ASTROBOTIC CUBEROVER™

Payload User's Guide

ASTROBOTIC

Publicly available document. Please contact Astrobotic Technology for more details.

www.astrobotic.com

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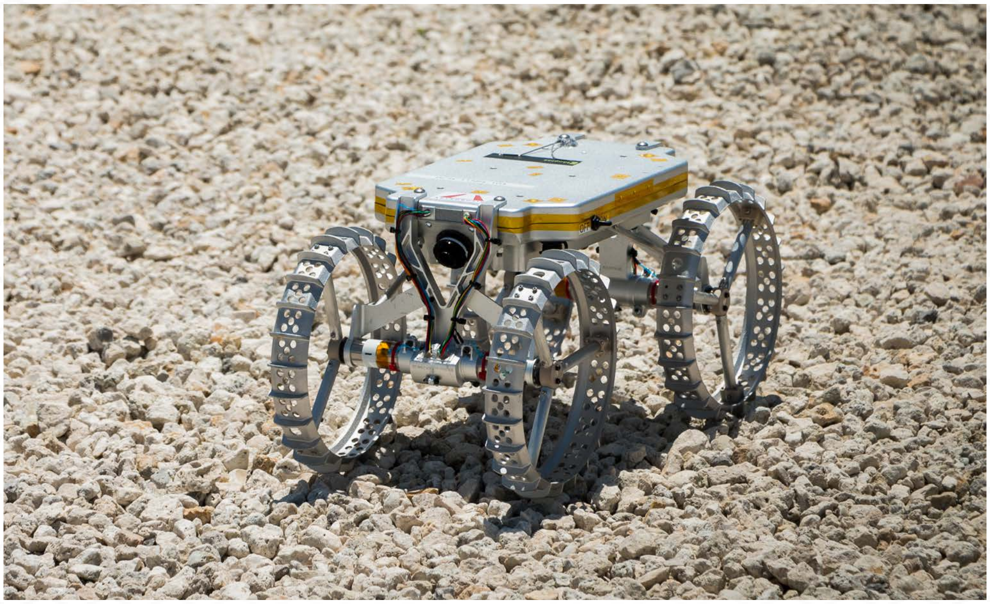
TABLE OF CONTENTS

CUBEROVER AT A GLANCE

CubeRover is Astrobotic's scalable planetary-class rover designed to revolutionize access to the Moon. CubeRover uses flight heritage and off-the-shelf components to perform science missions and technology demonstrations at a fraction of historical prices. Akin to CubeSats for the Lunar surface, each CubeRover unit, or "U", can support a 10 cm x 10 cm x 10 cm payload that weighs 1 kg. This standard configuration is scalable to sizes from 2U to 24U and larger to support payloads with diverse needs. With the CubeRover service, customers provide the payload, and Astrobotic provides the launch, lander, rover and mission operations.



KEY BENEFITS

CUSTOMIZABLE
CubeRover can be tailored to mission needs, including Lunar night survival and missions to craters and PSRs.

MODULAR
CubeRover supports internally- and externally- mounted payloads and can be transported on a variety of landers, providing flexibility for payload missions.

SCALABLE
CubeRovers of all sizes use the same power, thermal, structural, avionics, and software systems to minimize the cost and risk caused by non-recurring engineering.

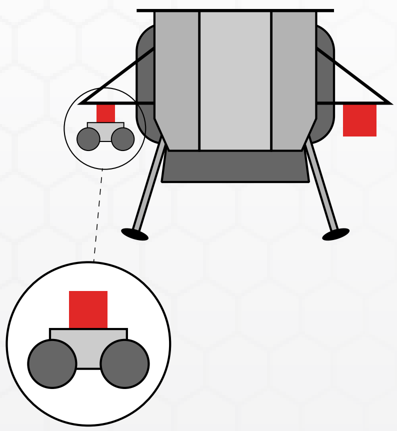
AFFORDABLE
CubeRover is orders of magnitude lighter than traditional rovers, offering significantly lower costs for payload customers.

TESTED
CubeRover is currently at Technology Readiness Level (TRL) 6, will reach TRL 7 in 2024 through a planned flight demonstration, and will reach TRL 9 in 2025 through an already-funded Lunar mission.

SERVICES OVERVIEW

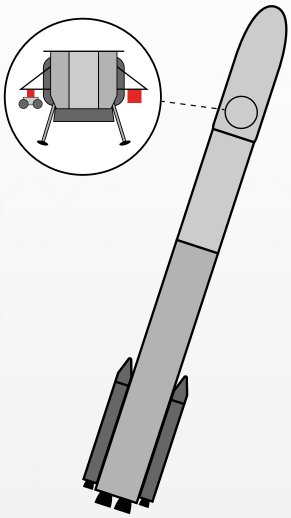
END-TO-END LUNAR DELIVERY

Astrobotic is a Lunar logistics company providing end-to-end payload delivery services to the Moon.



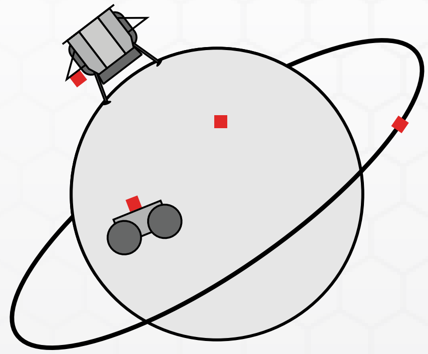
PAYLOAD INTEGRATION

On each mission, Astrobotic works with payload customers to integrate their payloads onto CubeRover and Astrobotic's Lunar landers, Peregrine and Griffin. CubeRover can also be integrated with non-Astrobotic landers.



LUNAR DELIVERY

Following integration, the payload is launched on a commercially-procured launch vehicle. The launch vehicle and lander safely deliver the CubeRover and payload to the Lunar surface.



PAYLOAD SERVICES

CubeRover provides power and data services to payloads during transit to the Moon and on the Lunar surface. Customers direct the CubeRover team where and when to drive their payload and collect data on the Moon.

Astrobotic's Payload Customer Service Program provides each customer with comprehensive support from contract signature to mission's end. This program equips the customer with the latest information on the mission and facilitates technical exchanges with Astrobotic engineers to ensure payload-to-spacecraft compatibility and overall mission success.

CUBEROVER PAYLOAD SERVICES

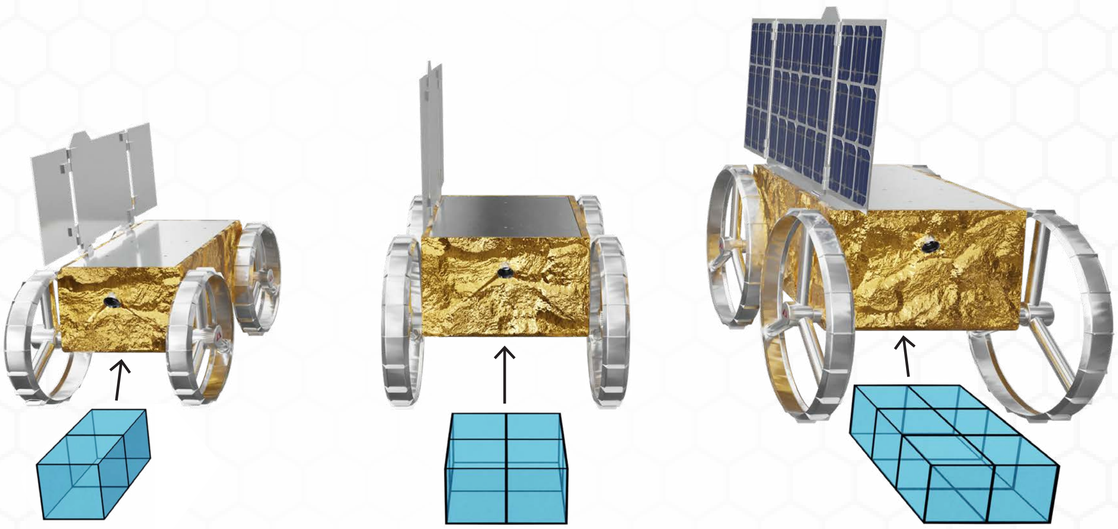
CubeRovers enable payload customers to carry out their own unique surface operations.

Companies, governments, universities, non-profits, and individuals can send and operate their payloads on the Moon's surface aboard a CubeRover at a price of $4.5M per kilogram of payload. Software payloads will be priced on a case-by-case basis. For high-mass payloads, bulk discount pricing is available.

Specifications are provided below for three CubeRover sizes (2U, 4U, and 6U), however larger CubeRover sizes are also available, including 12U, 24U, and larger. Standard payload configurations are enclosed within CubeRover's main structure. Custom payload accommodations outside the main structure and enhanced CubeRover capabilities are possible and can be discussed with the Astrobotic team.

Standard CubeRover sizes (2U, 4U, and 6U):

Payload volume configurations:



ROVER CLASS	2U	4U	6U
Rover Mass*	5 kg	8 kg	10 kg
Payload Mass	2 kg	4 kg	6 kg
Payload Volume	20 cm x 10 cm x 10 cm	20 cm x 20 cm x 10 cm	30 cm x 20 cm x 10 cm
Payload Power	1 W	2 W	3 W
Data Rate**	20 kbps	40 kbps	60 kbps

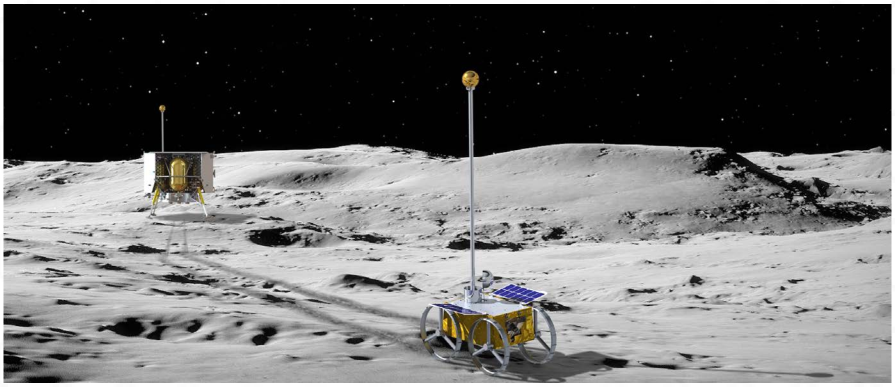
* "Rover Mass" includes the rover and rover-to-lander mounting and deployment system, but excludes the payload mass. The rover masses listed here are averages that may vary based on specific payload and mission accommodations.

** Data rates are lander-dependent and may vary depending on the exact lander and rover architecture for a given mission.

ENHANCED CAPABILITIES

CubeRover is an adaptable and scalable platform that can meet a wide variety of customer needs.

Astrobotic has developed a variety of enhanced capabilities that can be added to the standard CubeRover platform to fulfill additional mission requirements. Implementing enhanced capabilities will require additional engineering efforts that incur additional costs. Nonstandard requests will be evaluated on a payload-by-payload basis.



ENHANCED CAPABILITIES

SCALABILITY
To accommodate larger payloads, CubeRover can be scaled to sizes of 12U, 24U, and beyond.

LUNAR NIGHT SURVIVAL
Astrobotic has active NASA contracts to develop night survival capabilities for CubeRover to enable extended mission timelines.

LONG-RANGE COMMUNICATION
CubeRover can be equipped with a long-range comms system to enable direct-to-orbit communications.

INCREASED PERFORMANCE
CubeRover can provide additional power and bandwidth capabilities to meet customer requirements.

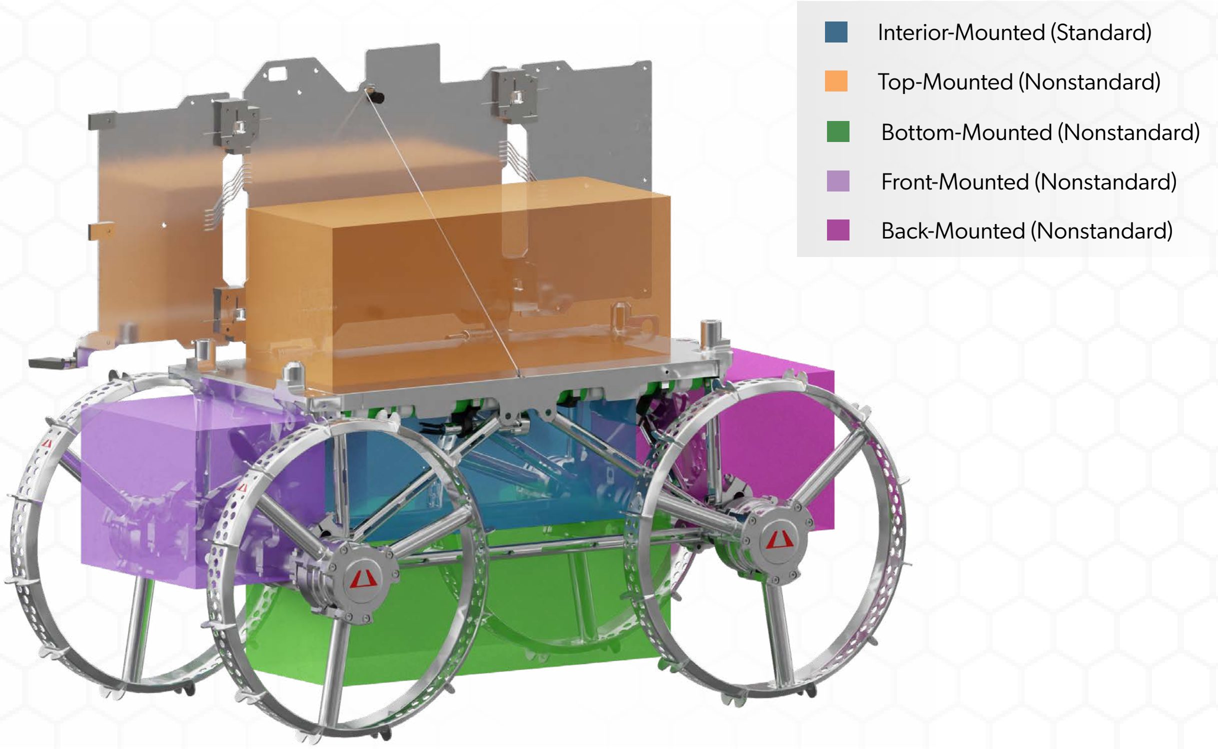
NONSTANDARD PAYLOAD ACCOMMODATIONS
CubeRover can accommodate payload placements in a variety of nonstandard locations to enable unique missions.

Additional information on enhanced capabilities is available upon request.
To learn more, please contact **lunarsurfacesystems@astrobotic.com**

PAYLOAD ACCOMMODATIONS

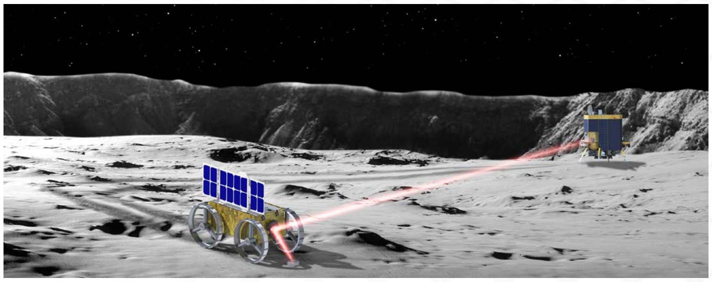
CubeRover offers several options for payload placement to enable unique mission objectives.

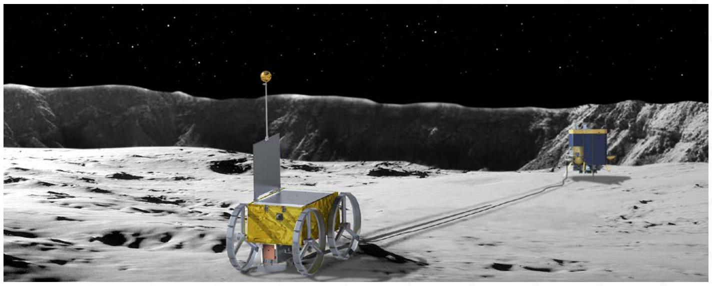
Astrobotic is committed to ensuring CubeRover payload customers complete their mission and acquire meaningful data. In support of this, CubeRover can offer additional flexibility for payload placement to meet customer needs. Nonstandard payload accommodations may incur additional costs and will need to be evaluated on a payload-by-payload basis.



NUMEROUS APPLICATIONS

1. Collect Lunar surface data and images
2. Perform experiments and validate new technology in the Lunar environment
3. Conduct resource prospecting and Lunar material collection
4. Provide rover marsupial operations or complimentary astronaut assistance
5. Deploy antennas, place cables, and establish other infrastructure elements on the Lunar surface





Examples of CubeRover missions using nonstandard payload accommodations.

PAYLOAD EXPERIENCE

1

SERVICES AGREEMENT

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

2

TECHNICAL SUPPORT

Astrobotic supports the payload customer by hosting regular integration working group meetings, participating in payload design cycle reviews, and facilitating payload testing with simulated rover interfaces. A CubeRover engineering unit can be made available to support payload testing and integration.

3

INTEGRATION

The payload is sent to the Astrobotic integration facility. Astrobotic accepts the payload and integrates it onto CubeRover. CubeRover is then subsequently integrated onto the lunar lander.

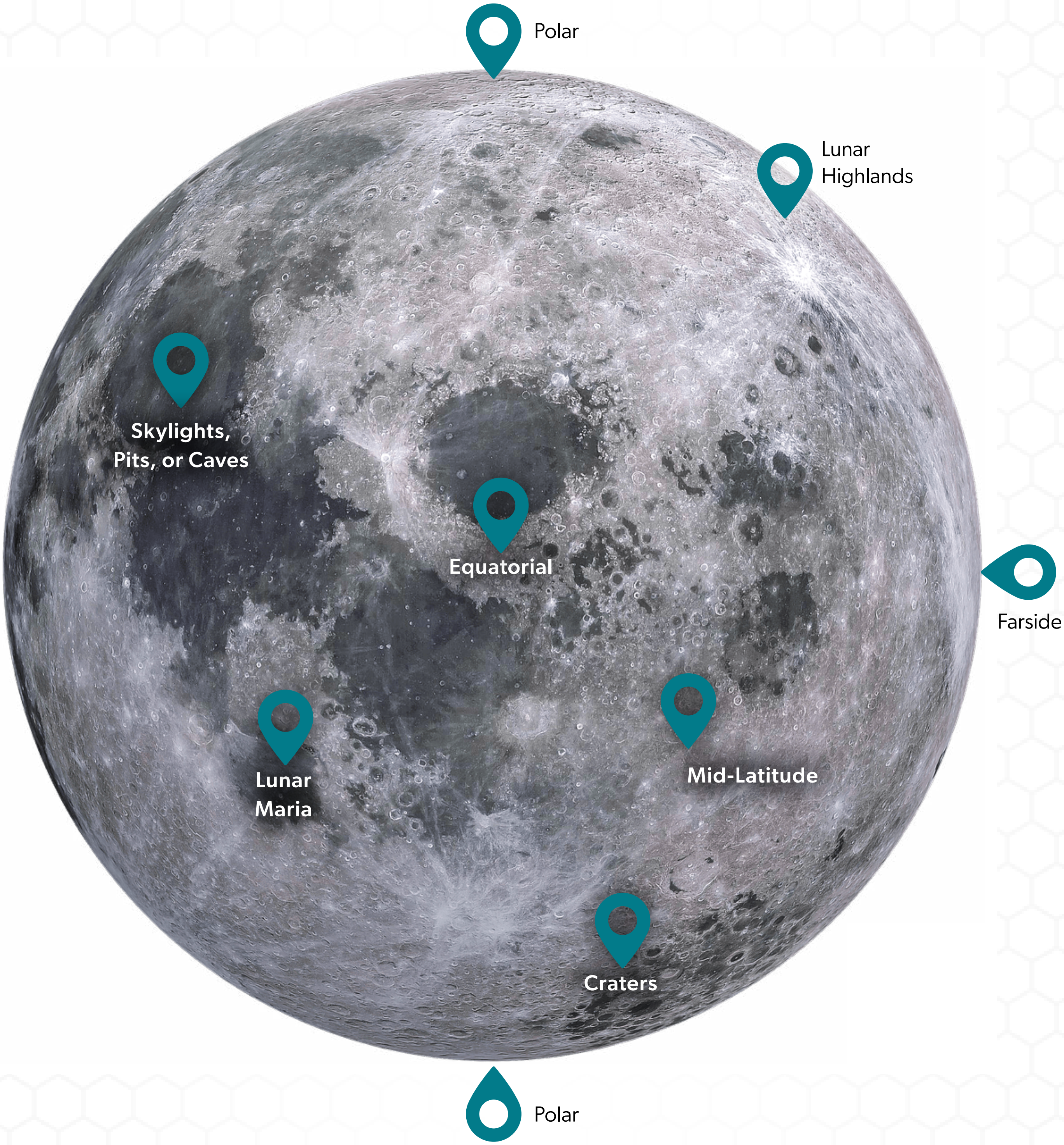
4

MISSION

The integrated rover is launched aboard the lander and commences its mission. The Astrobotic Mission Control Center connects the customer to their payload during the flight to the Moon and on the Lunar surface. All payload data collected on the Lunar surface is securely transferred to the customer.

CUBEROVER DELIVERY LOCATIONS

CubeRover has multiple configurations that enable payload operations anywhere on the Lunar surface, including polar and farside sites.

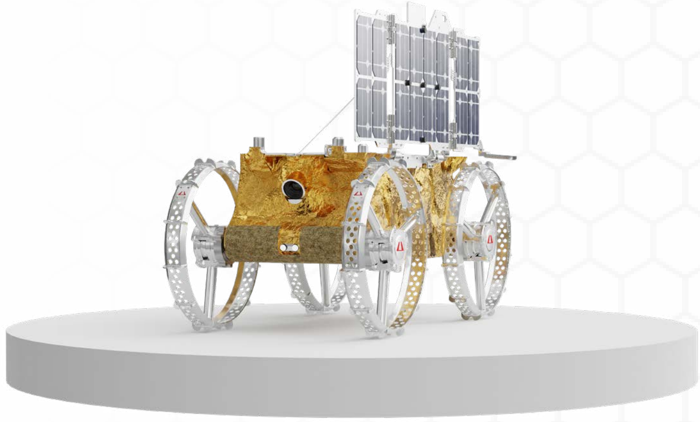



CUBEROVER

CUBEROVER SUBSYSTEMS OVERVIEW

CubeRover allows customers to achieve unique missions across the Moon using a standardized set of interfaces.

A core set of subsystems, known as the bus, define the CubeRover product line. The bus design enables safe payload traversability and operation on the Lunar surface. The systems of the CubeRover bus remain consistent throughout the product line, lowering the cost and risk across all CubeRover missions.



CUBEROVER SUBSYSTEMS

1 STRUCTURES
Provides the payload and CubeRover with a frame and protection from launch and landing environments.

2 THERMAL CONTROL
Regulates and controls thermal interfaces for the payload and CubeRover subsystems.

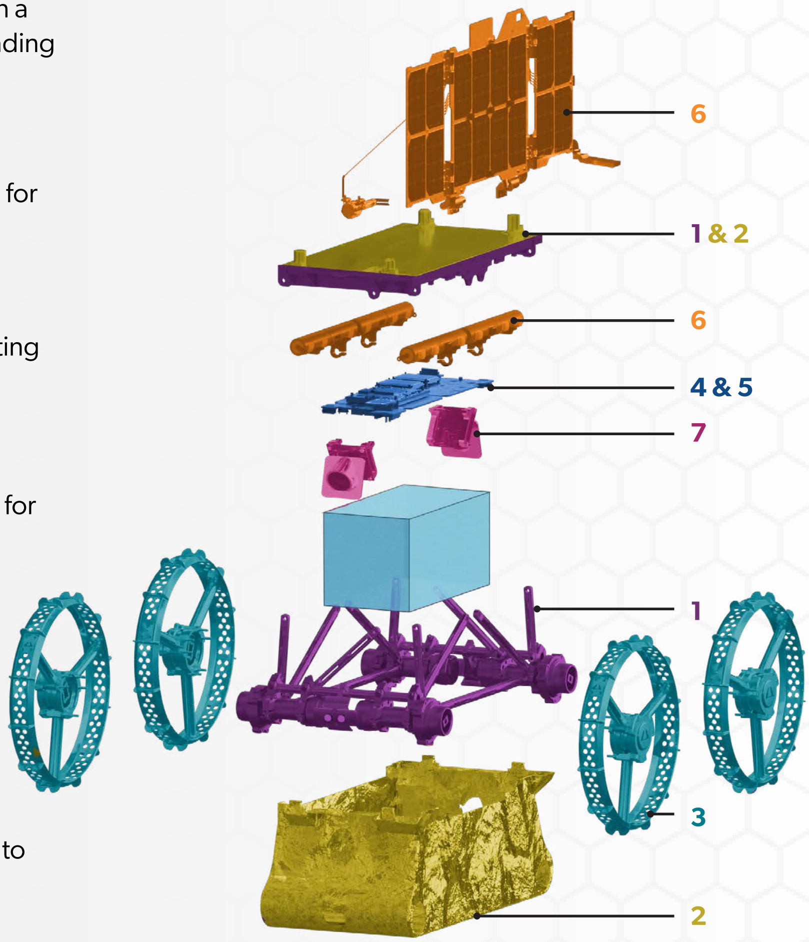
3 MOBILITY
Provides optimal performance for navigating the Lunar surface.

4 AVIONICS
Performs all command and data handling for the payload and CubeRover.

5 COMMUNICATIONS
Provides communication services that connect the customer's computer to the rover.

6 POWER
Generates, stores, and distributes power to the payload and CubeRover.

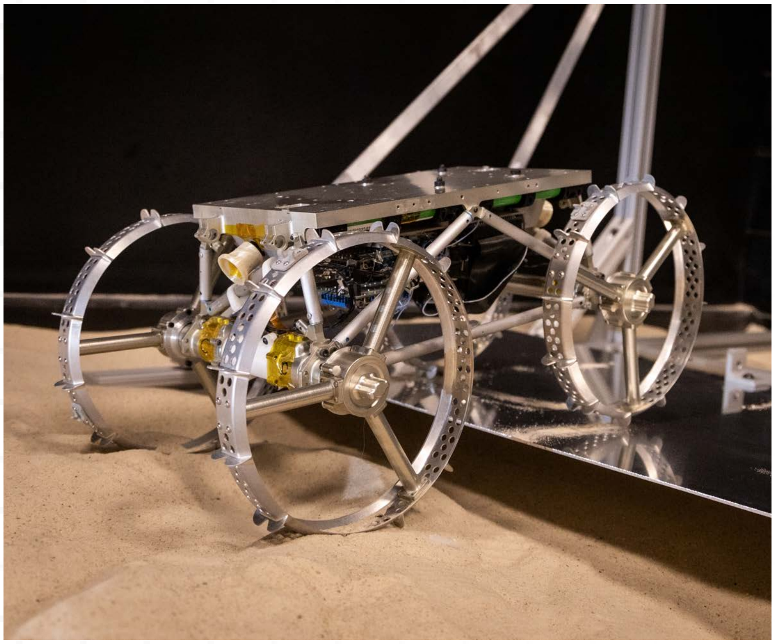
7 PERCEPTION & TELEOPERATION
Orients and controls CubeRover throughout the mission.



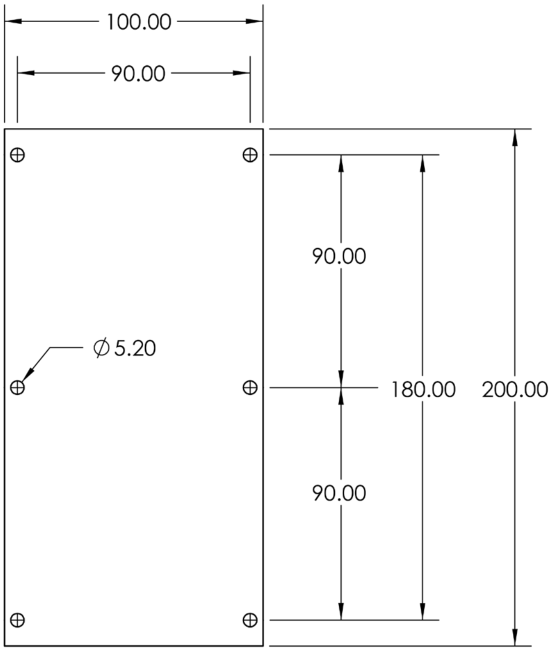
STRUCTURES

The CubeRover structure is strong, mass efficient, and simple, ensuring payload survival through launch and landing.

The key components of the CubeRover structure are the chassis frame and radiator surface. The chassis serves as the structural mounting interface for the rover's avionics, batteries, four drive actuators, cameras, and payload. The top panel of the structure functions as both a radiator and the mounting interface with the lander.



2U CubeRover Structure.



Bolt pattern for the 2U payload interface (all values are in units of mm).

KEY BENEFITS

PROTECTIVE
Machined from aerospace aluminum, composites, and advanced polymers, the chassis frame integrates structural and thermal components into a low-mass package. This structure is designed to protect customer payloads from launch vibrations, radiation, and Lunar regolith.

STANDARDIZED
All CubeRover frames provide a standardized bolt pattern interface to mechanically attach payloads. Bolt patterns for larger CubeRovers, as well as additional payload interface information, is available upon request.

STABLE
The structure's stiff frame improves the performance and sensing accuracy of CubeRover by keeping payloads and the CubeRover cameras precisely oriented while driving.

THERMAL CONTROL

CubeRover uses several methods of thermal control to guarantee payload survival in the harsh Lunar environment.

KEY COMPONENTS

RADIATOR - The top panel of CubeRover serves as a thermal heat sink for all components except the solar panels. All thermally-regulated components are grounded to the bottom of this space-facing radiator on the rover.

MULTI-LAYER INSULATION - The outside of the rover chassis is lined with a multi-layered insulation (MLI) blanket to reduce heat loss to deep space and to the regolith.

ELECTRIC HEATERS - Electric heaters are used to maintain payload temperature during the mission. If a payload is mounted external to the CubeRover, its thermal management can be accomplished using electric heaters and a conformal MLI implementation.

WHEEL SPOKES - A concern for any Lunar rover is the amount of heat lost through the wheel rims, both via conduction to the Lunar surface and via radiation to space. CubeRover's unique wheel structure uses long, thin, non-metallic wheel spokes to isolate and maintain the payload's temperature even when the wheel rims reach extremely cold temperatures.

PAYLOAD INTERFACE - The thermal interface between the payload and rover is determined on a case-by-case basis. A suitable conductive and radiative path is identified and designed to prioritize the thermal health of the payload during the mission.

MOBILITY

CubeRover uses high space-heritage motors, gearboxes, and encoders for optimal performance and reliability in navigating the Lunar surface.

CubeRover uses a fixed-axis, four-wheel independent drive with skid steering. Each actuator includes a motor, planetary gearhead, encoder, wire harnessing, thermal strapping, and wheel mount.

CubeRover mobility testing in regolith simulant.

3D-printed CubeRover wheel prototypes.

CubeRover's wheel rims provide high traction for traversing uneven Lunar terrain and loose regolith. Many types of mobility tests, including drawbar pull and slope climb tests, are performed at Astrobotic's Lunar Regolith Lab (LRL). These tests utilize GRC-1 Lunar regolith simulant and a reduced-mass rover to mechanically replicate the rover's soil-wheel interaction in a Lunar environment.

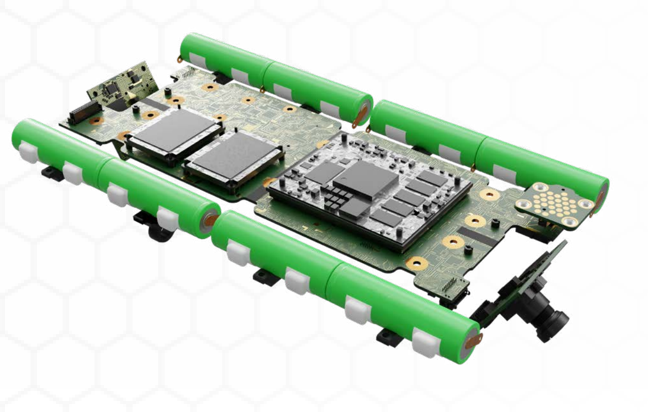
Results from 2U CubeRover mobility testing are shown in the table below. Mobility specifications for the 4U and 6U CubeRovers are available upon request.

RESULTS FROM 2U CUBEROVER MOBILITY TESTS	
Maximum Demonstrated Slope Climb	25°
Maximum Demonstrated Step-Up Height	10 cm
Standard Drive Speed	4 cm/s
Maximum Drive Speed	10 cm/s
Maximum Ground Clearance (on a Hard Surface)	7 cm

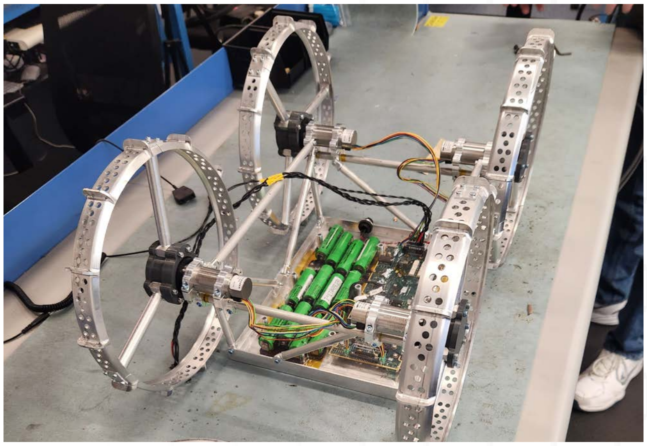
AVIONICS

CubeRover's avionics perform all command and data handling for the rover.

CubeRover's avionics are primarily comprised of an integrated avionics unit (IAU) that combines power distribution and management, data processing, controls, and communications. This simplifies the overall system into a low-mass package with a minimal number of potential failure points. The IAU is mounted directly to the radiator, allowing for the best possible heat transfer away from the sensitive circuits.



Model of integrated avionics unit.



Previous version of avionics unit integrated in CubeRover.

The IAU is comprised of a carrier board and processor board. The primary processor is responsible for parsing incoming commands from the ground, triggering the camera system, commanding the motor controllers, managing the storage and retrieval of system data, and managing payload commands. To ensure robust, safe operation of the IAU, a separate processor is used as a watchdog monitor which can 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. Additionally, CubeRover utilizes a 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.

AVIONICS	
Payload I/O Space	20 Pins Available
Data Storage	4 GB Maximum
CubeRover Safety Features	EDAC, Software Robustness

COMMUNICATIONS

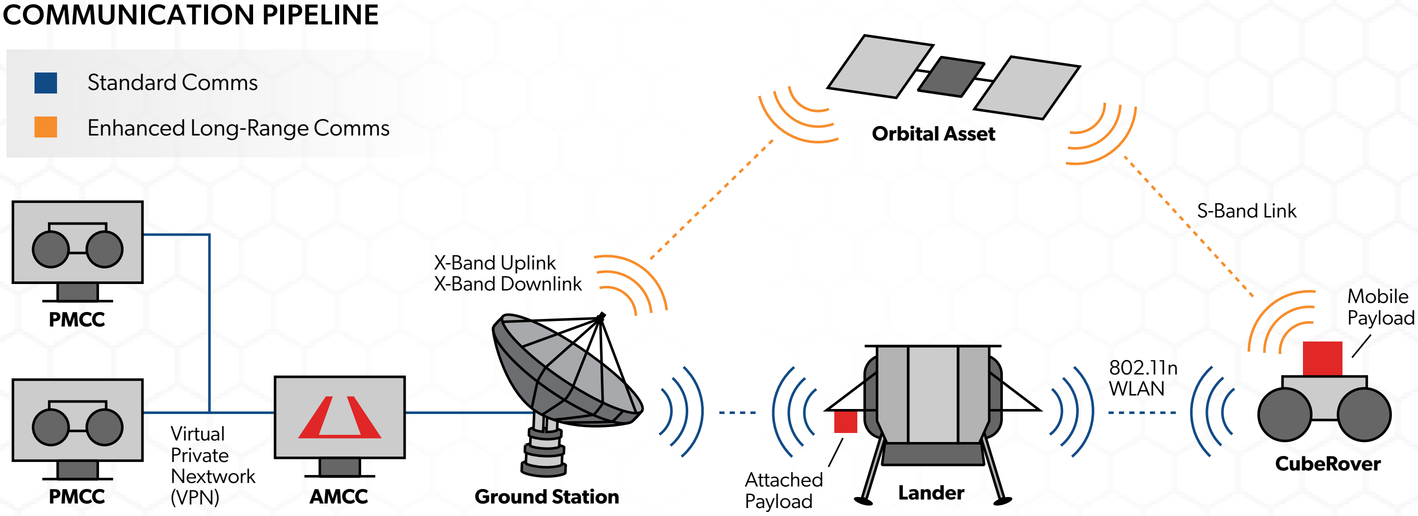
CubeRover leverages Astrobotic's lander communications network as a relay to receive commands and send telemetry data.

Downlinked payload data and uplinked payload commands are transferred between the customer's Payload Mission Control Center (PMCC) and the Astrobotic Mission Control Center (AMCC) using TCP/IP over a virtual private network (VPN). All data and commands are also stored in Astrobotic's telemetry database for redundancy.

The AMCC in turn communicates with the lander through ground station dishes, which utilize X-band frequencies for both uplink and downlink. Finally, the lander communicates with the CubeRover – and thus the customer payload – via a Serial RS-422 wired connection during transit and a 2.4 GHz 802.11n WiFi connection after CubeRover is deployed to the Lunar surface.

For payloads that must travel farther than 200 m from the lander (beyond the range of WiFi), or that require mission durations greater than one Lunar day, the WiFi system can be replaced with a long-range S-band communications system at additional cost. This S-band system enables CubeRover to communicate with Earth via a Lunar orbital relay satellite, rather than the lander, placing no communications-dependent limit on the CubeRover's range from the lander.

COMMUNICATION PIPELINE



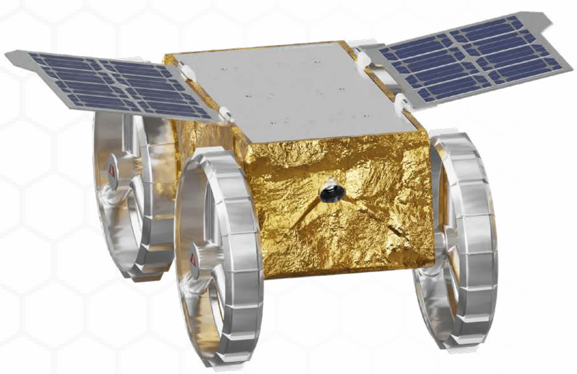
COMMUNICATIONS		
COMMS SYSTEM OPTIONS	STANDARD COMMS (VIA LANDER)	ENHANCED LONG-RANGE COMMS (VIA ORBITAL RELAY SATELLITE)
CubeRover Payload Wired Protocol	Serial RS-422	Serial RS-422
CubeRover Wireless Protocol	802.11n WiFi	S-band link
CubeRover Wireless Frequency	2.4 GHz	2.25 GHz
Communication Bandwidth	10 kbps per kg*	10 kbps per kg
CubeRover Range from Lander	200 m	No limit

* Data rates are lander-dependent and may vary depending on the exact lander and rover architecture for a given mission.

POWER

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

CubeRover utilizes a pogo pin-style electrical connector to receive power from the lander during transit to the Moon. Following egress from the lander, CubeRover deploys solar panels with flight heritage solar cells, which allows CubeRover to generate continuous power while roving. There are two standard options for solar panel configurations, one optimized for equatorial operations, and the other optimized for polar operations. These configurations allow CubeRover to operate successfully anywhere on the Moon.



Equatorial Configuration

Polar Configuration

CubeRover's avionics include DC-to-DC converters along with circuits to supply the required power for the various integrated circuits and subsystems, as well as manage the batteries and solar panels. Batteries are monitored and balanced by a dedicated battery monitor circuit. While the IAU operates at 28 Vdc, onboard power regulation provides several additional, lower-level DC voltages for the rover subsystems and customer payload. The DC-DC converters have a variety of over current and over voltage protections.

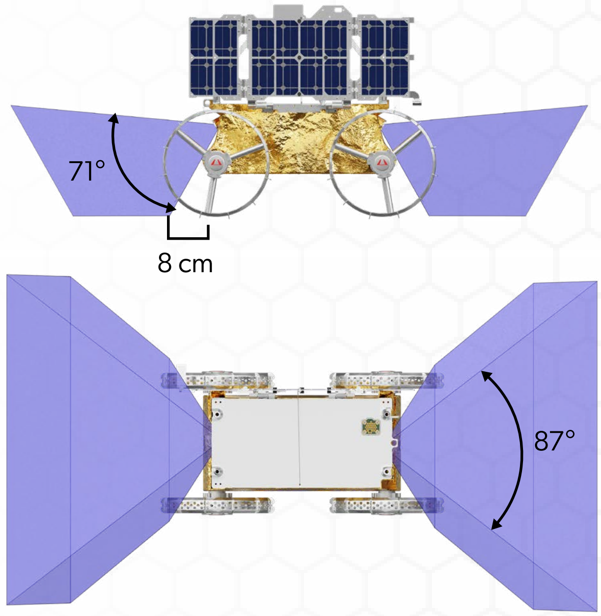
STANDARD PAYLOAD POWER	
Payload Power	0.5 W per kg continuous, 10 W peak
Payload Power Interface	28 Vdc
CubeRover Battery Composition	$LiFePo_4$

PERCEPTION AND TELEOPERATION

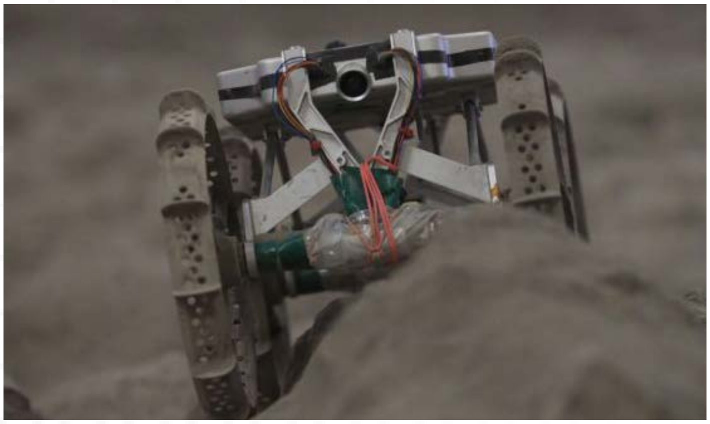
CubeRover's cameras and teleoperation system allow payload customers to monitor and drive the rover throughout the mission.

CubeRover is capable of capturing and transmitting images of varying sizes and compressions. Two monocular, 1.3 megapixel cameras are used for navigation. Additional customer camera arrangements are also possible. Please contact Astrobotic to learn more.

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 rover will travel over a given time. 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.



Camera vertical and horizontal fields of view.



CubeRover Camera.

Simulated CubeRover field of view.

TELEOPERATIONS	
Localized Precision	0.06 millimeters per meter
Nominal Speed	4 cm/s
Cameras	Front and rear view, 1.3 megapixel resolution

ENVIRONMENTS

MECHANICAL ENVIRONMENT

CubeRover's mechanical environments are enveloped by those of the launch and surface deployment phases.

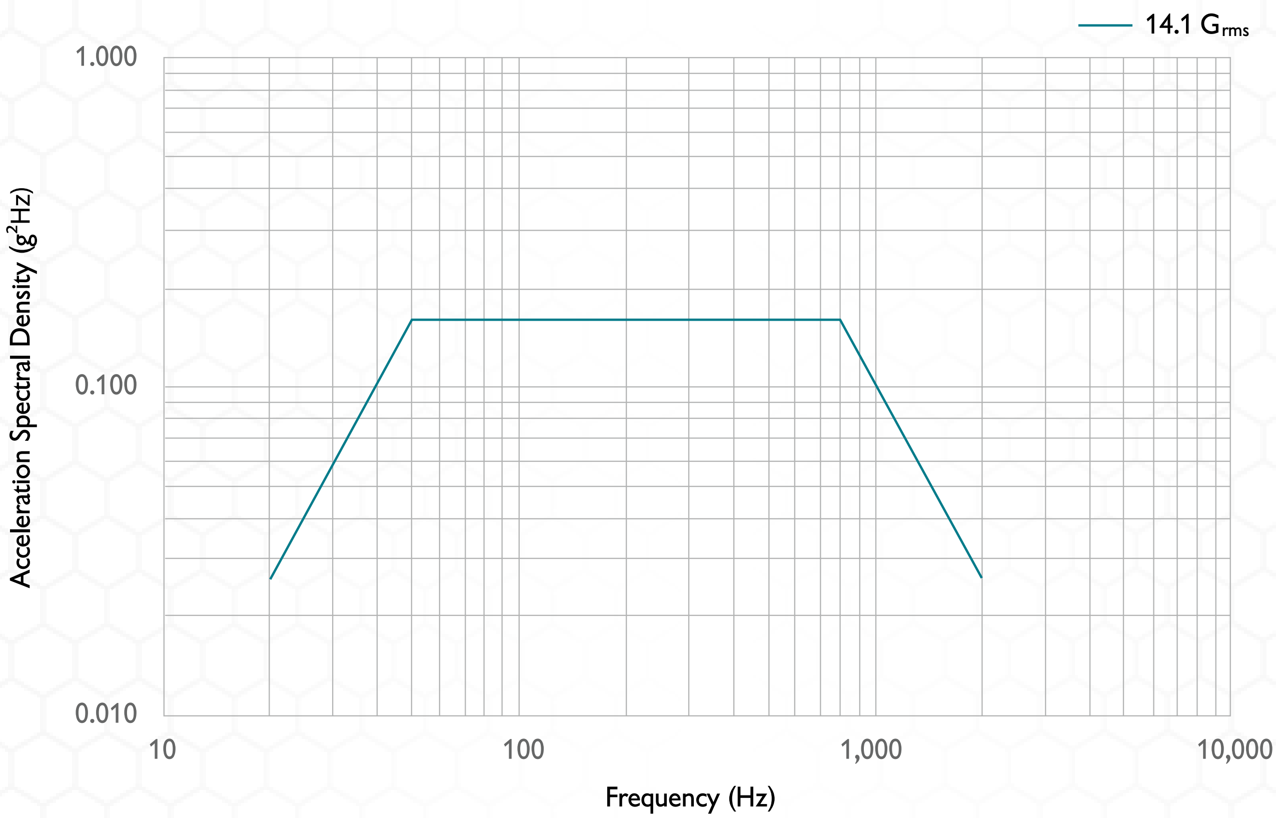
CubeRover's mechanical environments, presented below, are based on GSFC-STD-7000A (General Environmental Verification Standard (GEVS)) and apply to the majority of payload mounting locations. However, mission-specific configurations and payload placement may impact expected loads. Astrobotic will work with the customer to characterize payload-specific environments for relevant analysis and testing prior to integration.

SINE VIBRATION LOADS

Astrobotic performs a coupled loads analysis with the launch vehicle provider and develops sine vibration load profiles for each payload based on the mounting location, payload mass properties, launch vehicle, and specific lander configuration. Please contact Astrobotic for more details.

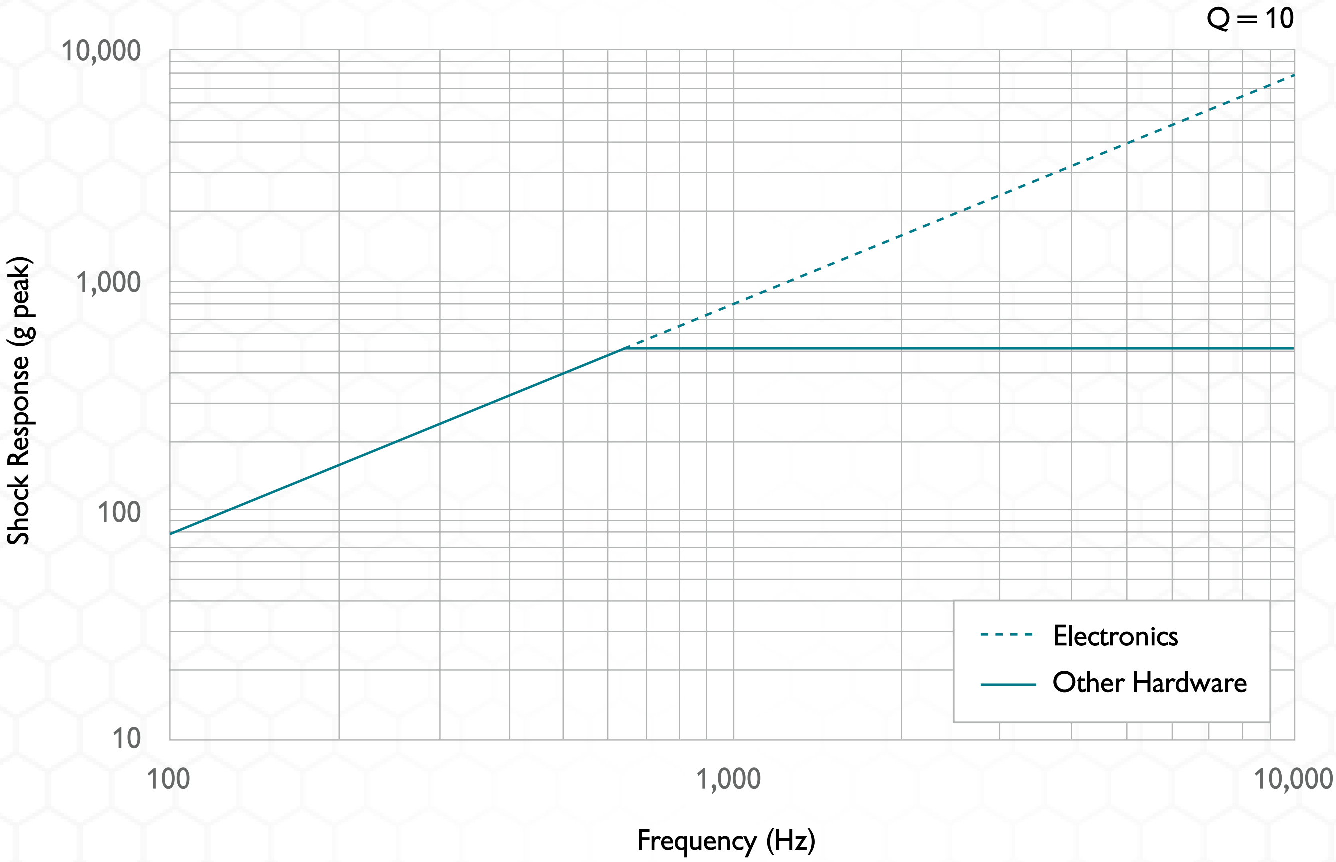
RANDOM VIBRATION LOADS

Random vibration loads on payloads can arise from unsteady engine combustion, exhaust noise, and turbulent flows along the launch vehicle. The plot below shows the limiting loads for random vibration along all axes. A duration of two minutes per axis may be assumed.



SHOCK LOADS

CubeRover payloads encounter multiple shock events during launch, landing, and deployment. Payloads should be prepared to endure a few shock events with limiting loads as shown in the plot below. Limiting shock loads are driven by the hold-down-release-mechanisms releasing during CubeRover deployment.



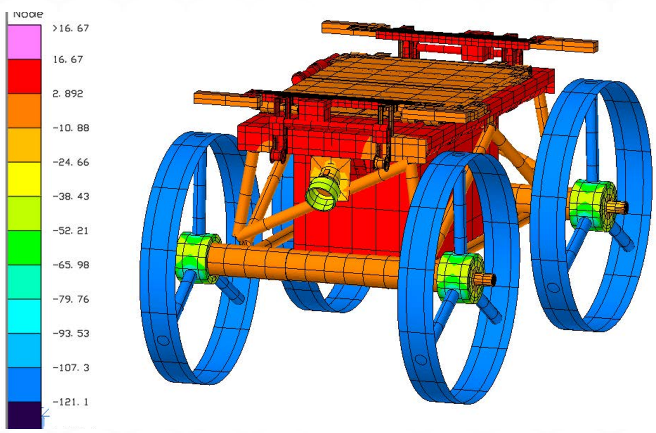
NOTE: Payloads may reference GSFC-STD-7000A (GEVS) for more details on sine, random, and shock environments and testing.

THERMAL ENVIRONMENT

CubeRover encounters a variety of thermal environments throughout a Lunar mission and uses its thermal control system to manage the payload's temperature.

From pre-launch until deployment, CubeRover's thermal environment is dependent on the rover's mounting location on the lander and the incident sunlight at that location throughout the mission. While CubeRover's thermal environment varies slightly from mission to mission based on its integration on the lander, CubeRover generally experiences a subset of the temperature ranges at the rover mounting interface. Approximate temperature ranges at the CubeRover mounting interface during a typical Astrobotic mission are shown in the table below.

Mission Stage	Lander Temperature Range (°C)
Pre-Launch and Launch	0 to 27
Transit	-40 to 60
Lunar Orbit	-120 to 100
Surface	-30 to 80



Representative example of CubeRover thermal analysis.

After deployment from the lander to the Lunar surface, excess thermal energy produced by the payload is dissipated through CubeRover's radiator to maintain the payload within its required temperature range. The nominal payload steady state heat dissipation that can be supported by CubeRover while stationary is shown in the table below.

CubeRover Class	Maximum Available Payload Steady State Thermal Dissipation	
	Polar Locations	***Equatorial Locations***
2U	15 Watts	13 Watts
4U	23 Watts	20 Watts
6U	30 Watts	26 Watts

PRESSURE AND HUMIDITY ENVIRONMENTS

PRESSURE ENVIRONMENT

CubeRover encounters a steep reduction of pressure during launch.

PRE-LAUNCH

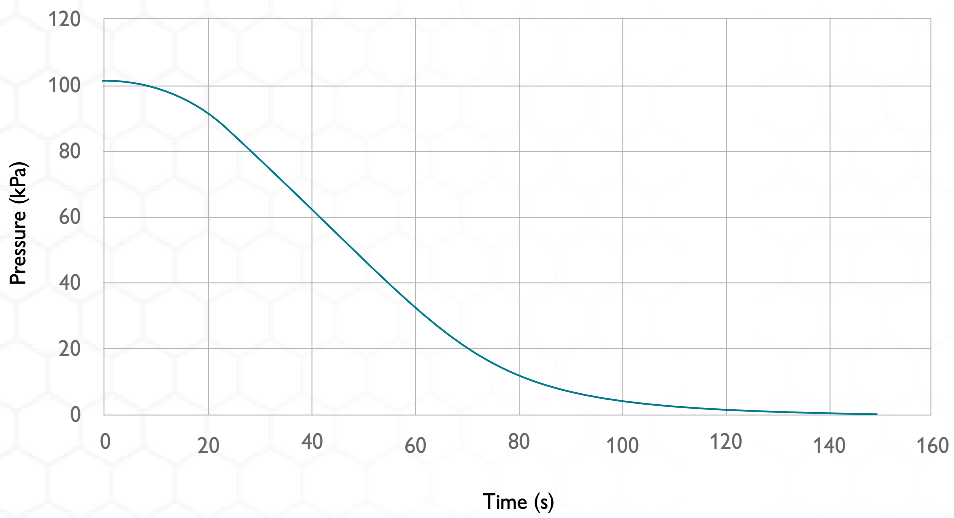
Prior to launch, CubeRover and the payload are exposed to standard atmospheric pressure, which has an average value of 101.25 kPa at sea level and will vary across the integration and launch sites based on their elevations and local weather conditions.

LAUNCH

During launch, CubeRover and the payload experience a steep pressure drop, which envelopes the pressure gradients experienced during all other mission phases. The plot below shows a typical pressure drop curve for launch. The 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

For the remainder of the mission, CubeRover and the payload will experience the vacuum of deep space, which has a nominal value of 3.2×10^{-5} kPa.



HUMIDITY ENVIRONMENT

CubeRover is maintained within a controlled humidity environment prior to launch.

LAUNCH

Prior to launch, CubeRover and the payload are kept to humidities of 50% ± 15% inside the climate-controlled integration and launch site facilities. The upper end of this range may occur during transportation, depending on the local climate conditions at the pick-up and drop-off locations.

REMAINING MISSION

Following launch, the payload will be exposed to the vacuum of space, which has 0% humidity.

PARTICLE AND CONTAMINANT ENVIRONMENTS

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

PRE-LAUNCH

Planetary Protection regulations govern the pre-launch particle and contaminant environments. Assembly and maintenance of CubeRover and payloads must occur in a 100k or ISO Class 8 cleanroom, which Astrobotic provides at the integration and launch facility sites. The payload customer must ensure compliance with Planetary Protection protocols prior to delivering the payload to Astrobotic's integration facility.

Astrobotic Headquarters contains two 100k (ISO Class 8) cleanrooms for integration activities.

TRANSIT, LUNAR ORBIT, AND LANDING

Firing the main and thruster engines of the lander during landing may expel a minute 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 OPERATIONS

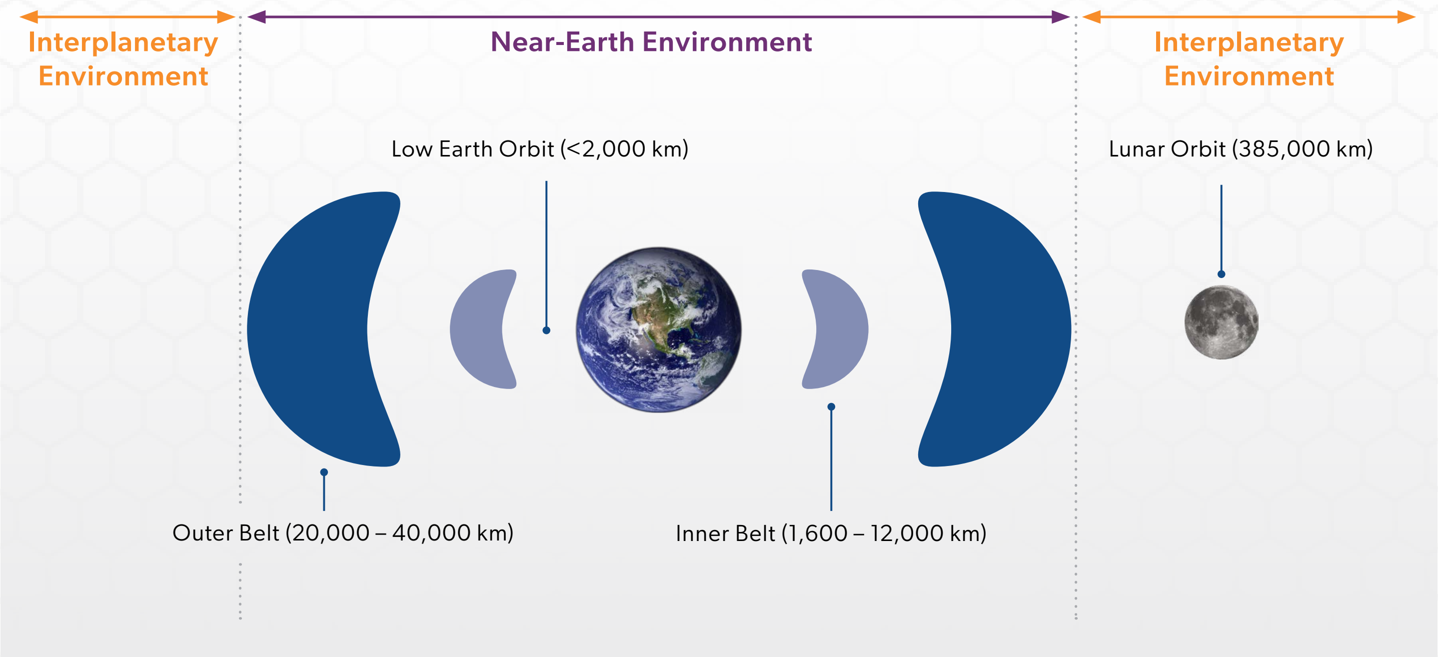
During landing, landers will displace an unknown amount of Lunar regolith, which may take several hours or days to fully settle. Lunar regolith is sharp and may cause damage to sensitive components if mounted outside the standard CubeRover payload envelope. Lunar regolith is also electrostatically charged, which may cause it to cling to payload surfaces if mounted outside the standard CubeRover payload envelope. Additional regolith lofting may occur due to post-landing CubeRover deployment, driving, and surface operations. 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

CubeRover encounters the following approximate ionizing radiation environments on a typical mission.

When CubeRover is delivered to the Moon on Astrobotic's Peregrine or Griffin landers, it may experience 3 to 15 days in the near-Earth environment during the launch and transit phases, and 14 to 38 days in the interplanetary environment from the transit phase onwards. The final trajectory will depend on the exact launch configuration and launch date.

The greatest exposure to radiation will occur in the near-Earth environment within the Van Allen radiation belts. The Van Allen belts contain energetic protons and electrons that are trapped in the Earth's magnetic field and generally follow the Earth's magnetic field lines. The general structure of the Van Allen belts can be seen in the highly simplified diagram below.



NEAR-EARTH ENVIRONMENT

The near-Earth environment is dominated by 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.

INTERPLANETARY ENVIRONMENT

The interplanetary environment is outside the shielding effects of Earth's magnetic field. A dose rate of 1 rad/day is predicted based on the expected ionizing radiation per Earth day in the interplanetary environment.

TOTAL IONIZING DOSE

The total ionizing dose (TID) typically is not expected to exceed 1 krad over the entire mission. 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

CubeRover and all payloads must be designed for compliance with the Control of Electromagnetic Interference Emissions and Susceptibility document (MIL-STD-461G) for radiated and conducted emissions.

The table below shows the appropriate testing to perform for active payloads. Please contact Astrobotic for additional information or the latest version of the relevant requirements for MIL-STD-461G.

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	Active Payloads

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.

MISSION OVERVIEW

PRE-LAUNCH TECHNICAL SUPPORT

Astrobotic's Payload Customer Service Program provides customers with all the tools necessary to design a payload that successfully interfaces with CubeRover.

The Payload Customer Service Program includes the following features:

PAYLOAD CUSTOMER SERVICE PROGRAM

1. Availability for general and technical inquiries.
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 testing.
6. Access to a CubeRover engineering unit to support payload functional 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 this PUG.

ENVIRONMENTAL TESTING

To ensure mission success for payload customers, CubeRover will undergo extensive testing to verify it can withstand the harsh environments during launch and surface operations.

Past CubeRover units have undergone vibration, thermal vacuum, EMI/EMC, and rover mobility qualification tests based on NASA standards. These successful tests have advanced CubeRover to a TRL of 6.

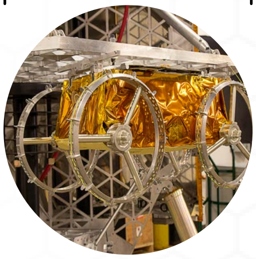
Highlights from CubeRover's completed test campaigns.

MISSION PHASES

INTEGRATION

After pre-launch technical development and CubeRover environmental testing, the next step is payload integration. Payloads must be delivered to Astrobotic 8-10 months prior to launch for integration with CubeRover. Integration of the CubeRover to the lander then typically begins 8 months prior to launch. Following integration, Astrobotic will perform functional tests to confirm successful integration.

L-8 to 10 months



Integration
The payload is integrated and tested with the CubeRover and lander.

LAUNCH

Two months prior to launch, the integrated lander is shipped to the launch site for integration to the launch vehicle. CubeRover and the payload remain powered down throughout launch site integration and through launch itself.

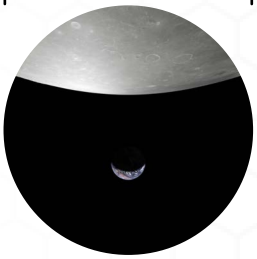
L-0 days

Sleep
The payload remains powered down through launch site processing and launch.

TRANSIT

Once the lander separates from the launch vehicle and begins its transit to the Moon, it will begin providing power to the CubeRover and payload. Astrobotic will perform an initial status check, which can be repeated periodically during transit as required. Throughout transit, CubeRover will transmit heartbeat data to the ground via its wired connection to the lander, as well as monitor and maintain safe thermal levels for the payload.

L+1 day



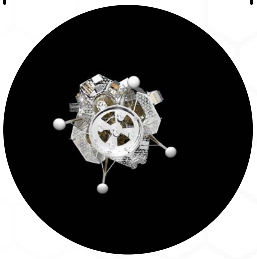
Transit Status Check
CubeRover powers on and performs a payload status check.

Heartbeat
CubeRover remains in a low power state, transmits heart-beat data, and maintains temperature.

LANDING

During landing, CubeRover returns to sleep mode, with the power provided to CubeRover kept to the minimum required for thermal management.

L+18 to 49 days at most



Sleep
CubeRover and the payload are again powered down for landing.

DEPLOYMENT

After landing, the lander will begin providing full power and data services to the CubeRover. Astrobotic ground operators will perform a wired status check that includes a test of the radio and verification that the rover is ready for deployment. Following the status check, operators will activate CubeRover's release mechanism. Once released, the CubeRover will gently lower to the ground on a set of tethers, sever the tethers, and come to rest.

L+10 days

Mission Wired Status Check
Powers on and performs status check including WiFi and charge state.

Deployment
Descends from lander on signal from Astrobotic.

SURFACE OPERATIONS

Following deployment, CubeRover enters the Surface Operations phase of the mission. During this phase, the primary objective is the completion of the customer's payload objectives for the mission.

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 Astrobotic-provided user interface that streams live data and images from the Lunar surface for real-time decision making. Spacecraft-to-Earth communication windows are nominally scheduled for cycles of 7 hours "on" and 1 hour "off", providing up to 87.5% uptime during surface operations.

Standard CubeRovers are not designed to survive or support operations after the first Lunar day. However, Astrobotic is developing CubeRover night survival capability through active NASA contracts and expects it to be available to customers in the near future at additional cost. Please contact Astrobotic for more information.

L+10 to 24 days at most

Operation
CubeRover performs surface operation tasks of driving, imaging, and collecting payload data.

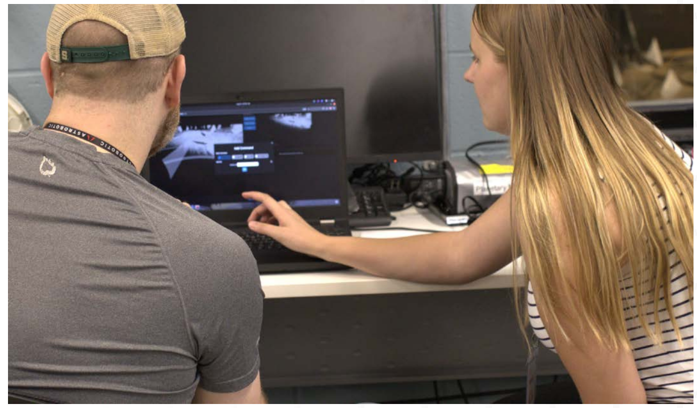
Maintenance
CubeRover performs system maintenance tasks.

MISSION OPERATIONS TOOLS

CubeRover's user interface allows payload teams to collaborate with Astrobotic operators throughout the mission.

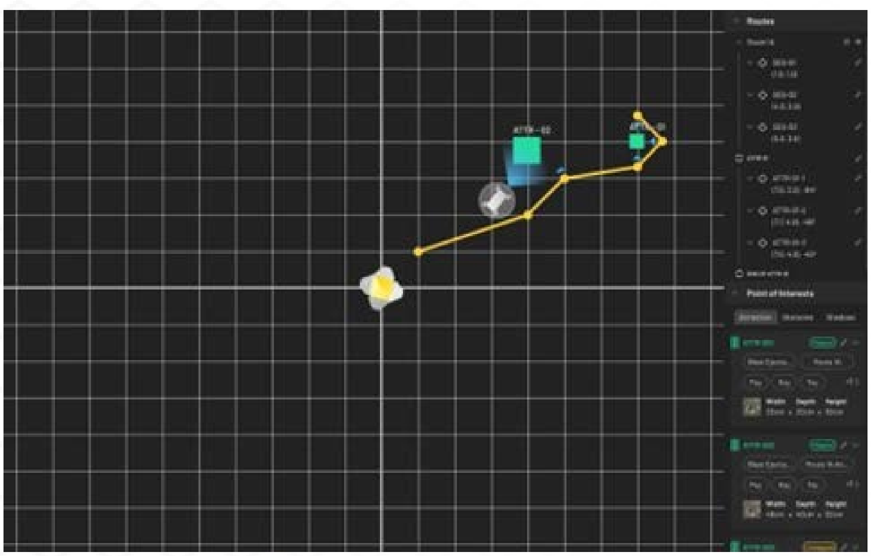
CubeRover comes with a user interface for sending commands to and receiving data from the rover. The interface is bundled as a software package that can be downloaded to customer computers, enabling customers to teleoperate the rover from their facilities via a direct connection to the AMCC.

The software is modular by design and features four primary interfaces: Map, Image Viewer, Telemetry Visualizer, and Command Line. Operators can select the interface element most relevant to each step of payload operations planning and execution.



MAP

The Map interface 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 maneuvers of the rover.



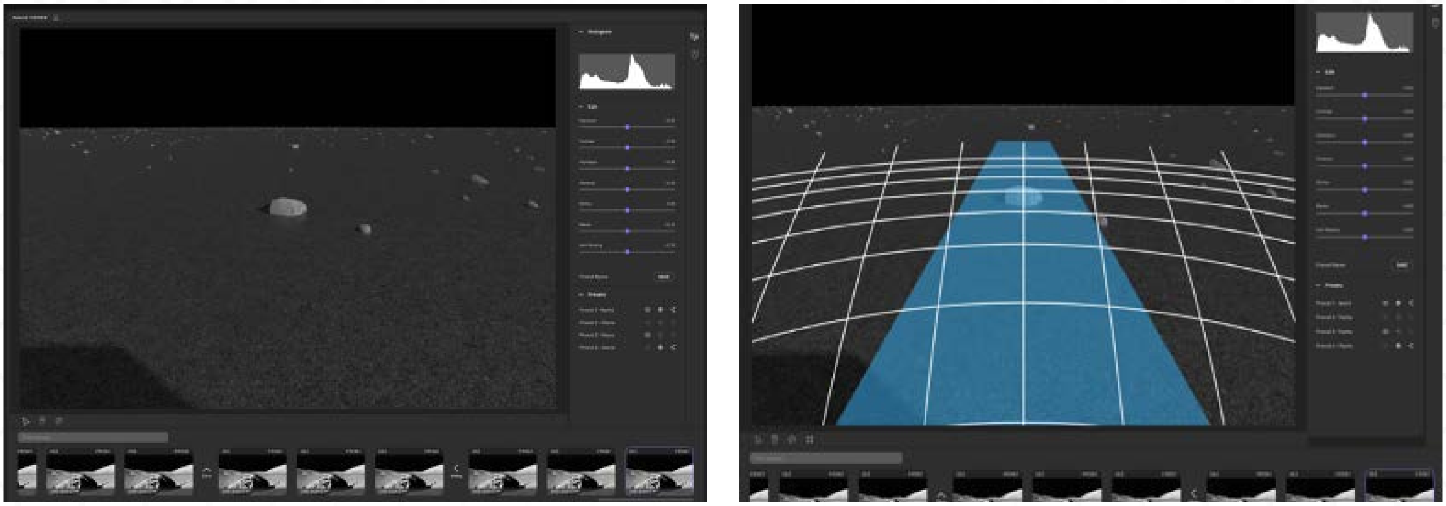
Example of the CubeRover Map interface.

TELEMETRY VISUALIZER

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

IMAGE VIEWER

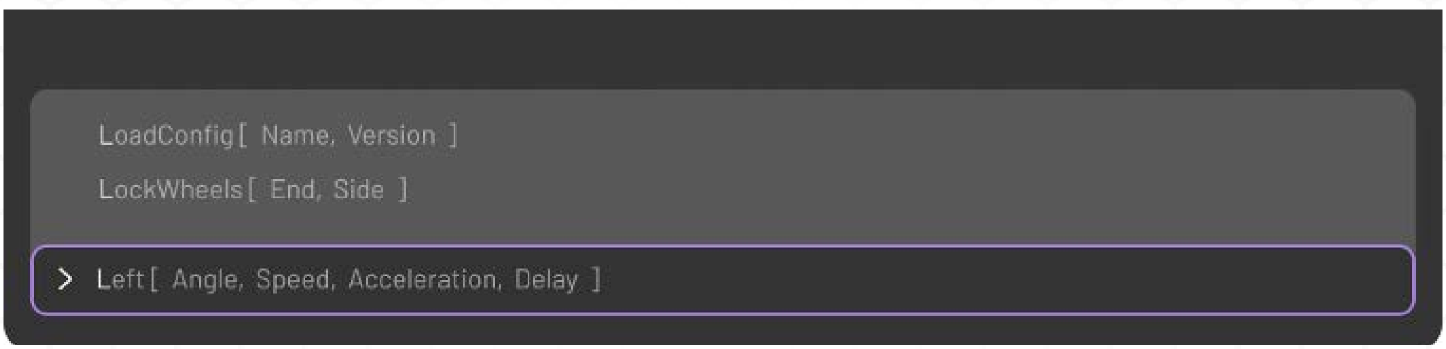
The image viewer is the primary tool operators use to understand the environment around CubeRover and is central to planning the rover's maneuvers. In addition to displaying images, the image viewer also now provides basic editing features, a timeline of past images, and a comprehensive feature for naming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



Example of the Image Viewer interface.

COMMAND LINE

The Command Line interface provides a suite of advanced auto-fill and checking features to ensure that commands are created quickly and safely by operators.

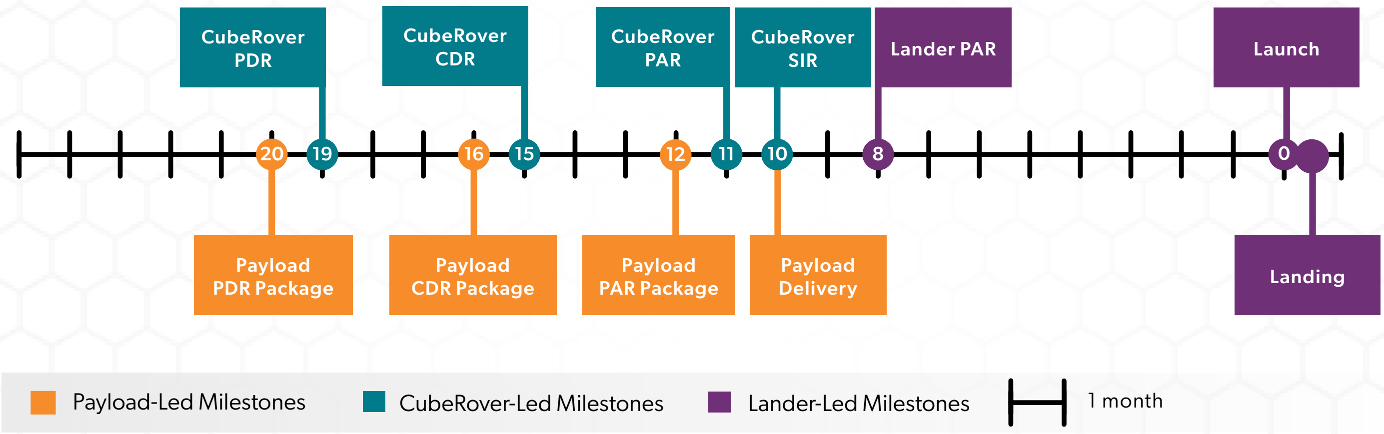


The Command Line interface.

MISSION MILESTONES

Following contract signature, an Astrobotic payload manager will work with the customer to develop a payload schedule that aligns to the CubeRover and lander mission schedules.

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



The first three major milestones are the Preliminary Design Review (PDR), Critical Design Review (CDR), and Payload Acceptance Review (PAR). Customers support these milestones by delivering Payload Packages 1 month prior to each review. These deliverables ensure Astrobotic milestone reviews are informed by the latest payload specifications. These milestones are followed by the System Integration Review (SIR) and the Lander PAR. Customers deliver their flight configuration of the payload for acceptance and integration on CubeRover between 10 to 8 months prior to launch. The completion of these milestones leads to launch followed by landing and surface operations on the Moon.

GLOSSARY

GLOSSARY OF UNITS

UNIT	SIGNIFICANCE
°	degree [angle, latitude, longitude]
°C	degree Celsius [temperature]
g	Earth gravity [acceleration; 9.8 m/s^2]
GB	Gigabyte [data storage]
Hz	Hertz [frequency]
kbps	kilobits per second [data rate]
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
CDR	Critical Design Review
EDAC	Error Detection and Correction
EMI/EMC	Electromagnetic Interference / Electromagnetic Compatability
IAU	Integrated Avionics Unit
LRL	Astrobotic's Lunar Regolith Lab
MLI	Multi-layer Insulation
PAR	Payload Acceptance Review
PDR	Preliminary Design Review
PMCC	Payload Mission Control Center
PSR	Permanently Shadowed Regions
PUG	Payload User Guide
Q	Quality Factor / Q Factor
SIR	System Integration Review
TCP/IP	Transmission Control Protocol / Internet Protocol
TID	Total Ionizing Dose
TRL	Technology Readiness Level
VPN	Virtual Private Network

CONTACT US

Astrobotic provides multiple support teams to address the specific needs of payload customers.

BUSINESS DEVELOPMENT

Our Business Development team is available to current and potential customers for 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 us and we will be happy to direct you to the appropriate Astrobotic team.

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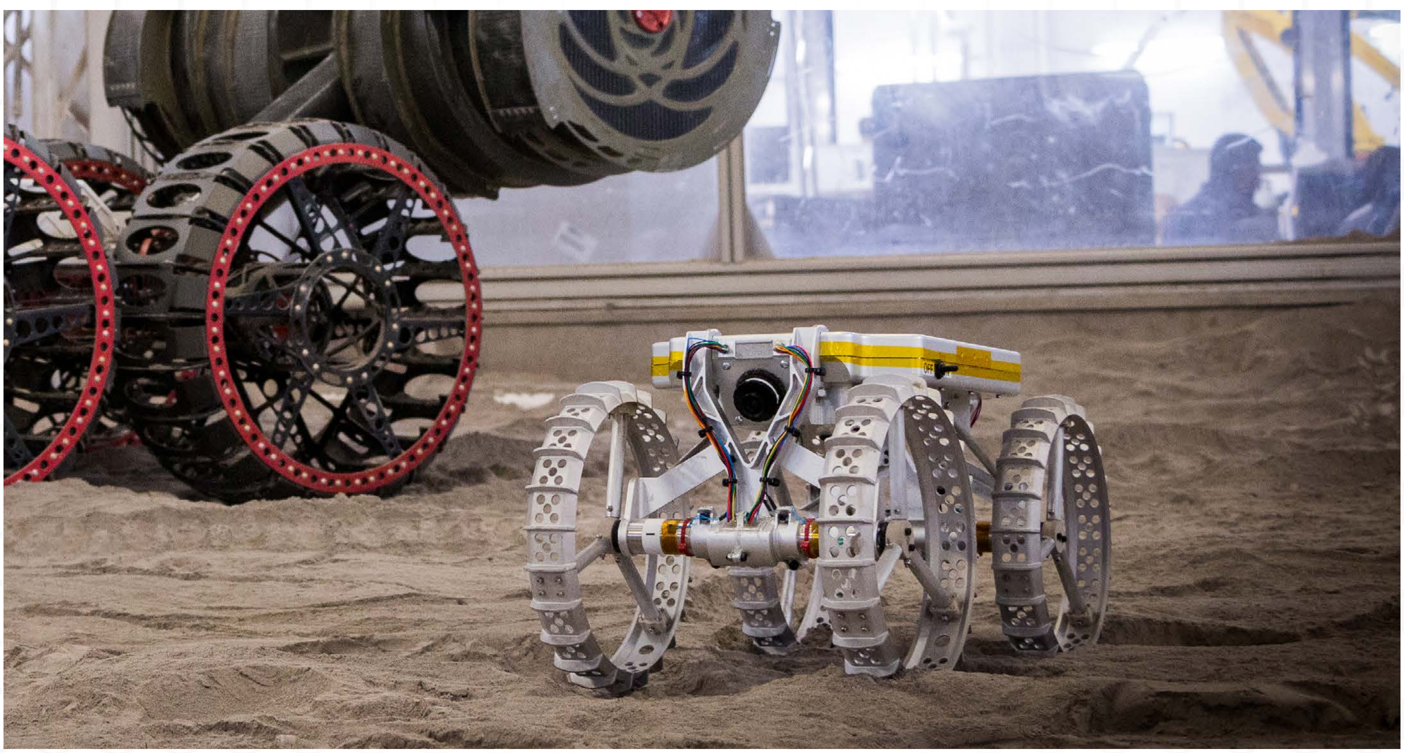

QUESTIONNAIRE

For a more personalized experience, please provide the following payload details when you contact us.

Payload Name

Payload Point of Contact: Name, Email, and Phone

Payload Mission Objectives

Payload Preferred Launch Date

Payload Preferred Delivery Location: Lunar Coordinates, Terrain Type, or Proximity to a Lunar Surface Feature

Payload Mass

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

Payload Power Needs: Number of Power Channels, Average Power, and Peak Power

Payload Communications Needs: Uplink Bandwidth and Downlink Bandwidth

Payload Concept of Operations

Additional Requirements

NOTE: You can also share your payload mission details with us through our website at the following link: ***Plan Your Mission***