Astrobotic Technology, Inc.

Peregrine Mission 1 (PM1)

ORBITAL DEBRIS ASSESSMENT RERPORT (ODAR)

ASTROBOTIC LICENSING APPLICATION

Astrobotic Technology, Inc.

1016 N. Lincoln Ave

Pittsburgh, PA 15233

Revision A Version 5
Date January 31, 2021

REQUIRED SIGNATURES

Lead Systems Engineer: (Ander Solorzano)	A Solorzano
Date (MM/DD/YYYY):	1/31/2021

Mission Operations Lead: (Tom Garvey)	Thomas R Garvey
Date (MM/DD/YYYY):	2/1/2021

Chief Engineer: (Kris Teaford)	Kris K. Teaford
Date (MM/DD/YYYY):	2/3/2021

Mission Director: (Sharad Bhaskaran)	Sharad Bhaskaran
Date (MM/DD/YYYY):	2/5/21

Safety & Missions Assurance Director: (Dan Silianoff)	Dan Silianoff
Date (MM/DD/YYYY):	2/2/21

REVISION HISTORY

Revision	Date	Description	Author	Approval
A	YYYY.MM.DD	Revision Title List of Changes	Initials	Initials
V3	2020.12.23	Incorporated significant mission and spacecraft description. Incorporated parameters and studies form flight dynamics. Changes from flight dynamics incorporated.	AAS	
V4	2021.01.12	Updated lots of information following System CDR	AAS	
V5	2021.01.28	Incorporated final corrections and edits	AAS	

TABLE OF CONTENTS

1 PURPOSE

This document establishes and communicates the Orbital Assessment Debris Report (ODAR) for Astrobotic Technology, Inc, Peregrine Mission 1 (PM1) spacecraft. This report follows guidelines according to the NASA-STD-8719.14B. This report follows reporting format per NASA-STD-8719.14B, Appendix A.

2 SELF-ASSESMENT REPORT

PDR/CDR Orbital Debris Assessment Report Evaluation: Astrobotic Peregrine Mission 1

(based upon ODAR version, dated January 28th, 2021)

	Launch Vehicle					Spacecraft					Comments
Reqm't #	**Compliant**	**N/A**	**Not Compliant**	**Std. Non-Compliant**	**Incomplete**	**Compliant**	**N/A**	**Not Compliant**	**Std. Non-Compliant**	**Incomplete**	*For all incompletes, include risk assessment (low, medium, or high risk) of non-compliance & Project Risk Tracking #*
4.3-1a 25-yr limit					X	X					
4.3-1.b <100 object x limit					X	X					
4.3-2 GEO +/- 200 km					X		X				Passing at 30 degrees inclination.
4.4-1 <0.001 Explosion Risk					X	X					
4.4-2 Passivate Energy Source					X					X	To be provided in future report. Likely N/A given EOM happens on surface of Moon.
4.4-3 Limit BU Long Term Risk					X					X	To be provided in future report. Likely N/A given EOM happens on surface of Moon.
4.4-4 Limit BU Short Term Risk					X					X	To be provided in future report. Likely N/A given EOM happens on surface of Moon.
4.5-1 <001 10cm Impact Risk					X	X					
4.5-2 Postmission Disposal Risk							X				
4.6-1a-c Disposal Method					X	X					
4.6-3 MEO Disposal					X	X					
4.6-4 Disposal Reliability					X	X					
4.7-1 Ground Population Risk					X		X				
4.8-1 Tether Risk							X				

3 ODAR SECTION 1: PROGRAM MANAGEMENT AND MISSION OVERVIEW

3.1 IDENTIFICATION OF THE HQ MISSION DIRECTORATE SPONSORING THE MISSION AND THE PROGRAM EXECUTIVE

Mission Directorate / Company: Astrobotic Technology, Inc.

Program Executive: John Thornton, CEO

Address: 1016 N Lincoln Ave, Pittsburgh, PA 15233

NASA Contract: Attention: 80HQTR18R0011R

3.2 IDENTIFICATION OF THE RESPONSIBLE PROGRAM/PROJECT MANAGER AND SENIOR SCIENTIFIC AND MANAGEMENT PERSONNEL

Program Manager / Mission Director: Sharad Bhaskaran

Chief Engineer: Kris Teaford

Senior Management: Dan Silianoff, Ander Solorzano, and Tom Garvey

3.3 IDENTIFICATION OF ANY FOREIGN GOVERNMENT OR SPACE AGENCY PARTICIPATION IN THE MISSION AND A SUMMARY OF NASA'S RESPONSIBILITY UNDER THE GOVERNING AGREEMENT(S)

Summary of NASA's responsibility under governing agreement(s): NASA has procured payload delivery services to the Moon from Astrobotic Technology, Inc via the Commercial Lunar Payload Services (CLPS) Program's Task Order 2 (TO2). Astrobotic will be flying 10 NASA payloads from various NASA centers and delivering them to the Moon. The NASA payloads are a collection of scientific instruments. Attention: 80HQTR18R0011R.

Summary of Foreign Space Agency Participation: DLR (Deutches Zentrum für Luft- und Raumfahrt), also known as the German Space Agency, has also procured commercial lunar delivery services directly from Astrobotic on the same mission. Astrobotic will be flying one DLR payload, a radiation dosimeter.

In addition to DLR, the Agencia Espacial Mexicana (AEM), also known as the Mexican Space Agency, has also procured commercial lunar delivery services directly from Astrobotic on the same mission. Astrobotic will be flying one AEM payload, a deployable rover self-assembly payload.

3.4 CLEAR SCHEDULE OF MISSION DESIGN AND DEVELOPMENT MILESTONES FROM NASA MISSION SELECTION THROUGH PROPOSED LAUNCH DATE, INCLUDING SPACECRAFT PDR AND CDR (OR EQUIVALENT) DATES

Milestone	Date
NASA Mission Selection	May 2019
Spacecraft Structure Test Model Campaign	August 2020

Launch Vehicle Kick-Off	March 2020
Payload Acceptance Review and Delivery Packages	December 2020
Payload Deliveries	January 2021 thru May 2021
MITTR Review 1	January 2021
Program SIR	March 2021
MITTR Review 2	July 2021
Integrated Vehicle Environmental Acceptance Test Campaign Start	August 2021
Launch Date	December 2021

3.5 BRIEF DESCRIPTION OF THE MISSION

Astrobotic's Peregrine Mission 1 (PM1) is a single-stage spacecraft launched on an American launch vehicle that will deliver payloads to Lacus Mortis (43.9˚ North, 25.1˚ East) on its first mission to the Moon. PM1's propulsion system is powered by TALOS rocket engines, which are designed to NASA-developed requirements for un-crewed deep space science missions. NASA will fully qualify the engines for spaceflight and fund production of the first flight units before they fly on Peregrine Mission One (M1) under an existing Tipping Point award.

PM1 will deliver 10 NASA payloads consisting of various scientific instruments such as mass spectrometers, magnetometers, and infrared camera imaging systems. The 10 NASA payloads are manufactured from various NASA centers. The 10 NASA payloads will remain attached to the lander. With the exception of a magnetometer antenna deployment on the surface of the Moon, the 10 NASA payloads do not have any large actuating parts (>10 cm) or large deployable elements (>10 cm). Some NASA payloads will deploy caps (<10 cm) to expose the science suite to the environment. Only 1 NASA payload, SEAL, has a cap that will be deployed in lunar orbit which measures 12.16 cm. These deployments are set to occur in lunar orbit and are actively controlled by mission operations.

PM1 will also deliver 8 commercial payloads, including one from DLR, the German Space Agency. These payloads range from science instruments such as radiation dosimeters to deployable rovers and time capsules. The deployable systems are set to deploy on the lunar surface during surface operations.

After conducting a detailed analysis of potential landing locations with our partners at Airbus, we selected a primary landing location for PM1 on a large flat plateau in the Lacus Mortis basin at 43.9° N latitude, 25.1° E longitude, with a target ellipse of 24 km by 6 km. Analysis shows that the level terrain and low boulder count of the Lacus Mortis plateau maximizes our probability of landing success, without the need for terrain relative navigation (TRN) and hazard detection and avoidance (HDA) technologies.

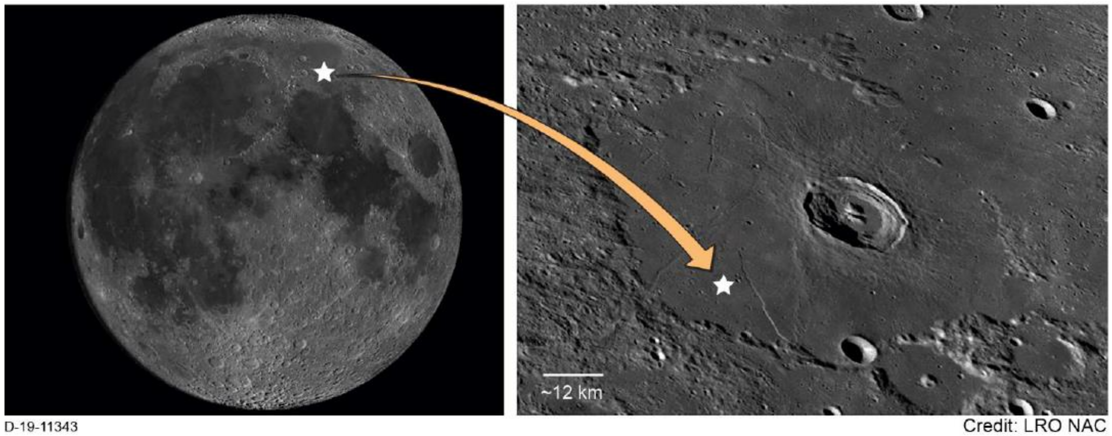


Figure 1. PM1 Lacus Mortis landing site

Upon landing, PM1 will decommission its propulsion system by venting gaseous Helium into the surrounding vicinity. PM1 is set to land at 55 hours after local sunrise at the Lacus Mortis site. Once landed, PM1 will not relocate to a different landing site or conduct asset retrieval operations. PM1 will safe its energy and radio frequency systems towards the onset of the first lunar night, roughly 240 hours after landing.

The total duration of the mission is set to be up to 57 days depending on arrival in lunar orbit. These include up to 10 Earth days (240 hours) of surface operations. The mission ends after the onset of the first lunar night at the landing site.

PM1 is set to launch on ULA's Vulcan-Centaur Test Flight 1. PM1 is set to use the Deep Space Network (DSN) for ground tracking and telemetry/commanding purposes.

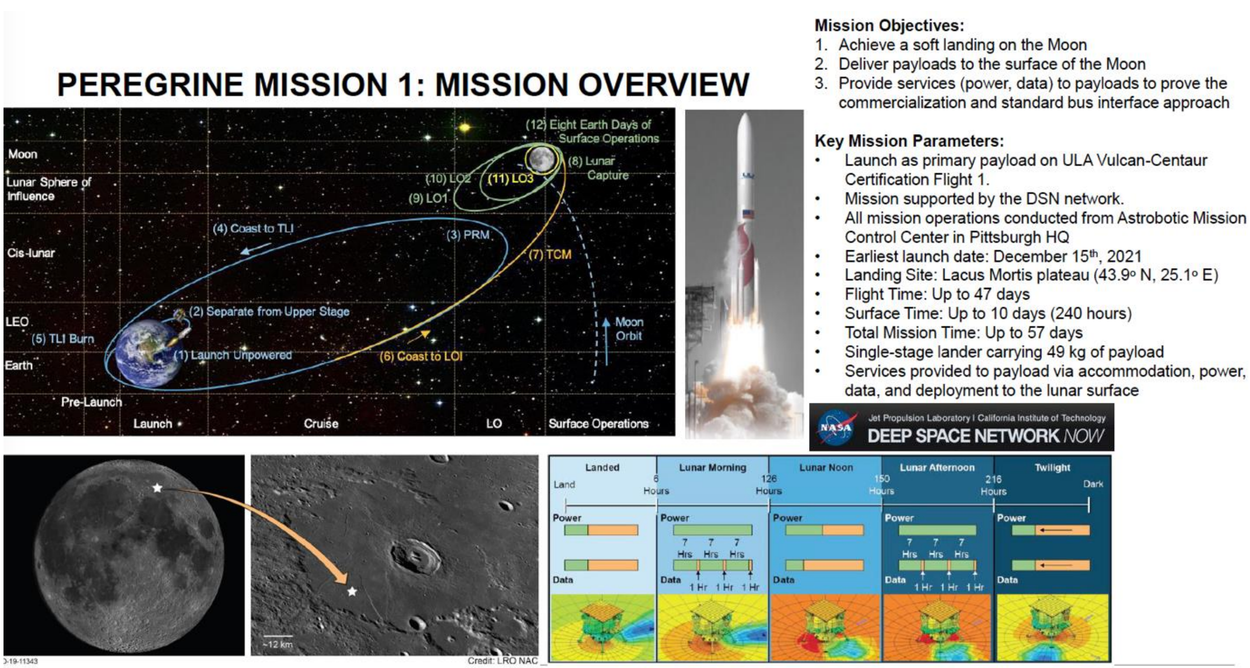


Figure 2. Peregrine Mission 1 Overview graphic

3.6 IDENTIFICATION OF THE ANTICIPATED LAUNCH VEHICLE AND LAUNCH SITE

Launch Vehicle Selected: Vulcan-Centaur Test Flight #1

Launch Vehicle Provider: United Launch Alliance (ULA)

Launch Vehicle Provider: Kennedy Space Center (KSC), Cape Canaveral, Florida

3.7 IDENTIFICATION OF THE PROPOSED LAUNCH DATE AND MISSION DURATION

Proposed Launch Date: The launch slot signed and agreed between ULA and Astrobotic covers the period from August 2021 to February 2022. The launch date is to be set within this time slot upon agreement with both parties.

Expected Mission Duration: The mission duration for PM1 is expected to be up to 57 days, including up to 10 Earth days (240 hours) for lunar surface operations.

3.8 DESCRIPTION OF THE LAUNCH AND DEPLOYMENT PROFILE, INCLUDING ALL PARKING, TRANSFER, AND OPERATIONAL ORBITS WITH APOGEE, PERIGEE, AND INCLINATION

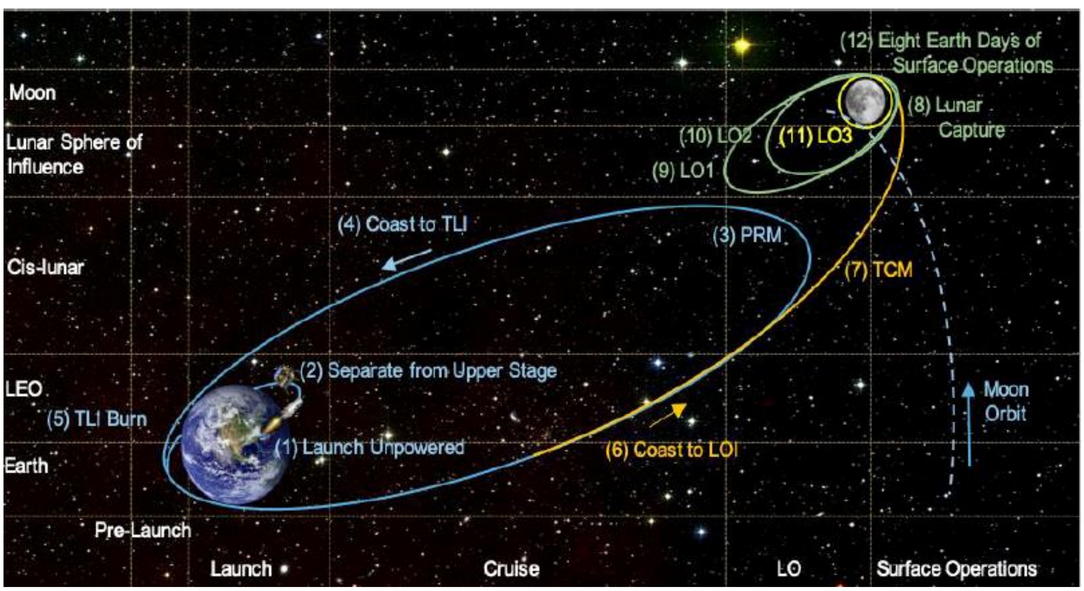


Figure 3. General overview of the PM1 trajectory profile

The figure above illustrates a general overview of our mission trajectory profile. Our mission is executed in six phases:

1. Pre-launch,
2. Launch,
3. Cruise,
4. Lunar Orbit (LO),
5. Lunar Descent, and
6. Surface.

Pre-launch involves all activities in the ground for integrating PM1 into the ULA Vulcan-Centaur launch vehicle. Most of this process will be done at the Payload Processing Facility (PPF).

The Launch phase begins with the Vulcan-Centaur launch and includes transit to low-Earth orbit (LEO), where the Centaur upper stage deploys Peregrine after performing an apogee raising burn known as the Earth-departure burn. Centaur and Peregrine may perform up to 1 coasting orbit around Earth at altitude of up to 500 km before Peregrine is deployed by the Centaur upper stage. Peregrine launches mostly in an unpowered configuration with the exception of its Power Control Assembly (PCA). The PCA is the only system on during launch which is needed for detecting the physical separation of Peregrine from Centaur to initiate power up procedures.

The Cruise phase begins when Peregrine separates from Centaur and orients to a sun-pointing attitude. Peregrine is dropped into a 500 km by 380,000 km orbit. Peregrine remains in this phase which includes 1 orbit around Earth. Peregrine is planned to perform a set of Trajectory Correction Maneuvers (TCMs) in this phase, as well as a Perigee Raise Maneuver (PRM) if needed to raise the second near-Earth Perigee up to 600km. (see Figure 4 for orbital parameters).

Parameter	At Separation from Launch Vehicle	At Next Perigee Passage
Epoch	15 Dec 2021 06:32:02.839	24 Dec 2021 14:01:36.955
Semi-Major Axis (km)	189736.9	189551.3
Eccentricity	0.963791	0.955677
Inclination (deg)	30.0	29.5
Right Ascension of the Ascending Node (deg)	13.5	12.8
Argument of Perigee (deg)	26.9	27.5
True Anomaly (deg)	0.070	0.000
Perigee Altitude (km)	492.0	2023.3
Apogee Altitude (km)	366225.6	364323.1

Keplerian Elements expressed in the Earth True-of-Date Coordinate Frame

Figure 4: Orbital Parameters for the separation orbit and the phasing loop orbit. The orbital parameters here use a December 15th, 2021 as a baseline epoch.

Lunar capture initiates the Lunar Orbit (LO) phase, which includes all lunar-orbit insertion (LOI) maneuvers, orbital payload deployments, and system checkouts prior to descent to the lunar surface. The LO phase contains three distinct orbits—LO1, LO2, and LO3—each with a different number of revolutions, shadow times, orbital periods, and total flight duration. Peregrine performs a ME braking burn to capture itself in LO. For LO1, Peregrine will orbit for up to three 12-hour revolutions before transitioning to LO2. LO2 serves as the stable staging or "parking" orbit for Peregrine in lunar orbit. In LO1 and LO2, Peregrine can supply the required payload services and perform any landing system checkout operations required while maintaining a power-positive state. PM1 is planned to perform a deployment of caps (<10 cm) from its payload science instruments to expose the science instrument to the vacuum environment. About three to two days prior to landing, Peregrine performs another main engine maneuver at LO2 that lowers it to LO3, a circular 100-km orbit. Below is a picture that graphically describes the lunar orbits.

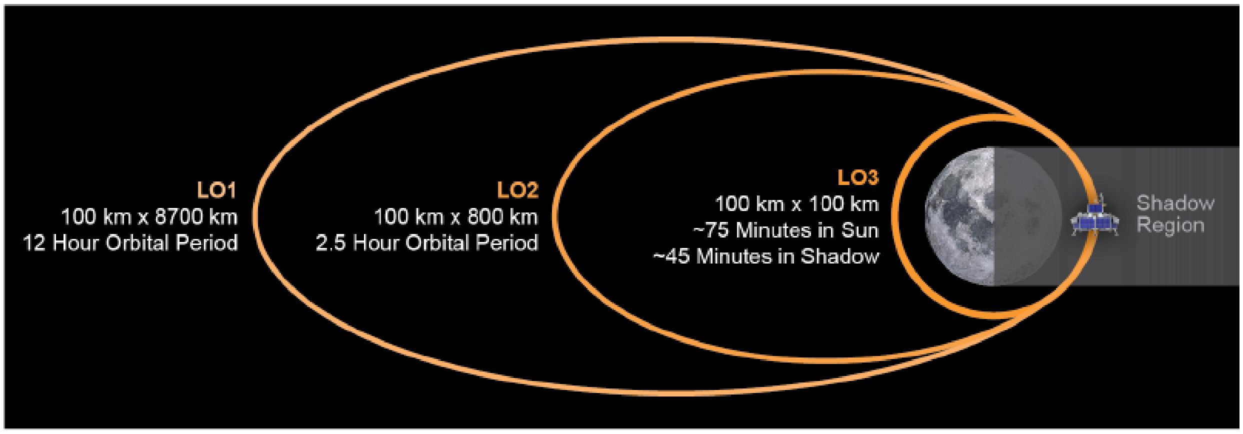


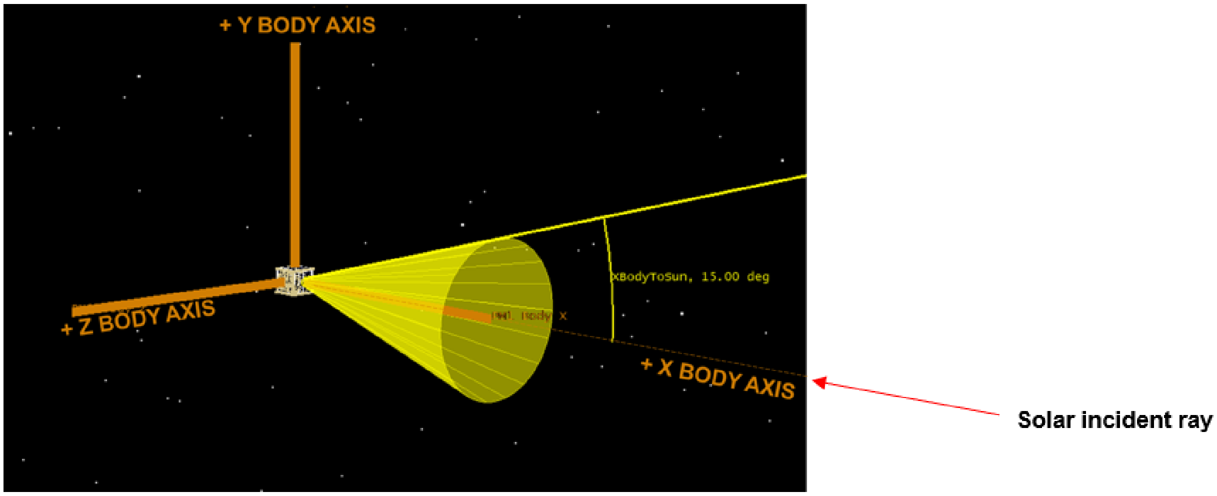
Figure 5. Graphical description of Peregrine M1 lunar orbit altitudes.

The landing operations begin at LO3 and will last up to 1 hour and 10 minutes. The landing operations will be done autonomously by Peregrine after the Astrobotic mission control team uploads the final landing command sequence. AMCC will have a communication link established to monitor the status and receive flight telemetry. The landing operations for Peregrine have multiple sub-phases. They are Unpowered Descent, Powered Descent (PD), Terminal Descent, and Terminal Descent Nadir. A Descent Orbit Insertion (DOI) maneuver at 100 km lunar altitude takes Peregrine into an elliptical lower elliptical orbit with a new periapsis (minimum altitude) of 15 km above the lunar surface. After DOI is performed, Peregrine enters the 1-hour Unpowered Descent phase where it uses its on-board ACS engines to perform attitude corrections in preparation for the PD phase. At around 15 km lunar altitude, the PD phase begins. During this phase, all five main engines fire continuously at maximum thrust to decelerate Peregrine along the tangential direction, parallel to the lunar surface. Between a 4 km and 2 km altitude from the lunar surface, the landing systems onboard Peregrine starts to measure altitude and velocity data, allowing Peregrine's guidance computing systems to converge on its state determination needed to achieve a safe landing. At a 2-km lunar altitude, Peregrine transitions to the Terminal Descent phase. For the last 300 m, Peregrine pitches to nadir pointing—defined as the legs pointed down towards the lunar surface—and proceeds until contact with the lunar surface. Prior to contact, Peregrine performs the last adjustments to the desired landing orientation for optimal payload surface operations. Force sensors attached to the footpads detect a positive ground contact and, after a predetermined number of the force sensors detect surface contact, all engines are cut off. Peregrine transitions to surface operations phase at this time.

Once Peregrine lands, the Surface phase begins and all surface payload operations are performed until the onset of the first lunar night.

3.9 DESCRIPTION OF THE SPACECRAFT'S MANEUVER CAPABILITY, INCLUDING BOTH ATTITUDE AND ORBIT CONTROL. GIVE THE TIME PERIOD DURING WHICH THE CAPABILITIES WILL BE EXERCISED.

PM1 contains five 100-lbf main axial engines and twelve 10-lbf ACS engines. Peregrine uses its main axial engines for commanded main engine maneuvers. Peregrine uses its ACS engines to maintain attitude control. Peregrine is designed to autonomously maintain a sun-pointing configuration with a 15° half angle cone with respect to Peregrine's primary +X axis using its ACS. The figure below illustrates this configuration.



PM1-L1RQ-26: Peregrine M1 shall tolerate at least 15 degrees of half-angle off-pointing variation from the solar incident ray normal the YZ plane.

Figure 6. Sun pointing configuration of PM1

All main engine maneuvers need to be commanded and uploaded from the ground. Peregrine does not have the capability to fire its main engines without a command upload from the ground. The maneuver summary table below shows an example of when main engine maneuvers are expected to occur.

Table 1. Maneuver Summary Table for Peregrine Mission 1

Maneuver	Start Time (UTCG)
Launch Vehicle Upper Stage Burn	12/15/21 6:32
Potential Trajectory Correction Maneuver 1	12/15/21 18:32
Perigee Raise Maneuver	12/19/21 22:06
Potential Trajectory Correction Maneuver 2	12/24/21 20:01
Potential Trajectory Correction Maneuver 3	12/26/21 20:01
Lunar Orbit 1 Injection	12/29/21 9:19
Lunar Orbit 2 Injection	12/30/21 9:18
Lunar Orbit 3 Injection	1/7/22 16:11

The plan and sequence for these planned maneuvers is described as follows:

1. Flight Dynamics team acquires enough orbit determination. Flight Dynamics passes vectors to GNC and GNC computes necessary maneuver upload parameter.
2. Mission Ops team has a review of the maneuver prior to upload.
3. Maneuver is uploaded to Peregrine. Mission Ops team watches telemetry for anomalies leading up to the maneuver.
4. Maneuver in progress:
   - AOS coverage with the S/C is required
   - Increased power for telemetry downlink may be established
   - Payload services discontinued
   - 10-12 minutes for slewing the +X axis away from sun point and into the burn direction

- 1-2 minutes for main engine burn
- 10-12 minutes for slewing the +X axis back to sun pointing
- Payload services resume after sun pointing is reestablished
- Nominal Transit Operations state and operations are resumed

5. Mission Ops team keeps receiving telemetry. FD team starts new orbit determination

Aside from the maneuvers described above, Peregrine will maintain the sun pointing orientation autonomously for most of the mission. The capability is accomplished by using only the onboard ACS. To accomplish this, Peregrine will use its 6 sun sensors (SSoC-D60), a Star Tracker (BST-200), and its IMU (LN-200) for navigation and guidance purposes. The 6 sun sensors and the star tracker are redundant to each other to achieve the sun pointing configuration. Sun pointing will be established as early as 30 minutes after separation from the Centaur upper stage section or as late as 3 hours after separation from the Centaur upper stage depending on whether a communication link is established with DSN and the link strength.

3.10 REASON FOR SELECTION OF OPERATIONAL ORBIT(S) (SUCH AS GROUND TRACK, SSO, GEO SYNC, INSTRUMENT RESOLUTION, CO-LOCATE WITH OTHER SPACECRAFT, …)

The Earth Orbit pass in the Cruise phase was selected due to PM1 being a first mission for Peregrine. Based on similar history of first flights, having operational flight time slag before a major mission critical event, such as Lunar Orbit Insertion, can give the operational team enough time to debug its platform, diagnose any anomalies, and calibrate the system. We selected this orbit to give us around 9 days of flight time prior to our Lunar Orbit Insertion.

The lunar orbit altitudes were selected to provide good operational and survival capabilities to the mission. LO2 is set to be a healthy parking orbit for Peregrine where it can manage its power, thermal, and communication resources adequately to provide the operational support in this orbit. LO3 is set as the 100 km circular orbit to allow Peregrine to get reasonably close to the surface before performing autonomous descent operations. Peregrine is expected to take pictures of the surface of the Moon at this 100 km altitude. In addition, the selection of the 100 km orbit allows Peregrine to minimize the landing dispersions and land within a certain ellipse size (24 km x 6 km) at the landing site given the orbit determination tracking performed at this altitude.

Peregrine is not planning on co-locating with any other spacecraft, orbital, or surface asset.

3.11 IDENTIFICATION OF ANY INTERACTION OR POTENTIAL PHYSICAL INTERFERENCE WITH OTHER OPERATIONAL SPACECRAFT

There are no planned interactions or rendezvous with any spacecraft during Earth orbit, lunar orbit, or lunar surface. We are communicating with the launch vehicle provider, ULA, to communicate our launch trajectory and orbit to ensure we have no interferences with other spacecraft.

4 ODAR SECTION 2: SPACECRAFT DESCRIPTION

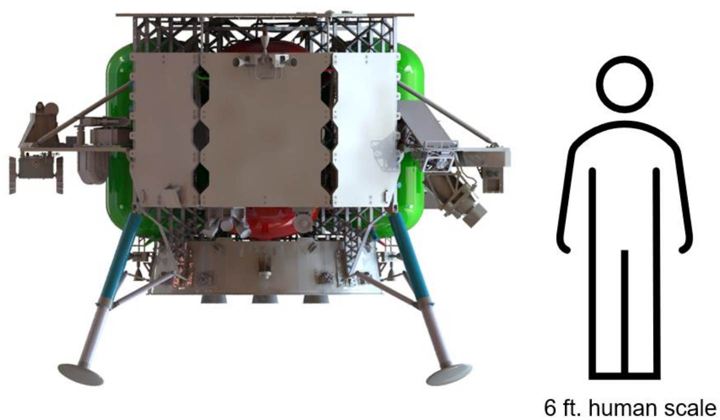
4.1 PHYSICAL DESCRIPTION OF THE SPACECRAFT, INCLUDING SPACECRAFT BUS, PAYLOAD INSTRUMENTATION, AND ALL APPENDAGES, SUCH AS SOLAR ARRAYS, ANTENNAS, AND INSTRUMENT OR ATTITUDE CONTROL BOOMS

4.1.1 PEREGRINE M1 OVERVIEW

A visual description of the Peregrine spacecraft is shown below.

PEREGRINE M1 SYSTEM CONFIGURATION - PEREGRINE M1 MK3

Peregrine M1 Specifications Overview	
Payload Mass	49.7 kg (109 lbs)
Vehicle Height	1.91 m (75.15")
Vehicle Width	2.56 m (100.87")
Dry Mass	479 kg (1,056 lbs)
Bus Voltage	24 Vdc – 33.6 Vdc
Wired Payload Interface	Serial, RS422
Wireless Payload Interface	WLAN 802.11b
Surface Ops Bandwidth	3,000 bps
Max Mission Lifetime	60 days
Engine Thrust	667 N (150 lbf)
Main Propulsion	5 TALOS main engines
Fuel / Oxidizer	MMH / MON-25
Attitude Control System	12 engines



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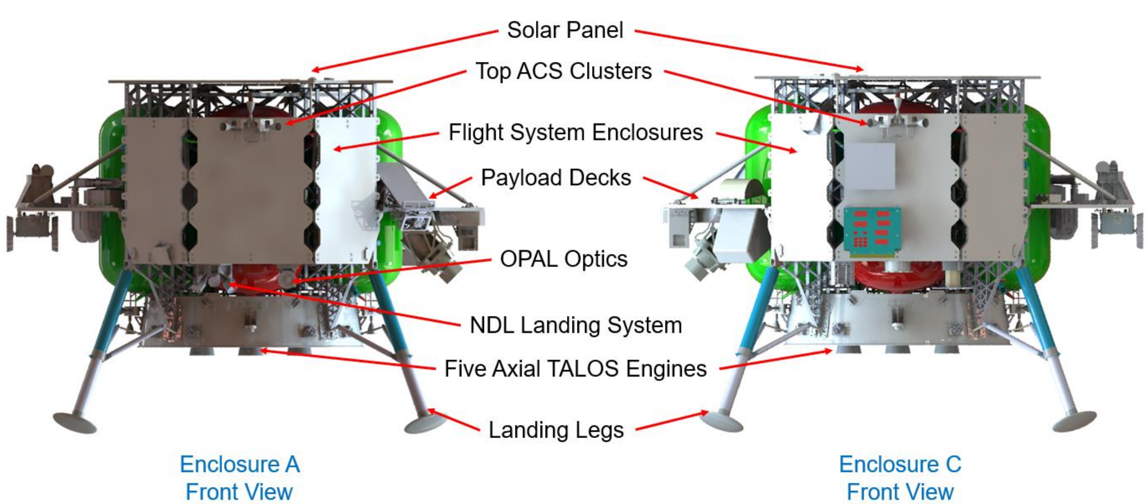
PEREGRINE M1 SYSTEM CONFIGURATION - PEREGRINE M1 MK3



ASTROBOTIC Proprietary Data in Accordance with Cover Page REV A.2 31

Figure 7. PM1 main parameters and system configuration. Not shown is the Multi-Layer Insulation (MLI) blankets.

Peregrine is a single stage lunar lander with a dry mass of 479 kg, a height of 1.91 meters, and a width of 2.56 meters. It does not have any components that deploy or unfold beyond this envelope for all cruise or lunar orbit phases. Peregrine has two enclosures and two payload decks. The enclosures are responsible for housing the critical flight systems such as the flight computer, the payload computer, the thermal computer, the propulsion computer, the critical guidance computing systems, and the power systems. Each enclosure has three panels each. The panels provide the radiator surface area for Peregrine to radiatively dissipate excess heat from its flight systems. The payload decks provide the surface area and attachment points for our payloads. Peregrine houses the fuel tanks in Enclosures A and C while the oxidizer tanks are on Decks B and D. The configuration of Peregrine with respect to the enclosures and panel is shown below.

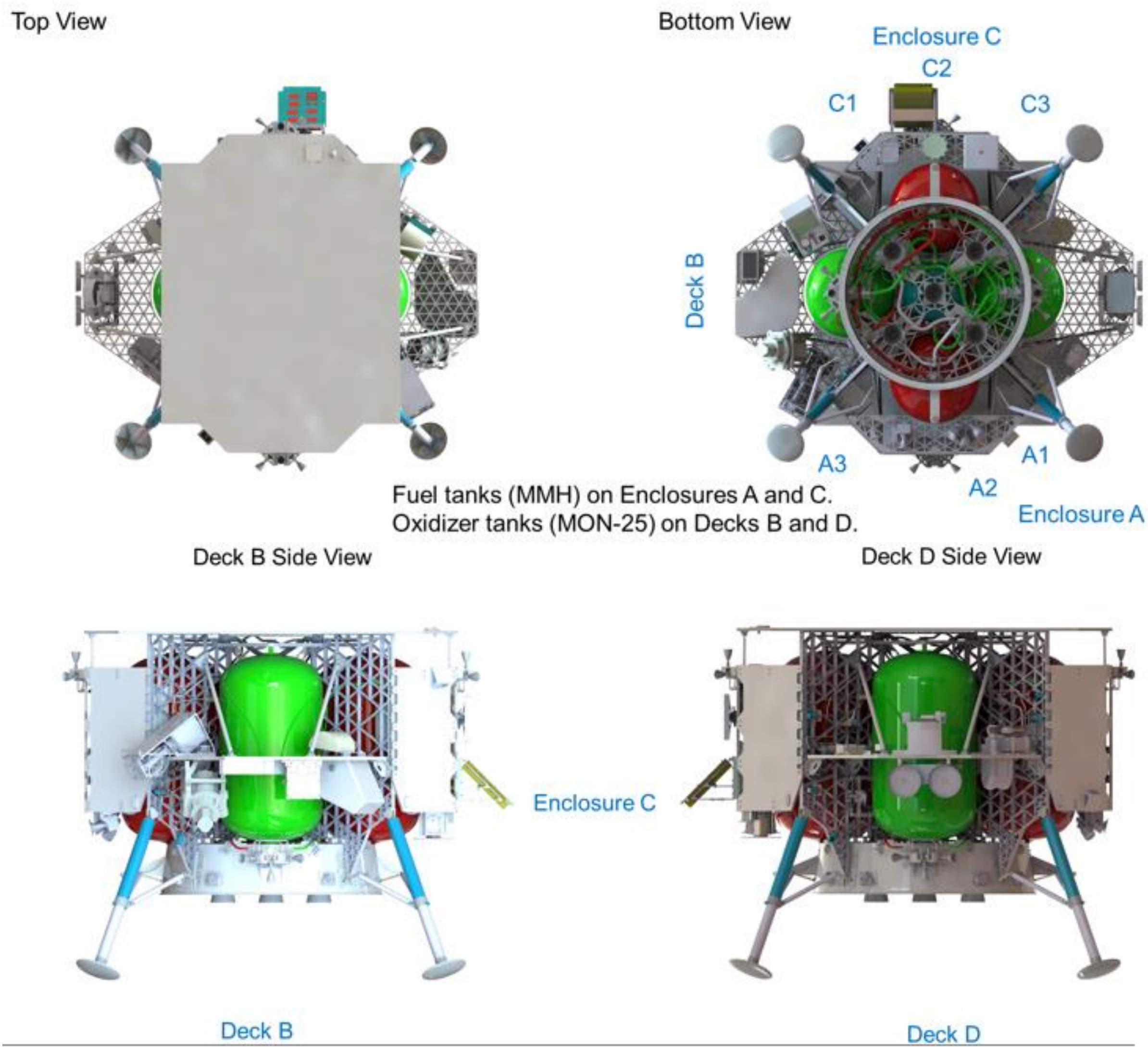


Figure 8. Peregrine Enclosures and Decks configuration and nomenclature

Peregrine has a fixed solar panel located on the top of the spacecraft. The spacecraft maintains a sun pointing orientation as described earlier by pointing this solar panel to the solar incident ray. The solar panel does not have any appendages or elements that extend or articulate beyond the defined surface area and fixed configuration. Peregrine has 5 main engines located at the bottom and center of the spacecraft and 12 ACS engines divided into 4 clusters of 3 engines each. Peregrine has three Low Gain Antennas (LGAs). Two LGAs are located on panels A1 and C1 on Enclosures A and C, respectively. They are fixed and do not articulate or deploy. They are a flat patch antenna. The third LGA is mounted on the solar panel substrate. The LGAs provide 90% communication coverage for all flight phases. As such, this is the only means of communication during the flight phases of the mission. Peregrine also has a Medium Gain Antenna (MGA) that is mounted on panel C1. The MGA is mounted to a gimbal system that allows to the MGA to pointed and articulated to specific orientation. The MGA is planned to be used only for lunar surface operations.

Aside from these systems, Peregrine is carrying 19 payloads on its first mission, 10 of which are NASA and 9 are commercial payloads, including payloads from foreign space agencies (DLR). The payload configuration is shown in the images below. As far as the payload go, a couple of the payloads, SEAL and MSolo, will perform lunar orbit deployments of instrument caps. SEAL will physically eject a cap (<10 cm) to expose the science instrument to the vacuum of space. MSolo will actuate a cap that stays attached to the payload. The actuation will also expose the science instrument to space. The remaining operations in lunar orbit, most of the physical deployments and appendage actuation will occur on the lunar surface. Peregrine will extend a 2.5 meter magnetometer boom for the MAG NASA payload. Peregrine will also deploy five payloads onto the lunar surface during surface operations. The five payloads are:

1. Astroscale/LDPC: Time-capsule payload from Japan. Payload will not move or actuate after deployment. The payload uses a Glenair Hold-Down Release Mechanism (HDRM) for deployment.
2. AEM payload: Rover self-assembly payload. Payload will provide its on lunar locomotion functions after deployment. They will likely stay within 10 meters of the lander given their communication constraints. The payload uses an electrically actuated spring-loaded deployment system.
3. Iris CubeRover payload: Rover payload. Payload will provide its on lunar locomotion functions after deployment. They will likely stay within 100 meters of the lander given their communication constraints. The payload uses a frangibolt deployment system.
4. Spacebit payload: Rover payload. Payload will provide its on lunar locomotion functions after deployment. They will likely stay within 20 meters of the lander given their communication constraints.
5. Yaoki/Dymon payload: Rover payload. Payload will provide its on lunar locomotion functions after deployment. They will likely stay within 10 meters of the lander given their communication constraints.

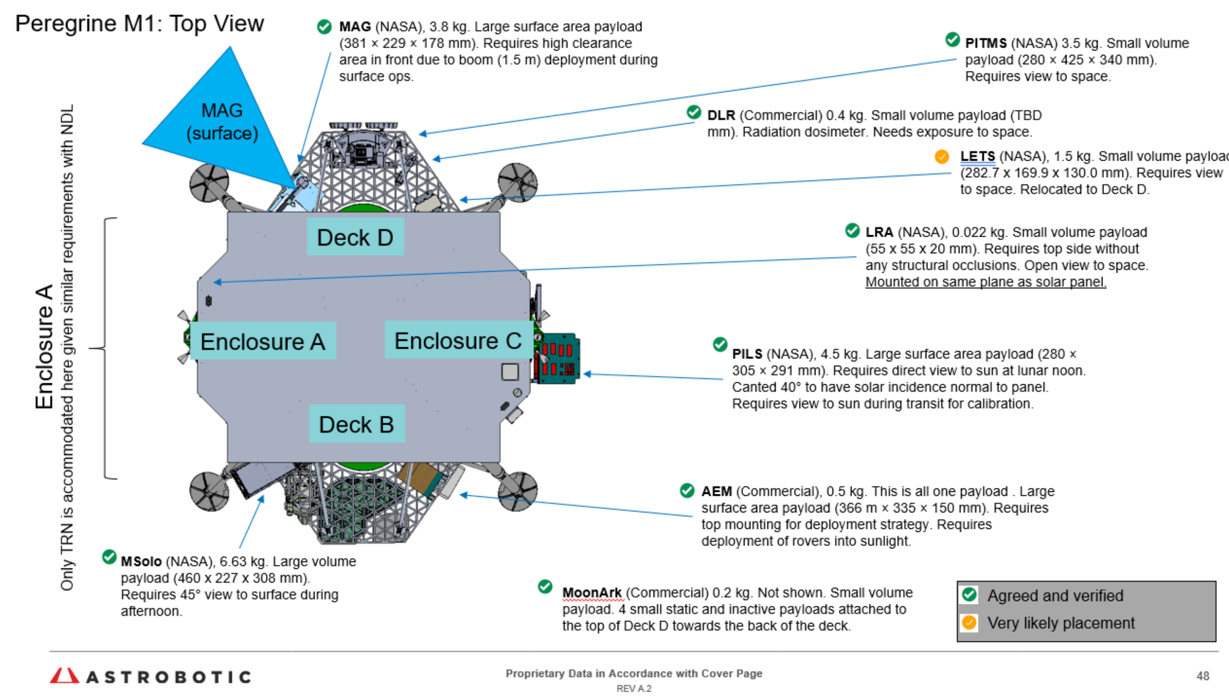


Figure 9. PM1 payload configuration view from the top.

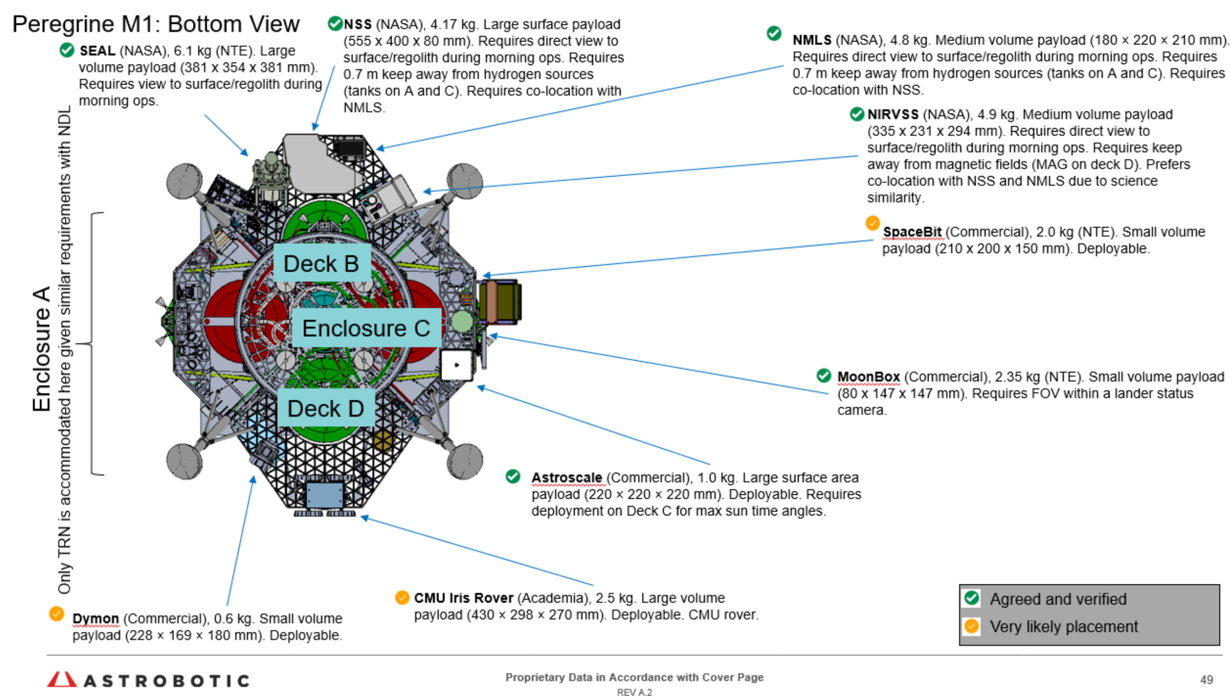


Figure 10. PM1 payload configuration view from the bottom.

4.2 DETAILED ILLUSTRATION OF THE ENTIRE SPACECRAFT IN THE MISSION OPERATION CONFIGURATION WITH CLEAR OVERALL DIMENSIONAL MARKINGS AND MARKED INTERNAL COMPONENT LOCATIONS

The overall dimensions of PM1 are shown below. These show the maximum dimensions for all flight operations. This is the operational configuration of Peregrine for all flight operations and it is the same configuration that gets encapsulated on the Vulcan-Centaur launch vehicle. As mentioned in the previous section, Peregrine M1 has one NASA payload, called MAG, that will deploy a 2.5-meter magnetometer boom after we land on the lunar surface. That is the only appendage on the mission that has this range of extension from fixed spacecraft volume.

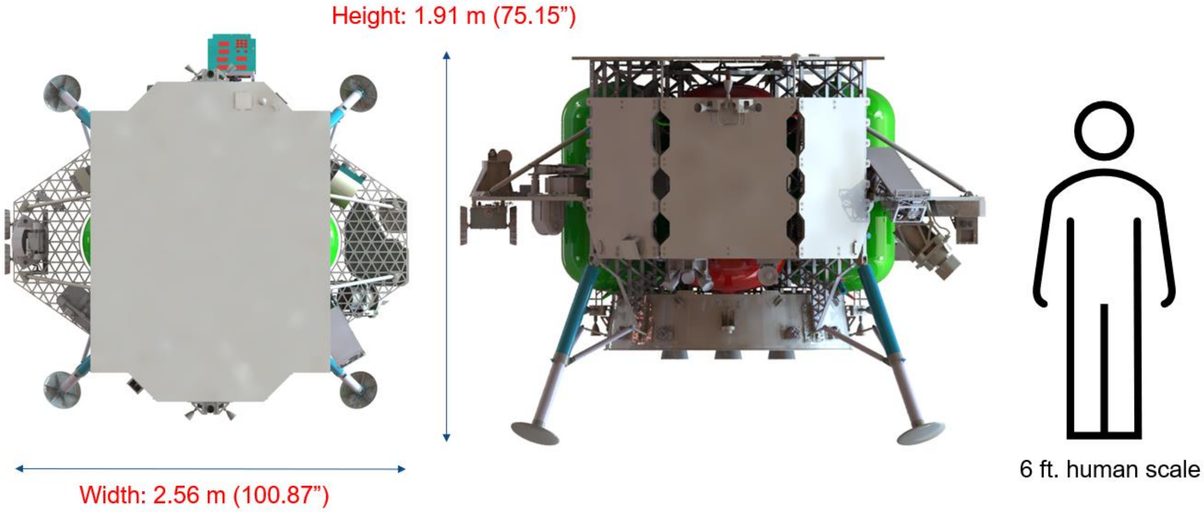


Figure 11. Overall dimensions of PM1 flight configuration.

As mentioned above, PM1 has two enclosures, Enclosure A and Enclosure C. They are responsible for housing the critical flight systems of Peregrine. These are the only two housings of Peregrine that contain internal components. Both enclosures have three panels, panels A1, A2, and A3 for Enclosure A and panels C1, C2, and C3 for Enclosure C. The panels provide the radiator surface area to maintain the components operating temperatures under the specified requirements. The panels also contain embedded Constant Conductance Heat Pipes (CCHP) to improve the heat dissipation of the flight systems attached to the enclosures. The figures below provide a detailed overview of the markings of the components on each of the panels as well as the radiative surface area and heat pipe layout.

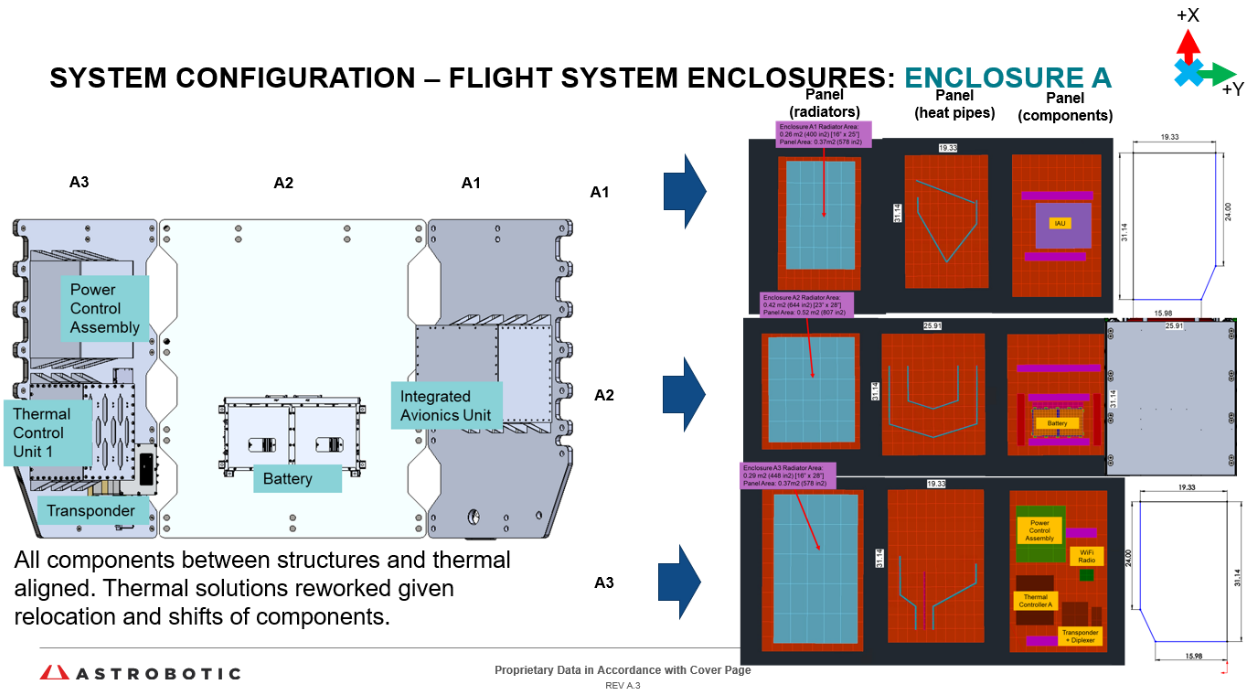


Figure 12. Enclosure A flight components layout

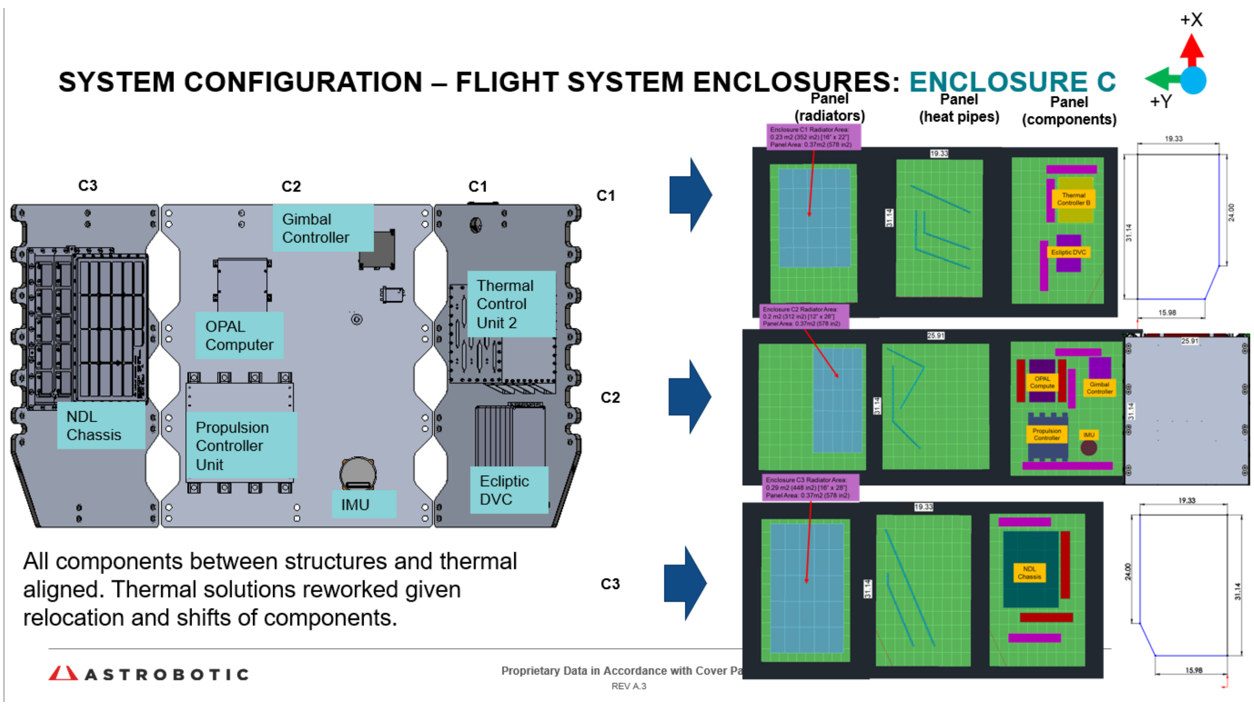


Figure 13. Enclosure C flight components layout

4.3 TOTAL SPACECRAFT MASS AT LAUNCH, INCLUDING ALL PROPELLANTS AND FLUIDS

Launch Mass (kg):	1481
Propellant Mass at Launch (kg):	996.6
Fuel (MMH) Mass at Launch (kg):	387.9
Oxidizer (MON-25) Mass at Launch (kg):	608.7
Pressurant (gHe) Mass at Launch (kg):	5.5

4.4 DRY MASS OF SPACECRAFT AT LAUNCH (MINUS ALL CONSUMABLES AND PROPELLANTS)

Dry Mass (kg):	479.0

4.5 IDENTIFICATION, INCLUDING TYPE, MASS AND PRESSURE, OF ALL FLUIDS (LIQUIDS AND GASES) PLANNED TO BE ON BOARD (INCLUDING ANY PLANNED FUTURE IN-SPACE TRANSFERS), EXCLUDING FLUIDS IN SEALED HEAT PIPES. DESCRIPTION OF ALL FLUID SYSTEMS, INCLUDING SIZE, TYPE, AND QUALIFICATIONS OF FLUID CONTAINERS SUCH AS PROPELLANT AND PRESSURIZATION TANKS, INCLUDING PRESSURIZED BATTERIES

4.5.1 PROPULSION SYSTEM

PM1 will fly the following propulsion system configuration:

- 5.5 kg Gaseous Helium (GHe) at max 4800 psi
- 388 kg Monomethylhydrazine (MMH, CH3(NH)NH2) at max 600 psi
- 609 kg MON-25 (solution of 25% Nitric Oxide (NO) in Dinitrogen Tetroxide (NTO, N2O4) and Nitrogen Dioxide (NO2)) at max 600 psi

The system containing the fluids listed above is roughly the shape of a cylinder of diameter 64 inches and height 57 inches. It comprises one pressurant COPV, four propellant COPVs, various smaller components (filters, valves, etc.), and titanium tubing. Of all the components, the COPVs have the lowest planned proof and burst ratios, at 1.25:1 and 1.5:1, respectively.

4.6 DESCRIPTION OF ALL PROPULSION SYSTEMS (E.G.: COLD GAS, MONO-PROPELLANT, BI-PROPELLANT, SOLID PROPELLANT, ELECTRIC, NUCLEAR)

PM1 uses a pressure fed hypergolic bi-propellant containing Multiple Oxides of Nitrogen – 25% (MON25) Nitrogen Tetroxide (NTO) and two containing Monomethyl Hydrazine (MMH).

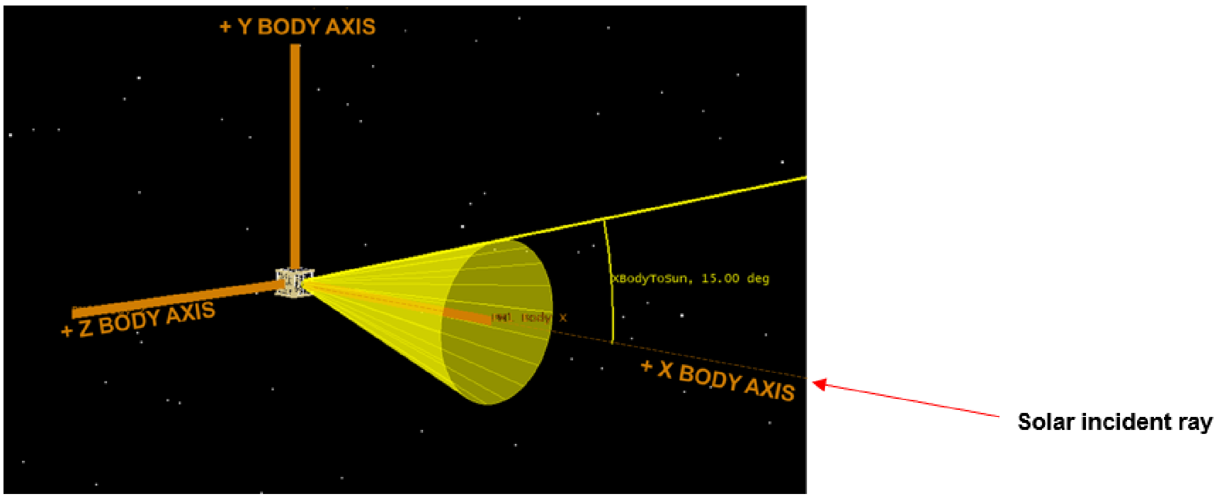
PM1 does not use any cold gas, solid propellant, electric, or nuclear propulsion systems.

PM1 is a single stage lunar lander platform and it does not have any staging elements.

4.7 DESCRIPTION OF ALL ACTIVE AND/OR PASSIVE ATTITUDE CONTROL SYSTEMS WITH AN INDICATION OF THE NORMAL ATTITUDE OF THE SPACECRAFT WITH RESPECT TO THE VELOCITY VECTOR

Peregrine uses its main axial engines for commanded main engine maneuvers. Peregrine uses its ACS engines to maintain attitude control. Peregrine is designed to autonomously maintain a sun-pointing configuration with a 15° half angle cone with respect to Peregrine's primary +X axis using its ACS. In this configuration, the velocity vector can be anywhere depending on the time of the launch date, lunar cycle, and season of the year.

The figure below illustrates this configuration.



PM1-L1RQ-26: Peregrine M1 shall tolerate at least 15 degrees of half-angle off-pointing variation from the solar incident ray normal the YZ plane.

Figure 14. Sun pointing configuration of PM1

All main engine maneuvers need to be commanded and uploaded from the ground. Peregrine does not have the capability to fire its main engines without a command upload from the ground. For commanded main engine maneuvers, Peregrine will slew away from sun pointing and point into the velocity vector to perform the maneuver. After the maneuver is concluded, Peregrine will slew back to a sun pointing configuration. Peregrine is expected to last 20-25 minutes between slewing to a main engine burn, performing a 1-2 minute main engine burn, and slewing back to sun pointing. The exception for this is lunar descent operations which last about 1 hour and 10 minutes.

4.8 DESCRIPTION OF ANY RANGE SAFETY OR OTHER PYROTECHNIC DEVICES

The following table lists out the potential range safety devices for the mission. These are the list of known systems that we need to declare at this point. We are working with our Range Safety officer to provide additional information and details as requested and to determine whether these are applicable items for Range Safety. The bulk amount of Range Safety information, however, will be provided by the launch vehicle provider, ULA.

Table 2. Potential List of Range Safety devices

Item Name	Manufacturer	Part #	Qty.	Function
3/8" (He) Pyrovalves	Triton Space	TS-60YTA100	3	These pyrovalves are used for priming the Peregrine propulsion system following separation from the Centaur upper stage. After priming, Peregrine will be capable of conducting any propulsive maneuvers with its main engines or ACS engines.
3/4" (He) Pyrovalves	Triton Space	TS-120YTA100	2	
1/4" (He) Pyrovalves	Triton Space	TS-20YTA100	2	
NDL Optical Head Lasers	NASA Langley	N/A	3	The NDL optical head has 3 Class 3B lasers. One laser per optical head. The optical head is completely unpowered for all pad operations, launch operations, and flight operations. It is only turned on in lunar orbit for a checkout and during the descent operations.
Bellows Actuator Pyrovalve	Technical Ordnance, Inc.	234207	1	The NASA SEAL payload has one pyrovalve that will be actuated in lunar orbit to expose the science suite to the vacuum of space. The actuation will release a cap (<10 cm) at a speed of 3 ± 1 m/s.

4.9 DESCRIPTION OF THE ELECTRICAL GENERATION AND STORAGE SYSTEM

The primary source of energy storage for Peregrine comes from a single 28-volt lithium ion battery. The battery is manufacture by ABSL/EnerSys. It contains an 8s16p (8 cells per string, 16 strings per battery) configuration of MJ1 18650 lithium ion cells. The nameplate capacity of the battery is 54.4 Ah (1582 Wh). The operating voltage range of the battery is 33.6 Vdc to 24 Vdc. A specsheet of the battery is provided in the appendix section.

The primary source of energy generation for Peregrine comes from a solar panel. The solar panel contains an arrangement of 288 XTE SF Supercell solar cells from Spectrolab. The cells are arranged into a 18s16p (18 cells per string, 16 strings per panel) configuration. The cell composition is GaInP2/GaAs/Ge. The solar panel is a single 2.53 m^2 fixed array mounted on the top of Peregrine. It does not have any deployable elements.

Both the battery and the solar panel are connected to Peregrine's main 28 Vdc bus which power the spacecraft and its components during the mission. Peregrine contains a Power Control Assembly (PCA) avionics system enclosure that is responsible for managing the storage, discharge, and distribution of power to the spacecraft. The PCA is also responsible detecting the physical separation of Peregrine from Centaur to initiate the power up procedures once it separates in orbit. Recall, that Peregrine launches mostly in an unpowered state with the exception of the PCA. For EOM, the PCA can passivate the energy systems in lunar orbit by disconnecting the battery from the bus if needed.

Aside from these energy systems, some payloads, especially rovers, contain a set of Li-Ion batteries. The energy for these battery are less than 30 Wh. The rovers are not expected to use batteries until surface operations. Instead, they rely on tethered power services from the lander to facilitate their needs in cruise and orbit.

4.10 IDENTIFICATION OF ANY OTHER SOURCES OF STORED ENERGY NOT NOTED ABOVE

This section is still in works. We are working with the payload teams to collect more information.

Below is a table of known parameters and stored energy devices.

Table 3. Other sources of stored energy systems onboard PM1

Device Type	Manufacturer	Part #	Qty.	Associated Party
82s16p Li-Ion Battery Module. 28 Vdc, 56 Ah battery	ABSL	MJ1 8s16p battery	1	Astrobotic's Peregrine M1. This is the main battery of Peregrine.
TiNi Frangibolt	TiNi		1	Peregrine M1 payload: NASA's MAG
TiNi Frangibolt	TiNi		1	Peregrine M1 payload: NASA's MSolo
TiNi Frangibolt	TiNi		1	Peregrine M1 payload: IRIS Rover
Glenair HDRM	Glenair		1	Peregrine M1 payload: Astroscale LDPC
Electrically controlled spring-loaded deployment system			1	Peregrine M1 payload: AEM rover self-assembly
Electrically actuated frangibolt deployment for Gimbal system	Tethers Unlimeted Inc.	Cobra HPX	1	Astrobotic's Peregrine M1. This system will be actuated on the lunar surface to allow gimbal control of higher gain antenna to support telemetry rates for surface.

4.11 IDENTIFICATION OF ANY RADIOACTIVE MATERIALS ON BOARD OR MAKE AN EXPLICIT STATEMENT THAT THERE ARE NO RADIOACTIVE MATERIALS ONBOARD

PM1 does not contain any radioactive elements on board.

4.12 DESCRIPTION OF ANY PLANNED PROXIMITY OPERATIONS OR DOCKING WITH OTHER SPACECRAFT IN LEO OR GEO, INCLUDING THE CONTROLS THAT WILL BE USED TO MITIGATE THE RISK OF A COLLISION THAT COULD GENERATE DEBRIS OR PREVENT PLANNED LATER PASSIVATION OR DISPOSAL ACTIVITIES FOR EITHER SPACECRAFT.

PM1 does not have any planned proximity or docking operations with any other spacecraft.

5 ODAR SECTION 3: ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

5.1 IDENTIFICATION OF ANY OBJECT (>1 MM) EXPECTED TO BE RELEASED FROM THE SPACECRAFT ANY TIME AFTER LAUNCH, INCLUDING OBJECT DIMENSIONS, MASS, AND MATERIAL

This section is in works. We are collecting information from the payloads.

Below is a table of known parameters and stored energy devices. The table is only applicable to components that physically separate from PM1 during nominal operations.

Table 4. Spacecraft Ejected or Deployed Components during Nominal Operations

Device Type	Party	Parameters
Payload instrument cap	NASA SEAL payload	• Mass: 0.3485 kg • Size: 7.239 x 8.6614 x 12.166 cm (2.85" x 3.41" x 4.79") • Material: Titanium and Aluminum • Time after LV Separation: TBD (At least 14 days after) • Deployment Location: Lunar Orbit
Dream Capsule Memorial Payload	Astroscale / LDPC payload	• Mass: 1.0 kg (NTE) • Size: 220 x 220 x 220 mm (NTE) • Material: TBD • Qty: 1 • Time for Event: At least 6 hours after landing on the Moon • Deployment Location: Lunar Surface
AEM rover payloads	AEM payload	• Mass: TBD • Size: TBD • Material: TBD • Qty: TBD • Time for Event: At least 6 hours after landing on the Moon • Deployment Location: Lunar Surface
SpaceBit Spider Robot	SpaceBit payload	• Mass: 2.0 kg (NTE) • Size: 210 x 200 x 150 mm (NTE) • Material: TBD • Qty: 1 • Time for Event: At least 6 hours after landing on the Moon • Deployment Location: Lunar Surface
IRIS Rover	CMU IRIS payload	• Mass: 2.5 kg (NTE) • Size: 430 x 298 x 270 mm (NTE) • Material: TBD • Qty: 1 • Time for Event: At least 6 hours after landing on the Moon • Deployment Location: Lunar Surface
Dymon Rover	Yaoki/Dymon payload	• Mass: 0.6 kg (NTE) • Size: 228 x 169 x 180 mm • Material: TBD • Qty: 1 • Time for Event: At least 6 hours after landing on the Moon • Deployment Location: Lunar Surface

5.2 RATIONALE/NECESSITY FOR RELEASE OF EACH OBJECT

For the NASA SEAL payload cap, the requirement is driven by NASA. They require to expose their science instrument to the vacuum of space to perform system calibration prior to landing on the Moon.

The other deployments in the lunar surface, NASA or commercial payloads, are driven by the customer.

5.3 TIME OF RELEASE OF EACH OBJECT, RELATIVE TO LAUNCH TIME

The deployment will happen in lunar orbit. Most likely in LO1 or in LO2. This is set to happen at least 10 days after launch.

5.4 RELEASE VELOCITY OF EACH OBJECT WITH RESPECT TO SPACECRAFT

We require that deploy devices from payloads are deployed with at least 0.0308 m/s of delta-V from Spacecraft. This will create at least a 1 km keepout sphere of the deployed system from the spacecraft.

5.5 EXPECTED ORBITAL PARAMETERS (APOGEE, PERIGEE, AND INCLINATION) OF EACH OBJECT AFTER RELEASE

This is to be determined per discussion with 3rd parties.

The primary phase for the deployment will occur in lunar orbit and these will be for deploying small instrument caps.

The orbits for consideration are:

- Lunar Orbit 1: 100 km x 8700 km
- Lunar Orbit 2: 100 km x 800 km
- Inclinations for both really vary based on arrival at the Moon due to landing time considerations

As a reminder, rovers and other payloads will be deployed on the lunar surface after a successful landing.

5.6 CALCULATED ORBITAL LIFETIME OF EACH OBJECT, INCLUDING TIME SPENT IN LEO

This is to be determined.

However, we think this is Not Applicable to Astrobotic PM1. The orbital lifetime calculation is not applicable to deployments in lunar orbit. Instead, we are required to limit debris deployed in lunar orbit.

5.7 ASSESSMENT OF SPACECRAFT COMPLIANCE WITH REQUIREMENTS 4.3-1 AND 4.3-2

Pertaining to planned nominal and normal operations for PM1, the requirements 4.3-1 and 4.3-2 are in compliance with the ODAR expectations. The table below summarizes the Astrobotic assessment.

Table 5. Requirements 4.3-1 and 4.3-2 Assessment

#	Requirement Text	Astrobotic Assessment Summary
4.3-1a	Debris passing through LEO – released debris with diameters of 1mm or larger: All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release.	Aside from the spacecraft as an entity, after separation from the Centaur upper stage, there is no planned deployment or release of debris from the spacecraft with diameter 1 mm or larger that will pass through LEO. Astrobotic's planned list of deployments will occur in lunar orbit. Hence, requirement is addressed. The launch vehicle may provide separation debris analysis specific to the Centaur system and our mission.
4.3-1b	Debris passing through LEO – released debris with diameters of 1mm or larger: The total object-time product shall be no larger than 100 object-years per mission. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to collectively follow the same 100 object-years per mission deployment limit.	Aside from the spacecraft as an entity, after separation from the Centaur upper stage, there is no planned deployment or release of debris from the spacecraft with diameter 1 mm or larger that will pass through LEO. Astrobotic's planned list of deployments will occur in lunar orbit. Hence, requirement is addressed. The launch vehicle may provide separation debris analysis specific to the Centaur system and our mission.
4.3-2	Debris passing near GEO: For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km , and also ensures that the debris is incapable of being perturbed to lie within that GEO +/- 200 km and +/- 15 _zone for at least 100 years thereafter. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to follow this requirement.	Aside from the spacecraft as an entity, after separation from the Centaur upper stage, there is no planned deployment or release of debris from the spacecraft with diameter 5 mm or larger that will pass through GEO. Astrobotic's planned list of deployments will occur in lunar orbit. Hence, requirement is addressed. The launch vehicle may provide separation debris analysis specific to the Centaur system and our mission.

6 ODAR SECTION 4: ASSESSMENT OF SPACECRAFT INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

6.1 IDENTIFICATION OF ALL POTENTIAL CAUSES OF SPACECRAFT BREAKUP DURING DEPLOYMENT AND MISSION OPERATIONS

To be provided in a future iteration of this ODAR report.

6.2 SUMMARY OF FAILURE MODES AND EFFECTS ANALYSES OF ALL CREDIBLE FAILURE MODES WHICH MAY LEAD TO AN ACCIDENTAL EXPLOSION

To be provided in a future iteration of this ODAR report.

6.3 DETAILED PLAN FOR ANY DESIGNED SPACECRAFT BREAKUP, INCLUDING EXPLOSIONS AND INTENTIONAL COLLISIONS

To be provided in a future iteration of this ODAR report if needed. We believe this is not applicable to our mission.

6.4 LIST OF COMPONENTS WHICH ARE PASSIVATED AT EOM. LIST INCLUDES METHOD OF PASSIVATION AND AMOUNT WHICH CANNOT BE PASSIVATED.

To be provided in a future iteration of this ODAR report if needed. We believe this is not applicable to our mission.

6.5 RATIONALE FOR ALL ITEMS WHICH ARE REQUIRED TO BE PASSIVATED, BUT CANNOT BE DUE TO THEIR DESIGN.

To be provided in a future iteration of this ODAR report if needed. We believe this is not applicable to our mission.

6.6 ASSESSMENT OF SPACECRAFT COMPLIANCE WITH REQUIREMENTS 4.4-1 THROUGH 4.4-4

To be provided in a future iteration of this ODAR report if needed. We believe this is not applicable to our mission.

7 ODAR SECTION 5: ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

Following is a description of Astrobotic's analysis of the potential for on-orbit collisions during flight, as well as a description of the plan to mitigate that potential down to 0%.

Peregrine is a lunar lander which briefly passes through LEO and GEO altitudes twice during its flight to the Moon- once at initial separation from the launch vehicle, and a second time during a single phasing loop between the Earth and the Moon.

Peregrine will be launched directly into a 30-degree inclination TLI orbit that has its apogee at lunar distance and perigee at 500km. Once separated from the launch vehicle, Peregrine will gain altitude quickly without needing to perform any propulsive maneuvers, exiting the LEO debris zone within 10 minutes post-separation.

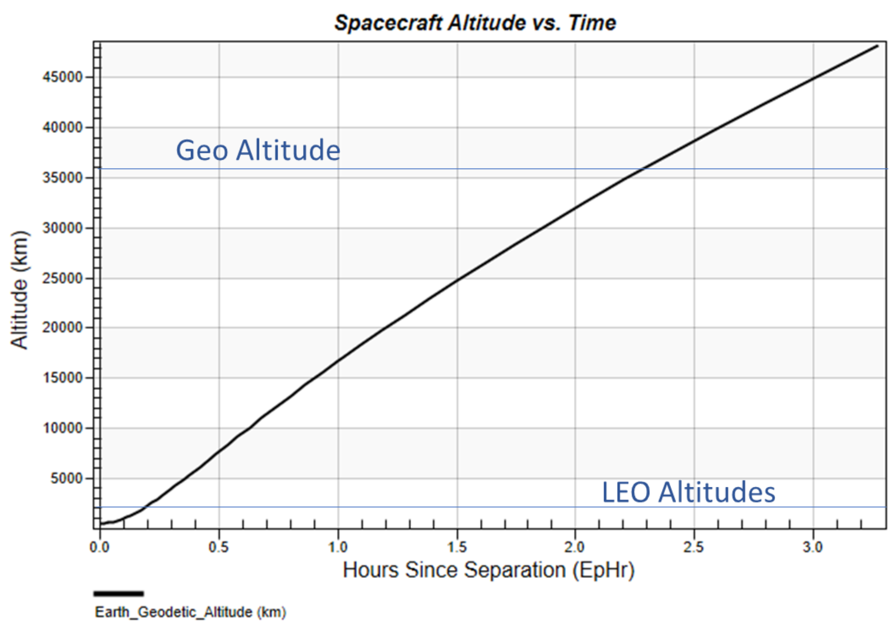


Figure 15: altitude over time for initial separation phase

The first propulsive maneuver performed by the lander will not occur until at least 12 hours post-separation, where there is a placeholder for a possible trajectory correction maneuver (see table in Section 3-9).

Once Peregrine reaches lunar distance, it will return to perigee once more, in a phasing loop. Astrobotic plans to perform a perigee raise maneuver (PRM) at apogee to ensure the phasing loop perigee is at least 600km in altitude. Depending on the exact date of launch, the natural perigee of this phasing loop may already be up to 2500km without performing a PRM. In any case, Astrobotic's analysis indicates that we have the DeltaV budget on any potential launch date to perform a PRM that will raise our perigee to at least 600km.

The decision to target a 600km minimum perigee was reached via a combination of analysis of the current debris field at different altitudes as well as a general concern about the increasing number of SpaceX Starlink satellites at 550km and how crowded that altitude may become by late 2021.

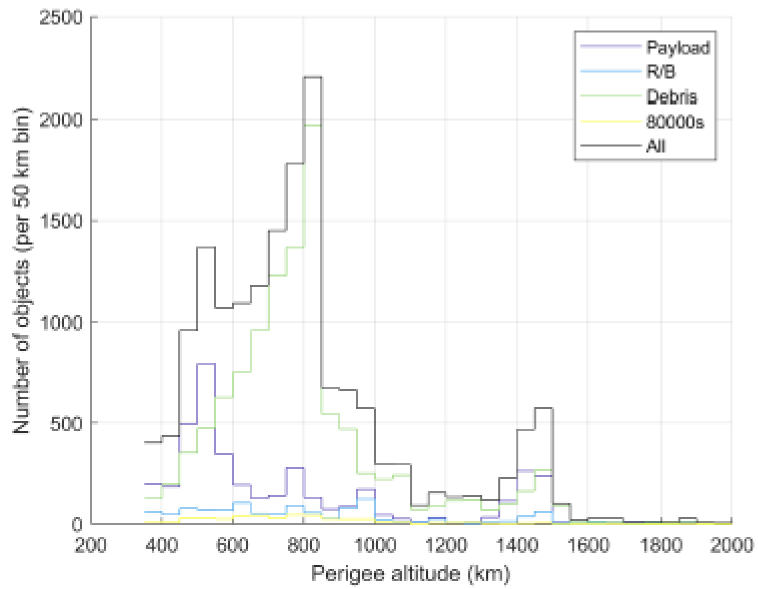


Figure 16: Objects in LEO as of October 2, 2020

Astrobotic will work with the Air Force Joint Special Operations Center (JSPOC) to receive and process object messages based on our ephemeris file deliveries, and is prepared to perform an avoidance maneuver on-orbit in the unlikely event that an object message persists to the point where an avoidance maneuver is required during the near-Earth portion of the lunar mission. We have a 31 m/s allocation of DeltaV budget for trajectory correction maneuvers, out of which we will take any small amount required for a correction maneuver, with the intent to perform the COLA maneuver during the timeframe allocated for a second TCM maneuver.

Astrobotic has performed a detailed analysis regarding the probability of receiving object messages based on our phasing loop orbit and uncertainties, as well as the likelihood of one of those messages coming close enough to our spacecraft that an avoidance maneuver needs to be performed. The diagram below shows the result of 10,000 Monte Carlo analyses performed of Peregrine's phasing loop trajectory at different altitude bins. Figure 8 shows the chance of Astrobotic receiving any object messages from JSPOC given the range of likely trajectories of our phasing loop. Figure 9 shows that for the 10,000 simulated primary trajectories, between 0.03-2.59 events would require maneuvering based on a conservative 1e-5 Pc mitigation threshold 0.5 days before the event and 10 m hard-body radius. Thus, only 0.0003-0.0259% of the trajectories would need to perform a COLA maneuver.

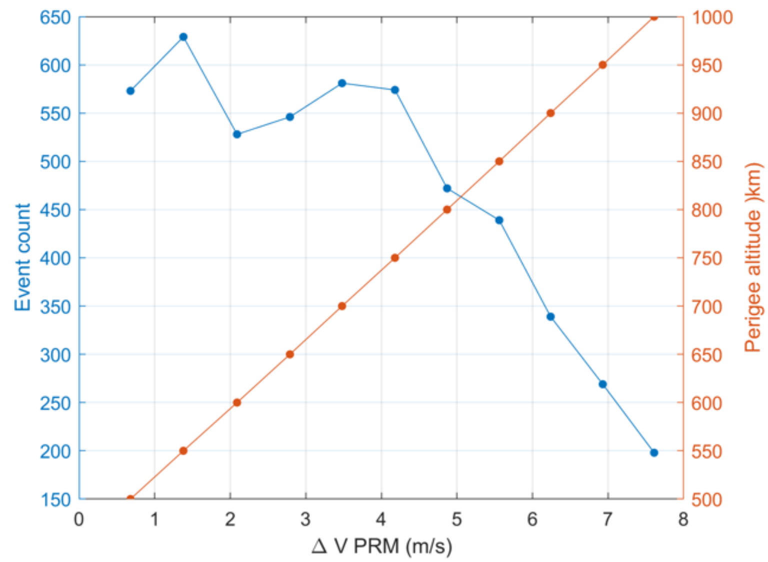


Figure 17: # of Trajectories (out of 10,000 potential trajectories) that produce an event message from JSPOC

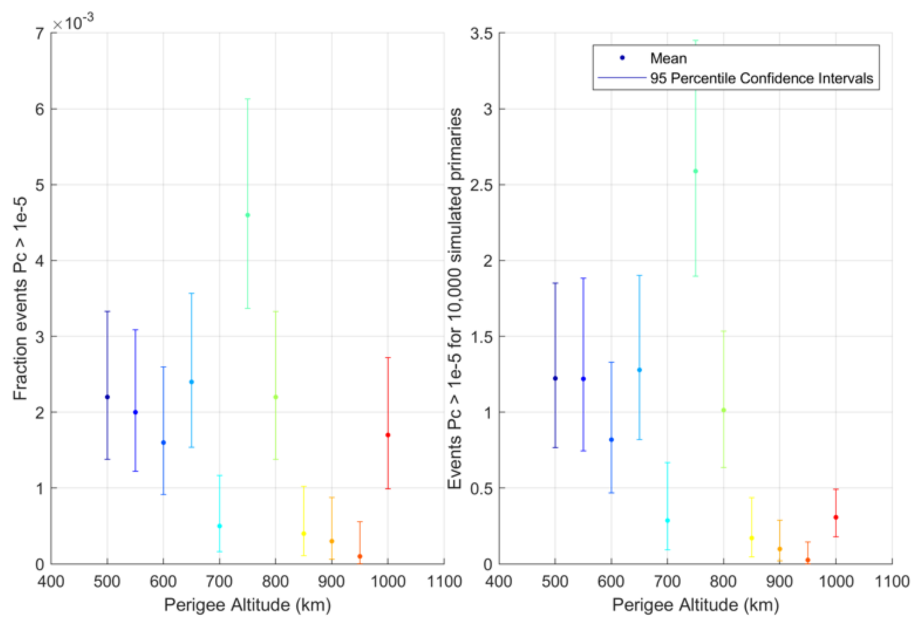


Figure 18: # of events in 10,000 trajectories that produce a Pc of > 1x10^-5 given different potential perigee altitudes

Regarding debris and COLA analysis in GEO altitudes, Astrobotic also included objects from the Space-Track TLE catalog at GEO altitudes in our event frequency analysis and found that only 1 out of 10,000 simulated trajectories generated an event message. Peregrine's path does not pass through the equatorial plane at GEO altitude where most objects are located, thus this was expected.

For the lunar orbit portion of our mission, Astrobotic has not performed a detailed lunar debris analysis, However, Astrobotic does plan to work directly with JPL MADCAP during the lunar portion of our mission to ensure that we are not in the path of lunar objects such as LRO. Astrobotic has already made contact with MADCAP, and has a plan to transmit ephemeris files and communicate with MADCAP on-orbit, given that we are also using JPL DSN as our ground station network for this mission.

In summary, given Peregrine's mission profile, the only measurable chance of needing to perform a collision avoidance maneuver occurs during the swing through our phasing loop perigee, where the spacecraft will pass through an altitude of 600km – 2500km depending on exact date of launch. During this time we have a 5% chance of receiving any event messages from JSPOC, and a < 0.026% chance of needing to perform a collision avoidance maneuver. In the unlikely event a COLA maneuver is required, Astrobotic will be working with JSPOC on-orbit to ensure we process any event messages we may receive and perform a COLA maneuver in an adequate timeframe, effectively reducing our chances of a collision to 0%.

8 ODAR SECTION 6: ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

Our spacecraft is a lunar lander and will not be remain in any orbit at the conclusion of its mission under nominal operations. Peregrine will only pass briefly thru LEO and GEO altitudes on its way to the Moon. Once in lunar orbit, Peregrine will perform a Descent Orbit Injection maneuver and land on the lunar surface where it will remain after performing 10 days of lunar surface operations. Peregrine is not expected to survive lunar nightfall on the surface and will be abandoned in-place. Peregrine's End of Mission occurs on the lunar surface.

9 ODAR SECTION 7: ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

9.1 DETAILED DESCRIPTION OF SPACECRAFT COMPONENTS BY SIZE, MASS, MATERIAL, SHAPE, AND ORIGINAL LOCATION ON THE SPACE VEHICLE, IF THE ATMOSPHERIC REENTRY OPTION IS SELECTED

Not applicable.

9.2 SUMMARY OF OBJECTS EXPECTED TO SURVIVE AN UNCONTROLLED REENTRY, USING NASA DAS, NASA OBJECT REENTRY SURVIVAL ANALYSIS TOOL (ORSAT), OR COMPARABLE SOFTWARE

Not applicable.

9.3 CALCULATION OF PROBABILITY OF HUMAN CASUALTY FOR THE EXPECTED YEAR OF UNCONTROLLED REENTRY AND THE SPACECRAFT ORBITAL INCLINATION

Not applicable.

9.4 ASSESSMENT OF SPACECRAFT COMPLIANCE WITH REQUIREMENT 4.7-1

Not applicable.

Table 6. Requirement 4.7-1 Assessment.

#	Requirement Text	Astrobotic Assessment Summary
4.7-1	Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules: a. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000). b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica. c. For controlled reentries, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000).	Not Applicable

9.5 SUMMARY OF THE HAZARDOUS MATERIALS CONTAINED ON THE SPACECRAFT USING ALL COLUMNS AND THE FORMAT IN PARAGRAPH 4.7.4.10.

The table below contains a list of preliminary hazardous materials. An update will be provided at a future iteration of this report.

Item #	Material	Contained in	Volume or Mass
1	Monomethylhydrazine (MMH, CH3(NH)NH2)	Fuel Tanks	388 kg at launch
2	MON-25 (solution of 25% Nitric Oxide (NO) in Dinitrogen Tetroxide (NTO, N2O4) and Nitrogen Dioxide (NO2))	Propellant Tanks	609 kg at launch

10 ODAR SECTION 8: ASSESSMENT FOR TETHER MISSIONS

10.1 TYPE OF TETHER; E.G., MOMENTUM OR ELECTRODYNAMICS

PM1 does not have any tether elements.

10.2 DESCRIPTION OF TETHER SYSTEM, INCLUDING AT A MINIMUM (1) TETHER LENGTH, DIAMETER, MATERIALS, AND DESIGN (SINGLE STRAND, RIBBON, MULTI-STRAND MESH), AND (2) END-MASS SIZE AND MASS

PM1 does not have any tether elements.

10.3 DETERMINATION OF MINIMUM SIZE OF OBJECT THAT COULD SEVER THE TETHER

PM1 does not have any tether elements.

10.4 TETHER MISSION PLAN, INCLUDING DURATION AND POSTMISSION DISPOSAL

PM1 does not have any tether elements.

10.5 PROBABILITY OF TETHER COLLIDING WITH LARGE SPACE OBJECTS

PM1 does not have any tether elements.

10.6 PROBABILITY OF TETHER BEING SEVERED DURING MISSION OR AFTER POSTMISSION DISPOSAL

PM1 does not have any tether elements.

10.7 MAXIMUM ORBITAL LIFETIME OF A SEVERED TETHER FRAGMENT

PM1 does not have any tether elements.

10.8 ASSESSMENT OF COMPLIANCE WITH REQUIREMENT 4.8-1

PM1 does not have any tether elements.

11 ODAR SECTION 9-14: LAUNCH VEHICLE

Sections 9 thru 14 are pertaining to the Launch Vehicle for PM1. As such the Launch Vehicle provider will provide those assessments separately.

For reference, Astrobotic shall launch on the following vehicle.

Launch Vehicle Name:	Vulcan-Centaur Certification Flight 1
Launch Vehicle Provider:	United Launch Alliance (ULA)
Launch Vehicle Number:	ULA assigned
Launch Site:	Kennedy Space Center (KSC)
Launch Date:	ULA Proprietary – refer to ULA. Public statement: Q4 2021

12 APPENDIX A: FORM 312

Attached separately from this document.