PEREGRINE: MISSION 1

Post-Mission Report

AUGUST 2024

Table of Contents

Post-Mission Report

Peregrine Spaceflight Summary

Astrobotic Completes Peregrine Mission One Review Board and Publishes Findings

Review board analyzes PM1 findings and Astrobotic's team enacts corrective actions for future missions

Astrobotic's Peregrine Mission One (PM1) launched aboard the maiden flight of United Launch Alliance's Vulcan rocket at Cape Canaveral, FL on January 8, 2024, at 2:18 am ET with the goal of landing on the Moon. At 3:16 am ET, the Peregrine spacecraft successfully activated its avionics and power management system, established communications with Astrobotic's Mission Control Center via NASA's Deep Space Network, and commenced spacecraft commissioning and operations.

During this commissioning phase, Peregrine's propulsion system was activated. This involved pressurizing the fuel and oxidizer tanks with helium from the pressurant tank by opening two Pressure Control Valves (PCVs), PCV1 and PCV2. Upon actuating (opening and closing) PCV2, helium began to flow uncontrollably into the oxidizer tank, causing a significant and rapid over pressurization of the tank. The tank then ruptured and subsequently leaked oxidizer for the remainder of the mission. This anomaly inhibited the propulsion system from pressurizing to the levels needed for Peregrine to land on the Moon.

After the propulsion anomaly occurred, the team stabilized the spacecraft and shifted mission priorities to gathering propulsion system data for a mission investigation, providing on-board payloads power and communications to capture science data, and obtaining performance data on the lander's subsystems to increase technology readiness levels for future missions. The Astrobotic team ultimately operated the spacecraft for 10 days and 14 hours as it traveled to and from cislunar space, and two science teams published scientific papers from the data collected by their payloads.

Although the in-flight anomaly prevented Peregrine from achieving its primary mission objective to land on the Moon, Astrobotic's Mission Control team was still able to operate the spacecraft with a compromised propulsion system and achieve several technological and scientific objectives. On January 13th, in consultation with NASA, Astrobotic made the decision to end Peregrine's mission in order to prevent any possibility of a space debris proliferation event in cislunar space. After traveling more than 535,000 miles, the mission team successfully conducted Peregrine's controlled re-entry into Earth's atmosphere over open water in the South Pacific on January 18, 2024, at 4:04 p.m. ET.

Review Board Analysis and Root Cause

After PM1's conclusion, Astrobotic assembled external experts for an incident investigation team and review board to analyze the mission. The board was chaired by independent third-party investigator Dr. John Horack, Professor and Neil Armstrong Chair, Ohio State University. This team included a total of 34 government, industry, and in-house multidisciplinary subject matter experts. The following is a summary of the board's findings, conclusions, and corrective actions.

After an extensive review of the events before, during, and after Peregrine's mission, the board concluded that the most likely cause of Peregrine's anomaly was the failure of a singular helium pressure control valve, called PCV2, within the propulsion system. PCV2 suffered a loss-of-seal capability, most likely due to a mechanical failure caused by vibration-initiated relaxation between threaded components internal to the valve. Spacecraft telemetry data (temperature, roll-rates, and tank pressure data) confirmed both the location and timing of the mission anomaly, which coincided with the position and autonomous sequence to open and close PCV2. All spacecraft data was consistent with a tank rupture and subsequent leak near the top of "Tank 5," the oxidizer tank located downstream from PCV2.

To confirm the mechanical failure mode of PCV2, the Astrobotic team replicated the suspected failure mode in ground testing by subjecting a spare flight PCV to similar conditions seen during the mission. In this testing, Astrobotic subjected the valve to qualification-level shock and vibe, pressurized cycling, and a final seat force and then measured the internal leak rate. After cycling under pressurization, the spare PCV began leaking at a rate that was roughly equivalent to that observed during PM1 in-space operations. Subsequent disassembly of the valve showed that a threaded joint in the valve was loosened, and that the primary seating O-ring in the valve had been damaged along the sealing surface.

The review board believes this to be a replication of the failure that occurred on Peregrine. The review board's findings were reported to the NASA Commercial Lunar Payload Services initiative as well as the NASA Science Mission Directorate leadership.

The investigative team and review board consisted of 34 government, industry, and in-house multidisciplinary subject matter experts and was chaired by independent third-party investigator Dr. John Horack, Professor and Neil Armstrong Chair, Ohio State University.

Events Leading to PCV2's Failure

The review board compiled a timeline of events to trace the contributing factors leading up to PCV2's failure, beginning with propulsion system integration and ending with integrated spacecraft systems testing.

Timeline of Development

1. In July 2019, Astrobotic contracted with an outside vendor for the development, build, and test of the propulsion feed system through a competitive selection process based on past performance, cost, and schedule. The chosen feed system design incorporated components from spaceflight-proven contractors and levied industry-standard development processes.

2. In Fall 2021, the feed system vendor suffered technical and supply chain issues, partly due to the COVID-19 pandemic. These issues were compromising the mission's schedule and jeopardizing the next stages of spacecraft integration and launch readiness.

3. In early 2022, Astrobotic made the decision to terminate the vendor's contract and complete the propulsion feed system in-house, which afforded the company greater schedule assurance and control. By this time, Astrobotic had already developed in-house propulsion development and test capabilities for a second, more complex lunar landing mission, Griffin Mission One (GM1), which enabled completion of Peregrine's propulsion system.

4. From April–November 2022, Astrobotic incrementally assembled the propulsion feed system and began encountering issues during testing with the original vendor's propulsion components. In particular, PCVs used to control helium pressure into the fuel and oxidizer tanks were repeatedly failing. As the company worked to resolve this issue, it faced the looming threat of missing the committed-to dates for spacecraft acceptance testing required for launch.

5. In August 2022, the team made the decision to pivot to an alternate PCV supplier that was already providing pyrotechnic valves for the feed system and could commit to the current schedule.

6. The new valves were delivered and installed. While conducting a final set of leak and proof tests, PCV1 encountered leaks, while PCV2 did not. PCV1 was easily accessible on the spacecraft, quickly repaired, and successfully passed another round of proof testing. The spacecraft was then fully assembled into flight configuration and successfully passed a rigorous acceptance test campaign which included vibration, acoustics, thermal vacuum (TVAC), and electromagnetic interference/compatibility (EMI/EMC) testing.

7. PCV2 was still carried as a risk because of the repairs that PCV1 had required. However, the likelihood of PCV2 failing was characterized as low because of a successful acceptance test campaign. Additionally, PCV2 was located deep within the spacecraft and removing it for additional testing, replacement, or repair would have required substantial spacecraft disassembly. This would have invalidated costly, time-intensive spacecraft acceptance tests that had already been completed and could not be rescheduled without missing Peregrine's scheduled launch date.

8. Facing the imminent risk of missing launch as well as potentially causing inadvertent damage during disassembly and reassembly, Astrobotic decided not to disassemble the spacecraft for preemptive alterations to PCV2 and opted instead to proceed to flight.

Forward Actions for Future Spacecraft Missions

The review board not only evaluated the cause of the vehicle's anomaly, but also any possible contributing factors due to the company's processes, procedures, structure, and philosophies. As a result of this investigation, the board recommended a set of corrective and preventative actions to mitigate risk for future missions. Astrobotic is committed to successful, precise lunar landings and wholly embraces the lessons learned that can only come from having designed, integrated, and flown a spacecraft. It is with that in mind the following corrective and preventative actions are being implemented.

- The primary PCVs for future landers have been redesigned to address the mechanical sealing flaw that was seen in failure replication testing. Additionally, all future valve designs will also be evaluated and tested at the component level specifically for similar mechanical sealing flaws.

- Future lunar landers will utilize multiple, dissimilar PCVs to ensure that no single valve failure can result in a loss of mission.

- Astrobotic personnel have been embedded at key supplier facilities to manage schedule compliance, quality standards, and technical performance. Additional oversight has been implemented at key suppliers to ensure a greater level of accountability and control.

- In addition to the valve anomaly, the Peregrine spacecraft experienced 24 total in-flight anomalies. Eight of these were mission critical and potentially mission-ending, all of which were resolved in real-time during flight by the company's Mission Control team. Five non-mission-critical in-flight anomalies were also resolved in real-time. The remaining eleven anomalies were deemed minor and analyzed post-flight with corrective and preventative actions being implemented for future missions.

- Additional quality management personnel have been brought onboard to further enhance Astrobotic's mission assurance. While this is still a commercially minded program, Astrobotic is augmenting quality management to focus deeply on key subsystem deliveries such as propulsion components.

- Astrobotic strategically reinforced its workforce by enlisting two industry experts with proven track records to strengthen future mission assurance:

    1. Steve Clarke, former Deputy Associate Administrator for Exploration in NASA's Science Mission Directorate, is now Astrobotic's Vice President of Landers & Spacecraft and with 40 years of expertise in executive leadership, systems engineering, program management, and operations

    2. Frank Peri, former Director for the Safety and Mission Assurance Office at NASA Langley Research Center, is now Astrobotic's Director of Engineering with a focus on safety and mission assurance. He brings 35 years of executive leadership, most recently leading the institutional safety and mission assurance program.

Looking Ahead

PM1 successfully operated in cislunar space for over 10 days and raised nearly all spacecraft subsystems to technology readiness level (TRL) 9. With this flight heritage now in place, Peregrine remains in Astrobotic's spacecraft catalogue for future science, exploration, defense, and commercial space missions as a configurable, low-cost, rapid-response platform.

Astrobotic's next mission is Griffin Mission One (GM1) as part of NASA's Commercial Lunar Payload Services (CLPS) initiative under the Artemis campaign. Currently manifested for GM1 are the joint rover demonstration mission with Astrobotic's CubeRover integrated with Mission Control's Spacefarer operations platform, the European Space Agency's (ESA) LandCam-X, and a NASA laser retroreflector array, LRA. Griffin will launch by the end of 2025 aboard a SpaceX Falcon Heavy and touch down at the lunar south pole.

A rendering of Astrobotic's Griffin lunar lander on the Moon

Peregrine Mission Account

A Note from the Team

Peregrine Mission One was the culmination of years of hard work, persistence, and vision from a small but committed group of individuals who believe in our future in space. While the mission did not turn out as we had planned, it was an important step forward in designing, integrating, launching, and operating robotic spacecraft that will make the Moon a more accessible place in the future. This irreplaceable experience and the associated lessons learned will make lunar missions more capable, more repeatable, and less costly. Our team's inspired resolve has never been stronger.

We are also deeply grateful for the overwhelming support we received during Peregrine's journey through space. We have read your emails and social media posts, and proudly shared your notes at our headquarters with those that designed Peregrine, built it, and flew it in Mission Control.

In the spirit of increasing the likelihood of future mission success for all, we are publishing this Post-Peregrine Report. The report begins with an overview of the mission, anomaly findings, and a path forward; it ends with a more detailed account of Peregrine's entire journey, from launch to mission end.

The space industry stands on the brink of an exciting and sustainable lunar future, and Astrobotic plans to contribute its time, talent, and resources to continue onward to the Moon.

— THE ASTROBOTS

Peregrine Mission Account

Launch, Separation, and Power

The Peregrine lunar lander was shipped to Cape Canaveral for payload processing on Oct 27th, 2023. Peregrine arrived on October 31st, was unloaded, inspected, and received a functional checkout in preparation for fueling on November 6th. Propellant loading activities occurred over the course of 10 days, then final MLI closeouts and “remove before flight” procedures were executed, signaling that the spacecraft was prepared for final launch vehicle encapsulation activities. Astrobotic monitored Peregrine and all launch site activities closely prior to launch.

Nov 17, 2023

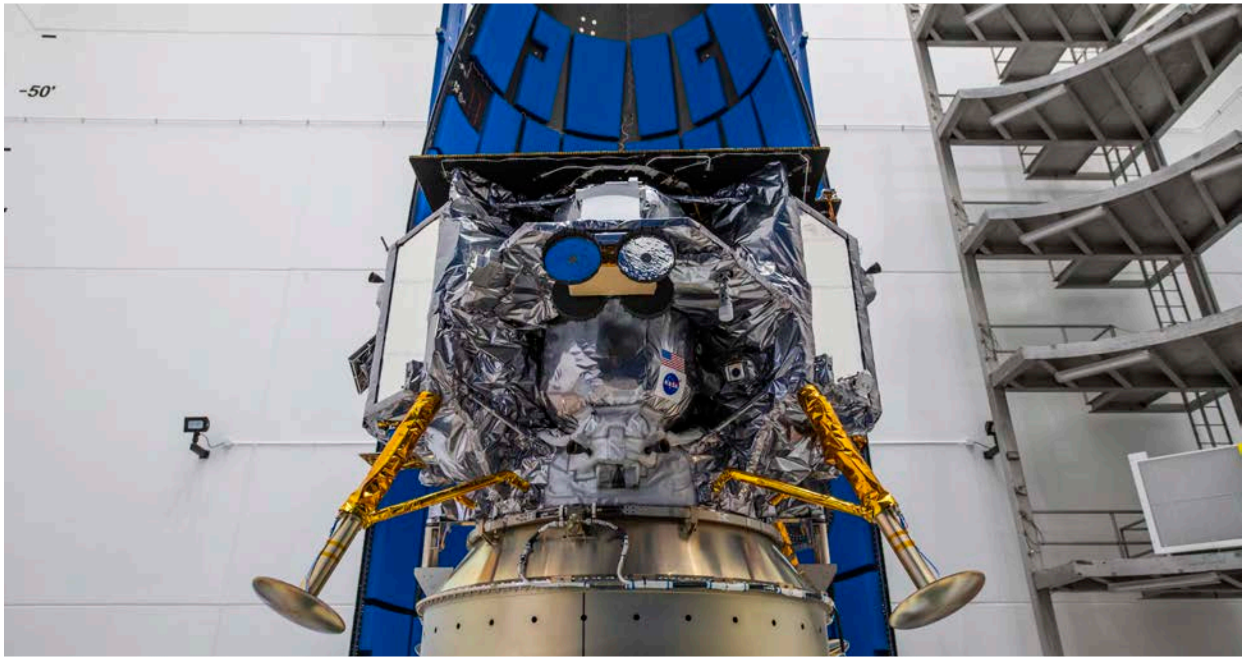


FIGURE 1: Peregrine during encapsulation. *Photo credit: ULA.*

Astrobotic Mission Control Center (AMCC) operations began on day of launch at L-2 hours. The Astrobotic team began by following pre-launch checkout procedures and approving the switch to internal spacecraft power. At L-30 minutes, the Astrobotic Flight Director (FD) conducted a final internal systems poll for “Go” for launch. Additionally, the Ground Controller (GC) confirmed DSN readiness for the nominal first station pass, the FD relayed an affirmative “Go” for launch to the Astrobotic team, who confirmed that Astrobotic was a “Go” for launch during a final poll. At 2:18:38 am ET on January 8th, 2024, ULA’s Vulcan rocket lifted off the launch pad carrying Peregrine Mission One (PM1). Vulcan successfully and precisely placed PM1 into its targeted translunar injection (TLI) orbit. At 03:09:05 am ET, PM1 separated from the Vulcan upper stage, shearing the breakwires and activating power to the lander main bus. Immediately following separation and prior to the first acquisition of signal (AOS), Relative Time Sequences (RTS) enabled the successful power on and configuration of the transponder, GNC sensors, and camera systems. At ~7 minutes after separation, PM1 entered the first AOS window and established a successful downlink connection, and Astrobotic received telemetry from its first spacecraft in the AMCC. It was determined that the spacecraft was in a nominal attitude with a slight spin around the x-axis as expected and all subsystems were functioning as expected. With all other subsystems activated and the Propulsion Control Unit (PCU) initialized, the RTS moved into the propulsion initiation sequence.

Jan 8, 2024
02:18 am ET

FIGURE 2: PM1 launch on ULA Vulcan. *Photo credit: ULA.*

The PCV2 Failure

PM1 began its autonomous propulsion initiation sequence soon after separation. The propulsion initiation sequence is done via a Relative Time Sequence (RTS), which executes a discrete set of preprogrammed and thoroughly tested commands. In the lander's propulsion system architecture, gaseous helium (GHe) flows from the pressurant tank to the fuel (MMH) tanks or oxidizer (MON-25) tanks through its feed system to achieve and maintain the needed pressures in the tanks. The GHe flow and pressure is controlled by a pair of pressure control valves (PCVs), named "PCV1" for the fuel tanks and "PCV2" for the oxidizer tanks. As the first step in the propulsion system initiation process, the feedlines were vented and the priming pyrotechnic (hereafter, "pyro") valves were actuated. After waiting 20 minutes to ensure the system was primed, the remaining pyros were actuated, opening the main fuel and oxidizer valves and the fuel pressurant, oxidizer pressurant, and high-pressure helium lines. The spacecraft state at this point was nominal and operable.

Jan 8, 2024
03:10 am ET

FIGURE 3: This image was taken by camera 1 moments after successful separation from United Launch Alliance's Vulcan rocket. Counterclockwise from top left center is the DHL MoonBox, Astroscale's Pocari Sweat Lunar Dream Time Capsule, and a Peregrine landing leg. In the background is our big blue marble, our home planet, Earth.

As the next step in the propulsion initiation sequence, PCV1 and PCV2 were actuated autonomously. PCV1 was actuated first and demonstrated functional and nominal system performance. It managed to open and close correctly as observed by live telemetry. PCV2 was then autonomously actuated. After the PCV2 was determined to autonomously close off, telemetry showed a continued and uncontrolled rise of pressure in the oxidizer tanks downstream of PCV2 and also a decrease of pressure in the helium tank. Less than 90 seconds later, the pressure transducers (PTs) downstream of PCV2 and located on the oxidizer tanks pegged, or saturated, at their highest readable value. The propulsion operator and Flight Director immediately began troubleshooting the telemetry. In the meantime, the remainder of the initiation sequence completed, establishing autonomous Attitude Control System (ACS) operations and executing a planned autonomous slew to a Sun-pointing orientation. At 04:41:02 am ET, 92 minutes after separation from Vulcan, a rapid uncontrolled attitude change was observed in live spacecraft attitude telemetry. Given the rapid rise in oxidizer tank pressure and pegging of PTs that had been observed, the team assessed that one of the oxidizer tanks had likely ruptured due to over-pressurization, causing an external leakage of oxidizer, which was in turn applying an external torque to the lander that caused it to enter a rapid tumble. Three attempts were made by the propulsion operator to cycle and re-seat the PCV2 valve to stop the GHe pressurant from continuing to flow into the oxidizer tank, but a continuous decrease in GHe pressure upstream of PCV2, measured by the pressure transducer in the helium tank, indicated that even when closed, the PCV2 valve was leaking internally. A post-mission investigation later confirmed this assessment, and that the failure of the PCV2 valve to fully reseat was the most likely root cause of the anomaly.

Jan 8, 2024
06:06 am ET

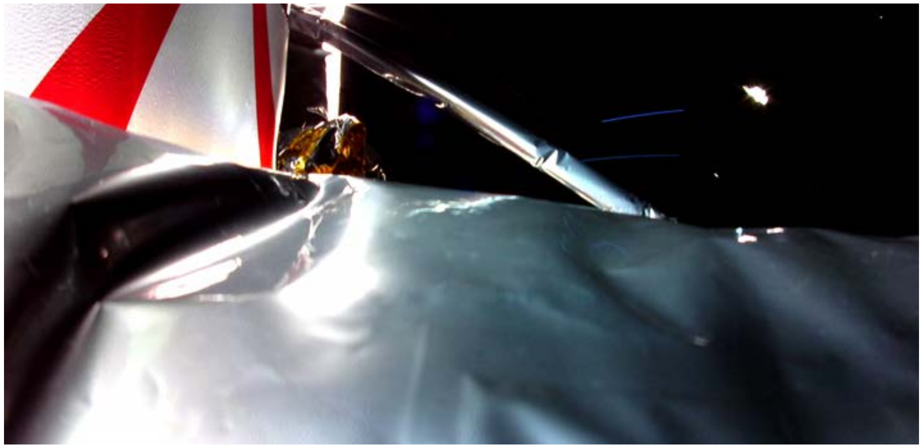


FIGURE 4: This image was taken by camera 2 and shows Multi-Layer Insulation (MLI) in the foreground. The disturbance of the MLI was the first visual indication that aligned with our telemetry data pointing to a propulsion system anomaly.

The force of the initial tank rupture and leak decreased over the course of ~ 5 minutes, until the ACS algorithm was able to regain control and begin to slow the spin rate of the spacecraft. After ~ 2 hours, the leak had slowed, but the spacecraft's ACS algorithm was unable to account for the thrust provided by the leak and return the spacecraft to a complete Sun-pointing orientation. During this period, on-shift flight controllers continued to operate Peregrine, collecting as much data about the spacecraft as possible while adjusting for the anomalous situation. An image was taken with onboard cameras (figure 3), the thermal team adjusted heater operations, two NASA payloads, Linear Energy Transfer Spectrometer (LETS) and Neutron Spectrometer System (NSS), were powered on for operational checkouts and data collection. Amongst the images later returned by one of Peregrine's cameras, Camera B, was a view of the multi-layer insulation (MLI) near the suspected oxidizer tank rupture, appearing to be puffed up relative to photos taken by the same camera prior to launch (figure 4). This provided the first visual evidence of the anomaly by showing a displacement in the MLI thermal blankets that were wrapped around the lander and supported the hypothesis of a ruptured oxidizer tank.

Jan 8. 2024
06:50 am ET

FIGURE 5: This image was taken by camera 1. Just left of center in the image is the DHL MoonBox payload covered in MLI, which contains hundreds of thousands of messages from the people of Earth. Visible to the right of MoonBox and near the bottom center of the photo is Astroscale's Pocari Sweat Lunar Dream Time Capsule. The bottom center right of the image shows one of Peregrine's landing legs obscured by the electrical interface where Peregrine was connected with the launch vehicle.

As the battery state of charge continued to drop, it was determined that the mission would be lost if we were unable to return to a Sun-pointing orientation and begin to charge the batteries prior to the end of the current communications contact window with NASA's Deep Space Network (DSN). The Propulsion, Thermal, and GNC teams worked to assess the operable state of the propulsion system. As the AOS window neared its end, a slew-to-attitude command was queued by the GNC team for upload to the lander. The new attitude hold would point the lander towards the direction of the Sun. With only three minutes to spare before commanding functions were lost, the Flight Director approved the command to execute a slew command based on the team's improvised calculations and assessment of the lander state. Shortly after the maneuver was performed, the team observed a recharge of the power system, indicating that the maneuver was successfully performed, and the lander was beginning to recharge its power heading into the planned loss of signal (LOS) window. In the following AOS contact window, it was reconfirmed that Peregrine was successfully charging its battery and maintaining Sun-pointing control with its ACS thrusters.

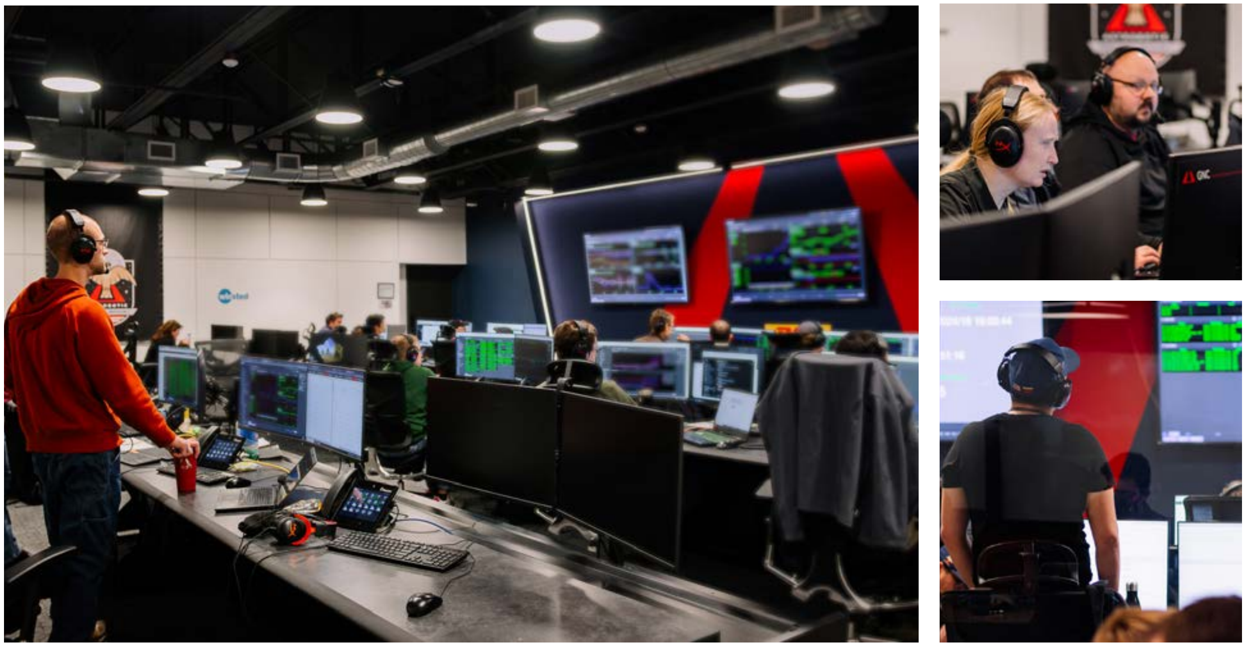


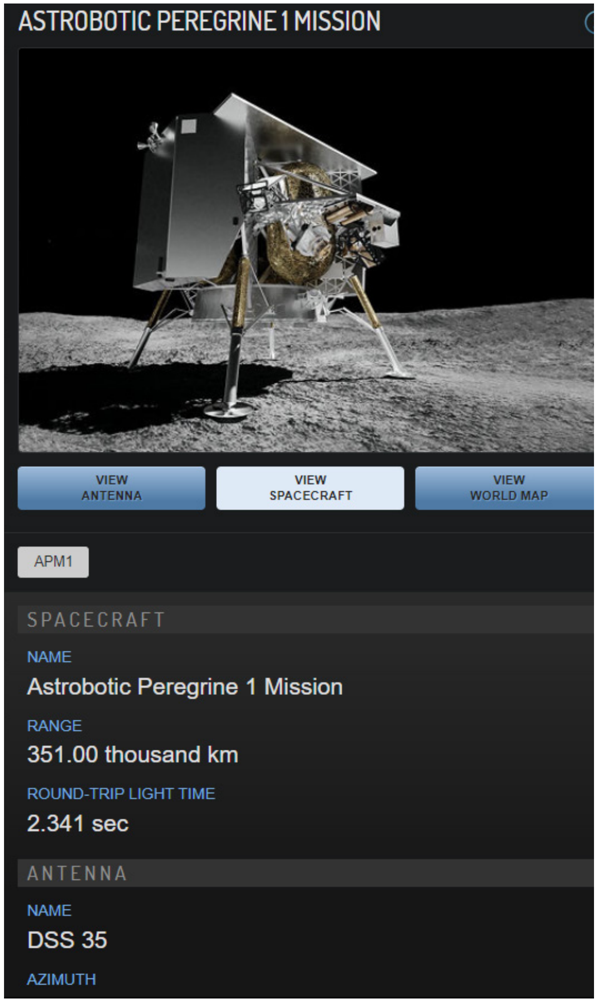
FIGURE 6: Astrobotic Mission Control Center (AMCC) directing PM1 from Astrobotic's HQ in Pittsburgh, PA.

Lunar Transit and Mission Operations

Following the anomaly and recovery of its Sun-pointing orientation, Peregrine continued on its planned transit to the Moon. PM1 had nominally planned a phasing loop prior to Lunar Orbit Insertion (LOI) to provide additional time for operational checkouts of the lander. Peregrine's transit trajectory was a highly-elliptical Earth orbit with its apogee at lunar distance, and Peregrine's transit was planned to complete 1.5 loops – i.e., travel to lunar distance, back to Earth, and to lunar distance again – prior to intercepting and landing on the Moon. Unfortunately, the loss of leaked oxidizer created uncertainty in Peregrine's ability to execute the necessary Trajectory Correction Maneuvers (TCMs), let alone attempt LOI and landing. Moreover, the loss of oxidizer and increased oxidizer pressure resulted in an abnormally high fuel-to-oxidizer mix ratio in the main engine chambers, making engine burns hotter and placing the engines at risk of heat-related damage. Based on these factors and stakeholder input, Astrobotic made the difficult decision to call off PM1's lunar landing attempt and shift to a controlled Earth re-entry. With the landing called off, Astrobotic shifted its focus to maximizing the remaining lifespan of Peregrine and returning as much lander and payload data as possible. As its understanding of the spacecraft state continued to evolve, the team planned each contact window in a manner that maximized the flight operations of each spacecraft system and prioritized as many payload operations as possible. Each lander subsystem team developed new processes and procedures to adapt to and overcome the various challenges resulting from the anomaly.

Jan 13, 2024
07:33 am ET

FIGURE 7: This image was taken by camera 4. Top center: Carnegie Mellon University's IRIS rover wheels. Right: United States of America flag and NASA logo affixed to Peregrine's tank D.



To maximize the data return from the payloads, the Astrobotic Payload Management Team (PMT) operators worked with payload teams to develop new procedures that could be uploaded to the lander. While the original mission plan called for only a few payload checkouts during transit, the new procedures included as many payload operations as feasible in each communication window.

Four days after launch, Peregrine had reached lunar distance, the spacecraft remained stable and operable and had collected and returned data from all nine of the payloads designed to communicate with the lander (the other 11 payloads were passive payloads). Two NASA payloads, Linear Energy Transfer Spectrometer (LETS) and Neutron Spectrometer System (NSS), and one commercial payload, The German Aerospace Center (DLR)'s M-42 Radiation Detector, collected publishable scientific data. The remainder of the payloads performed checkouts, tests, and collected non-scientific data that will be valuable for instrument calibration and operation on future missions. Figure 8 shows a screenshot of DSN ranging data showing Peregrine at near lunar distance.

FIGURE 8: Screenshot of DSN ranging data showing Peregrine at near lunar distance.

In addition to its success returning payload data, PM1 was able to operate the majority of the lander's subsystems and components, raising most of them to TRL 9 (Figure 9). Only a few systems and components remain at lower TRL because cislunar space did not provide the full relative operational environment (e.g., landing sensors and landing legs), or because the system could not be operated through a full operational cycle (e.g., the propulsion controller), or due to the propulsion issue, specifically the anomalous PCV2 itself, which is currently undergoing a redesign and requalification for Griffin Mission 1 and beyond.

Astrobotic Lander TRL Advancement on PM1

LANDER SUBSYSTEM	TRL	COMMENT
Avionics – Flight Computer	9	Full mission functionality verified during 10 days in cislunar space
Avionics – Thermal Controller	9	Full mission functionality verified during 10 days in cislunar space
Avionics – Power Controller	9	Full mission functionality verified during 10 days in cislunar space
Avionics – Propulsion Controller	8	Valve controllers not exercised through extended duration burns
Power	9	Full mission functionality verified during 10 days in cislunar space
R/F Comms	9	Full mission functionality verified during 10 days in cislunar space
GNC – excluding TRN	9	Full mission functionality verified during 10 days in cislunar space
GNC – TRN	7	Not exercised for descent and landing in a lunar environment
Thermal	8	Active elements not exercised in lunar environment extremes
Propulsion	8	Active elements not exercised in lunar environment extremes

FIGURE 9

Jan 18, 2024
02:27 am ET

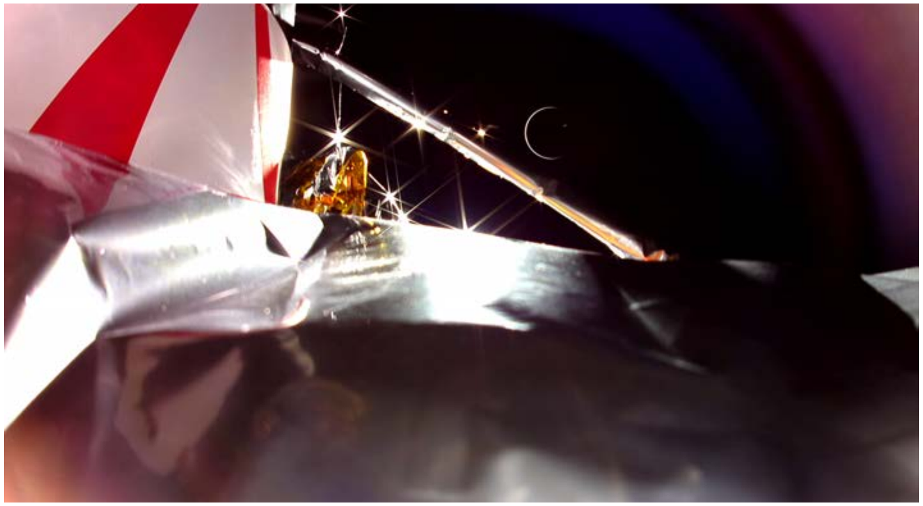


FIGURE 10: This image was taken by camera 2. The first attempt to take this photo yielded an oversaturated image, with the Sun making the image too bright to see the Earth. As a result, the team precisely slewed the spacecraft to reposition the Sun to be hidden behind the thin payload deck strut just to the left of Earth, which produced the starburst effects on the vehicle and revealed the Earth's crescent.

After reaching lunar distance and rounding apogee, Peregrine began its return trip to Earth. New ranging data was soon received which, when used to update the predicted thrust of the leak in the orbit determination model, showed that the phasing loop perigee had degraded to the point that Peregrine was instead on a collision trajectory to re-enter Earth's atmosphere.

Because the leak led to an anomalously high fuel mixture ratio, Astrobotic reached out to the axial engine vendor, who theorized that the axial engines could be operated at the high mixture ratio for short duration pulses. In order to test this theory, Astrobotic developed a procedure to command the center engine to fire for 200 ms, which resulted in an above nominal axial thrust and a temperature increase on the thermistor located on the engine valve. This confirmed the high mixture ratio, but also demonstrated that the engine could be used in short pulses. The flight dynamics and propulsion teams then developed various maneuver scenarios that could return Peregrine to a lunar or sun-synchronous orbit, or a re-entry trajectory with Earth. Astrobotic weighed the options at hand, and after consulting with NASA, ultimately determined that the safest and most responsible course of action was to allow the spacecraft to re-enter Earth's atmosphere, limiting the risk that the spacecraft could create orbital debris in cis-lunar space due to continued operation of an anomalous propulsion system.

A maneuver plan was developed that would move the re-entry ellipse east over a land-free zone in the Pacific Ocean. The maneuver plan consisted of a pulse train of engine burns, followed by a waiting period to confirm engine state of health, specifically the thermal state, keeping in mind the high fuel combustion rate. Prior to the start of the maneuver, two autonomous command sequences were developed in the event that the spacecraft had drifted away from its Sun-pointing orientation and communications were lost. Both of these were tested on our Production Flatsat prior to upload, verifying functionality. In total, four pulse trains were executed over the course of a day, and the spacecraft was turned to utilize the thrust of the leak to our advantage. These actions resulted in a controlled and safe re-entry over the South Pacific Ocean and over unpopulated areas.

In the final day of operation, as PM1 entered its last AOS window with DSN, operators in the AMCC monitored telemetry, while Astrobotic staff gathered in an onlooking conference room to listen to the voice loop. After a challenging 10 days, at 4 PM EST on January 19, 2024, DSN reported a loss of signal of Peregrine over the South Pacific Ocean. Though Peregrine Mission One did not reach the Moon, the entire Astrobotic team came together to maximize the duration of the mission, testing systems and gaining valuable experience operating a spacecraft. The team's dedication, resilience, and perseverance led to a safe, controlled re-entry, and will directly contribute to successful landing on the Moon of Astrobotic's next Moon mission, Griffin Mission One, and future missions.

Jan 19, 2024

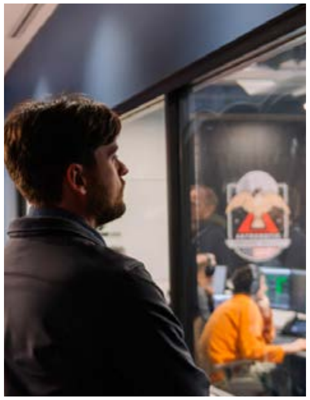


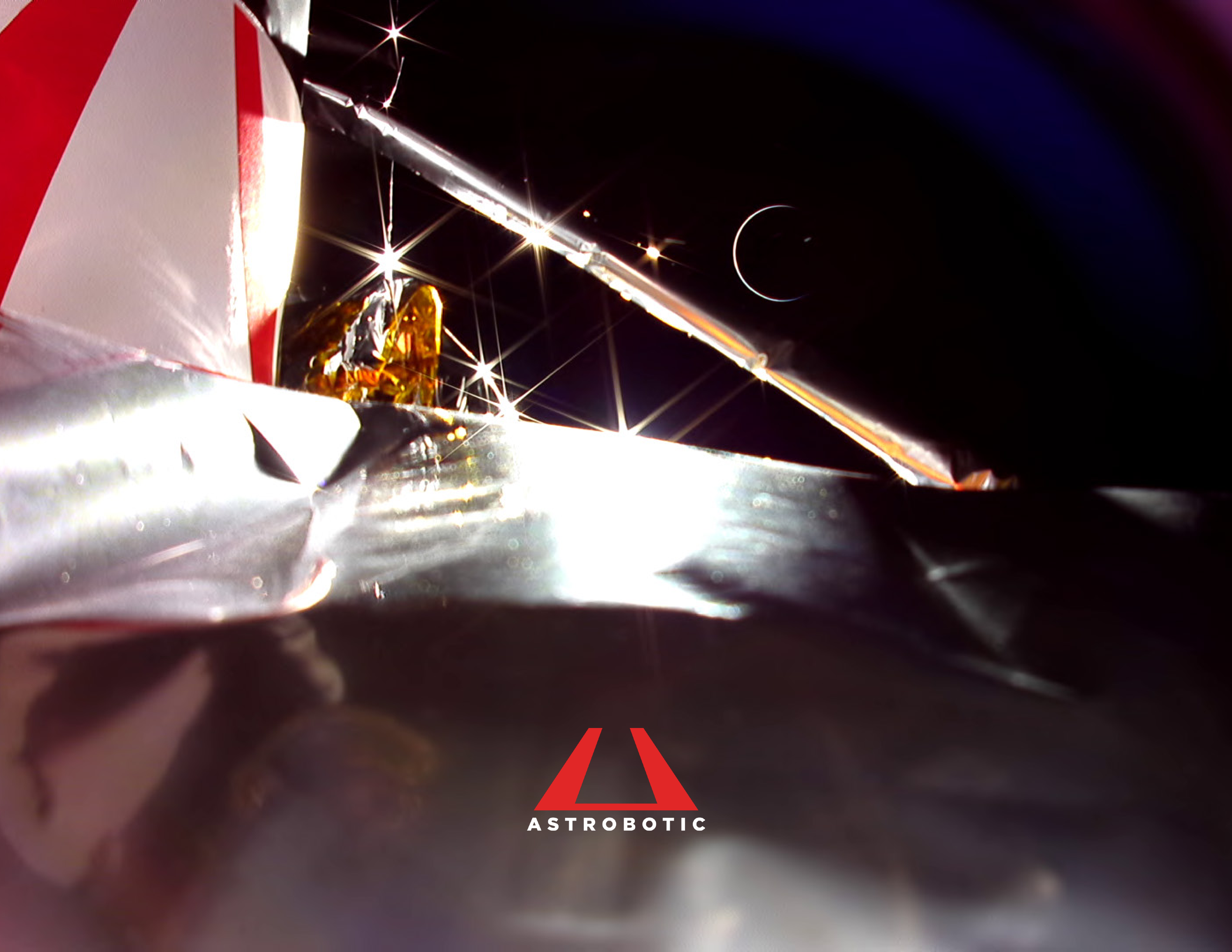
FIGURE 11: Astrobots (left) and Astrobotic's CEO John Thorton (right) looking into Astrobotic's Mission Control Center (AMCC) during the final moments of PM1.

Keep Shooting for the Moon

Commercial lunar services are poised to revolutionize access and operations on the Moon by conducting missions quickly and at a lower cost. These missions embrace a higher risk tolerance than traditional planetary space missions, work with much less funding than has been traditionally seen for such programs, but increase the cadence of science, exploration, and commercial activity with regular mission manifests. Like many pioneering ventures in space, the path to success in this new commercial lunar paradigm involves learning from failures, improving, and flying again.

Our team worked diligently to design, build, integrate, and operate the first American commercial lunar lander in cislunar space. After facing the reality that our ambitious first mission could not achieve its primary objective, the team responded resiliently, collectively working to recover the spacecraft, repurpose the mission, and learn as much as possible for future missions. We are proud of our team and sincerely appreciate the space community for their moral support and technical assistance throughout PM1's final days in space. Astrobotic's team is re-energized and ready to head back to the launch pad with Griffin Mission One.

Photo credit: ULA.


ASTROBOTIC