Mission Definition Review - Team 27

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List Of Acronyms

SCI	Science	(1.3)
SC	Spacecraft Constraint	(1.3)
CC	Customer Constraints	(1.3)
EOL	End of Life	(1.4)
ConOps	Concept of Operations	(1.4)
CDH	Computer Hardware System	(1.4)
SRR	Systems Requirements Review	(1.5)
MDR	Mission Definition Review	(1.5)
PM	Project Manager	(1.5)
CS	Chief Scientist	(1.5)
LSE	Lead Systems Engineer	(1.5)
DPMR	Deputy Project Manager of Resources	(1.5)
PDR	Preliminary Design Review	(1.5)
NASA	National Aeronautics and Space Administration	(1.6)
SiPM	Silicon Photomultiplier	(1.7)
FSU	Fayetteville Sridmtate University	(1.7)
SpaceX	Space Exploration Technologies Corp.	(1.7)
RIDM	Risk-Informed Decision Making	(1.8.1)
FMEA	Failure Mode and Effect Analysis	(1.8.2)
OSHA	Occupational Safety and Health Administration	(1.8.3)
PPE	Personal Protective Equipment	(1.8.3)
LOTO	Lockout/Tagout	(1.8.3)

LRD	Launch Readiness Date	(1.9.1)
LCR	Life Cycle Review	(1.9.1)
MRR	Mission Readiness Review	(1.9.1)
SMSR	Safety and Mission Success Review	(1.9.1)
KDP	Key Decision Points	(1.9.1)
SRB	Standing Review Boards	(1.9.1)
SIR	System Integration Review	(1.9.1)
PRR	Production Readiness Review	(1.9.2)
SAR	System Acceptance Review	(1.9.2)
GNC	Guidance Navigation and Control	(1.10.1)
MCCET	Mission Concept Cost Estimate Tool	(1.10.2)
NICM	NASA Instrument Cost Model	(1.10.2)
MCR	Mission Concept Review	(1.11.1)
CCB	Change Control Board	(1.11.1)
RFA	Requests For Action	(1.11.1)
ADV	Advisories	(1.11.1)
PA	Program Analyst	(1.11.2)
SHINE	Schools and Homes In Education	(1.12)

Disclaimer

Team 27 does not have a Thermal or Mechanical Engineer. The team was unable to complete the Thermal and Mechanical sections for this deliverable.

1 Mission Definition Review

1.1 Mission Statement

Through past and current lunar exploration, it has been found that the Earth's Moon had volcanic activity about 3.8 to 3 billion years ago.[1] During volcanic eruptions, magma would reach the surface and, while subjected to the lower surface temperatures, began to harden into a crust layer. During this process, the magma continued flowing under the surface, and lava tubes were formed. As the eruptions subsided, the magma would eventually exit the subsurface entirely and leave hollowed lava tubes. Throughout the years the Moon's surface has experienced impacts from micrometeorites, which created a number of lunar pits and caves that can allow entry into the lava tubes. Current data suggests that lunar pits and caves can protect humans and equipment from extreme fluctuations in temperature and radiation, which would allow long-term habitation of humans for future exploration on the moon.[2]

This mission aims to determine if the Mare Ingenii lunar pit is a viable option for sustained human presence on the Moon, to develop precursor lunar robotic missions and to define those scientific activities that astronauts will conduct on the Moon.[3] This mission aims to measure the strength and direction of magnetic fields correlated with lunar swirls using a magnetometer. This mission also seeks to identify the amount of radiation present within and outside the Mare Ingenii pit to determine the radiation's effects on the microclimate of the pit via using a Silicon Photomultiplier measuring photon counts to determine radiation amount and type.[4] As previously stated, this mission aims to determine if lunar pits can provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure.[5] Muon imaging will be used to collect data on the characteristics within the Mare Ingenii lunar pit in order to define the depth, height, variations in terrain, and entry access. The structural integrity will be determined by sourcing the thickness and structural data acquired from muon imaging as well. All of these objectives and goals shall be obtained via the use of a single rover, and will improve the understanding of the composition of the Moon as well as how a sustained presence on the Moon will impact human health.

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1. Heng-Ci Tian et al., "Surges in volcanic activity on the Moon about two billion years ago," *Nature communications* 14, no. 1 (2023): 3734–3734.
2. Raymond P. Martin and Haym Benaroya, "Pressurized lunar lava tubes for habitation," *Acta Astronautica* 204 (2023): 157–174, ISSN: 0094-5765, https://doi.org/https://doi.org/10.1016/j.actaastro.2022.12.013, https://www.sciencedirect.com/science/article/pii/S0094576522006853.
3. Engineering National Academies of Sciences and Medicine, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (Washington, DC: The National Academies Press, 2023), ISBN: 978-0-309-47578-5, https://doi.org/10.17226/26522, https://nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science.
4. Hamamatsu Photonics, "MPPCs (SiPMs) / MPPC Arrays," 2024, accessed November 10, 2024, https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array.html.
5. Lunar Exploration Analysis Group (LEAG), "The Lunar Exploration Roadmap: Exploring the Moon in the 21st Century: Themes, Goals, Objectives, Investigations, and Priorities.," 2016, accessed November 10, 2024, https://www.lpi.usra.edu/leag/roadmap/US-LER_version_1_point_3.pdf.

1.2 Science Traceability Matrix

The science objectives for the mission are categorized into two science goals: "develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon" and "provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure."[67] The first two science objectives fall within the first science goal, which includes determining the location of magnetic fields within and around the Mare Ingenii pit and discovering the effects of radiation on the pit's microclimate to gauge the sustainability of human life. The last two science objectives are beneath the second goal, which includes determining the characterization of the Mare Ingenii pit to determine the viability of human habitation and discovering the structural integrity of the pit to evaluate its capabilities of supporting human life.

To determine the location of magnetic fields, a fluxgate magnetometer with a measurement range between 0 and 23 nT shall be used upon landing.[8] Since both instruments selected for this objective have very low noise and considerable measurement capabilities, they shall conduct the samples for this objective. The final science objective for the first science goal is to determine the effect of radiation on temperature, humidity, and pressure within the lunar pit, which will be measured every second. This will allow researchers to have extensive data for comparison between peak and minimum radiation levels. The selected instruments for this objective will be capable of withstanding the environment inside the Mare Ingenii pit and shall be active until comparative data has been collected.

When measuring the omnidirectional dimensions of the Mare Ingenii pit to determine the viability of human habitation for the first science objective of the second science goal, the measurements shall be taken every 45m of the 180m-diameter pit to ensure the entirety of the pit is surveyed.[9] This will allow for comparisons in any overlapping areas and will allow for the possibility of errors in measurements. The last science objective is to determine the structural integrity within the Mare Ingenii lunar pit and better understand its capabilities to support human life. A silicon photomultiplier will examine the pit's structural integrity by observing the flux of muons beginning with the pit's surface and continuing after dropping into the pit.

6. Tian et al., "Surges in volcanic activity on the Moon about two billion years ago."

7. National Academies of Sciences and Medicine, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*.

8. Georgiana Y. Kramer et al., "Characterization of lunar swirls at Mare Ingenii: A model for space weathering at magnetic anomalies," *Journal of Geophysical Research: Planets* 116, no. E4 (2011), https://doi.org/https://doi.org/10.1029/2010JE003669, eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2010JE003669, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2010JE003669.

9. Lunar Reconnaissance Orbiter Camera, "Pits | Lunar Reconnaissance Orbiter Camera," 2024, accessed November 14, 2024, https://www.lroc.asu.edu/atlases/pits/6.

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
"Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon" - Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032	Determine the location of any potential surface magnetic fields within and around the Mare Ingenii lunar pit, specifically those correlated with lunar swirls.	Identify the magnitude and direction of magnetic fields present in a range of 15km.	Detect magnetic fields in the 0-500nT range over an area of 10km.	nanoTesla range:	0-500 nT	-20,000-20,000 nT	3-Axis Fluxgate Magnetometer Model AP235	The magnetometer must be capable of measuring in nanotesla.
				Noise level:	-0.32-0.32 RMS nT/Hz	0.3 nT RMS/√Hz		
				nanoTesla range:	0-500 nT	-60,000-60,000 nT	Bartington Fluxgate Magnetometer, 3-axis, Aerospace/Space	Mission must determine the thickness of the Mare Ingenii pit's walls, floor, and ceiling to determine its structural integrity.
	Determine the effect of radiation on temperature, humidity, and pressure within lunar pits to determine if they can sustain human life.	Identify the percentages of Alpha, Beta, and Gamma radiation and fluctuation in temperature, humidity and pressure within the Mare Ingenii pit.	Detect temperature, humidity, and pressure changes during peak ranges of Alpha, Beta, and Gamma radiation percentages every second.	Radiation levels:	0-1,370 W/m2	0-1,500 W/m2	Active Radiation Environment Sensor	
				Temperature range:	16-18 °C	0-60 °C	Model HMP60 Humidity Sensor + Model DI-808	Rover will land within 1 meter of the Mare Ingenii pit in the Thomson M crater.
				Wavelength range:	400-700 nm	300-980 nm	Silicon Photomultiplier	
				Photon pitch:	10-100 μm	15-47 μm		
				Dark count:	10–2000 kHz/mm2	25-110 kHz/mm2		Mission must collect 5 data samples of magnetic field strength from the landing site to the opening of the Mare Ingenii pit.
				Recovery time:	< 46 ns	7-95 ns		
				Temperature range:	16-18 °C	-200-1,000 °C	PT1000 Class F0.3 + Pressure-Temperature	
				Pressure range:	10(-12)-10(-10) torr	0-30 torr		
"Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure" - (Lunar Exploration Analysis Group (LEAG) Habitation: HAB-SAT Report, Priority Objectives	Characterize the depth, height, terrain variation, and ease of access within lunar pits/caves to determine the viability of human habitation.	Define the characteristics of the Mare Ingenii pit within a vertical distance of 55m and a diameter of 180m.	Identify the omnidirectional dimensions of the Mare Ingenii pit every 45m.	Measurement Range:	55 m	70 m	MID-360 LiDAR	The instrument used to collect radiation levels must be capable of measuring in Alpha, Beta, and Gamma percentages.
	Determine the structural integrity within the Mare Ingenii lunar pit to determine if it can support human life.	Define the thickness and structure of the Mare Ingenii pit utilizing the flux of muons.	Detect the thickness of the Mare Ingenii pit's walls, floor, and ceiling in meters every 40m.	Wavelength range:	400-700 nm	300-980 nm	Silicon Photomultiplier	Rover must drop into the Mare Ingenii pit to determine the microclimate, structural integrity, and viability of human habitation of the pit.
				Photon pitch:	10-100 μm	15-47 μm		
				Dark count:	10–2000 kHz/mm2	25-110 kHz/mm2		
				Recovery time:	< 46 ns	7-95 ns		

Table 1: The Science Traceability Matrix of the mission.

1.3 Mission Requirements

The following table outlines the Mission Requirements in a "flow-down," structure, beginning with the fundamental constraints and limits outlined by the customer (L'Space), and then branches out to its corresponding requirements whether it be a Science (SCI), or Spacecraft Constraint (SC). Each level of flow corresponds to its color; a darker color signifies a higher level of flow, while a lighter color signifies a lower level of flow within a foundation.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
CC - 0.0	The mission shall adhere to customer constraints.	Parameters outlined in document, in relation to the given constraints and requirements	N/A	CC 0.1 - CC 0.10 MG - 1.0	Analysis	All	Met
CC - 0.1	System must adhere to mass constraint of 350 kg	Limited by the mission task, and to ensure not to over exceed mass capacity during transport.	CC - 0.0		Inspection	All	Met
CC - 0.2	System must adhere to dimension constraint of 2 m x 1.25 m x 1.25 m during transit	Limited by spacecraft transport dimensions; cannot exceed due to constraint.	CC - 0.0		Inspection	All	Met
CC - 0.3	System must explore the lunar/pits caves and perform surface science operations	Outlined mission statement and goal for research.	CC - 0.0		Inspection	Payload	Met
CC - 0.4	System must not exceed cost constraint of $425M	Limited by set amount of allocated funding. Cannot exceed due to unavailable funds.	CC - 0.0		Inspection	All	Met
CC - 0.5	System must be ready to launch by March 1st, 2030, at Cape Canaveral.	Hard deadline, set by mission timeline.	CC - 0.0		Inspection	Payload	Met
CC - 0.6	System cannot have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof; System must not exceed radioactive material cumulative mass of 5g	The usage of the RTG is prohibited, in accordance with the mission.	CC - 0.0		Inspection	Electrical, Structural, Mechanical	Met
CC - 0.7	System will be transported on a separate, primary vehicle launch (rocket) with power sufficient during transport. No scientific data will be collected during transit	Transportation structuralization and unavailability of research during transit.	CC - 0.0		Inspection	Structural	Met
CC - 0.8	System shall arrive at target destination adhering to landing site constraints: given a 100m diameter landing zone, it shall not exceed a slope of 10 degrees, and should traversal be necessary to the science site or lunar cave, it must no be no further than 5 km from the landing zone (only applicable for mobile vehicle)	Landing site parameters/criterias outlined in mission.	CC - 0.0		Analysis	Structural, Mechanical	Met
CC - 0.9	System shall communicate data to Earth via relay of spacecraft orbiting the Moon; spacecraft must be able to communicate with the orbiting spacecraft directly, and primary mission orbiter which shall remain in a circular polar orbit of 100km during the mission's lifespan	Communications necessary in order to establish control, navigation, and data collection.	CC - 0.0		Demonstration	Electrical, Communication, Mechanical	Met
CC - 0.10	System shall undergo analog testing in a comparable volcanic environment; drop testing is necessary should the landing site not have a traversable entrance, and tether or winch system	Necessary to evaluate mission success and analyze potential faults and feasibility.	CC - 0.0		Test	All	Met

Table 2: Mission Requirements. Please see Figure 12 in the Appendix for the full Requirements Table.

1.4 Concept of Operations

The lunar rover surface mission is designed with specific operational phases, each with its own purpose, milestones, and timeframes to ensure effective utilization of time and resources until the mission's End of Life (EOL). These phases as illustrated in the mission's Concept of Operations (ConOps), with an emphasis on timeline specifics and major operational tasks.

Phase 1: Initial Deployment and System Activation (T+0 to T+7 Days)

The Power Conservation Phase begins during pre-launch and continues throughout the mission's lifespan. This phase involves initial programming of power management protocols into the rover's Computer Hardware System (CDH). Once on the lunar surface, the rover will execute these protocols autonomously based on the control engineering that has been done, by making adjustments remotely from the mission control room based on ongoing performance data output sent to earth.

Upon touchdown, the mission begins with the critical deployment and activation of all systems. This phase spans approximately one week and includes safely deploying solar arrays, power sources, initializing communication links, and analyzing environmental conditions. This period also involves diagnostics to confirm that all systems are operational and that the rover is ready for the research activities. Each component is calibrated correctly via remote control of the rover, which allows subsequent operations to proceed without interruptions. Calibration ensures that onboard sensors such as magnetometers, radiation sensors, humidity sensors, and mobility systems operate accurately since the lunar conditions are harsh. Temperature and pressure sensors are calibrated to begin collecting data every few seconds for detailed measurements of the pit's microclimate. This phase also includes adjusting the LiDAR system for depth mapping and establishing its data collection intervals for surveying the pit. The rover will navigate to pre-defined waypoints done to demonstrate its mobility and the functionality of its navigation systems. These activities aim to verify the rover's operational readiness for more complex scientific tasks and provide initial data about the lunar surface composition and environmental conditions.

Phase 2: Lunar Swirl Analysis Phase (T+8 to T+28)

Once the rover is fully deployed at the landing site the rover will study magnetic anomalies and surface composition associated with lunar swirls using specialized instruments such as magnetometers and spectrometers once the rover touches the landing site. The rover will navigate to specific coordinates to capture high-resolution images and gather spectral data of the swirls, analyze the magnetic field strengths, and conduct preliminary surface material analysis.

Phase 3: Traverse mode to the Pit and Comprehensive Data Collection (T+29 to T+49 Days)

After completing the research objectives for lunar swirls, the rover will traverse for 1 kilometer to the pit and enter it. Inside, the rover employs multiple instruments to assess the pit's structure and safety for potential human habitation. LiDAR measurements are taken every 45 meters to build a complete profile of the pit's layout, overhangs, and potential lava tubes. Meanwhile, structural data from the Silicon Photomultiplier is collected every 40 meters along the pit's walls in (X,Y,Z) + T + E. to examine geological features. Radiation, temperature, and humidity readings will be taken at predefined intervals to analyze the pit's microclimate and to determine radiation protection levels.

Phase 6: Lunar Night Survival Mode (T+50 to T+63 Days)

During this phase, the rover will transition into a conservative operational mode due to the absence of sunlight, which impacts its power supply and the extreme cold conditions of the lunar environment at night. Critical systems such as thermal regulators will operate on minimal power to protect core components from the cold. System health and battery levels will be monitored continuously to ensure the rover can resume operations once the rover is able to get solar energy.

Phase 7: Second Cycle Operations and Extended Missions (T+64 to T+75 Days)

After surviving the lunar night, the rover will re-initiate its systems and adjust its mission objectives based on the first cycle's findings and the remaining resources. This phase allows for the extension of the mission to new areas of interest or deeper exploration of previously visited sites. Adjustments will be made to explore new scientific targets or further investigate intriguing findings from earlier in the mission by the chief scientist.

Phase 8: Final Data Transmission and End of Life Procedures (T+76 to T+77 Days)

As the mission approaches its end, this phase focuses on concluding active operations and securing all systems. The rover will transmit all remaining scientific data to Earth, ensuring that no information is lost. The end of life phase is designed to safely conclude all mission activities. It involves a systematic shutdown of the rover's systems and securing of any potential environmental hazards. The rover's final position will be documented for future missions, and a last communication will be sent to Earth to signal the official end of operations, marking the successful completion of the mission's objectives.

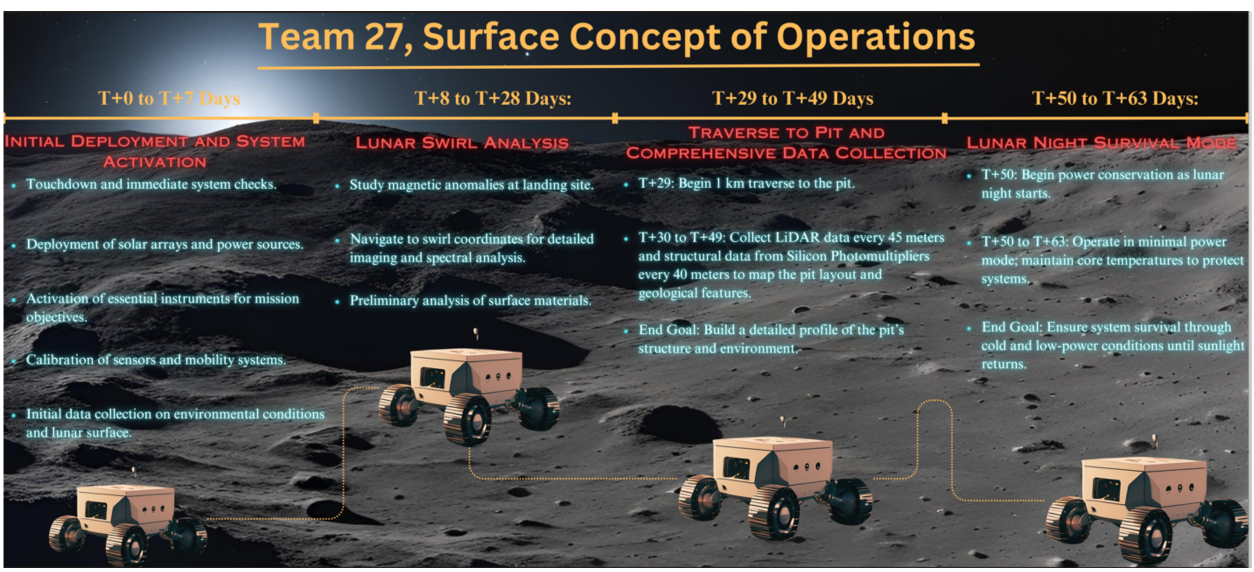


Figure 1: Part 1 of the Concept of Operations graphic.

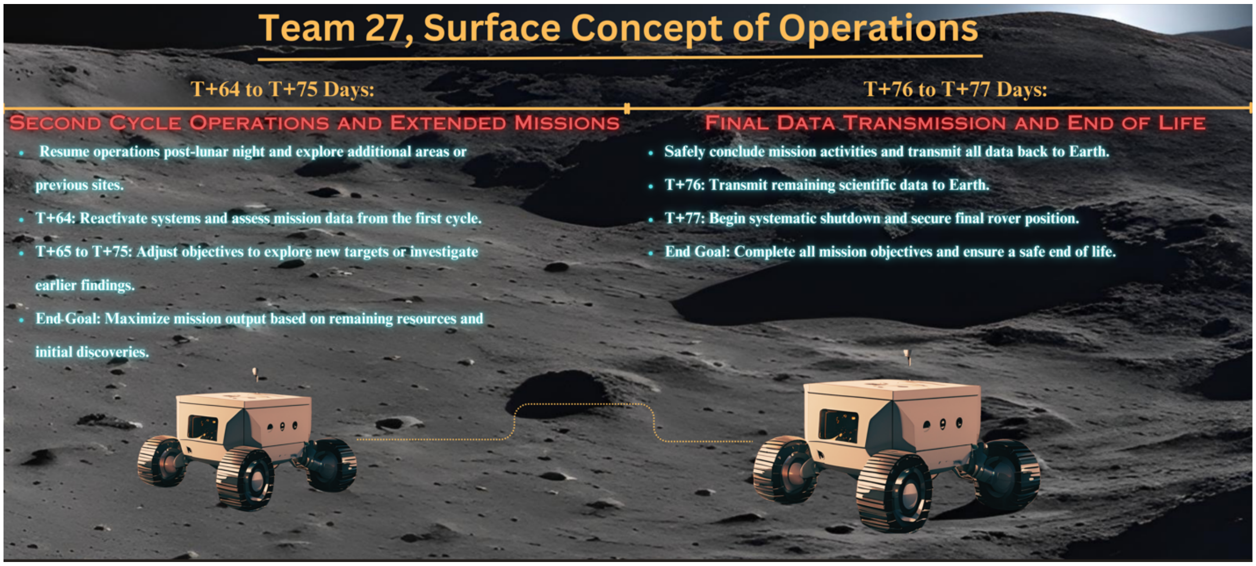


Figure 2: Part 2 of the Concept of Operations graphic.

1.5 MCA Team Management Overview

In the weeks leading up to the submission of the Systems Requirements Review (SRR), Team 27 faced unforeseen challenges that led to several re-arrangements of the team's organization of roles, which indicate the members' primary and secondary roles (Figure 3 and 4, respectively). The team also underwent the loss of the Thermal Engineer during the Mission Definition Review (MDR).

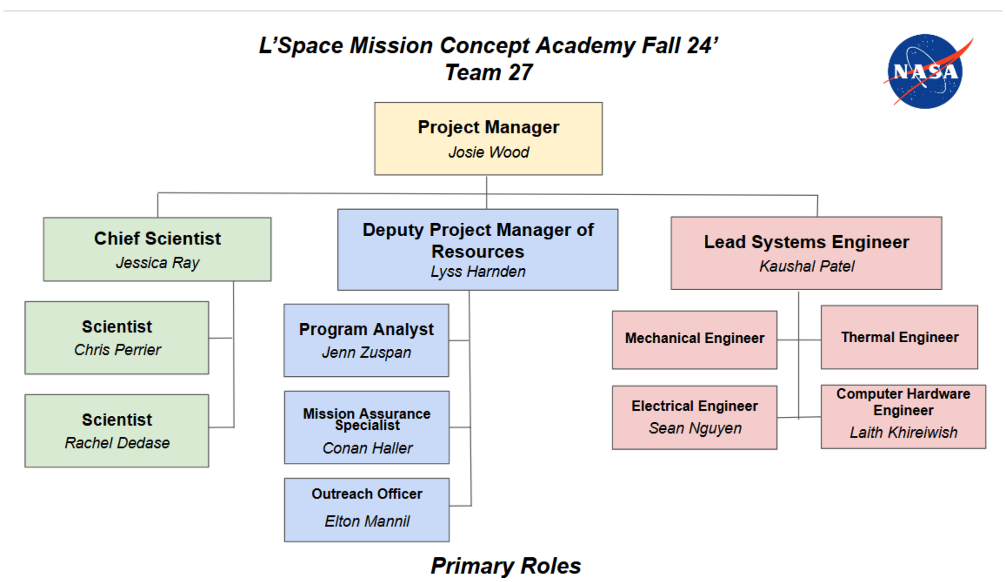


Figure 3: Organization of the primary roles of the members of Team 27.

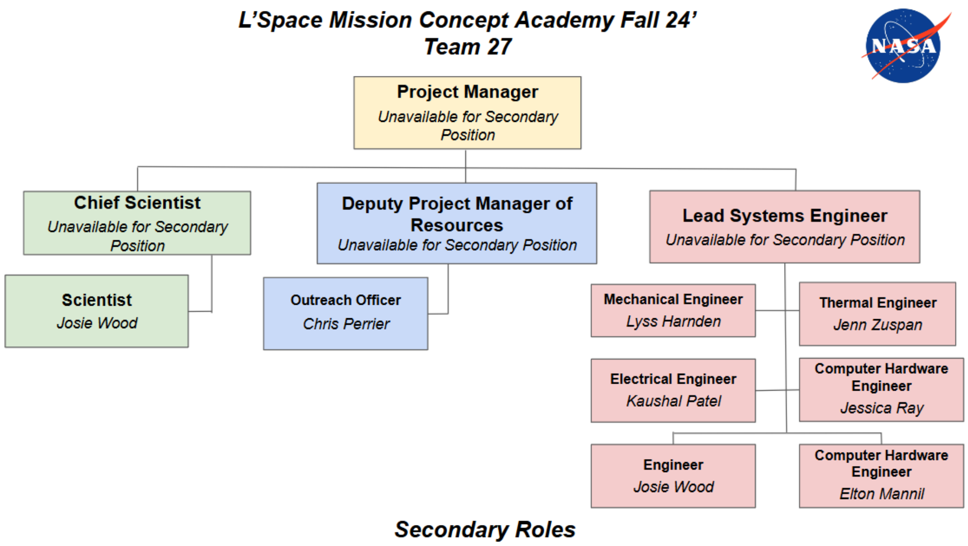


Figure 4: Organization of the secondary roles of the members of Team 27.

Team leads were originally voted for collectively by the team after listening to the candidates' elevator pitches during a group meeting. Additionally, leads for primary roles within each sub-team were arranged based on academic and related experience, as well as time availability to commit to the academy. For example, the Outreach Officer position, a role that has very little assigned tasks for the SRR, was given to a team member with a heavy schedule and limited time to give to this deliverable. In contrast, the lead Mechanical Engineer, who is substantially depended on for a significant portion of the SRR pertaining to the spacecraft's mechanical subsystem, was initially given to a team member currently studying and completing research in the field of mechanical engineering. For the MDR and forward, a secondary position as a Computer Hardware Engineer was taken on by a team member who completed substantial work within this role for the SRR.

As discussed in the SRR, Team 27 was informed a week before the SRR deadline that it had lost its lead Mechanical Engineer, challenging team leads to promptly respond in re-assigning Mechanical Engineer tasks to ensure they would be covered as best as possible. This proved to continue to be a difficulty for Team 27 to completely handle for the MDR as well, challenging the Lead Systems Engineer (LSE) of the team to attempt to balance primary tasks and leadership along with covering the mechanical engineering tasks. Unfortunately, the Mechanical Engineer tasks were not able to be completed in full.

In the weeks leading up to the submission of the MDR, Team 27 heard news that it would also be losing its lead Thermal Engineer. This posed another challenge for the engineering sub-team and team as a whole and was sudden and unforeseen. Thus, Team 27 did not have the means or time to complete all Thermal Engineer tasks in full by the MDR submission deadline.

For the Preliminary Design Review (PDR), Team 27 plans to work as much as they can to collectively fill in the gaps for both the Mechanical and Thermal Engineer sections– or any other gaps that may unexpectedly arise during the weeks leading up to the PDR submission deadline. This will require voluntary participation by members who have completed their primary work and are looking to help the team out as a whole, in addition to efforts by team leads to do their best to take initiative in filling those gaps as best as possible.

Methods for organization, workload, and decision-making have been decided on, established, and altered as the team has gained more experience working with one another. For the MDR specifically, in order to ensure proper time management across the team, new expectations were introduced up front by the Project Manager (PM), Chief Scientist (CS), LSE, and Deputy Project Manager of Resources (DPMR). After the MDR Instructions document was distributed by L'SPACE, each of the sub-team leads sent its own announcement in the corresponding sub-team Discord channel (i.e. engineering, science, or programmatics) about expectations moving forward from the SRR, which included details on a new system that required a first draft by a precise deadline (determined by the PM), methods for sharing work and communicating with the entire programmatics team, office hours, and attendance in meetings. All leads enforced that all drafts would be sent publicly within the respective sub-team Discord channel, that communication and questions would be held publicly in this same Discord channel for the whole team to stay up-to-date on what was being worked on within each sub-team (unless reaching out for personal matters), specific hours that each team lead would be available to answer any questions, and the expectation that meetings are attended. Figure 17 depicts one of the announcements sent by a team lead to its sub-team.

After each of the CS, LSE, and DPMR sent their announcements, the PM sent an overarching announcement to the entire server reiterating general expectations and announcing the precise deadline for first drafts for the MDR, November 6th by 11:59PM. The announcement also contained a document written by the PM discussing guidelines moving forward and the implementation of a two-strike system, to combat the issue of failing to make corrections of work in a timely manner and ensure the team mentor was involved should the situation begin to affect or hinder the work of the team as a whole (Figure 16). Additionally, the PM organized a group meeting for the team to review first drafts together, which was determined after the results of a when2meet filled out by as many team members as possible. After the first draft deadline, the PM sent another announcement detailing the precise deadline for final drafts for the MDR, November 15th by 11:59PM. Another group meeting was organized by way of when2meet results to review the final MDR document as a team and make any last-minute changes if necessary.

Team 27 plans to continue utilizing these strategies moving forward, as it proved to be of significant benefit to the team as a whole to have strict deadlines organized for first and final drafts, allowed communication to be more fluent and for members to have an understanding of what was going on within each sub-team when group meetings rolled around to discuss sub-team-specific and collective team topics, and emphasized efforts and high-quality work.

1.6 Project Management Approach

The leads of Team 27 have established the amount of personnel needed. The entire team at any phase shall not exceed 54 persons, while the distribution of said 54 persons will change depending on which Phase of the mission is active. Figure 5 displays the distribution of personnel during the different phases of the mission. The total personnel of the mission is compromised of Administrators, Managers, Technicians, Scientists, and Engineers. For the remainder of this section, the key as pictured in Figure 18 in the Appendix.

Additional Information

	Phase C	Phase C	Phase C-D	Phase D	Phase D	Phase E-F
# People on Team	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6
Science Personnel:	2	2	2	2	2	20
Engineering Personnel:	20	20	20	20	20	16
Technicians:	15	15	15	15	15	0
Administration Personnel:	6	6	6	6	6	6
Management Personnel:	11	11	11	11	11	11

Figure 5: The amount of personnel per division at any point in time.

The administrative team consists of six personnel. This total excludes the DPMR who serves as the team's single manager. Its members include a Program Analyst, Mission Assurance Specialist, Outreach Officer, Lawyer, Accountant, and Operational Staff. Defined by L'SPACE, the Program Analyst, Mission Assurance Specialist, and Outreach Officer have responsibilities such as tracking mission costs and schedules, determining mission risks and developing mitigation strategies, and planning outreach events of the mission, respectively. The lawyer is in charge of tasks such as ensuring the mission's legal compliance with federal regulations (such as environmental laws, privacy concerns, and more), enforcing contracts between the National Aeronautics and Space Administration (NASA) and any partners or suppliers, and handling claims related to risks that may arise during the mission. Next, the Accountant takes care of the strict adherence to the budget, preparing financial reports and keeping detailed records of transactions, and making sure funding is spent in line with any rules or regulations. The operational staff is responsible for guaranteeing that each mission phase has the necessary resources to be successfully completed on-time and generally ensuring the smooth execution of the mission overall. All administrative personnel will be needed for Phases C-F. Figure 6 displays the complete organizational chart of the Administration Team.

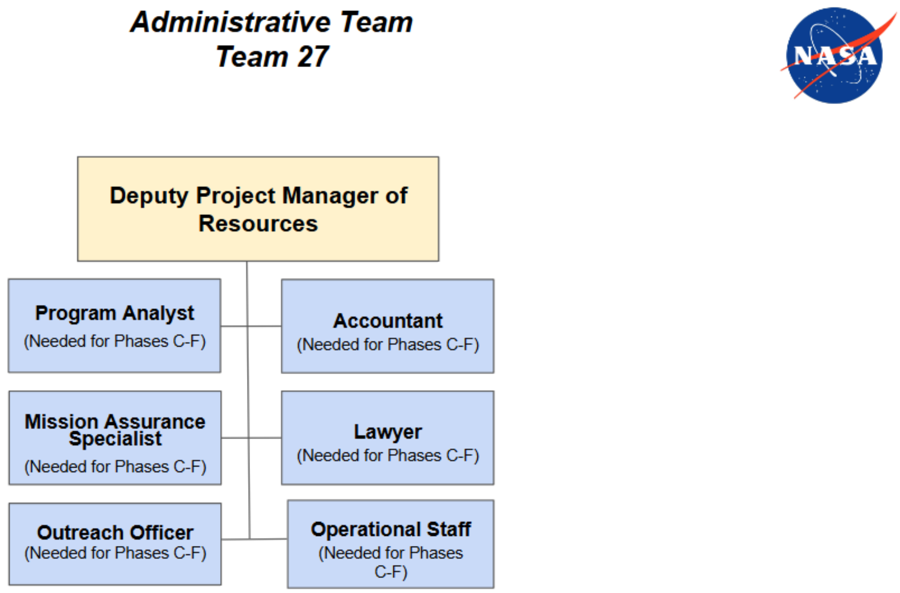


Figure 6: The organizational chart of the Administration Team.

The science team consists of the Chief Scientist, who oversees three managers: the Environmental Science Manager, the Speleologist Manager, and the Physicist Manager. During phases C and D, the Environmental Science Manager manages three technicians, the Speleologist Manager leads a team of one Speleologist and three technicians, and the Physicist Manager supervises a Physicist and two technicians. The technicians of each section focus on creating instruments for each science objective, while the scientists and their managers ensure its proper creation. There are only two science personnel during these phases since research and decisions about instruments have previously been completed. During phases E and F, the science team increases its science personnel to twenty, but the managers and technicians personnel are unchanged. This increase is necessary because more scientists are needed during and after the launch of the mission. The scientists can ensure the data received is accurate, instruments perform as expected, and draw conclusions based on the information received. Figure 7 displays the full organizational chart of the Science team.

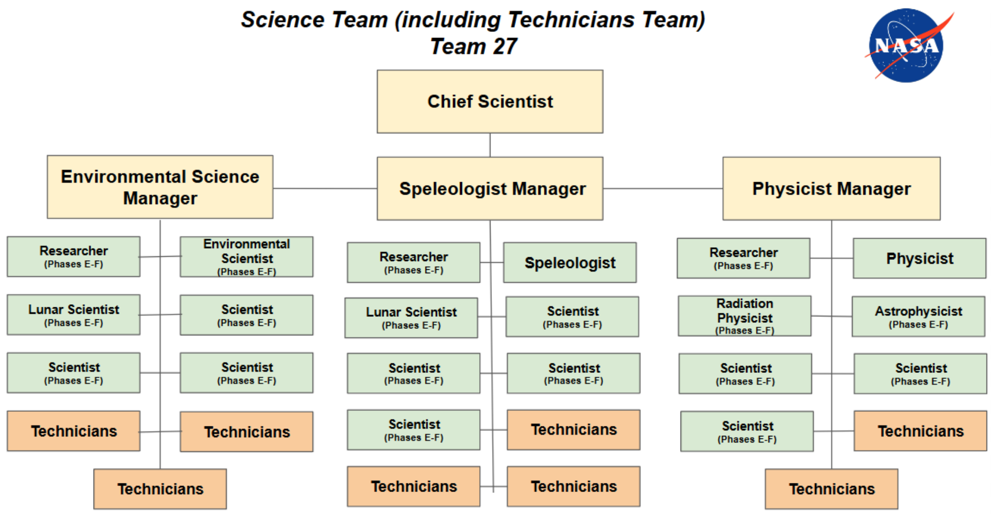


Figure 7: The organizational chart of the Science Team.

The organizational structure for the engineering team is outlined and designed in such a way to ensure that every aspect of the rover's functionality, resilience, and mission objectives are meticulously planned and executed. At the heart of the engineering team is the Lead Systems Engineer, who bears the responsibility of the operation of the rover, and the rover having to successfully complete the mission by performing its necessary scientific tasks on the Moon as determined by the chief scientist. Due to these, the Lead Systems Engineer needs to understand all the engineering principles that are used within the rover and each of the subsystems requirements.Supporting the Lead Systems Engineer are four specialized leads, each overseeing a critical area of the rover's design: Electrical, Computer Hardware, Mechanical, and Thermal Engineering. Each of these leaders manages a team of engineers and technicians who focus on their work on respective domains.

Under the Lead Electrical Engineer, the team includes specialized engineers. The Test Engineer rigorously checks that electrical components operate reliably under simulated lunar conditions, while the Battery Engineer optimizes energy storage for extended operations, recognizing that recharging isn't an option on the lunar surface. The Strategic Electrical Engineer develops high-level power management strategies to handle the unpredictable lunar environment, while the Controls Engineer focuses on automated systems that maintain stable power distribution. Finally, the Power Electronics Engineer focuses on power conversion and regulation, ensuring that each part of the rover receives the appropriate amount of energy, regardless of changes in power demand. Supporting these engineers, Technicians in Phase C-D assist in the assembly, testing, and troubleshooting of the electrical systems, providing essential support as the mission progresses through design and development phases.

The Lead Computer Hardware Engineer is in charge of the computing and data handling systems, overseeing the reliability and safe handling of data processing, storage, and communication. This role ensures that all data generated by the rover's sensors are accurately processed and transmitted back to Earth. Within this team, the Signal Processing Engineer manages data from the mission's sensors, including radiation and muon detection, while the Radiation Engineer designs protective measures to shield the rover's electronics from lunar radiation. A Software Developer writes code to control data acquisition, navigation, and other key functions, allowing the rover to operate autonomously. Additionally, the Design Verification Engineer tests these systems in simulated lunar conditions, and the Electromagnetics Engineer works to prevent electromagnetic interference with communications and other systems. Technicians in this team assist with setup, calibration, and testing of the computing systems to make sure everything runs smoothly.

The Lead Mechanical Engineer oversees the rover's structural framework and mobility systems, focusing on ensuring the rover can withstand the Moon's demanding terrain and gravitational conditions. The Design Engineer within this team is tasked with creating robust structural components that meet mission weight constraints while ensuring durability against impact and wear. Testing these designs is the responsibility of the Test Engineer, which puts these designs through software simulations to ensure they can handle lunar stresses by providing an outlook in the future. The Strategic Mechanical Engineer focuses on the longevity of moving parts like wheels and joints, which will be in constant contact with abrasive lunar dust. Quality is overseen by the Quality Control Engineer, who performs detailed inspections and tests to catch potential weaknesses early. Finally, the Automation Engineer manages the rover's mobility system, implementing controls that allow the rover to navigate obstacles on the lunar surface. Technicians here support the assembly, testing, and maintenance of all mechanical parts.

The Lead Thermal Engineer works with all the other lead engineers to regulate the rover's temperature. Without proper thermal management, the rover's components could overheat or cause stability and sensitivity issues, failing the mission and its objectives. The stability and sensitivity issues are parameters that are analyzed by the control engineer and given to the thermal engineering ensuring that those parameters are met. The Lead Thermal Engineer designs and implements passive and active thermal control measures to maintain operational temperature ranges for all critical systems. Assisting in these efforts, the Thermal Engineers work closely on designing insulation and cooling solutions that prevent components from overheating or freezing. Thermal Engineers for Phase C-D test these systems during the design and development stages, ensuring they will perform as expected in the lunar environment. The thermal engineering team is also supported by Technicians in Phase C-D, who assist in installing, testing, and troubleshooting thermal management systems to confirm they meet mission requirements.

Each of these lead engineers and their teams and technicians along with the lead systems engineer for the whole mission bring essential skills and expertise to the mission. Together, they ensure that the rover will be able to autonomously conduct scientific tasks on the Moon, collect critical data on lunar pits, and withstand the environmental challenges it will face. Figure 8 displays the full organizational chart of the Engineering team.

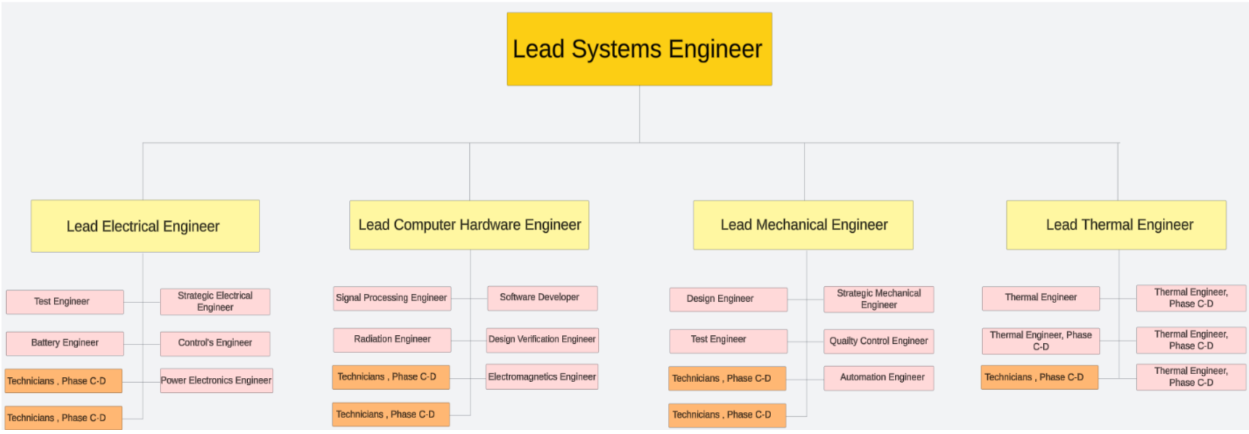


Figure 8: The organizational chart of the Engineering Team.

The Management Team is composed of 11 total members: 1 Project manager, 1 Deputy Project Manager of Resources, 1 Lead Systems Engineer, 1 Chief Scientist, 4 Lead Engineers, and 3 Lead Scientists. It was determined that there must be four lead engineers in order to allow for maximum support in the building of the Team's rover; thus each subsystem (i.e. Thermal, Mechanical, Computer Hardware, and Electrical) shall have a manager to oversee all technicians and engineers. The science subteam requires three lead scientists as managers to assist in directing technicians through scientific instrument testing and ensuring all science goals and objectives are met. Figure 9 displays the full organizational chart of the Manager team.

Lastly, Figure 9 displays the entire organizational chart for all members of Team 27. Note that certain positions are only needed for select phases, not all.

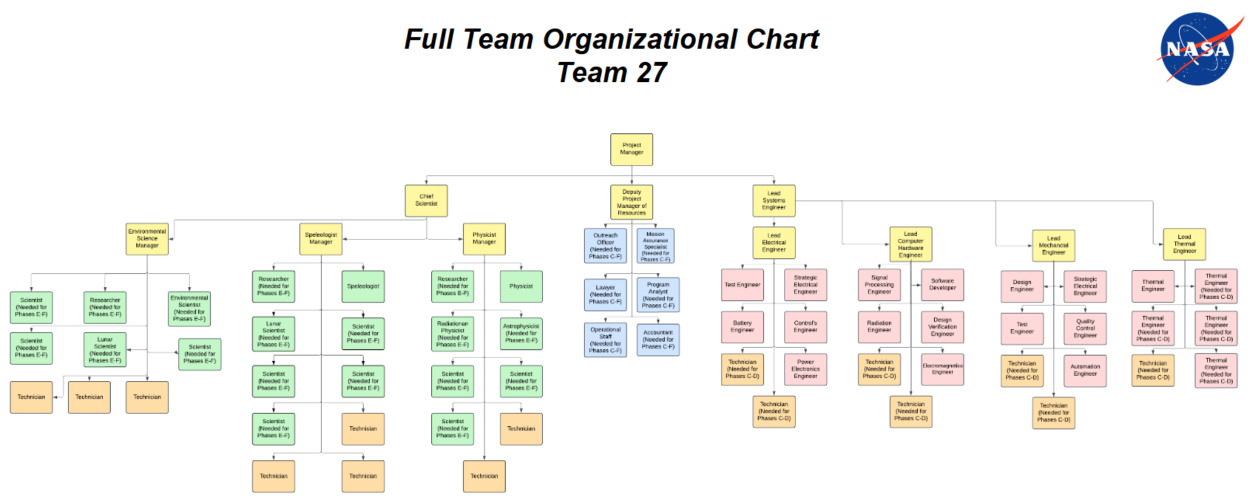


Figure 9: The full organizational chart of Team 27.

1.7 Manufacturing and Procurement Plans

The following section details the manufacturing and procurement plans for all subsystems.

Mechanical Subsystem

The Mechanical Subsystem procurement plans were not created.

Electrical Subsystem

The electrical subsystem is the spacecraft's vitality system, supplying, generating, and distributing power throughout the spacecraft's interface and subsystems. The components identified are essential and required for the spacecraft's interaction with the corresponding subsystems, as well as in accordance with mass, size, cost, and power efficiency, with a preference for U.S. based companies.

The power storage system's primary supplier is Blue Canyon Technologies, with their 6.8 Ah Flight Proven Spacecraft Battery Pack, which has configuration of a 2P8S of Li-Ion cells, 198 Wh capacity, operating voltage range of 24V - 33.6V, and current capacity of 6.8 Ah.[10] Two battery packs connected in parallel (2P) will be utilized to ensure a sufficient amount of power available for the subsystem. The reasoning for the selection of Blue Canyon Technologies product, over other competitive vendors, is due to their availability of the product; it has been developed, research, and tested within a similar space environment, and in addition, Blue Canyon Technologies's devices and components have utilized and selected in the past, such NASA's recent upcoming PolSIR mission, with Blue Canyon Technologies, being selected built two 12U CubeSat buses for the mission, as well as providing mission operations services. Furthermore, because Blue Canyon Technologies, is a U.S. based company, acquiring security clearances for secret and top-secret level missions is more acquirable, compared to other foreign-based companies; recently the U.S. Air Force had contracted Blue Canyon Technologies to develop and deliver a spacecraft for deep space satellite maneuverability studies.[11]

The secondary supplier for the power storage system is Pumpkin Space; although the company does not have any power storage product with the same specifications to the Blue Canyon Technologies battery pack, their products do facilitate an understanding of designing and power storage units, albeit catering towards more smaller-based spacecraft.[12] In regards to this, Pumpkin Space will be contracted to make a similar battery pack to Blue Canyon Technologies' 6.8 Ah Flight Proven Spacecraft Battery Pack, for the spacecraft. In addition to having a background in power-storage development, the company has created and interacted with NASA projects before, such as NASA's ALBus CubeSat system, utilizing Pumpkin Space to design and build the ALBus solar panels, in addition to their utilization of Pumpkin CubeSat Kit 3U structure.[13] Additionally, similar

10. SATNow, "6.8 Ah Flight Proven Spacecraft Battery," 2024, accessed November 16, 2024, https://www.satnow.com/products/batteries/blue-canyon-technologies/98-1186-2p8s.

11. Blue Canyon Technologies, "RTX's Blue Canyon Technologies Selected by NASA to Provide Multiple Spacecraft Uses for PolSIR Mission," 2024, accessed November 16, 2024, https://www.pumpkinspace.com/news/pumpkins-pmdsas-solar-panels-enable-high-power-nasa-cubesat.

12. Pumpkin Space, "Power and Energy," 2024, accessed November 16, 2024, https://www.pumpkinspace.com/store/c28/Power_%26_Energy.html.

13. Pumpkin Space, "Pumpkin's PMDSAS Solar Panels Enable High-Power NASA CubeSat," 2019, accessed November 16, 2024, https://www.pumpkinspace.com/news/pumpkins-pmdsas-solar-panels-

to Blue Canyon Technologies, Pumpkin Space is also a U.S. based company, with prior space development with the U.S. government, such as their contract with the U.S. Space Force's EWS Rapid Revist optical Cloud Imager (ROCCI) mission, with the spacecraft utilizing Pumpkin Space's 12U SUPERNOVA bus.[14]

The power generation system's primary supplier is AZUR SPACE, with their Triple Junction Solar Cell 3G30C-Advanced (8 x 4 cm) being utilized, with 348 cells being deployed in order to provide a surface area of 1.05m^2.[15] The reasoning for selecting AZUR SPACE over other competitive vendors, is due to their availability of the product, already being developed, research, and tested, as well as their previous mission interactions with NASA, despite being a foreign-based company based in Heilbronn Germany; AZUR SPACE's triple-junction cells (3G-LILT) were embed in the NASA Europa Clipper spacecraft's solar arrays, with the Europa Clipper mission being launched in October 14, 2024, becoming one the largest, and first mission designed to a conduct a detailed study of Jupiter's moon Europa.[16][17]

The secondary supplier is Spectrolab, a Boeing Company subsidiary; although the company does not have any products with the same specifications as AZUR SPACE's triple-junction solar cells, their background within solar cell developments and panels, are well qualified, with their previous products being developed and tested for NASA's missions, such as the Opportunity Rover on Mars, which utilized a triple-junction cell developed by Spectrolab, over exceeding the predicated mission's lifespan of 90-days, extending up to 14 years.[18][19] Additionally, unlike AZUR SPACE, Spectrolab is a U.S. based company, with their headquarters located in Sylmar, California, allowing for easier access and approval for top-secret and secret level clearances missions.[20]

The power distribution system's primary supplier is Bradford Space, with their Supernova PDCU, a 28V, 300-1500W solar array, battery and load management system. The reasoning for selecting Bradford Space's product, over other competitive vendors, is due to its market availability, previous development and testing, and research collected from the product.[21][22] Although Bradford Space is based in Heerle, Netherlands, and Belval,

enable-high-power-nasa-cubesat.

14. Pumpkin Space, "Pumpkin 12U Bus+Payload Complete Environmental Testing," 2022, accessed November 16, 2024, https://www.pumpkinspace.com/news/pumpkin-12u-buspayload-complete-environmental-testing.

15. SATSearch, "Triple Junction Solar Cell 3G30C-Advanced (8 x 4 Cm)," 2024, accessed November 16, 2024, https://satsearch.co/products/azur-space-triple-junction-solar-cell-3g30c-advanced-8-by-4-cm.

16. Azur Space Company, "50 Years' Experience in High-Efficiency Solar Cell Technology," 2024, accessed November 16, 2024, https://www.azurspace.com/index.php/en/company.

17. Semiconductor Today, "5N Plus' AZUR Solar Cells Head to Jupiter Aboard NASA's Europa Clipper," 2024, accessed November 16, 2024, https://www.semiconductor-today.com/news_items/2024/oct/5nplus-azur2-161024.shtml.

18. Spectrolab, "Providing Power to the Mars Rover," 2024, accessed November 16, 2024, https://www.spectrolab.com/prd/rover.pdf.

19. Elizabeth Howell, "Opportunity: Longest-Running Mars Rover," 2022, accessed November 16, 2024, https://www.space.com/18289-opportunity-rover.html.

20. Spectrolab, "About Spectrolab," 2024, accessed November 16, 2024, https://www.spectrolab.com/company.html.

21. Bradford Space, "Supernova Power System," 2024, accessed November 16, 2024, https://www.bradford-space.com/products/avionics-pcdu.

22. SATSearch, "Supernova PDCU," 2024, accessed November 16, 2024, https://satsearch.co/products/

Luxembourg, it is a U.S. owned company.[23] Additionally, Bradford Space products have been selected in and utilized in the past, with a more recent selection of the Supernova PDCU, to be utilized in the LuSEE-Night lunar mission by the Brookhaven National Laboratory.[24]

The secondary supplier for the power storage system is Ibeos; although many of their applications of power distribution systems are catered towards smaller spacecraft, their speciality within the electrical distribution system, makes them a great candidate for potentially making a PDCU, similar to Bradford Space's if needed.[25] Additionally, Ibeos was recently recognized in NASA's Annual Smallsat State of the Art Report in 2021.[26] Furthermore, Ibeos is a U.S. based company, being headquartered in Virginia, allowing for easier access and approval for top-secret and secret level clearance missions.[27]

In terms of development time, and output, many of the components are commercially off-the-shelf products (COTS), and readily available to be developed; the integration of the components into the system estimated time is between 6-9 months, to account for interfacing, testing, and communicating between several vendors and subsystems. This development period may increase should one of the COTS products be unavailable, relying on the secondary supplier to develop a similar product on short notice; this may delay development by 2-3 months depending on how late early the unavailability recognition is spotted. This estimation in conjunction with "Phase C" which is the final robotics system design and fabrication phase and the eventual implementation of all interfacing subsystems in "Phase D," which is the assembling of the components.[28]

Thermal Subsystem

The Thermal Subsystem procurement plans were not created.

CDH Subsystem

It is the CDH subsystem that forms the backbone of the mission and is responsible for the proper command execution, data processing and distribution, power regulation, and spacecraft-to-Earth communications. An effective procurement strategy has been developed to ensure reliability and effectiveness in the CDH subsystem by selecting first- and second-source vendors with experience, dependability, and compatibility with mission requirements for every critical component in adherence with NASA's procurement guidelines 1370.1 (NPD 1370.1).[29]

Boeing Company has been selected as the prime supplier for the RAD750 Processor,

bradford-supernova-pcdu.

23. Bradford Space, "Bradford Space: About Us," 2024, accessed November 16, 2024, https://www.bradford-space.com/about.

24. Bradford Space, "Bradford Space's Post," 2024, accessed November 16, 2024, https://www.linkedin.com/company/bradford-space.

25. Ibeos, "Ibeos: Standard Products," 2024, accessed November 16, 2024, https://www.ibeos.com/standard-products.

26. Ibeos, "Ibeos Featured in NASA'S Annual Smallsat State of the Art Report," 2024, accessed November 16, 2024, https://www.ibeos.com/post/ibeos-featured-in-nasa-s-annual-smallsat-state-of-the-art-report.

27. Ibeos, "About Ibeos," 2024, accessed November 16, 2024, https://www.ibeos.com/about.

28. NASA, "NASA Systems Engineering Handbook," 2024, accessed November 16, 2024, https://soma.larc.nasa.gov/mmx/pdf_files/NASA-SP-2007-6105-Rev-1-Final-31Dec2007.pdf.

29. P. A. Trisha Jansma, "A Field Guide to the NASA Procedural Requirements for Systems Engineering," in *2008 IEEE Aerospace Conference* (2008), 1–16, https://doi.org/10.1109/AERO.2008.4526678.

which is the brain of the CDH, because of its experience and proven reliability in space missions, including the Mars Curiosity rover.[30] Its backup supplier is Lockheed Martin Corporation, with robust aerospace-grade processors with an excellent record of performance in similar applications. The field-programmable gate array is sourced principally from Raytheon Technologies Corporation, known for its advanced FPGA solutions designed for space applications. The backup is Northrop Grumman Corporation, which offers high-performance FPGAs whose dependability in space missions has been demonstrated over time.

Space Exploration Technologies Corp. (SpaceX) fabricates the Radiation-Hardened SSDs, crucial in this mission for data storage, applying expertise in the most state-of-the-art, robust SSDs that can survive radiation effects in space. The second source is Maxar Technologies Inc., with a history of radiation-hardened storage products designed for reliability. Further, the first source for the non-volatile memory is General Dynamics Corporation, which supplies solutions that would maintain the integrity of data during power disruption, while the second source is Honeywell Aerospace, which supplies solid products in memory tested on several missions in space.

The main unit PMU, which is vital for power regulation in the CDH subsystem, comes from Analog Devices, Inc., known for their high-efficiency DC-DC converters and power regulation designed for space applications. Texas Instruments acts as the redundant source that delivers dependable power management solutions with a focus on efficiency and reliability in space environments. The major communication interfaces, such as I2C, UART, and SpaceWire, are supplied primarily by L3Harris Technologies for faultless data transfer to and from the subsystems and Earth. The backup is Teledyne Technologies Incorporated, which also offers great communication interface solutions, showing its support on multiple critical space missions.

Where applicable, components such as the SpaceWire Data Bus are procured from SpaceX as Commercial Off-The-Shelf to take advantage of existing technologies and decrease development time and costs while ensuring reliability.[31] Conforming to NASA's policy not to manufacture any items in-house for which there are commercial sources, all critical components with available commercial sources are acquired from qualified contractors. Proprietary or highly specialized items that form part of the uniqueness of the mission are designed, built, and tested at NASA facilities to protect control of key technologies. Timescales for lead suppliers are estimated in the region of six to twelve months, depending on how simple or complex the component may be, combined with supplier capacity. Any backup suppliers require three to six months to create due to qualification and integration. These lead times are carefully coordinated with the overall mission schedule so that primary suppliers can deliver on time. If a primary supplier is unavailable, ex-

30. Aksel Rasmussen et al., "Supplier selection for aerospace and defense industry through MCDM methods," *Cleaner Engineering and Technology* 12 (2023): 100590, ISSN: 2666-7908, https://doi.org/https://doi.org/10.1016/j.clet.2022.100590, https://www.sciencedirect.com/science/article/pii/S2666790822001951.

31. David Anhalt, Daniel Brophy, and James A. Faist, "Leveraging Emerging Commercial Innovations into NASA's Next Generation Space Communication and Navigation Architecture," in *34th AIAA International Communications Satellite Systems Conference* (American Institute of Aeronautics / Astronautics, 2016), https://doi.org/10.2514/6.2016-5705, eprint: https://arc.aiaa.org/doi/pdf/10.2514/6.2016-5705, https://arc.aiaa.org/doi/abs/10.2514/6.2016-5705.

tended lead times of back-up suppliers are factored into the project's contingency plans which allow for adjustments in the schedule without affecting the mission timeline.

This strategic procurement plan provides the strength of leading aerospace contractors, as well as reliable COTS suppliers, in guaranteeing the robustness of the CDH subsystem and, by extension, mission success. Establishing backup suppliers and matching their lead times to the mission schedule will mitigate effectively the risk of supplier unavailability. This approach makes for mission continuity and sustains the integrity and functionality of the CDH subsystem throughout the mission duration.

The procurement strategy for subsystems of CDH is, therefore, directed to the acquisition of quality components from experienced and reliable suppliers who can ensure function and sustainability for each subsystem under extreme space conditions. The proposed strategy will be in line with NASA procurement guidelines and will incorporate strong contingency plans to guard against disruptions that could affect not just the near-term mission but the overall long-term sustainability of the mission.

Payload Subsystem

Magnetometers

The primary supplier is Applied Physics Systems, offering their 3-Axis Fluxgate Magnetometer Model AP235. This magnetometer was chosen for its fast sampling rate of 30 samples per second, which is essential for detecting and measuring the magnetic fields in the lunar swirls with high precision. Applied Physics Systems is well-established in the field of scientific instrumentation, making them a dependable choice for the mission's needs.

As a backup supplier, Metrolab was selected, which provides a similar fluxgate magnetometer. Metrolab is a respected name in geomagnetic field mapping and is known for producing reliable instruments that are widely used in both scientific and industrial applications. Their products offer a suitable alternative if the primary supplier is unavailable, maintaining our mission's integrity.

For the second primary magnetometer, the Bartington 3-Axis Fluxgate Magnetometer from GMW Associates was chosen. This model is especially suited to extreme temperature conditions, with an operational range of -55°C to 65°C, making it ideal for the harsh environment of the Moon. Bartington Instruments has significant expertise in space and aerospace applications, ensuring this magnetometer will function effectively in the lunar environment.

For the secondary magnetometer, PNI's RM3100 Magneto-Inductive Magnetometer was selected. Known for its precision and reliability, this sensor offers 23 times better resolution and 33 times less noise than traditional Hall-effect sensors, providing highly accurate magnetic field data. With a wide detection range and exceptional stability under various environmental stresses, including thermal shock, mechanical shock, and radiation the RM3100 is well-suited for the harsh conditions of space exploration. Its small size, low power consumption, and high dynamic range make it an ideal choice for demanding aerospace applications.

ARES (Active Radiation Environment Sensor)

Fayetteville Sridmtate University (FSU) has been designated as the primary supplier for the active radiation environment sensor for this lunar mission. With an extensive background in materials research and radiation detection, FSU is well-equipped to develop a sensor capable of accurately measuring and monitoring radiation levels on the Moon. This institution's facilities include a materials research facility and a prototyping lab that support advanced sensor development for extreme environments such as the lunar surface. Their experience with high-efficiency radiation detectors made for use in challenging conditions directly aligns with the mission's objectives. FSU's experience with federal projects further reinforces its capacity to deliver a high-performance, reliable sensor.

As a backup, Syrnatec Inc. offers a strong alternative, specializing in radiation-hardened microelectronics and advanced telemetry sensors. Syrnatec's expertise in aerospace technology ensures their microelectronic sensors and interfaces serve as a reliable backup, supporting continuous progress on the mission if FSU's sensor faces delays. Their experience in microelectronics, which is suited for radiation-heavy environments, makes Syrnatec a solid secondary choice

Silicon Photomultiplier

The primary supplier for the mission's Silicon Photomultiplier (SiPM) is Syrnatec Inc., a company specializing in the design of radiation-hardened microelectronics. Syrnatec's extensive experience in producing high-performance, radiation-tolerant components is critical for space applications where devices must endure high radiation levels without degradation. Their expertise in radiation-hardened microprocessors and custom design services makes them well-suited to develop a SiPM that can reliably perform under the harsh conditions of the Moon's surface.

In addition to Syrnatec, Golden Altos Corporation has been selected as the secondary supplier. Golden Altos brings substantial experience in space-level assembly, having worked extensively with military and aerospace components since 2006. Golden Altos also has an in-house environmental testing laboratory, allowing for evaluation of the SiPM under extreme simulated space conditions, including high radiation exposure and temperature fluctuations. Moreover, their expertise in hermetic packaging ensures that the SiPM will be securely sealed to protect it from environmental factors such as vacuum and radiation. Their ability to produce custom microcircuits further enhances their capability to fulfill the SiPM design.

MID-360 LiDAR

The primary supplier for the 360-degree LiDAR scanner is Livox, specifically their Mid-360 model. The Mid-360 stands out due to its unique rotating mirror hybrid-solid technology, which enables it to provide a 360° horizontal FOV and 59° vertical FOV. This LiDAR system is designed for omnidirectional scanning, which is ideal for mapping lunar pit walls. This system's advanced capabilities and fast availability through online distribution make it an ideal choice as the primary supplier for the mission.

For the secondary supplier, Lightware LiDAR offers the SF40-C, a 360-degree LiDAR scanner with a range of 0.2 to 100 meters and the ability to provide 20,000 readings per second. This high-performance sensor is well-suited for the requirements of the lunar mission. The SF40-C's rapid scanning capabilities allow for precise mapping of the lunar pit walls. Lightware also has this model available through online distribution allowing for a quick replacement sensor if deemed necessary.

Optical Particulate Monitor

The primary supplier for the optical particulate monitor is South Coast AQMD, featuring their Lunar Outpost Canary-S model (LOCS). The LOCS excels in real-time measurement of particulate matter (PM1.0, PM2.5, and PM10), utilizing dual Plantower PMS5003 laser particle counters for high sensitivity across a range of particle sizes. This versatile sensor also measures temperature, humidity, and pressure while allowing the integration of up to three additional gas sensors (e.g., ozone, CO, SO2), making it ideal for comprehensive environmental monitoring on a lunar rover. This sensor has proven its reliability through extensive field testing, including its use in NASA's MAIA mission. Its performance in such demanding conditions highlights its durability, making it a strong fit for the challenging environment of lunar exploration.

For the secondary supplier, AirPhoton provides an alternative with their particulate monitoring systems. AirPhoton's technology is already proven in space-grade applications, including the NASA MAIA mission also and the SPARTAN network. Their systems, which feature both optical and filter-based measurements, are designed for harsh environments and can be customized for specific mission needs. This capability allows precise adaptation for use on a lunar rover, ensuring accurate detection and analysis of airborne particles. Their experience and proven track record in demanding conditions make them a reliable secondary choice for optical particulate monitoring.

Humidity Sensor

The HMP60 Humidity Sensor by Dataq Instruments is a primary choice for measuring relative humidity in extreme environments, offering a range of 0-100% relative humidity and a temperature tolerance from -40°C to 60°C. Its robust design ensures reliability and accuracy, making it well-suited for the harsh conditions of lunar exploration.

For a secondary option, the Farmer Boy DOL Sensors Humidity Sensor also provides a 0-100% relative humidity measurement range with a similar temperature range of -40°C to 60°C, offering a reliable alternative continuing to satisfy mission requirements.

Pressure-Temperature Sensor

TAELCO's PTSW-EP Series Combined Pressure and Temperature Sensor is purpose-built for aerospace purposes providing a dual output for both pressure and temperature measurements. Its lightweight and small construction are ideal for weight and space-sensitive environments, which is essential for aerospace systems. Standard models are readily available, and custom requests are quickly addressed to ensure the sensor fits specific mission requirements.

L-com's PRT800-217-501 Pressure Sensor offers reliable pressure measurement with a wide operating temperature range from -20°C to +85°C. It is designed to withstand harsh environments and is suitable for aerospace applications that demand precision and durability. The sensor's ability to handle a great range of conditions makes it also an effective choice.

1.8 Risks and Safety

1.8.1 Risk Analysis

In order to identify the risks associated with this mission, the subsystem requirements and trade studies done for mechanical, power, CDH, thermal, and instrumentation were thoroughly looked over by utilizing the Risk-Informed Decision Making (RIDM) guidelines provided by NASA.[32] The identified risks were tracked in the risk summary table, with at least 2 risks for each subsystem, along with the likelihood of the risks occurring and the criticality of the consequences should they occur. The likelihood and consequences of the risks were inserted into the risk matrix, which is color-coded with the critical nature of each risk labeled. This section will analyze the risks associated with the mission and propose plans on how these risks will be approached.

For risk ID 1, given that the quality of the materials used is crucial in how long the system can function for, there is a possibility of improper materials being used which can result in damage to the system, thus the system could deteriorate and fail over time. For risk ID 2, since the space and lunar environment exposes the mechanical system to extreme temperatures, solar radiation, micrometeorites, and debris, there is a possibility that the mechanical system cannot endure these interactions, resulting in either reduced or no functionality and ultimately leading to mission failure. These risks can be mitigated through being familiar with the properties of the materials being used on the mission and how they interact with the environment and physical hazards, as well as testing in order to predict the limits of the system.[33]

For risk ID 3, given that 200Wh of power is needed to maintain base-line operations, there is a possibility that this amount of power can fluctuate and not be met, resulting in the battery power being discharged and depleting overall power capacity.

For risk ID 4, since the lunar surface has regolith and debris present, there is a possibility of the regolith and debris obstructing the system, resulting in the vehicle either undergenerating or not generating the power needed due to the decreased collection of solar energy. In order to mitigate this risk, the vehicle will engage in active movement so that the vibrations can remove the debris and prevent the obstruction of the solar array system and allow sufficient power generation that is required for the vehicle to operate. In addition to active movement, the battery pack will have a surrounding protective cage that will protect it from mild trauma present in the lunar environment.

For risk ID 5, given that there are sharp objects present on the lunar surface, there is a possibility of a sharp object penetrating the electrical system, resulting in a short or open in the circuit which can ultimately terminate operations prematurely.

For risk ID 6, since the spacecraft will have multiple components that must work together and depend on each other reliably, there is a possibility that the communication interface will malfunction, resulting in communication failure and data loss through failure to reliably transfer data between different subsystems. For risk ID 7, given that the CPU

32. NASA, "NASA Risk-Informed Decision Making Handbook," 2010, accessed November 16, 2024, https://ntrs.nasa.gov/api/citations/20100021361/downloads/20100021361.pdf.

33. Theodore Swanson, "Wear and Tear - Mechanical," 2008, accessed November 16, 2024, https://ntrs.nasa.gov/citations/20090005236.

must be able to handle complex commands and allow collaboration with all systems of the vehicle, there is a possibility that the CPU fails to execute these commands, resulting in the subsystems not being synchronized and the vehicle not being able to perform the required operations for the mission. In order to mitigate these risks, software error-detection, correction algorithms, redundancy protocols, and continuous diagnostic monitoring will be implemented to ensure that networks and data remain available in case there are malfunctions.

For risk ID 8, since space has high-radiation activity, there is a possibility of the SRAM failing to endure this radiation, resulting in damage to the equipment and the loss of ability to store and handle data collected during the mission. In order to mitigate this risk, radiation-hardened SSDs and non-volatile memory will be used to give better shielding from radiation for the SRAM, memory modules will be duplicated with automatic switching, and regular evaluation of memory integrity will be implemented.

For risk ID 9, given that the lunar environment presents extreme temperature changes to the vehicle, there is a possibility of a passive TCS causing consistent heating which can lead to the components being less effective due to operating outside of the ideal temperature range of 253.15K to 328.15K. For risk ID 10, since the chassis is exposed to the extreme temperatures on the Moon, there is a possibility of the TCS failing to minimize the thermal fatigue of the chassis that is caused by significant temperature changes and high temperatures, resulting in cracks in the material and shortening the vehicle's lifespan. In order to mitigate these risks, a cryo-cooler and insulating MIL will be installed to ensure stable temperatures, as well as intentional movement of the vehicle towards or away from certain temperatures depending on if the temperatures are over- or under-exceeding the ideal temperature range.

For risk ID 11, given that the lunar environment has presence of high-radiation, it is possible for the instruments' operations to become compromised, resulting in the instruments becoming damaged or less effective at their intended purpose.

For risk ID 12, since the lunar surface contains regolith and debris, there is a possibility that the instruments can become physically damaged, resulting in issues with completing their assigned tasks and communication with other subsystems.

Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Mechanical	3	4	→	M	Quality of the materials used is crucial in how long the system can function for, there is a possibility of improper materials being used which can result in damage to the system, thus the system could deteriorate and fail over time	Active
2	Mechanical	4	5	→	M	The space and lunar environment exposes the mechanical system to extreme temperatures, solar radiation, micrometeorites, and debris, there is a possibility that the mechanical system cannot endure these interactions, resulting in either reduced or no functionality and ultimately leading to mission failure.	Active
3	Power	2	5	↓	W	200Wh of power is needed to maintain base-line operations, there is a possibility that this amount of power can fluctuate and not be met, resulting in the battery power being discharged and depleting overall power capacity.	Active
4	Power	3	3	→	M	The lunar surface has regolith and debris present, there is a possibility of the regolith and debris obstructing the system, resulting in the vehicle either undergenerating or not generating the power needed due to the decreased collection of solar energy.	Active
5	Power	2	4	↓	W	There are sharp objects present on the lunar surface, there is a possibility of a sharp object penetrating the electrical system, resulting in a short or open in the circuit which can ultimately terminate operations prematurely.	Active
6	CDH	2	4	→	M	The spacecraft will have multiple components that must work together and depend on each other reliably, there is a possibility that the communication interface will malfunction, resulting in communication failure and data loss through failure to reliably transfer data between different subsystems.	Active
7	CDH	2	5	↓	M	The CPU must be able to handle complex commands and allow collaboration with all systems of the vehicle, there is a possibility that the CPU fails to execute these commands, resulting in the subsystems not being synchronized and the vehicle not being able to perform the required operations for the mission.	Active
8	CDH	1	3	↓	M	Since space has high-radiation activity, there is a possibility of the SRAM failing to endure this radiation, resulting in damage to the equipment and the loss of ability to store and handle data collected during the mission.	Active
9	Thermal	2	3	→	M	Given that the lunar environment presents extreme temperature changes to the vehicle, there is a possibility of a passive TCS causing consistent heating which can lead to the components being less effective due to operating outside of the ideal temperature range of 253.15K to 328.15K.	Active
10	Thermal	2	4	→	M	Since the chassis is exposed to the extreme temperatures on the Moon, there is a possibility of the TCS failing to minimize the thermal fatigue of the chassis that is caused by significant temperature changes and high temperatures, resulting in cracks in the material and shortening the vehicle's lifespan.	Active
11	Instrumentation	1	2	↓	W	Given that the lunar environment has presence of high-radiation, it is possible for the instruments' operations to become compromised, resulting in the instruments becoming damaged or less effective at their intended purpose.	Active
12	Instrumentation	3	4	↓	W	Since the lunar surface contains regolith and debris, there is a possibility that the instruments can become physically damaged, resulting in issues with completing their assigned tasks and communication with other subsystems.	Active

L = Likelyhood (1-5)
1 = Not likely
5 = Extremely likely
C = Consequence (1-5)
1 = Low consequence
5 = High consequence

LxC Trend
↓ - Decreasing (improving)
↑ - Increasing (worsening)
→ - Unchanged
NEW - Added this month

Approach
A - Accept
M- Mitigate
W - Watch
R - Research

Criticality
HIGH
MED
LOW

Table 3: All risks identified for the spacecraft of the mission, including the corresponding risk matrix.

1.8.2 Failure Mode and Effect Analysis (FMEA)

The following section details the Failure Mode and Effect Analysis (FMEA) for all subsystems.

Mechanical Subsystem

The Mechanical Subsystem FMEA plans were not created.

Electrical Subsystem

In the Electrical Subsystem, three failure modes have been identified within each subassembly function. The severity values are high due to the electrical subsystem being an essential aspect of the spacecraft's vitality, and life-support; should it fail, all other subsystems will subsequently fail as well. Additionally, many of the failure modes are easily monitorable and detectable, hence the low detectability value.

The biggest concern across all subassembly functions, is the failure mode caused by exceeding or under exceeding operating temperatures for each subassembly; although there is sufficient amounts of insulation provided by the MLI, and cooling provided the by the Cryo-cooler, the biggest threat to the electrical subsystem, is caused by the freezing temperatures found within the lunar night, with temperatures reaching up to 140.15K, however, this can be negated with the lunar pit's insulating properties, with an average of 290.15K throughout the lunar night.[34] However, betting on a singular insulating property of the lunar pit is not viable, and as such precautionary measures must be considered such as improved thermal insulation during the developmental phase.

Another critical concern found across all subassembly functions, is the failure mode caused by the presence of lunar debris; lunar debris is very fine, and sharp, and may cause obstruction of essential components from interfacing between each others, such as a solar cell being obstructed by an accumulation of lunar debris, preventing solar power generation being sent to the PDCU. In addition to reduced power output, power connectors may be subjected to internal clogging and scratching, and material degradation. One instance of reduced output due to regolith, albeit in a different environment, is the Sojourner rover on Mars reduced PV cell power output; the accumulation of dust deposition caused a cell efficiency of 0.28%/day.[35]

Additionally, although rare, sharp debris may be able to penetrate and cut an electrical circuit, causing an open within the system. Depending on where the open is on the circuit, the consequence may stem from a catastrophic failure, or loss of efficiency or subsystem utilization. An open may also be caused by excessive heat generation, causing the circuit to "short" and burn an open. Although this is negated by a fuse-system and other protective measures, it is still possible, should the preventative protocols fail.

On another note, blunt physical trauma caused by a large fall, or collision may also cause significant damage to the electrical system, rendering key components such as the battery packs, and solar cell array being useless or under-performing. To negate this, a "drop-test" during the testing phase will be implemented to determine safe falling thresholds for the spacecraft.

In addition to the specific failure modes; the electrical system as a whole must be able to generate 200Wh of power; this is to ensure spacecraft instrument functionality and essential resources such as communication, navigation, and heating. (Table 15 in the Appendix)

34. Tyler Horvath, Paul O. Hayne, and David A. Paige, "Thermal and Illumination Environments of Lunar Pits and Caves: Models and Observations From the Diviner Lunar Radiometer Experiment," e2022GL099710 2022GL099710, *Geophysical Research Letters* 49, no. 14 (2022): e2022GL099710, https://doi.org/https://doi.org/10.1029/2022GL099710, eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2022GL099710, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2022GL099710.

35. Kristen John and Amy Fritz, "Advancements in Lunar Dust Mitigation and Leveraging the Contamination Control Community," 2024, accessed November 16, 2024, https://ccmpp.gsfc.nasa.gov/2023_presentations/13-John.pdf.

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Power Generation of Solar Array System	Obstruction blocking solar cell surface area, preventing it collecting solar energy and converting it to usable power.	The solar array system will output/generate less power for the spacecraft.	4	Lunar regolith or similar debris may obsecure or block the solar cell from obtain direct solar energy.	6	Active movement of the vehicle ensures debris is removed from vibration.	3	72	Solar Array "clean-up" procedures such as spacecraft movement to remove debris from unstable movement, potential removing debris and obstruction from the solar-array system.
	Reduction of performance of solar cell from extending past safe temperature threshold.	Insufficient amount of power generation will cause the spacecraft to shut-down or operate at lower power levels; power management mode, result in limited instrument usage.	8	Excessive overheating of too much insulation and direct sunlight, or insuffcient amount of insulation and heat to ensure solar cell operating temperature is not under-exceed.	2	Active thermal mitigation such as the cryo-cooler and insualting MIL will ensure temperature is stabilized.	3	48	Depending on the temperature, whether it is exceeding or under-exceeding, tactical movement of the spacecraft towards or away more insulating environment such as lunar pits, aid in temperature regulation.
	Solar cell abnormal failure such as short circuit, electrical open, etc.	Open in the solar array system circuit can cause reduction of power generation or complete failure depending where the open or short is.	8	Sharp debris, or regolith may cause opens in the electrical circuit system.	2	Active management of PDCU and alternative circuit paths will ensure the open or short is manageable or contained.	1	16	Opens in the circuit system, will require specific commanded shut-downs or reduction in other instrument performance in order to ensure the integrity of system.
Power Storage of Battery Packs	Reduction of performance or integrity of battery packs from extending past safe temperature thresholds.	Battery performance is reduced, potentially reducing battery voltage, amperage, and power capacity, and output.	8	Excessive overheating of too much insulation or lack of insulation can cause the batteries to fail or perform at reduced operating level due to battery material/intergrity being compromised.	2	Active thermal mitigation such as the cryo-cooler and insualting MIL will ensure temperature is stabilized.	2	32	Depending on the temperature, whether it is exceeding or under-exceeding, tactical movement of the spacecraft towards or away more insulating environment such as lunar pits, aid in temperature regulation. Additionally, because it is more insulated, being the battery pack; it can be more regulated.
	Physical damage of battery packs from physical trauma, puncture, and derivatives of similar nature.	Complete battery unit failure, and significant reduction is power performance and integrity.	9	Physical trauma, such as abrupt drop, sharp physical puncture, and direct collision with terrain, can cause the battery to become physically damaged; depending the level of trauma, the battery may perform at a reduced operating capacity, or in some cases, rendered inoperable.	2	The structural cage of the battery pack wills protect the batteries from moderate trauma.	3	54	The action is dependent on level of damage from physical trauma; if the damage is minimal, mission operations can continue at reduced operational capacity. If the damage is severe, the mission may need to prepare for disposal and recovery.

Table 4: A portion of the Electrical Subsystem FMEA Chart. Please see the appendix for the rest.

Thermal Subsystem

The Thermal Subsystem FMEA plans were not created.

CDH Subsystem

In the CDH subsystem, two identified failure modes are the inability of the CPU to execute commands and inability of the SRAM to support radiation. Any of these failure modes presents high risks which may affect the mission's success. A comprehensive mitigation strategy has to be in place to ensure the reliability and functionality of a CDH subsystem.[36]

First critical failure mode is at the CPU-in this case, a RAD750 processor-which can fail due to hardware defects, software bugs, or radiation-induced errors.[37] Failure of the CPU to execute commands will have the immediate effect of being unable to control commands, which in turn means that the spacecraft cannot carry out key operations of collecting scientific data, subsystem maintenance, and communication with Earth Mission Control. This is a failure that would amount to the total loss of operational capability and would put mission objectives in jeopardy, leading to losses of irreplaceable scientific data. The reason being that the CDH subsystem is implemented with a redundant RAD750 processor, which in case of the failure of the primary CPU, is turned on automatically for continuity of operations. In addition, special software error-detection and correction algorithms help to timely identify and correct small CPU faults before they turn into catastrophic failures.[38] All that is crowned with continuous diagnostic tool monitoring with a view to further enhance the capability for taking advance measures in view of possible CPU problems and by this way

36. C. Kara-Zaitri et al., "An improved FMEA methodology," in *Annual Reliability and Maintainability Symposium. 1991 Proceedings* (1991), 248–252, https://doi.org/10.1109/ARMS.1991.154443.

37. Richard W. Berger et al, "The RAD750TM - A Radiation Hardened PowerPCTM Processor for High Performance Spaceborne Applications," 2001, accessed November 16, 2024, https://dacemirror.sci-hub.se/proceedings-article/f7d646ee0f6ca32a9392f86fc000ddf2/the-rad750sup-tma-radiation-hardened-powerpcsup-tm-processor-for.pdf.

38. Seyed Ghassem Miremadi et al., "Two software techniques for on-line error detection," *[1992] Digest of Papers. FTCS-22: The Twenty-Second International Symposium on Fault-Tolerant Computing*, 1992, 328–335, https://api.semanticscholar.org/CorpusID:27589301.

maintain the integrity and functionality of the CDH subsystem.

The second critical failure mode involves the SRAM within the CDH subsystem that could degrade or get corrupted due to long-term exposure to space radiation. This may further cause data loss or corruption due to such degradation and hence compromise the integrity of the stored mission data, including scientific measurements and telemetry logs. Data corruption can result in incorrect scientific conclusions, degraded decision-making potential, and overall system reliability, therefore affecting the mission objectives. Due to the fact that SRAM is a radiation-sensitive component, the CDH subsystem uses radiation-hardened SSDs and non-volatile memory to avoid data corruption in high-radiation conditions.[39] Besides that, duplicate memory modules have been implemented through which automatic switching to back-up memory is possible in case of primary SRAM failure, and thus data loss can be avoided along with operational stability. Additional shielding of memory components against radiation exposure, together with error-correcting codes, provides mechanisms for real-time detection and correction of corrupted data and thus assurance of accuracy and dependability of mission data.

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
CDH Subsystem	1. CPU unable to execute commands	- Loss of spacecraft control	10	- Hardware defects	4	- Redundant RAD750 processor (automatic switchover)	2	80	- Maintain redundancy protocols
		- Inability to collect scientific data		- Software bugs		- Software error-detection and correction algorithms			- Regular software updates and testing
		- Mission objectives jeopardized		- Radiation-induced errors		- Continuous diagnostic monitoring			- Enhance radiation shielding
		- Communication failure with Earth Mission Control							
CDH Subsystem	2. SRAM failure due to radiation	- Data loss or corruption	9	- Long-term exposure to space radiation	5	- Use of radiation-hardened SSDs and non-volatile memory	3	135	- Implement more robust radiation shielding
		- Compromised mission data integrity				- Duplicate memory modules with automatic switching			- Upgrade to more radiation-resistant
		- Incorrect scientific conclusions				- Error-correcting codes and additional shielding			- Regular memory integrity checks
		- Degraded decision-making potential							

Table 5: The CDH Subsystem FMEA Chart.

Payload Subsystem

The severity ratings of the instruments' possible failure due to the inability to withstand the hazards of the lunar environment is given a high rating of 9-10 due to the high threat to human lives. Lack of research on the lunar pit's microclimate due to instrument failure can lead to the possibility of the lunar pit being a fatal environment for humans. Operational failures are given a relatively medium rating for severity, for the threat to human safety is less prominent. However, inaccurate or inadequate data can cause issues in terms of research objectives.

The Active Radiation Sensor is more likely to withstand the hazards of the lunar environment due to its use in previous lunar missions. Hence, the occurrence of its failure due to lunar environmental hazards is given a rating of 2. Similarly, the 3-Axis Fluxgate Magnetometer Model AP235 and the Bartington Fluxgate Magnetometer, 3-axis, Aerospace/Space are two instruments that have also been used in previous lunar missions and have greatly withstood the lunar environment. Thus, both of their ratings for the occurrence of their failure due to lunar environmental hazards are given a rating of

39. LW Townsend, "Overview of active methods for shielding spacecraft from energetic space radiation," 2001, accessed November 16, 2024, https://pubmed.ncbi.nlm.nih.gov/11770543/.

1. Furthermore, the Silicon Photomultiplier (SiPM) has been used in previous space missions. However, the environment in which they operated is not exactly equal to the lunar environment. Thus, the occurrence of its failure due to lunar environmental hazards is given a rating of 3.

The Model HMP60 Humidity Sensor + Model DI-808 has never been tested in a lunar environment. Due to the unfamiliarity of whether it could withstand lunar environmental hazards, the occurrence of its failure due to the hazards is given a medium rating of 5. Similarly, the MID-360 LiDAR has never been used on the moon. However, it has been tested in a relevant environment. Therefore, the occurrence of its failure due to lunar environmental hazards is given a rating of 4. On the other hand, the PT1000 Class F0.3 + Pressure-Temperature has never been tested on the moon, mainly being used in the environment of Earth's atmosphere. Thus, it is less likely to withstand the hazards of the lunar environment. The occurrence of its failure due to such hazards is given a high rating of 8.

The majority of the instruments' operational failures can easily be detected. Therefore, their detection ratings are relatively low, meaning they are most likely to be detected.

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Active Radiation Environment Sensor	Unable to withstand physical hazards from lunar environment	Cannot pursue part of the science objective about the determination of the lunar pit sustaining human life in terms of radiation	9	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	2	Protection for the instrument, instrument built to withstand physical hazards	1	18	Remove radiation as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to detect radiation levels between 0 W/m² and 1,370 W/m²	Incorrect or no data about radiation levels of lunar pit collected	7	Faulty operation	1	Multiple operational tests for instrument	2	14	Remove radiation as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to detect Alpha, Beta, and/or Gamma radiation	Inaccurate determination of lunar pit's radiation environment	9	Corrupted data, faulty operation	2	Multiple operational and data tests for instrument	5	90	Utilize the available type of radiation detected
3-Axis Fluxgate Magnetometer Model AP235	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of locating potential magnetic fields	6	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	1	Protection for the instrument, instrument built to withstand physical hazards	1	6	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to measure magnetic fields in the nanoTesla range of 0 nT to 23 nT	Unable to detect potential magnetic fields	4	Faulty operation	1	Multiple operational tests for instrument	2	8	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to operate with a low noise level range of -0.05 RMS nT/√Hz to 0.05 RMS nT/√Hz	Collected magnetic field data corrupted by instrument's noise	3	Faulty operation and/or build	1	Multiple operational tests, instrument built with care for noise	1	3	Determine if data can still be utilized or saved from corruption of noise
Bartington Fluxgate Magnetometer, 3-axis, Aerospace/Space	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of locating potential magnetic fields	6	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	1	Protection for the instrument, instrument built to withstand physical hazards	1	6	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to measure magnetic fields in the nanoTesla range of 0 nT to 23 nT	Unable to detect potential magnetic fields	4	Faulty operation	1	Multiple operational tests for instrument	2	8	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to operate with a low noise level range of -0.05 RMS nT/√Hz to 0.05 RMS nT/√Hz	Collected magnetic field data corrupted by instrument's noise	3	Faulty operation and/or build	2	Multiple operational tests, instrument built with care for noise	1	6	Determine if data can still be utilized or saved from corruption of noise
Model HMP60 Humidity Sensor + Model DI-808	Unable to withstand physical hazards from lunar environment	Cannot pursue part of the science objective about the determination of the lunar pit sustaining human life in terms of humidity	9	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	5	Protection for the instrument, instrument built to withstand physical hazards	1	45	Remove humidity as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to measure temperature range of 16 °C to 18 °C	Incorrect or no data about humidity levels of lunar pit collected	5	Faulty operation	2	Multiple operational tests for instrument	2	20	Rely on PT1000 Class F0.3 + Pressure-Temperature for temperature readings

Table 6: A portion of the Payload Subsystem FMEA Chart. Please see the appendix for the rest.

1.8.3 Personnel Hazards

In determining the hazards that personnel may experience while working on the mission, research was conducted to determine the unique hazards in labs, offices, and manufacturing facilities. The hazards were determined based on the guidelines and protocols given by safety and hazard handbooks and provided by NASA and Occupational Safety and Health Administration (OSHA). The safety of personnel while working on this mission is of utmost importance and is what will be focused on in this section.

Common risks among all workspaces and facilities include fire and explosion hazards,[40] slips, trips, elevated platform falls, and musculoskeletal injuries from repetitive motion and heavy lifting. In order to mitigate these hazards personnel will be required to go through proper mandatory training on proper lifting techniques and stretching exercises, maintain cleanliness of the floors by keeping them dry and free of obstacles, and wear proper footwear so as to prevent slips and trips. The facility will provide guardrails and safety harnesses for elevated platforms, lifting aids for heavy objects, and anti-slip maps. Both the facility and personnel will be responsible for ensuring that flammable materials are properly stored in fire-resistant containers or cabinets, the facility will have fire extinguishers in multiple locations around the buildings, a working fire suppression system at all times, regular fire drills, and smoking only being allowed in designated smoking areas.

There is also the risk of psychological distress among personnel while working on the mission. Psychological distress can not only cause harm to the employees' health and well-being, but can also negatively affect the operations of the mission and their peers through job performance, productivity, mission engagement, capability and general functioning.[41] Project managers, team leaders, and peers can support those that are experiencing psychological distress by acknowledging the circumstances that their co-workers are going through, see if any adjustments can be made to accommodate them, and provide access to breaks, stress management programs, and mental health resources.

In manufacturing facilities, the most common hazards that personnel will come across are crushes, pinch points, amputations, burns, damage to eyesight, electrical shock, and exposure to loud noise. In order to prevent and mitigate these hazards all personnel will be required to wear Personal Protective Equipment (PPE) which includes proper electrical PPE to protect from electrical shock, protective eyewear, and hearing protection devices such as earplugs or earmuffs. The facility will be required to install machine guards and safety interlocks with signage to protect personnel from debris, sparks, and moving parts. The facility will also be required to enforce Lockout/Tagout (LOTO) procedures, have regular testing to ensure safety of all mechanical and electrical equipment, monitor noise levels in workspaces to ensure exposure is not above 85 decibels average over an 8 hour work period, and provide personnel with hearing exams annually at a minimum.[42][43]

Other hazards can be found in the office and laboratory facilities. For office settings, ergonomics issues are common and can be alleviated by utilizing ergonomic workstations and encouraging regular periods of time to move around. For laboratory settings, safety hazards include toxic chemical exposure/inhalation, poor air quality, and improper contact and exposure control. In order to mitigate and prevent toxic chemical exposure and inhalation, facilities will be required to provide working fume extractors and ventilation, regularly evaluate the inhalation hazards in the facilities, and ensure that any concentration

40. National Aeronautics and Space Administration, "NASA Hazardous Chemical Storage Requirements," 2024, accessed November 14, 2024, https://nodis3.gsfc.nasa.gov/OPD_docs/NID_8715_140_.pdf.
41. Occupational Safety and Health Administration, "Workplace Stress - Guidance and Tips for Employers," 2024, accessed November 14, 2024, https://www.osha.gov/workplace-stress/employer-guidance.
42. Occupational Safety and Health Administration, "Control of Hazardous Energy (Lockout/Tagout) - Overview," 2024, accessed November 14, 2024, https://www.osha.gov/control-hazardous-energy.
43. Occupational Safety and Health Administration, "Occupational Noise Exposure - Overview," 2024, accessed November 14, 2024, https://www.osha.gov/noise.

of chemicals and/or toxic substances are within OSHA Permissible Exposure Limits. For mitigating the hazards that arise from improper contact and exposure control, all personnel will be required to wear PPE and engage in the proper labeling, storage, and disposal of all substances and equipment.[44]

1.9 Schedule

1.9.1 Schedule Basis of Estimate

In developing the mission schedule and making estimates for milestones, important dates, and more, the basis was constructed using multiple outlets. However, there were two main contributors that helped set these guidelines. Firstly, constraints defined and provided by L'SPACE were strictly followed in ensuring that the mission of Team 27 as a whole, and each of its individual phases, would meet specific timeline scheduling and unfold successfully. Secondly, NASA handbooks and previous mission documentation were referenced for mission scheduling. This allowed additional knowledge on procedural requirements and life cycles to be more closely understood, and guided Team 27 in complying with NASA standards and guidelines for mission scheduling.

Given by L'SPACE, there are very specific scheduling rules that must be followed and implemented, which primarily drove the structure of the schedule basis of estimate for the mission. For starters, within the Mission Task document, there exists an overarching Launch Readiness Date (LRD) that is required to be followed by all teams. The LRD constraint states that a team's space vehicle must be ready to launch by the date March 1st, 2030. Thus, in order to meet the LRD, Team 27's entire proposed mission schedule was built carefully such that it led to this established LRD. Additionally, the Mission Task document notes that analog system testing in a volcanic environment is required to be completed by all teams prior to launch. This required Team 27 to directly plan this testing and led to its intentional insertion into the schedule, which is vital to ensuring that the spacecraft can suitably operate on the lunar surface and perform the tasks it will set out to do. Again, because of this constraint, Team 27 made sure to implement these testing plans into the overall mission schedule, specifically during Phase D. The Mission Task document also includes information about how many days should be spent traveling to the launch site, how many days should be spent there, and when personnel should leave. Therefore, dates even as seemingly small as these have also been precisely determined and incorporated into the mission schedule close to the LRD. So, it is clear that L'SPACE materials served as the starting point in figuring out the schedule basis of estimate for the mission.

However, in order to more specifically set dates for the aforementioned plans, as well as general phase beginning dates, the events that occur during each phase–Key Decision Points (KDP), meetings, and more–or in between milestone tasks, and critical post-launch time points, Team 27 looked to the guidance of NASA and its order for Life Cycle Review (LCR) directly. Specific LCRs are associated with each stage of a mission, and often

44. Occupational Safety and Health Administration, "Chemical Hazards and Toxic Substances - Overview," 2024, accessed November 14, 2024, https://www.osha.gov/chemical-hazards.

require Standing Review Boards (SRB). Therefore, based on the fact that KDPs typically occur at least thirty days after the SRB's snapshot report is complete,[45] and taking into account travel time for personnel that will be attending the KDPs based on flight durations, Team 27 deliberately planned the dates for each KDP within phases. For example, what allowed even further confirmation in choice for specific KDP dates, such as January 28, 2030 for both the Mission Readiness Review (MRR) and Safety and Mission Success Review (SMSR) to take place, was insightful explanations such as the detail that the MRR occurs four to six weeks before the launch date of a mission,[46] and that the SMRS occurs two weeks to a month before the launch date of a mission.[47] Further, previous NASA missions, such as Apollo 17, were referenced to estimate specific dates such as the lunar arrival date of March 5th, 2030, where it was reasoned that from the launch site to the lunar surface, it would take about four days.[48]

It was also significant that Team 27, overall, considered scenarios where delay may occur, and so margins for delay were also included in meticulous planning of each important date within the mission schedule accordingly.

1.9.2 Mission Schedule

High Level Schedule Overview

There are four major phases that remain in the mission: final robotic system design and fabrication, system assembly and launch, operations and decommissioning.[49] To move to a new stage in the mission, KDP must be completed.[50] These have different series of LCR associated with them, which often require SRB. The KDP occurs at least 30 days after the SRB's snapshot report is complete.[51] These are conducted at NASA Headquarters in Washington D.C., so it's important to schedule travel time for needed personnel, which is the project management team along with staff in other fields depending on the mission needs at that time. The tasks in between the major milestones[52] of the mission

45. Kevin Michael Gilligan, *NASA Standing Review Board Handbook* (Washington, DC: National Aeronatics / Space Administration, 2023), https://doi.org/10.17226/26522, https://ntrs.nasa.gov/citations/20230001306.
46. National Aeronatics and Space Administration, "Preferred Reliability Practices: Mission Readiness Review.," 1997, accessed November 11, 2024, https://extapps.ksc.nasa.gov/Reliability/Documents/Preferred_Practices/1215-6.pdf.
47. Office of Safety and Mission Assurance, "Safety and Mission Success Review.," 2024, accessed November 11, 2024, https://sma.nasa.gov/sma-disciplines/smsr.
48. National Aeronautics and Space Administration., "Apollo 17: Mission Details," 2011, accessed November 11, 2024, https://www.nasa.gov/missions/apollo/apollo-17-mission-details/.
49. NASA, "SEH 3.0 NASA Program/Project Life Cycle.," 2023, accessed November 16, 2024, https://www.nasa.gov/reference/3-0-nasa-program-project-life-cycle/.
50. NASA, "Chapter 2 - NPR 7120.5E," 2024, accessed November 16, 2024, https://nodis3.gsfc.nasa.gov/displayCA.cfm?Internal_ID=N_PR_7120_005E_&page_name=Chapter2#Table2-5.
51. NASA, "NASA Standing Review Board Handbook," 2023, accessed November 16, 2024, https://ntrs.nasa.gov/api/citations/20230001306/downloads/SRB%20Handbook%20Official%20Rev%20C%201-24-23_Final%20v2.pdf.
52. Office of the Chief Engineer, "NPR 7123.1D - Appendix G. Life-Cycle and Technical Review Entrance and Success Criteria," 2023, accessed November 16, 2024, https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7123_001D_&page_name=AppendixG.

are based on other analog missions and the general required tasks in between milestones An overview of the major milestones of the mission are shown in Table 7 below.

Phase C Beginning	12/23/2024
Critical Design Review	3/1/2026
Production Readiness Review	3/1/2026
System Integration Review	12/20/2026
KDP D:	1/5/2027
Phase D Begins	**1/1/2027**
System Acceptance Review	1/5/2029
Operational Readiness Review	1/17/2030
Mission Readiness Review	1/28/2030
Safety and Mission Success Review	1/28/2030
KDP E: Launch	3/1/2030
Phase E Begins	3/1/2030
Lunar Arrival	3/5/2030
Critical Events Readiness Review	3/18/2030
Post Launch Assessment Review	3/30/2030
KDP F: Decommissioning Review	5/23/30
Phase F Begins	5/28/30
Disposal Readiness Review	6/4/30

Table 7: Schedule Overview.

1.Final Robotic System Design and Fabrication (phase C):

This first phase involves the creation of the mechanical and electrical subcomponents, propulsion, payload systems and thermal systems to create an overall working system. This phase will begin after the completion and review of the PDR, which is KDP E. Since the PDR will be complete on December 8th, 2024, phase C is set to begin on December 23rd, 2024, with a review of the KDP C. This review will take one week to discuss with the team and make necessary changes by December 30th 2024.

Then, subsystem simulation testing will occur to prepare for the subsystem CDRs.[53] This will take five months, ending on May 30th, 2025 to account for changes that may need to be made based on the simulation results. The subsystem CDRs will be completed and reviewed one month later on July 30th, 2025. Following the subsystem CDRs, the complete system will undergo simulation testing, which will take six months to complete The CDR and the Production Readiness Review (PRR) will take place at the same time. Finally the CDR and PRR will be completed for review on March 30th, 2026.

The final milestone of this phase is the System Integration Review (SIR) , which confirms the verification that the systems segments, components, and subsystems are on

53. TRW, “Total Ozone Mapping Spectrometer Earth Probe (TOMS-EP) Critical Design Review Data Package.,” 1992, accessed November 16, 2024, https://ntrs.nasa.gov/api/citations/20110023613/downloads/20110023613.pdf.

schedule to be ready for integration.[54] To prepare for the DIR, the team will begin with reviewing and improving the CDR, which will be done on April 1st, 2026. Then the integration plan for the fabrication of the system will be made by June 15th, 2026, followed by the procedure plan which will be completed on August 15th, 2026. Finally, the technicians will be trained for about three and a half months, ending on November 20th, 2026. Finally, the system integration review will be written, then reviewed on December 20th, 2026. This document will then be discussed at the SRB meeting on January 5th 2027, the success of this meeting serves as KDP D, and marks the beginning of Phase D.

ii) System Assembly and Launch (phase D)

Phase D consists of completing rigorous testing that mimics lunar conditions is needed to fix or change anything within the system that might hinder the mission's data collection and overall functionality.Testing that is needed includes thermal vacuum, vibrational,[55] overall environmental testing,[56] and drop testing based on the mission's plan. To integrate the system with the launch vehicle, multiple checks and launch tests will need to be done. These tests are necessary to ensure all systems are robust enough to handle the intensity of the launch, space travel, and landing conditions of the lunar surface. All components must function perfectly in harsh conditions, as even a slight malfunction could lead to mission failure.

Phase D begins with manufacturing of the system, starting with subsystem fabrication, and ending with verification and validation. This will check that the system complies with established acceptance criteria by August 5th, 2027. After this testing at the pit in Flagstaff, Arizona will be done for one week, ending on August 12th, 2027. Immediately following this will be the teams travel to glenn research center for drop testing, which will be completed by August 19th, 2027. Based on the testing results, the technical data package is updated by October fifth, 2027, followed by the final certification package on January fifth, 2028. The as-is built hardware and software designs are baselined by February fifth, 2028. The procedure for the systems safety, shipping and handling, checkout, operational plan and procedure is developed by the team and completed by June fifth 2028. The acceptance data package is then created by August fifth 2028. After the acceptance of data packages success, the team will analyze the system and create a plan to sustain it, including a thorough analysis of possible single point failures and their success. Finally, all of the testing results are compiled into the System Acceptance Review (SAR) by January fifth 2029.

After the success of the SAR, the operational readiness review is developed. During this time the supporting and enabling products including facilities, equipment, software tools, and databases are tested, which will take four months, ending on April fifth, 2029. The list of single point failures based on testing results is updated based on the results of the testing and is finished by May fifth, 2029. Then, the operational supporting and enabling products are installed at each site and are completed by August fifth, 2029. Users and operators train on the correct operation of the system for three and a half months,

54. NASA, "NASA Systems Engineering Handbook."

55. Crystal Instruments, "Satellite Vibration Testing," 2024, accessed November 16, 2024, https://www.crystalinstruments.com/satellite-vibration-testing.

56. NASA, "Space Environmental Testing at the NASA Space Power Facility," 2024, accessed November 16, 2024, https://www.nasa.gov/wp-content/uploads/2015/11/space-testing.pdf.

concluding on November 15, 2029. Finally, the decommission and operation plans are baselined by November 21, 2029. This information is then compiled into the Operation Readiness Review, finalized on January 17, 2029.

Next, the team prepares the MRR and for the SMSR meeting.[57] They begin checking that the system and support elements demonstrate functioning as expected by January 21, 2030. Then the verification that the system and support elements are properly configured for flight and mission operations is completed by January 25, 2030. This information is then compiled to the MRR which is ready for the SMSR meeting on January 28, 2030. Once testing is finished, the system is launched on the set date, March 1st, 2030. This serves as KDP E, moving the mission into Phase E.

iii) Operations (phase E):

The first thing to occur in Phase E is the system's lunar arrival. From launch, it will take approximately four days for the spacecraft to land on the moon.[58] The post launch assessment review is the first milestone completed during this phase, which often takes about 30 days after the launch date to complete.[59] To begin, the launch and early operations performance are verified which will be done in three days after the lunar arrival. The system and science instrument performance availability after landing on the moon is then analyzed and verified until March 10, 2030. During this time, the spacecraft is deploying and activating all systems until March 15, 2030. The Critical Events Readiness Review is then completed to begin traversing to the first lunar site for surface testing. This is followed by the confirmation of mission operations and ground data availability by March 19, 2030. Any in-flight anomalies and responsive actions, including autonomous fault protection are documented by March 20, 2030. The significant changes to the system, support system, operations and staffing are documented by March 25, 2030. Plans for post launch development have been addressed and documented by March 27th, 2030. This information is then compiled into the Post Launch Assessment Review (PLAR) by March 30th, 2030.

Shortly after the post launch assessment review, the data collection of the magnetic anomalies and surface composition was completed on April 3, 2030. The rover then follows the operations as described in Section 1.4, with the final data transmission occurring on May 22, 2030. The decommissioning review is completed by May 23, 2030, serving as KDP F, which is followed by an SRB on May 26, 2030.

iv) Decommissioning (phase F):

The final phase begins on May 28, 2023 and includes deactivating the robotic system once it is confirmed that the data collection and preservation is finished. To confirm this, the disposal readiness review is submitted June 4, 2030. Then the system travels to the disposal location, arriving on June 5, 2030. All systems are shut down and exposed to the harsh lunar environment for disposal on June 6, 2030.

57. NASA, "SMSR," 2024, accessed November 16, 2024, https://sma.nasa.gov/sma-disciplines/smsr.

58. NASA, "Apollo 17," 2024, accessed November 16, 2024, https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo17info.html.

59. NASA, "Chapter 7: Mission Inception," 2024, accessed November 16, 2024, https://science.nasa.gov/learn/basics-of-space-flight/chapter7-2/.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
1	**Critical Design Review**		0%	12/23/24	3/1/26	434	31
1.1	KDP Team Review	Entire Team	FALSE	12/23/24	12/30/24	8	
1.2	Subsystem Simulation Testing	Engineers and Scientists	FALSE	12/30/24	5/30/25	152	
1.3	Subsystem CDRs	Engineers and Scientists	FALSE	5/30/25	7/30/25	62	
1.4	Complete System Simulation Testing	Engineers and Scientists	FALSE	7/30/25	1/30/26	185	
1.5	Schedule Margin			1/30/26	3/1/26	31	
1.6	◆ Critical Design Reveiw		FALSE	3/1/26	3/1/26	1	
2	**System Integration Review**		0%	3/1/26	1/5/27	311	17
2.1	CDR team review and improvement	Entire Team	Not complete	3/1/26	4/1/26	32	
2.2	Integration plan	Engineers and Scientists	Not complete	4/1/26	6/15/26	76	
2.3	Procedure plan	Engineers and Scientists	Not complete	6/15/26	8/15/26	62	
2.4	System integration training	Technicians	Not complete	8/15/26	11/20/26	98	
2.5	System Integration Review	Entire Team	Not complete	11/20/26	12/20/26		
2.6	Schedule Margin			12/20/26	1/5/27	17	
2.7	◆ KDP Meeting 6		Not complete	1/5/27	1/5/27	1	
3	**System Acceptance Review**		0%	1/5/27	1/5/29	732	62
3.1	Manufacturing Verification and Validation	Engineers, Technicians	Not complete	1/5/27	8/5/27	213	
3.2	Testing in Flagstaff Arizona	Engineers, Managers, Scientists	Not complete	8/5/27	8/12/27	8	
3.3	Testing in Glenn Research Center	Engineers, Managers, Scientists	Not complete	8/12/27	8/19/27	8	
3.4	Update technical data package	Engineers, Managers, Scientists	Not complete	8/19/27	10/5/27	48	
3.5	Final certification package	Engineers, Scientists	Not complete	10/5/27	1/5/28	93	
3.6	Baseline as-is built hardware and software design	Engineers, Scientists	Not complete	1/5/28	2/5/28	32	

Table 8: A portion of the Gantt chart for the mission. Please see the full chart in the appendix.

1.10 Budget

1.10.1 Budget Overview

The total mission cost is $352,317,047, which exceeds the budget of $300,000,000. This overrun is attributed to the inclusion of a costly secondary science instrument, that the team has submitted a change request for its removal, as described in Section 1.11.1. The cost breakdown includes personnel, travel, outreach, and direct costs as shown in Table 9 below.

Personnel	Travel	Outreach	Direct Costs
$ 45,856,279	$ 448,844	**$ 3,264,470**	$ 288,648,266

Table 9: Budget overview

The personnel cost is $71,590,800 total across the lifecycle, consisting of salaries for the 79 team members. The groups of personnel change throughout the lifecycle based on what is needed for each phase in the mission. The total travel cost a total of $448,844, accounting for trips to Key Decision Points (KDPs), system development and testing, and the mission launch. The direct costs consist of six subsystems: Mechanical ($27,160,000), Power ($16,914,000), Thermal Control ($23,112,360), Communication and Data Handling (CDH) ($34,145,000), Guidance Navigation and Control (GNC) ($11,577,500), and Science Instrumentation ($124,565,000). The outreach costs $3,264,470.

1.10.2 Budget Basis of Estimate

In developing the mission budget and making estimates for overall costs within each area–personnel, travel, direct costs, and more–the basis was constructed using multiple outlets. However, there were two main contributors that helped set these guidelines. Firstly, constraints and tools defined or provided by L'SPACE were strictly followed in ensuring that the mission of Team 27 as a whole, and each of its areas of cost within the budget, would meet specific budgetary limits without exceeding them or underutilizing the available funds. Secondly, NASA and other outside sources related to areas of allocation determined for this mission were referenced for developing a basis of estimate for the mission.. This allowed additional knowledge on cost requirements and allocation of funds across areas within a budget to be more closely understood, especially within context of other missions, and guided Team 27 in complying with NASA standards and guidelines for mission budgeting.

Given by L'SPACE, there are specific budgetary rules that must be followed and implemented, which primarily drove the structure of the budget basis of estimate for the mission. For starters, within the original Mission Task document, there existed an overarching mission budget of $425 million that was required to be followed by all teams. However, this budget was cut and reduced to an overarching mission budget of $300 million, which is now the required budget to be adhered to by all teams. The Mission Task document also gives strict guidelines on how to go about choosing what, for example, flights to take or hotels to choose, by providing specific sources, because of how drastically the budget changes based on the choice. Thus, as instructed, coach tickets for all flights were purchased after identifying the highest fare, determined by calculating from the furthest possible airport location to the point of destination, and as listed by the U.S. General Services Administration.[60] For example, this was the process followed in selecting flights for personnel to Cape Canaveral, Florida for the mission launch, as well as flights for portions of the team's personnel to travel to Washington the NASA Glenn Research Center in Cleveland, Ohio for spacecraft testing prior to launch. Additionally, the Mission Task document notes strict salaries of each person on the team per year–$60,000 per year for administrators and technicians, $80,000 per year for scientists and engineers, and $120,000 per year for managers–which is the foundation and totality of the personnel allocation for the mission budget. For hotel costs, Team 27 chose partners,[61] established by FedRooms, estimated meal costs per diem[62] as instructed, and car rental costs based on the current average weekly per location, accounting for at least one SUV and one sedan.[63]

Another largely significant tool that Team 27 used in determining the budget basis of estimate, and specifically related to engineering subsystem costs, was the L'SPACE Mission Concept Cost Estimate Tool (MCCET), built using information from the NASA In-

60. U.S General Services Administration, "Airfare rates - City Pair Program," 2024, accessed November 12, 2024, https://www.gsa.gov/travel/plan-a-trip/transportation-airfare-rates-pov-rates-etc/airfare-rates-city-pair-program.

61. Fedrooms, "Home," 2024, accessed November 12, 2024, https://www.fedrooms.com/home.html.

62. U.S. General Services Administration, "Per diem rates," 2024, accessed November 12, 2024, https://www.gsa.gov/travel/plan-book/per-diem-rates.

63. Enterprise, "Home," 2024, accessed November 12, 2024, https://www.enterprise.com/en/home.html.

strument Cost Model (NICM).[64] This required Team 27 to collect details such as the mass, maximum power, and design life. These details allowed Team 27 to develop costs for specific subsystems and sub-teams overall. For example, for the electrical subsystem of the spacecraft, the overall cost was found by utilizing the specific electrical subsystem formula determined by the MCCET, (1516 x Electrical Mass^0.74, with Team 27's found total maximum power of electrical components inputted. This gave a total electrical subsystem cost of about $9,900,000, accounting for inflation by adjusting the 2004 costs to the year 2024,[65] and this same process was used to set each engineering subsystem's budgetary allocation. It must be noted that every cost calculated by the MCCET accounts for inflation to ensure utmost, recent accuracy in producing the overall mission budget.

Reference to NASA in developing specific areas of the budget was also a part of determining the overall budget. After setting an initial estimate for outreach, for example, activities and opportunities to showcase the mission and broad importance of it as well as STEM in general to the public was more accurately determined based off of previous NASA outreach activities, such as the 2025 Student Launch Challenge.[66] This activity, for example, allows students to design a rocket in teams and undergo reviews throughout the year for it. Team 27 then developed broader ideas for university students, such as challenges where students propose their unique and innovative solutions to mission-related problems and allowing winners to collaborate with mission team members. Using estimations for costs to host activities of this sort, as well as loosely referencing a visual provided by L'SPACE showcasing a mission budget breakdown example Figure 10, Team 27 opted to set the outreach allocation cap of the mission budget to about 1%. This budget breakdown chart was used as a guide for other subsystems and areas of the budget initially in allocating funds to each and allowing for margins in the case where costs turn out to be much larger than predicted (or if additional, unpredicted costs come up along the way). However, the actual mission cost breakdown for Team 27 has changed considerably as more precise calculations and costs have refined the overall mission budget.

64. Joseph Mrozinski, "NASA Instrument Cost Model (NICM) Version 9c," 2020, accessed November 12, 2024, https://www.jpl.nasa.gov/go/nasa-instrument-cost-model/.

65. US Inflation Calculator, "Inflation Calculator," 2024, accessed November 12, 2024, https://www.usinflationcalculator.com/.

66. Beth Ridgeway, "NASA Announces Teams for 2025 Student Launch Challenge," 2024, accessed November 12, 2024, https://www.nasa.gov/centers-and-facilities/marshall/nasa-announces-teams-for-2025-student-launch-challenge/.

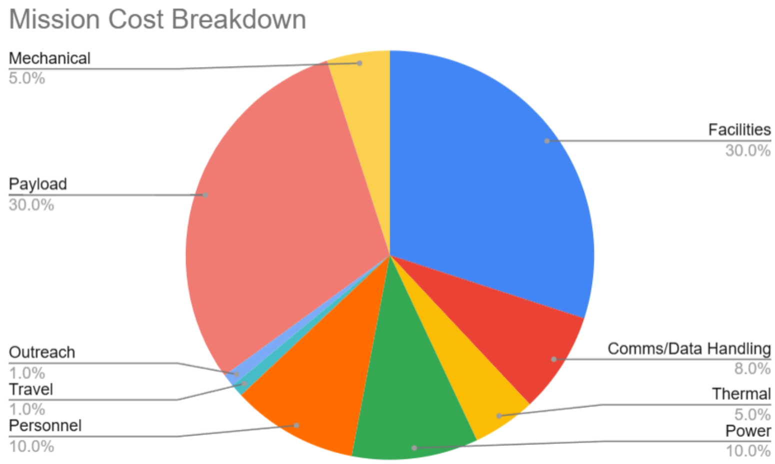


Figure 10: A pie chart provided by L'SPACE of an example mission cost breakdown.

1.10.3 Personnel Budget

There are four types of personnel that are necessary to hire for the mission. Science personnel work on the mission experiment and analysis of collected mission data. Engineering personnel consists of a diverse team with expertise for each of the rovers subsystems including systems, mechanical, electrical, and thermal. They are responsible for designing, building, and testing the mission concept, as well as ensuring mission operations run smoothly. Technicians are responsible for assisting the engineers and scientists with manufacturing, assembly, and testing of instruments and systems for the mission concept. Administration personnel work on administrative and human resources tasks, and tracking the budget, schedule, and outreach for the mission. Project management organizes the mission personnel, budgets, and schedule. The salaries for each type of personnel is listed in Table 10.

Science Personnel	$80,000 / year
Engineering Personnel	$80,000 / year
Technicians	$60,000 / year
Administration Personnel	$60,000 / year
Project Management	$120,000 / year

Table 10: This table lists who will be necessary to hire, along with their corresponding salaries.

Each phase of the mission has different needs of personnel, leading to varying salary costs as shown in Figure 11. Administrators and managers are the backbone of the mission team, therefore stay constant throughout. There will be 6 administration personnel and 11 management personnel throughout the mission. The management team consists of the Project Manager, Deputy Project Manager of Resources, Chief Scientist and two other Scientist Managers, Lead Systems Engineer and Lead Engineers for each discipline (Mechanical, Thermal, Electrical, and Command and data handling), and a manager for Technicians. The number of administrative personnel is based on the percentage of the programmatics subteam for a 6 person team, along with accounting for HR, and other administrative tasks. During phases c and d, the final design, fabrication, system assembly, testing, launch and checkout take place, requiring engineers and technicians more than scientists. For these phases, there will be 5 engineers in each engineering field: Mechanical, Electrical, Command data and handling, and Thermal, leading to a total of 20. There will be 4 technicians working to fabricate the various subsystems, and assemble the total system, leading to a total of 15. There will be 2 scientists during this time to ensure the engineering design is compatible with the necessary science for the mission. Phases E and F consist of operations, sustainment, and closeout of the mission, therefore requiring more scientists and engineers than technicians. During these last phases, there will be 20 scientists to analyze the collected data from the mission. There will only be 16 engineers during this time, as they still have an important role for decommissioning efforts, but less are needed. There are no technicians for these phases because there is no longer any part of the system that is being built or tested.

A 28% cost margin is allocated for personnel to account for any costs due to unforeseen circumstances such as overtime, temporary staff, variability of benefits, and salary adjustments throughout the mission.

Additional Information

	Phase C	Phase C	Phase C-D	Phase D	Phase D	Phase E-F
# People on Team	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6
Science Personnel:	2	2	2	2	2	20
Engineering Personnel:	20	20	20	20	20	16
Technicians:	15	15	15	15	15	0
Administration Personnel:	6	6	6	6	6	6
Management Personnel:	11	11	11	11	11	11

NASA L'SPACE Mission Concept Academy Budget - *YOUR MISSION NAME HERE*

Mission Phase	Phase C	Phase C	Phase C-D	Phase D	Phase D	Phase E-F	
Year	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Cumulative Total**
PERSONNEL							
Science Personnel	$ 160,000	$ 164,160	$ 168,320	$ 172,480	$ 176,640	$ 1,808,000	$ 2,649,600
Engineering Personnel	$ 1,600,000	$ 1,641,600	$ 1,683,200	$	$ 1,766,400	$ 1,446,400	$ 8,137,600
Technicians	$ 900,000	$ 923,400	$ 946,800	$ 970,200	$ 993,600	$ -	$ 4,734,000
Administration Personnel	$ 360,000	$ 369,360	$ 378,720	$ 388,080	$ 397,440	$ 406,800	$ 2,300,400
Project Management	$ 1,320,000	$ 1,354,320	$ 1,388,640	$ 1,422,960	$ 1,457,280	$ 1,491,600	$ 8,434,800
Total Salaries	$ 4,340,000	$ 4,452,840	$ 4,565,680	$ 2,953,720	$ 4,791,360	$ 5,152,800	**$ 26,256,400**
Total ERE	$ 1,211,294	$ 1,242,788	$ 1,274,281	$ 824,383	$ 1,337,269	$ 1,438,146	**$ 7,328,161**
Personnel Margin	$ 1,554,362	$ 1,594,776	$ 1,635,189	$ 1,057,869	$ 1,716,016	$ 1,845,465	**$ 9,403,677**
TOTAL PERSONNEL	$ 7,105,656	$ 7,479,954	$ 7,863,858	$ 5,213,178	$ 8,660,488	$ 9,533,145	$ 45,856,279

Table 11: Personnel Allocation and Cost per Fiscal Year

1.10.4 Travel Budget

There are multiple events throughout the duration of the mission's lifecycle that will require some or all of the team to travel to various locations, including key decision points (KDP's), system testing, and mission launch. Travel costs are estimated based on commercial coach flight tickets,[67] rooms from partnered hotels,[68] and meals per diem[69] for each person along with car rentals for the team,[70] that are based on the current average weekly per location, accounting for at least one SUV and one sedan.

i) Key Decision Points

Since this mission is a category 2 project, the KDPs must be conducted in Washington D.C. at NASA Headquarters, so the Mission Directorate Associate Administrator can sign off. There will be one trip in each of the phases C, D, and E. For each of these meetings, the total stay for the trip will be 5 days. The project management team (11 people) is expected to attend each of these meetings. The other personnel attending KDP meetings vary based on the need of the mission at that time.

The System Integration Review (SIR) is KDP D (during phase C), therefore 4 engineers (one from each subteam), and 4 technicians (one for each subsystem) will attend as well. The launch is KDP E, so all personnel will already be traveling to the launch site, as accounted for in launch cost. The decommissioning review is KDP F; this requires scientists to verify that all data has been collected, and the engineering team will need to ensure the system is ready to carry out the decommissioning process. Therefore, there will need to be 6 scientists and 2 engineers present.

Based on the average commercial coach flight ticket price from various locations around the US, each ticket will be $500. The per diem costs for lodging and food in Washington D.C. are $300 per night and $70 on the first and last days of travel and $92 during the stay respectively. Two cars will be used for the team for each trip, with a price of $400/week per car.

ii) System Development

Throughout phases C-D of the mission, the engineering and science team will need to travel to ensure the system is being developed properly. Budget will be allocated for the entire team to meet for one week per fiscal year during each of these phases. The destination of these trips will vary depending on where the system is being manufactured. Therefore, to make a conservative estimate for this cost, the price of a long distance flight from California to Glenn research center is used, which is $330 per person. Based on the hotel costs from other travel throughout the mission, it will be estimated at $200 per night, and the meals will be $80 per day. There will be a budget for 4 SUVs for these trips, using a price of $300/week per car. Note that this budget may not be one consecutive week with the whole team, but may consist of different subteams meeting at various times. It is assumed that during phase E-F, the needed personnel will be working in the same location, so no travel will be needed.

iii) System Testing

A portion of the team will need to travel to the NASA Glenn Research Center in Cleveland, Ohio to conduct drop testing for our system. This will occur during phase D of the

67. U.S. General Services Administration, “City Pair Program (CPP),” 2024, accessed November 16, 2024, https://www.gsa.gov/travel/plan-a-trip/transportation-airfare-rates-pov-rates-etc/airfare-rates-city-pair-program.

68. Fedrooms, “Home,” 2024, accessed November 16, 2024, https://www.fedrooms.com/home.html.

69. U.S. General Services Administration, “Per Diem Rates,” 2024, accessed November 16, 2024, https://www.gsa.gov/travel/plan-book/per-diem-rates.

70. Enterprise, “Reserve,” 2024, accessed November 16, 2024, https://www.enterprise.com/en/reserve.html#car_select.

mission. The total stay for this trip will be 1 week. The flight cost based on the average commercial coach flight ticket price from various locations is $350. The lodging per person is $160 per night. The meals per diem are $60 on the first and last day of travel, and $80 during the stay. Three cars will be used for the team for the trip, with a price of $300/week per car.

A portion of the team will also need to travel to the black point lava flow in Flagstaff, Arizona. The total stay for this trip will be 1 week. The flight cost based on the average commercial coach flight ticket price from various locations is $350. The lodging per person is $150 per night. The meals per diem are $60 on the first and last day of travel, and $80 during the stay. Three cars will be used for the team for the trip, with a price of $450/week per car.

The key personnel for these meetings are the management team, along with 2 engineers per focus, and 2 scientists, leading to a total of 14 people.

iv) Mission Launch

All team members (79) who have worked on the mission will travel to Cape Canaveral, Florida for launch. This will be a total stay of 5 days, arriving two days prior and departing two days after the launch date. The flight cost based on the average commercial coach flight ticket price from various locations is $380. The lodging per person is $208 per night. The meals per diem are $55 on the first and last day of travel, and $75 during the stay. Eleven cars will be used for the team for the trip, with a price of $400/week per car.

A cost margin of 20% is included in the cost to account for any delays or rebooked flights, and extra travel needed throughout the mission. The travel costs for each phase of the mission, along with the total of $448,844 are shown in Table 12.

TRAVEL							
Total Flights Cost	$ 7,260	$ 7,260	$ 9,500	$ 7,260	$ 37,280	$ 41,004	**$ 109,564**
Total Hotel Cost	$ 22,000	$ 22,000	$ 28,500	$ 22,000	$ 38,432	$ 28,500	**$ 161,432**
Total Transportation Cost	$ 1,200	$ 1,200	$ 800	$ 1,200	$ 5,600	$ 800	**$ 10,800**
Total Per Diem Cost	$ 12,320	$ 12,320	$ 7,904	$ 12,320	$ 12,655	$ 7,904	**$ 65,423**
Travel Margin	$ 8,556	$ 8,556	$ 9,341	$ 8,556	$ 18,793	$ 15,642	**$ 69,444**
Total Travel Costs	$ 51,336	$ 52,671	$ 58,959	$ 55,340	$ 124,487	$ 106,050	**$ 448,844**

Table 12: Travel Costs per Fiscal Year

1.10.5 Outreach Budget

The Outreach Budget was developed to reflect the necessary costs for conducting outreach activities throughout the mission's phases, from Year 1 to Year 6. The budget includes categories such as outreach materials, venue costs, travel expenses, services, personnel costs, and a margin for unforeseen expenses. The estimates for each category are explained below.

OUTREACH BUDGET							
Total Outreach Materials	$180,000	$180,000	$180,000	$180,000	$180,000	$162,000	**$1,062,000**
Total Outreach Venue Costs	$85,000	$85,000	$85,000	$85,000	$85,000	$50,000	**$475,000**
Total Outreach Travel Costs	$30,000	$30,000	$30,000	$30,000	$30,000	$25,000	**$175,000**
Total Outreach Services Costs	$86,000	$86,000	$86,000	$86,000	$86,000	$62,000	**$492,000**
Total Outreach Personnel Costs	$74,000	$74,000	$74,000	$74,000	$74,000	$70,000	**$440,000**
Outreach Margin	$15,000	$15,000	$15,000	$15,000	$15,000	$10,000	**$85,000**
Total Outreach Costs	$834,000	$482,220	$494,440	$506,660	$518,880	$428,270	**$3,264,470**

Table 13: The Outreach Budget breakdown for the mission.

Outreach Materials Costs: The materials budget covers the production and distribution of printed materials, such as brochures, posters, and other promotional items. These materials are essential for engaging the public, educating them about the mission, and providing tangible takeaways.[71] The costs are estimated based on the quantity and quality of materials required for each event throughout the mission timeline.

- The cost of outreach materials includes printed materials, brochures, event signage, and merchandise.
- Year 1 to Year 5: A steady cost of $180,000 per year was projected based on quantities and printing costs
- Year 6: The cost decreases to $162,000, assuming fewer materials are required as the project concludes.
- Total: $1,062,000 over the mission period.

Outreach Venue Costs: The venue costs are for renting spaces for public outreach activities, such as exhibitions, presentations, and community events. Venues will need to accommodate both small and large audiences depending on the nature of the event.[72] These costs have been estimated based on the number of planned events and the average rental price for the venues, considering varying venue sizes and locations across different phases.

- These costs cover the rental of venues for public outreach activities such as exhibitions and presentations.

71. Johnson Brown, “Examples of Tailoring and Customization,” 2019, accessed November 16, 2024, https://www.nasa.gov/reference/3-0-nasa-program-project-life-cycle/#hds-sidebar-nav-1..
72. US Inflation Calculator, “Inflation Calculator,” 2024, accessed November 16, 2024, https://www.usinflationcalculator.com/.

- Year 1 to Year 5: The projected cost is $85,000 annually for venue rentals.
- Year 6: The cost is reduced to $50,000, assuming fewer events.
- Total: $475,000 for the duration of the mission.

Outreach Travel Costs: The travel costs cover expenses related to the transportation of team members and outreach materials to and from event locations. This includes travel expenses such as airfare, car rentals, and fuel costs for the outreach team. The estimated costs take into account the number of events, geographic spread, and the need for staff to attend multiple events, both locally and regionally.

- Travel costs account for transportation, lodging, and per diem for team members attending outreach events, conferences, and community engagement activities.
- Years 1 to 5: Travel is estimated at $30,000 annually.
- Year 6: The cost decreases slightly to $25,000, reflecting fewer outreach events that require travel.
- Total: $175,000 across the mission period.

Outreach Services Costs: The services costs include fees for external services such as event coordination, AV equipment rentals, and professional speakers or facilitators. These services ensure that each outreach event runs smoothly and effectively engages the public. The estimate is based on the required services for each event, with adjustments for more complex events requiring additional external support.

- This category includes the cost of external services such as event coordination, technical support (AV, web streaming), and professional services.
- Years 1 to 5: Services are estimated at $86,000 annually, covering a wide range of professional support needed for the outreach activities.
- Year 6: A reduction to $62,000 accounts for the smaller scale of outreach efforts towards the end of the project.
- Total: $492,000 for all six years.

Outreach Personnel Costs: The personnel costs include salaries and compensation for the individuals organizing and executing the outreach activities. This includes outreach coordinators, event managers, and support staff. The costs were estimated based on the number of personnel needed, the duration of their involvement, and the typical salary rates for these roles.

- These costs cover the salaries of personnel dedicated to outreach, such as project coordinators and community liaisons.

- Years 1 to 5: Personnel costs are projected at $74,000 per year, reflecting the need for a team to handle ongoing outreach efforts.
- Year 6: A small reduction to $70,000 is projected, assuming fewer personnel are required towards the end of the mission.
- Total: $440,000 throughout the mission.

Outreach Margin: The margin represents a contingency fund allocated for unexpected costs or additional needs that arise during the execution of outreach activities. This fund ensures that the outreach plan remains flexible and adaptable to unforeseen changes or challenges.[73] The margin has been calculated as a percentage of the total outreach costs, ensuring adequate coverage for potential adjustments during the mission.

- A small margin is included to accommodate unforeseen expenses and adjustments in the outreach plan.
- Years 1 to 5: The margin is $15,000 annually.
- Year 6: The margin decreases to $10,000, as fewer activities are planned.
- Total: $85,000.

Total Outreach Costs: The total outreach costs were calculated by summing the costs from all categories over the six-year mission period. The final budget for outreach totals $3,264,470, which is slightly over the target of $3 million but within a reasonable margin considering the scale of activities planned.[74] These estimates were based on expected outreach activities, the venues required, travel needs, professional services, and staffing, with adjustments made for the reduced intensity of outreach as the mission progresses into its final year.

1.10.6 Direct Costs

The direct costs for the mission consist of the costs for each subsystem, science instrumentation, and the manufacturing and test facility costs. The costs of the subsystems and payloads do not occur until the second fiscal year of Phase C, after the final design is approved, and end after the mission has launched. The spacecraft cost margin is 20% to account for any mistakes in manufacturing or damage from tests. The total mission cost is $352,317,047, which is significantly over the $300,000,000 budget. The main factor to the overcost is a secondary science instrument that the team has submitted a change request form to remove from our system as stated in Section 1.11.1. The direct costs are summarized in Table 14

73. NASA, “NASA Systems Engineering Handbook.”
74. Calculator, “Inflation Calculator.”

DIRECT COSTS							
Mechanical Subsystem		$ 2,000,000	$ 2,000,000	$ 3,000,000	$ 3,000,000		$ 10,000,000
Power Subsystem		$ 1,980,000	$ 1,980,000	$ 2,970,000	$ 2,970,000		$ 9,900,000
Thermal Control Subsystem		$ 4,648,000	$ 4,648,000	$ 1,992,000	$ 1,992,000		$ 13,280,000
Comms & Data Handling Subsystem		$ 4,000,000	$ 4,000,000	$ 6,000,000	$ 6,000,000		$ 20,000,000
Guidance, Nav, & Control Subsystem		$ 3,350,000	$ 2,010,000	$ 670,000	$ 670,000		$ 6,700,000
Science Instrumentation		$ 25,130,000	$ 25,130,000	$ 10,770,000	$ 10,770,000		$ 71,800,000
Spacecraft Cost Margin		$ 8,221,600	$ 7,953,600	$ 5,080,400	$ 5,080,400		$ 26,336,000
Total Spacecraft Direct Costs	$ -	$ 50,612,170	$ 50,203,123	$ 32,860,027	$ 33,652,570	$ -	**$ 167,327,890**
Manufacturing Facility Cost		$ 13,247,465	$ 13,247,465	$ 13,247,465	$ 13,247,465		$ 52,989,860
Test Facility Cost		$ 12,642,500	$ 12,642,500	$ 12,642,500	$ 12,642,500		$ 50,570,000
Facility Cost Margin		$ 2,588,997	$ 2,588,997	$ 2,588,997	$ 2,588,997		$ 10,355,986
Total Facilities Costs	$ -	$ 29,219,414	$ 29,959,867	$ 30,700,320	$ 31,440,773	$ -	**$ 121,320,376**

Table 14: Direct Cost Summary.

1.Mechanical Subsystem

The main parts of the mechanical subsystem consist of the chassis, motor controller, and rover body. The total cost without manufacturing for the mechanical subsystem is \$10,000,000. It is projected to weigh approximately 250 kg, making its estimated cost \$10,000,000, with a manufacturing cost of \$13,200,000, and facility cost of \$3,960,000. Due to the fact that it is the frame of the device, it will be heavily developed in Phase C, and require further development in Phase D as it needs to be compatible with most other subsystems, which might cause it to change as testing progresses.

2.Power Subsystem

The power subsystem consists of three types of parts, two lithium battery packs, 348 junction solar cells, and one supernova power conditioning and distribution unit. The total cost without manufacturing for the power subsystem is \$9,900,000. The lithium battery packs weigh about 2.4kg, and have a power draw of 380.8Wh. This results in a cost of \$4,800,000, with a manufacturing cost of \$1,500,000, and facility cost of \$1,892,500. The junction solar cells weigh about 0.903 kg and have a power draw of 1Wh, resulting in a main cost of \$2,600,000. They will have a manufacturing facility cost of \$800,000 and testing facility cost of \$1,025,000. Finally, the supernova power conditioning and distribution unit weighs 1 kg and will have a power draw of approximately 1,500 Wh, resulting in a main cost of \$2,500,000. It will have a manufacturing cost of 800,000 and testing facility cost of \$997,500. This leads to a total power subsystem cost of \$9,900,000. Since this subsystem mostly interacts with other parts of the device, it is estimated that 40% of the cost will be used for its isolated development in Phase C, and 60% of the cost will be used for development in phase D.

3.Thermal Control Subsystem

The thermal subsystem consists of multi-layered insulation, and a DS mini. The total cost without manufacturing for the thermal subsystem is \$13,280,000. The mass of the multi-layered insulation is 18.03, and it has no power draw as this is an added material on the design. It will have a cost of about \$5,466,000 with a manufacturing facility cost of \$1,733,860 and a testing facility cost of \$2,160,000. The DS mini is 1.2 kg and has a power draw of 45W, making the cost \$7,814,000 with a manufacturing cost of \$2,846,000 and testing facility cost of \$3,092,500. This leads to a total thermal control subsystem cost (without manufacturing or testing) of \$13,280,000. It is expected that this subsystem will be primarily developed individually in Phase C, and not change much in Phase D since its interaction with the system doesn't depend much on other subsystems. Therefore, it's assumed that 70% of the cost will be used in Phase C, and 30% of the cost will be used in Phase D.

4.Communication Data Handling Subsystem

The Communication Data Handling Subsystem (CDH) has four sections that cost is allocated to develop: The command processing unit, communication interfaces (I2C, UART, CAN), data storage, and redundant systems. The total cost without manufacturing for the CDH subsystem is $20,000,000. The command processing unit is 1.2kg and costs $5,200,000 with a manufacturing cost of $1,600,000 and a testing facility cost of $2,040,000. The communication interfaces cost $3,750,000, have a manufacturing cost of $1,150,000 and a testing facility cost of $1,477,500. The data storage costs $4,980,000 with a manufacturing cost of $1,620,000 and a testing facility cost of $1,985,000. The redundant systems cost is $6,000,000 with an estimated manufacturing cost of $1,900,000 and a testing facility cost of $2,372,500. The CDH subsystem will be more heavily developed as an assembly with the payload subsystem to ensure collected data can successfully be transferred back to earth. This will result in 40% of the cost in FY 2 and 3, and 60% of the cost in FY 4 and 5.

5.Guidance, Navigation, and Control Subsystem

The Guidance, Navigation, and Control (GNC) Subsystem consists of four major types of components: two navigational cameras and four hazard cameras, four shape memory alloy tires, and six steering and stepper motors. The total cost without manufacturing for the GNC subsystem is $6,700,000 The navigational and hazard cameras costs are calculated together because they are similar systems. Their total mass is 1.32 kg, and the power draw is 13.2 W, resulting in a cost of $2,500,000, with a manufacturing cost of $800,000 and test cost of $997,500. The shape memory alloy tires are 40 kg in mass, and are estimated to cost $2,700,000 total. The manufacturing and facility costs are estimated to be $900,000 and $1,080,000. Lastly, the steering and stepper motors 0.12 kg and have an estimated total cost of $1,500,000. They will have a manufacturing cost of about $500,000 and a facility cost of $600,000. This subsystem is the backbone of our systems ability to traverse on the moon to collect our data. Therefore, it will be heavily focused on in the beginning of development in Phase C-D, using about 70% in FY 2 and 3 and 30% in FY 4 and 5.

6. Science Instrumentation

The science instrumentation of the system consists of eight instruments total. The total cost without manufacturing for the science instrumentation is $71,800,000 The costs for each instrument are shown in Table 20. These will be developed primarily in FY 2 and 3, as they are the drivers of the mission, it is vital that their success is ensured from an early stage. It also must be developed early since other subsystems such as CDH, and power, are affected by their ability to operate properly on their own. Therefore, 70% of the cost is allocated to FY 2 and 3, and 30% of the cost is allocated to FY 4 and 5.

1.11 Scope Management

1.11.1 Change Control Management

Team 27 has made substantial changes since the Mission Concept Review (MCR) and the SRR. Changes made to the SRR after receiving MCR feedback were comprehensively explained in the SRR. Now, the lengthy system of requesting changes is detailed below, as well as small changes made within the MDR based on previous content. There was also a change request submitted during this deliverable.

In submitting change requests, the PM of the team must fill out a form to identify what the area of change is (engineering, science, etc.) and what level the change is. The level of the change depends on the amount of risk associated with the change. High risk changes are listed as level Extreme, and must be reviewed before a Change Control Board (CCB) in order to get approval for the change. The PM is also required to describe the change requested to be made, provide reasoning for the change and how it would impact the mission, and provide an updated timeline if the change is to hinder the progress of the mission. Additionally, for Team 27 specifically, the PM has implemented a system to track the change requests made by the team. This has been done through the creation of a Google folder, where all change requests made are documented and numbered, starting with #01, within a spreadsheet titled *Change requests tracker*. This process was followed by Team 27 in submitting a change request to eliminate a secondary payload instrument called the PT1000. The reason for requesting this removal was due to the cost of the instrument, which caused the team's estimated total mission costs to exceed the constraint of $300 million by about $24 million. The team seeks to replace this secondary instrument with a cheaper alternative. The change request document is shown in Figure 19 in the Appendix, where further details can be found.

Feedback from any deliverable is presented in the form of mandatory Requests For Action (RFA) and suggested Advisories (ADV). For Team 27, feedback is incorporated after the PM first reviews all documented suggestions as listed from team mentors, and records which changes need to be made by each sub-team in a shared spreadsheet. The CS, LSE, and DPMR are then presented this updated spreadsheet, and, after their collective approval, each sub-team leader communicates the changes necessary to their respective sub-team. Any additional changes made within each sub-team are recorded by the corresponding team lead, which are then reported to the PM and subsequently recorded in the Google spreadsheet. This process was followed by Team 27 in applying feedback from the MCR to the SRR. It was also followed in applying feedback from the SRR to the MDR, and will be for feedback from the MDR to the PDR.

One small change that was made in the MDR based on previous content was the redistribution of personnel across sub-teams. This change was decided among team leads to be made during a team lead meeting, where the PM, DPMR, CS, and LSE were present. It was made after an in-depth discussion of the number of managers needed across the mission, dependent on the number of personnel present in each sub-team across phases. The team leads determined that the number of managers needed to be increased, which in turn altered the number of personnel within the administrative and management categories. After making this change, it was documented by the DPMR within a Google spreadsheet recording all changes made within the MDR. It was also listed as a low priority change to distinguish it from addressing an RFA or ADV.

Another small change made in the MDR was the inclusion of the updated STM (see Section 1.2), which was officially modified after the approval of a change request to remove the previous science objective "Determine if 10% of oxygen can be pulled from regolith in lunar conditions." The change request was approved for deliverables after submission of the SRR, allowing the CS to make the change of incorporating an updated STM with the removed science objective within this deliverable. This small change was also documented by the DPMR within the aforementioned Google spreadsheet and listed as a low priority change to distinguish it from addressing an RFA or ADV.

ALL CHANGES MADE PRIOR TO SUBMISSION OF MDR

Change #	If a response to an ADV or RFA, list the number here	Request for change number if applicable	Sub team of change	Who proposed the change	What was the change	Date added to table	Has the change been made?
#01	LOW PRIORITY	--	Team leads	Team leads	Changing personnel numbers for mission	11/8	Yes
#02	LOW PRIORITY	--	Science	Team 27	Inclusion of updated STM after approved change request	11/8	Yes

Figure 11: Documented low-priority changes made within the MDR.

1.11.2 Scope Control Management

Team 27 has experience in putting plans for scope control into action for the MDR. Methods for scope control that have been and will continue to be used during the course of the mission should a scope change be needed are discussed below.

When the budget for the mission was significantly cut by L'SPACE, going from \$425 million to \$300 million, Team 27 sat together in a meeting to discuss plans for descoping to lower its calculated mission budget at the time, which was \$311,735,749. The Program Analyst (PA) worked with the rest of the team to determine allocations of funds within each sub-team and realm at the time, including each engineering subsystem, programmatics, and science. Additionally, the CS spoke to the programmatic advisor of L'SPACE for suggestions on the team's mission budget based on the previous budgetary constraint. Ultimately, the following changes were made: the manufacturing cost was estimated to be a lower amount–estimated due to an incomplete mechanical subsystem–than before, outreach costs were cut, direct costs were re-calculated based off of precise calculations rather than over-accounting percentages, the spacecraft margin was set, and test facilities costs were re-calculated and altered. In the end, this resulted in Team 27's budget being reduced to an amount of \$295,634,140, and was submitted to L'SPACE for approval.

This process of descope for the mission budget allowed Team 27 the opportunity to develop methods and plans for scope control should a scope change be needed. It also allowed the team to put scope control plans into action in areas other than the budget. For example, Team 27 decided to reduce details within the areas of the mission to essentials only, specifically for the mechanical subsystem, where final components and costs were not wholly confirmed. This allowed the team to focus on producing stronger subsystems for other engineering areas while ensuring the mechanical subsystem had a less-detailed but sufficient foundation to ensure the success of the entire spacecraft. Furthermore, this led to further refinement of a more accurate overall mission budget. Additionally, to ensure personnel and resources are allocated properly across sub-teams and mission phases, and because the new budget constraint allowed for greater monetary allocation to personnel (alluding to the several million dollar difference between the new budget constraint of $300 million and updated, submitted budget of $295,634,140), Team 27 decided to increase the number of managers and decrease the previous number of administrative personnel to balance the personnel sub-teams. Increasing the scope by means of personnel increase and re-distribution of management across sub-teams ultimately lead to a change in overall budget, as one of the reasons for doing so was because of the margin that allowed for a greater number of personnel (from 51 personnel before to 54 personnel now) of varying salary earnings. It is changes like these that Team 27 will use in order to increase and decrease scope, depending on the situation within each area of the mission. For example, it could be decided that a larger number of funds be allocated to outreach in order to ensure utmost public enlightenment on the mission, its goals, and why it benefits all. This could be reasoned due to a greater-than-expected amount of funds being left over of the overall budget mission that is not needed for other areas of the mission. Or, in another case, Team 27 could choose to focus more on the science of the mission and increase scope to emphasize science with the knowledge that one of the engineering subsystems will not be as robust as the rest.

However, it was found at last minute that the cost for a secondary payload instrument had not been wholly accounted for, and put the team over the $300 million budget constraint by about $24 million. Team 27 acted quickly and decided that this instrument could be replaced since it was secondary, practicing descoping to cut down on the budget by submitting a change request. The scope of the mission will not be decreased should this change request be approved and the instrument replaced, as they will both serve the same function–to measure temperature and pressure–but the replacement will assist in putting the team's budget back on track with a much cheaper cost. Though a budget that meets the mission constraints is not currently displayed in this deliverable, Team 27 hopes to present one that does with the replacement of this instrument moving forward and within the PDR.

1.12 Outreach Plan

The outreach plan aims to increase public awareness and engagement with the mission, promoting the value of space exploration and inspiring the next generation. It is designed to raise public awareness and foster a deeper appreciation for the mission's scientific goals and objectives. Targeted outreach will inspire curiosity in space exploration and STEM disciplines by engaging a broad audience, from young students to university scholars and underrepresented communities. Using a team of twelve members, each with specialized expertise, this outreach plan is equipped to provide enriching, hands-on experiences that connect diverse communities with real-world science and engineering challenges linked to the mission.

Engaging K-12 Schools

Outreach efforts will prioritize engaging local K-12 schools to introduce students to the mission and space science. To make Science, Technology, Engineering, and Mathematics (STEM) concepts accessible, the plan includes:

- **Presentations and Classroom Visits:** Team members will visit schools to give appropriate discussions and engage with the curriculum. This presentation will introduce the mission, explain its scientific objectives, and connect the purpose of space exploration to technological advancements that benefit society.

- **Interactive STEM Activities:** Students will participate in hands-on activities, such as building simple models of spacecraft components or simulating mission tasks. By applying STEM concepts through these activities, students will experience how scientific principles apply to real-world space missions.

- **Mission Challenges and Research Projects:** Schools will be invited to participate in a mission challenge where each student can design and build spacecraft models, conduct research projects related to the mission, and propose ideas for similar missions. This approach will help them grasp the complexity and scope of space exploration.

- **Workshops and Summer Camps:** The focus includes workshops and summer camps, which focus on students and families to explore mission-related topics through engaging projects like arts and crafts, model-building, and simulations of mission tasks. These events promote family participation and deliver memorable, hands-on learning experiences that bring space science to life.

Schools and Homes In Education (SHINE) is offered four days a week and uses a project-based STEAM (Science, Technology, Engineering, Arts and Math) curriculum to kindle excitement about learning. Activities like this will emphasize problem-solving and critical-thinking skills and highlight future career opportunities related to the mission in space science, engineering, and technology.[75]

University and College Outreach

At the university level, outreach efforts will connect students in STEM programs with real-world applications of their studies through targeted engagement initiatives, including:

- **Collaborations with University Departments:** The team will partner with academic departments to host talks, guest lectures, and workshops, where members will share their professional experiences and detail how the mission contributes to space exploration. These events will offer insights into careers in space missions, inspiring students to explore science and engineering fields directly related to the mission.

- **Research Opportunities and Internships:** University students will be offered research opportunities and internships to work on mission-related projects. Faculty collaborations will enable students to contribute directly to mission research while gaining hands-on experience in scientific and engineering processes related to space exploration.

75. William Center, “Wilkes University’s Sidhu School of Business and Leadership Students Volunteer with SHINE of Luzerne County,” 2019, accessed November 16, 2024, https://news.wilkes.edu/2019/04/09/wilkes-universitys-sidhu-school-of-business-and-leadership-students-volunteer-with-shine-of-luzerne-county/.

- **University Competitions:** Competitions will be organized or sponsored, challenging students to propose innovative solutions to mission-related problems. Winning teams are given the chance to collaborate with mission team members, helping to develop new ideas and foster an interest in space mission design and problem-solving.[76] As part of the challenge, teams will design, build, and fly a high-powered amateur rocket and scientific payload. They also must meet documentation milestones and undergo detailed reviews throughout the school year.

Community Centers and Public Engagement

The outreach plan aims to expand mission-related STEM access for underrepresented groups by collaborating with community centers.[77] Planned activities include:

- **Public Exhibitions and Events:** Community centers will host exhibitions and interactive displays that introduce the mission to broader audiences. These events will feature live demonstrations, models of spacecraft components, and informational talks that make space exploration more accessible and relatable.

- **Volunteer Programs and Mentorship:** Team members will participate as mentors and volunteers at community events, where they will host interactive discussions that demonstrate how space science connects to everyday life. Mentorship opportunities will encourage sustained interest in STEM and foster lasting connections within the community.

- **Hands-On Workshops and Seminars:** Through practical workshops, community members will build small spacecraft models, explore satellite technology, and engage with mission-related topics. These workshops are designed to make space science approachable for all ages and abilities, nurturing interest and understanding in space exploration.

Outreach to Underrepresented Communities

The outreach plan prioritizes diversity and inclusion in STEM, with a special focus on engaging underrepresented communities. This includes:

- **Partnerships with Diversity Initiatives:** Collaborations with organizations that support STEM education in underrepresented communities will provide mentorship, resources, and learning opportunities tailored to the mission. These partnerships ensure that these communities have access to mission resources and STEM career paths.

- **Culturally Relevant Programming:** To ensure the mission's message reaches all backgrounds, programming will be customized to meet cultural needs, including offering sessions in multiple languages. This approach fosters inclusivity and broadens the mission's reach.

76. Taylor Goodwin, "NASA Announces Teams for 2025 Student Launch Challenge," 2024, accessed November 16, 2024, https://www.nasa.gov/centers-and-facilities/marshall/nasa-announces-teams-for-2025-student-launch-challenge/.

77. Center, "Wilkes University's Sidhu School of Business and Leadership Students Volunteer with SHINE of Luzerne County."

By collaborating with organizations focused on diversity, the outreach plan will address the importance of representation in STEM, building connections with communities that may face barriers to accessing STEM resources and career guidance.[78]

Global Outreach via Digital Media

A global audience will be engaged through a strategic digital outreach campaign that extends the mission's impact beyond local communities. This digital approach includes:

- **Social Media Campaigns:** Platforms like Instagram, Twitter, and Facebook will share mission milestones, behind-the-scenes content, and educational posts. By providing regular updates and interactive media such as infographics and video tutorials, social media will build an engaged community of space enthusiasts around the world.

- **Online Webinars and Live Streams:** Webinars and live streams will allow the global audience to interact with team members, ask questions, and learn about mission details in an engaging virtual environment. These events will include demonstrations, Q&A sessions, and presentations that allow viewers to experience mission updates and explore space science topics.

- **Collaborations with Global STEM Networks:** Partnerships with international STEM organizations and space agencies will promote the mission on a global scale, inspiring STEM activities worldwide. By engaging with established networks, the mission's outreach will reach diverse audiences across geographical and cultural boundaries, spreading the excitement and educational value of space exploration.

Conclusion

This outreach plan strategically aligns with the mission's scientific objectives by creating educational opportunities and fostering connections with local, national, and global communities. By engaging K-12 schools, universities, community centers, underrepresented groups, and a digital audience, the plan ensures that the mission's relevance and excitement are communicated to diverse audiences. Through presentations, interactive activities, research opportunities, and online platforms, the outreach plan aims to inspire future generations of scientists, engineers, and space enthusiasts, all while strengthening the public's understanding of the mission and its contributions to space exploration.

1.13 Conclusion

In this document, Team 27 has established the full scope of personnel needed for the entire lifetime of the mission, including the number of managers, administrators, technicians, scientists, and engineers needed. The Concept of Operations for the mission was also created, with an insightful diagram detailing the important landmarks of each mission phase.

Team 27 would like to note the loss of the Thermal Engineer of the team during the deliverable, which resulted in the Thermal Failure Mode and Effective Analysis section

78. NASA, "NASA Systems Engineering Handbook."

being incomplete as the rest of the team was unable to make additional time to pick up the responsibility of this section. This is also true for the Mechanical Failure Mode and Effective Analysis section, as Team 27 does not have a Mechanical Engineer. As the rest of the team was able to complete their work to the highest standard within the deadline of the deliverable, it was decided that no extension request form would be submitted. To complete this deliverable, Team 27 established a new system with deadlines for first and final drafts of work over a time period of three weeks to ensure all work was shared and reviewed by multiple people within the team.

Team 27 also established a detailed mission schedule and budget that encompasses the entirety of the mission. Notably, the mission underwent a severe budget cut, changing the new budget of the mission from $425 million to $300 million. This resulted in a reduction of Outreach cost, test facilities spending, manufacturing processes, and direct costs. Despite the cut to funding, a large-scope Outreach plan has been made that includes but is not limited to promotion on social media, within K-12 schools, and within universities.

If Team 27 had additional time, and members, the team would have completed the Mechanical and Thermal Failure Mode and Effective Analysis sections to complete that portion of the MDR. The team would have also created manufacturing and procurement plans for the Mechanical and Thermal subsystems.

In preparation for the PDR, Team 27's PM has already established a schedule of when all RFA's must be implemented into existing sections. All changes are tracked in the *Changes Made* spreadsheet, as noted in the Change Control Management section. Thus, the Team Leads plan to make it a priority that all changes are completed and properly recorded. The team would also like to make it a goal to establish the needed mechanical subsystem drawings, as was required for the SRR. As of 11/17/2024, it has been decided that the PM will proceed onward as the co-LSE so that the LSE can complete the Mechanical and Thermal subsystems as required. In this position, the PM will be in charge of assisting the remaining engineers with their work, proof-reading it, and communicating with the team about all engineering decisions, as was previously the LSE's job.

The science subteam also desires to remedy the missing information of the Silicon Photomultiplier instrument, which was noted in the SRR. A careful re-evaluation of TRL levels for other instruments shall also be conducted to ensure Team 27 properly reports the TRL of the payload subsystem, and spacecraft overall.

Lastly, Team 27 recognizes that there was some issues with labeling of figures and tables in the SRR. While this was due to a LaTeX compiling error, the Team looks to remedy these formatting issues with a newly coded document starting in the MDR, and continuing into the PDR to ensure linearity across the rest of the deliverables.

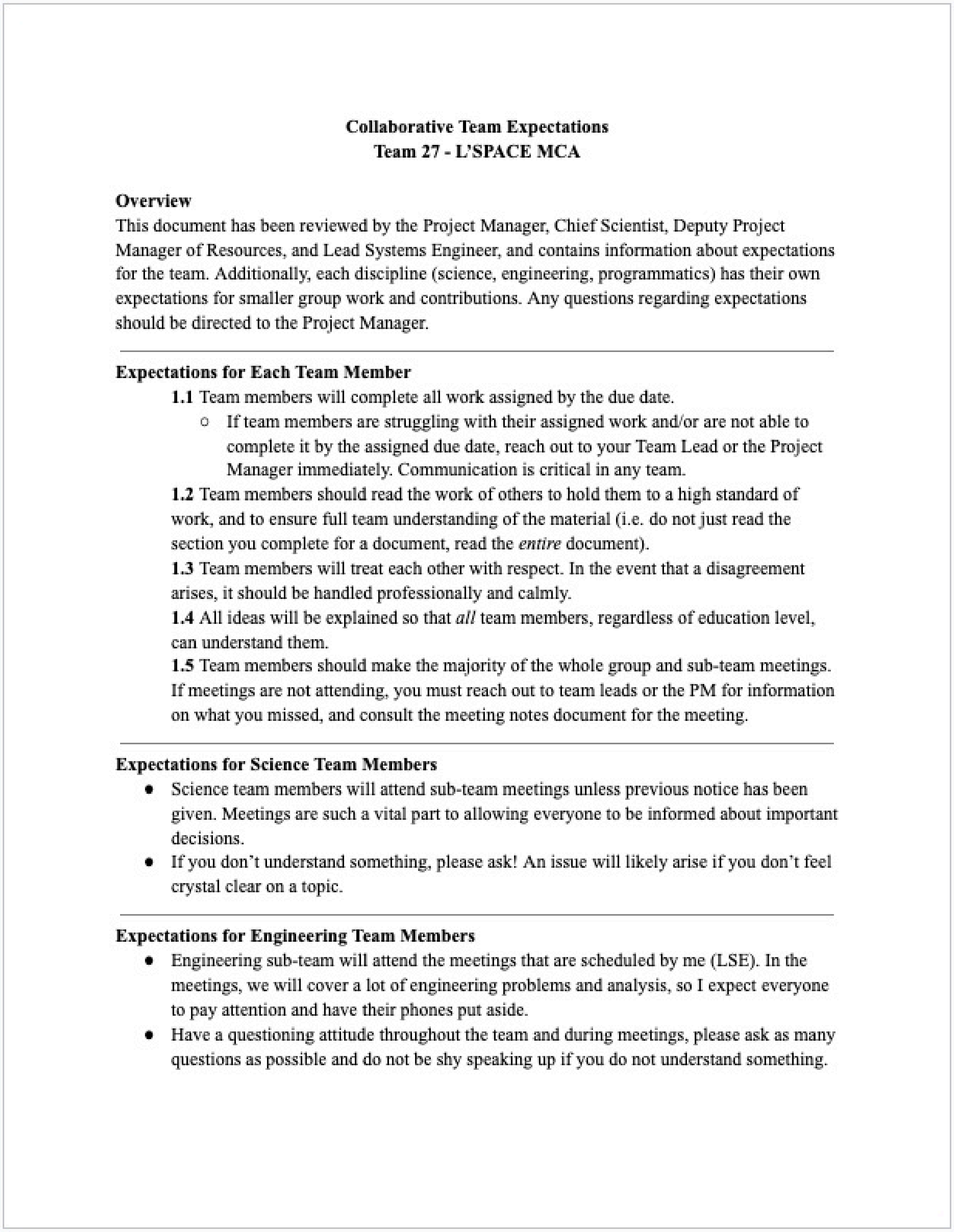
2 Declaration of Generative AI and AI-assisted technologies in the writing process

Team 27 did not use any Generative AI in the writing process of the Mission Definition Review.

3 Appendix

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
CC - 0.0	The mission shall adhere to customer constraints.	Parameters outlined in document, in relation to the given constraints and requirements	N/A	CC 0.1 - CC 0.10 MG - 1.0	Analysis	All	Met
CC - 0.1	System must adhere to mass constraint of 350 kg	Limited by the mission task, and to ensure not to over exceed mass capacity during transport.	CC - 0.0		Inspection	All	Met
CC - 0.2	System must adhere to dimension constraint of 2 m x 1.25 m x 1.25 m during transit	Limited by spacecraft transport dimensions; cannot exceed due to constraint.	CC - 0.0		Inspection	All	Met
CC - 0.3	System must explore the lunar/pits caves and perform surface science operations	Outlined mission statement and goal for research.	CC - 0.0		Inspection	Payload	Met
CC - 0.4	System must not exceed cost constraint of $425M	Limited by set amount of allocated funding. Cannot exceed due to unavailable funds.	CC - 0.0		Inspection	All	Met
CC - 0.5	System must be ready to launch by March 1st, 2030, at Cape Canaveral.	Hard deadline, set by mission timeline.	CC - 0.0		Inspection	Payload	Met
CC - 0.6	System cannot have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof; System must not exceed radioactive material cumulative mass of 5g	The usage of the RTG is prohibited, in accordance with the mission.	CC - 0.0		Inspection	Electrical, Structural, Mechanical	Met
CC - 0.7	System will be transported on a separate, primary vehicle launch (rocket) with power sufficient during transport. No scientific data will be collected during transit	Transportation structuralization and unavailability of research during transit.	CC - 0.0		Inspection	Structural	Met
CC - 0.8	System shall arrive at target destination adhering to landing site constraints: given a 100m diameter landing zone, it shall not exceed a slope of 10 degrees, and should traversal be necessary to the science site or lunar cave, it must no be no further than 5 km from the landing zone (only applicable for mobile vehicle)	Landing site parameters/criterias outlined in mission.	CC - 0.0		Analysis	Structural, Mechanical	Met
CC - 0.9	System shall communicate data to Earth via relay of spacecraft orbiting the Moon; spacecraft must be able to communicate with the orbiting spacecraft directly, and primary mission orbiter which shall remain in a circular polar orbit of 100km during the mission's lifespan	Communications necessary in order to establish control, navigation, and data collection.	CC - 0.0		Demonstration	Electrical, Communication, Mechanical	Met
CC - 0.10	System shall undergo analog testing in a comparable volcanic environment; drop testing is necessary should the landing site not have a traversable entrance, and tether or winch system	Necessary to evaluate mission success and analyze potential faults and feasibility.	CC - 0.0		Test	All	Met
MG - 1.0	The mission shall conduct scientific research of the Mare Ingenii Pit in relation to the sustainability of human infrastructure.	In conjunction with the Mission Goal: "Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon" and ""Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure"	CC - 0.0	SCI - 1.1 SCI - 1.2 SC - 1.3	Demonstration	All	Met
SCI - 1.1	The mission shall investigate magnetic fields within and around the Mare Ingenii Pit	To observe and analyze the abnormal magnetic fields	MG - 1.0		Analysis	Science, Communication	Met
SCI - 1.2	The mission shall analyze the viability of human habitation within the lunar pit.	To identify the plausibility of lunar colonial/mission infrastructure.	MG - 1.0	SCI - 1.2.1 SCI - 1.2.2 SCI - 1.2.3	Analysis	Science	Met
SCI - 1.2.1	The mission shall determine the properties of radiation on temperature, humidity, and pressure within the pit.	To determine the pit's sustainability in terms of colonial/mission infrastructure.	MG - 1.0		Analysis	Science, Communication, Mechanical	Met
SCI - 1.2.2	The mission shall identify and characterize the depth, height, terrain variation, and ease of access within the lunar pit.	To determine the lunar pit's infrastructure and identify its strengths and weaknesses for colonial/mission infrastructure.	SCI - 1.2.1		Analysis	Science, Navigation, Communication	Met
SCI - 1.2.3	The mission shall analyze the lunar pit's structural integrity.	To determine the lunar pit's infrastructure and identify its strengths and weaknesses for colonial/mission infrastructure.	SCI - 1.2.1		Analysis	Science	Met
SC - 1.3	The mission shall utilize a spacecraft for the duration of the mission and to fulfill mission research.	Mission requires a method of conducting research in a controlled and measurable manner.	MG - 1.0 SCI - 1.1	SC - 1.3.1 SC - 1.3.2 SC - 1.3.3	Demonstration	All	Met
SC - 1.3.1	The spacecraft shall be able to traverse the lunar terrain in regards to its mission.	The Mare Ingenii Pit has a diameter of 130m; the spacecraft must be able to traverse the pit to fulfill its mission.	SCI - 1.1	SC - 1.3.1.1 SC - 1.3.1.2	Testing	Structural, Mechanical, Navigation	Blank
SC - 1.3.1.1	The spacecraft will be remotely piloted to navigate the lunar terrain via cameras.	In order to navigate the spacecraft, a visual representation is needed to guide the device forward.	SCI - 1.1		Demonstration	Structural, Mechanical, Navigation	Met
SC - 1.3.1.2	The spacecraft mobility parameters must be able to withstand the traversal conditions of the lunar plane.	The terrain of the lunar surface is very harsh with its sharp rocks, and micron-sized regolith dust. Its mobility features must be able to withstand these conditions.	SCI - 1.1		Demonstration	Structural, Mechanical, Navigation	Met
SC - 1.3.2	The spacecraft shall have sufficient power to maintain mission operations.	Spacecraft functionality is derived off its power.	SCI - 1.1		Demonstration	Electrical	Met
SC - 1.3.3	The spacecraft shall transmit and receive data to the corresponding entities for research and data collection.	Data obtained by the spacecraft must be transmitted to the research team (orbiter, space station, etc.) to be analyzed for scientific research. Must adhere to the CC - 0.9 restriction.	SCI - 1.1		Demonstration	Communications	Met
SC - 1.3.3	The spacecraft shall transmit and receive data to the corresponding entities for research and data collection.	space station, etc.) to be analyzed for scientific research. Must adhere to the CC - 0.9 restriction.	SCI - 1.1		Demonstration	Communications	Met
SC - 1.3.4	The spacecraft will be equipped with scientific instruments to accomplish its mission tasks.	Data collection of scientific tools/instruments is crucial composing it into data that can be researched/analyzed.	SCI - 1.1	SC - 1.3.4.1 SC - 1.3.4.2 SC - 1.3.4.3 SC - 1.3.4.4 SC - 1.3.4.5	Demonstration	Science, Mechanical, Electrical	Met
SC - 1.3.4.1	The scientific instrument shall be able to manipulate and measure lunar surface temperatures.	In order to accomplish the requirements outlined in SCI-1.1.1, the spacecraft must be able to measure surface temperature (or even manipulate) to identify the amount of heat needed for lunar regolith to produce 10% yield of oxygen.	SC - 1.3.4		Demonstration	Mechanical, Electrical, Communications	Met
SC - 1.3.4.2	The scientific instrument shall detect magnetic fields in the 0-5000nT range over an area of 10km.	In order to accomplish the requirements outlined in SCI-1.2, the spacecraft must be able to measure the magnetic fields within the area.	SC - 1.3.4		Demonstration	Mechanical, Electrical, Communications	Met
SC - 1.3.4.3	The scientific instrument shall detect radiation percentages of Alpha, Beta, and Gamma radiation.	In order to accomplish the requirements outlined in SCI-1.3.1, the spacecraft must be able to measure the radiation within the area.	SC - 1.3.4		Demonstration	Mechanical, Electrical, Communications	Met
SC - 1.3.4.4	The scientific instrument shall be able to determine terrain characteristics.	In order to accomplish the requirements outlined in SCI 1.3.2, the spacecraft must be able to identify the depth, height, and ease of access within lunar pits.	SC - 1.3.4		Demonstration	Mechanical, Electrical, Communications, Navigation	Met
SC - 1.3.4.5	The scientific instrument shall be able measure muon flux variations.	In order to accomplish the requirements outlined in 1.3.3, the spacecraft must be able to penetrate and measure the amount of muon flux variation.	SC - 1.3.4		Demonstration	Mechanical, Electrical, Communications	Met

Figure 12: The complete Requirements chart for the mission.



Collaborative Team Expectations
Team 27 - L'SPACE MCA

Overview
This document has been reviewed by the Project Manager, Chief Scientist, Deputy Project Manager of Resources, and Lead Systems Engineer, and contains information about expectations for the team. Additionally, each discipline (science, engineering, programmatics) has their own expectations for smaller group work and contributions. Any questions regarding expectations should be directed to the Project Manager.

Expectations for Each Team Member

1.1 Team members will complete all work assigned by the due date.
  - If team members are struggling with their assigned work and/or are not able to complete it by the assigned due date, reach out to your Team Lead or the Project Manager immediately. Communication is critical in any team.

1.2 Team members should read the work of others to hold them to a high standard of work, and to ensure full team understanding of the material (i.e. do not just read the section you complete for a document, read the *entire* document).

1.3 Team members will treat each other with respect. In the event that a disagreement arises, it should be handled professionally and calmly.

1.4 All ideas will be explained so that *all* team members, regardless of education level, can understand them.

1.5 Team members should make the majority of the whole group and sub-team meetings. If meetings are not attending, you must reach out to team leads or the PM for information on what you missed, and consult the meeting notes document for the meeting.

Expectations for Science Team Members
- Science team members will attend sub-team meetings unless previous notice has been given. Meetings are such a vital part to allowing everyone to be informed about important decisions.
- If you don't understand something, please ask! An issue will likely arise if you don't feel crystal clear on a topic.

Expectations for Engineering Team Members
- Engineering sub-team will attend the meetings that are scheduled by me (LSE). In the meetings, we will cover a lot of engineering problems and analysis, so I expect everyone to pay attention and have their phones put aside.
- Have a questioning attitude throughout the team and during meetings, please ask as many questions as possible and do not be shy speaking up if you do not understand something.

Figure 13: The original Team Expectations document, as first introduced in Section 1.5. Part 1.

- Draw out any ideas you have for anything and show it to the team, a picture is worth a thousand words!

Expectations for Programmatics Team Member

- General expectations for each team member will be followed within the programmatics sub-team.
- All messages sent in the programmatics channel on Discord will be required to be read and reacted to to ensure all teammates are up-to-date and actively understanding and processing information sent out.
- Members in the programmatics sub-team will maintain communication through private messages with their team lead (DPMR) and public channel conversation.
- Progress on tasks by each team member will be regularly sent into the public programmatics Discord channel, so that all are aware of what is being worked on and can review each other's work to ensure high quality.
- Programmatics sub-team meetings have required attendance for all of its members.

Resources Available for Team Members

- MCA Resources Folder – [link]
    - This google drive made by MCA Staff contains several templates as well as directions for what to do for deliverables.
- Weekly Role Meetings
    - Role meetings can be attended for questions that are unable to be answered by the team. We ask you to take notes during the meetings you attend and share these with the team to ensure total team understanding.

Weekly Role Specific Meeting Schedule - FA24

10/14 - 12/6

Time (PT)	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
12:00 PM					
1:00 PM					
2:00 PM		Electrical Engineer Meeting Click to Join Zoom			CDH Engineer Meeting Click to Join Zoom
3:00 PM			Mechanical Engineer Meeting Click to Join Zoom		
4:00 PM			Thermal Engineer Meeting Click to Join Zoom	Science Meeting Click to Join Zoom	
5:00 PM	Program Analyst Meeting Click to Join Zoom		Mission Assurance Meeting Click to Join Zoom		
6:00 PM					

Figure 14: The original Team Expectations document, Part 2.

- Project Manager Availability – Josie Wood
  - I have my Discord notifications on, so feel free to send me a message whenever and I will get back to you when I can. I typically am working/have class 9-6 Monday through Friday, but I typically respond within two hours (unless it's past 11pm and I'm sleeping).
- Chief Scientist Availability – Jessica Ray
  - My availability is ever changing since I don't have a set schedule as an online student. If a question or concern arises, don't hesitate to message me; I should respond within 4 hours max.
- Lead Systems Engineer Availability – Kaushal Patel
  - ➢ My availability varies, but I'm free mostly in the evenings starting from 6:30pm Monday through Friday until 9pm. For weekends I'm mostly free throughout the whole day. I prefer to be on call rather than texting so we do not waste time texting and going back and forth. Discord works for me, so if you have any questions or want to talk, DM me on Discord and we can go from there.
- Deputy Project Manager of Resources Availability – Lyss Harnden
  - Please feel free to send me questions via Discord DM at any time, I will get back to you within 1-2hrs. I am free Monday through Friday 7am-11pm CT; on weekends I have less availability due to making time for loved ones and hobbies! However, you can still expect a response by me during the weekend within a few hours.

Figure 15: The original Team Expectations document, Part 3.

Updates to Team Expectations

Hello everyone. As you should have noticed, there have been some major changes that your Team Leads have addressed. These are non-negotiable. We will not be saying "You can have more time to do your work! Submit it when you can!" This is unacceptable, and quite frankly lacks the scope of real-world due dates. Your future boss isn't going to give you an extension because you failed to meet your deadline due to poor time management. As was mentioned in the L'Space meeting on Tuesday, your mission would have high risk of being canceled due to failure to meet deadlines.

As some of you may fondly remember, I talked last week Sunday about how what you get out of this academy is what you put in. If you want something to present to an interviewer, do your work so you have something to proudly share.

That being said, I will not be answering the 11pm messages of frantic "I can't complete my work" anymore. I will strictly have office hours from 5-8pm Monday-Friday for you to ask me questions as long as you have spoken to your Team Leads prior to then. Anything not sent to me between these time frames will be ignored until the next time I am available. I am really bad at sticking to just answering messages within a set time, but I will be forcing myself to do this so that I have time for classes (and I wanna play Assassins Creed man). Appointments may be scheduled with me on a case-by-case basis outside of these hours. As your PM, my duties will include reminding you of due dates, scheduling group meetings, overseeing everyone's work that is **submitted to their Team Lead,** and mitigating conflicts. If you have a conflict with your team lead, feel free to message me. Otherwise, you will rarely be in direct contact with me unless I message you first. This is to follow the hierarchy structure that we established as a team for the Team Organization deliverable.

It should also be noted that three major changes will happen:

- Non-negotiable deadlines will be set for all deliverables for when work must be submitted by. **If you don't submit your work to your team lead prior to the deadline, your work isn't going into the deliverable** (unless you have spoken to me or a Team Lead about an extension). I will be sending reminders of this hard deadline so you don't forget to meet it.
- This was already a requirement, but if you're not attending meetings you must consult the meeting notes or watch the meeting recording. All information about deadlines and tasks is going to be shared over meetings, and if you're not attending them or taking the time to make up the meeting you missed, you're not going to know what's happening in the team. Thus, if you are given a deadline or task in a team meeting you are not present in, I highly recommend that you actually watch the meeting afterwards so you know this task was assigned to you! If you end up not doing what was assigned during the meeting, that's not good!
- Lastly, we will be enforcing a two strike rule. The first strike is when your Team Lead receives no work from you, or work that is unacceptable. If this is not corrected in a timely manner, your second strike will be ***me***. If I reach out to you about work needing to be done or work that needs to be fixed, and you don't do it, we will be turning you into the loving hands of Darcy and staff.

Lastly, if you have read all of this, please react to this message with a weather effect of your choice (ex snowflake, cloud, tornado). Please don't duplicate emojis so I know who has made it to the end! If no more weather emojis are left, feel free to move onto plants.

Figure 16: The team expectations document moving forward from the SRR, written by the PM.

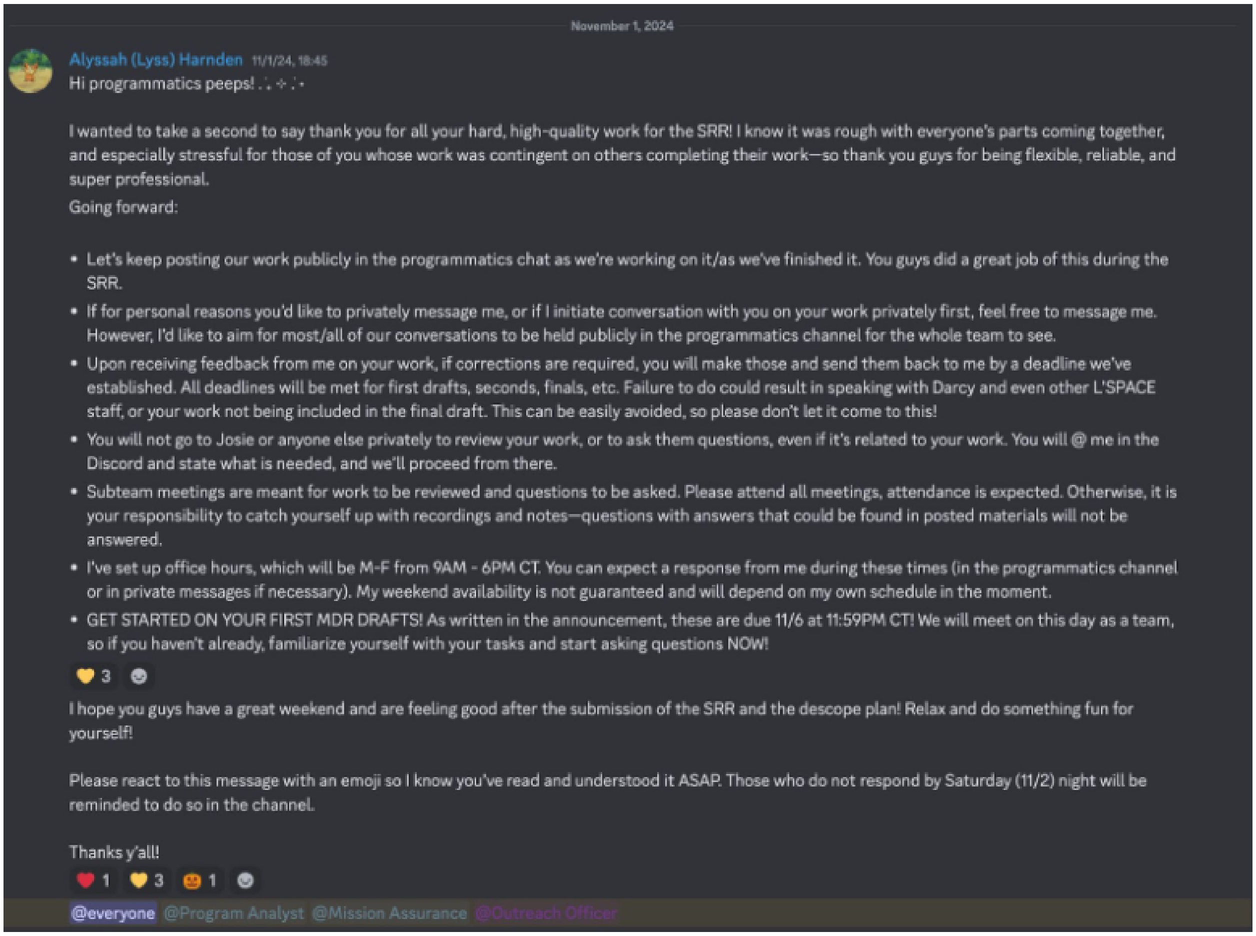


Figure 17: The MDR expectations announcement sent by the DPMR in the programmatics channel via Discord.

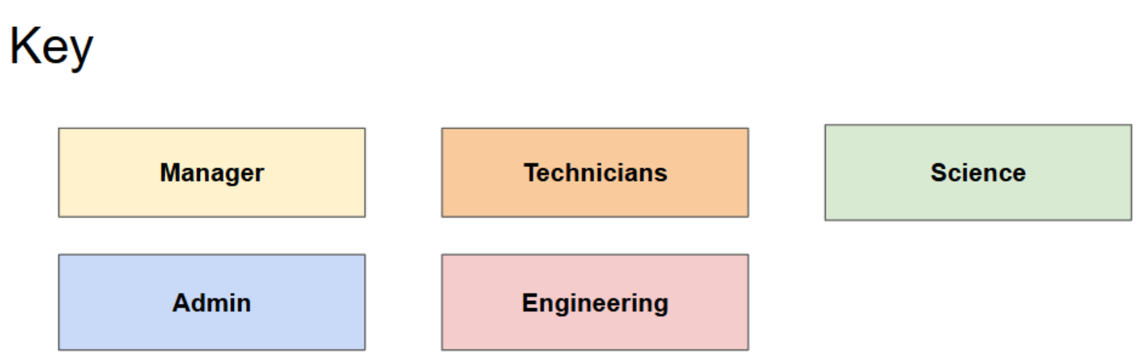


Figure 18: The color-coded key of the organizational charts.

Solar Cell Array Data for Spacecraft

Solar Cell Efficiency:	30%
Solar Cell Temperature Coefficient:	88%
Solar Cell EOL Environment	93%
Solar Panel Packing Density	90%
Solar Panel AOI	99%
MPPT Efficiency, Line Loss, Diode	85%
Power delivered to EPS	253.1 W/m²
Average power needed from PEL/Profile	200.0 Wh
Add in growth margin	20%
Solar array area needed	0.95m²
Designer margin	10%
Total array needed:	1.05m²

Table 15: A table detailing the Solar Cell data for the spacecraft.

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Power Generation of Solar Array System	Obstruction blocking solar cell surface area, preventing it collecting solar energy and converting it to usable power.	The solar array system will output/generate less power for the spacecraft.	4	Lunar regolith or similar debris may obsecure or block the solar cell from obtain direct solar energy.	6	Active movement of the vehicle ensures debris is removed from vibration.	3	72	Solar Array "clean-up" procedures such as spacecraft movement to remove debris from unstable movement, potential removing debris and obstruction from the solar-array system.
	Reduction of performance of solar cell from extending past safe temperature threshold.	Insufficient amount of power generation will cause the spacecraft to shut-down or operate at lower power levels; power management mode, result in limited instrument usage.	8	Excessive overheating of too much insulation and direct sunlight, or insufficent amount of insulation and heat to ensure solar cell operating temperature is not under-exceed.	2	Active thermal mitigation such as the cryo-cooler and insualting MIL will ensure temperature is stabilized.	3	48	Depending on the temperature, whether it is exceeding or under-exceeding, tactical movement of the spacecraft towards or away more insulating environment such as lunar pits, aid in temperature regulation.
	Solar cell abnormal failure such as short circuit, electrical open, etc.	Open in the solar array system circuit can cause reduction of power generation or complete failure depending where the open or short is.	8	Sharp debris, or regolith may cause opens in the electrical circuit system.	2	Active management of PDCU and alternative circuit paths will ensure the open or short is manageable or contained.	1	16	Opens in the circuit system, will require specific commanded shut-downs or reduction in other instrument performance in order to ensure the integrity of system.
Power Storage of Battery Packs	Reduction of performance or integrity of battery packs from extending past safe temperature thresholds.	Battery performance is reduced, potentially reducing battery voltage, amperage, and power capacity, and output.	8	Excessive overheating of too much insulation or lack of insulation can cause the batteries to fail or perform at reduced operating level due to battery material/intergrity being compromised.	2	Active thermal mitigation such as the cryo-cooler and insualting MIL will ensure temperature is stabilized.	2	32	Depending on the temperature, whether it is exceeding or under-exceeding, tactical movement of the spacecraft towards or away more insulating environment such as lunar pits, aid in temperature regulation. Additionally, because it is more insulated, being the battery pack; it can be more regulated.
	Physical damage of battery packs from physical trauma, puncture, and derivatives of similar nature.	Complete battery unit failure, and significant reduction is power performance and integrity.	9	Physical trauma, such as abrupt drop, sharp physical puncture, and direct collision with terrain, can cause the battery to become physically damaged; depending the level of trauma, the battery may perform at a reduced operating capacity, or in some cases, rendered inoperable.	2	The structural cage of the battery pack wills protect the batteries from moderate trauma.	3	54	The action is dependent on level of damage from physical trauma; if the damage is minimal, mission operations can continue at reduced operational capacity. If the damage is severe, the mission may need to prepare for disposal and recovery.
	Unnecessary battery discharge or parasitic draw.	Battery output is being depleted at a constant or distinct rate, reducing battery intergrity and output performance.	4	Malfunction intruments or subsystems, can cause a parasitic draw or battery discharge from the battery storage system, reducing the output capabilites of systems, as well as the battery storage's life-span.	3	Active management of PDCU will manage the parasitic draw or discharge via shut-down of active usage or reset. Additionally, the PDCU has a built in redundant under voltage-lockout system to monitor under-voltage systems.	3	36	Identification of the parasitic draw or unnecessary discharge is critical, and once identified, can be regulated to be shut-off or reset to maintain battery storage intergrity and output.
Power Distribution of PDCU	Open in the distribution circuit, whether it be towards an instrument, or power source.	Distribution unit will fail to supply power to affected circuit.	9	Opens in the distribution system can be caused by intial shorts, which can cause the circuit to overheat or burn the circuit, creating an open; alternative a sharp object or intensive physical trauma can an open in the short.	2	In order to prevent an open in the system by physical trauma, the wires are insulated and protected. Additionally, the built-in shortage protections will prevent the wires from heating up and burning the circuit.	1	18	Opens within the system will require specific commanded shut-down or reduction in other instrument performance in order to ensure the integrity of the system. If open can be corrected via alternative circuit paths; the operations of that circuit may be continued; if they are not, shut-down is necessary.
	Short in the distribution circuit, wheter it be towards an instrument or power source.	Distribution unit will supply a surplus of defecit of power to affected circuit.	7	Shorts in the distribution can be caused by exposed wiring, or unnecessary grounded contact with "hot" circuits.	2	The PDCU has a built-in short-circuit protection system, alongside with a with a reverse polarity protection, preventing substantial damage should there be a shortage.	2	28	Short in the systems will require specific commanded shut-down or reductions in other instruments or system perforamnce to ensure the integrity in the system. Shorts can regulated if they are not signicant in affecting other systems; alternative circuits may be enacted to ensure proper utilization of instrument/system.
	Reduction of performance or integrity of PDCU from extending past safe temperature thresholds.	Decreased power distribution output or reduction in performance.	9	Excessive overheating from too much insulation or lack of insulation can cause the PDCU to fail; causing the PDCU to operate at a reduced operating capacity.	2	Active thermal mitigation such as the cryo-cooler and insualting MIL will ensure temperature is stabilized.	3	54	Depending on the temperature, whether it is exceeding or under-exceeding, tactical movement of the spacecraft towards or away more insulating environments such as lunar pits, can aid in temperature regulation. Additionally, utilzation of on-board thermal instruments such as the cryo-cooler can help regulate the tempearature.

Table 16: The Full Electrical Subsystem FMEA Chart

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Active Radiation Environment Sensor	Unable to withstand physical hazards from lunar environment	Cannot pursue part of the science objective about the determination of the lunar pit sustaining human life in terms of radiation	9	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	2	Protection for the instrument, instrument built to withstand physical hazards	1	18	Remove radiation as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to detect radiation levels between 0 W/m² and 1,370 W/m²	Incorrect or no data about radiation levels of lunar pit collected	7	Faulty operation	1	Multiple operational tests for instrument	2	14	Remove radiation as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to detect Alpha, Beta, and/or Gamma radiation	Inaccurate determination of lunar pit's radiation environment	9	Corrupted data, faulty operation	2	Multiple operational and data tests for instrument	5	90	Utilize the available type of radiation detected
3-Axis Fluxgate Magnetometer Model AP235	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of locating potential magnetic fields	6	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	1	Protection for the instrument, instrument built to withstand physical hazards	1	6	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to measure magnetic fields in the nanoTesla range of 0 nT to 23 nT	Unable to detect potential magnetic fields	4	Faulty operation	1	Multiple operational tests for instrument	2	8	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to operate with a low noise level range of -0.05 RMS nT/√Hz to 0.05 RMS nT/√Hz	Collected magnetic field data corrupted by instrument's noise	3	Faulty operation and/or build	1	Multiple operational tests, instrument built with care for noise	1	3	Determine if data can still be utilized or saved from corruption of noise
Bartington Fluxgate Magnetometer, 3-axis, Aerospace/Space	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of locating potential magnetic fields	6	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	1	Protection for the instrument, instrument built to withstand physical hazards	1	6	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to measure magnetic fields in the nanoTesla range of 0 nT to 23 nT	Unable to detect potential magnetic fields	4	Faulty operation	1	Multiple operational tests for instrument	2	8	Replace the science objective about locating potential magnetic fields with a new science objective
	Fail to operate with a low noise level range of -0.05 RMS nT/√Hz to 0.05 RMS nT/√Hz	Collected magnetic field data corrupted by instrument's noise	3	Faulty operation and/or build	2	Multiple operational tests, instrument built with care for noise	1	6	Determine if data can still be utilized or saved from corruption of noise
Model HMP60 Humidity Sensor + Model DI-808	Unable to withstand physical hazards from lunar environment	Cannot pursue part of the science objective about the determination of the lunar pit sustaining human life in terms of humidity	9	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	5	Protection for the instrument, instrument built to withstand physical hazards	1	45	Remove humidity as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to measure temperature range of 16 °C to 18 °C	Incorrect or no data about humidity levels of lunar pit collected	5	Faulty operation	2	Multiple operational tests for instrument	2	20	Rely on PT1000 Class F0.3 + Pressure-Temperature for temperature readings
	Fail to detect temperature during peak ranges of radiation percentages every second	Cannot pursue part of the science objective about the determination of radiation effects on humidity	4	Faulty operation, slow response	4	Multiple operational and data tests for instrument	4	64	Replace the part of the science objective about the determination fo radiation effects on humidity
PT1000 Class F0.3 + Pressure-Temper ature	Unable to withstand physical hazards from lunar environment	Cannot pursue part of the science objective about the determination of the lunar pit sustaining human life in terms of temperature and pressure	9	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	8	Protection for the instrument, instrument built to withstand physical hazards	1	72	Remove pressure as a factor in the science objective of determining the sustainance of human life in the lunar pit; rely on Model HMP60 Humidity Sensor + Model DI-808 for temperature readings
	Fail to measure pressure in the range of 10^{-12} to 10^{-10} torr	Incorrect or no data about pressure levels of lunar pit collected	6	Faulty operation	6	Multiple operational tests for instrument	2	72	Remove pressure as a factor in the science objective of determining the sustainance of human life in the lunar pit
	Fail to measure temperature in the range of 16 °C to 18 °C	Incorrect or no data about temperature levels of lunar pit collected	6	Faulty operation	6	Multiple operational tests for instrument	2	72	Rely on Model HMP60 Humidity Sensor + Model DI-808 for temperature readings
MID-360 LiDAR	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of determining the viability of human habitation	10	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	4	Protection for the instrument, instrument built to withstand physical hazards	1	40	Replace the science objective about determining the viability of human habilitation with a new science objective
	Fail to make measurements up to 55 meters	Inadequate measurements of lunar pit dimensions	4	Faulty operation	2	Multiple operational tests for instrument	2	16	Determine if inadequate data could still be utilized
	Fail to detect dimensions every 45 meters	Inaccurate detection of lunar pit's dimensions	7	Faulty operation, slow response	2	Multiple operational and data tests for instrument	2	28	Determine if detection data could still be utilized
Silicon Photomultiplier	Unable to withstand physical hazards from lunar environment	Cannot pursue the science objective of determining the structural integrity of the pit to support human life	10	Sharp, fine lunar regolith; micrometeoroids; high radiation environment	3	Protection for the instrument, instrument built to withstand physical hazards	1	30	Replace the science objective about determining the structural integrity of the pit to support human life with a new science objective
	Fail to detect thickness of lunar pit every 40 meters	Inadequate measurements of lunar pit's thickness	4	Faulty operation, slow response	5	Multiple operational and data tests for instrument	2	40	Determine if inadequate data could still be utilized

Table 17: The full Payload Subsystem FMEA Chart.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN	Phase E 2025	2026	2027
1	**Critical Design Review**		0%	12/23/24	3/1/26	434	31			
1.1	KDP Team Review	Entire Team	FALSE	12/23/24	12/30/24	8				
1.2	Subsystem Simulation Testing	Engineers and Scientists	FALSE	12/30/24	5/30/25	152				
1.3	Subsystem CDRs	Engineers and Scientists	FALSE	5/30/25	7/30/25	62				
1.4	Complete System Simulation Testing	Engineers and Scientists	FALSE	7/30/25	1/30/26	185				
1.5	Schedule Margin			1/30/26	3/1/26	31				
1.6	◆ Critical Design Reveiw		FALSE	3/1/26	3/1/26	1				
2	**System Integration Review**		0%	3/1/26	1/5/27	311	17			
2.1	CDR team review and improvement	Entire Team	Not complete	3/1/26	4/1/26	32				
2.2	Integration plan	Engineers and Scientists	Not complete	4/1/26	6/15/26	76				
2.3	Procedure plan	Engineers and Scientists	Not complete	6/15/26	8/15/26	62				
2.4	System integration training	Technicians	Not complete	8/15/26	11/20/26	98				
2.5	System Integration Review	Entire Team	Not complete	11/20/26	12/20/26					
2.6	Schedule Margin			12/20/26	1/5/27	17				
2.7	◆ KDP Meeting 6		Not complete	1/5/27	1/5/27	1				
3	**System Acceptance Review**		0%	1/5/27	1/5/29	732	62			
3.1	Manufacturing Verification and Validation	Engineers, Technicians	Not complete	1/5/27	8/5/27	213				
3.2	Testing in Flagstaff Arizona	Engineers, Managers, Scientists	Not complete	8/5/27	8/12/27	8				
3.3	Testing in Glenn Research Center	Engineers, Managers, Scientists	Not complete	8/12/27	8/19/27	8				
3.4	Update technical data package	Engineers, Managers, Scientists	Not complete	8/19/27	10/5/27	48				
3.5	Final certification package	Engineers, Scientists	Not complete	10/5/27	1/5/28	93				
3.6	Baseline as-is built hardware and software design	Engineers, Scientists	Not complete	1/5/28	2/5/28	32				

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN	Phase E 2025	2026	2027
3.7	Plan and procedure	Engineers, Scientists	Not complete	2/5/28	6/5/28	122				
3.8	Acceptance data package	Engineers, Scientists	Not complete	6/5/28	8/5/28	62				
3.9	Plan to sustain the system	Engineers, Scientists	Not complete	8/5/28	11/5/28	93				
3.5	Schedule Margin			11/5/28	1/5/29	62				
3.6	◆ System Acceptance Review		Not complete	1/5/29	1/5/29	1				
4	**Operational Readiness Review**		0%	1/5/29	1/17/30	378	58			
4.1	Test operational supporting and enabling products	Engineers, Scientists, Technicians	Not complete	1/5/29	4/5/29	91				
4.2	Update list of all single point failures	Engineers	Not complete	4/5/29	5/5/29	31				
4.3	Install operational supporting and enabling products at various sites	Technicians	Not complete	5/5/29	8/5/29	93				
4.4	Baseline decommission and operation plans	Engineers, Scientists	Not complete	8/5/29	11/21/29	109				
4.5	Schedule Margin			11/21/29	1/17/30	58				
4.6	Operational Readiness Review		Not complete	1/17/30	1/17/30	1				
5	**Mission Readiness Review**		0%	1/17/30	1/28/30	12	4			
5.1	System and support elements demonstrate functioning as expected	Engineers	Not complete	1/17/30	1/21/30	5				
5.2	Verify that support elements and system have been properly configured for flight/mission operations	Engineers	Not complete	1/21/30	1/25/30	5				
5.3	Mission Readiness Review	Entire Team	Not complete	1/25/30	1/28/30	4				
5.4	Safety and Mission Success Review	Entire Team	Not complete	1/28/30	1/28/30	1				
5.5	Schedule Margin			1/25/30	1/28/30	4				

Table 18: The full Gantt chart for the mission. Part 1.

Phase E		
2025	2026	2027
J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
5.6	◆ KDP E: Launch		Not complete	1/28/30	1/28/30	1	
6	**Critical Events REadiness Review**		**0%**	**3/5/30**	**3/18/30**	**14**	**4**
6.1	Lunar Arival	Task owner (individual(s) or subteam)	Not complete	3/5/30	3/5/30	1	
6.2	Verify launch and early operations performance are available	Task owner (individual(s) or subteam)	Not complete	3/5/30	3/7/30	3	
6.3	Observe spacecraft and science instrument performance availability	Scientists	Not complete	3/7/30	3/10/30	4	
6.4	Deployment and activation of all systems	Task owner (individual(s) or subteam)	Not complete	3/10/30	3/15/30	6	
6.5	Schedule Margin			3/15/30	3/18/30	4	
6.6	◆ Critical Events Readiness Review		Not complete	3/18/30	3/18/30	1	
7	**Post Launch Assessment Review**		**0%**	**3/18/30**	**3/30/30**	**13**	**65**
7.1	Confirm availability of mission operations and ground data collection	Scientists	Not complete	3/18/30	3/19/30	2	
7.2	Document any in-flight anomalies and responsive actions taken	Scientists	Not complete	3/19/30	3/20/30	2	
7.3	Document need for significant changes	Scientists	Not complete	3/20/30	3/25/30	6	
7.4	Plans for post-launch development documented	Scientists	Not complete	3/25/30	3/27/30	3	
7.5	Schedule Margin			3/27/30	5/30/30	65	
7.6	◆ Post launch assessment review		Not complete	3/30/30	3/30/30	1	
8	**Decommissioning Review**		**0%**	**3/18/30**	**5/23/30**	**67**	**2**
8.1	Collect data for magnetic anomalies and surface composition	Scientists	Not complete	3/18/30	4/3/30	17	

Phase E		
2025	2026	2027
J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
8.2	Traverse to lunar pit	Scientists	Not complete	4/3/30	4/8/30	6	
8.3	Complete pit readings	Scientists	Not complete	4/8/30	4/23/30	16	
8.4	Lunar night survival mode	Scientists	Not complete	4/23/30	5/6/30	14	
8.5	Second Cycle Operations	Scientists	Not complete	5/6/30	5/21/30	16	
8.6	Final data transmission	Scientists	Not complete	5/21/30	5/22/30	2	
8.7	Schedule Margin			5/22/30	5/23/30	2	
8.8	◆ Decommissioning Review		Not complete	5/23/30	5/23/30	1	
8	**System shutdown**		**0%**	**5/23/30**	**6/6/30**	**15**	**2**
8.1	Decommissioning Review SRB	Scientists	Not complete	5/23/30	5/26/30	4	
8.2	Disposal Readiness Review	Scientists	Not complete	5/26/30	6/4/30	10	
8.3	Travel to disposal location	Scientists	Not complete	6/4/30	6/5/30	2	
8.7	Schedule Margin			6/5/30	6/6/30	2	
8.8	◆ System shutdown and exposure to lunar conditions		Not complete	6/6/30	6/6/30	1	

Table 19: The full Gantt chart for the mission, Part 2.

Instrument	Mass	Cost	Manufacturing Facility Cost	Test Facility Cost
Model HMP60 Humidity Sensor + Model DI-808	99 g + 453 g	$4,900,000	$1,500,000	$1,920,000
Lunar Outpost Canary-S	2.27 kg	$11,600,000.00	$3,800,000	$4,625,000
PT1000 Class F0.3 + Pressure-Temperat ure	6 kg	$39,400,000.00	$13,600,000	$15,905,000
Silicon Photomultiplier	TBD	TBD	-	-
Active Radiation Environment Sensor	2.01 kg	$7,900,000.00	$2,500,000	$3,120,000
MID-360 LiDAR	265 g	$4,300,000	$1,400,000	$1,717,500
3-Axis Fluxgate Magnetometer Model AP235	150 g	$2,800,000	$900,000	$1,117,500
Bartington Fluxgate Magnetometer, 3-axis, Aerospace/Space	94 g	$900,000	$300,000	$360,000
Total		$71,800,000	$24,000,000	$28,765,000

Table 20: Science instrument costs.

Deliverable Maturity Matrix

Deliverable Maturity	MCR	SRR	MDR	PDR
Mission Concept	**Baseline**	Updated	Updated	Updated
Vehicle Systems	Preliminary	**Baseline**	Updated	Updated
Cost and Schedule	Preliminary	Preliminary	**Baseline**	Updated
Risks	Preliminary	Preliminary	Preliminary	**Baseline**

Maturity Key	
Preliminary	Major architectural aspects of design are initially conceptualized
Baseline	Major architectural aspects of design are complete
Updated	Major architectural aspects of design are updated

At Baseline, TBD/TBR for these should be resolved

Team Number	**27**
Date of Request	**11/17/2024**
Area of Change	Science
Change Level*	Minor

*Minor changes include low risk, high certainty, and are well understood. Does not need a CCB.

Moderate changes include medium risk, some degree of uncertainty, and may have some SMEs questioning its validity. May need a CCB.

Extreme changes include high risk, high uncertainty, and will require a CCB before being accepted.

Description of requested change: What is the change your team is requesting to make on the mission?
Team 27 would like to replace a secondary payload instrument that measures temperature and pressure. This instrument is the PT1000, which is classified as a Probe Mounted In-Situ Instrument. The replacement instrument will be REMS (Boom 2), with a TRL of 5.
Reason for change and its impact:

Figure 19: The change request document submitted by Team 27 to eliminate the PT1000, Part 1.

What is the reason your team wanted to make this change? How will this impact your mission? Think in terms of cost, schedule, and scope*.

The reason the team wants to make this change is because the instrument is far too costly. After reanalysis of the budget after the reduction from $425 million to $300 million, an analysis of all payload instruments was done. Using the MCCET, it was calculated that the PT1000 alone would cost $50.2 million. This has put the mission over budget by ~$24 million. Thus, as the instrument is simply a secondary, the team would like to eliminate it and replace it with a cheaper alternative. When replacing with the alternative instrument, this would help to descope the cost of the mission and thus provide greater margin within the budget because the new instrument merely costs $2.2 million rather than $50 million.

Enter the inflation rate (Default for 2023 is 154.44%)	166.08%	Inflation rate calculator
Enter the number you recieved from the CER formula	1019.987979	The CER provides a cost that is orginally i thousands of dollars. It needs to be multip account for inflation, and then 1000 to be t tool does the math for you.
Estimated cost with inflation (Without Wraps)	$1,693,996.04	

Wrap Costs	Cost Estimate	Info
Management Costs	$90,000.00	?
Systems Engineering Costs	$80,000.00	?
Product Assurance Costs	$70,000.00	?
Integration & Test Costs	$250,000.00	?

Final manufacturing cost per unit (manufacturing + wraps)	$2,200,000.00	Rounded up to the nearest $100K

Timeline and action plan:

When can this change be expected to be implemented by? Use academy deliverables as key milestones (MCR, SRR, MDR, PDR) that signify a particular date. How will this change be implemented? What key personnel will be responsible for its completion?

Team 27 has already begun preparing for this change by researching alternative instruments instead of the PT1000 that can measure pressure and temperature in the lunar environment. The team would like to implement this change as soon as possible, preferably starting in the MDR but not limited to also starting in the PDR. The science subteam, specifically the Chief Scientist, will be in charge of updating the relevant payload subsystem sections to include this change. Engineers, specifically the Mechanical Engineer, will also have to consider how this change of instruments will impact the design of the rover.

Trade Study if relevant:

If your change consists of swapping one thing for another (system related changes), you must complete a trade study. Include a screenshot of it below. If your change does not fall into this category, leave this blank.

Figure 20: The change request document submitted by Team 27 to eliminate the PT1000, Part 2.

Temperature Measurement Secondary Instrument					
Criteria	**Explanation**	**Grade**	**Weight**	**REMS (Boom 2)**	**PT1000 Class F0.3 + Pressure-Temperature**
Cost	The mission's budget requires this secondary instrument to be less than $25M, which would cause the mission to be unaccomplishable.	10 = Less than $10M, 5 = Between $17 and 15M, 1 = Between $25 and 23M, 0 = Over $25M	35%	10	0
Reliability	The likelihood of the instrument's ability to successfully measure the environmental factors of the Mare Ingenii pit.	10 = Lowest possibility of failure, 5 = Somewhat high chance of failure, 1 = Very high likelihood of failure, 0 = Impossible	35%	7	9
Accuracy	As the temperature and pressure vary instantaneously, the accuracy of a tool to measure them should be the highest possible.	10 = Extremely accurate, 5 = Not very accurate, 1 = Slightly accurate, 0 = Not accurate	25%	9	7
Heritage	Instruments previously used on the lunar surface are considered the highest level of heritage because they're known to be successful in the environment.	10 = Used on a previous lunar rover, 5 = Used in a slightly similar space mission, 1 = Unsuccessfully used/ mission was cancelled, 0 = No heritage	5%	8	0
		TOTALS:	100%	86.00%	49.00%

*Scope would be defined as the relevant work, such as tasks performed by the mission, or the deliverables of these tasks and their quality / quantity.

Mentor Response	Select an option
Date of Response	
When2meet Link (If CCB is needed)	
Reason for Response	

Figure 21: The change request document submitted by Team 27 to eliminate the PT1000, Part 3.

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