vehicles throughout the flight profile, including ground segments, captive carry, and launch vehicle ascent. The predicted environmental conditions experienced by a typical payload are detailed in the following subsections. This payload environment data is provided for initial planning purposes only. Mission-specific analysis of expected payload environments is performed by Virgin Orbit as a standard service, and documented in the ICD.

### 5.1 VEHICLE COORDINATE SYSTEM

For interpretation of the quasi-static acceleration and random vibration environments relative to the LauncherOne payload orientation, the standard LauncherOne launch vehicle coordinate reference frame is provided in **FIGURE 11**. In this right-handed coordinate system, the positive X-axis is aligned with the launch vehicle longitudinal centerline. Roll is defined about the X-axis, pitch is about the Y-axis, and yaw is about the Z-axis. When in a horizontal, captive-carry configuration, the Z-axis is oriented inverse to the gravity vector and the Y-axis is parallel to the ground pointing out of the left side of the launch vehicle and carrier aircraft.

**FIGURE 11/**  
LAUNCH VEHICLE  
COORDINATE SYSTEM



### 5.2 PAYLOAD CONSTRAINTS

LauncherOne accommodates a wide range of payload masses up to 500 kg / 1100 lbm and can support a payload center of mass up to +/50mm laterally and 0.6m axially from the payload to launcher separation plane.

## 5.3 ACCELERATION FROM QUASI-STATIC LOADS

**TABLE 4** provides representative maximum predicted quasi-static limit loads for LauncherOne at the payload center of gravity. These are general quasi-static loads predictions for a single spacecraft with mass greater than 65kg. Predictions are further defined and verified by mission-specific Coupled Loads analysis. The values provided in the table bound the maximum acceleration for all phases of flight. As driving load cases are derived during aircraft operations, ultimate safety factors per FAR 25.303 should be applied (F.S. = 1.5).

**TABLE 4/**  
LAUNCHERONE PRIMARY PAYLOAD  
DESIGN LOAD FACTORS

Type	Axial [x]	Lateral [y, z]
Acceleration [g]	-3g / +7g	+/- 5g

**Note: Positive axial acceleration indicates compressive loads**

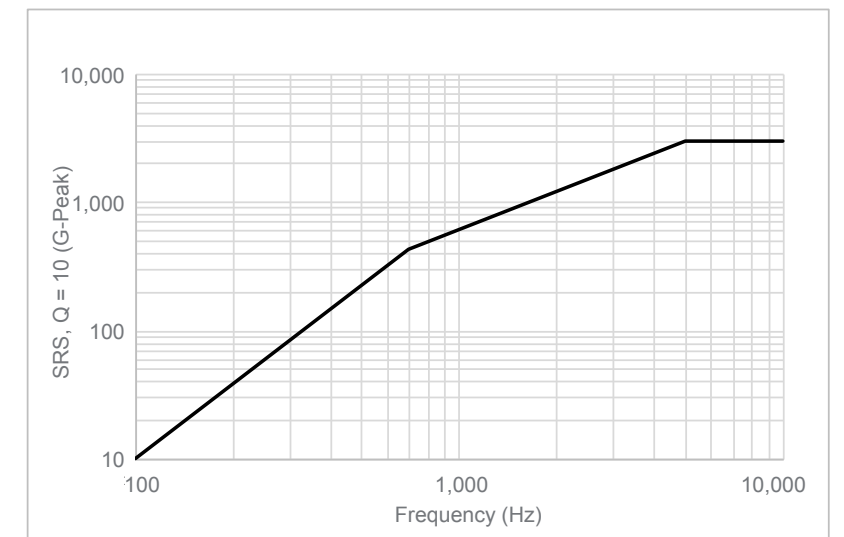
### 5.4 SHOCK ENVIRONMENT

The maximum predicted shock response spectrum at the standard payload-to-launcher interface from all launch vehicle events is shown below in **TABLE 5** and **FIGURE 12**. For mission unique adapters, this shock value will be recomputed at the specific interface of your spacecraft. In many cases, due to the addition of payload adapter structure, this value is lower.

**TABLE 5/**  
LAUNCHERONE DESIGN LOAD FACTORS  
AT THE STANDARD INTERFACE

Frequency [Hz]	LauncherOne Max Predicted Shock Environment [G-Peak]
100	10
700	430
5000	3000
10000	3000

**FIGURE 12/**  
MAXIMUM PREDICTED SHOCK ENVIRONMENT  
AT THE STANDARD PAYLOAD INTERFACE



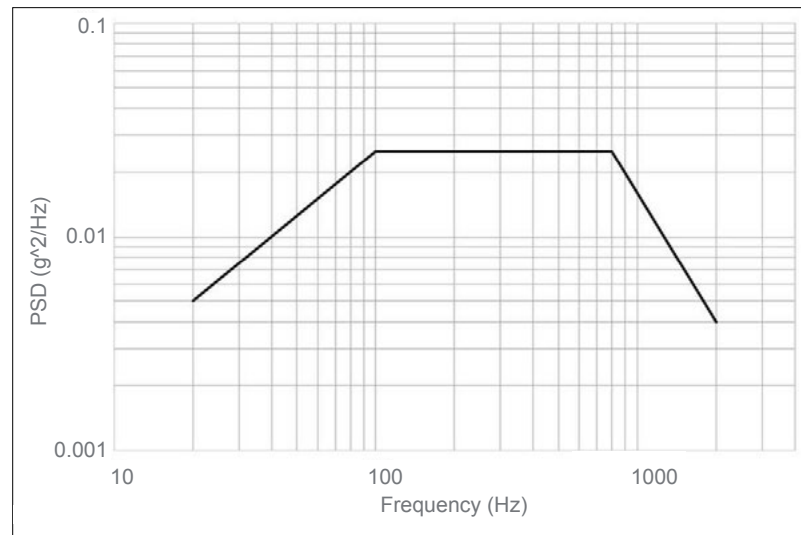
## 5.5 RANDOM VIBRATION

The LauncherOne primary payload predicted maximum random vibration environment in the axial and lateral direction, as measured at the standard 24" diameter interface, is shown below. For mission unique adapters, this environment will be recomputed at the particular interface of your spacecraft.

**TABLE 6/**  
LAUNCHERONE MAXIMUM PREDICTED  
RANDOM VIBRATION ENVIRONMENT AT  
THE STANDARD PAYLOAD

Frequency (Hz)	Power Spectral Density (PSD) (g <sup>2</sup> /Hz)
20	0.005
100	0.025
800	0.025
2000	0.004
<b>grms</b>	<b>5.5</b>

**FIGURE 13/**  
MAXIMUM PREDICTED RANDOM VIBRATION  
ENVIRONMENT AT THE STANDARD PAYLOAD  
INTERFACE



## 5.6 ACOUSTICS

The maximum predicted acoustic environment for a typical payload fill factor is defined in **TABLE 7** and **FIGURE 14**. For missions of very large or small fill factors, a mission unique acoustic analysis is performed.

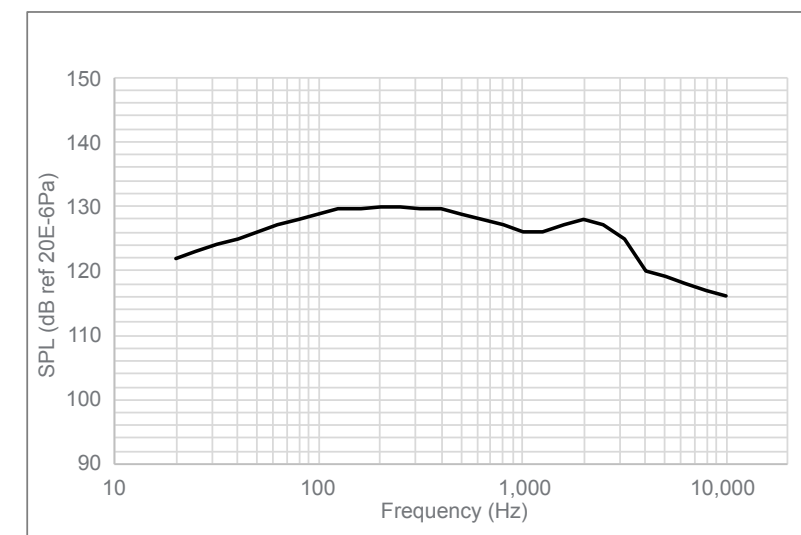
**TABLE 7/**  
MAXIMUM PREDICTED  
ACOUSTIC ENVIRONMENT

Frequency (Hz)	Sound Pressure Level (SPL) [dB, Reference: 2e-5 Pa]	Frequency (Hz)	Sound Pressure Level (SPL) [dB, Reference: 2e-5 Pa]
20	122.0	500	128.7
25	123.0	630	128.0
31.5	124.0	800	127.0
40	125.0	1,000	126.0
50	126.0	1,250	126.0
63	127.0	1,600	127.0
80	128.0	2,000	128.0
100	128.7	2,500	127.0
125	129.5	3,150	125.0
160	129.7	4,000	120.0
200	130.0	5,000	119.0
250	130.0	6,300	118.0
315	129.7	8,000	117.0
400	129.5	10,000	116.0

**Overall Sound Pressure Level (OASPL) = [dB RE: 20e-6 Pa]**

**Overall Sound Pressure Level (OASPL) = 141.40**

**FIGURE 14/**  
MAXIMUM PREDICTED  
ACOUSTIC ENVIRONMENT



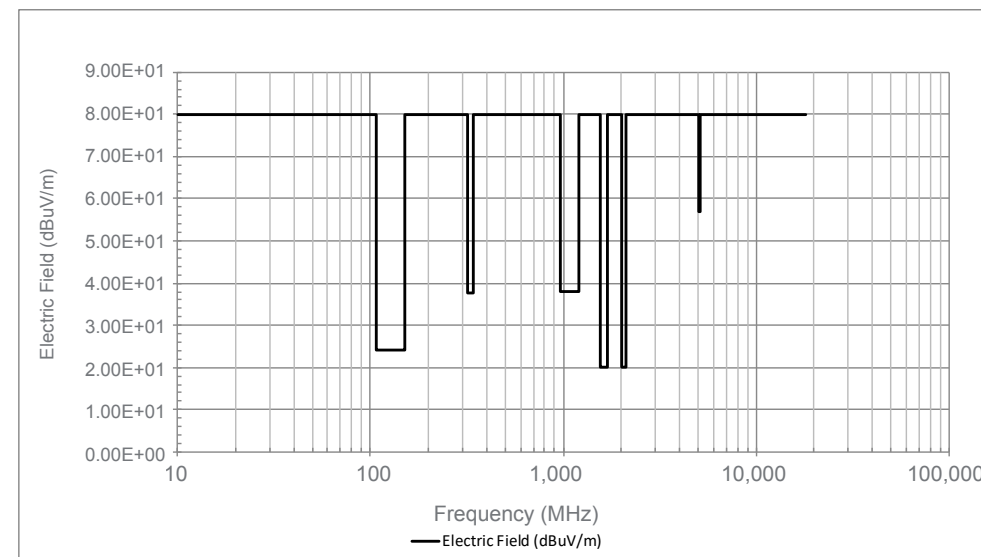
## 5.7 PAYLOAD RADIO FREQUENCY (RF) CONSTRAINTS

As with most modern launch vehicles, there is potential for electromagnetic interference (EMI) with launch vehicle avionics given the proximity of launch vehicle communications systems to the payload. Payload RF transmissions are permitted during captive carry, ascent, and shortly after separation but are subject to the results of an EMI/EMC compatibility analysis conducted by Virgin Orbit. Maximum permissible payload electric field emissions are defined in **TABLE 8** and **FIGURE 15**, and provided here as guidance for the customer.

**TABLE 8/**  
MAXIMUM SPACECRAFT  
ELECTRIC FIELD EMISSIONS

Frequency [RF susceptibility, MHz]	Electric Field [dBuV/m]	Frequency [MHz]	Electric Field [dBuV/m]
10	8.00E+01	1,559	8.00E+01
108	8.00E+01	1,559	2.00E+01
108	2.40E+01	1,680	2.00E+01
152	2.40E+01	1,680	8.00E+01
152	8.00E+01	2,015	8.00E+01
320	8.00E+01	2,015	2.00E+01
320	3.77E+01	2,120	2.00E+01
340	3.77E+01	2,120	8.00E+01
340	8.00E+01	5,020	8.00E+01
960	8.00E+01	5,020	5.68E+01
960	3.80E+01	5,100	5.68E+01
1,215	3.80E+01	5,100	8.00E+01
1,215	8.00E+01	18,000	8.00E+01

**FIGURE 15/**  
MAXIMUM ALLOWABLE SPACECRAFT  
ELECTRIC FIELD EMISSIONS



## 5.8 SPACECRAFT INTENTIONAL EMITTERS AND RECEIVERS

For spacecraft with intentional emitters (transmitters) and receivers: additional information must be provided if the user intends to transmit intentionally during any phase of processing/integration, Captive-Carry Flight, or Free-Flight. Following the guidance of FCC DA:13-445 "GUIDANCE ON OBTAINING LICENSES FOR SMALL SATELLITES" and the EELV-SIS; the collected information includes:

- Center frequency
- Peak Power
- Occupied bandwidth & datarate
- Modulation
- Emitter/signal Identifier (traceable to FCC Emissions Designator)
- Antenna gain characteristics
- ConOps Plan for Ground Test and Activation after Deployment

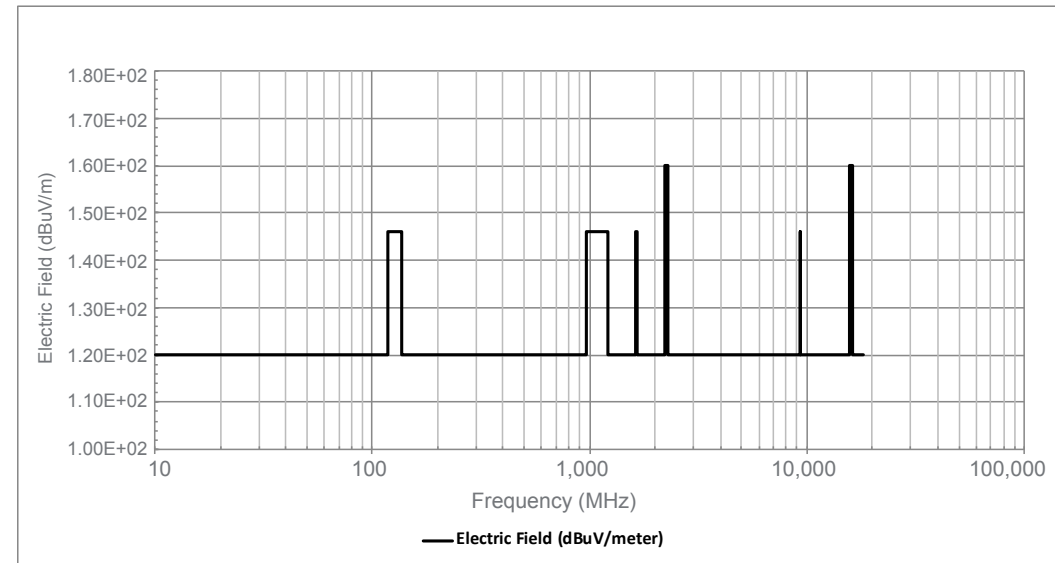
S/V Receiver list, including known in-band and out-of-band susceptibilities must be provided, if the User determines the equipment may be susceptible to damage by RF or DC/AC magnetic fields. This can be waived by the P/L User, however they assume full responsibility for malfunction or damage of S/V components.

**TABLE 9/**  
MAXIMUM LAUNCH/CARRIER VEHICLE  
ELECTRIC FIELD EMISSIONS

Frequency [RF Emissions, MHz]	Electric Field [dBuV/m]	Frequency [MHz]	Electric Field [dBuV/m]
10	1.20E+02	2,200	1.20E+02
118	1.20E+02	2,200	1.60E+02
118	1.46E+02	2,290	1.60E+02
137	1.46E+02	2,290	1.20E+02
137	1.20E+02	9,310	1.20E+02
960	1.20E+02	9,310	1.46E+02
960	1.46E+02	9,350	1.46E+02
1,215	1.46E+02	9,350	1.20E+02
1,215	1.20E+02	15,700	1.20E+02
1,637	1.20E+02	15,700	1.60E+02
1,637	1.46E+02	16,200	1.60E+02
1,642	1.46E+02	16,200	1.20E+02
1,647	1.46E+02	18,000	1.20E+02
1,647	1.20E+02		



**FIGURE 16/**  
**MAXIMUM ALLOWABLE LAUNCH VEHICLE/  
 CARRIER AIRCRAFT ELECTRIC FIELD EMISSIONS**



## 5.9 THERMAL AND HUMIDITY ENVIRONMENT

Once the customer payload arrives at the Virgin Orbit Payload Processing Facility, it will remain in a temperature and humidity controlled environment from the time the shipping container is opened through captive carry until drop. Upon arrival in Long Beach the payload will process in a cleanroom designed to maintain the following environment:

- Temperature: 63–77°F (17.22–25 °C)
- Relative Humidity: 40–60%
- ISO Class 8 (100k)

Post-encapsulation the Payload Fairing is transported to the spaceport in the Payload Transportation and Integration Trailer. Equipped with a cleanroom designed to maintain the following environment:

- Temperature: 63–77°F (17.22–25 °C)
- Relative Humidity: 40–60%
- ISO Class 8 (100k)

Once the payload fairing is mated to the launch vehicle filtered purge air will be provided to maintain the following bulk fairing environment:

- Temperature: 63–77°F (17.22–25 °C)
- Relative Humidity: ≤60%
- Supplied air consistent with ISO Class 8 (100K)

When the aircraft is ready for take-off the purge air will transition to filtered dry nitrogen gas from the aircraft. The gas will be supplied below an altitude of 10,000 ft. The nitrogen gas system will maintain the following bulk fairing environment:

- Temperature: 60 ±20 °F (15.5 ±11.1 °C)
- Relative Humidity: ≤60%
- Supplied gas consistent with ISO Class 8 (100K)

Above 10,000 ft. the nitrogen is turned off and the payload is supplied with filtered engine bleed air. The engine bleed air system will maintain the following bulk fairing environment:

- Temperature: 60 ±20 °F (15.5 ±11.1 °C)
- Relative Humidity: ≤60%
- Supplied air consistent with ISO Class 8 (100K)

Short outages of conditioned air may be required when changing configurations. At the customer's request, electrical power is provided to the payload during captive carry for internal spacecraft thermal control.

During powered flight and until fairing separation, the payload will be exposed to an equivalent radiative heat flux emanating from a 200 deg F surface with an emissivity of 0.9.

## 5.10 FAIRING PRESSURE ENVIRONMENT

During ascent, the maximum depressurization rate for LauncherOne is less than 2758 Pa/second (0.4 psi/second) from liftoff through immediately prior to fairing separation, except for a brief period during the transonic spike, in which there is a time-averaged decay rate that is no higher than 0.55 psi/sec for no more than 5 seconds.

## 5.11 SPACECRAFT QUALIFICATION AND COMPLIANCE

In order to validate the design requirement compliance and qualification of the spacecraft to the flight environments, verification documents detailing the test and analysis levels are mandatory to ensure spacecraft survivability on launch and overall mission success. Required design requirement verifications include (but are not limited to):

- Safety Factors
- Mass Properties
- Volume
- Structural Fundamental Frequency
- Dynamic Loads and Environments

Additionally, information regarding verification logic, safety & handling, and qualification/acceptance for interfaces and integrated system tests may be required.

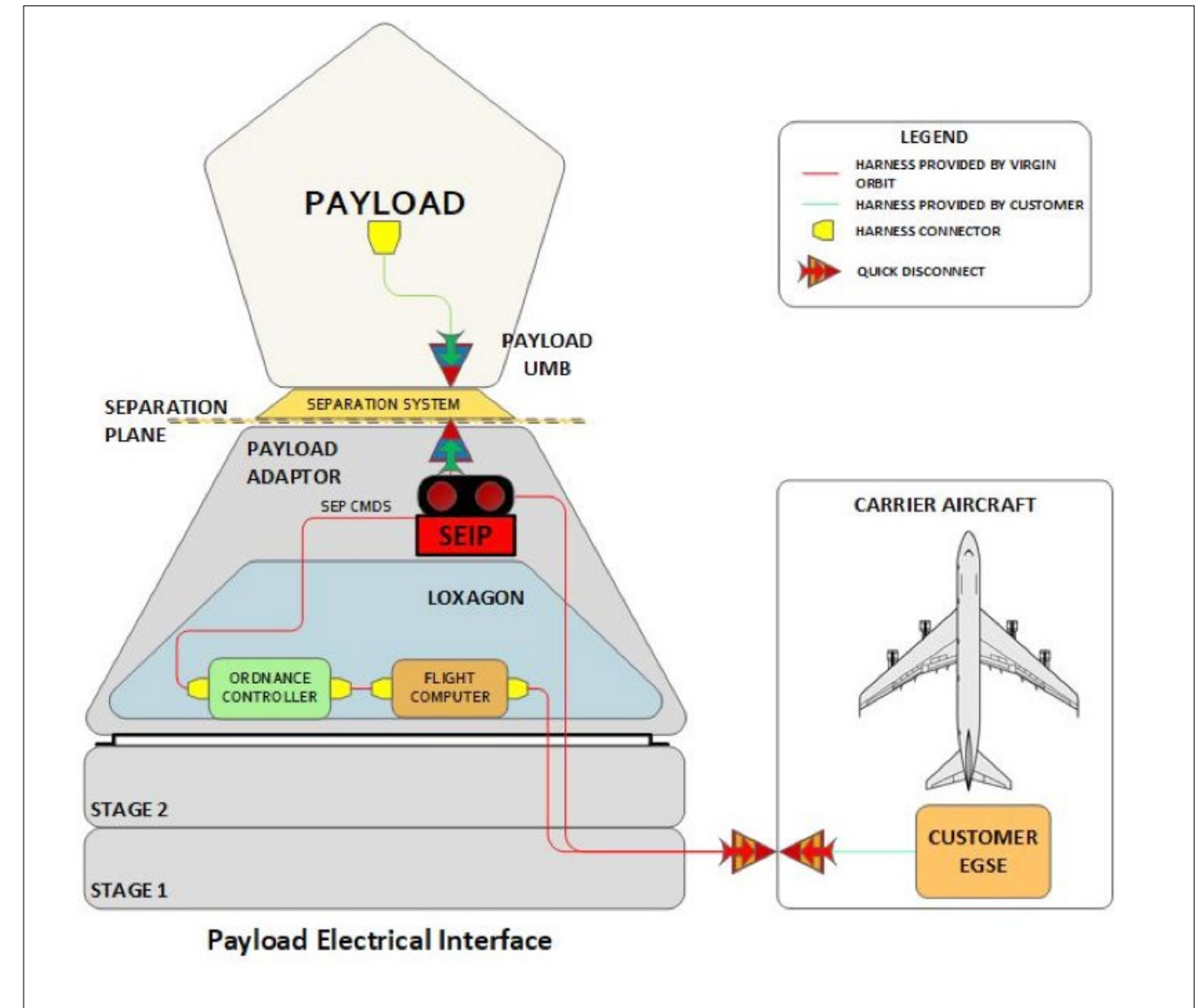
## 5.12 SEPARATION SYSTEM SIGNAL

For the standard launch vehicle-to-payload electrical interface scheme, the LauncherOne payload controller provides a primary and redundant separation signal directly to the payload separation system. The payload controller is capable of providing multiple signals enabling multi-spacecraft missions.

## 5.13 SPACECRAFT ELECTRICAL INTERFACE

At the customer's request, the payload adapter wire harness can include a spacecraft umbilical connector to provide a connection from the spacecraft to customer electrical ground support equipment (EGSE). This extra harness can be used to supply power and provide a data connection to the payload during storage and vehicle-level integration. These payload accommodations are defined in **TABLE 10**. The Payload Electrical Interface is shown below in **FIGURE 17**. Payload communication over 8 twisted pair wires to GSE can be supported to provide Command and Telemetry during ground processing at the customer's request.

**FIGURE 17/**  
PAYLOAD ELECTRICAL  
INTERFACE DIAGRAM



**TABLE 10/**  
PAYLOAD ELECTRICAL ACCOMMODATIONS

Description	Provision
Voltage	Harnessing capable of supporting 28 Vdc power +/- 4 Vdc up to 3A is provided during ground operations and captive carry. Additional amperage capacity can be made available upon request. Users who are unfamiliar with Section 19 of DO-160G should seek further guidance to ensure compatibility with Payload and Electrical Support Equipment electronics.
Electrical Bonding	The payload chassis is electrically bonded to L/V structure with no more than 200 milliohms, combined across multiple metal-to-metal and metal-to-composite joints. The carbon fiber composite layup has been evaluated and provides adequate charge-bleed path to prevent on-orbit charging of the Payload Adapter [PLA] and S/V structures for typical L1 mission designs. Alternative electrical bonding requirements shall be negotiated by electromechanical ICD for L/V-P/L interfaces."

## 5.14 SPACECRAFT SEPARATION SIGNALS

The standard interface to the payload, including separation is supported by a standard configuration of:

- Eight (8) Twisted Shielded Pairs 22 awg from the 747 Payload Interface Rack through the umbilical to the SEIP
- Eight (8) pairs of Double Twisted Shielded Separation Commands
- Eight (8) Breakwires from the launch vehicle to the payload for separation indication to the payload.
- Two (2) Breakwires from the payload to the launch vehicle for separation indication to the launch vehicle.
- One (1) Ethernet Communication line for payload use.
- One (1) RS-422 Communication line for payload use.

Modification for additional separation commands for standard ordnance separation commands is available.



ABOUT  
VIRGIN  
ORBIT

## 6 ABOUT VIRGIN ORBIT

Virgin Orbit is a United States company with corporate headquarters and production in Long Beach, California, and propulsion, test and launch operations facilities in nearby Mojave, California. A vertically integrated approach and the close proximity of engineering, manufacturing, and operations functions are our keys to the production of reliable, low-cost launch vehicles. In addition to launches originating from Mojave, LauncherOne is capable of operating from a variety of spaceports worldwide.

### 6.1 CORPORATE OVERVIEW

Virgin Orbit is part of the Galactic Ventures family, along with our sister companies Virgin Galactic and The Spaceship Company (TSC). With almost 500 dedicated employees, Virgin Orbit's exclusive focus is on the small satellite launch market. Virgin Orbit maintains separate manufacturing and test facilities from Virgin Galactic and TSC.

**FIGURE 18/**  
THE VIRGIN ORBIT FAMILY



## 6.2 LAUNCH VEHICLE PRODUCTION AND TEST FACILITIES

The Virgin Orbit headquarters is an 180,000 square foot / 16,700 square meter facility in Long Beach, California, housing office space and a large manufacturing floor. The vast majority of our design, engineering, manufacturing, integration, assembly, and test activities occur in this facility. The Virgin Orbit engineering team works directly adjacent to the LauncherOne production and assembly line featuring state-of-the-art manufacturing equipment and custom-built test rigs.

**FIGURE 19/**  
HEADQUARTERS IN LONG BEACH,  
CALIFORNIA FOR MANUFACTURING  
AND INTEGRATION



High-energy structure, and propulsion testing is performed near the Mojave Air and Space Port in Mojave, California. Liquid propulsion, composite tank, and overall stage testing is performed here at one of eight test stands. LauncherOne engine acceptance testing is supported by horizontal test stands, and completed stage tests are performed on the vertical tests stands.

**FIGURE 20/**  
LIQUID PROPULSION TEST SITE AND  
NEWTON 3 HOT FIRE TEST ON TEST  
STAND TWO



## 6.3 SPACEPORT FACILITIES

The high-inclination launch service location is the Mojave Air & Space Port (MHV), a spaceport licensed by the FAA for commercial horizontal launch operations of reusable vehicles, such as our 747 aircraft. Additional launch sites employ similar architecture. The mobile launch capability provided to LauncherOne eliminates the need for extensive infrastructure associated with ground launch. “Clean pad” operations are entirely mobile and involve only the Cosmic Girl carrier aircraft, with LauncherOne mated underwing, and ground support trailers.

Launch operations for all spaceports are managed from Virgin Orbit’s Long Beach control room. Launch operations are additionally supported by a launch engineer on console in the 747-400 and teams on console at the headquarters facility in Long Beach. Software operated by vehicle controllers in the control room receives telemetry and commands the launch vehicle, as well as ground systems aboard the ground support trailers as needed prior to separation from the 747 aircraft.

**FIGURE 21/**  
FULLY-INTEGRATED LAUNCHERONE  
VEHICLE



DOCUMENT  
REFERENCE

## 7.1 LIST OF ACRONYMS

CAD	Computer-Aided Design
CCAFS	Cape Canaveral Air Force Station
C/CAM	Collision/Contamination Avoidance Maneuver
CLA	Coupled Loads Analysis
EGSE	Electrical Ground Support Equipment
ESPA	EELV Secondary Payload Adapter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
GSE	Ground Support Equipment
ICD	Interface Control Document
LEO	Low Earth Orbit
LOX	Liquid Oxygen
LSA	Launch Services Agreement
MHV	Mojave Air and Space Port
N3	Newton 3 [1st stage engine]
N4	Newton 4 [2nd stage engine]
OSHA	Occupational Safety and Health Administration
PPF	Payload Processing Facility
PSC	Planetary Systems Corporation
PSD	Power Spectral Density
RAAN	Right Ascension of Ascending Node
RF	Radio Frequency
RP	Rocket Propellant
SLF	Shuttle Landing Facility
SSO	Sun-Synchronous Orbit

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# LAUNCHERONE SERVICE GUIDE

Virgin Orbit, LLC / Version 1.2 / July 2019

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