CUBEROVER

PAYLOAD USER'S GUIDE

Publicly available document, please contact Astrobotic Technology for more details.
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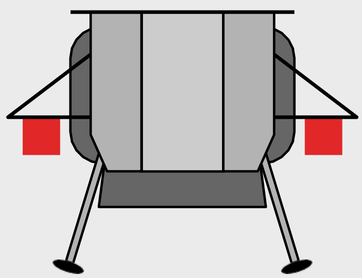
ASTROBOTIC

TABLE OF CONTENTS

ABOUT US

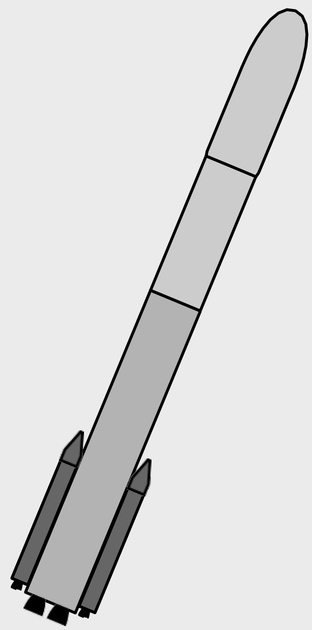
WHAT WE DO

We're the Moon company and more. We specialize in making space missions feasible and more affordable for science, exploration, and commerce. And we think the Moon is a great place to start. As a lunar logistics company, we provide end-to-end delivery services for payloads to the Moon.



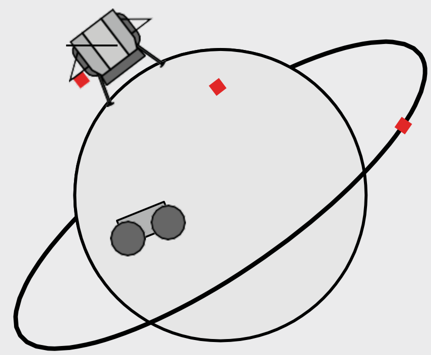
PAYLOAD INTEGRATION

On each mission, Astrobotic works with payload customers to integrate their payloads onto its lunar landers, Peregrine and Griffin, and its rovers, CubeRover and Polaris.



LUNAR DELIVERY

The Peregrine or Griffin landeris launched on a commercially procured launch vehicle and safely delivers payloads to lunar orbit and the lunar surface.



PAYLOAD SERVICES

Peregrine and Griffin provide power and data services to payloads during transit to the Moon and on the lunar surface. CubeRovers and the Polaris rover provide power and data services on the lunar surface.

Each payload customer receives comprehensive support from contract signature to end of mission. The Payload Customer Service Program equips the customer with the latest information on the mission and facilitates technical exchanges with Astrobotic engineers to ensure payload compatibility with our lunar products and overall mission success.

ASTROBOTIC'S MOBILITY AS A SERVICE

Companies, Governments, Universities, Non-Profits, and Individuals can carry and operate payloads across the Moon's surface at a price of $4.5M per kilogram of payload.

CubeRovers are designed to be scalable and flexible to meet the demands of payload customers. This enables payload customers to carry out their own unique surface operations.

CubeRovers are available in the following sizes:

ROVER CLASS	2U	4U	6U
Rover Mass	3 - 4 kg	6 -8 kg	10 - 12 kg
Payload Capacity	Up to 2 kg	Up to 4 kg	Up to 6 kg

For every kilogram of payload, CubeRovers provide:

POWER: 0.5 W/kg

BANDWIDTH: 10 kbps

Additional engineering units are available upon request.

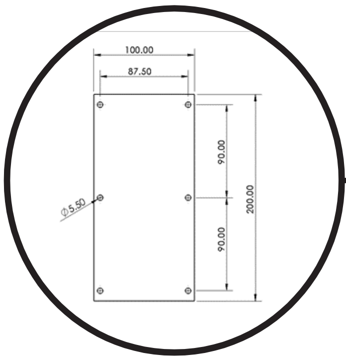
To learn more, please contact info-pm@astrobotic.com

PAYLOAD SERVICES

SERVICES AGREEMENT

1

Following contract signature, the payload customer relates to their payload manager to begin development of a schedule and an Interface Control Document.



TECHNICAL SUPPORT

2

Astrobotic supports the payload customer by hosting regular integration working group meetings, participating in payload design cycle reviews, andfacilitating payload testing with simulated rover interfaces. An engineering unit is provided to support payload testing and integration.

INTEGRATION

3

The payload is sent to the Astrobotic integration facility. Astrobotic accepts the payload and integrates it onto the Lander.

MISSION

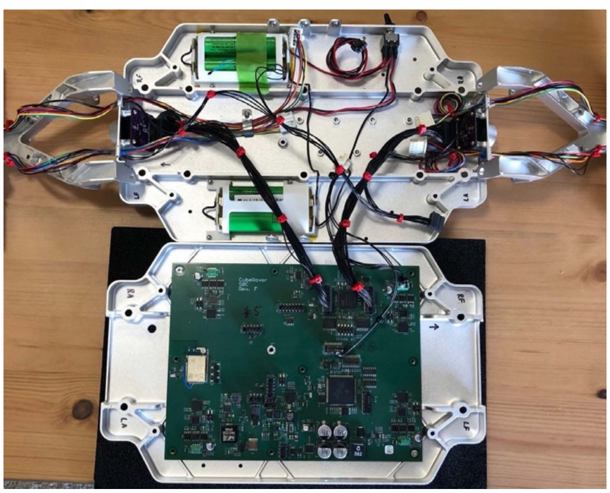
4

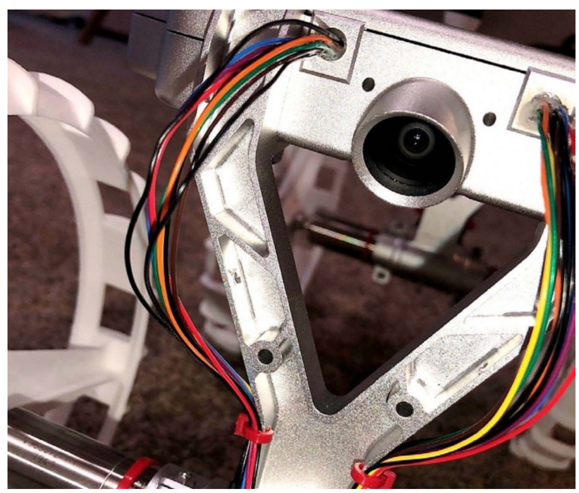
The integrated rover is launched aboard the Lander and commences its mission. The Astrobotic Mission Control Center connects the Payload Customer to their payload for monitoring and operations during flight and on the lunar surface after training from Astrobotic.

CUBEROVER SERVICES & SUPPORT

CubeRover engineering units perform similar to flight units and are the perfect tool to practice payload integration and prepare for lunar missions.

Astrobotic is committed to ensuring CubeRover payload customers complete their mission and acquire meaningful data. **In support of this, one CubeRover engineering unit is provided to CubeRover payload customers prior to flight integration**. An engineering unit facilitates payload functional testing and operations in a relevant environment without damaging flight hardware. Engineering units are equipped with flight analog hardware and software to simulate expected operational performance.

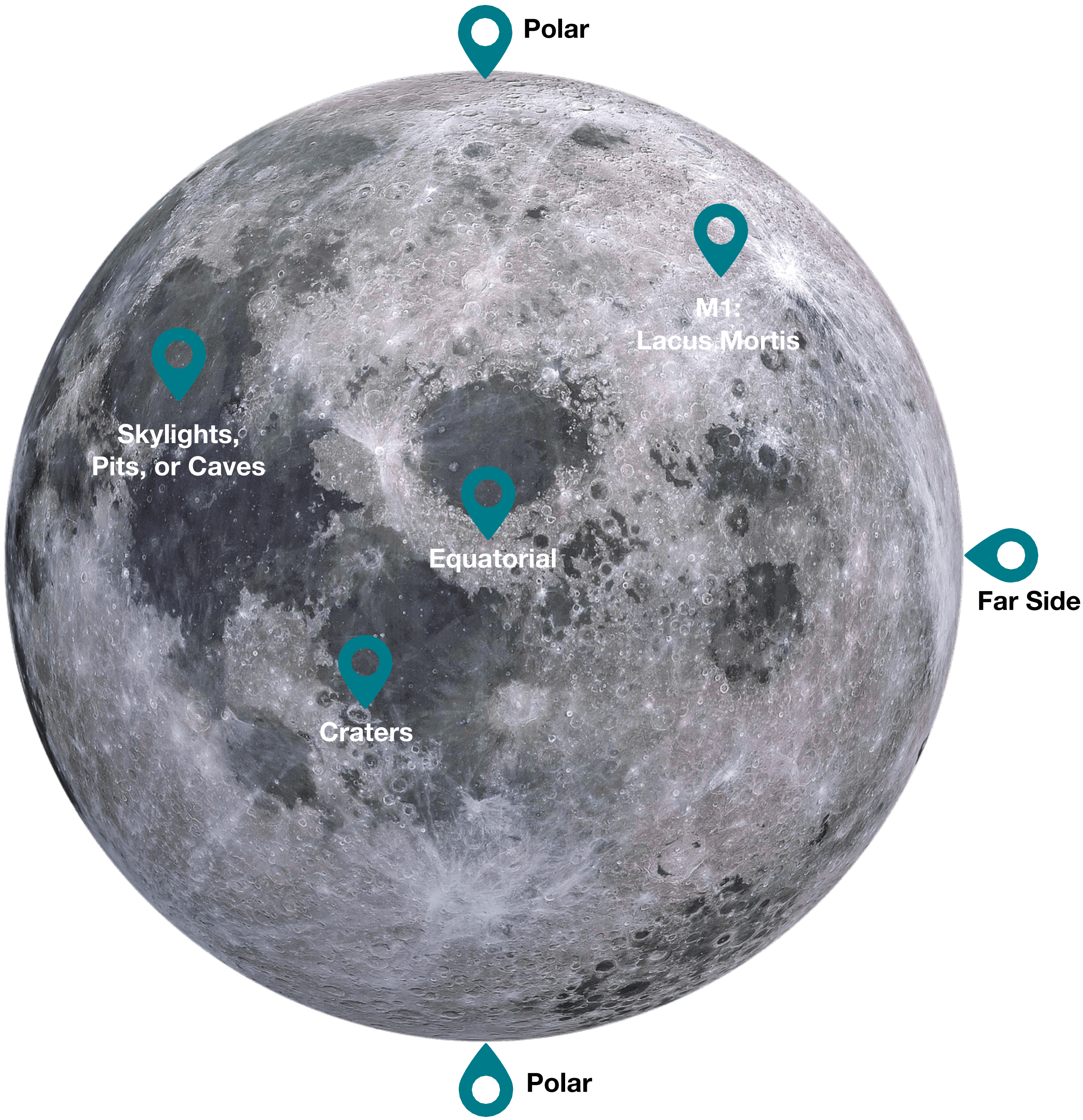




Additional engineering units are available upon request. To learn more, please contact info-pm@astrobotic.com

CUBEROVER DELIVERY

The CubeRover can safely deliver payloads across the surface at numerous locations on the moon.



ASTROBOTIC LUNAR SERVICES

Astrobotic is here to support the success of your payload mission. The standard payload interfaces and services are defined to enable nominal payload missions. This Payload User's Guide (PUG) provides an overview of these standard interfaces and services.

Astrobotic can accommodate payloads with needs outside of the standard interfaces and services at additional cost. Please contact Astrobotic to discuss any nonstandard requests such as custom interfaces, accommodations of large or unusual geometries, or payload design consulting services, etc.

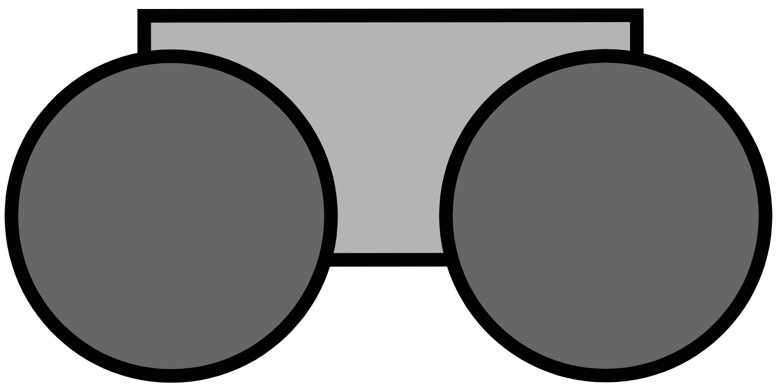
The Payload Customer Service Program is a standard service for all payload customers to receive the tools necessary to design a payload that successfully interfaces with CubeRover.

The following features are included as part of the program:

PAYLOAD CUSTOMER SERVICE PROGRAM

1. Availability for general and technical
2. Bi-weekly technical exchanges with Astrobotic mission engineers.
3. Access to the Astrobotic library of payload design resources and standards.
4. Technical feedback through payload milestone design reviews.
5. Facilitation of lander-rover-payload interface compatibility
6. Provision of a customer-owned engineering unit to support payload testing and integration.

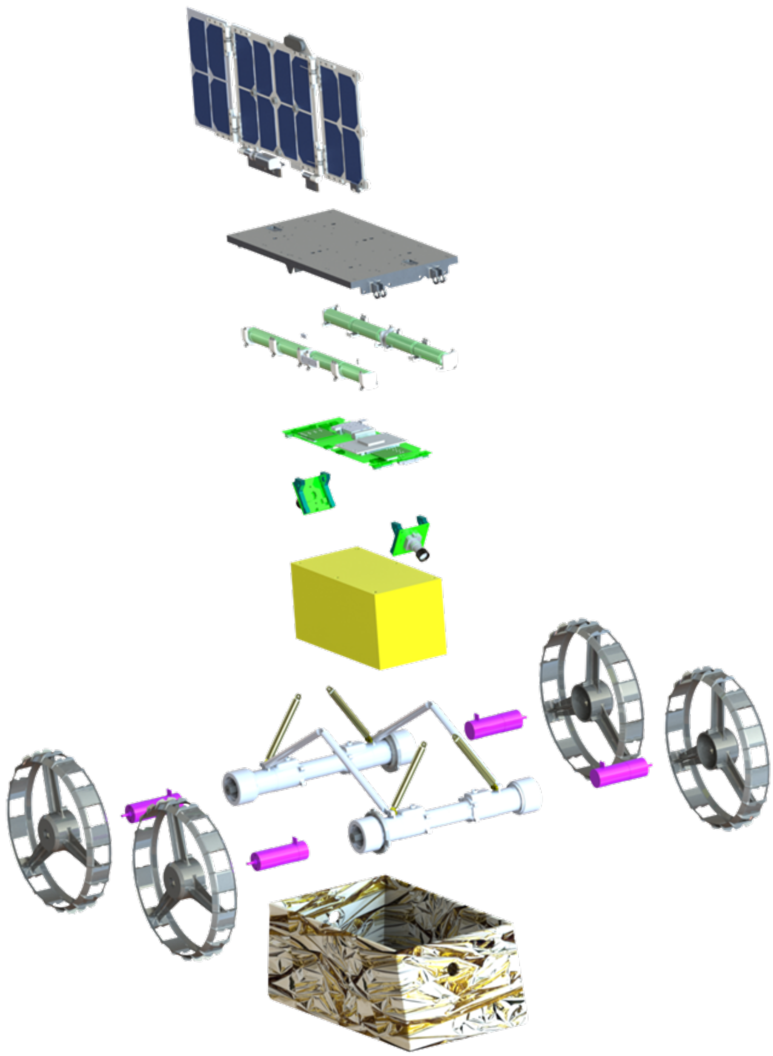
NOTE: Access to materials within the Astrobotic library is not always restricted to signed customers. Please contact Astrobotic for more information on obtaining the latest version of any document referenced within the PUG.



CUBEROVER

THE CUBEROVER AT A GLANCE

The CubeRover delivers payloads across the Moon after deploying to the lunar surface. This unique offering allows customers to design payloads using standardized CubeRover interfaces. After payloads are assembled and flight qualified, they are delivered to Astrobotic for integration and testing onboard the CubeRover.



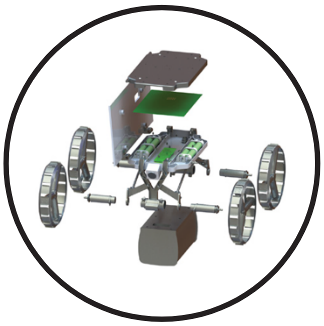
This is the configuration and specifications of the 2U CubeRover.

SPECIFICATIONS	
2U CubeRover Height	40 cm
2U CubeRover Length	50 cm
2U CubeRover Width	28 cm
2U CubeRover Mass	up to 5 kg

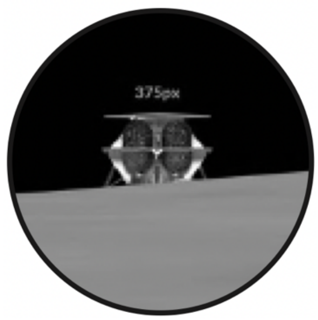
CUBEROVER BUS SYSTEMS

A core set of systems, known as the bus, define the CubeRover product line.

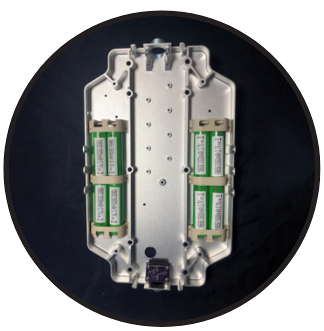
The spacecraft bus design enables safe payload traversability and operation on the lunar surface. The bus systems of the CubeRover, listed below, remain consistent throughout the product line providing confidence in flight-proven design for future missions. These subsystems are described in greater detail in subsequent pages.



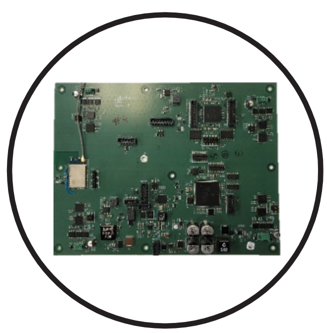
STRUCTURE



TELEOPERATION



POWER



AVIONICS

COMMUNICATIONS

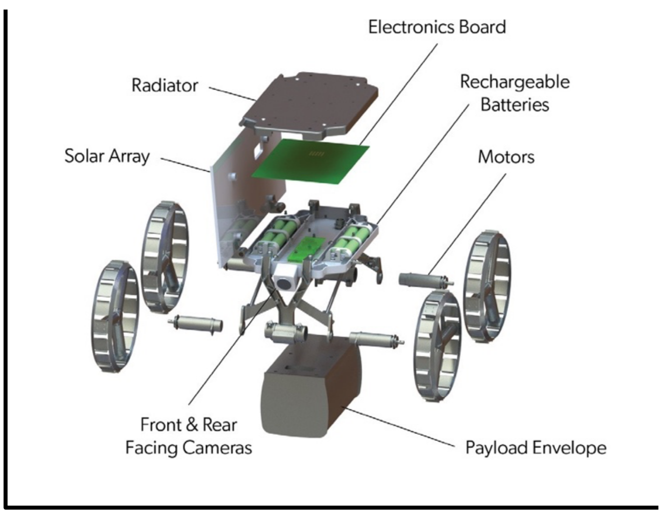
STRUCTURES

The Structure of CubeRovers is stout, stiff, and simple for survivability during launch and landing.

The CubeRover structure is strong and mass efficient, with the key components being the chassis frame andradiator surface. The chassis is a machined aluminum design that merges structural and thermal needs into a low-mass package. The radiator similarly integrates mounting and thermal grounding needs along with the deployment interface. The remaining structural components include the solar panel and mounts for the cameras, actuators, batteries, and payload.

The chassis subassembly serves as the structural mounting interface for the four drive actuators, cameras, and payload. Mounting configurations may vary depending on payload requirements, please contact Astrobotic formore information.

The radiator surface serves as the thermal heat sink for all components except the solar panels, and as the surface for lander fixturing. The integrated avionics unit, cameras, battery packs, payload, lander electrical interface, and hold-down and release mechanisms are each directly mounted to the radiator.



The CubeRover driveline is four-wheel drive and skid steer, unsuspended and driven by four, flight qualified actuator modules. Each actuator includes a motor and planetary gearhead, encoder, wire harnessing, thermal strapping, and actuator wheel mount. These actuators bolt directly to forks extending below the chassis and are thermally grounded to the radiator. Each output shaft passes through the fork axle using a combination bearing and sealed component and mates to an aluminum wheel hub.

STRUCTURES	
Main Structure Material	Aluminum
2U CubeRover Payload Mass Capacity	Up to 2 kg
2U CubeRover Payload Dimensions	20 x 10 x 10 cm

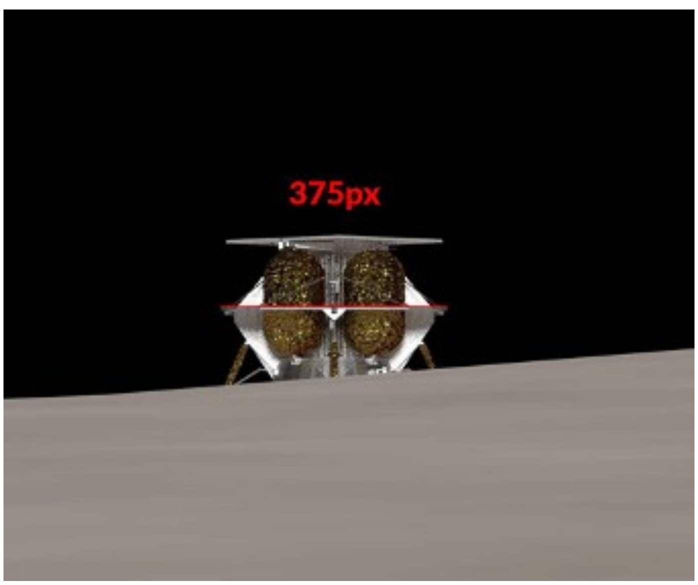
TELEOPERATION

The CubeRover Teleoperation System allows payload customers to monitor and drive the rover throughout a user defined mission.

The CubeRover teleoperation system is designed to minimize the risk of mission critical failures and maximize mission functionality.

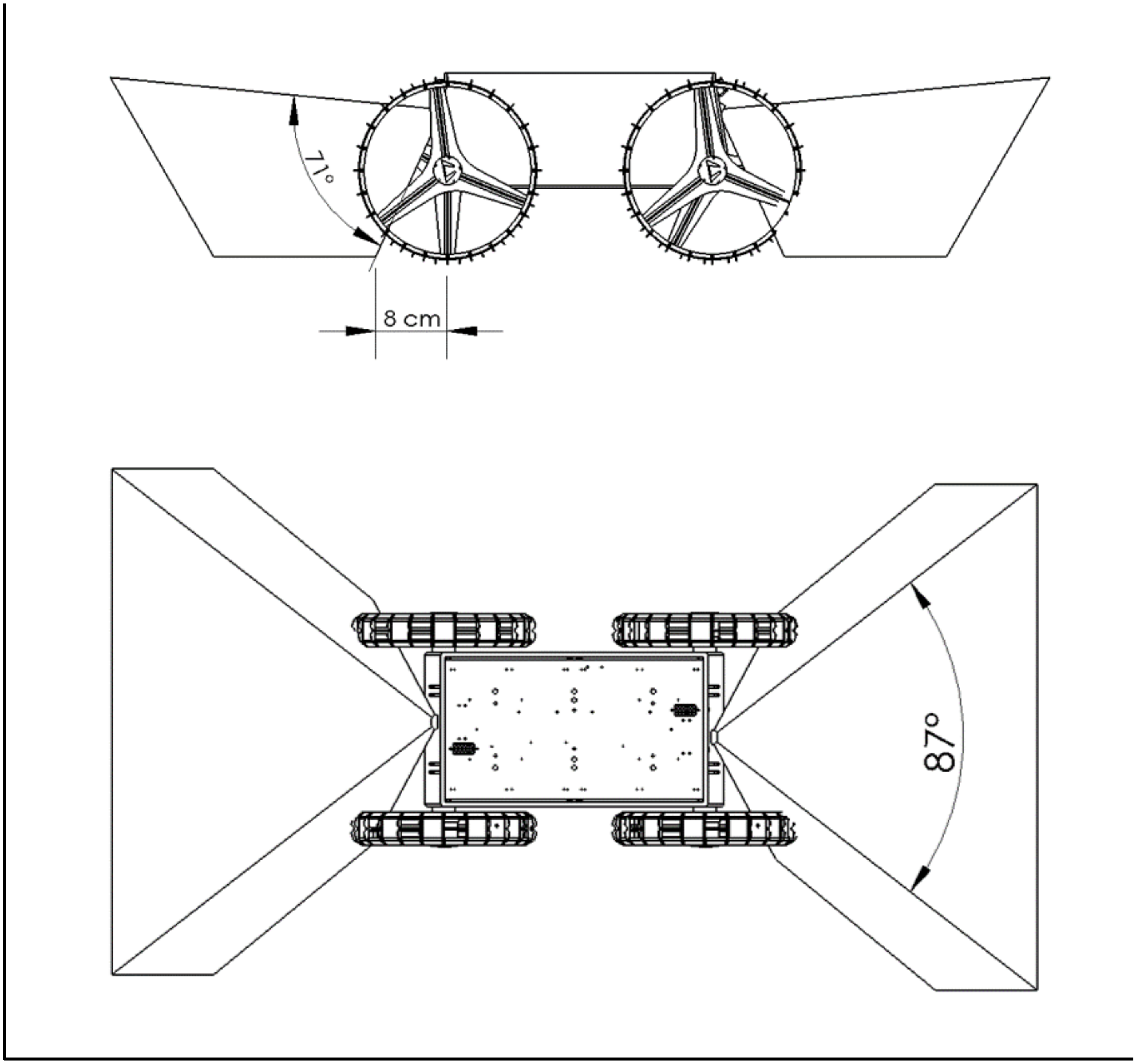
The system utilizes a combination of visual odometry and onboard sensors to determine its position relative to the Peregrine Lander. Absolute localization is conducted by measuring the size of known components on the lander in an image and then using that information to calculate the distance of the CubeRover from the lander. Rotation can be inferred similarly by comparing the relative positions of key features on the lander. During periods of operation when localization precision is not necessary or when the lander is not visible from the CubeRover, the system will use a combination of wheel and visual odometry to calculate position relative to the last known starting point. The current localization software provides a precision of 0.3 cm from 50 m away. The simulated image at right shows how this software operation is performed.

Within the constraints of safety, the ground control subsystem is designed to achieve the highest possible speed made good, which is a measure of how much distance the CubeRover will travel over a given time. The top speed is 10 centimeters per second and the nominal speed is 4 centimeters per second. The speed made good is directly affected by a variety of factors such as move distance, move planning time, operational time, image size, effective bandwidth, and transmission delays.



The Peregrine Lander is used as a reference to determine relative position.

The CubeRover is capable of capturing and transmitting a variety of images of varying sizes and compressions. Two monocular, 16-megapixelcameras are used for navigation and localization.This means that for every move the CubeRover makes, it is capable of sending multiple driving resolution images to contextualize the final rover position and increase operator awareness of theenvironment. The CubeRover is also capable of cropping images to specific regions, which allows operators to observe far away features in high resolution without the need to transmit afull resolution image. The fields of view for each CubeRover camera are shown below.



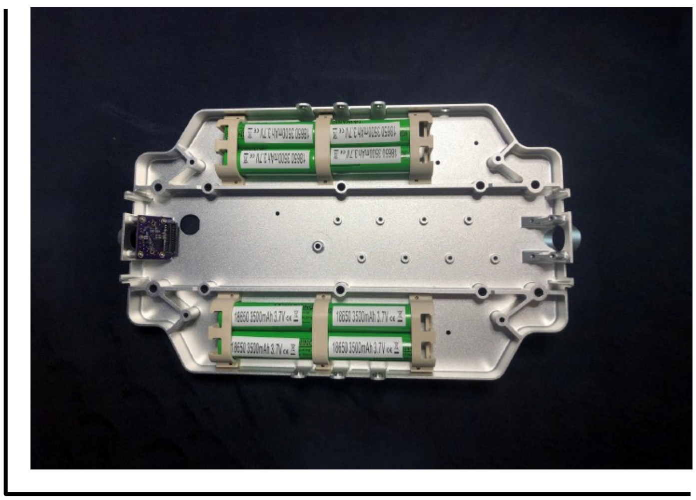
Camera vertical and horizontal fields of view.

TELEOPERATIONS	
Localized Precision	0.06 millimeters per meter
Nominal Speed	4 cm/s
Camera	Front and rear view, 16-megapixel resolution

POWER

The CubeRover is rechargeable, allowing it to generate continuous power during nominal mission operations.

The CubeRover utilizes pogo pins to receive power from the Peregrine or Griffin Lander in transit to the Moon. Each CubeRover utilizes a solar array that is mounted to the top of the radiator and deployed following egress from the lander. Flight heritage solar cells allow the CubeRover to generate continuous power during roving. This implies that at any given time, regardless of orientation with respect to the sun, most of the solar panel surface area has a significant view factor to dark space.



The avionics includes a number of DC-to-DC convertersalong with circuits to supply the required power for
the various integrated circuits and subsystems, as wellas manage the batteries and solar panels. Batteries are monitored and balanced by a dedicated battery monitor circuit. The batteries are charged through the use of the solar panels and a solar charging circuit.

In addition to battery management, a number of supply voltages are generated and regulated on the IAU utilizing a 28Vdc. The selected DC-DC converters havea variety of over current and over voltage protections.

POWER	
Payload Power	0.5 W per kg continuous, 10 W peak
Payload Power Interface	28 Vdc
CubeRover Battery Composition	Lithium-ion

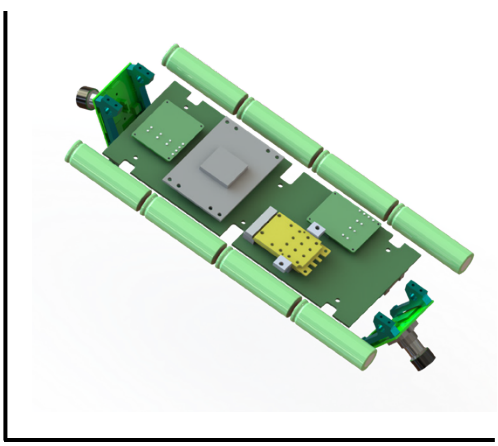
AVIONICS

The CubeRover Avionics perform all command and data handling for the rover.

The avionics system of the CubeRover is primarily comprised of an integrated avionics unit (IAU) that integrates all power distribution and management, data processing, controls, and communications. The only electrical components that are not completely integrated onto the board are the cameras, batteries, solar panels, motors, and a small number of temperature sensors. This approach is taken to simplify the overall system and enable the success of a small, capable lunar rover.

The integration of the bulk of the avionics system into a single integrated unit has several advantages. First, it eliminates the need for much of the typical wiring harness. This reduces mass and volume as well as the number of potential failure points from failed connections. Thermal design is also simplified by removing the need for thermally strapping many boards to the radiator. The IAU is simply mounted directly to the radiator allowing for the best possible heat transfer away from the sensitive circuits. Finally, the high degree of integration reduces the mass and size of the solution by eliminating the bulk of multiple boards, board mounts, and ancillary components. The IAU is comprised of a carrier board and processor board and is shown below.

The primary processor is responsible for parsing incoming commands from the ground, triggering the camera system to take an image, commanding the motor controllers, managing the storage and retrieval of system data, and managing payload computation commands. This processor stores and forwards payload data and receives teleoperated commands from ground control. To ensure robust, safe operation of the IAU, a separate processor is used as a watchdog monitor. The watchdog monitor has the ability to reset or power cycle the radio and the main processor if an error is detected. The watchdog monitor also controls the temperature sensors, heaters, and solar- battery charging circuit.



The primary flight software integrated on the microprocessor utilizes a lightweight real time operating system. This enables efficient interleaving of the various tasks being run at any given time while reducing the risk of one process blocking another. In addition, the CubeRover utilizes flight heritage software framework developed by NASA. The primary flight software receives and interprets all incoming commands from the ground through the radio. Based on these commands, the software transitions into one of several modes: roving, imaging, standby, general operations, or a safe mode. In all situations, the primary flight software monitors the inertial sensors, various thermistors, and any error signals or interrupts from the other integrated circuits on the IAU. In the case of a fault based on these data, the software can enter into a safe mode and, as appropriate, take action to safeguard the payload.

AVIONICS

AVIONICS	
Payload I/O Space	20 Pins Available
Data Storage	32 GB Maximum
CubeRover Safety Features	EDAC, Software Robustness

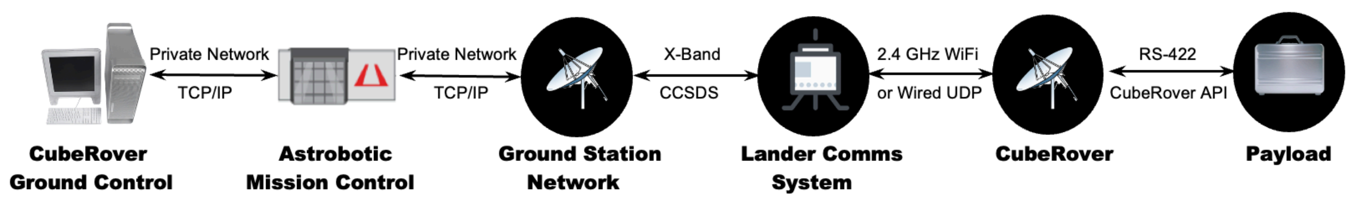
COMMUNICATIONS

Astrobotic's Peregrine and Griffin lander serve as the primary communications node for CubeRovers relaying data between the CubeRover payload and Astrobotic's Mission Control Center.

The CubeRover leverages Astrobotic's Lander communications network as a relay to receive commands for the rover and to send telemetry data to the customer's Payload Mission Control Center. CubeRover commands are sentto Astrobotic's Mission Command using TCP/IP through a private network. Within Astrobotic's ground systems, the commands for the rover will be sent to the command processor, where format and data size will be verified before the packet is sent to the Network Management Center (NMC) using the Payload UDP Packet (PUP) protocol as referenced in Astrobotic's Payload ICD. During transit, the ground stations transmit the commands to the lander through a frequency in the X-band range for uplink and the lander forwards the commands to the CubeRover through a Serial RS-422 wired connection.

Once deployed the CubeRover uses 2.4 GHz 802.11n Wi-Fi radio using TCP/IP to communicate with the lander. Customer payloads communicate with the CubeRover using a wired RS-422 connection. This information is thenrelayed to the Ground Station Network. All CubeRover downlinked data and uplinked commands are stored in Astrobotic's telemetry database for redundancy. All data will be sent through a private network to the customer'smission control center.

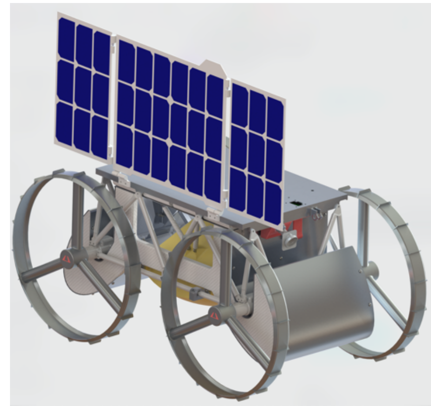
COMMUNICATION PIPELINE



COMMUNICATIONS	
CubeRover Payload Wired Protocol	Serial RS-422
CubeRover Payload Wireless Protocol	802.11n Wi-Fi
CubeRover Payload Frequency	2.4 GHz
R/F Communication Capability to Earth	10 kbps per kg

CUSTOM CONFIGURATIONS

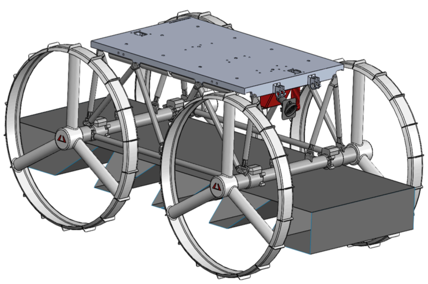
Astrobotic has proven flexible and innovative when accommodating nonstandard payload configurations.



While the base CubeRover product line includes 2 cameras, the 4U and 6U models are capable of accommodating 4 dual stereo 5 megapixel cameras upon special request. This enables larger FOV and a wide variety of post mission image processing capabilities. The unit can supply wireless charging capabilities.

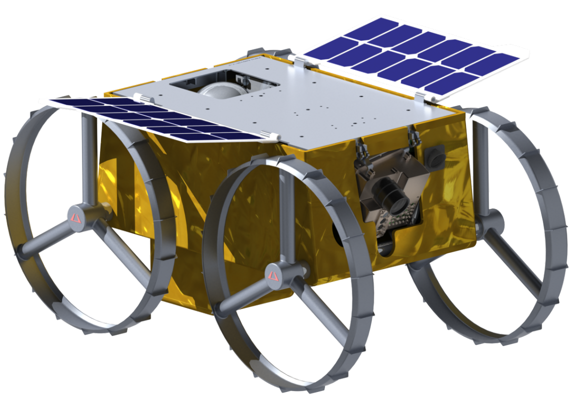
Other nonstandard accommodations made by the rover development team involves payload geometry widely outside of the specified payload volume.

To the upper right you can see a payload that wraps around the axels, narrowly avoiding the FOV of the 2 front cameras. This design also entails a tailored thermal design.

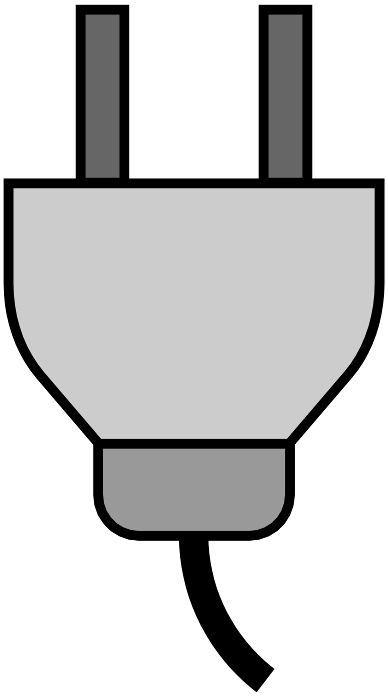


Another payload involving custom geometry outside of the payload bay is shown to the left. You can imagine even lunar surface operations are heavily effected and tailored to accommodate the stringent turning radius constraints due to the payload.

Another great example of the CubeRover products accommodating unique payload needs can be seen on the lower right. Internal geometry can be altered to allow payloads to penetrate through the rover to protrude far above the rover. Internal hardware is adjusted to make sure the mission has the greatest chance of successfully capturing the science it desires.



Finally, to the left we can see hardware protruding out from the MLI. This custom imaging system is stationed outside of the standard payload volume into the lunar environment.



INTERFACES

PRESSURE AND HUMIDITY ENVIRONMENT

PRESSURE ENVIRONMENT

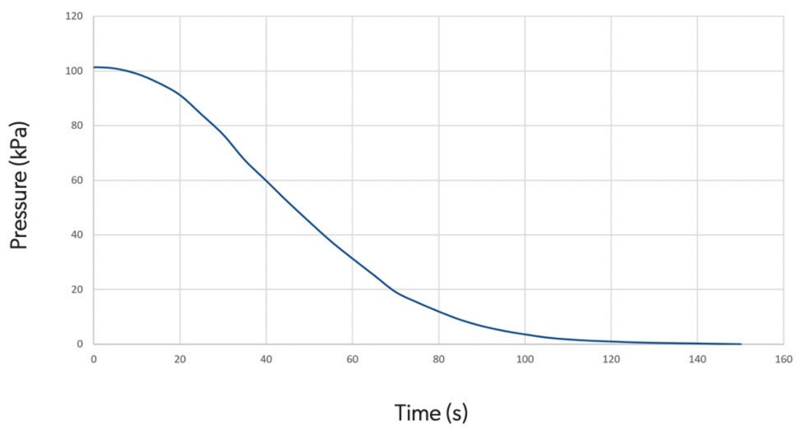
The CubeRover encounters the following approximate pressure environments on a typical reference mission.

PRE-LAUNCH

101.25 kPa represents the average atmospheric pressure at sea level; the actual value depends on the respective locations of the integration and launch facilities.

LAUNCH

This is a typical pressure drop curve for launch, which envelopes the pressure drop for all other mission phases. The pressure drop is expected to surpass –2.5 kPa/s only briefly during transonic flight as the launch vehicle exceeds the speed of sound and will not exceed -5.0 kPa/s.



REMAINING MISSION

3.2×10-5 kPa represents the vacuum of the space environment.

HUMIDITY ENVIRONMENT

The CubeRover encounters the following approximate humidity environments while on mission.

LAUNCH

The integration and launch facilities are climate-controlled to 50% ± 15% humidity. The higher humidityvalues may occur during transportation and depend on the local climate of the facilities' locations.

REMAINING MISSION

The vacuum of the space environment has 0% humidity.

PARTICLE & CONTAINMENT ENVIRONMENT

The CubeRover encounters the following approximate particle and contaminant environments on a typical reference mission.

PRE-LAUNCH

Planetary Protection regulations govern the Pre-Launch particle and contaminant environment. Assembly and maintenance of the CubeRover and payloads must occur in a 100k or ISO Class 8 cleanroom. The integration and launch facilities provide suitable cleanrooms for Pre-Launch activities.

Astrobotic Headquarters and Integration Facility contains two ISO Class 8 cleanrooms for Integration.

CRUISE, LUNAR ORBIT, AND SURFACE

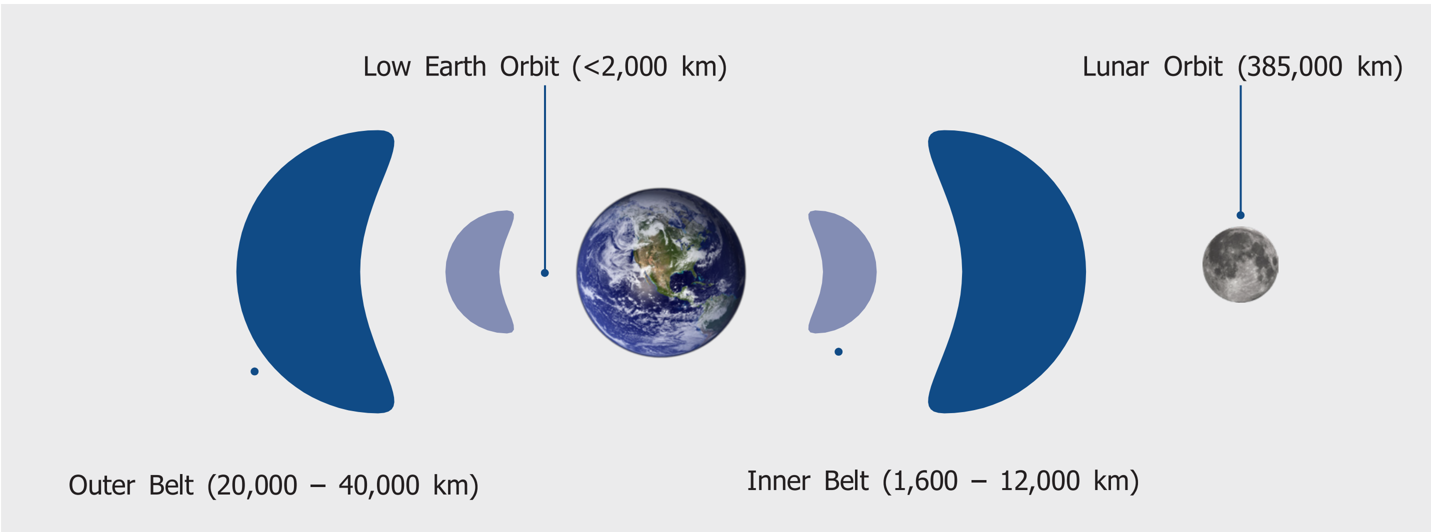
The firing of main and thruster engines of the lander during landing may expel a small amount of propellant. Following touchdown on the lunar surface, the propulsion system of the lander could be required to vent excess helium pressurant, which may carry trace amounts of fuel and oxidizer. These propellant residuals are unlikely to affect payloads; however, payload customers may design for shielding of sensitive components if so desired.

SURFACE

During the landing procedure, landers will displace an unknown amount of lunar regolith, which may take several hours or days to fully settle. Lunar regolith is sharp and may cause damage to sensitive components if mounted outside the standard CubeRover payload envelope. Lunar regolith is also electrostatically charged, which may cause it to cling to payload surfaces if mounted outside the standard CubeRover payload envelope. The payload customer is responsible for identifying at-risk payload systems if mounted outside the standard CubeRover payload envelope and implementing mitigation strategies such as shielding or deployable dust covers if necessary.

RADIATION ENVIRONMENT

The CubeRover encounters the following approximate ionizing radiation environments on a typical reference mission. The Van Allen radiation belts contain energetic protons and electrons that are trapped in the Earth's magnetic field and generally follow the magnetic field lines. The overall structure of the Van Allen belts can be seen from the highly simplified diagram in the figure below.



When a CubeRover is mounted to Astrobotic's Peregrine or Griffin lander, it may experience 3 to 15 days in the near-Earth environment, during the Launch and Cruise phases, and 14 to 38 days in the interplanetary environment, from Cruise phase onwards. The final trajectory depends on the launch date selected by the lander, however.

NEAR-EARTH ENVIRONMENT

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 dayin the near-Earth environment.

INTERPLANETARY ENVIRONMENT

The interplanetary 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 theinterplanetary environment.

TOTAL IONIZING DOSAGE

The total ionizing dosage typically is not expected to exceed 1 krad. The CubeRover 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 particle event.

ELECTROMAGNETIC ENVIRONMENT

The rover and all payloads must be designed for compliance with MIL-STD-461G for radiated and conducted emissions. The table below shows the appropriate testing to perform based on payload type, defined on the following page. Please contact Astrobotic for additional information or the latest version ofthe relevant Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility (MIL-STD-461G) document.

EMI CATEGORY	REQUIREMENT	APPLICABILITY
Conducted Emissions	CE102	Active Payloads
Conducted Susceptibility	CS101 CS114 CS115 CS116	Active Payloads
Radiated Emissions	RE102	Active Payloads
Radiated Susceptibility	RS103	Payloads with Antennas

These tests characterize the interference, susceptibility, and compatibility of the rover and payloads to ensure appropriate electrical interfacing that does not induce significant interference, noise, or performance degradation into the integrated system. Additionally, these tests inform compliance with other external standards and regulations such as Range Safety. Please contact Astrobotic for the latest version of the relevant Range Safety User Requirements Manual Volume 3 (AFSCMAN91-710V3) document.

PAYLOAD

Astrobotic recognizes four payload types. A payload may be either passive or active as well as either static or deployable; this results in the four distinct payload types detailed below. The standard payload interfaces, services, and operations are informed by the payload type.

	STATIC	DEPLOYABLE
PASSIVE	**Static Passive** • Remains attached to lander • Does not perform mission tasks *Example: Memorabilia*	**Deployable Passive** • Detaches from lander • Does not perform mission tasks *Example: Surface time capsule*
ACTIVE	**Static Active** • Remains attached to lander • Performs mission tasks *Example: Sampling tool*	**Deployable Active** • Detaches from lander • Performs mission tasks *Example: Science instrument*

The CubeRover provides payloads with standard and well-defined interfaces to support their missions. The following pages outline the standard physical, functional, and ground segment interfaces for payloads.

The service interfaces, which provide power and data to payloads, vary both by payload type and mission phase. Service interfaces are described in the Mission Operations section. Astrobotic is able to accommodate nonstandard interfaces upon request.

Please contact Astrobotic for additional information or the latest version of the Interface Control Document (ICD), which provides a comprehensive description of the standard interfaces.

PAYLOAD MECHANICAL INTERFACES AND REQUIREMENTS

CR-ME-001: The payload shall abide by a self-contained maximum volume constraint defined as 20 cm X 10 cm X 10 cm, as shown in Figure 1. The payload does not need to fill the maximum volume.

CR-ME-002: The payload shall abide by a maximum mass constraint defined as 2 kg.

CR-ME-003: The payload shall provide a center of gravity offset that does not interfere with the stability of the geometric center of the 20 x 10 x 10 cm available payload envelope by maintaining a geometric center +/- 1 cm.

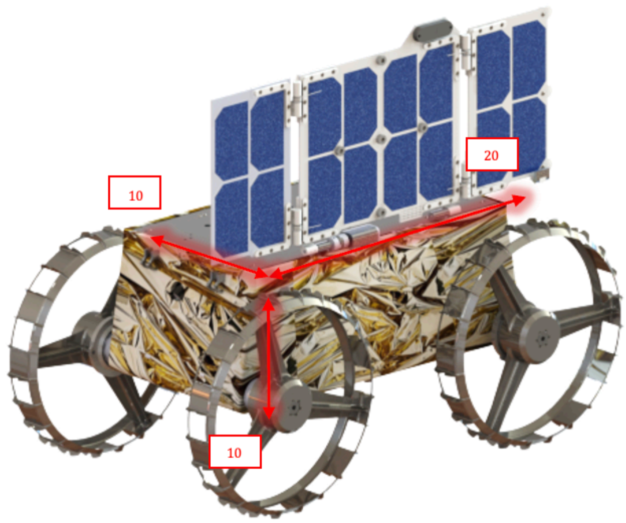


Figure 1: Payload Size

CR-ME-004 The payload customer shall provide the principal moments of inertia for the payload, with an accuracy of at least 10,000 g-mm^2 computed about the center of gravity of the payload.

CR-ME-005: The payload shall provide up to 6 attachment points, as shown in Figure 2, that will accept a threaded connection of M5x0.8 to a depth of at least 15mm, designed to withstand installation torque at 8.7 Nm and a clamp load of 8700 N. The payload mass does not include the mass of the six fasteners.

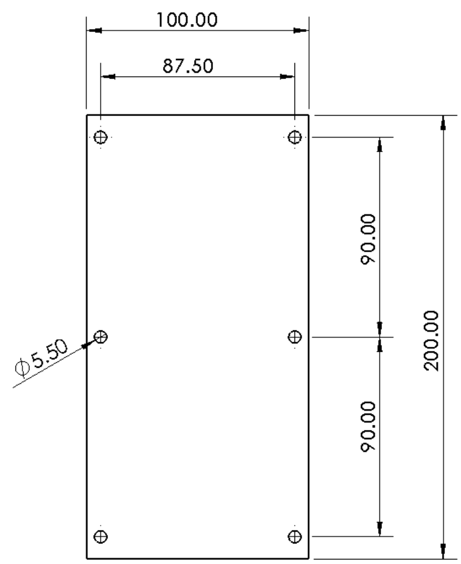


Figure 2: Payload Bolt Pattern (top view)

CR-ME-006: The payload customer shall submit the following applicable qualification reporting to the rover team:

- Material Outgassing
- Thermal Operational/Survival
- Sinusoidal vibration
- Random vibration
- Shock
- Mass, CG & moment of inertia data
- Pressure-venting

CR-ME-007: The payload shall withstand prolonged temperatures of the range -20 to 60°C.

CR-ME-008: The payload external surfaces shall accommodate MLI wrapping by rover team.

CR-ME-009: The payload material selection shall satisfy NASA-EEE-INST-002.

CR-ME-010: The payload shall not be pressurized, contain any pressurized or sealed compartment,

and shall not contain any undeclared stored mechanical, chemical, electrical, thermal, or radio-isotopic energy.

CR-ME-011: The payload shall be radioactively isolated from the spacecraft via multilayer insulation (MLI) or equivalent.

PAYLOAD ELECTRICAL INTERFACES AND REQUIREMENTS

CR-EL-001: The payload shall include the following electrical connector, as shown in Figure 3.

- Payload-side connector: Samtec P/N ISD2-10-D-S
- Crimp terminal: Samtec P/N CC81L or CC81R

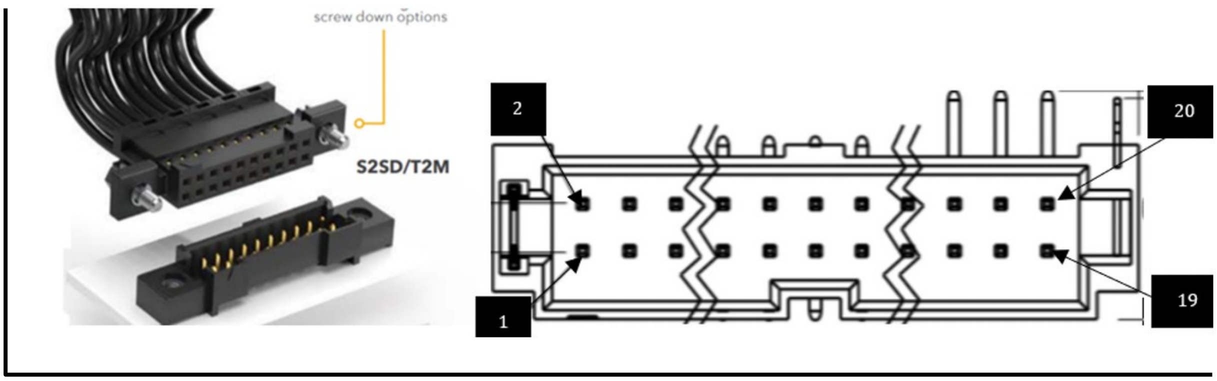


Figure 3: Connector Image & Pin Out

CR-EL-002: The payload shall mount the payload-side electrical connector(s) with sufficient length to ensure it is within reach of mating connector.

CR-EL-003: The payload shall provide the payload pin configuration as shown in the following table.

TABLE 1: CONNECTOR PIN OUT

PIN #	FUNCTION	ELECTRICAL SPECIFICATION
1	Payload RS-422 Ground	GND
2	Payload RS-422 TX+	0.0 to +0.3 (min) / +6.0 (max) | 0.0 to +2.0 (min) / +4.0 (min)
3	Payload RS-422 TX-	0.0 to +0.3 (min) / +6.0 (max) | 0.0 to +2.0 (min) / +4.0 (min)
4	Payload RS-422 RX+	0.0 to +0.3 (min) / +6.0 (max) | 0.0 to +2.0 (min) / +4.0 (min)
5	Payload RS-422 RX-	0.0 to +0.3 (min) / +6.0 (max) | 0.0 to +2.0 (min) / +4.0 (min)
6	Temperature Supply	Analog signal 3.3V
7	Temperature Sense	Analog signal 1.0 - 3.0V
8	Heater +	28V, 5W
9	Heater -	GND
10	Payload Power +	28VDC, 0.5W continuous, 5W max
11	Payload Power -	GND
12	Reserved I/O	High speed 0 – 3.3V
13	Reserved I/O	High speed 0 – 3.3V
14	Reserved I/O	High speed 0 – 3.3V
15	Reserved I/O	High speed 0 – 3.3V
16	Reserved I/O	High speed 0 – 3.3V
17	Reserved I/O	High speed 0 – 3.3V
18	Reserved I/O	High speed 0 – 3.3V
19	Reserved I/O	High speed 0 – 3.3V
20	Reserved I/O	High speed 0 – 3.3V

CR-EL-004: The payload shall receive 28VDC and 2 W of electrical power from the lander per the above table, toheat the payload during transit to the Moon.

PHYSICAL INTERFACES: 2U CUBEROVER

PAYLOAD GROUNDING, BONDING, AND ISOLATION INTERFACE REQUIREMENTS

CR-GB-001: The payload shall provide one contact point for the internal payload electrical circuit common ground for the payload structural and conductive elements.

CR-GB-002: The payload shall comply with Class S bonding guidelines, per NASA-STD-4003.

CR-GB-003: The payload shall implement EMI/EMC filters to test against MIL-STD-461.

CR-GB-004: The payload shall submit applicable payload frequency reporting (i.e., rotary, sound, etc.).

PAYLOAD POWER INTERFACES AND REQUIREMENTS

CR-PR-001: If the payload chooses to exercise the availability of power from the rover, the payload shall accommodate an operational power of 28VDC+/- 10% voltage output.

CR-PR-002: The payload shall consume an average power of 0.5 W/kg for operation excluding power for heaters, with a maximum of 10W/kg.

CR-PR-003: The payload shall provide a “stowaway” power service state to comply with an “off” power mode. This mode shall not receive or deplete power or signal and will be the state of the payload during launch, lunarascent/descent, and emergencies.

CR-PR-004: The payload shall provide an “active” power service state to comply with an “on” power mode.This mode shall allow full functionality of the payload and will be the state of the payload during operation upon the lunar surface.

CR-PR-005: The payload customer shall submit the following applicable qualification reporting to the rover team:

- Power states
- State power consumption
- State descriptions
- State anticipated durations
- Payload data transmission details

PAYLOAD DATA INTERFACES AND REQUIREMENTS

CR-DI-001: The payload customer shall submit the following applicable qualification reporting to the rover team:

- Mission Success Criteria
- Communication Latency
- Wireless Interface
- Heartbeat

CR-DI-002: If a payload chooses to exercise the use of a data interface with the rover, the payload shall use a UART RS-422 interface with the following specifications:

- Compatible with the 100 Ohm, 0.5W, termination resistor on the rover Serial RS-422 receiver circuit.
- Capable of providing a differential signal greater than ± 0.3 V but not exceeding ± 6 V when connected to CubeRover.

CR-DI-002.02: The payload shall use a minimum standard baud rate of 9,600 bps, with a maximum of 25Mbps.

CR-DI-003: The payload shall be allocated a maximum of 32 Gb of data storage space.

CR-DI-004: The payload customer shall submit the communication protocol to the CubeRover team:

- Payload data transmission packet details
- Packet integrity method (checksum, parity, etc.)
- Expected data transmission rate
- Hardware handshaking requirements

PAYLOAD TIME SYNCHRONIZATION INTERFACE AND REQUIREMENTS

Astrobotic offers time synchronization for payloads during operations. If the payload would like to take advantage of the time synchronization feature of the rover, a request may be sent from the payload to the rover. Timestamps will be relayed to the payload as agreed upon in the mission success and operations reports.

CR-TS-001: The payload shall use UTC reference and J2000 format for timekeeping purposes

CR-TS-002: The payload shall maintain time synchronization uncertainty between the rover and payload, below 20 ms during open communications windows.

CR-TS-003: The payload shall provide time synchronization services only to the rover when in the ON power service mode.

PAYLOAD THERMAL INTERFACES AND REQUIREMENTS

The main heat path between the payload and the CubeRover is through the payload bolts that secure the payload to the rover. The conductance through each bolt is no less than 1.25 K/W (or 0.8 W/K). Since the payload only receives power from the rover's power supply and at moderated rate, the maximum heat output from the payload is known. The CubeRover's radiator is sized to accommodate the estimated continuous power consumption of the both the rover and the payload. The payload may be required to use heaters to maintain its own internal temperature if the payload power consumption is low for extended periods of time. The following requirements are for the baseline CubeRover product, and can be tailored alongside thermal redesign efforts as payloads are assessed on a case-by-case basis. CubeRover products have, and will continue, to make adjustments to accommodate a variety of payloads.

CR-TI-001: Payload shall accommodate conductance limits through each payload mounting bolt as no less than 1.25 K/W (or 0.8 W/K).

CR-TI-002: Non-radiating surfaces should be covered with Multi-Layer Insulation (MLI) blankets, maintaining a surface resistivity of at least 107 Ω/square.

CR-TI-003: Payload Customers shall notify Astrobotic of any nonstandard features, such as geometry outside of the standard payload bay, for tailoring of thermal design.

EQUIPMENT INTERFACE

CR-EI-001: The rover team shall provide, within the Astrobotic Mission Control Center (AMCC), one payload console seat.

CR-EI-002: The rover team shall enable the launch of payload customer virtual machine with installedtools including:

- Google Chrome web browser
- Voice communications application for IP-based voice communication
- Astrobotic-approved software

CR-EI-003: The rover team shall provide a VPN connection with login credentials unique to payload customer.

CR-EI-004: The payload customer shall maintain and oversee the payload customer Payload Mission Control Center (PMCC).

CR-EI-005: The payload customer shall operate the PMCC onsite or remotely, via VPN, to the AMCC payload console seat.

PHYSICAL INTERFACES: 2U CUBEROVER

CR-EI-006: The rover team shall provide approved rover telemetry relative to the mission or specific to the payload customer PMCC.

CR-EI-007: The rover team shall forward payload telemetry to the payload customer PMCC.

CR-EI-008: The rover team shall forward payload telecommands from the payload customer PMCC.

CR-EI-009: The payload team shall flag telecommands as hazardous according to categories defined in the table below.

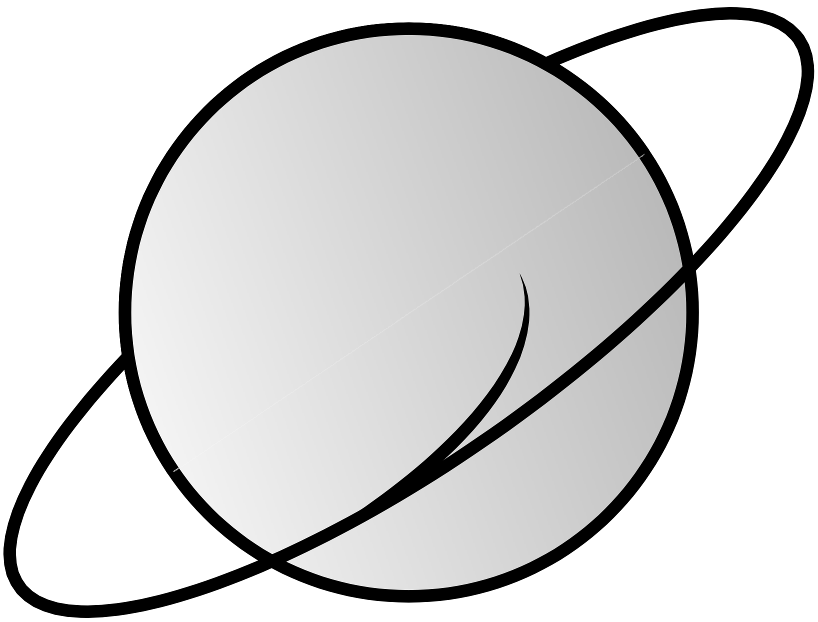
TABLE 2: ASTROBOTIC HAZARDOUS COMMAND CATEGORIES

CATEGORY	DESCRIPTION
Independent	Execution of payload Independent Telecommand has no impact to the rover, e.g., general data logging.
Dependent	Execution of payload Dependent Telecommand may have an impact to the rover, e.g., rover movement.
Hazardous	Execution of payload Hazardous Telecommand has an impact, potentially critical, to the rover, e.g., egress.

CR-EI-010: The payload shall utilize the telecommand dictionary, compliant with the defined hazardous command categories.

TABLE 3: PAYLOAD CUSTOMER TELECOMMAND DICTIONARY EXAMPLES

COMMAND NAME	DESCRIPTION	USAGE	HAZARD CATEGORY
drive_forward	Rover moves forward a configurable distance.	During surface checkout phase on the ROVER and following deployment from the ROVER	Dependent
drive_backward	Rover movesbackward a configurable distance.	During surface checkout phase on the ROVER and following deployment from the ROVER	Dependent
log	Rover sends log data from requested time interval.	During surface checkout phase on the ROVER and following deployment from the ROVER	Independent



MISSION

THE CUBEROVER MISSION

INTEGRATION

L-90 days

Service
Is integrated and tested with the Peregrine Lander.

CubeRover integration with Astrobotic's Peregrine and Griffin landers starts 8 months ahead of expected launch, therefore CubeRover payloads are requested 8-12 months in advance of launch to integrate the payload with the CubeRover. CubeRover payloads are to be delivered to theAstrobotic integration facility where the customer payload will be integrated with the CubeRover and then the Peregrine or Griffin Lander. After integration, Astrobotic will perform functional tests to confirm successful integration. The integrated lander willthen be sent to the Kennedy Space Center (KSC) in CapeCanaveral, FL. Integration with the Launch Vehicle starts 2 months ahead of expected launch, during which the CubeRover customer payload is to remain powered off.

LAUNCH

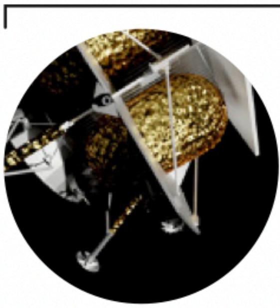
L-0 days

Sleep
Remains powered down.

During the prelaunch phase, Astrobotic will evaluate the payload via environmental, functional, and integration testing for maximum likelihood of mission success. Hardware will be transported in the OFF state fixed to the designated rover, eliminating wired, wireless, and time synchronization capabilities. After launch, cruise, orbit, descent, and lunar touchdown, the rover will perform preparation activities and diagnostic checks before deploying to the lunar surface. CubeRover remains powered down in sleep mode tosurvive launch conditions.

TRANSIT

L+1 day



Transit Status Check
Powers on and performs status check.

Heartbeat
Remains in a low power state, transmits heartbeat and maintains temperature.

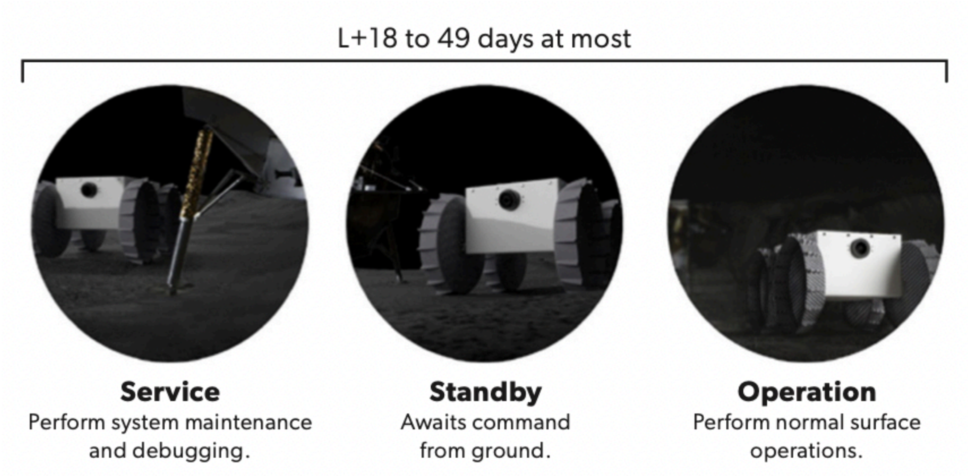
CubeRover stays in sleep mode until the lander begins providing nominal power; this is to trigger a transition to transit mode. CubeRover monitorsand maintains safe thermal levels and transmits aheartbeat through wired communications via the lander to the CubeRover ground systems.

LANDING

During landing, the CubeRover returns to sleep modewith minimal external power provided by the lander forthermal management.

DEPLOYMENT

After landing, the Peregrine or Griffin lander provides power to the CubeRover. The CubeRover then performsa wired status check and re-establishes connection with ground systems. On command from the ground, the CubeRover transitions to mission mode where it performs a wired status check that includes a test of the radio and verifies the rover is ready for deployment.The CubeRover mission team then activates the release mechanism upon a signal from Peregrine or Griffin via Astrobotic. Once released, the CubeRover gently lowers to the ground and comes to rest.



Following deployment, the CubeRover enters the Surface Operations phase of the mission. During this phase, the primary objective is the completionof the customer's payload objectives for the mission. Once on the ground, CubeRover performs a Mission Wireless Status Check, transitions to standby mode, and awaits commands from the ground to begin payload operation. The CubeRover remains in standby until commanded to take action: either by driving, imaging, collecting payload data, or performing system maintenance tasks. Customers direct Astrobotic operators to issue commands using the CubeRover provided user interface that streams live data and images fromthe lunar surface for real-time decision making.

The rover is not designed to survive or support operations after the first lunar day. Customers should plan for services for approximately 8 Earth days after touchdown. Thereafter, the landing site begins to rotate into lunar twilight and the spacecraft may continue to provide services on an ad hoc basis, depending on availability, until the onset of lunar night. The rover will deploy as scheduled, no earlier than 6 hours after touchdown. After the rover is deployed from the lander, wired, wireless, and time synchronization services will be enabled.

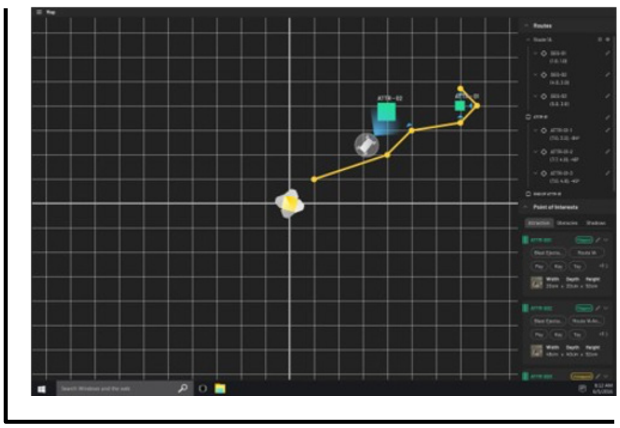
The payload may perform preparation activities and diagnostic checks as a part of its initial payload operation procedures. Spacecraft to Earth communication windows are nominally scheduled for cycles of 7 hours “on” and 1 hour “off” for up to 80% uptime during surface operations. The spacecraft may have to enforce a 24-hour“siesta” with limited power and bandwidth services at lunar noon in equatorial locations to prevent overheating.

CUBEROVER MODES OF OPERATION

ROVER MODES	DESCRIPTION
Ground Only Modes	
Service	Service allows access to all rover subsystems and allows for diagnostics and integration with Peregrine Lander.
Transit Modes	
Transit Status Check	Peregrine initiates transit mode by providing power to the rover. The Transit Status Check evaluates the rover and payload state and determines if it is safe to transition to the heartbeat mode. If the check fails, it sends the rover to the Transit Safe mode.
Heartbeat	Heartbeat mode is the primary mode of operation during transit. The CubeRover maintains contact with the ground through a "heartbeat" while monitoring and maintaining a safe internal temperature.
Transit Safe	Transit Safe is one of two safety modes available to the rover. It provides low level debugging abilities to ground systems while keeping most of the rover powered down.
Mission Modes	
Mission Wired Status Check	Following landing, the rover is commanded from Heartbeat to Mission mode for the first time. The Mission Wired Status Check performs a diagnostic report on all system functions except for those restricted by the deployment system. This includes a confirmation that wireless communications are functioning nominally; following deployment, this will be the only way to communicate with the rover. Thermistors will be monitored to confirm that all components are within operational temperature ranges. The onboard heater can be used to warm the rover if needed. Finally, this status check also ensures the rover is fully charged and charges the rover if needed.
Deployment	Deployment is initiated by Astrobotic Mission Control at the request of the CubeRover team. Peregrine provides a power (release) signal to CubeRover, which activates the deployment mechanism releasing the CubeRover.
Mission Wireless Status Check	The Mission Wireless Status Check is a general diagnostic check after the rover has deployed from the lander.
Standby	In Standby mode, the rover waits for a command while transmitting heartbeat and other telemetry to the ground systems.
Driving	When driving or turning, the CubeRover enters Driving mode. The rover remains in Driving mode until the command is completed. This can occur concurrently with the Imaging and System Maintenance modes.
Imaging	When taking a photo, the CubeRover enters Imaging mode which includes the taking, cropping, scaling, compression, and transmission of images. This can occur concurrently with the Driving and System Maintenance modes.
Payload Operations	During payload operations the CubeRover diverts its primary power source to customer supplied payloads, facilitating uninterrupted data flow through the onboard microprocessor and the payload electronics.
System Maintenance	The System Maintenance mode allows for a variety of low impact commands to be executed such as resetting specific avionics components or removing images from the system memory. This can occur concurrently with the Driving and Imaging modes.
Mission Safe	Mission Safe mode shuts down all non-critical CubeRover components and provides low level debugging abilities to ground systems.

CUBEROVER USER INTERFACE

The CubeRover user interface is designed to enable a diverse set of lunar missions by allowing teams of operators with different roles and responsibilities to collaborate with Astrobotic operators during the mission. The primary objective of the user interface is to allow simple command sending and receiving to and from the CubeRover, however, it is also modular to allow operator prioritization of interface elements that are particularly relevant to their role in ensuring mission success. This software platform is provided with the CubeRover and can be downloaded to customer computers for teleoperation at customer facilities via a direct connection to Astrobotic's Mission Control Center. Listed below are the key features that have been developed.



The teleoperated map as seen by the CubeRoverPayload Customer.

MAP

The map is a tool for planning rover missions and maneuvers. It contextualizes the rover's position and orientation relative to the lander and other features of the lunar surface, the understanding of which is critical to achieving the scientific objectives of the mission. It also provides tools for helping plan complicated but common maneuvers for the rover.

TELEMETRY VISUALIZATION

The telemetry visualization tool enables users to interpret non-image data from the rover to monitor for safety and science objectives.

IMAGE VIEWER

The image viewer is the primary tool operators use to understand the environment around CubeRover and is central to planning the rover's maneuvers. In addition to displaying images, the image viewer also now provides basic editing features, a timeline of past images and a comprehensive feature for naming and tracking points of interest on the lunar surface.

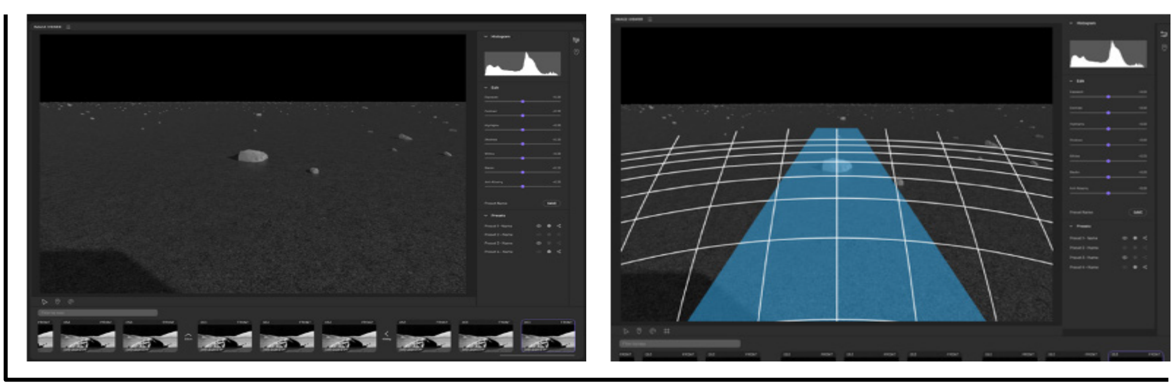
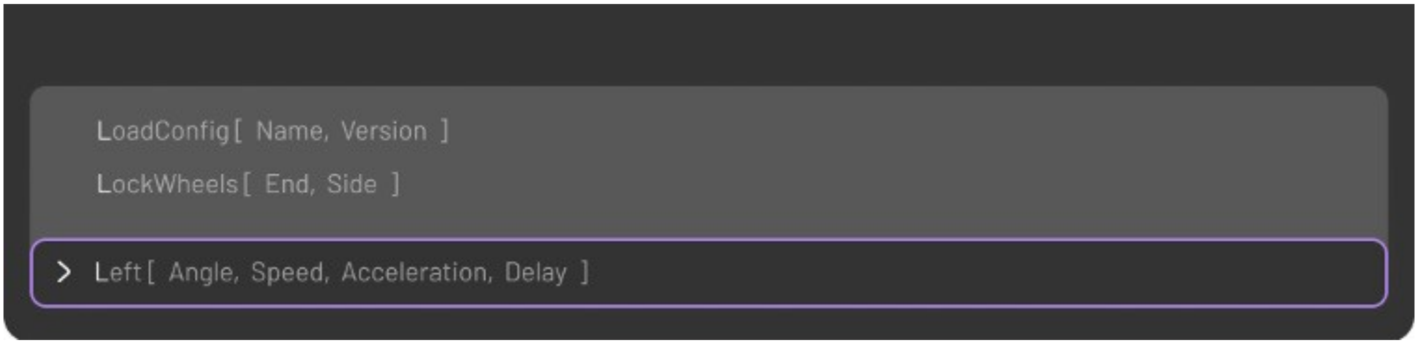


Image Viewer Interface.

COMMAND LINE

The command line provides a suite of advanced autofill and checking features to ensure that commands are created quickly and safely by operators.

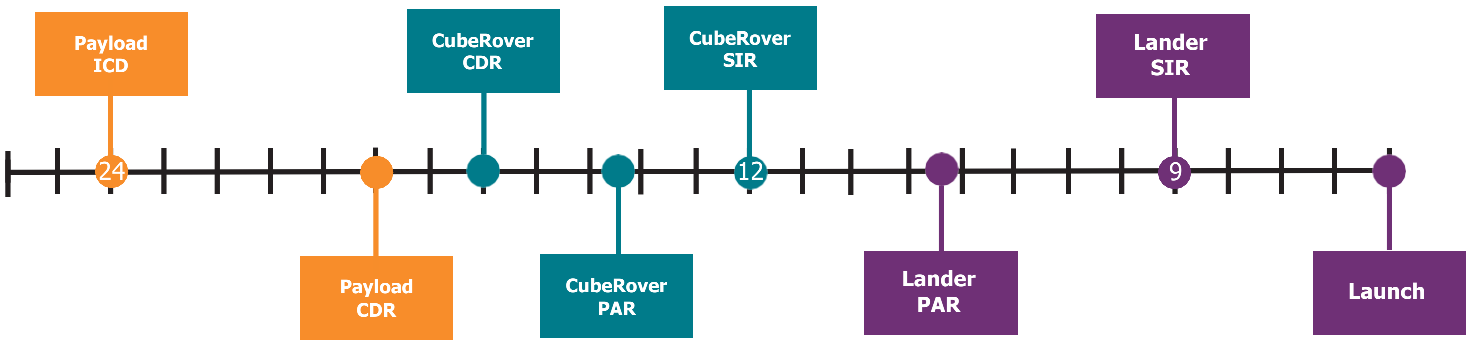


The command line interface.

CUBEROVER PAYLOAD INTEGRATION

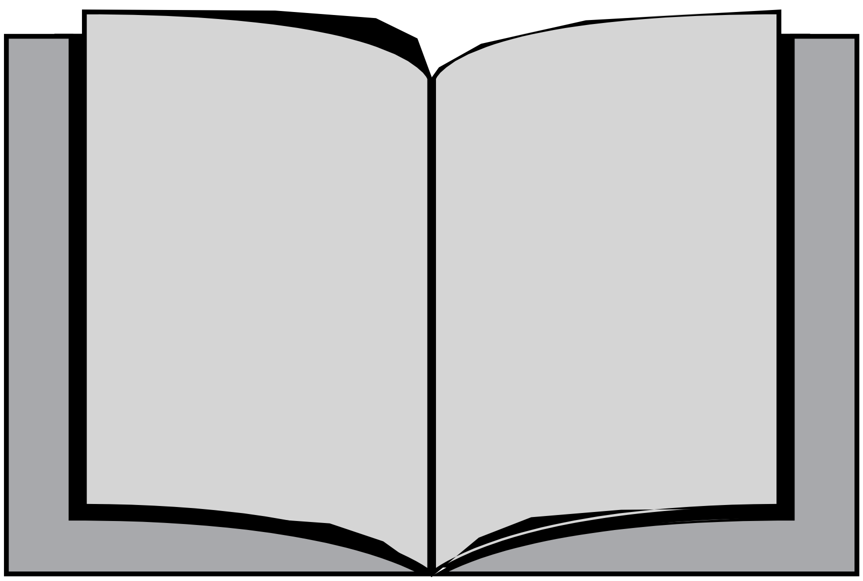
Following contract signature, a payload manager works with the customer to develop a CubeRover payload schedule and align it to the mission schedule.

The diagram below provides a high-level overview of Astrobotic's lander and CubeRover schedules. Astrobotic recognizes that a full set of formal milestone reviews is not necessary for every payload and works with the customer to appropriately tailor the schedule to the payload type and complexity.



PAR takes place at the Astrobotic integration facility and is led by the Astrobotic payload management team; it is mandatory for every payload. The relevant payload deliverables for the CubeRover PAR must be submitted to Astrobotic prior to the CubeRover PAR at L-10 months. The physical testing aspect of the PAR can be completed separately prior to Integration such that the customer can plan to deliver their flight configuration of the payload for acceptance and integration on the CubeRover between 10 and 8 months prior to launch. Leniency in the deadline is possible for less complex payloads utilizing fully standard interfaces.

Payload milestones prior to PAR are customer-led at facilities of the customer's choosing. For major milestones, as agreed upon during schedule development, an Astrobotic representative must be included in the review panel. This flexibility in payload schedule is achieved by means of payload deliverables packages that ensure Astrobotic milestone reviews are informed by the latest payload specifications.



GLOSSARY

GLOSSARY OF UNITS

UNIT	SIGNIFICANCE
bps	bits per second [data rate]
dB	decibel [sound pressure level referenced to $20x10^{-6}$ Pa]
°	degree [angle, latitude, longitude]
°C	degree Celsius [temperature]
g's	Earth gravitational acceleration [9.81 m/s2]
Hz	Hertz [frequency]
kg	kilogram [mass]
kPa	Kilopascal [pressure]
m	meter [length]
N	Newton [force]
%	percent [part of whole]
rad	rad [absorbed radiation dose]
s	second [time]
$	United States dollars [currency]
V (dc)	Volt (direct current) [voltage]
W	Watt [power]

GLOSSARY OF TERMS

TERM	SIGNIFICANCE
AMCC	Astrobotic Mission Control Center
APR	Astrobotic Payload Requirement
EMI	Electro-Magnetic Interference
FPGA	Field Programmable Gate Array
GNC	Guidance, Navigation, and Control
IAU	Integrated Avionics Unit
IWG	Integration Working Groups
LOI	Lunar Orbit Insertion
PMCC	Payload Mission Control Center
SEC	Standard Electrical Connector
SEU	Single Event Upset
UDP/IP	User Datagram Protocol / Internet Protocol
TLI	Trans-Lunar Injection
VPN	Virtual Private Network

GLOSSARY OF DOCUMENTATION

DOCUMENT	SIGNIFICANCE
ICD	Interface Control Document The document defines the final lander-payload interfaces and is signed by Astrobotic and the customer; the IDD is used as a template for this document.
PIP	Payload Integration Plan The document details the Payload Acceptance Review and Integration schedules as well as verification and validation procedures.
POP	Payload Operations Plan The document details the appropriate handling of the payload system; it is produced in part by the payload customer and guides Astrobotic operations.
PSA	Payload Services Agreement The document serves as the initial contract between Astrobotic and the payload customer; it defines programmatic expectations.
PUG	Payload User's Guide The document provides a high-level overview of the vehicle, mission, as well as the interfaces and services provided to payloads. *(this document)*
SOW	Statement of Work The document outlines the responsibilities of Astrobotic and the payload customer; it is part of the PSA.

GLOSSARY OF MILESTONES

DOCUMENT	SIGNIFICANCE
CDR	Critical Design Review The review focuses on the final design of the lander/payload and determines readiness to proceed with fabrication and testing.
FRR	Flight Readiness Review The review focuses on the integrated launch vehicle and determines readiness to proceed with launch operations.
LRR	Launch Readiness Review The review focuses on the integrated launch vehicle and determines readiness to fuel the vehicle and proceed with launch operations.
ORR	Operational Readiness Review The review focuses on the ground segment and determines end-to-end mission operations readiness.
PAR	Payload Acceptance Review The review focuses on the flight-model payload and determines readiness to integrate with the lander.
PDR	Preliminary Design Review The review focuses on the preliminary design of the lander/payload and determines a feasible design solution to meet mission requirements exists.
SIR	System Integration Review The review focuses on the flight lander/payload systems and determines readiness to proceed with assembly and testing.
TRR	Test Readiness Review The review focuses on the integrated lander and determines readiness to proceed with testing.

CONTACT US

Astrobotic provides several points of contact to address the varied needs of payload customers.

BUSINESS DEVELOPMENT

Our Business Development team is available to current and potential customersfor questions on the products and services we provide.

CUSTOMER RELATIONS

Our Customer Relations team is available to signed customers for general programmatic inquiries.

PAYLOAD MANAGEMENT

Our Payload Management team is available to signed customers for any mission-specific or technical needs.

To begin your payload journey, please contact usand we will be happy to direct you to the appropriate Astrobotic team member.

Email us at:
info-pm@astrobotic.com

We can also be reached using the following contact information:

1016 N. Lincoln
AvenuePittsburgh, PA
15233

412-682-3282

www.astrobotic.com
contact@astrobotic.com

QUESTIONNAIRE

For a more personalized experience, please include your specific payload needs when you contact us.

Payload Name

Payload Point of Contact: Name, Email/Phone

Payload Mission Objectives

Payload Preferred Launch Date

Payload Delivery Location: Lunar Destination [Orbit/Surface], Additional Parameters (e.g., orbital altitude, orbital inclination, surface region, proximity to a lunar surface feature)

Payload Mass

Payload Dimensions: Length x Width x Height, Description of Shape

Payload Power Needs: Nominal Power [Yes/No], Power (Release) Signal [Yes/No], Additional Needs

Payload Communications Needs: Wired Communication [Yes/No], Wireless Communication [Yes/No], Nominal SurfaceBandwidth [Yes/No], Heartbeat Bandwidth [Yes/No], Additional Needs

Payload Concept of Operations

Additional Requirements

NOTE: You can also share your payload mission details with us through our website. ***Configure Your Mission!***