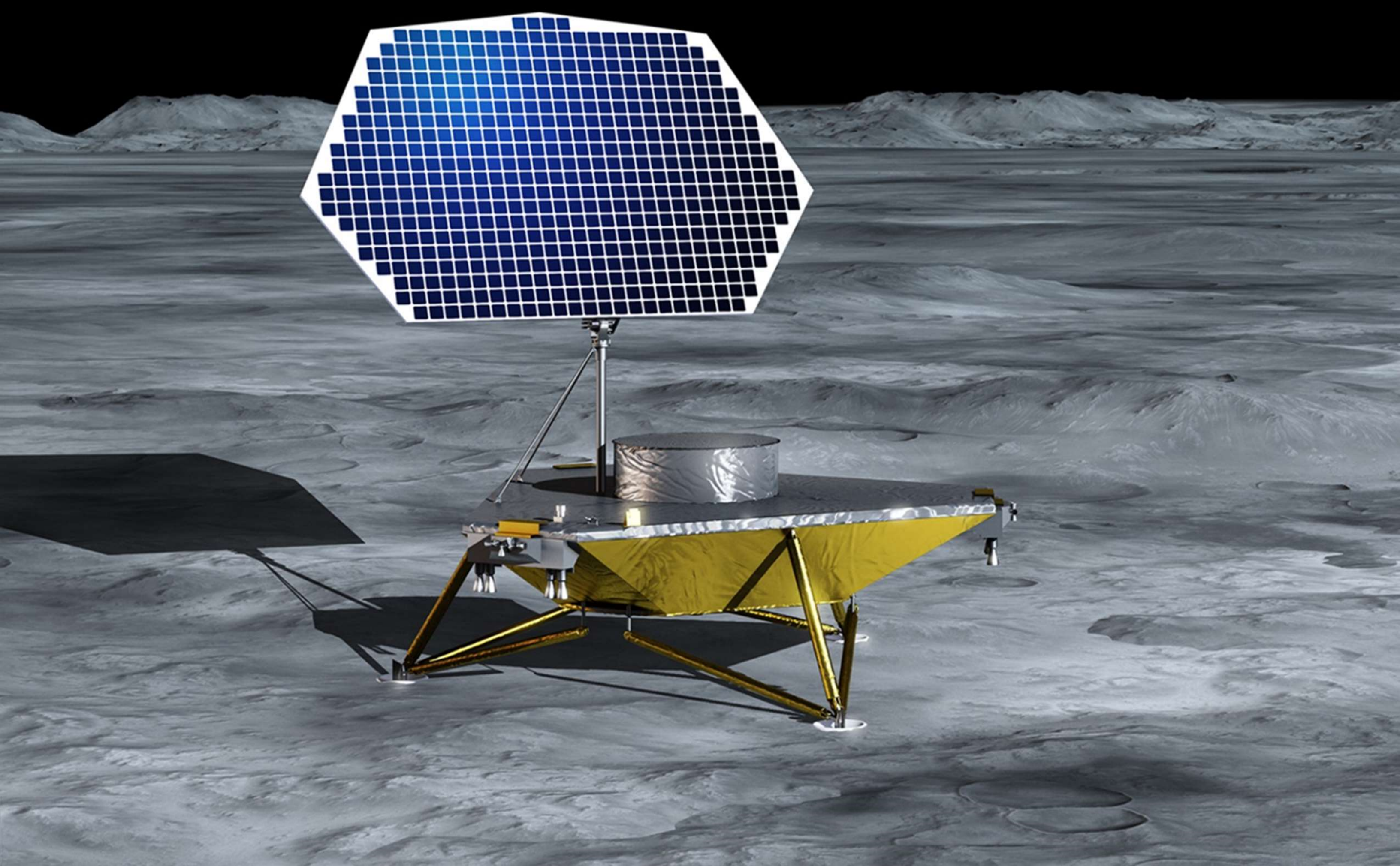
McCANDLESS LUNAR LANDER

User's Guide

September, 2019



CONTENTS

1.0 INTRODUCTION....3
1.1 Lunar Transportation Service 3
1.2 Lockheed Martin's Relevant Capabilities....3
1.3 Bruce McCandless 4

2.0 MCCANDLESS LUNAR LANDER 5

3.0 PAYLOAD MASS AND VOLUME CAPABILITIES 6
3.1 Payload Mass 6
3.2 Payload Volume....6
3.3 Mechanical Interfaces 7
3.4 Rover Accomodations....8

4.0 PAYLOAD ELECTRICAL AND THERMAL INTERFACES 9
4.1 Payload Power 9
4.2 Payload Thermal Interfaces 9
4.3 Data Interfaces 10
4.3.1 Asynchronous RS-422 Command and Data 10
4.3.2 Synchronous RS-422 Data (Payload Output) 10
4.3.3 Non-Standard LVDS Command (Payload Input) 10
4.3.4 Non-Standard LVDS Telemetry (Payload Output)....10
4.3.5 Spacewire....10

5.0 LANDING SITE SELECTION 11
5.1 Global Access 11
5.2 Landing Site Accuracy and Touchdown Safety....11

6.0 ENVIRONMENTS 12
6.1 Dynamic Environments 12
6.2 Radiation Environments....13
6.3 Ground Operations Environments 13

7.0 MISSION INTEGRATION 14
7.1 Assembly And Integration....14
7.2 Test....15

8.0 MISSION OPERATIONS....16

1.0 INTRODUCTION

The McCandless Lunar Lander User's Guide outlines Lockheed Martin's commercial lunar mission services. This guide describes the lander configuration, payload capabilities and interfaces, landing site options, testing and facilities, and mission operations. In addition to standard capabilities described here, the lander can be customized to mission-specific needs.

For Further Information

- Lunar mission needs vary widely. Potential users should contact Lockheed Martin to explore how McCandless can meet their specific lunar transportation requirements.
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1.1 LUNAR TRANSPORTATION SERVICE

Lockheed Martin offers lunar transportation services on McCandless to commercial, institutional, and government customers around the world. McCandless is fully designed and built in the US, but Lockheed Martin is fully capable of supporting international customers with necessary licensing. McCandless can provide dedicated missions for a single customer or ride-share opportunities for multiple, smaller payloads. Typical services include pre-launch integration and testing of customer payloads, launch, transportation to the Moon's surface, provision of power, operational commanding and data return, and deployment of releasable payloads such as rovers. NASA selected Lockheed Martin as a pre-qualified provider for the Commercial Lunar Payload Services (CLPS) program in 2018, providing an efficient contracting path for NASA-funded teams to launch payloads on McCandless missions.

1.2 LOCKHEED MARTIN'S RELEVANT CAPABILITIES

Lockheed Martin has been building planetary spacecraft since the Viking landers of the 1970s. Working with NASA and JPL, Lockheed Martin has helped send planetary missions across the solar system, some of which are shown in Figure 1-1. The same planetary exploration organization

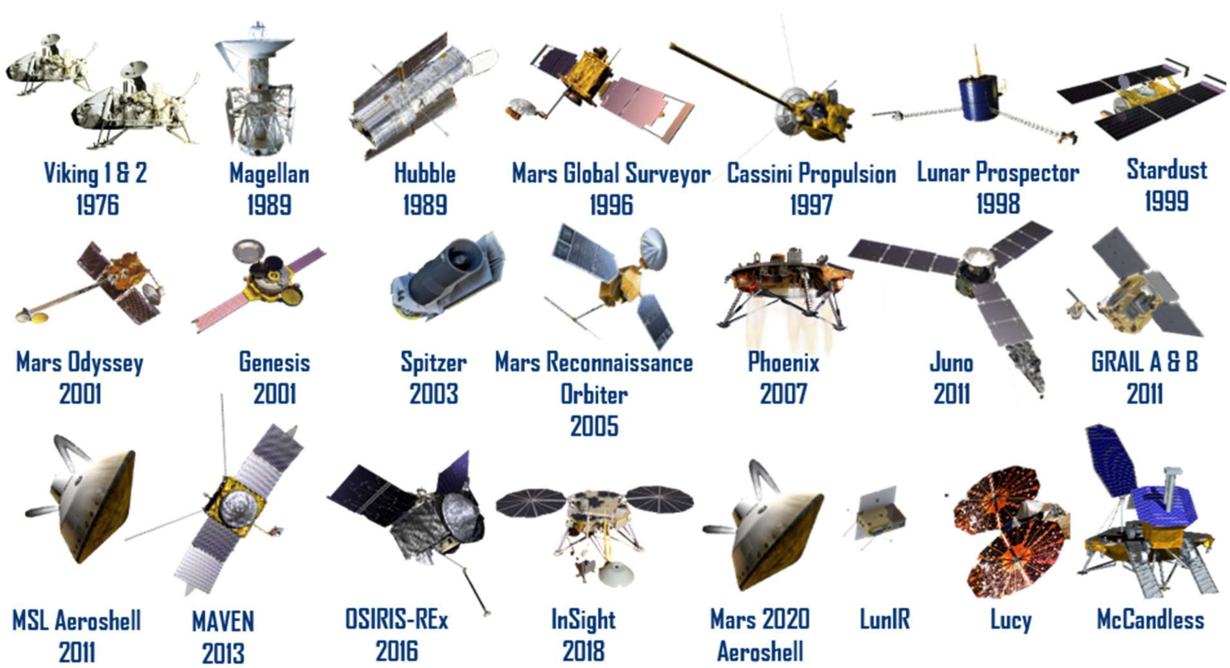

Figure 1-1 McCandless is based on Lockheed Martin's experience developing, testing, and/or operating dozens of planetary spacecraft in collaboration with NASA and JPL.

within Lockheed Martin that developed spacecraft like the GRAIL lunar orbiters and Phoenix and InSight Mars landers is developing McCandless. The team also incorporates commercial practices from the LM2100 and LM1000 satellite product lines. An experienced team, established facilities, a design based on flight-proven subsystems, and the ability to share resources across multiple programs help make McCandless low-risk and price competitive.

Planetary missions are often cost-capped and constrained by inflexible planetary launch windows. For decades, Lockheed Martin has demonstrated excellent schedule and budget performance on planetary missions. Government Accountability Office (GAO) annual reports on NASA project performance during 2009-2019 show five of six planetary missions in which Lockheed Martin had a major role met their original schedule and budget targets (Figure 1.2). The exception was InSight, which was delivered to the launch site on schedule but delayed by instrument development issues. McCandless schedules and budgets are based on program execution experience from similar prior missions, providing confidence that McCandless will deliver customer payloads to the Moon on schedule.

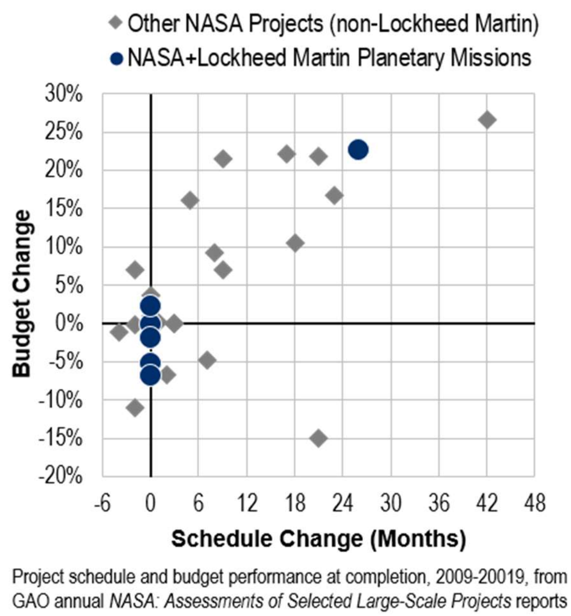

Figure 1-2 Lockheed Martin has demonstrated reliable cost and schedule performance for planetary spacecraft.

1.3 BRUCE MCCANDLESS

The McCandless Lunar Lander is named in honor of astronaut Bruce McCandless II. McCandless is well known for flying the Manned Maneuvering Unit (MMU) jetpack in the world's first untethered spacewalk on STS-41B and for helping deploy the Hubble Space Telescope on STS-31. Though he is often remembered as a Shuttle-era astronaut, he joined the astronaut corps during the Apollo program in 1966. He was not assigned to an Apollo flight crew; instead he supported the Apollo program in Mission Control as CAPCOM ('capsule communicator') for the historic Apollo 11 launch and moonwalk (Figure 1-3). Bruce worked extensively with Lockheed Martin while developing the MMU, and after retiring from NASA in 1990, he decided to join the company. During more than two decades with Lockheed Martin, Bruce was an advocate for space exploration and commercial space development and a mentor who shared his spaceflight and lunar exploration experience with many younger colleagues. Long after his partial retirement, Bruce continued to advise his co-workers, and to challenge us to more ambitious goals until he passed away in December 2017. We celebrate his legacy by returning to the world he helped to explore a half century ago.

Figure 1-3 The lander's name honors Apollo 11 CAPCOM and Lockheed Martin engineer Bruce McCandless II.

2.0 MCCANDLESS LUNAR LANDER

The McCandless Lunar Lander (Figure 2-1) is a medium-class lander designed to support sophisticated lunar surface science and exploration missions with demanding size, weight, power, and data requirements (Table 2-1). A wide top deck provides adaptable accommodations for a single large external payload up to 350 kg, such as a rover, or a combination of smaller payloads for multiple customers. Two internal payload bays protect payloads from thermal and dust environments. A gimbaled solar array supports landing at any latitude and provides high power from nearly dawn to dusk, maximizing payload operating time during a single lunar day. Landing legs provide high ground clearance over rugged terrain, while the low deck height eases payload access to the surface. Precision landing capabilities enable operating near features of interest.

The McCandless hardware design, flight and ground software, and operations concept are adapted from Lockheed Martin's current generation of NASA planetary spacecraft, such as the InSight Mars lander, OSIRIS-REx asteroid sample return mission, and upcoming Lucy mission to the Trojan asteroids. For example, the avionics, propulsion, and landing gear are closely derived from equivalent systems on InSight. This design maturity supports rapid, low-cost development, and provides confidence in mission success and schedule.

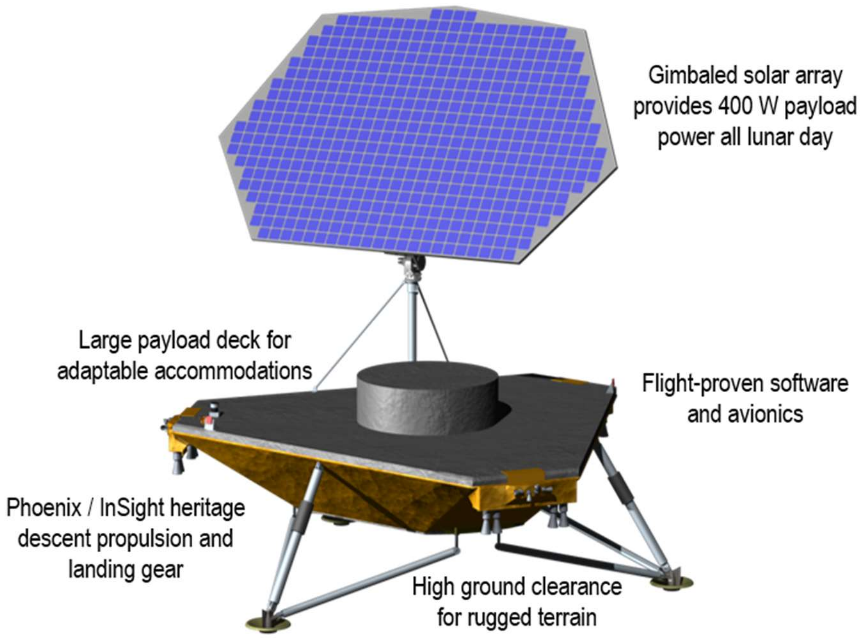

Figure 2-1 McCandless provides volume, mass, power, and telemetry for sophisticated payloads and complex missions.

Table 2-1 Highly capable standard features are adaptable to mission-specific needs.

Capability	Standard	Optional Enhancements
Cargo mass	Up to 350 kg	Evolvable to > 1000 kg
Payload power (landed)	400 W, 28 Vdc	
External payload volume	>4 m^3 external, above deck	Deployment Mechanisms
Internal payload bay volume	Two 0.4 m^3 internal compartments	Deployment Mechanisms
Surface mission duration	300 hours, nearly a full lunar daylight period	Lunar night survival or lunar night operations
Landing precision	< 2 km landing zone	< 100 m landing zone
Return data rate to Earth	100 kbps	>1 Mbps
Data storage	48 gigabits	
Payload data interfaces	LVDS, RS-422, MIL-STD-1553, Spacewire	WiFi, Ethernet

3.0 PAYLOAD MASS AND VOLUME CAPABILITIES

The McCandless Lunar Lander provides considerable payload mass and volume capabilities to support advanced science and exploration missions to the lunar surface.

3.1 PAYLOAD MASS

The baseline McCandless Lander can deliver a total payload mass of up to 350 kg to the lunar surface. Payload mass performance varies on the order of 10% depending on desired lunar landing site location and over time due to the Moon's changing orbital velocity and declination. Customers with smaller payloads that will be delivered as part of a ride-share mission generally do not need to consider the lander capacity. Customers with large payloads that may use the lander's full capacity should contact Lockheed Martin for specific performance discussions. Future evolution of the McCandless design will support payload mass greater than 1000 kg.

3.2 PAYLOAD VOLUME

McCandless offers both external and internal payload accommodations. External payloads are mounted on the top deck and exposed to the space and lunar surface environment. Available external volume dimensions are displayed in Figure 3-1. The external payload envelope accommodates large, monolithic payloads. Maximum standard payload height shown in Figure 3-1 is negotiable and exceptions may be approved, if needed. Depending on mission requirements, the solar array gimbal range of motion can be constrained to avoid interference with taller payloads. For instance, a rover taller than the illustrated envelope could be deployed early in the lunar day to avoid interfering with solar panel motion. Some portions of the deck area within the payload envelope will be reserved for radiator surfaces, antennas, or sensor fields of view. The sizes and locations of these areas are not specified in the illustrated payload envelope because they depend on mission-specific factors such as the landing site latitude. If needed, the upper deck can be extended to accommodate large payloads. Lockheed Martin will work with payload customers to develop acceptable payload layouts.

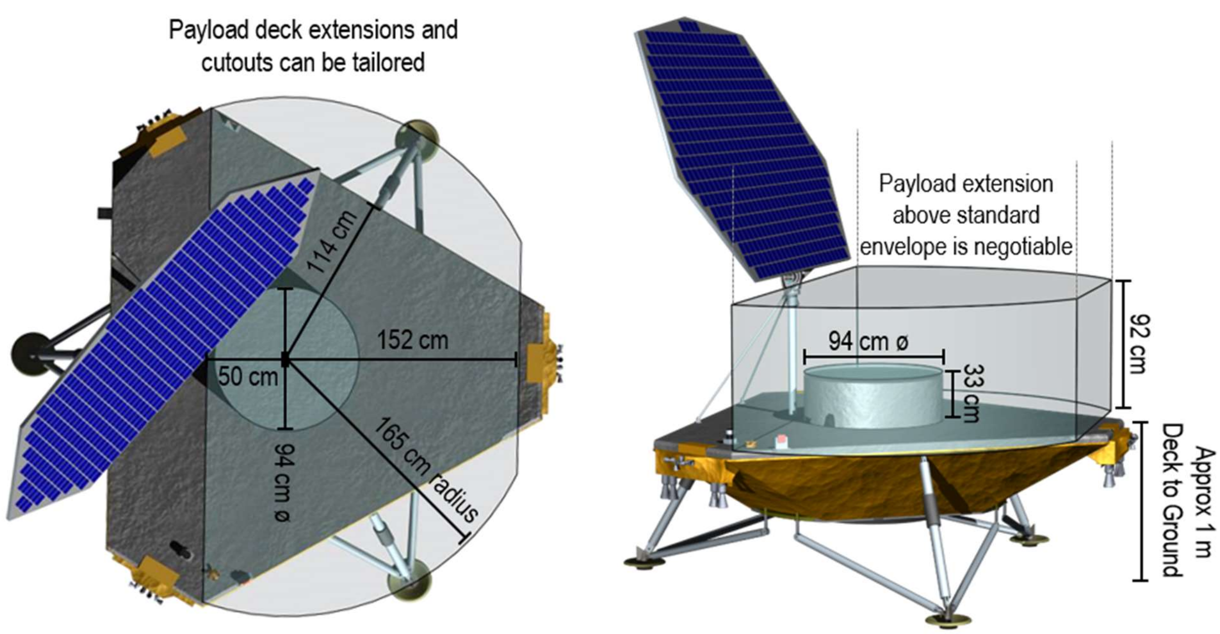

Figure 3-1 McCandless offers a large external payload volume with access to the surface.

Internal space for payloads is available below the lander top deck. The internal structure consists of a central structural cylinder surrounded by six bays separated by vertical panels. Two of these bays are allocated for internal payloads. The internal payload bays provide a protected thermal environment which is not directly exposed to solar or lunar thermal flux or to deep space. The two payload bays are nominally oriented facing roughly north and south.

The internal volume of the payload bays has a distinct shape which is shown in Figure 3-2. The second payload bay is a mirror image of the volume shown here. Payloads in these bays may be supported on the lower deck, suspended from underneath the upper deck, or attached to the vertical side panels. Optional cutouts in the external facing side panel can provide visibility to the lunar surface for internally mounted sensors. If a payload is too large for the payload bay geometry shown, the upper or lower decks can be extended to enlarge the bay.

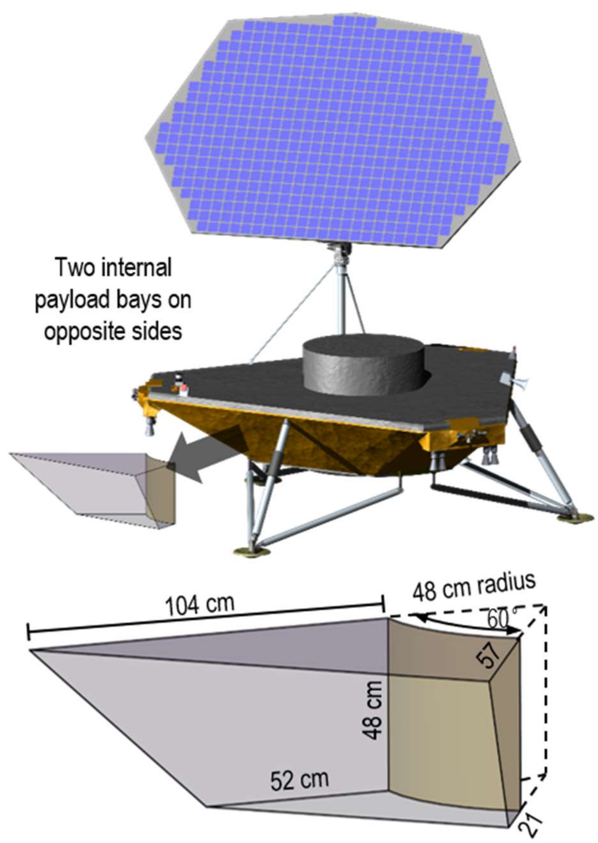

Figure 3-2 Two internal payload bays provide protected cargo volume below the main deck.

As a non-standard service, payloads can be mounted underneath the bottom deck of the lander. However, space is limited. It may be more suitable to mount such payloads on the edge of the upper deck pointed towards the surface.

For more information about payload volume capabilities, please contact Lockheed Martin.

3.3 MECHANICAL INTERFACES

The upper and lower decks of the lander offer adaptable positioning of fastener locations, without the need for standardized attachment locations or additional mounting adapter plates. Lockheed Martin will provide standard #8 or #10 mounting fasteners (shear-type NAS9921 or similar), washers, shims, and thermal isolators if needed. Other fastener sizes are available per request.

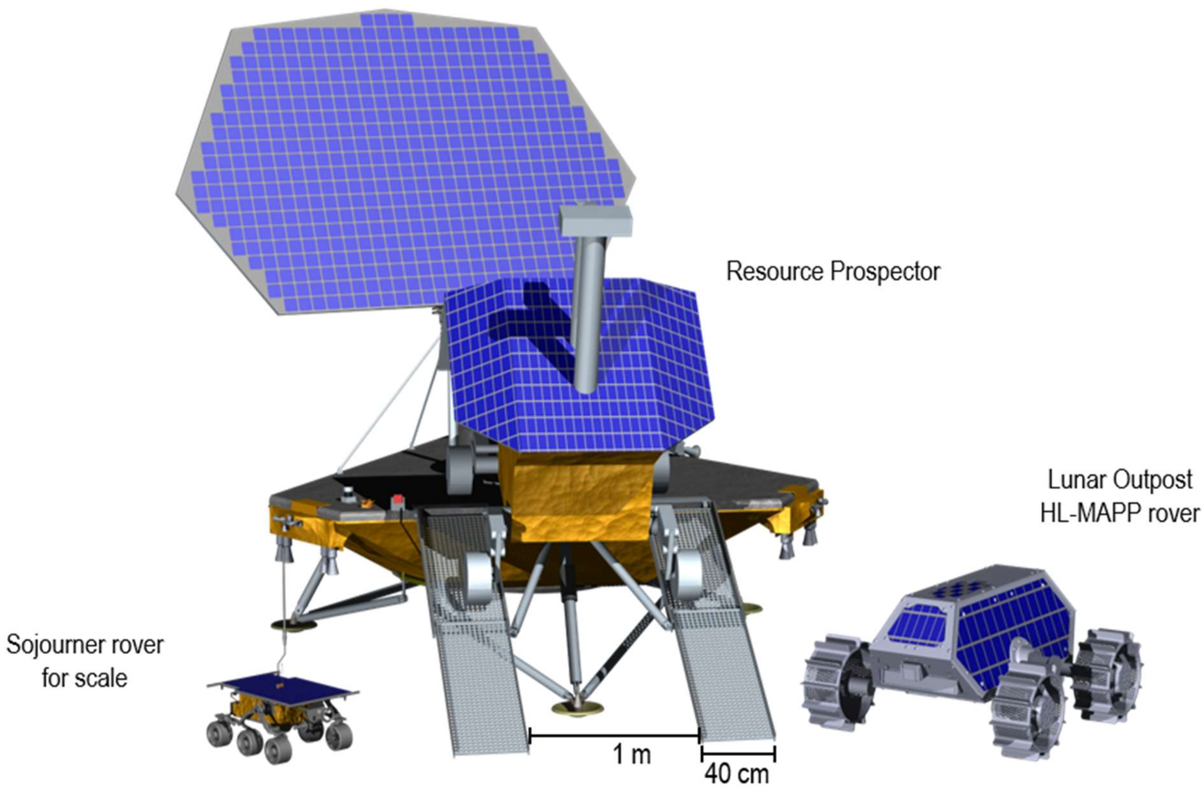

Figure 3-3 McCandless can transport and deploy small to medium class lunar rovers using deployment hardware provided by the customer or by Lockheed Martin.

3.4 ROVER ACCOMODATIONS

McCandless is designed with the needs of lunar rovers in mind. A few examples of McCandless's rover compatibility are shown in Figure 3-3. The primary payload deck is low to the ground to make rover egress as easy as possible. The deck is nominally 1 m high but this will depend on lunar surface slopes, rocks, and craters. Since rover designs, geometry, and requirements vary, customers may provide their own egress hardware tailored to their rovers, or Lockheed Martin can provide ramps as a mission-unique service. Large rovers with a mass above 100 kg will typically attach to the top circumference of the raised structural cylinder on the upper deck. Smaller rovers may be mounted at distributed locations around the deck. Small rovers or other types of releasable payloads could also be stored below deck in an internal payload bay (Figure 3-4).

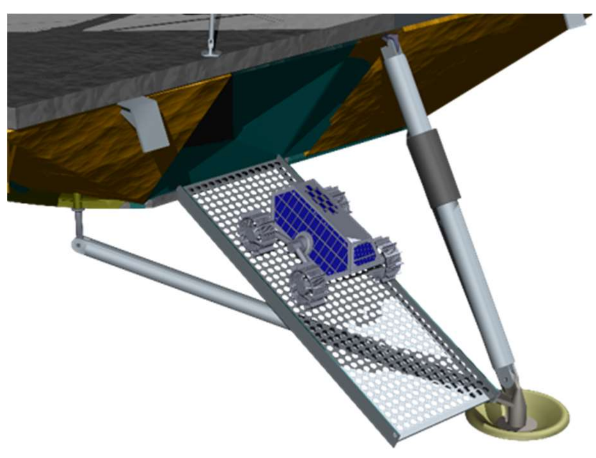

Figure 3-4 Small rovers can be deployed from the internal payload bays.

4.0 PAYLOAD ELECTRICAL AND THERMAL INTERFACES

McCandless is designed for power-rich surface operations with the longest practical surface operations duration during a single lunar day. The solar array is gimbaled for Sun tracking from dawn to dusk. Lander thermal management is sized to operate spacecraft systems through the high-temperature environment of equatorial lunar noon so that a mid-day dormant phase is not necessary. This allows about 300 hours of surface operations duration during the mission. Lockheed Martin is also developing future power and thermal enhancements for McCandless to survive the long, cold lunar night and support extended multi-day operations or to operate payloads during lunar night.

Figure 4-1 McCandless can support high-power payloads like resource extraction experiments.

4.1 PAYLOAD POWER

McCandless provides 400 W of average payload power during lunar surface operations. Higher peak power draws can be accommodated by the battery. Payloads are nominally expected to be dormant during cruise to the Moon. However, up to 125 W can be provided during cruise for instrument checkout operations or heater power. Payload power voltage is nominally 28 VDC. Multiple types of payload power switches are available, as shown in Table 4-1. The standard payload circuit provides up to 3 A current. McCandless can also provide a limited number of 5 A pyro firing circuits, such as for devices which use NASA Standard Initiators.

Table 4-1 Available Power Interfaces.

Switch Type	Max Current Over 30 Sec
Standard Load Switch	3 A
High Current Switch	10 A
Low Current Switch	0.5 A

4.2 PAYLOAD THERMAL INTERFACES

McCandless thermal design is necessarily tailored to each mission. Thermal solutions are driven by payload locations and power profiles, and by landing site latitude which determines lunar surface temperature and the path of the Sun in the sky during the surface mission. The lander thermal design is primarily passive, using surface blankets and coatings to manage heat input and rejection. Supplemental heaters prevent temperatures from dropping too low, particularly during cruise to the Moon. High-power payloads generally should radiate heat perpendicular to the top deck (i.e. up, towards deep space). External payloads or internal payloads suspended underneath the upper deck can use heat spreaders to distribute energy across a larger area of the deck as a radiator.

Lockheed Martin will conduct an integrated thermal analysis for each mission to ensure each payload is thermally compatible with the lander and with other payloads. Payload customers are responsible for providing simplified component-level thermal models in a compatible file format specified in the Interface Control Document (ICD), and payload upper and lower Allowable Flight Temperature (AFT) limits. The lander provides heater power channels for each payload and supports mechanical thermostat control or software-defined temperature limits. If a payload uses heaters or thermo-electric coolers, they count in the payload's mass, power, and volume allocation.

4.3 DATA INTERFACES

McCandless provides an Earth-to-Moon command link for payloads, and a Moon-to-Earth data return link for customer data. Nominal payload data return rate is 100 kbps in the standard configuration. If needed, an optional high data rate return link >1 Mbps can be provided. Payload data downlink can be scheduled for continuous 24/7 operations, or at a reduced operational tempo such as once per day depending on mission needs.

Onboard the lander, the standard data interfaces between the lander avionics and the payloads are RS-422, LVDS (Low Voltage Differential Signal), Spacewire, or MIL-STD-1553, as described below. Optional upgrades can support ethernet or WiFi 802.11n payload data interfaces.

4.3.1 Asynchronous RS-422 Command and Data

The spacecraft provides an RS-422 Asynchronous Serial low-speed command and telemetry interface for payloads. This consists of an NRZL (non-return-to-zero level) differential data signal. Commands and data transmitted on this interface are transmitted as Most Significant Byte first, Least Significant Bit first. Commands and data can be sent in multiples of 32 bits (4 bytes) or 8 bits (single byte). This interface transmits individual bytes with start, stop, and parity bits for each byte of data. Parity can be configured as even or odd.

4.3.2 Synchronous RS-422 Data (Payload Output)

The spacecraft provides a high-speed telemetry interface for the payload. This is an RS-422 Synchronous Serial interface, consisting of a set of three differential signals: Clock, Data, and Frame (active low), with a maximum clock frequency of 6 MHz. Data transmitted on this interface must be in multiples of 32 bits, and is transmitted as Most Significant Bit first, Most Significant Byte first.

4.3.3 Non-Standard LVDS Command (Payload Input)

The spacecraft provides an LVDS synchronous serial command interface to the payload, consisting of three differential signals: Clock, Data, and Frame (active low), with a maximum clock frequency of 33 MHz. The clock duty cycle is 50% +/- 10%. The data transmitted on this interface is defined to be Most Significant Byte first, Most Significant Bit first.

4.3.4 Non-Standard LVDS Telemetry (Payload Output)

The spacecraft provides an LVDS synchronous serial telemetry interface for the payload consisting of differential Clock, Data, and Data Strobe (DSTROBE, active low) lines. Data transmitted on this interface is defined to be Most Significant Byte first, Most Significant Bit first. The interface is defined for DSTROBE widths of one (1) to five (5) clock cycles, with one (1) clock cycle width corresponding with 20 bits of reported data, the Least Significant Bit of the data synchronized to the rising edge of the DSTROBE signal, and the other valid DSTROBE widths corresponding with 12 bits of reported data, also with the data's LSB synchronized to the rising edge of the DSTROBE signal.

4.3.5 Spacewire

Spacewire is a 2 to 200 Mbps serial link defined by the ECSS-E50-12A standard. It is bi-directional and full-duplex. Spacewire links can send application information in discrete packets, as well as time and control information.

5.0 LANDING SITE SELECTION

The landing site for a specific mission can be selected by the primary mission customer. Typically, Lockheed Martin collaborates with a science team to identify and validate a landing site. The customer science team identifies several candidate locations in the region of interest, and Lockheed Martin evaluates them for landing site safety and engineering suitability. Landing site selection will respect protection of historically significant lunar landing sites, the International Telecommunications Union designated radio frequency Shielded Zone of the Moon on the far side, and other protected areas.

5.1 GLOBAL ACCESS

McCandless is designed to provide global access to the Moon, including the equator, mid-latitudes, and the poles. McCandless is capable of landing on the far side of the Moon. However, because lunar orbital communications relay is not currently available, initial missions will be limited to landing sites on the near side of the Moon with line-of-sight communications to the Earth. Landing sites within ±82° longitude and ±83° latitude are generally visible from the Earth continuously. An additional strip around the limb of the Moon to about ±97° longitude and a few degrees beyond the poles is intermittently visible on a monthly or seasonal cadence depending on lunar libration and local terrain. Future missions can operate on the lunar far side when communications relay is available, and upgrades to the McCandless communications systems to support relay have already been identified.

5.2 LANDING SITE ACCURACY AND TOUCHDOWN SAFETY

All planetary landers have a distributed area around the target point where landing may occur due to imperfect navigation and vehicle performance. Smaller landing zones are desirable because they enable landing closer to targets of interest, and permit selection of a safe landing site within a region that may have topographic hazards. Recognizing the importance of small landing zones, the McCandless flight dynamics team has applied its planetary landing experience from Phoenix, InSight, and OSIRIS-REx to provide exceptional landing site accuracy. Whereas other lunar landing systems have landing zones that extend tens of kilometers, McCandless can land in a 2 km zone in its baseline configuration. For missions requiring more precise landing, an upgrade to terrain-relative optical navigation provides <100 m landing site accuracy.

McCandless is designed to land on slopes of at least 12 degrees and has enough ground clearance to land over a 40 cm rock or crater rim. With these rugged capabilities and narrow landing zone, safe landing sites can be found in most areas of the Moon using available orbital imagery from Lunar Reconnaissance Orbiter and other sources. If necessary for mission objectives, Lockheed Martin will consider landing sites with steeper slopes up to 20 degrees. (For comparison, Surveyor V landed on a 19.5 deg slope in a crater).

6.0 ENVIRONMENTS

Payload environments encompassing ground processing, launch, and in-space operations are presented in this section. Environments data in this edition of the User's Guide are for preliminary payload design and assessment of payload compatibility only. An Interface Control Document (ICD) will document mission-specific environments analysis for flight payloads, to include random vibration environments. McCandless can launch on any one of several intermediate class launch vehicles such as Atlas V, Vulcan, Falcon 9, or Ariane 5. (Missions conducted for NASA will use US launch services.) Data provided below is intended to envelope multiple launch vehicle options. However, actual launch environments will depend on the launch vehicle selected for a specific flight.

6.1 DYNAMIC ENVIRONMENTS

Design limit loads for axial and lateral loads are provided based on a combination of quasi-static and oscillatory loads on the primary spacecraft. The loads shown in Figure 6-1 encompass ground transportation, launch, lunar descent, and touchdown dynamics. Loads experienced by the payload will depend on payload mass, mounting location, and structural dynamics interactions between spacecraft and payload. Smaller payloads will experience higher loads than shown. A payload dynamics analysis will be conducted to provide recommended loads for payload design and test planning.

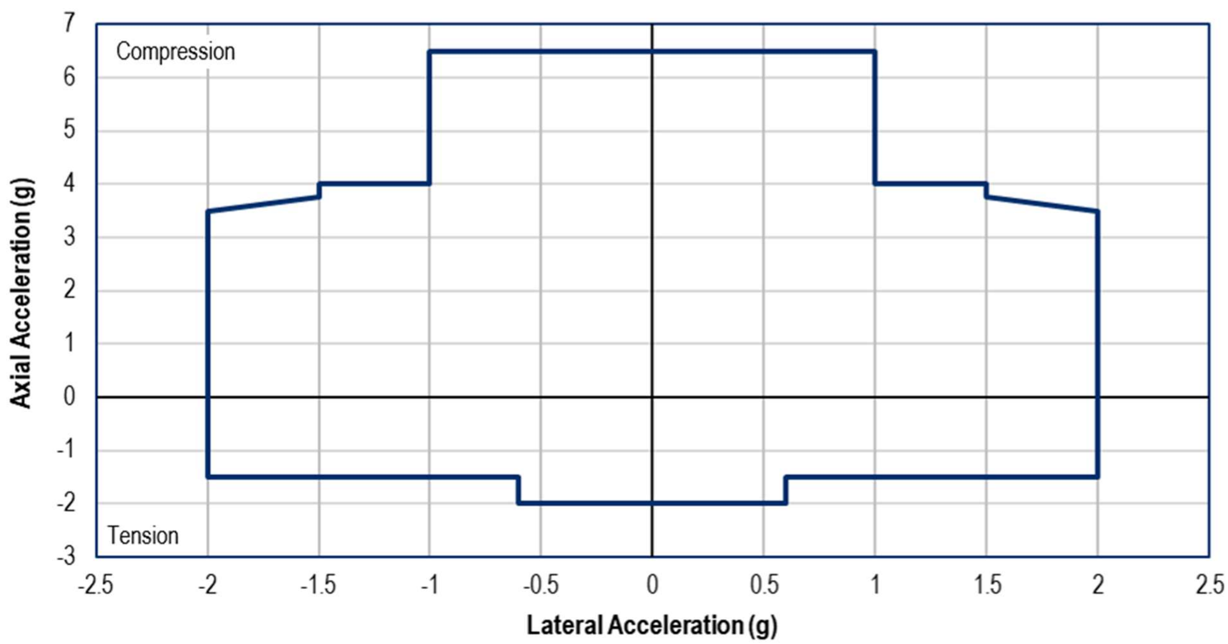

Figure 6-1 Payload design limit load factors envelope at the spacecraft center of mass.

Acoustic environments for payloads are driven by launch. These generally peak shortly after liftoff due to acoustic energy reflected from the launch pad, and again during the transonic phase of ascent. Acoustic environments are shown in Figure 6-2.

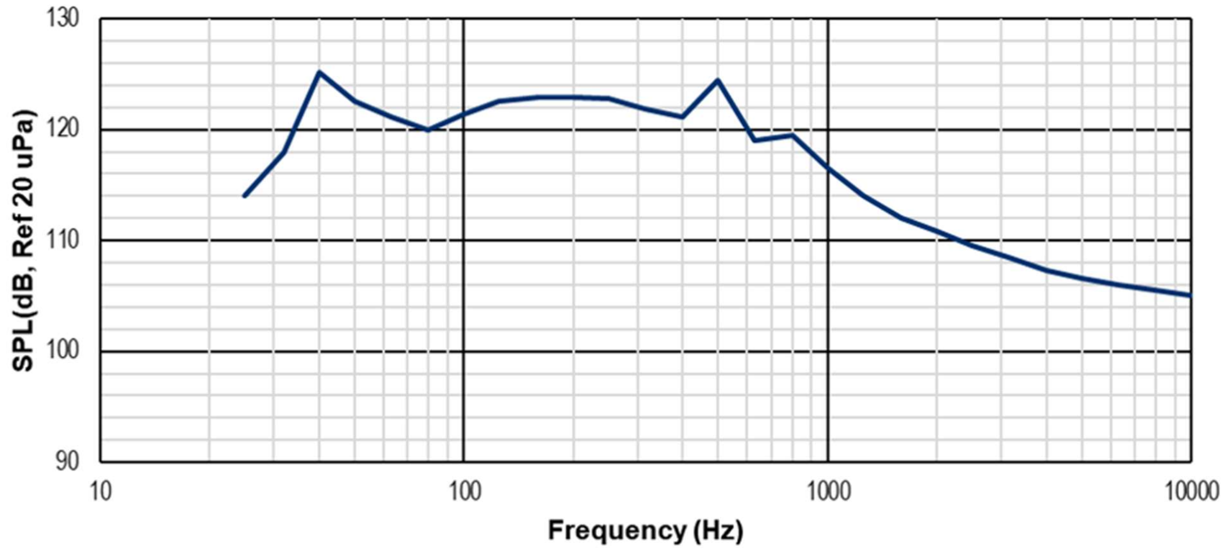

Figure 6-2 Acoustic limit levels during launch and ascent.

Shock response for a payload mounted on the top deck in the vicinity of the solar array release mechanisms is shown in Figure 6-3. Shock environments for payloads mounted on the central cylinder and lower deck are expected to be lower than shown here.

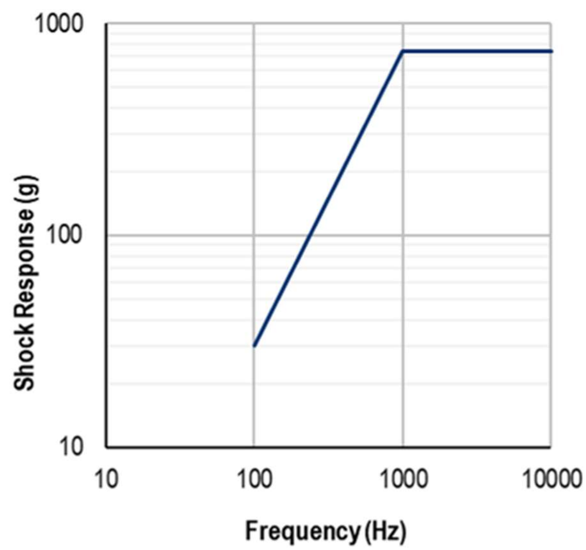

Figure 6-3 Typical maximum payload shock levels for acceptance test

6.2 RADIATION ENVIRONMENTS

The McCandless trajectory passes through the Earth's Van Allen radiation belts only once during the outbound cruise phase, which reduces radiation exposure compared to trajectories that use multiple elliptical phasing orbits. Total Ionizing Dose (TID) inside a reference 2.5 mm (100 mil) of aluminum shielding is predicted to be <5 krad (Si), including a Radiation Design Factor (RDF) of 2.

6.3 GROUND OPERATIONS ENVIRONMENTS

During ground processing and handling, such as during assembly, test, ground transportation, and pre-launch activities, the spacecraft will be in a controlled environment as shown in Table 6-1. Payloads should be designed for both horizontal and vertical processing.

Table 6-1 Terrestrial Environments

Control Parameter	Low Limit	High Limit
Temperature	+5°C	+45°C
Temperature Change Rate	N/A	+5°C/hr
Pressure	70 kPa (525 torr)	101 kPa (760 torr)
Relative Humidity	30%	70%

7.0 MISSION INTEGRATION

Lockheed Martin will assign a Mission Manager and payload integration engineers for each flight who are responsible for customer interactions, payload integration, and coordinating the requirements of multiple payloads to prevent resource conflicts. A payload Interface Control Document will define the specific payload interfaces with the lander and mission operations, and flight environments.

7.1 ASSEMBLY AND INTEGRATION

The McCandless Lunar Lander offers all the services and interfaces for successful integration and operation of many possible science and commercial payload instruments and components.

A comprehensive and collaborative approach to payload integration shortens schedule, reduces cost and risk, and maximizes the opportunities to identify and resolve potential operational issues before launch. The initial focus of the experienced payload integration team is to cultivate strong engagement between payload and lander teams in order to develop clear and accurate interface requirements. The team also defines expectations and activities in order to meet payload needs and blend the unique organizational cultures of the payload partners. This approach prepares the team for integration risk reduction (such as testbeds and fit checks), monitoring ICD compliance and managing changes, preparing for and completing integration with the spacecraft, and supporting the payload in flight system testing.

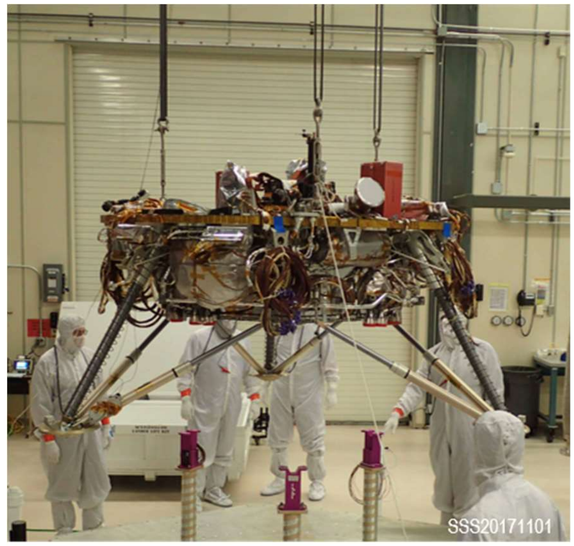

Figure 7-1 Payloads are typically delivered 8 months before launch for integration onto the lander.

Space Simulation Lab (SSL)
- Highbay 40×40 ft
- Vacuum Chamber 29 ft Dia × 65 ft High
- 2× 40 Ton Cranes, 87 ft Hook Height
- Class 100,000 Clean Room

Reverberant Acoustic Lab (RAL)
- Highbay 47×36 ft
- 40 Ton Crane, 72 ft Hook Height
- Class 100,000 Clean Room
- Acoustic Chamber 18×19×68 ft High

Multipurpose Test Facility (MTF)
- Highbay
- Pressure Test
- 20 Ton Crane, 40 ft Hook Height
- Class 100,000 Clean Room

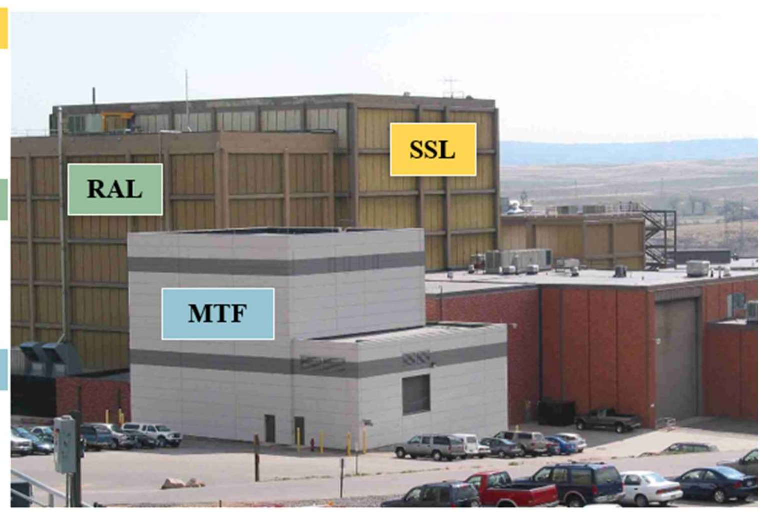

Figure 7-2 Lockheed Martin has established facilities for planetary spacecraft assembly, functional tests, and environmental tests on the same campus, enabling efficient production of McCandless.

Typical payloads will be delivered to the planetary spacecraft factory at Lockheed Martin's Waterton facility south of Denver, Colorado eight months before launch. The payload customer team will have the opportunity to perform post-delivery checkouts if desired before handoff to the Assembly, Test, and Launch Operations (ATLO) team for mechanical integration (Figure 7-1). By integrating payloads early at the factory, they can be included in integrated system-level functional and environmental tests with the lander. This improves the likelihood that surface operations will go smoothly and achieve mission objectives in the time available. Integrated testing may also save customers costs by reducing the amount of payload testing required before delivery. For customers who prefer later delivery, payloads can be integrated to the lander at the launch site, approximately 6 weeks before launch. Late integration is suited to simple payloads with few interfaces and operational modes.

7.2 TEST

The McCandless Lunar Lander will go through a test program that combines the best of heritage planetary mission test lessons learned with the streamlined processes used on the LM2100 and LM1000 commercial satellite product lines. The sequence of tests includes fit checks, electrical tests, functional and performance tests, and environmental tests. The integrated spacecraft and payload stack begins the environmental test program five months prior to launch. The Denver facilities include all necessary test chambers, labs, and clean rooms on-site. Primary test facilities for planetary spacecraft are shown in Figure 7-2. The payload integration process prevents schedule slips by developing a test and verification schedule capable of absorbing delays, using risk-reduction activities for the interfaces prior to integration and test, and maintaining open lines of communications throughout the full program.

The spacecraft and payloads are shipped to the launch site approximately seven weeks prior to launch. Late-arriving payloads will be integrated at this time. At the launch site all payloads will be part of the integrated stack tests that occur after the spacecraft is mated with the launch vehicle.

8.0 MISSION OPERATIONS

Lockheed Martin's Deep Space Exploration Mission Operations group will operate McCandless missions from the Mission Support Area (MSA) in the Denver, Colorado facility. The MSA was first used to operate a planetary spacecraft in 1989 with Magellan and has now operated 17 planetary missions such as Mars Odyssey and Stardust. The team currently operates one Mars lander and six other planetary spacecraft from the MSA. McCandless operations will share core processes and procedures, experienced personnel, facilities, and ops approach with a long history of successful flight missions.

The Mission Ops team focuses on consistency, automation, personnel cross-training, and maximizing commonality to reduce cost and ensure mission success. Mission operations begin early in the development life cycle with Mission Ops staff participating in design reviews, developing and implementing engineering objectives, and supporting payload sequencing activities. They build, review, and test command products early in development to ensure successful program milestones, as well as a smooth transition to efficient day-to-day operations after launch. Flight-proven workstation displays, telemetry databases, and spacecraft performance analysis software are adapted from previous missions for flight operation of the McCandless Lunar Lander and its payloads.

During flight, the Lockheed Martin MSA will receive payload telemetry over a secure network and transmit it to the customer's payload operations center. The customer can then provide payload operations command sequences for Lockheed Martin to radiate to the spacecraft. Payload uplinks are accomplished through pass-through commands that automatically route any instrument-level control data through the spacecraft RF link to the payload. Similarly, payload health & status and science telemetry is routed and stored on the McCandless lander for downlink at the next opportunity. More complex control of a payload, such as autonomous response to an indicator, and higher-priority routing of data are available as enhanced options. Lockheed Martin can also provide additional payload operations and operations planning services. Customers who will perform complex near-real time operations with frequent commanding through the lander, such as operating robotic arms or rovers, may consider locating an operations center at the Lockheed Martin facility for maximum efficiency.

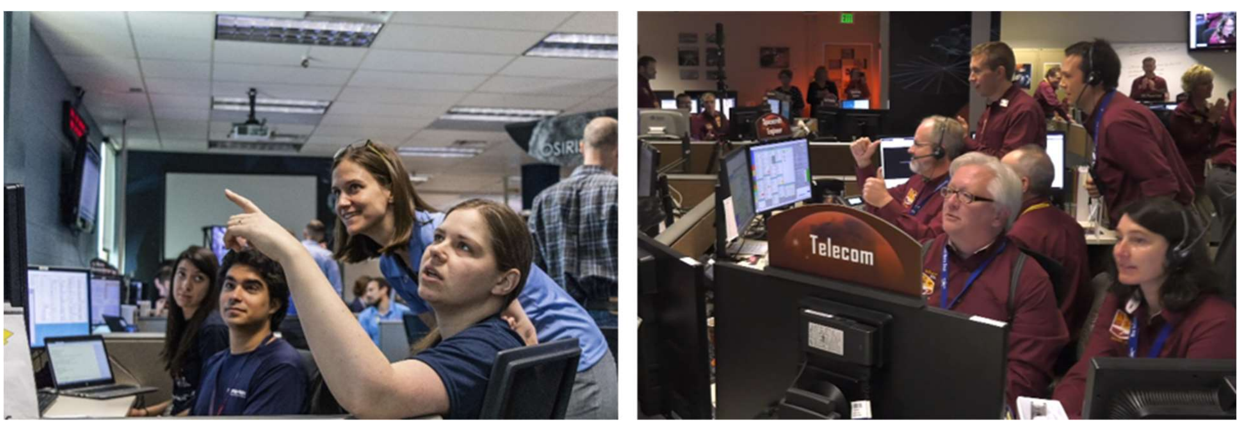

Figure 8-1 Lockheed Martin's experienced Deep Space Exploration Mission Operations team and established Mission Support Area will operate McCandless lunar missions affordably and effectively. OSIRIS-REx (l) and InSight (r) mission operations shown.