National Aeronautics and Space Administration

Commercial Lunar Payload Services (CLPS)

Payload User's Guide

ORBITBeyond

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Orbit Beyond, Inc. (OBI), an approved contractor under NASA's CLPS program, is committed to providing reliable, repeatable, and affordable delivery services to cislunar space, including the Moon's surface. OBI develops payload delivery platforms at a cost and scale that will enable rapid and sustained exploration of our celestial neighbor and beyond. OBI will manufacture and operate spacecraft on missions to the Moon, delivering commercial payloads and test artefacts to their destinations in cislunar space

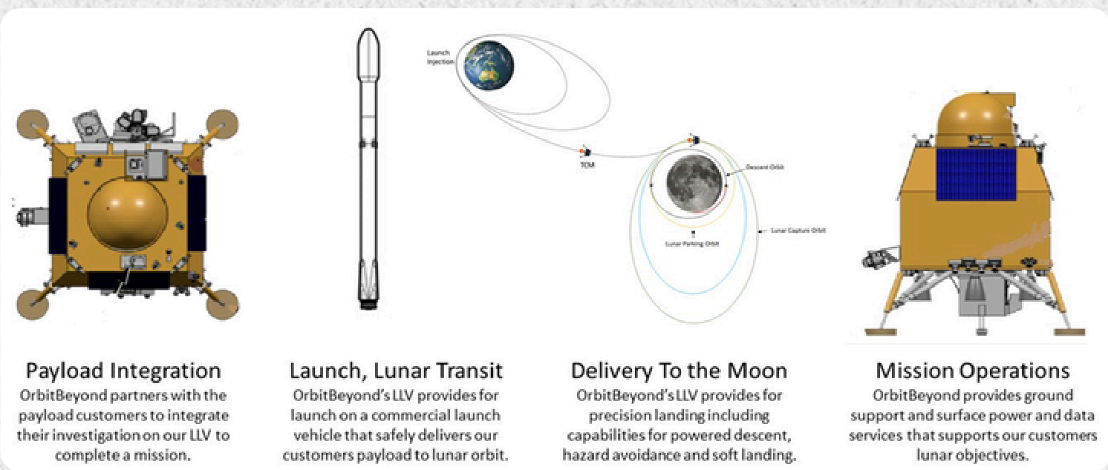
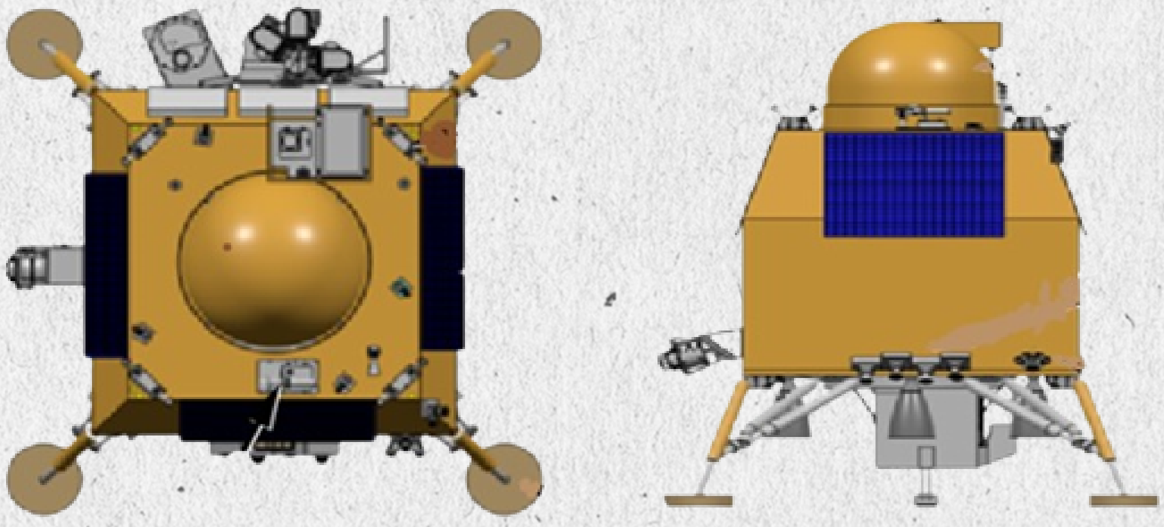


Figure 1: OBI Payload Services

At OBI, we bring in an innovative, next generation commercial model of space exploration backed by a strong System Engineering focus and efficient Program Management capabilities. Our core team consists of industry leaders who have cumulative experience of over many years in the space industry. This experience is augmented by engineers drawn from varied engineering disciplines, industries and global exposure. Each of our customers is provided comprehensive support from contract signature to end of mission through partnership with our experienced engineering team that provides all information required for our Lunar Landing Vehicle (LLV) payload integration, compatibility and operations to assure mission success.

OBI's commercial lunar payload services are based on an extensible lander platform that enables safe transport of scientific and technology payloads from Earth to the lunar surface, the operation of the payloads in the lunar environment, and the successful return of each payloads' data. OBI is accepting payloads to be delivered into lunar orbit or to the lunar surface. This document provides general information to payload developers about flight opportunities, interfaces, environment, flight support hardware, policies, and top-level processes for flying on board the OB1 LLV.

A. OBI Lunar Lander Vehicle (LLV)



- Spacecraft: OB1 Lunar Lander Vehicle (OB1 LLV)
- Payload Surface Delivery Capacity: 500kgs
- **Launch Vehicle:** Falcon-9, Dedicated-launch, 3600 kgs at launch
- **Injection:** Trans-Lunar Injection (TLI)
- **LLV Comm:** S-Band TTC 2/128Kbps and X-Band Payload Data Transmission 2Mbps/DTE/ Lunar Relay Satellite
- **Safety / Mission Assurance:** The LLV architecture is a dual chain single mode -fault tolerant for all vehicle critical systems ensuring mission success
- **Mission Control:** Mission Control Center at Merritt Island, Florida
- **Lunar Landing Sites:** Equatorial/South Polar Region /Far-Side
- **Landing Accuracy:** Within 50 meters of targeted landing site
- **Power Generation:** 650 W Peak during transit and 700W on surface
- **Power Available for Payloads:** 400W peak during Transit and 460W on the Surface.

A.1 LLV System Overview

The OB1 LLV consists of eight subsystems that enable safe payload delivery to lunar orbit and the lunar surface. These subsystems include structure, propulsion, guidance and navigation, power, avionics, communications and these subsystems are additionally supported by flight software and thermal control subsystems.

A.1.1 Structures

The main structure of the LLV consists of a central cylinder, three main decks, eight side panels, inside stiffener panels, landing gear (with shock absorber), launch vehicle interface ring, solar panel support structure, payload mounting support structure, and associated fasteners. The fuel and oxidizer tanks housed inside the central structural cylinder. Avionics, sensors, power systems and the batteries are on the middle deck. The communication antennas, along with other payload elements, are mounted on the top deck, bottom deck, and the outside panels. The Main Engines are at the bottom deck with a thrust frame with alignment provisions. The bottom deck also has a thermal shield to protect the vehicle from ME plume heating and plume-induced debris during landing.

The structure panels are manufactured of aluminum honeycomb core with carbon fiber reinforced plastic (CFRP) and aluminum face sheets. A standard Beyond Gravity Payload Adapter System (PAS) 1194 (47 inch) launch vehicle payload adapter and clamp band separation system interfaces to the 1575-mm (62.01 inch) diameter bolted interface on the Falcon 9. The structure has undergone structural analyses and meets or exceeds lateral and longitudinal fundamental frequency requirements of the launch vehicle.

The four-legged landing gear system is comprised of mission-proven hardware from the CH-3 Vikram lander with demonstrated performance that exceeds the landing conditions of the CP-22 mission profile. A set of crushable aluminum honeycomb footpads is used to dampen landing loads during touchdown. Crushable honeycomb is also used in the primary and secondary landing gear struts to mitigate any lateral loads and to accommodate any lunar surface irregularities at the chosen landing site.

The payload will primarily be housed on the top, bottom and the sides of the LLV, with a payload mounting interface to allow for flexibility with the mounting of the payloads. Overall, the LLV is rated to support up to 500kg of payload mass for safe delivery to the lunar surface.

A.1.2 Propulsion

OB1 LLV is powered by five ISRO-developed 800 N radiatively cooled, pressure-fed, deep-throttleable MEs. These engines are identical to those on Chandrayaan-3, with a maximum thrust of 800 N (180 lbf) at a nominal specific impulse (Isp) of 312s.The engine includes a high pressure drop injector with an integral solenoid valve. We use redundant stepper motor-controlled flow control valves (TFCVs) mounted upstream of engines for throttling as low as 45% of maximum thrust. The TFCVs are controlled using a Throttleable Engine Control Electronics Module (TECEM) that receives the signal from the On-Board Computer (OBC) and issues commands to the TFCVs. We provide separate solenoid operated flow control valves for oxidizer and fuel.

A.1.3 Guidance, Navigation and Control (GNC)

The Guidance, Navigation and Control (GNC) system processes sensor outputs to determine the vehicle's position, velocity and attitude during flight. This is especially important during landing, where quick decisions need to be made in order to secure a safe landing spot free of any obstacles that may hamper the mission. The LLV uses optical crater navigation for absolute position/attitude estimation. Inputs from the sun sensors, star trackers and inertial measurement units allow the GNC to determine the craft's orientation and position, which is important for solar power generation, thermal control and flight maneuvers. Earth based ranging is used to track the velocity and position of the craft. A GNC camera system and HDA LiDAR are used during the final descent to guide the lander to a safe location at the landing site.

A.1.4 EPS

The EPS uses a fault-tolerant Maximum Power Point Tracking (MPPT) EPS controller for power conditioning, regulation, and distribution. Up to 700 W of power is generated by three body-mounted solar arrays (SAs) using qualified quad-junction, surface mount technology (SMT), 4G32C cells. A battery using 16 of Saft's geostationary satellite-qualified VES-180 lithium-ion cells (100 A-hr. at 38.2 V with a deep 55% depth-of-discharge (DOD)) provides power storage. Power regulation is provided through a redundant 96.8% efficient gallium nitride (GaN) regulator to 28v ± 4v and distributed to three internally redundant power distribution units (PDUs), which distribute power to the vehicle systems and the payloads. LLV power generation capacity and the Power available to payloads is shown in table below.

Table 1: LLV Power Generation and Availability for Payloads

	Transit*1		Landing*2		Surface	
	Avg Power (W)	Peak Power (W)	Avg Power (W)	Peak Power (W)	Avg Power (W)	Peak Power (W)
Lander Subsystems	225	265	265	1908	206	206
Generated Power	747	747	-	-	650	750
Available power available for payloads	**522**	**482**	**-**	**-**	**444**	**544**

*1 - Calculated for current TLI mission design trajectory
*2 - Peak power supported by 100 A-hr. battery with less than 40% DOD, well within the allowable 55% DOD.

Out of 3 PDUs, two are for vehicle systems and one dedicated to payloads. Distribution of power is under the control of the EPS computer through a serial bus interface. Functional control of critical systems is controlled through a CAN bus serial interface from the OBCs. All power switching and distribution is through low, medium, and where necessary high current solid-state switches, with settable current limits with delays.

A.1.5 Avionics

The LLV Avionics subsystem includes the telemetry, tele-command, communication and tracking, (Section 2.1.j), GNC, and imagery subsystems. The LLV avionics architecture has redundancy in critical modules, providing a single point failure tolerance. The avionics subsystem has two computers managing all spacecraft functions: the OBC and crater navigation computer (CNC). The OBC manages flight-critical communications with GNC sensors, ME controllers, RCS thrusters, EPS subsystem, RF communications subsystem, cameras, and payload components. The OBC is responsible for fault detection, isolation, and recovery (FDIR). It maintains the real-time clock, handles sequencing commands, performs real time synchronization, controls the different components of the propulsion system, acquires payload telemetry data, and sends real-time telemetry to the RF radio. The Single Board Computer CNC manages optical navigation components, such as the navigation doppler LIDAR (NDL), hazard detection and avoidance cameras and crater navigation cameras. The CNC is responsible for the navigation algorithms of the Landing GNC, and Crater Navigation (CNav). It passes the resulting Selenocentric position data and hazard detection and avoidance (HDA) command information to the OBC to guide the LLV to a safe landing position. The OBC and the CNC have two internal processors. The primary processor controls the LLV. The redundant processor monitors the lander in hot-redundant mode. If a fault is detected, the watch-dog timer triggers, and the faulty element is isolated.

The LLV provides for 10 cameras, with a field of view of 83°. The landing system uses two cameras for CNav functions and two cameras for HDA imaging with two cameras providing navigation redundancy. Five cameras are mounted equidistant on the lander's edges about 3.2 m off the surface providing panoramic images of the horizon and the lunar sky. The remaining camera, mounted near the lander base, monitors the LV separation. Except for the four cameras used for navigation, **the orientation of the other six cameras can be tweaked to monitor the payloads deployment /operation if required.**

A.1.6 Communications and Tracking (C&T)

OBI's LLV communications and tracking (C&T) subsystem uses Direct to Earth (DTE) Telemetry, Tracking, and Command (TT&C) communications throughout the mission profile using S-Band. DTE X-Band downlink (D/L) is also used for higher bandwidth data downlink from the lunar surface using a steerable medium gain antenna to overcome multi-path losses due to low-Earth elevation. Flight heritage S-Band transponders and the X-Band transmitter ensure the highest confidence in C&T system performance.

- Payload Wired: Serial RS-422/Ethernet
- Data Link Protocol: CCSDS 732.0-B-3.
- Wireless connectivity requirements for payloads as per NASA's guidelines shall be provided on request.

For far side lunar missions and payload operations, OBI provides lunar orbiter satellites-based communication.

A.1.7 Thermal Control

Thermal control for the LLV is accomplished with both passive elements and active heaters to maintain all components and payloads within their operating and storage temperature limits. Spacecraft orientation during lunar transit cruise is passive thermal control (PTC), which uses a 3-revolution per hour rotation rate with the thrust axis (Z axis) perpendicular to the sun line. With this approach, all payloads are partially exposed to the Sun during lunar transit cruise. The thermal design is mission specific depending on the mission profile and desired lunar landing site. Thermal management is achieved by the following means.

- Multi-layer insulation (MLI) to protect the LLV and the Payloads from incident environmental heat fluxes.
- Radiators with surfaces to reject heat produced by on-board equipment and to reduce the absorption of external solar fluxes.
- Active electrical heaters (main and redundant) to maintain temperatures of LLV and Payload components (Active Heating)
- Looped heat pipes for dispersion of heat from components having high heat flux (Passive Cooling).

A.1.8 Flight Software (FSW)

The FSW can perform many top-level functions, each controlled autonomously at multiple scheduled or state-adaptive events or in response to MCC commands. Many sub-functions are performed by FSW across distinct Modes of operation from prelaunch through launch and spaceflight to surface operations. The FSW receives commands from the MCC and passes commands to various systems that are digitally linked. Time-Sync is sent to all payloads. The FSW re-scales full-resolution images into thumbnail versions. The FSW is supported by continuous command and data communications during transit and upon landing, LLV monitors the acceleration and angular velocity to detect any motion or shock events during lunar surface operations.

A.1.9 Imaging Systems

The LLV provides up to 10 cameras, with four being used in the precision landing systems. The imaging system of the LLV provides a full 360° view of the landing site. The edge of the lander to the horizon are covered by the imaging system.

A.2 Mission Profile

The LLV is designed for global access to the Lunar Surface, as well as supporting payload operations of both hard mounted and deployable payloads such as rovers.

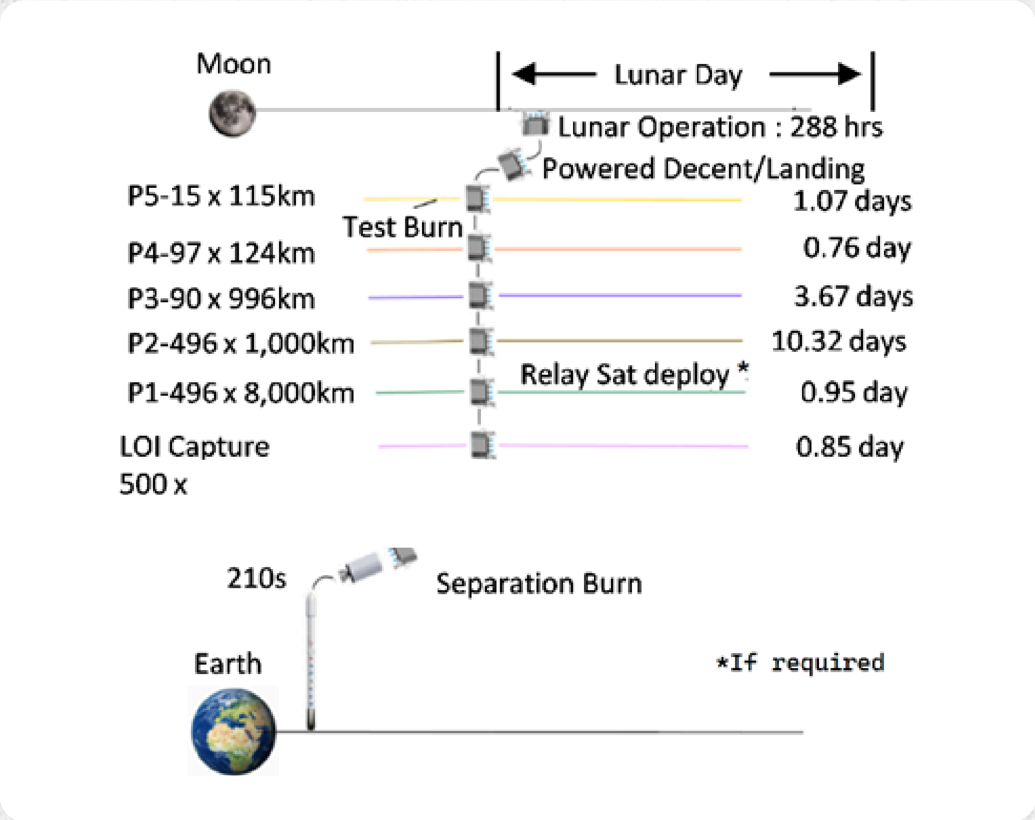


Figure 2: Example TLI Mission Trajectory

A.2.1 Trajectory/Mission Modes

OBI defines Mission Modes as follows:

- Mode 0: Post “LLV to Launch Vehicle” Integration
- Mode 1: Prelaunch (Day of Launch)
- Mode 2: Launch
- Mode 3: In-space Post Insertion
- Mode 4: In-space Operations
- Mode 5: Powered Decent Initiation/ Landing
- Mode 6: Post Landing, Safing & Surface Configuration
- Mode 7: Lunar Surface Operations
- Mode 8: Decommission/End of Mission Operations
- Mode 9: Safe Mode

A.2.2 Orbit Knowledge

OBI conducts regular Doppler shift measurements of the LLV throughout visibility periods and 2-way tone ranging over S-band at regular intervals to establish the orbit before planning a maneuver, as well as after completion of the maneuver to verify performance. 1-sigma uncertainty in states of the LLV in lunar orbits provided by OBI (up to separation of an orbital payload) shall be better than those defined in **Table 2.**

Table 2. Preliminary Orbit Determination

	Definitive	Propagated (10hr)
Position (RMS)	500 m	800 m
Velocity (RMS)	0.05 m/s	0.2 m/s

A.2.3 In-Orbit Attitude

Onboard attitude determination and control system (ADCS) provides 1-sigma performance at orbital separation of a payload in lunar orbit (Maximum epoch time-tag error of ≤ 2s) as defined in Table 3.

Table 3. Attitude Performance

	Knowledge	Control
Attitude	Better than +/- 0.01 degrees	Up to 0.2 degrees (all axes)
Attitude Rate	Better than +/- 0.01 degrees/sec	As low as 0.01 degrees/sec

A.2.4 Descent and Landing

The Powered Descent and Landing (PDL) will be controlled by the Landing GNC algorithms. State estimation, trajectory guidance, attitude and translation control through actuator commanding. Hazard Detection and Avoidance (HDA) software is integrated into the Flight Computer (FC), whereas the Crater Navigation (CNav) software runs on a separate high-performance CNav Computer (CNC).

Prior to the PDL initiation (PDI), a pre-deorbit checkout of the landing system (sensors, actuators and software) is performed, including execution of a 5-10 second main propulsion system (MPS) test burn under control of the Landing GNC. This validates performance and assesses system readiness. Afterwards the MCC uplinks the necessary command for committing the vehicle to PDI. From that point on, the lunar descent is autonomous. The PDI process begins before the perilune of the elliptical descent orbit once the starting point of the predetermined descent trajectory is made. Soft-touchdown will occur under 16 minutes to within 50 m of the predetermined touchdown point (100 m ellipse). Descent to touchdown includes the following four dedicated phases: powered descent, hazard avoidance, final approach, and landing. The LLV will provide lander position data with an accuracy of 30 m during descent.

During the final 300 m of the descent, HDA will be used for avoiding hazards larger than 30 cm and slopes exceeding 10°. The distance between landed LLV and any hazard will be larger than 3 meters. The HDA is based on Camera and LIDAR sensors for mapping and safe site selection. This HDA algorithm is hardware-accelerated, utilizing an FPGA and has been demonstrated safe site selection probability and confidence level of > 99% and 96.4%, respectively. Main navigation sensors are CNAv Cameras, IMU, Navigation Doppler LIDAR and short-range altimeter.

B. Payload Interface

The LLV provides a payload envelope that ensures safe stowage during flight and sufficient ground clearance upon landing for commercial payloads. Each payload accommodation will take into consideration its individual field of view (FOV), unobstructed surface access, and LLV interface to meet payload requirements. Payload locations are optimized specific to the mission profile and are located on the craft to both maximize the ease of integration and survivability during the lunar descent stage. The payload components are protected from any thruster and plume effects throughout the full mission duration. All payloads are mounted using standard aerospace fasteners, either to the primary structure or to a bracket.

B.1 Mechanical Interface

The OB1 LLV has a total payload capacity of 500kg. In addition to considering total mass capability, each payload will be assessed on a case-by-case basis to ensure the structural integrity of the lander and an appropriate overall mass distribution. Hard wired communication with the payloads is provided by OBI through an RS-422 interface.

Mounting locations are based on science objectives to ensure ideal locations for science data collection. All payloads shall be mounted above the plume plane(s) and protected from debris and thruster effects. Payloads are mounted via direct- or bracket-mounted interfaces to one of the three lander decks. OBI provides all mounting adaptors, isolators, fasteners, and brackets needed to mount payload components.

B.1.1 Payload Volumes and Mounting Locations

The LLV accommodates a wide range of payloads by providing a flexible mounting solution to accommodate payload pointing and mounting requirements. Payloads may choose from a variety of mounting locations depending on payload dimensions and mass. The LLV's three payload mounting decks support multiple payload accommodation zones. Each mounting deck is comprised of four structural honeycomb aluminum segments that we define as zones that can be configured for unique payload application and also provides separate zones for lunar environment interactive payloads and environmentally dissociated payloads ensured combined mission success.

B. Payload Interface

Alternate mounting locations, such as on the vertical enclosures or internal shear panels, are also available. External Payload accommodation options and volumes are given in Figure 3. Table 4 – provides accommodation volumes both internal and external. Figure 4 depicts the options for mounting of rover payload in stowed and deployment configuration.

Table 4- Payload Accommodation Volumes

Sl. No	Payload	Payload Dimensions
1	Top Deck	4 payloads of dimensions 1000x250x500mm each
2	Side Panel	1 payload of size 1150x1150x1150mm per side 2 payloads of size 900x900x900mm per side 3 payloads of size 600x600x600mm per side
3	Internal Payloads	4 payloads internally of size 850x850x550mm each

B. Payload Interface

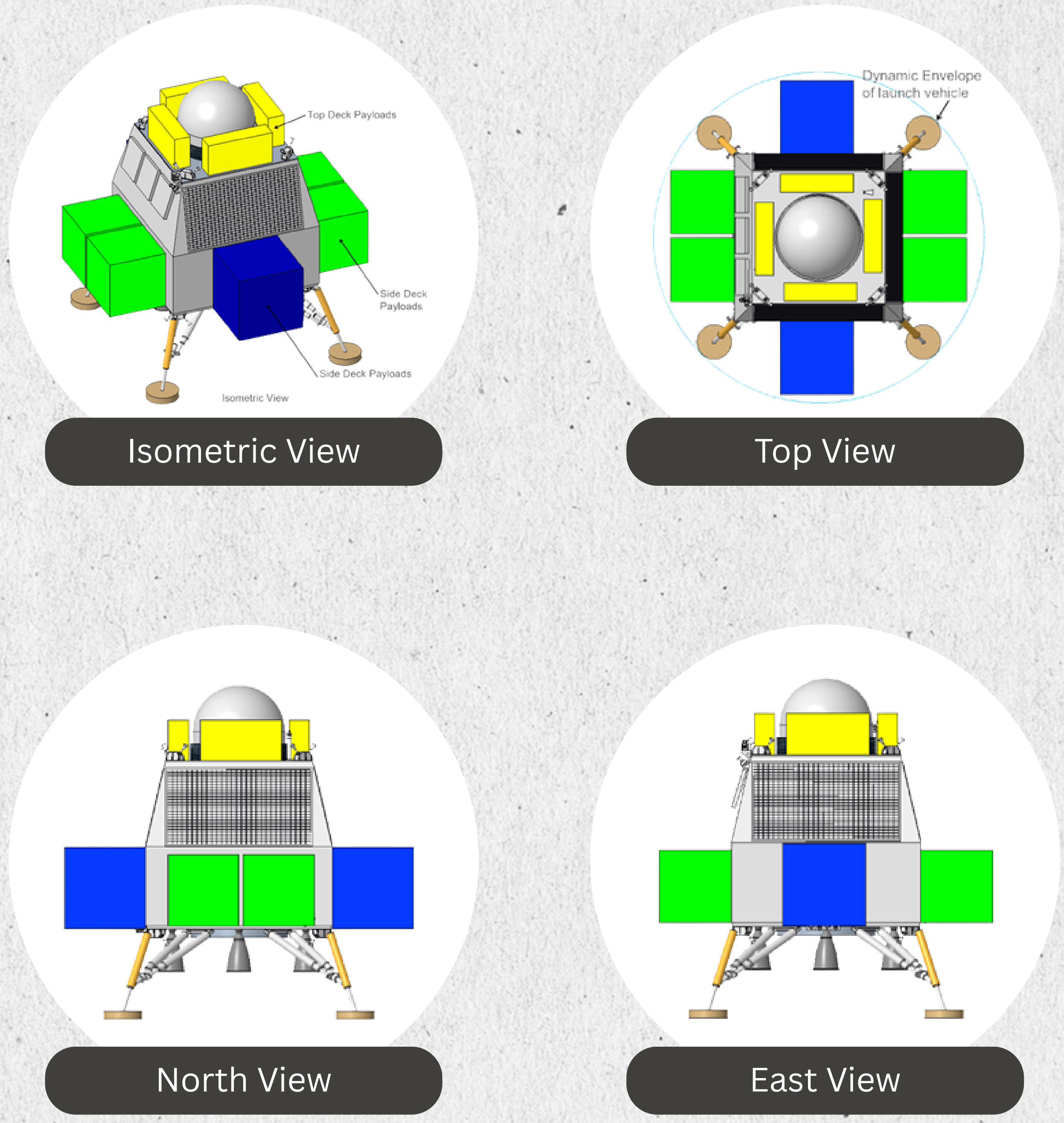


Figure 3- Payload Accommodation External

B. Payload Interface

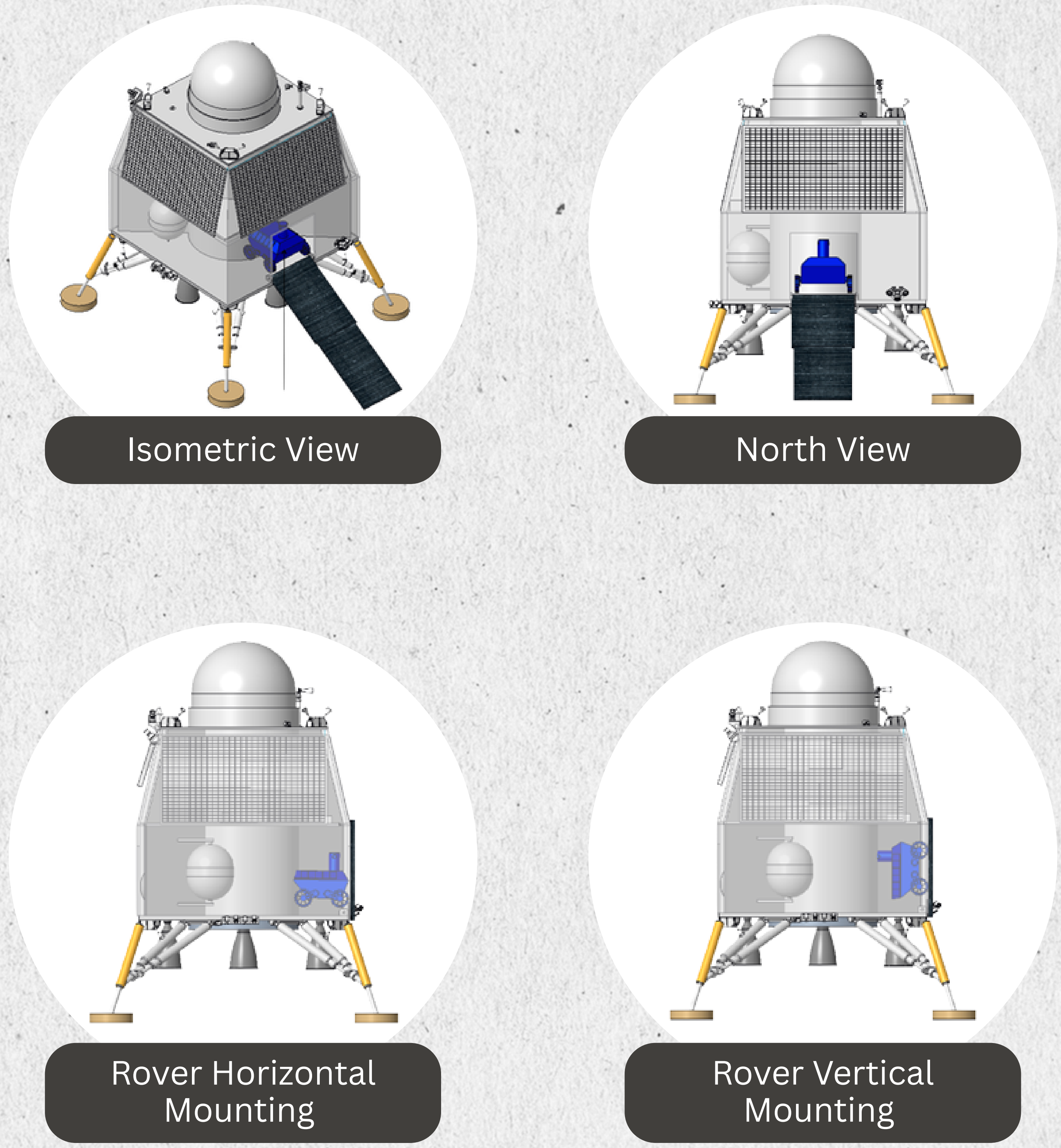


Figure 4- Payload-Rover Internal Accommodation Stowed and deployed

B.1.2 Payload Mounting Interface

All non-deployable payloads will be mounted directly to the lander panel using standard aerospace fasteners. If any out-of-plane orientation of the payload is required, the additional interface bracket (as part of the payload) is either to be provided by the payload customer, or OBI can be contracted to design and manufacture this hardware.

Mounting of deployable payloads may vary depending on the type and nature of the deployment mechanism/dispenser. As part of the integration process, the payload ICD, including number of fasteners and bolt pattern, will be verified for compatibility and mechanical strength.

B.*1.3 Release Mechanisms*

Due to the mission-critical nature of orbital payload deployments prior to landing, OBI recommends the use of the either Canisterized Satellite Dispenser (CSD) by RocketLab/Planetary Systems Corp/other NASA qualified dispenser suppliers, or Marmen band clamp/Frangibolt type of separation mechanisms. OBI shall coordinate the selection, procurement, testing, and integration of any release mechanisms most suitable for the payload design.

For lunar surface deployable payloads, OBI recommends the use of hold-down and release mechanism type devices, but the customer may select the device most suited to the payload design provided that it meets the following requirements.

- non-pyrotechnic (preferred)
- Creates minimal debris
- Imparts no shocks greater than specified below on the lander upon actuation. The actual shock level shall be finalized as part of detailed payload integration analysis.

housed within the payload unit (preferred).

Table 5:Payload Induced Shock level

Frequency Band (Hz)	Induced Shock (g) [Q=10]
1000	600

The LLV provides power lines and power release signal services to the release mechanism interface. The payload customer is responsible for integrating the release mechanism into their payload design such that it correctly interfaces with these provided services and employs the appropriate arm and fire techniques to satisfy Range Safety requirements.

B.2 Thermal Management

Thermal control for the LLV is accomplished with both passive elements and active heaters to maintain all components and payloads within their operating and storage temperature limits. If a payload generates excessive thermal energy by design or due to the science contained within and if additional thermal removal support from the LLV is required, the payload may leverage the looped heat pipe system of the LLV. The payload shall be designed to transfer heat via conduction via a hot/cold plate interface that will be provided to the exterior of the payload. The payload shall provide a mounting location where a cold sink is to be mounted to conduct thermal energy away from the payload. OBI will provide the cold sink and necessary heat pipe circuitry to interface with the payload's hot interface.

B.3 Power and Data Interface

Power is provided to the payload via an 8 pin Amphenol D38999/26FC8PN connector (typical). Payload telemetry transmission and receive will be via RS422 interfaces and connectivity shall be provided via a 22 pin Amphenol D38999/20FC35SN connector which provides enough contacts for two separate RS422 channel sets as well as channels for thermocouples readings to be relayed back to fight computer as well as payload integrated heater control that is to be controlled via the flight computer.

Payloads are allocated two power circuits as a standard service. One circuit can be used for the instruments and the other power circuit can be used to perform deployments or actuations within the payload. The power provided is 28 ± 4 Vdc and the power circuits are current-limited, current-monitored, current spike protected, and over-voltage-protected.

B. Payload Interface

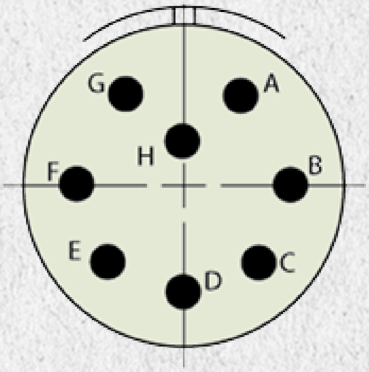


Figure 6: Power Connector Pin Definition

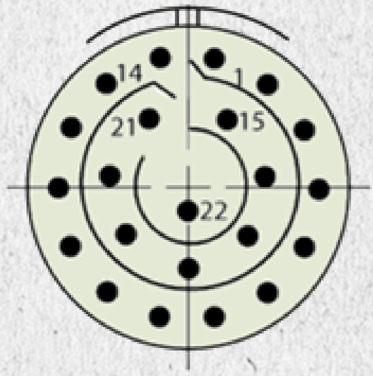


Figure 5: Data Connector Pin Definition

Table 6: Power Connector

Channel	Pin
Power Channel 1	A
	B
Power Channel 2	E
	F
Not Assigned	C, D, G, H

Table 7: Data Connector

Channel	Pin
RS-422 Channel 1	1
	2
RS-422 Channel 2	3
	4
Thermocouple Channel 1	5
	6
Thermocouple Channel 2	7
	8
Internal Payload Heater 1 Activation	9
	10
Internal Payload Heater 2 Activation	11
	12
Not Assigned	13 – 22

Nominal power services are provided throughout all phases of the mission except Launch. The power (release) signal services are available only during the Lunar Orbit phase for orbital deployment payloads and during the Surface phase for surface deployment payloads. No power services are provided during spacecraft maneuvers or emergency procedures. Power services are available only while the payload is attached to the lander. Deployable payloads take full control of their own power generation and consumption following release from the lander.

Table 1 shows power that can be supplied continuously or in a duty cycle manner to the payload complement from Earth orbit through lunar surface operation completion. The power listed for each mission phase is the total available to be divided among the payloads.

The LLV operates with one common ground with a standard star grounding configuration. Payloads must conform to this approach by employing proper grounding, bonding, and isolation schemes within their own payload design and by providing contact points for the payload structural and conductive elements as well as internal electrical circuit common ground, OBI will provide grounding straps as specified.

B.4 Data Interface

OBI uses standard data interfaces to simplify payload integration. Wired data services are provided through a bus network utilizing RS422 protocol. Therefore, wired data services are available only while the payload is attached to the lander. OBI will provide wifi interface if required for payloads after deployment from lander.

B. Payload Interface

Network Protocols - Payloads can use four networking protocols to interface with the lander. Surface deployable payloads are recommended to select wired data interface from below for communications prior to deployment from the lander in addition to the wireless data interface after deployment. Additional Digital and Analog IO interfaces shall be made available upon specific need.

- SpaceWire high-speed wired communication (LLV Hardware and Not for Payloads)
- Serial RS-422 with a minimum baud rate of 115.2 kilobits per second (kbps).
- Ethernet high-speed wired communication using TCP/IP.

Wireless communication after deployment shall be in accordance with NASA's guidelines (S/UHF Band)

Ground Stations - Ground station network (KSAT Lunar Network—Inuvik (13 m antenna), Kourou (15 m antenna), and the Byalalu (18.3 m and 32 m antennas), Goonhilly (32 m antenna) collectively supports near continuous visibility during transit, LLO mission phases. This network also provides near continuous visibility for landing sites in the near side of the moon. For landing sites in the far side OBI shall provide the Comm link to Earth through an orbiter relay. Additional ground stations shall be added to Ground network for specific payload data requirements including near- real time communication needs such as Rover operations.

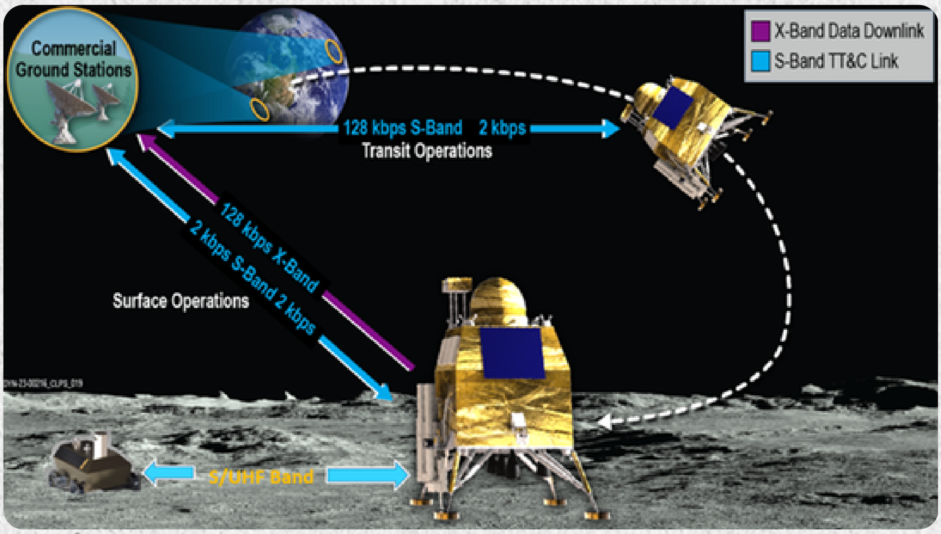


Figure 7:LLV-RF Communication links

Ground stations also support the two-way ranging and doppler shift measurements and periodically synchronize the LLV's internal clock. One-way latency in the connection between the customer and their payload on the Moon is nominally less than 4 seconds, although increases in latency may occur during unique mission events.

Onboard Storage - OBI will make use of the available onboard data storage to manage lander data as well as antenna time for downlink of payload data. There will be two modes for payload data downlink: (a) real-time, and (b) retrieval of stored data from onboard memory. Payload data will be captured as a sequence of compressed files, with encryption. Payload data will be returned to the ground via the CCSDS File Delivery Protocol (CFDP) over the telemetry, if the data rate required is 128kbps during transit and less than 2kbos on the surface. OBI will provide X band data transmission at 2 Mbps from the nearside DTE using Dual Gimbal medium gain antenna, or using a lunar orbiter relay satellite from the far side of the moon. Timestamping – The LLV provides a time-at-the-tone time synchronization signal with an accuracy of 125 milliseconds to payload customers. The Time Synchronization packet will be a CCSDS packet with a Primary Header (48 bits) and a Secondary Header (64 bits).

Encryption – The LLV implements CCSDS Space Data Link layering for framing, encryption, virtual channels, etc. Encryption is applied to stored and transmitted data.

User Access to Payload Data - OBI provides access to a representative for each payload to support the duration of that payload's operation, either at the MCC or remote POC site. In addition to data access provided via our network, all relevant data are shared with each payload team via recommended CCSDS File Delivery Protocol (CFDP).

B.5 Lander Emulator

OBI provides payload development teams with a LLV emulator at least 10-months prior to the required delivery of each payload to allow for verification of interface/software during payload development. The LLV emulator is comprised of an all-software simulation of the vehicle. The simulation environment can be configured for each phase of the mission. Real I/O communication interfaces will be available to interface with the payload system.

B.*6 Payload Emulator*

Interfacing with each payload system will be an important part of avionics integration testing and mission operations testing. This testing will be performed in the Vehicle Avionics Integration Lab (VAIL). If real payload hardware is available in time for this integration, payload emulator system from payload team can be used.

B.7 Payload Environments

The following environments are based on the SpaceX Falcon 9 (reference latest versions of the Falcon 9 Payload User's Guide) as the mission reference launch vehicle (OB1 LLV is compatible with other launch vehicles such as Blue Origin's New Glenn).

Payload customers are expected to qualify their payloads to the levels specified in this section. Appropriate exceptions shall be communicated to OBI by payload team for evaluation and approval. In the case of any conflicts or ambiguities in individual criteria, the mutually agreed more stringent standard shall be adopted.

OBI will use NASA 7002B standard testing in excess of any expected mission operations limits by varying safety factors. This mission envelope is determined by the launch and landing profiles and guides the test definition. The shock, vibration, and acoustic loads are driven by the launch environment, which are defined in the appropriate launch vehicle user's guide.

B.7.1 Environmental Compatibility Verification

Prior to launch, OBI requires that payload customers verify the compatibility of their systems with the LLV's maximum expected flight environments. OBI initiates this process by providing the applicable environments. The payload customer then summarizes its approach to environmental compatibility verification, and the process concludes with the customer providing test data to OBI. *Table 8* summarizes the typical verification activities performed by the customer and provides test levels. Mission-unique limit levels and coupled loads analysis levels will be developed during the payload integration process and will serve as the basis for the verification activities. Alternate verification approaches may be acceptable, but coordination with OBI is required.

Table 8: Payload Environmental Compatibility Verification

Environment	Verification Activities and Test Levels
Quasi-Static Loads (Section 4.2.1)	• Qualification: Limit levels x 1.25 • Proto-qualification: Limit levels x 1.25, acceptance duration. • Acceptance: Limit levels x 1.0
Sine Vibration (Section 4.2.2)	• Qualification: Limit levels x 1.25, two octave/minute sweep rate. • Proto-qualification: Limit levels x 1.25, four/two octave/minute sweep rate. • Acceptance: Limit levels x 1.0, four octave/minute sweep rate
Acoustic, Shock, and Random Vibration (Sections 4.2.3-4.2.5)	• Payload customers will provide details and justification showing compatibility of payload hardware to acoustic, shock, and random vibration environments presented herein. • OBI uses the following standards as references when developing spacecraft/component test campaigns: GEVS (GSFC-STD-7000), SMC-S-016, or NASA-STD-7001A. • Test campaigns that do not align with methodologies presented in the above standards should have sufficient accompanying justification.
Electromagnetic (Section 4.6)	• OBI standard service includes an electromagnetic compatibility assessment. • Payload customers will provide for electromagnetic interference/compatibility testing to be conducted for RF-sensitive payloads and may request insight into relevant testing performed.
Pressure (Section 4.4)	• OBI recommends venting analyses be conducted and may request insight into relevant analyses performed.
Thermal (Section 4.3)	• OBI recommends thermal cycle and thermal vacuum testing be conducted and may request insight into relevant testing performed.

B.8 Mechanical Environment

The OB1 LLV and its integrated payloads will encounter the highest level of mechanical stresses during launch. As such the mechanical environment is given in the appropriate launch vehicles user guides. Vibrational and quasi-static loads created by any payloads during operations will be included in the mounting analysis to determine the reactions and any effects to other payloads and lander components. OBI provides a standard accommodation for a mounting location that is designed to support a payload for an anticipated (based on past missions) drilling force and so that torques on the lander are within acceptable limits. OBI offers this analysis support if required by payload team to select the best interface for payload components to limit negative interactions with other components.

The following environments envelope over 90% of the payload mounting locations on the LLV. Final mission payload compliment and payload attachment requirements may impact expected loads. OBI works with our payload customers to develop payload specific environments for relevant testing and analysis prior to integration. Loads.

During flight, the payload will experience a range of axial and lateral accelerations. OBI performs a coupled loads analysis with the launch vehicle provider and develops sine vibration.

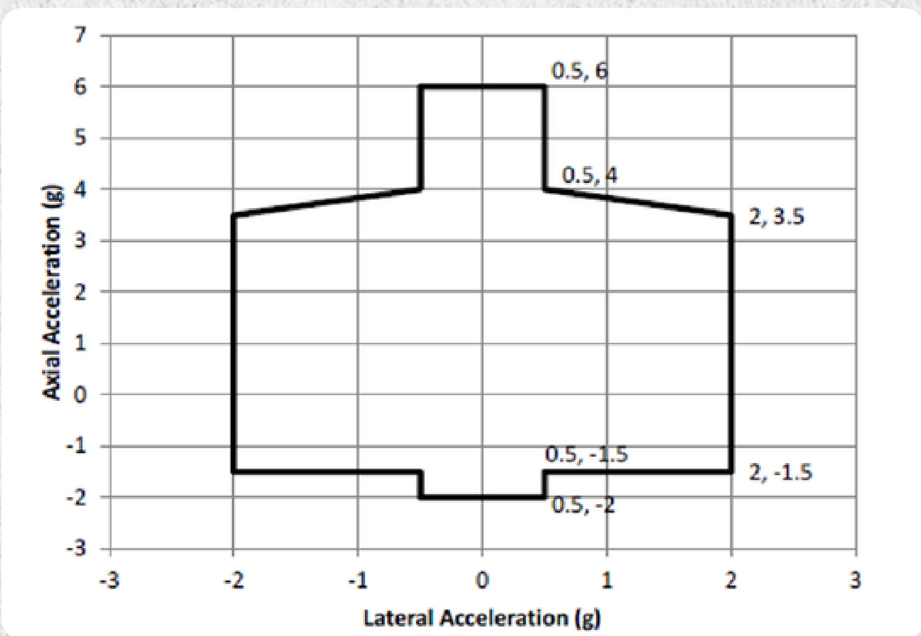


Figure 8: Design Load Factors

Axial acceleration is determined by the vehicle thrust history and drag, while maximum lateral acceleration is primarily determined by wind gusts, engine gimbal maneuvers, first stage engine shutdowns, and other short-duration events. Falcon 9 Design Load Factors are shown using the envelope plotted in *Figure 9 and Figure 10*. This is the maximum range of axial and lateral accelerations.

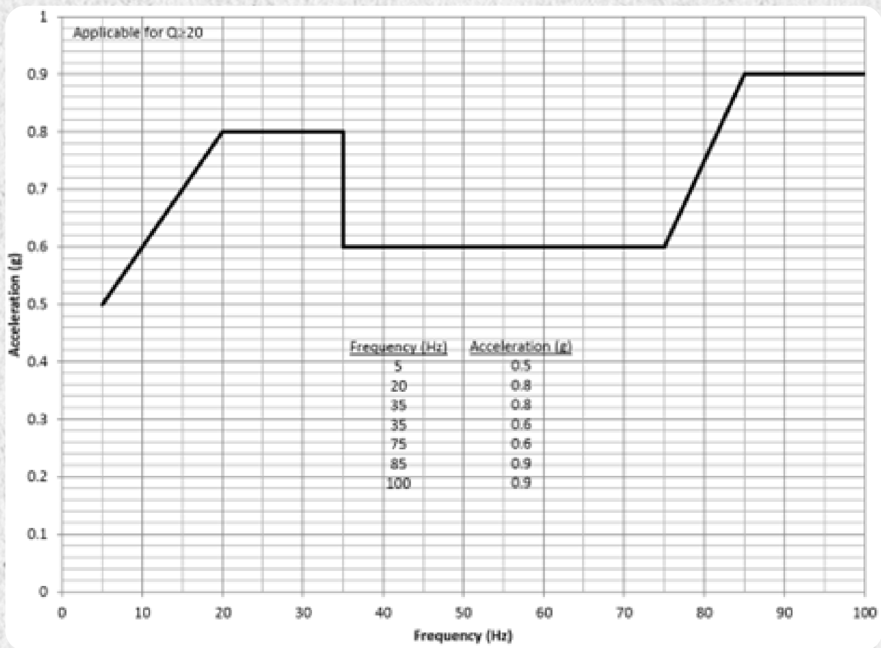


Figure 9: Axial Equivalent Sine Environment for Falcon 9

The design load factors provided here are expected to be conservative for the integrated LLV (lander plus all mission payloads) with the following basic characteristics: a fundamental bending mode greater than 10 Hz, a fundamental axial mode greater than 25 Hz, and all secondary structure minimum resonant frequencies above 35 Hz. A positive axial value indicates a compressive net-center of gravity acceleration, while a negative value indicates tension. Actual spacecraft loads, accelerations, and deflections are a function of both the launch vehicle and integrated LLV structural dynamic properties and can only be accurately determined via a coupled loads analysis

B.8.1 Sine Vibration

Maximum predicted sinusoidal vibration environments represent the levels at the top of the SpaceX Falcon 9 payload attach fitting for Q=20 through Q=50, and envelope all stages of flight. Maximum predicted sinusoidal vibration environments for Falcon 9 are shown in *Figure 9 and Figure 10*. These environments represent the vibration levels at the top of the LLV attach fitting for Q=20 through Q=50, and envelope all stages of flight. Coupled load analysis will be used to modify these levels, if necessary, to reflect the levels at the LLV interface.

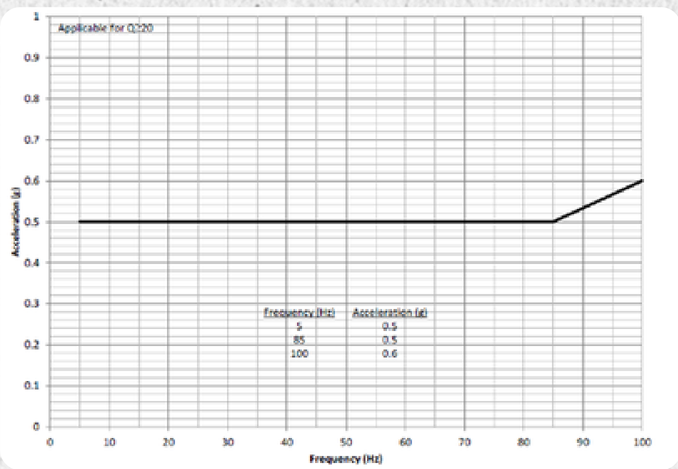


Figure 10: Lateral Equivalent Sine Environment for Falcon 9

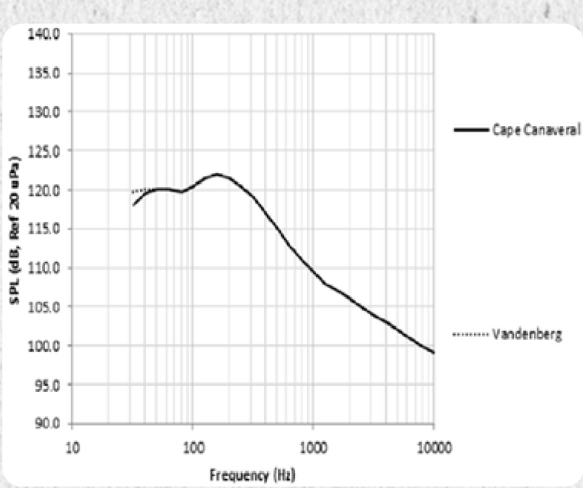


Figure 11: Payload Acoustic Maximum Predicted Environments (Full Octave)

B.8.2 Acoustic

During flight on the SpaceX Falcon 9, the integrated LLV will be subjected to a varying acoustic environment. Levels are highest at lift off and during transonic flight, due to aerodynamic excitation. *Figure 11* shows the maximum predicted acoustic environment.

B.8.3 Shock

The OB1 LLV encounters four shock events during its ride on the SpaceX Falcon 9 flight that are characterized as shock loads:

1. Vehicle hold-down release at lift-off
2. 2nd stage separation
3. Fairing separation
4. Integrated LLV release and separation

Of the shock events, (1) and (2) are negligible for the payload relative to (3) and (4) due to the large distance and number of joints over which shocks (1) and (2) will travel and dissipate. Maximum shock loading (3) and (4) is measured and scaled for various preloads required for the payload fairing and integrated LLV separation systems. The resulting maximum shock environment predicted at Lander interface for fairing separation and lander separation (for a 937-mm clamp band separation system) is shown in derived at the P95/50 statistical level. Actual shock from the integrated LLV-specific separation system requires a final analysis of the LLV and its associated payload (total mission compliment) mass properties.

Table 9: Expected Shock Environment

Frequency (Hz)	SRS (g)
100	30
1000	1000

B.8.4 Random Vibration

The Random vibration loads for payload are derived from the LLV structure due to the acoustic environment. The maximum predicted random vibration environment at the LLV interface will be at the top of the SpaceX Falcon 9 Payload Attach Fitting (PAF) as shown in Figure 9. This environment is derived from flight data measured at the top of the PAF and does not account for any additional attenuation as the vibration traverses the mission specific payload adapter or spacecraft interface. The smooth line is an envelope of all flight events (liftoff, Stage 1 ascent, and S2 burns) and is derived at a P95/50 statistical level.

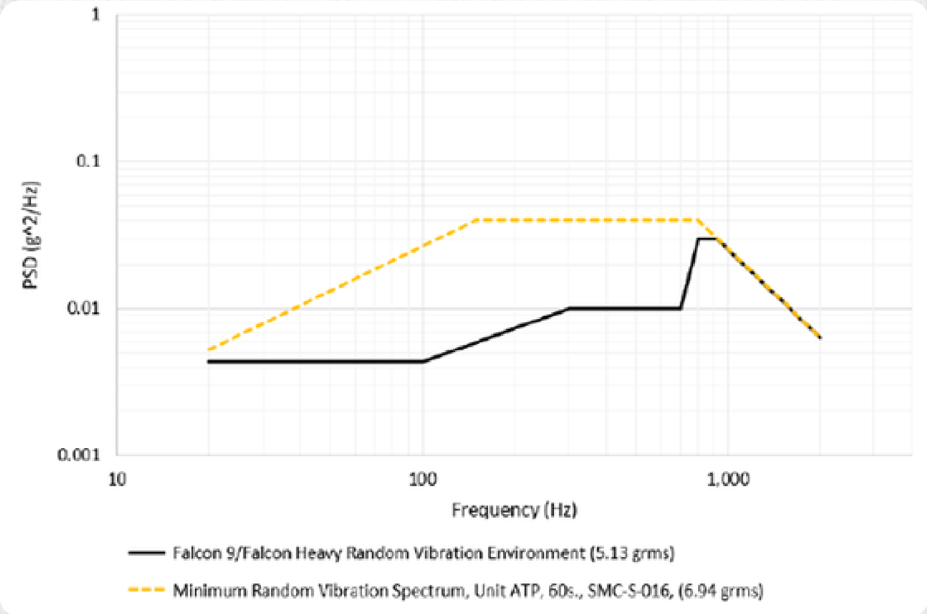


Figure 12: LLV Qualification Loads for Random Vibration

The random vibration environment is derived from the maximum response due to multiple forcing functions. These forcing functions can be broken into three frequency bands as listed below:

1. Low Frequency (0 - 100Hz)
    a. Excitations driven by global vehicle motion and modes.
    b. CLA and sine vibration envelope this region
2. Mid Frequency (100Hz – 600Hz)
    a. Excitation due to aeroacoustics.
    b. Acoustic excitation and aero buffet are primary drivers in this region.
3. High Frequency (600Hz – 2000Hz)
    a. Excitation due to structure borne vibration
    b. Merlin Vacuum (MVac) forcing functions

Payloads with sensitive components that are not tested to the above vibration levels shall be assessed on a case-by-case basis.

B.9 Thermal Environment

Thermal environments can vary widely depending on the positioning and line-of-site requirements of each payload. OBI works with each payload provider to make sure the payload is maintained in a suitable environment, beginning with an analytical model of the integrated payload. The LLV/Payload interface thermal conductance is a maximum of 0.1 W/K (e.g. nearly adiabatic) with OBI providing, and verifying, the thermal interface.

B. Payload Interface

The LLV encounters the following approximate thermal environments on a typical reference mission. OBI's thermal analysis process will determine the best thermal interface for payloads that do not require an adiabatic interface. OBI will work with the payload teams to refine their thermal management controls keeping them inside their survival and operation limits once they are part of our lander design. OBI will supply the thermal model analysis data to the payload teams for the transit and surface ambient thermal environments after the mission CDR, at least six months prior to the first planned payload delivery. The OBI high-fidelity thermal model will run multiple integrated thermal analyses to determine the best combination of thermal controls to be implemented for payload and ensure the payload thermal control schemes maintain payloads within their operating and non-operating temperature ranges throughout lunar transit and surface environments. Collaboration with the payload teams ensures the right payload mounting location and thermal instrumentation combination is implemented, while also allowing our team to provide recommendations for surface coating selection and MLI placement.

Table 10: Anticipated Thermal Environments of a Typical Mission*

Environment	Description
0°C to 30°C Pre-Launch	The integration and launch facilities are climate-controlled to provide this specific temperature range.
0°C to 27°C Launch	Throughout the Launch phase, the integrated Lander is encapsulated in an environmentally controlled launch vehicle payload fairing.
-60°C to 100°C Cruise	The thermal environment is significantly colder for objects in shadow and much hotter for objects in direct sunlight.
-120°C to 100°C Lunar Orbit	The thermal environment is significantly colder for objects in shadow, particularly during lunar eclipse, and much hotter for objects in direct sunlight, which can be compounded by light and infrared radiation from the lunar surface.
-30°C to 80°C Lunar Surface	The thermal environment is significantly colder for objects in shadow and much hotter for objects in direct sunlight. This range is relevant for the nominal lunar surface operations duration and does not include lunar night or missions to equatorial latitudes.

**NOTE: The corresponding thermal environments of the payload depend on mounting location and the incident sunlight at that location throughout the mission. OBI works with each customer to develop payload-specific environments for relevant system testing prior to payload integration.*

B. Payload Interface

Each mission payload is responsible for supplying a thermal model to OBI early in the payload integration process. OBI will use this model to perform an integrated thermal analysis used to analyze the payload unique thermal control approach. OBI has the tools to either passively or actively support a payloads thermal requirements, and to verify that these requirements are met through analysis and/or integrated thermal vacuum testing. The payload must implement a thermally isolating connection to the LLV. This allows the payload to more effectively regulate its own thermal environment using passive methods, such as Multi-Layer Insulation (MLI), conductive gap fillers to isolate or couple payloads to the mounting hardware, radiators and coatings, or active methods, such as internal heaters.

The LLV's top-side receives the most incident solar radiation and resulting heat during the cruise and lunar orbit phase. Underside of the lander is in near perpetual shadow and hence the lower extremes for anticipated temperature for those phases. The most extreme thermal environments occur during the lunar orbit phase as the LLV cycles through the hot and cold as it passes through the moons shadow. The movement of the sun throughout a lunar day and the reflection of light from the lunar surface creates a thermal environment that is very specific to a payload's mounting location on the LLV. The OB LLV is equipped with optical solar reflectors, which can be shared with payloads to avoid the need for dedicated radiators. If a dedicated radiator is needed, OBI will ensure maximum view of deep-space by moving the payload component to the edge of the deck or through the use of thermal straps to transfer heat to a radiator with an appropriate view factor.

B.9.1 Payload Interface Temperatures

A sample mission specific temperature profile at the payload interface, during the lunar day, is given below.

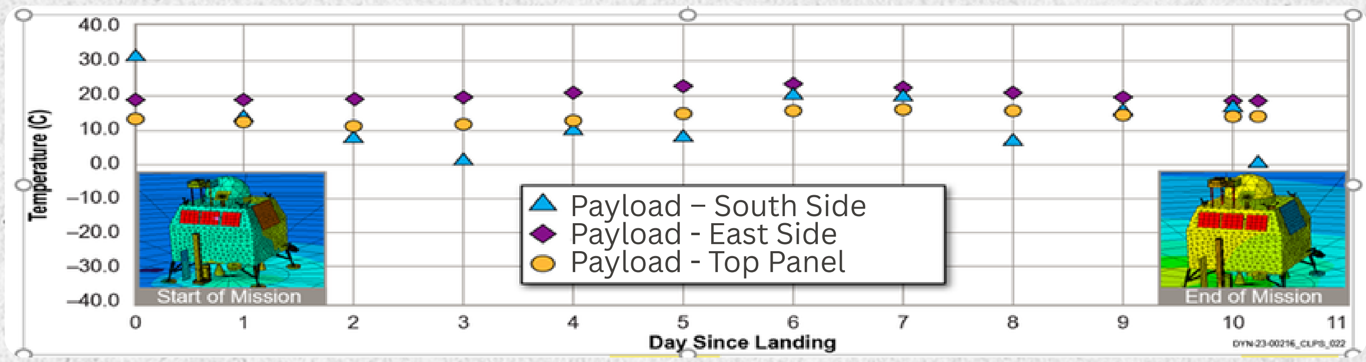


Figure 13:-Lander Temperature Profile

B.10 Pressure and Humidity Environment

B.10.1 Pre-launch

Payload integration facility shall be maintained at a positive pressure to avoid contamination and at 55% humidity. Payload integration facility, transport container, and launch facility shall be climate controlled. The actual environment depends on the respective locations of the integration and launch facility. Higher humidity's up to 90% may occur during transportation and depend on the local climate of the facility location.

B.10.2 Launch

Inside the Falcon 9 launch vehicle, the payload fairing internal pressure will decay at a rate no larger than 0.40 psi/sec (2.8 kPa/sec) from liftoff through immediately prior to fairing separation, except for brief periods during flight, where the payload fairing internal pressure will decay at a rate no larger than 0.65 psi/sec (4.5 kPa/sec), for no more than 5 seconds.

B.10.3 Post-Launch

Post launch the payloads are exposed to deep space vacuum environment (6.7 x 10-5 kPa)

B.11 Particle and Containment Environment

The OB1 LLV encounters the following approximate particle and contaminant environments shown in table below on a typical reference mission.

Table 11:Particle and Containment Environment

Mission Phase	Description
Pre-Launch	Planetary Protection regulations govern the Pre-Launch particle and contaminant environment. Assembly and maintenance of the lander and payloads must occur in a 100k or ISO Class 8 cleanroom. The OBI integration and launch services provider facilities provide suitable cleanrooms for Pre-Launch activities. The payload customer must ensure compliance with Planetary Protection protocols prior to integration with the lander.
Cruise, Lunar Orbit, And Surface	The firing of main and thruster engines expels a minute amount of propellant. Following touchdown on the lunar surface, the propulsion system is made safe by venting excess helium pressurant, which may carry trace amounts of fuel and oxidizer. These propellant residuals are unlikely to affect payloads; however, payload customers may design for shielding of sensitive components if so desired.
Surface	During the landing procedure, the LLV will displace an unknown amount of lunar regolith (region and location dependent), which may take several hours or days to fully settle. Lunar regolith is sharp and may cause damage to sensitive components. Lunar regolith is also electrostatically charged, which may cause it to cling to payload surfaces. The payload customer is responsible for identifying at-risk payload systems and implementing mitigation strategies such as shielding or deployable dust covers if necessary.

B.12 Electromagnetic Environment

The LLV and payloads must be designed for compliance with MIL-STD-461G for radiated and conducted emissions. Table 12 shows the appropriate testing to perform based on payload type.

Table 12. Radiated and Conducted Emissions

Category	Requirement	Application
Conducted Emissions	CE102	Active Payloads
Conducted Susceptibility	CS101 CS114 CS115 CS116	Active Payloads
Radiated Emissions	RE102	Active Payloads
Radiated Susceptibility	RS103	Active Payloads with Antennas

These tests characterize the interference, susceptibility, and compatibility of the lander and payloads to ensure appropriate electrical interfacing that does not induce significant interference, noise, or performance degradation into the integrated system. Additionally, these tests confirm compliance with other external standards and regulations such as Range Safety.

B.13 Radiation Environment

Payloads on the OBI's LLV will spend less than 1.74 hours passing through the inner and outer radiation belts. The LLV will receive a Total Ionizing Dosage (TID) of less than 1 krad. The LLV may experience a day in the near-Earth environment (<2,000 km), during the launch and cruise phases, and 4 to 6 days in the lunar transfer environment (Outer Belt (20,000 – 40,000 km) Inner Belt (1,600 – 12,000 km)), from Cruise phase (Lunar Orbit (385,000 km)). The final trajectory depends on the launch date selected by the launch vehicle and in many cases the launch vehicle's co-manifested payload.

B.13.1 Non-ionizing

The primary sources of radiated emissions from the OB1 LLV are the RF antennas. For payloads, EMI levels will be calculated and provided to the customer based on the location of the payload with respect to the RF antennas. All payloads must comply with MIL-STD-461G standard for radiated emissions and susceptibility.

B.13.2 Ionizing Radiation

Total Ionizing Dosage (TID) for the mission is 3krad (Si) for 1mm Aluminum absorber thickness, most of which is accumulated in the lunar transfer phase until crossing beyond the outer Van Allen Belt. Payload developers designing for radiation tolerance for this mission for Single Event Effects (SEEs) can assume a Linear Energy Transfer threshold (LETth) of 30MeV-cm2/mg of Si (unshielded).

The near-Earth environment is defined by the trapped radiation within the Van Allen belts and is expected to be 20 rads/day. This ionizing dosage is based on expected electron as well as heavy ion and proton radiation per Earth day in the near-Earth environment.

B. Payload Interface

The lunar transit environment is defined as outside of the shielding effects of Earth's magnetic field. An ionizing dosage of 1 rad/day is predicted based on expected electron radiation per Earth day in the interplanetary environment.

The total ionizing dosage typically is not expected to exceed 1 krad. The LLV is designed to mitigate destructive events within its own electronics caused by nominal radiation for a period of eight months.

NOTE: These values do not take into account the potential for a solar event such as solar flares, storms.

C. Payload Integration

Team OBI uses an orderly process for executing the end-to-end activities required to integrate lunar payloads utilizing tools and expertise having successfully integrated and operated over 400 complex NASA scientific payloads. Each PDs primary contact will be an assigned Payload Integration Manager (PIM), who will be able to connect the PD team with the rest of the LLV design team. The PIM will provide our customers with current information on the mission, facilitate technical exchanges with the engineering team and provide sufficient review to ensure all NASA sponsored and/or commercial customer payload mission, integration and test, lunar transit and post lunar landing requirements are accommodated. The PIM's job is to ensure the safe launch, integration, operation, and data return for each mission payload.

C.1 Technical Support

C.1.1 Customer Agreement

On mission's Authority to Proceed (ATP), our payload customers have immediate support from our PIM to begin the integration planning process. OBI begins customer service through the Payload Integration Services Agreement (PISA). The PISA specifies the primary management and technical responsibilities for the payload and Team OBI technical support and defines, either directly or by reference documentation, management roles and responsibilities, flight and ground safety, lander interface design, verification and testing, operational, launch site processing requirements, resource and interface, and schedule tracking commitments.

The Development and Integration process is tailored to the particular investigation and the team developing and integrating the payload. Every payload/investigation must meet certain safety requirements and reliability criteria. OBI determines the number of meetings required for each particular payload, along with the schedule and meeting cadence, at the beginning of the integration process. As time progresses, the team may collectively determine what level of engagement is required until the payload is launched, and operated. However, the work will vary depending on payload complexity in order to help each payload gauge the amount or type of work will be involved.

Major activities include: 1) Kickoff; 2) PIM tag-ups throughout the integration process; 3) Milestone/Safety reviews; 4) Verification requirements/testing coordination; 4) Shipping/final packaging/mass verification of hardware prior to handover; and 5) Pre-launch activities and final configuration at launch site with deliverables verified through PIPR and PIRR.

Immediately after award, a kick-off meeting will be held to facilitate BI and payload team to share data related to LLV capabilities and constraints, and payload requirements and constraints, enabling detailed accommodation analysis and the Interface Control Document (ICD) preparation process. The OBI PIM will discuss LLV capabilities, mission duration, communications capabilities, power capabilities, mission operations timeline, payload accommodation, and thermal considerations during transit and surface operations. Payloads will discuss the payload interface, development process, accommodation requirements, and operations.

C.1.2 Payload Integration Working Group (PIWG)

OBI supports out PDs through our PIM with a regular cadence of Payload Integration Working Group (PIWG) meetings, participation in payload design reviews, test readiness reviews and facilitating payload testing (both with simulators and flight hardware) and support through mission simulation testing and operations. OBI participates in any requested payload design cycle reviews and facilitating payload testing through simulated lander interfaces to assure a successful integration. The PIM will explain what the paperwork expectations are for data submittals, other deliverables, meeting attendance, and more. PDs will be guided along the way, and there are resources and people to support each Payload in providing required documentation, data input, etc. While much of the development and integration work is handled online using Team OBI database tools, teleconferences, emails, etc., at any given time throughout the process, face-to-face meetings may be required as agreed to. A list of data deliverables and associated due dates is provided in table below.

Table 13. Payload Required Documents/Inputs to OBI

Artifact	Provider	Due Data
Payload Requirements Document (PRD) including development status/schedule	All Payloads	Kickoff + 1 Week
CAD Model	All Payloads	Kickoff + 1 Week; updates as req.
Payload ICD Draft Inputs	All Payloads	Mission PDR+ 2 Weeks
Final Landing Site Inputs	Payloads, OBI	Mission PDR+ 3 Weeks
Prelim Drawing for Mating bolt Pattern (with CAD update)	All Payloads	PIPR minus 2 Weeks
Preliminary pinout and connector location	All Payloads	PIPR minus 2 Weeks
Finite Element Models/Interface Models	All Payloads	PIPR minus 2 Weeks
Thermal Analysis Models	All Payloads	PIPR minus 2 Weeks
Command & Telemetry Dictionary	All Payloads	PIPR minus 2 Weeks
PL Concepts of Operations	All Payloads	PIPR minus 2 Weeks
Preliminary FCC Information	All Payloads	Mission CDR minus 1 month
Preliminary Safety Plan Inputs (MSPSP)	All Payloads	Mission CDR minus 1 month
Final Drawings for Mating Bolt Pattern (with CAD update)	All Payloads	Mission CDR minus 2 Weeks
Final pinout & connector location	All Payloads	Mission CDR minus 2 Weeks
Payload ICD Input Updates	All Payloads	Mission CDR plus 2 Weeks
Final Payload ICD Inputs, including special Handling Reqs	All Payloads	Mission CDR plus 2 Weeks
EMI/EMC Test Report	All Payloads	PIRR minus 2 months
Materials Outgassing Repot	All Payloads	PIRR minus 2 months

Table 13. Payload Required Documents/Inputs to OBI

Artifact	Provider	Due Data
Vibration Test Report All Payloads PIRR minus 2 months	All Payloads	PIRR minus 2 months
Final FCC Information	All Payloads	PIRR minus 2 months
PL Procedures and Operations Handbook	All Payloads	PIRR minus 2 months
Final PL Acceptance Data Package (ADP) Inputs	All Payloads	PIRR minus 2 months
Any necessary payload handling support hardware	All Payloads	Payload Delivery
Mechanical fasteners for payloads	As Specified	Payload Delivery
Final Safety Plan Inputs (MSPSP)	All Payloads	Environmental TRR + 1 month
Final Payload Data Report	OBI	Launch + 10 Weeks

C.1.3 Payload Interface Control Document (ICD)

The PIM works with payload teams to establish and maintain ICDs for each payload to define lander-to-payload, space-to-ground, operations, and launch vehicle interfaces. Final ICD will include mechanical, thermal, optical, electrical, software/data and payload unique appendices to the ICD. The ICDs will include information relevant for successful I&T including integration, handling, storage, environments, GSE, contamination, checkout, notching, and safety constraints and requirements. These ICDs are subject to mission and specific payload requirements, fully describing both sides of the interface. Initial ICDs will be established at kickoff and presented during the mission CDR review.

C.1.4 Payload Integration Analysis

OBI performs Integration Analysis to ensure that the mission induced mechanical and thermal environment throughout the mission profile including during transport, integration, testing, launch, lunar transit, touchdown impact, and on lunar surface will be less than those specified in General Environmental Verification Standard (GEVS), GSFC-STD-7000A Analysis includes payload accommodation analysis, structural load finite element analysis, and thermal analysis. Team OBI uses provided payload specific CAD, FEM, and Thermal Models for these analyses with format and details decided in collaboration with the payload teams. Multiple updates to these analyses will be performed after key milestones (Mission PDR/CDR) or design and development phase completion.

C.1.4.1 Structural Dynamics and Loads Analysis

OBI performs integrated LLV-payload structural dynamics and load analyses using Finite Element Models (FEMs) including vibration, quasi-static, sine-vibration, random vibration, shock, touchdown analysis, and coupled load analysis with the LLV. Based on analysis results, LLV structural design will be updated to ensure that the load transmitted to the payload is below the prescribed limits, throughout the mission. Analysis supports LLV design updates and verifies requirements for the built hardware. The analyses results will also be used for test predictions and test result evaluation, as well as to minimize testing requirements. LLV finite element analysis results will be correlated with test results to update LLV models for as built configuration.

C.1.4.2 Mission Thermal Analysis

OBI performs integrated LLV-payload thermal analysis using provided payload thermal models. This analysis defines temperature limits and improves the integrated LLV-payload design to ensure an appropriate thermal management system, for the full mission profile.

C.2 OBI Provided LLV Software Emulators

OBI provides payload development teams with LLV emulator at least 10-months prior to the required delivery of each payload to allow for verification of interface software during payload development. The LLV emulator will be comprised of an all-software simulation of the vehicle. The simulation environment can be configured for each phase of the mission. Real I/O communication interfaces will be available to interface with the payload system.

C.3 Milestones and Deliverables

Team OBI Payload Integration Schedule provides required milestones and reviews as part of the mission Master Milestone Schedule (MMS). Integration activities ensure that the information exchange between the PD and the LLV are timely and support integration and flight readiness milestones. Payload specific milestones and reviews and their purpose are provided by color code in table below and provide for an orderly process for executing activities required to integrate lunar payloads. This structure provides a process flow tailorable to the specific needs and maturity of each payload. The process covers the entire lifecycle, mission Authority to Proceed (ATP) to the return of data results from experiment operation. Integration activities ensure that the information exchange between the Payload developers and the LLV are timely and support integration and flight readiness milestones.

Table 14. OBI Integration Milestone Reviews

PISA	**Payload Integration Services Agreement** – As discussed in ***Section A.6.1.1*** Customer Agreements.
Kickoff	**Kickoff Meeting** – Introductory meeting with payload customers to introduce Team OBI, provide overview of lander capabilities, payload integration including the ICD, acceptance and integration launch and surface operations plans.
SRR	**Science Requirements Review** – functional and performance requirements review for payload systems and individual payload plans to ensure requirements and initial concepts for accommodations will satisfy the mission.
MPDR	**Mission Preliminary Design Review** – Ensures mission requirements for both lander and payloads are properly formulated and correlated with the Program objectives.
LCDR	**Lander Critical Design Review –** Demonstrates the maturity of the LLV design for the integrated lander and payloads is appropriate for full-scale fabrication, assembly and test. LCDR determines that the technical effort is on track to complete flight and ground system development and mission operations.
MCDR	**Mission Critical Design Review** Mission CDR objectives evaluate (1) the integrity of the program integrated design, including project and support infrastructure; (2) the program's ability to meet mission requirements with appropriate margins and acceptable risk within cost and schedule constraints; and (3) whether the integrated design is mature to continue with the final design and fabrication phase.

Table 14. OBI Integration Milestone Reviews

LIPR	**Lander Integration Planning Review –** LIPR objectives evaluate the readiness of the program, including its projects and supporting infrastructure, to begin the system Assembly, Integration, and Test (AI&T) with acceptable risk and within cost and schedule constraints. Control plans specifically related to Verification and Validation are updated.
PIPR	**Payload Integration Readiness Review** – Ensures the payloads are ready to be integrated into the LLV. Reviews interfaces, components and subsystems are available and ready to be integrated onto the lander. Reviews integration facilities, support personnel, and integration plans and procedures are ready for integration.
LTRR	**Lander Test Readiness Review –** LTRR objective is the integrated readiness of the LLV spacecraft to begin integrating vehicle systems and payloads into the flight model (FM)
PIRR	**Payload Integration Readiness Review** – Ensures the payloads are ready to be integrated into the LLV. Reviews interfaces, components and subsystems, integration facilities, support personnel, plans and procedures.
PIRR-pi	**PIRR Parallel Integration (pi)** – The payload customer delivers the fully-assembled flight configuration payload to Team OBI. For safe integration with the LLV, each payload must complete all verification and validation activities without failures. PIRR series integration allows for multiple payloads to be integrated at the same time. Team OBI can accommodate late payload delivery with integration post environmental testing.
MTRR	**Mission Integration Test Readiness Review** – Ensures that the test article (both hardware and software), test facilities, support personnel and test procedures are ready for testing and data acquisition, reduction and control. Reviews that all lander/payload interfaces are under strict configuration management.
FOR	**Flight Operations Review –** Evaluates the readiness of the program, including its projects, ground systems, personnel, procedures, and user documentation, readiness to operate the LLV flight system and associated ground systems are compliant with program requirements and constraints during the operations phase. This includes the Payload operating procedures and experiment timelines for surface operations.
MRR	**Mission Readiness Review –** MRR objectives evaluate the mission design for the integrated lander and payloads meets all mission performance requirements and achieves all mission science requirements.
LRR	**Launch Readiness Review –** LRR examines tests, analyses and audits the integrated LLV's readiness for a safe and successful launch and subsequent flight operations ensuring all flight and ground hardware, software, personnel and procedures are operationally ready.
PSR	**Pre-ship Review** – PSR ensures the completeness and readiness of each item of hardware and associated software/firmware, prior to release for shipment of the integrated LLV (lander and payload) to the launch site.

Table 14. OBI Integration Milestone Reviews

FRR	**Flight Readiness Review –** FRR objectives evaluate the readiness of the program and its projects, the Payload, ground systems, launch vehicle, personnel, and procedures for a safe and successful launch and flight/mission.		
MCR	**Mission Closeout Review –** MCR provides end of mission final technical report to Payload teams. This report documents programmatic and technical accomplishments, reviews, activities performed, and lessons learned. Technical data includes trajectory analysis for transit and lunar landing as well as surface operational performance (e.g., thermal, communications, and power) to assist with future planning. Payload functionality and environment are reviewed, with discussion of any key findings. This is the final milestone of the program.		
Key:	*Payload Review*	*LLV Review*	*Mission Review*

OBI provides the products as shown in table below to NASA and commercial payload teams.

Table 15. Team OBI Deliverables to Payload Developers

Artifact	Delivery	Due Date
Thermal Environments for The Full Mission Profile.	All payloads	ATP+8 weeks; at Payload Delivery - 9 mo.
LLV Geometry	All Payloads	ATP+8 weeks; Payload Delivery - 9 mo.
Data Rights - Identify Any Limitations or Restrictions on Data Rights in Accordance with Contract.	All Payloads	Science Requirements Review
Specify Temperature Sensors	All Payloads	Mission Prelim Design Review
Identify Wi-Fi system to support - Deployable	All Payloads	Mission Prelim Design Review
Identify Image System used for any Deployable	All Payloads	Mission Prelim Design Review
Identify MLI Performance Characteristics	All Payloads	Mission Prelim Design Review
Identify Mounting Interface and Fastener and Harness Interfaces	All Payloads	Mission Prelim Design Review

Table 15. Team OBI Deliverables to Payload Developers

Artifact	Delivery	Due Date
Thruster, Plume, & Venting of Propellants Analysis Report	All Payloads	Mission Prelim Design Review
Interface Control Document	All Payloads	Preliminary MCDR, Final PIRR
Sine Vibration Test Levels - For Each Payload with A First Fundamental Frequency Below 100 Hz	All Payloads	Expected Payload Delivery -8 months
Do NO Harm Verification Statement	All Payloads	Payload Delivery -4 months
Materials List Verification Statement	All Payloads	4-months before delivery of the final payload manifest
Payload Procedures and Operations Handbook	All Payloads	PIRR – 4 months, Final Update L-30 days
Materials Usage List	All Payloads	Payload Delivery(s) -9 months. Final Launch -4 months.
Lander Emulator	All Payloads	Payload Delivery -10 months
Mission Communication Architecture (i.e. Periods of Communication Coverage and Periods of Loss of Signal) Including the Uplink and Downlink Schedule.	All Payloads	ATP plus 6-months. Final 6-months prior to integration of the payloads.
Command Verification Test and Reports	All Payloads	Pre-Ship Review
Power Quality Test and Report	All Payloads	Pre-Ship Review
Closeout Photos	All Payloads	Launch plus 1 week

OBI provides the products as shown in table below to NASA and commercial payload teams.

C.4 Payload Processing

OBI's AI&T Manager is responsible for engineering and test-conductor services including the integration and verification of the flight, ground, and science data systems. The integration team prepares the test procedures and work instructions, perform required training, calibrate systems, tools and GSE, and document all non-conformances and dispositions for mission testing. Detailed step-by-step procedures document the integration and test activities that involve the LLV as well as for mission payload hardware, including a description of the activity or test objective, the required equipment and personnel, environmental conditions for the activity or test, and any steps to ensure equipment and personnel safety. Planetary Protection regulations govern the Pre-Launch particle and contaminant environment. Assembly and maintenance of the lander and payloads must occur in a 100k or ISO Class 8 cleanroom.

The LLV with payloads installed proceeds to an environment test readiness review. Team OBI will ensure that the LLV and all co-manifested payloads cannot interfere with, or harm each other (e.g. physical interference, Wi-Fi, EMI/EMC, off gassing, or other operational interferences) – DO NO HARM. The integrated LLV is shipped to the test facilities in an environmentally controlled shipping container. In the case of late-arriving payloads, contingency plans, including mass model installation, will be executed. Opportunities exist to integrate payloads on the lander after full environmental testing is completed if required.

Throughout the integration and test process numerous ground and functional tests are performed including: 1) a visual inspection of any payload mounting and launch locks; 2) functional and environmental testing; 3) aliveness test through daily power-up and quick check of functionality; 4) communication and commanding verification tests before, during and after thermal vacuum testing; 5) power quality test verifying power draw is appropriate for the payload throughout the expected mission phases; 6) polarity tests; 7) alignment measurement baselines; 8) camera calibrations and alignments; 9) deployment tests that verify the motion of all mechanisms; and 10) systems degaussed and tested to assure magnetic cleanliness requirements.

Prior to launch, an end-to-end Mission Sequence Test (MST) is performed between the LLV and the payloads. The MST exercises key mission events to verify all hardware and software supports all flight phases using operation procedures and timelines. The MST will use the designated network test facilities to provide a simulated ground link between the LLV radios and the ground network. The MCC will communicate with the LLV and payloads using the same ground software that will be used for the mission. The MST validates that the complete mission system from the MCC, network, LLV and payloads. Various data flows/rates, dump-data, imagery, and uplink commands will be exercised. Additionally, the ETE verifies the MCC and Payload POCCs to receive and process real-time and dump data. Team OBI will work with each payload team to define the entry and exit criteria. Nominal and contingency scenarios will be rehearsed. After the test, a comprehensive review by OBI and Payload teams assesses mission readiness before transport.

C.5 Ship to Launch Site

Once the fully integrated lander is certified, the lander is delivered to the launch site where the payloads may perform any final functional tests and the LLV is integrated with the launch vehicle. The lander is shipped in a nearly flight-ready configuration which does not require any mechanical assembly or integration of components at the launch site. OBI provides for safe, climate-controlled transportation of the integrated lander to the launch site (delivery to the SpaceX PPF). The integrated LLV will always be transported in an environment-controlled container within the specified safe speed limits. The shipping containers will be designed to meet the following environment requirements: ISO 8 (Class 100,000) Clean Area; Ambient Air Temperature between 0ºC and 30ºC; and Relative Humidity between 35% and 65%.

C.6 Launch Site Integration

SpaceX is nominally contracted to provide launch services. Based on our current launch acquisition and execution plan, the timeline described below is based on the current Launch Services Agreement with SpaceX. The launch vehicle has enough excess performance; to both mitigate against any injection requirement variations from the reference mission.

C. Payload Integration

The below timeline provides the required site integration and processing schedule, beginning at contract signature and proceeding through launch. To mitigate risk, the mission schedule supports a readiness for launch delivery between L-3 and L-1 months to accommodate changes to the SpaceX primary mission schedule that may affect the actual mission launch date.

- Signature/Kickoff (L-24 to L-22 months) - SpaceX furnishes a mission manager that serves as single point of contract with the OB1 LLV launch Site Manager from contract signature award through launch. The mission manager will work with OBI to create a spacecraft-to-launch vehicle ICD.
- Launch Vehicle Unique Design and Analysis (L-12 months) - All mission-unique design and analysis results are delivered by SpaceX to OBI and the ICD is prepared for signature at this milestone. The ICD describes all integrated mission LLV requirements.
- Deliverables to Launch Vehicle (L-12 to L-3 months) – Information required and provided by OBI for the integrated mission LLV: 1) Payload Safety Data; 2) Finite Element models; 3) Environmental Analysis including thermal and EMI; 4) Environmental test data that includes approach to qualification and acceptance testing, test configuration, methods, schedule and test results provided prior to flight; 5) Launch Site Operations Plan including hazardous procedures that need approval by range safety; 6) information in support of any reviews during the mission integration process; and 7) Logo for launch vehicle.
- Launch Campaign Kickoff (L-3 months) - Verifies that all people, parts and paper are ready for the shipment of the integrated mission LLV to the launch site and are ready to begin launch site processing activities.

C.7 Launch Site Processing

- Spacecraft Processing (L-30 to 10 days)- - SpaceX provides an ISO Class 8 (Class 100,000) PPF four weeks prior to launch for processing the integrated LLV, including equipment unloading, unpacking/packing, final assembly, nonhazardous flight preparations, and payload checkout. The PPF is designed to accommodate hazardous operations for LLV propellant loading performed by OBI with assistance from SpaceX personnel. Office space is provided for OBI and GSE and operations personnel including up to two mission payload participants. SpaceX monitors relative humidity, temperature and cleanliness in the PPF using particle counters. After encapsulation and prior to launch vehicle mate, SpaceX verifies purge media source and ducting cleanliness to ensure contamination control. This assures the mission payloads are maintained in an ambient environment between 35% and 56% relative humidity and between 0º C and 30º C prior to lander rollout at the launch site.
- Joint Operations and Integration (L-10 to L-0 days) - Joint operations begin ten days before launch. SpaceX performs the adapter mate and fairing encapsulation of the integrated LLV at the PPF. Fairing encapsulation is performed in the vertical orientation. SpaceX then transports payload to the launch vehicle integration hanger. Transportation is performed in the vertical orientation, and environmental control is provided throughout the transportation activity. Once at the launch vehicle integration hangar, the encapsulated assembly is rotated to horizontal and mated with the launch vehicle already positioned on its transporter-erector.
- Launch Readiness Review (LRR) – LRR is conducted two days prior to launch to verify readiness to proceed and with the countdown and launch including launch range and FAA concurrence. The LRR will review readiness to initiate and conduct launch, flight, and mission operations including the status of the LLV and individual mission payloads, the launch vehicle, ground systems including the Mission Operations Center and commercial communications systems.

C. Payload Integration

- Integrated Launch Vehicle Roll-Out and Launch (L-0 days) - Falcon 9 is designed for rollout and launch on the same day but roll-out will be defined by the primary SpaceX payload requirements. Rolling out early will be negotiated as part of the ICD with SpaceX and not pose a problem for the integrated OB1 LLV.
- Spacecraft Control Center (Countdown and Launch)– SpaceX provides a control center where the integrated LLV team can monitor launch, orbital insertion and separation including voice, video and internet connectivity and accommodations to include support of up to two payload participants. OBI does not anticipate any operations from the control center other than control of EGSE prior to launch to assure a full battery charge in the case of a launch recycle or scrub.
- Recycle and Scrub (Contingency) - In the event of a launch scrub, the transporter-erector and launch vehicle will stay vertical. Remaining on the pad provides uninterrupted payload-to-EGSE connectivity through the T-0 umbilical, eliminating the need to relocate EGSE from the instrumentation bay to the hangar after a scrub. However, for any long-duration launch postponements, SpaceX will return the vehicle on the transporter-erector to the hangar. Based on duration additional status checks may be conducted prior to the next roll-out/launch opportunity.
- Post Launch (L+1 days)– Package up shipping container, any GSE and tools and return to OBI facilities in Houston Texas. At launch plus 8 weeks OBI will assess and provide payload teams with the SpaceX flight report that details flight environments, separation state and a description of all mission-impacting anomalies and progress on their resolution.

D. PAYLOAD LUNAR TRANSIT AND SURFACE OPERATIONS

The integrated OB1 LLV is launched and begins its mission. The OBI Mission Control Centre (MCC) serves as the data hub for the OBI lunar missions, providing standardized, transparent, and safe networking to payload customers. Payload Control Centers (PCCs) are supported and are remote from the MCC. Remote users will have access to the MCC voice loop remotely for communications with on-site personnel. Commercial payloads can implement custom MCC applications to monitor and control the payload. Payload telemetry and data are transmitted from the LLV to the MCC and then to the PCCs without modification of the data. While in contact with the LLV during transit, the MCC reports its status including the position and orientation state vector.

LLV Post Touchdown - MCC confirms exact position and LLV begins post-landing configuration. Remaining helium, fuel pressure, gas and oxidizer pressure are vented. Clearing of fuel and oxidizer lines. Post touchdown the S-Band/ dual gimbal medium gain antenna will orient and begin the download of highest priority data, the health of the LLV and its systems and payloads will be verified.

LLV System Check - Following a successful touchdown, the LLV transitions to surface operational mode. The craft establishes communication with Earth and performs a system check.

Mission Operations - The LLV power and data services to payloads for the nominal lunar surface operations period. Payload egress procedures and other hazardous operations are permitted and timelined to initiate.

Payload Operations - Begin with a predetermined initial sequence of actions that will be performed including a 360° image of the landing site. As appropriate, post checkouts and instrument components are deployed and begin their operations. All payloads are fully functional and operating within 72 hours of touchdown.

End of Mission (EOM) - Prior to designated EOM, the LLV transitions to hibernation mode and discontinues all payload services. Dependent on landing location, lunar night signifies the end of mission; future missions may support an extended mission with lunar night survival for the LLV and payloads.

D. PAYLOAD LUNAR TRANSIT AND SURFACE OPERATIONS

D.1 Surface Deployable Payload Operations

Each surface deployable payload is provided a time to perform deployment and any payload-specific preparations. The following compliant arm and fire techniques are negotiated for implementation in any payload design requiring this capability.

- CHARGE - Deployable payloads charge their batteries with power provided by the LLV.
- DIAGNOSTIC - The payload customer performs any necessary system diagnostic checks and firmware or software updates for the payload.
- ARM — The payload deployment is armed by means of a specific customer command to transition the payload to Mission mode and internally distribute power services to the release mechanism.
- FIRE — The power (release) signal serves as the fire command. Upon customer request, OBI provides the defined power signal to the Standard Electrical Connector (SEC) interface.
- POWER – OBI maintains power authority over attached payloads and can, by the removal of nominal power services, render payload release mechanism devices inert.
- RELEASE - A diagnostic check may be performed by the payload customer to verify internal power sources and wireless communication. OBI will confirm payload separation is achieved using lander camera.
- OPS - The payload transitions to its mission operations, allowing the use of internal power systems for surface payloads and onboard radios.

D.2 Lunar Orbit Payload Deployment

Payloads are typically deployed in either the velocity or anti-velocity direction. The LLV will perform a small separation burn following orbital payload deployment to minimize collision. Deployable payloads need to provide verification of release. OBI will work with specific customer requirements to identify the available and preferred lunar orbits for orbital deployments for each mission. To ensure safe lunar orbit operations for all payloads, orbital deployments may occur at varied altitudes for each payload.