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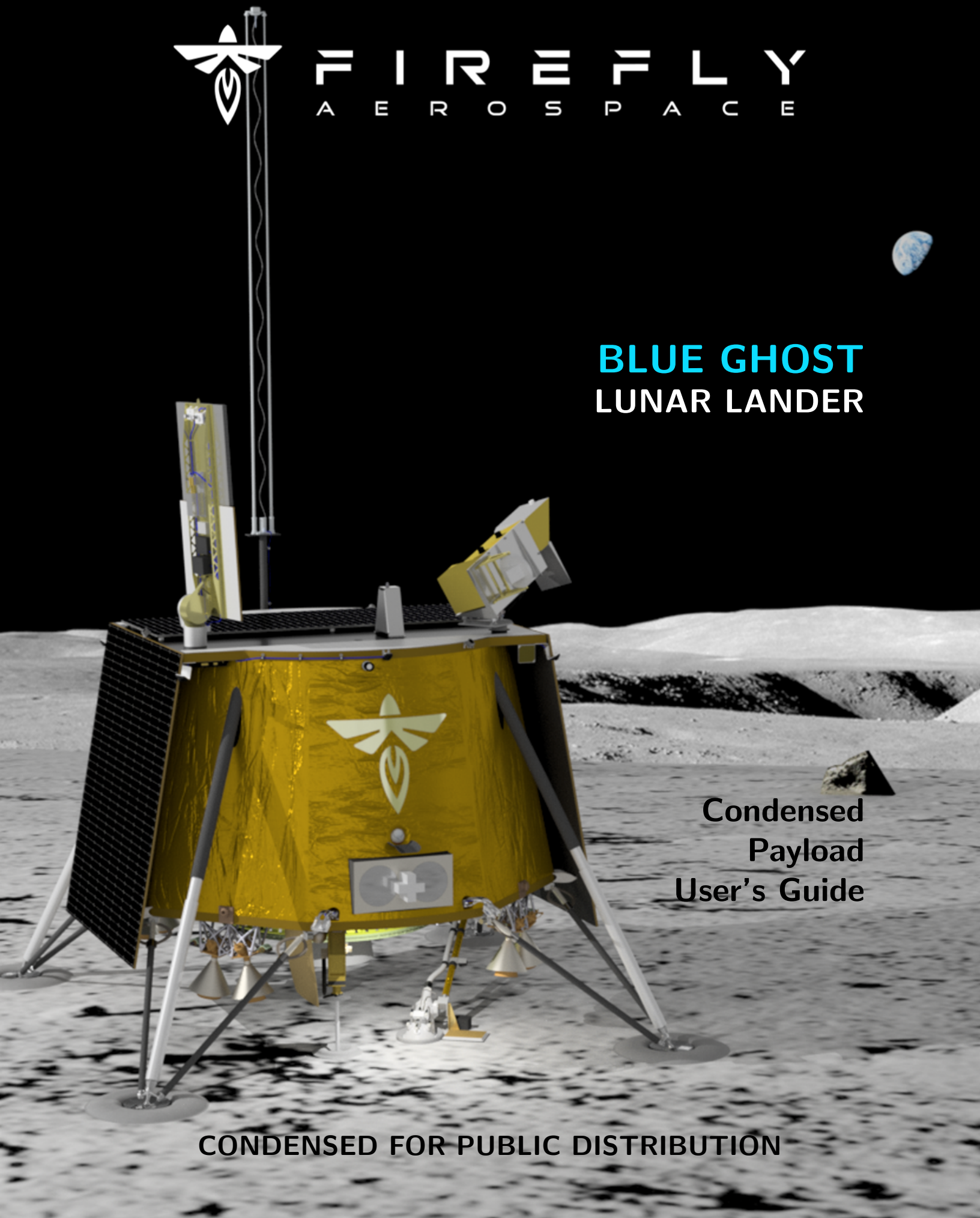

BLUE GHOST
LUNAR LANDER

Condensed Payload User's Guide

CONDENSED FOR PUBLIC DISTRIBUTION

Cover image: Artist's rendering of Blue Ghost operating the NASA-sponsored 19D Payloads in Mare Crisium on Firefly's 2023 mission.

Making Space for Everyone

Here at Firefly, we dedicate ourselves to providing an unrivaled customer experience, while concurrently providing economical and convenient access to space for small Payloads. Whether your Payload's destination is Low Earth Orbit or the surface of the Moon, this access is achieved through the design, manufacture, and operation of reliable vehicles, with a "simple/soonest" approach to technology selection, thus increasing accessibility, and lowering the cost barrier to space.

Striving to maintain transparency in a rapidly evolving launch and in-space services market, Firefly employs a customer-responsive method to mission management and mission assurance. This means that as a commercial customer, you will receive candid insight into key technical and schedule statuses. As a government customer, you have the option of more extensive insight into the engineering rigor that Firefly not only institutes within our designs, but also with the quality systems imposed on each vehicle as well.

As a customer, you will be provided a dedicated Mission Manager, who's number one priority is ensuring excellent customer service and support throughout your mission's campaign. Our team possesses exemplary industry heritage and expertise, having several decades of experience in both government and commercial launch and spacecraft programs. At Firefly, we recognize the importance our vehicles play in satisfying your mission objectives. Whether your needs are to make profit by selling an on-orbit capability, scientific monitoring and Earth observation, interplanetary exploration, or National Security, we're here to ensure your Payload gets to its destination reliably, on-time, at a low cost, and with the resources needed to complete its mission. If you have any questions regarding integrating your Payload onto one of our vehicles, please feel free to contact me directly.

We welcome you to explore the capabilities of the Blue Ghost lander within this Payload User's Guide. Information about our other launch and in-space vehicles can be found on our website.

Cheers,

Shea Ferring
Vice President of Mission Assurance

Overview

This condensed user's guide provides a summary for preliminary mission planning for customers. The contents found herein are not intended to be mission specific and are superseded by any mission-specific documentation provided by Firefly Aerospace, Inc ("Firefly"). Once a Payload Service Agreement is in place, we welcome Payload-specific details and information. A detailed and unabridged Payload User's Guide is also available to potential payload customers and developers after a mutual non-disclosure agreement is executed.

Contact Firefly

Please contact Firefly Aerospace Payload Services with inquiries into the suitability of the Blue Ghost lander for your mission.

Payload Services	Firefly Aerospace Inc. 1320 Arrow Point Drive Suite 109 Cedar Park, TX 78613 moon@firefly.com www.firefly.com

Contents

List of Figures iii

List of Tables iii

List of Acronyms iv

1 Lander Overview 1

2 Lunar Mission 1
- 2.1 Landing Sites . . . 1
- 2.2 Payload Delivery Capability . . . 2
- 2.3 Mission Operations . . . 3

3 Payload Services and Operation 4
- 3.1 Power . . . 4
- 3.2 Telecommunications . . . 5
- 3.3 Thermal Control . . . 5
- 3.4 Deployment . . . 6
- 3.5 Payload Operation . . . 6

4 Lunar Vision 7

List of Figures

1 Lander configurations . . . 2
2 Payload volumes . . . 4
3 Firefly Mission Control Center . . . 4
4 Vertically-integrated future capability . . . 7

List of Tables

1 Lander Payload capacity . . . 3
2 Payload mass, size, and location options . . . 3
3 Lander power availability . . . 5
4 Lander downlink capability . . . 5

List of Acronyms

C&DH Command and Data Handling
CLPS Commercial Lunar Payload Services
FF Firefly
FoV Field of View
FTP File Transfer Protocol
GSN Ground Station Network
GTO Geosynchronous Transfer Orbit
IOT In-Orbit-Testing
LLO Low Lunar Orbit
LOI Lunar Orbit Insertion
MCC Mission Control Center
MLI Multi-Layer Insulation
NASA National Aeronautics and Space Administration
SUV Space Utility Vehicle
PDR Preliminary Design Review
PL Payload
POC Payload Operations Center
SDG Satellite Data Gateway
SSC Swedish Space Corporation
TLI Trans-Lunar Injection

1 Lander Overview

Firefly's "Blue Ghost" lander was selected by NASA's Commercial Lunar Payload Services (CLPS) program to deliver a suite of ten Payloads (PLs) to the lunar surface in mid-2023, with a mission award price of $93.3 million. These PLs will operate using lander-provided data and power resources through an entire lunar day and beyond lunar dusk in Mare Crisium. The capabilities of the lander exceed those needed to complete the missions of the NASA-sponsored PLs, and the following resources remain available for commercial use:

- 50 kg Payload capacity
- 6 Mbps surface downlink average
- 2 kbps transit downlink average
- 10 Mbps downlink peak
- 0.2 kbps uplink average
- 2 kbps uplink peak
- 38 W total remaining transit PL power average
- 196 W peak power per PL
- 300 W total remaining surface PL power average

If you have a PL or an idea for a mission that falls within the envelope described above, we encourage you to reach out to us soon so that we can reserve your space on this historic mission.

In addition to our mission to Mare Crisium, we anticipate following missions to a number of lunar surface and orbit destinations. Our mature lander design has passed Preliminary Design Review (PDR) for multiple configurations in order to accommodate the needs of different landing sites. We describe possible missions in Section 2 and describe how the Blue Ghost design accommodates PL needs in Section 3.

2 Lunar Mission

2.1 Landing Sites

Nearly any landing site on the near side of the Moon is achievable with our lander, including the lunar poles. Our baseline lunar capture orbit is near-polar, providing access to any surface location for nearly identical ΔV values (the Moon rotates slowly enough that the equatorial velocity is insignificant). Communication back to the Mission Control Center (MCC) presently requires line of site to Earth, limiting transmission from polar regions to times when the Moon's orbit about the Earth brings the relevant pole into view. However, the lander is designed to survive through communications blackout periods and to operate autonomously so long as the sun is shining. On-board processing and storage are used to operate PLs and store data gathered during blackouts so that they can be transmitted when communications become available again (usually after 8–20 days).

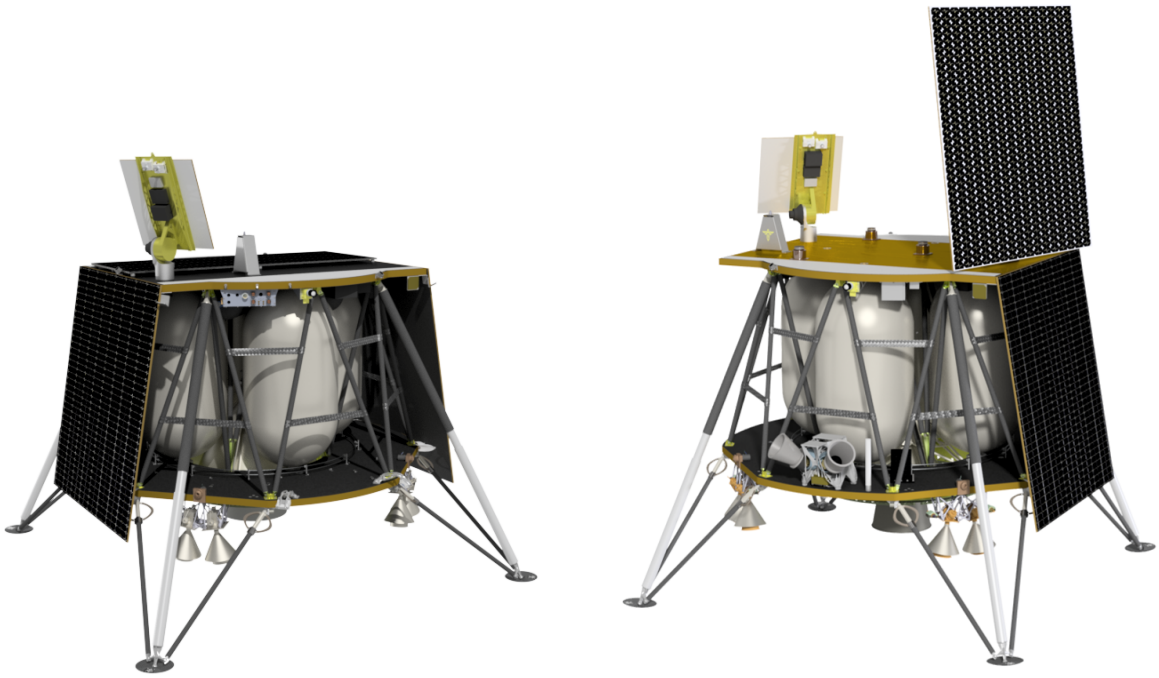

Figure 1: Blue Ghost is configured with either fixed or steerable solar arrays as appropriate to the landing site.

Blue Ghost is designed to operate for as long as it is illuminated, up to 14 days in most locations. There are two baseline lander configurations to accommodate power and thermal solutions at different latitudes (Figure 1). Mid and equatorial latitudes use three fixed solar arrays (left). For polar missions, the lander has less radiation area and accommodates longer operating periods at sites where extended periods of illumination are available. Extended operation at the poles is achieved through use of a deployable panel with a single-axis gimbal to track the Sun at any solar azimuth (right).

2.2 Payload Delivery Capability

In Table 1, we outline the PL mass capabilities of our lander, both to the surface and to Low Lunar Orbit (LLO), for different launch scenarios. Higher launch apogee increases PL mass capability, but also increases launch cost. The PL distribution between LLO and the surface can be varied, but we assume that most of our PLs will require operation on the lunar surface. PLs requiring deployment in high or elliptical lunar orbit can also be accommodated. In addition to considering total mass capability, each PL will be assessed on a case-by-case basis to ensure the structural integrity of the lander and an appropriate overall mass distribution.

Table 1: Lander Payload capacity for various configurations.

Launch Orbit	Payload to 250 km, kg	Payload to Surface, kg	Total Payload, kg
Super GTO	–	85	85
Super GTO	20	81	101
TLI	–	155	155
TLI	20	150	170

Payloads may choose from a variety of mounting locations depending on PL dimension and mass. Bounding parameters are given in Table 2. The Field of View (FoV) available to each PL location can be approximated from Figure 2. Small PLs may be accommodated outside the shown volumes.

Payloads will be attached to the decks either directly using inserts, or using adapter plates. The latter option makes it easier to integrate a PL late in the integration process, but has the disadvantage of increased mass and cost. When early integration is an option, use of inserts is therefore the preferred method. We perform a custom installation of each insert in order to provide optimal FoV and orientation of the PL.

For each PL, a Firefly Mission Manager works with the PL team early in the process to make sure that we can accommodate your mission needs. In addition to mass and volume considerations, we review your bill of materials to ensure that there are no incompatibilities with either the lander or with other PLs (for example, due to outgassing).

Table 2: Our lander provides Payload configurations with a variety of power line options.

Option	Location (Quantity)	Maximum Mass	Allowable Volume	Typical Payload
1	Below top deck (3), Above bottom deck (12)	10 kg	38×13×23 cm	Radiation measurement, archive or time capsule
2	Above bottom deck (1)	30 kg	115×31×35 cm	Drill, spectrometer, camera, instrument requiring surface or horizon FoV
3	Below bottom deck (2)	30 kg	69×45×50 cm	Rover, drill, surface sampling instrument, excavator, CubeSat dispenser
4	Below bottom deck (2)	50 kg	69×45×65 cm	Rover, drill, surface sampling instrument, excavator, CubeSat dispenser

2.3 Mission Operations

The lander MCC is located at our Cedar Park, TX headquarters. Pictured in Figure 3, the MCC provides operations services such as command and control of the lander and simulators, tracking, trajectory design, and orbit determination. It is connected via secure protocol to the Swedish Space Corporation

(SSC) Ground Station Network (GSN). PLs can either be operated from the Firefly MCC by a PL team representative, or remotely from a Payload Operation Center.

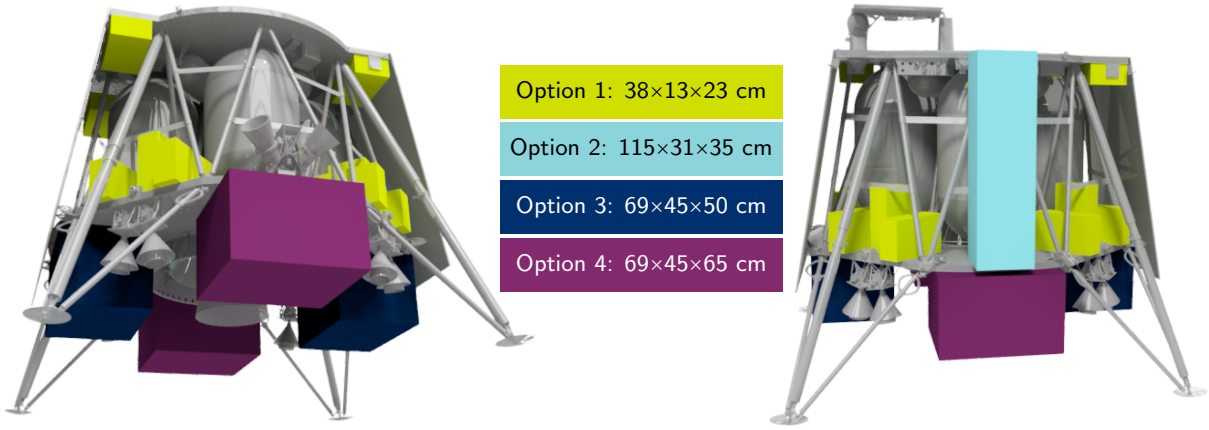

Figure 2: Payload volumes and locations on the lander.

Figure 3: Firefly's existing Mission Control Center operates the lander and Payloads throughout the mission.

3 Payload Services and Operation

3.1 Power

Our lander provides nominal power services on the ground, in orbit, and on the lunar surface. Keep-alive power is provided to the PLs during launch if needed. The spacecraft also provides a signal to power on the PLs upon completion of In-Orbit-Testing (IOT) or upon landing on the lunar surface, as desired. As outlined in Table 3, power can be supplied continuously or in a duty cycle manner to the PLs from Earth orbit through lunar surface operation completion. The power listed for each mission phase is the total available to be divided among the PLs.

Table 3: Our lander supplies power to the Payloads during all mission phases.

Mission Phase	Nominal Power, W	Peak Power, W
Launch Readiness	170	170
Launch and Separation	10	10
Earth/Lunar Orbit	270	650
Lunar Descent	30[1]	170
Lunar Surface Operations	450	650

3.2 Telecommunications

The lander supports usable data downlink rates of at least 10 Mbps from the lunar surface to the SSC network while maintaining at least 3 dB margin (Table 4). A minimum of 2 kbps downlink is available throughout transit (except during lunar eclipse), and during Safe Mode operation. We can increase average transit data through periodic usage of our high-gain antenna. For example, 2 minutes of high gain operation per day yields an average of about 15 kbps through transit. 2 kbps uplink is available throughout the mission.

Table 4: Our lander provides data services with good margin for all mission phases.

Antenna	Transmission Location	Ground Antenna Diameter	Telemetry Rate	Margin
Low Gain	LLO	13 m	2 kbps	3.7 dB
High Gain	Lunar Surface	13 m	10 Mbps	3.2 dB

For rovers or other PLs deploying from the lander, we can provide a Wi-Fi signal for communication between the PL and lander. We work with the PL provider to make sure that data rates are sufficient over the anticipated range of travel.

We invite a representative for each PL to support the duration of that PL's operation, either at the Firefly MCC or at a Payload Operations Center (POC). We offer console and security training for each PL team. All telecommand data pass through the Satellite Data Gateway (SDG). The SDG archives all commands and telemetry. Our server separately archives all transmitted commands and decoded telemetry. Decoded telemetry is broadcast on our secure network for access by the MCC and POC. In addition to data access provided via our network, all relevant data are shared with each PL team via secure encrypted File Transfer Protocol (FTP).

3.3 Thermal Control

Thermal environments can vary widely depending on the positioning and line-of-site requirements of the PL. We work with each PL provider to make sure the PL is maintained in a suitable environment, beginning with an analytical model of the integrated PL. The PL provider is responsible for supplying a thermal model to Firefly early in the PL integration process. Once received, Firefly performs an

[1] Higher power usage is possible, but increases the duration of the battery recharging period that begins after landing.

integrated thermal analysis and then finalizes the PL thermal control approach for each PL. We have the tools to either passively or actively support your PL's thermal requirements, and to confirm these requirements are met through both analysis and integrated thermal vacuum testing. In general, we will thermally isolate each PL from the spacecraft to provide maximum control of the PL temperature. The optimal configuration of heat pipes, radiators, Multi-Layer Insulation (MLI), and active heaters is determined for each PL, with heater duty cycles powered by automated control loops.

3.4 Deployment

Firefly has significant experience with mechanisms, including thrust vector control actuators and mission-critical fairing latches. Because we understand that each PL mission has unique requirements, we do not offer a one-size-fits-all solution. We have the expertise needed to develop a custom deployment mechanism for your PL, to integrate and validate your proprietary deployment mechanism, or to integrate industry standard in-orbit deployment mechanisms such as canisterized dispensers.

3.5 Payload Operation

We recognize the importance of automated/scripted command sequencing for long-haul cislunar missions, and for human intervention to ensure mission success when corrective actions are required. Our approach baselines automated execution of simulator-validated scripts supplemented with human commanding during cislunar flight, Lunar Orbit Insertion (LOI), and to a limited extent, during descent & landing operations.

The lander includes omnidirectional coverage on the low-gain antennae for commanding, and the command receiver is always powered on. The command processor in the Command and Data Handling (C&DH) system includes the functionality to power on/off the PLs based on ground commands. In specific modes, such as Safe Mode or Descent, commands to power a specific PL may be prohibited. PLs may be powered off autonomously by fault protection on the spacecraft at any time.

During lunar surface operations, the power state of each PL is commandable and further operations such as mode changes, download of data, and data processing such as compression or event detection, are available. All commands are implemented with acknowledgments for verification by operators so that they are successfully processed on-board. Real-time status of PLs, such as bus voltage and supply current, are downlinked in the periodic lander housekeeping telemetry.

In polar regions, communications blackouts occur periodically. To enable extended duration missions, remote interface units possess the on-board data processing and storage needed for autonomous PL operation through a communications blackout. So long as the lander remains illuminated, it will continue operating. PL data are stored for transmission to the GSN once line of site is reestablished.

4 Lunar Vision

Recognizing the importance of the Moon to the future plans of both the US government and commercial industry, we are leading a number of efforts to develop a future lunar architecture supporting advanced lunar surface capabilities. Our Beta launch vehicle (Fig. 4) will permit dedicated Trans-Lunar Injection (TLI) launch (250 km × 380,000 km) for Blue Ghost, as well as for other landers of similar size, increasing launch flexibility and PL mass to the lunar surface. This vertically integrated capability from the surface of the Earth to the surface of the Moon will uniquely position Firefly in terms of ability to control schedule and prevent delays. Our Beta vehicle will be available for lunar missions beginning in 2024.

At present, no commercial or US entity possesses the infrastructure needed to communicate with the far side of the Moon, effectively limiting US missions to only half of the lunar surface. Firefly's Space Utility Vehicle (SUV) will expand our reach by providing transformative telecommunication capabilities to all surface locations, including the far side, while simultaneously increasing PL mass deliverable to the surface. The SUV is a solar-electric space tug capable of delivering a lander to LLO without that lander expending any on-board propellant, meaning more PL can be delivered to the lunar surface.

Once delivered to LLO by the SUV, the lander can detach and perform its landing sequence. Meanwhile, the SUV remains in LLO, where it serves as a communications relay for the lander and surface PLs. The SUV allows communication with any point on the Moon as it flies over, and can carry larger, and higher power communications systems than can easily be hosted on a lander, meaning higher data rates can be achieved for PLs on the near surface. As more missions are flown and the number of orbiting vehicles increases, a constellation grows, providing near-continuous coverage after only three missions.

Long-term use cases for an SUV include beaming power to the surface for lunar nighttime lander and PL survival, and sample return via rendezvous with landers in LLO. We project our earliest lunar SUV missions for 2024, well in advance of the date needed to support telecommunications for future manned missions.

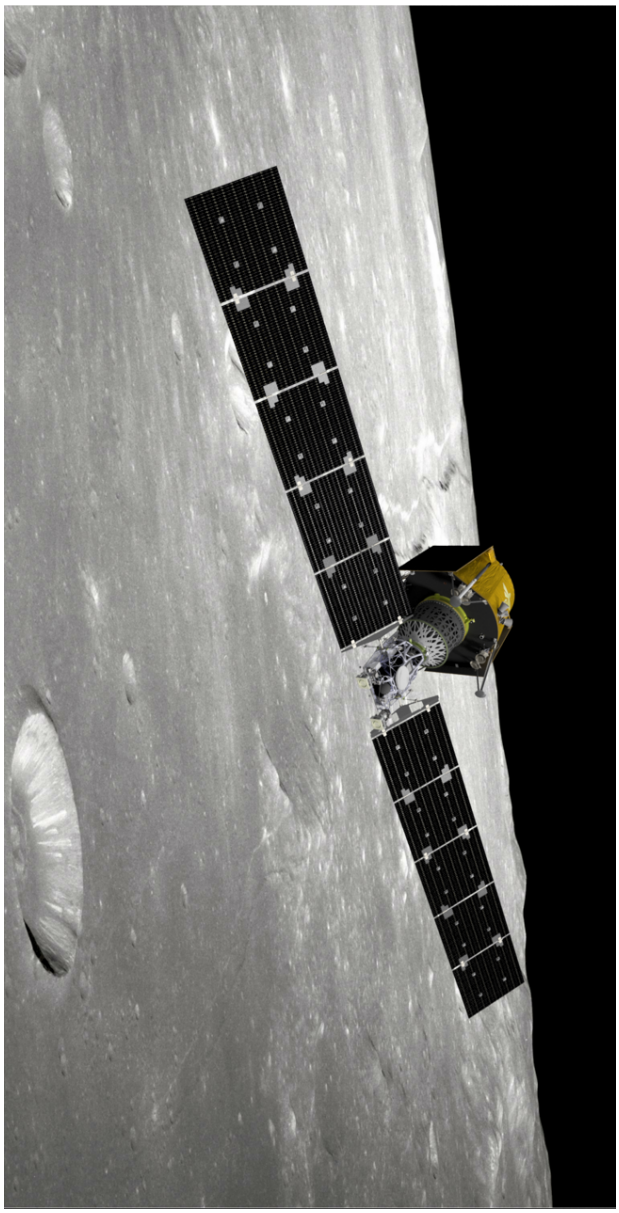

Figure 4: Blue Ghost hitches a ride to LLO aboard the SUV. Background image credit: NASA.

We are excited about our role in the future lunar economy and grateful for the present opportunities afforded to us by our CLPS contract with NASA. While recognizing that we compete with other talented organizations, we are confident that we offer the most proven lander solution for your PL and we believe that Firefly offers the greatest potential to serve your future needs. We look forward to learning how our mission can serve yours.'

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