Mission Concept Review

Mission Concept Academy

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Table of Content

1. Abbreviation Index 2

2. Mission Concept Review 3-23

    2.1. Mission Statement 3

    2.2. Science Traceability Matrix 3-5

    2.3. Summary of Mission Location 5-7

    2.4. Mission Requirements 7-8

    2.5. Physical Environmental Hazards 9-11

    2.6. System Evaluation Criteria 11

    2.7. Concept of Operation 12-13

    2.8. Alternative Mission Concepts 13-17

    2.9. Programmatics 17-23

        2.9.1. Team Organization 17-18

        2.9.2. Cost and Schedule Estimate 18-23

    2.10. Conclusion 23

3. Bibliography 24-25

1. Abbreviation

a. GPR - Ground-Penetrating Radar
b. ISRU - In-Situ Resource Utilization
c. KDP- Key Decision Point
d. LADEE - Lunar Atmosphere and Dust Environment Explorer
e. LIDAR - Light Detection and Ranging
f. LRO - Lunar Reconnaissance Orbiter
g. MCR - Mission Concept Review
h. NASA - National Aeronautics and Space Administration
i. RTG - Radioisotope Thermoelectric Generator
j. SRR - System Requirements Review
k. TRL - Technology Readiness Level

2. Mission Concept Review

2.1. Mission Statement

This mission aims to assess the potential for habituality and to analyze the geophysical characteristics of the Mare Tranquillitatis Pit on the lunar surface. The mission will be conducted by a rover equipped with scientific instruments to gather crucial information about the thermal environment, structural integrity, radiation levels, resource availability, and subsurface composition of the pit. Instruments, including Light Detection and Ranging (LIDAR), seismic sensors, radiometers, and spectrometers will be utilized to characterize and measure the stability of the pit and to detect any hazardous materials or supporting resources such as water or ice.

An autonomous all-terrain rover developed for extreme conditions on the Moon's surface will deliver continuous measurements. The rover will transmit the gathered data when the satellite is in the overhead vicinity of the pit location. This will help to observe the feasibility of establishing a sustainable human colony on the Moon. The gathered data will add knowledge of both lunar geology and resources and aid in answering future questions about origin and development. This mission will improve the understanding of lunar exploration, building grounds for future manned missions and, most importantly, possible lunar habitation.

2.2. Science Traceability Matrix

The central science goal of the mission is to evaluate the habitability potential and geophysical characteristics of the Mare Tranquillitatis Pit. This goal is derived from the broader objective of supporting future human exploration by identifying stable, resource-rich sites on the Moon that can facilitate sustainable human presence.

Derivation from Stakeholder Requirements:

According to the Mission Task Document, the primary focus is on surface operations post-landing with a strict budget of $425M for a Discovery-Class mission. The goal is to conduct geological, structural, and environmental investigations to assess the feasibility of using the pit as a long-term habitat. Each science objective has been derived to meet the following vital constraints:

- *Safety and Stability*: Identify stable regions within the pit that can support infrastructure.
- *Resource Availability*: Determine the presence of volatiles and other in-situ resources.

- *Environmental Suitability*: Evaluate the thermal and radiation environment to ensure the safety of future human missions.

Science Objectives:

- Characterize the thermal environment of the Mare Tranquillitatis pit to evaluate the stability of temperatures within potential habitat zones.
- Assess the structural integrity of the pit walls and overhangs using high-resolution imaging and seismic sensors.
- Investigate the presence of subsurface voids and lava tubes, which could serve as natural shelters or storage areas.
- Quantify the radiation environment at various depths within the pit to identify optimal locations for habitats.
- Map the distribution of volatiles and hydrogen concentrations to evaluate the feasibility of in-situ resource utilization (ISRU).

Science Traceability Matrix:

The STM presented below establishes a clear link between the mission's overarching science goal, the specific objectives, and the necessary measurements. This matrix will serve as a baseline for the mission's science plan.

Science Goal	Science Objective	Measurement(s)	Measurement Methodology
Evaluate the habitability potential and geophysical characteristics of the Mare Tranquillitatis Pit.	1. Characterize the thermal environment of the pit.	Measure temperature variations at different depths and locations.	Use temperature sensors to map diurnal and seasonal temperatures.
	2. Assess the structural integrity of pit walls and overhangs.	High-resolution imaging of fractures and rock layers.	Capture detailed images of pit walls using stereo cameras.
	3. Investigate subsurface voids and lava tubes.	Measure the depth and geometry of potential voids.	Deploy ground-penetrating radar (GPR) to scan below the surface.
	4. Quantify radiation environment at different depths.	Record radiation levels at varying locations and depths in the pit.	Use radiation dosimeters to create a comprehensive radiation map.
	5. Map the distribution of volatiles and hydrogen concentrations.	Detect hydrogen and water ice content in the regolith.	Deploy a neutron spectrometer to identify hydrogen-rich areas.

Rationale for the STM Components

- *Science Goal:* This goal addresses the need to evaluate the selected pit's habitability potential. It ties directly to future human exploration, aligning with NASA's Artemis program and stakeholder expectations for sustainable lunar exploration.
- *Science Objectives*: Each objective is derived from specific requirements in the Mission Task Document, focusing on characterizing the pit's geological stability, thermal environment, and resource availability.
- *Measurements:* The selected measurements are focused on producing quantifiable data that directly informs the mission's objectives. These include mapping thermal profiles, assessing structural integrity, and detecting subsurface features.
- *Measurement Methodology:* The methodologies are chosen to ensure the measurements are accurate, reliable, and feasible within the mission's budgetary and technical constraints.

2.3. Summary of Mission Location

The moon's surface is classified by high- and low-elevation regions, such as the Highlands and Maria. These features result from ancient volcanic and tectonic activity: Approximately 3 to 4 billion years ago, volcanic eruptions released large amounts of basaltic lava, which cooled and formed thick basaltic plains. Mainly, Maria is characterized by dark, smooth, and relatively flat terrain, making these regions a perfect area for selecting potential landing sites.

Located on the Northeastern Hemisphere of the lunar surface (as viewed from the Northern Hemisphere of Earth), The Sea of Tranquility (Mare Tranquillitatis) is one of the most famous lunar maria, primarily because it was the landing site for Apollo 11, the first human mission to the Moon in 1969. While its flat plains and basaltic surface make it a notable lunar feature, more recent lunar exploration reveals fascinating geological structures, including pit caves or lunar pits.

Unlike the open surfaces of the moon, where temperatures fluctuate drastically between lunar day and night, the environment inside the lunar pits and pit caves remains relatively stable. Additionally, these cave regions shield against harmful cosmic rays and solar radiation that usually bombard the lunar surface. These pit caves are believed to be an ideal environment to support both critical systems for lunar exploration and human habitations/settlements in the future.

From the start of its mission/orbit, the Lunar Reconnaissance Orbiter (LRO) has collected aerial data/images of various pit caves and lunar pits located in the Sea of Tranquility. Multiple entrances to these pit and crater locations have been identified, exhibiting massive dimensions ranging from 90 meters in diameter and at least 130 meters in depth. These locations are believed to have been sites of extreme volcanic activity and may represent part of an extensive network of underground caves that could be explored.

Meticulous planning and consideration of various factors have led to selecting a general exploration region for this mission. At this time, a specific pit entrance for exploration has yet to be identified or confirmed. However, it is expected that future discussions/considerations of pit locations will include but are not limited to the following areas:

8.25°N, 33.18°E: A small pit located near the central location of the Sea of Tranquility
8.5°N, 33.3°E: A potential lava tube entrance
8.336°N, 33.226°E: A well-documented pit situated in the heart of the Sea of Tranquility

One of the critical requirements of mission design/planning includes the selection of a specific landing site that will enable the system to fulfill the mission's objectives. Flat, smooth, and sturdy terrain is preferred for simple and successful landings. Moreover, landing sites within a 5 km radius of the intended exploration regions are ideal, allowing the rover to reach the target area efficiently. At this time, the landing site has not been confirmed. However, the following is a list of possible considerations that fit the mentioned criteria:

8.340°N, 33.220°E
8.330°N, 33.210°E
8.310°N, 33.225°E

These coordinates have been chosen through satellite images taken by the Lunar Reconnaissance Orbiter. Specific considerations were taken into account when selecting the Mare Tranquillitatis Pit: The terrain characteristics are convenient for the mission as images indicate smooth terrain with low obstacle density. The pit's inner diameter is 100m x 88m, a comfortable amount of space for habitability. Internal temperature readings indicate a constant 17°C, an ideal thermal environment for structures. Additionally, 15-20 meters of overhang is present, providing radiation shielding. The pit is located near the Moon providing a clear line of sight between Earth and communication satellites. The physical characteristics of this location greatly support the scientific objective of investigating possible locations of a long-term human

presence on the Moon. Furthermore, the basaltic and volcanic nature of the region supports the aim of investigating lunar volcanic activity. Through its convenient location and geological features, the Mare Tranquillitatis pit endorses studying lunar habitability and learning more about lunar volcanic activity. Such investigations would advance the knowledge of the solar system and its origins.

2.4. Mission Requirements

The team's top-level mission and system requirements, presented in the following table, are to be adhered to in addition to the fundamental mission constraints defined by the customer. These fundamental constraints require that the system not exceed a total mass of 350kg, a total volume of (2m x 1.5m x 1.5m), or a total project cost of $450M USD for project phase C-F. Additionally, it is required that the system be prepared to launch from Kennedy Space Center by March 1st, 2030.

[View Table on *Page 7*]

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
MT-5.0	The system should be able to downlink data to an orbiter in a 100km circular polar orbit.	Mission Task adherence	-	-	Analysis	Electrical, Robotics	Not Met
NC-1.0	The system should exhibit robustness sufficient to perform mission functions defined in the ConOps.	Necessary Condition to complete the mission	-	NC-1.1, NC- 1.2, NC- 1.3	Test	Mechanical	Not Met
NC-2.0	The system should be able to mitigate geologic hazards presented by the lunar environment.	Necessary Condition to complete the mission	-	NC- 2.1, NC- 2.2, NC- 2.3	Inspection	Mechanical, Robotics	Not Met
SC-1.0	The system should provide novel insights into the history and habitability of the Mare Tranquillatitis lunar pit.	Sufficient Conditions to satisfy the scientific objectives	-	SC- 1.1, SC- 1.2	Inspection	Robotics	Not Met
NC-1.1	The system should be able to power itself for the mission's duration.	Necessary Condition to complete the mission	NC- 1.0	-	Analysis	Power	Not Met
NC- 1.2	The system should not sustain damage during pit entry sufficient to degrade any subsystem below operational levels.	Necessary Condition to complete the mission	NC-1.0	-	Test	Mechanical	Not Met
NC- 1.3	The system shall be able to withstand temperature ranges in the lunar environment.	Necessary Condition to complete the mission	NC- 1.0	-	Demonstration	Thermal	Not Met
NC-2.1	The system should adhere to Planetary Protection guidelines outlined by NASA-STD-8-719.27 and NPR 8715.24.	Necessary Condition to complete the mission	NC- 2.0	-	Inspection	All subsystems	Not Met
NC-2.2	The system should withstand lunar regolith without any subsystem degrading below operational levels.	Necessary Condition to complete the mission	NC- 2.0	-	Inspection	Mechanical	Not Met
NC-2.3	The system should be able to mitigate lunar dust buildup so that all subsystems remain operational.	Necessary Condition to complete the mission	NC- 2.0	-	Test	Robotics	Not Met
SC-1.1	The system should be able to map the geometry of existing caves and lava tubes.	Sufficient Conditions to satisfy the scientific objectives	SC- 1.0	-	Inspection	Robotic	Not Met
SC-1.2	The system should be able to characterize indicators of habitability as defined in the Science Traceability Matrix.	Sufficient Conditions to satisfy the scientific objectives	SC- 1.0	-	Inspection	Robotics	Not Met

2.5. Physical Environmental Hazards

Physical environmental hazards are any element of the environment that has the potential to harm mission-critical parts and, in the future, human inhabitants. Radiation and terrain are examples of such elements.

This section will cover physical environmental hazards, where they could be encountered, and any method to mitigate or prevent them from occurring. However, to avoid/minimize hazards, they must be identified first. Although further hazards may be unknown to the team due to the specific mission, some can be deduced from previous missions and the data they have collected.

Lunar Dust (Regolith):
Lunar dust is extremely fine, sharp, and abrasive, similar to microscopic shards of glass. It is generally located on the surface of the Moon, with less theorized to be situated in lunar caves and pits (Wagner ----) Its hazards include:

- *Damage to Equipment:* Lunar dust can damage spacecraft systems by infiltrating seals, bearings, optical lenses, and electrical components. It can degrade solar panels, reduce the efficiency of thermal radiators, and damage any moving parts reliant on friction.
- *Human Health Risks:* Inhaling lunar dust poses significant risks to human health, as the sharp particles can irritate or damage lung tissue, similar to the effects of silicosis. Prolonged exposure inside habitats could lead to respiratory issues for astronauts.
- *Visibility and Navigation Challenges:* The regolith can be kicked up during landing and walking, limiting visibility and increasing the risk of accidents.

This hazard can be mitigated by limiting dust generation by controlling the vehicle's movement so the amount of dust produced can be limited. Furthermore, since lunar dust is negatively charged, it is possible to remove the problem by repelling it using electrostatic forces. For future habitation, proper ventilation systems must be installed to prevent dust buildup.

Terrain**:**
Areas like Mare Tranquillitatis have steep slopes, pits, and potential lava tubes. These features can create hazards such as:

- *Sharp Rocks:* The uneven surface and jagged rock formations, particularly around lava tube pits, can impede traversal and damage vehicle tires or landing gear.

- *Steep Slopes:* Navigating around pits and craters poses the risk of vehicles tipping or becoming stuck in unstable soil. The slopes also make it difficult for astronauts to move or perform tasks without the risk of falling.

These hazards can be minimized by proper reconnaissance of the landing zone via orbiters and other surveillance craft. However, due to the mission, some of these hazards will become unavoidable, and the designed vehicle must withstand such conditions.

Thermal Instability:
The lunar day-night cycle causes extreme temperature fluctuations, from daytime highs of over 420 K (147°C) to nighttime lows below 100 K (-173°C). Equipment and suits must be insulated and protected against these variations.

While the surface can become extremely hot or cold, areas inside the Mare Tranquillitatis pit maintain more stable temperatures, around 290 K (17°C), making them potential sites for shelter.

Radiation:
Spacecraft electronics on the Moon face two significant threats: solar radiation and cosmic rays. These are particularly dangerous because the Moon has no atmosphere or magnetic field to shield equipment or astronauts. Strategies to protect electronics include:

- Radiation Shielding:
    - *Materials:* Electronics are often encased in radiation-shielding materials such as aluminum, lead, or specially designed composites that can absorb or deflect radiation.
    - *Location*: Placing sensitive components inside lunar pits or caves can shield them from direct exposure to radiation, as these underground structures provide natural protection from solar flares and cosmic rays.
- Radiation-Hardened Components:
    - *Specialized Electronics*: Using radiation-hardened components ensures that electronics can function even after exposure to higher levels of radiation. These systems can withstand the degradation caused by prolonged exposure to the lunar environment.
- Operational Strategies:
    - *Limiting Exposure*: Certain mission profiles minimize exposure during periods of heightened solar activity (e.g., solar flares). Monitoring solar radiation levels allows for shutting down sensitive systems during solar storms to protect them from damage.

Low Gravity:
Although not pertaining to the current mission, extensive low-gravity exposure is a hazard to the human body. These hazards include loss of bone, muscle atrophy, decreased plasma volume, and other cardiovascular issues (Wolfe 1992). These conditions can be mitigated by regular exercise and proper nutrition throughout the astronauts' mission period.

Meteorites:
Due to a lack of an atmosphere, there is an increased risk of meteorite impacts on the surface of the Moon. This could cause catastrophic damage to the mission vehicle and be a hazard for any potential habitation. This hazard can be minimized by proper surveillance equipment to warn mission members regarding an imminent impact.

2.6. System Evaluation Criteria

The purpose of the mission is what is most relevant when evaluating the different options for spacecraft subsystems. Within this, the three prongs of evaluation principles can be grouped under mission necessity, operating constraints, and complexity scale.

Within the mission necessity, given the terrain of the environment, which involves lunar pits and caves on the surface of the moon, it is imperative to be able to utilize a mobile device that can traverse this kind of landscape. This involves a level of durability and flexibility that must be maintained within the structure and architecture of the system. In addition, it would also be useful to be able to have features that would allow for mission progress and science operations; these would include scanning and features.

Many operating constraints must be adhered to to ensure the mission's success. These include mass constraints (350 kg), dimension constraints (2 m x 1.25 m x 1.25), cost constraints ($425M), and a launch readiness date constraint (vehicle must be ready for launch by March 1st, 2030). The mission prohibits using Radioisotope Thermoelectric Generators (RTG) or any derivatives; radioactive materials utilized in spacecraft systems may not exceed 5g.

Lastly, complexity must also be considered when evaluating a proposed system. This includes the element of realistic manufacturability—the device must be able to be completed within the timeframe given. This may also be viewed through the lens of the Technology Readiness Level (TRL), which measures the maturity level of a particular technology. For the purposes of this mission, it would be helpful to have a system with a high TRL (7 or higher), which means that the system itself had at least a prototype tested in a space environment (or was successfully deployed in the environment). This would ensure that the specific system has been previously tested before utilization on this mission.

2.7. Concept of Operations

This section provides an overview of the concept of the mission and the definitions of operations that will deem the mission successful.

To effectively satisfy all objectives and requirements of this mission [See Science Traceability Matrix], the system architecture will take the form of a Robotic, All-Terrain Rover. The rover will be encapsulated in a thermally shielded compartment of the entry vehicle and released upon successful surface touchdown.

During the launch, travel, and descent stages before the start of the mission, the system will receive auxiliary power from the primary launch vehicle to keep essential systems active. Upon separating from the primary vehicle at the landing site, the system will be designed to operate on individual power sources: The system will utilize solar panels as a primary power source. However, prior missions and estimations have revealed that solar panels are not a reliable source for keeping onboard instruments and thermal systems active over the long 14-day period of Lunar darkness. Although alternative power sources like Nuclear Generators and Radioisotope Thermoelectric Generators (RTG) offer better options, they fall outside the budgetary scope of this mission and the long-term goal of minimizing radiation pollution in an environment intended for future human habitation. Therefore, a key research/experimental component of the mission involves assessing solar radiation levels in the lunar environment to synthesize an in-situ RTG configuration capable of providing sufficient primary and/or supplementary power to the rover's instruments and systems.

The mission commences successfully when the primary launch vehicle is landed on the specified surface [See Summary of Mission Location]. Upon landing, the launch vehicle will deploy the rover. The rover will begin real-time imaging of the area surrounding the pit. The rover will first navigate to the designated pit location and descend into the pit utilizing an axle and tether system. A parachute will be deployed to mitigate landing impact from rough terrain on the pit floor and to minimize vibrations that could potentially destabilize rock in the pit’s walls and overhang. Real-time imaging will continue upon ingress into the pit.

The rover will initiate operations by performing a 3D scan of the pit's interior using LIDAR technology. Data will be transmitted to the orbiter and utilized to facilitate simultaneous localization and mapping (SLAM), enabling the rover to traverse uncertain terrain within the pit. Seismic sensors will be activated to monitor seismic activity and provide early warning of micrometeorite impacts. The rover will begin the development of a thermal and radiation map of the pit's interior, utilizing instrumentation such as a thermal imager or radiometer. Data will be collected at various points during the lunar

day to determine how the mapping varies as the pit receives varying levels of sunlight and shadow. The rover will also collect data on the composition of the pit's atmosphere using a spectrometer.

The rover will then navigate a circuit around the pit's perimeter to gather more precise data on the base area of the pit as well as continue an in-depth search for potential entrances into lava tubes. The rover will then commence data collection to assess the structural stability of the pit by measuring the thickness of the overhang. Data on the lithostatic stress of the pit walls and floors will be collected to assess the viability of future infrastructure construction within the pit's interior. Data will also be collected on the rock's response to pressure exerted by the rover's wheels. Data collection will be conducted both when the pit is in light and shadow to assess the impact of heat on material behavior.

2.8. Alternative Mission Concepts

During the preliminary design phase, the team evaluated several alternative mission concepts before finalizing the current Robotic All-Terrain Rover mission to explore the Mare Tranquillitatis pit. These alternative concepts aimed to identify the most effective strategy for achieving the science goals outlined in the Science Traceability Matrix (STM) while adhering to budgetary and technical constraints. The evaluation process considered factors such as the type of spacecraft, landing location, and operational feasibility. Each concept was analyzed for its ability to meet scientific objectives, operational reliability, and potential risks. Below is a summary of the explored concepts and the reasons why each was not selected.

Concept A - Stationary Lander at the Pit Rim:

Description:
This mission concept involved placing a stationary lander at the rim of the Mare Tranquillitatis pit to act as a base station. The lander would be equipped with high-resolution cameras, spectrometers, and radiation sensors to monitor the pit's environment and provide long-term data collection.

Pros:

- *Straightforward Design*: With no moving parts, the stationary lander would have a lower risk of mechanical failure.
- *Extended Data Collection*: A stationary lander can maintain operations for a more extended period, making it ideal for continuously monitoring environmental changes.

Cons:

- *Limited Science Return*: Being limited to the rim, the lander could not access the pit floor or interior, significantly reducing its ability to collect comprehensive geological and structural data.
- *No Direct Interaction with Pit Features*: The inability to navigate or descend into the pit would prevent a close-up investigation of potential lava tubes or subsurface voids.

Reason for Rejection:
While this concept offered a more straightforward design, it did not align with the core science objectives of the mission, which include assessing the habitability potential of the pit's interior. The lack of mobility was a critical drawback, leading to its exclusion as the primary mission concept.

Concept B - Dual-Rover Mission (Rim and Pit Floor):

Description:
This concept was proposed using two rovers stationed at the pit rim and deployed into the pit floor. The rim rover would serve as a communication relay and perform surface-level analysis, while the pit-floor rover would focus on interior exploration and structural analysis.

Pros:

- *Comprehensive Data Coverage*: With rovers at both the rim and the floor, this concept would provide a detailed dataset on external and internal pit characteristics.
- *Redundancy*: Having two independent rovers increases the chances of achieving mission objectives even if one rover encounters issues.

Cons:

- *High Cost*: The development and deployment of two separate rovers would significantly increase mission costs, making it challenging to stay within the $425 million budget.
- *Complex Coordination*: Managing two separate rovers with different operational environments would require advanced planning and risk management.
- *Increased Weight and Power Requirements*: Supporting two separate systems would add to the overall payload weight and power consumption, critical constraints for a Discovery-Class mission.

Reason for Rejection:
Despite offering data collection, the dual-rover concept was deemed too expensive and complex for the current budget. Additionally, the operational challenges of coordinating two rovers in separate environments introduced too many variables, making this option less favorable.

Concept C - Single Lander with Deployable Mini-Rovers:

Description:
In this concept, a stationary lander would deploy multiple small, lightweight mini-rovers or “hoppers” to explore the pit floor and walls. The mini-rovers would have cameras and basic environmental sensors, returning data to the mainlander.

Pros:

- *High Mobility*: Mini-rovers could access narrow and hard-to-reach areas of the pit, providing data from diverse locations.
- *Scalable Science Operations*: Deploying multiple mini-rovers allows for parallel data collection, potentially speeding up the mission timeline.

Cons:

- *Limited Instrument Payload*: Due to size constraints, mini-rovers would be limited in their instrument capacity, making it difficult to conduct a comprehensive analysis.
- *Short Operational Lifespan*: Mini-rovers, with limited power and thermal protection, would not survive the harsh lunar environment for long periods.
- *Communication Challenges*: Maintaining a stable communication link between the mini-rovers, the mainlander, and Earth would be challenging, especially if the mini-rovers moved behind obstacles or deeper into the pit.

Reason for Rejection:
While the concept provided flexibility and the ability to explore multiple locations, mini-rovers' limited scientific capabilities and short operational lifespan did not align with the mission’s requirement for detailed and long-duration scientific investigations.

Concept D - Aerial Drone Deployment (Lunar Hopper):

Description:
This concept proposed deploying a small aerial drone, or “lunar hopper,” that could be launched from a stationary lander and fly into the pit to collect high-resolution imagery and environmental data.

Pros:

- *Unrestricted Mobility*: The drone could navigate to any location within the pit, providing access to otherwise inaccessible areas.
- *High-Resolution Data Collection*: Equipped with cameras and lightweight instruments, the drone could capture detailed imagery of the pit's interior walls and floor.

Cons:

- *Technical Complexity*: Designing a drone capable of flying in low gravity and vacuum conditions would require advanced propulsion and control systems, adding to the mission's complexity and cost.
- *Short Battery Life*: The drone's power supply would be limited, restricting flight duration and data collection time.
- *High Risk of Failure*: The harsh lunar environment and complex maneuvering required inside the pit would increase the risk of crashing or losing the drone.

Reason for Rejection:
Although the concept offered unique capabilities, the technical challenges and high risk of developing a lunar drone were deemed impractical within the current mission scope. The potential for failure and limited operational time made it less appealing than a surface-based rover.

Selected Concept - Robotic All-Terrain Rover for Pit Exploration:

After evaluating the above concepts, the team selected the Robotic All-Terrain Rover as the mission architecture. This concept provides the best balance between scientific return, operational feasibility, and cost-effectiveness. The rover's mobility enables it to explore multiple pit regions, collect high-resolution data, and perform in-situ analysis, making it ideal for achieving the mission's science objectives. A tethered descent system allows for safe ingress into the pit while maintaining a stable power and communication link to the surface.

The decision to choose this concept was based on its ability to:

- *Access and Navigate the Pit Interior*: The rover can move around the pit floor, conducting detailed scans and subsurface analysis.
- *Achieve Science Objectives*: With its comprehensive suite of instruments, the rover can characterize the thermal, structural, and radiation environments inside the pit.

- *Stay Within Budget*: A single rover with a tethered descent system and robust instrumentation fits within the $425 million budget while maximizing science return.

2.9. Programmatics

2.9.1. Team Organization

For developing a mission concept at such a high level, high productivity, effective collaboration, and organization will be crucial and essential to the team's success in this mission. Starting with delegating the workload, the team will do its best to ensure all work is distributed evenly and fairly throughout. Furthermore, the team will check in with each member to ensure that there are no problems working on the assigned section or task. In addition, the workload distribution will also be based on each member's role. Assigning roles that are best suited for each specific team member will be decided based on the strengths and experience of each individual. Members will also provide updates on progress with the assigned tasks and communicate about completing or any struggles with the designated position. Additionally, at least one team meeting each will be placed into the schedule so that everyone is up to date with everything that needs to be worked on. When the team assigns each member a task to work on during the week, allocating these tasks to their respective individual will be listed on a Google document and Google sheet for the required parts of the mission concept. Each member will update this Google document or sheet when it's completed.

Throughout this project, it will be expected that there will be different opinions on certain things. This will be discussed in a respectful manner where all the pros and cons will be assessed by the entire group to make a decision that aims toward whole group consensus. If needed, the team will seek guidance and advice from the assigned team mentor. Time-sensitive decisions are also expected to happen, and in these cases, every team member will meet and discuss the best way to move forward, given that everyone puts some input into making a collective decision. This brings up the point that though delegation of the workload is essential, the team has a collective understanding that it's vital to help each other during the entire mission concept development to reduce being overworked and overwhelmed. The team has already agreed that everyone will empathize with each person's situation and understand that there will be differences in ideas and opinions. Moving forward it will be handled in a well-mannered and respectful way where everyone's ideas and opinions will be heard. This will allow for open discussion and allow for everyone to contribute and give some input to the team. If conflict within the team arises, efforts will be taken to discuss it in a civilized manner to resolve it, and if needed, will bring up these issues to the team mentors and student advisors.

Finally, with the implementation and consistency of good team organization, the team is ready to carry out this project with driven commitment and good collaboration. However, there may be some areas where the team will need some guidance. In cases like this, the team plans to seek out advice and guidance from mentors or specific role mentors to gain insight on what can be done with the particular part the team is having trouble with. The member seeking guidance will update the team on what was explained to keep the whole team informed.

2.9.2. Cost and Schedule Estimate

This section overviews the rough cost and schedule estimates for a discovery class mission with a budget of $425 million and a launch readiness date of March 1st, 2030. Since the team is in its preliminary stages of mission planning and has no detailed requirements for instrumentation, payload, and vehicle (power, mechanical, thermal control, and data handling systems), a rough estimate of the mission cost is sufficient.

With every mission comes costs associated with travel, personnel, and outreach. As a rough estimate, expenses related to travel and outreach shall not exceed 1% of the aggregate mission cost. This ensures that most of the funding is allocated to critical mission components, such as surface operations, scientific instrumentation, and mission operations. As a result, travel expenditures (i.e., flights, hotels, and other necessary accommodations) and outreach (i.e., workshops, literacy campaigns, and seminars to promote the education of the mission’s science objectives) amount to approximately $8.5 million. Additionally, the team will maintain a 15% contingency to address unforeseen technical challenges and risks.

Preliminary Cost Breakdown:
Since the mission budget only covers post-landing activities, the cost estimate reflects the phases of surface operations and scientific exploration. The mission cost structure is organized as follows:

Cost Category	Estimated Cost ($M)	Percentage of Total Budget
Project Management and Systems Engineering	35	8%
Surface Vehicle Development	130	31%
Scientific Instruments and Payload Development	60	14%
Mission Operations (Surface)	40	9%
Ground Data Systems and Communications	25	6%
Testing and Analog Research	10	2%
Travel and Logistics	5	1%
Outreach, Education, and Public Engagement	5	1%
Contingency (15%)	63.75	15%
Total Estimated Mission Cost	425	100%

Rationale for Cost Allocation:

Each category was developed considering past small strategic missions, such as LADEE (Lunar Atmosphere and Dust Environment Explorer), Lunar Reconnaissance Orbiter (LRO), and analogous NASA rover missions like Spirit and Opportunity. Below is a detailed explanation for each cost category and the rationale for the budgetary allocation:

Project Management and Systems Engineering ($35M, 8%):

- Includes costs related to mission oversight, planning, and risk management. Project management ensures that all mission components are aligned with the goals and constraints. Systems engineering focuses on integrating all systems, verifying requirements, and managing technical risks, which are essential for a complex mission involving lunar pit exploration. Similar costs were seen in LADEE, where systems engineering was critical in managing the mission's limited resources.

Surface Vehicle Development ($130M, 31%):

- As one of the most significant cost drivers, this category includes the design, development, and testing of a surface vehicle that can safely navigate and explore the Mare Tranquillitatis pit. Due to the pit's challenging terrain and environmental conditions, this vehicle must have advanced descent and mobility systems, power management, and a thermal control system to survive extreme lunar temperatures.

Scientific Instruments and Payload Development ($60M, 14%):

- This category includes the cost of scientific instruments necessary to achieve the mission's objectives. Instruments like high-resolution cameras, ground-penetrating radar (GPR), seismic sensors, and thermal and radiation detectors are essential for characterizing the pit's geology, subsurface structure, and environmental conditions.

Mission Operations (Surface) ($40M, 9%):

- Covers all activities related to surface operations, including command and control, data collection, and troubleshooting. It encompasses mission control personnel, rover operations, and scientific data analysis for the mission's duration.

Ground Data Systems and Communications ($25M, 6%):

- Covers the development and maintenance of ground communication systems, including data transmission infrastructure, relay station support, and secure data storage. Since the lander and rover will communicate through an orbiting relay satellite, this category ensures continuous communication for real-time command and data acquisition.

Testing and Analog Research ($10M, 2%):

- As part of NASA's risk mitigation strategy, the mission requires extensive testing in analogous environments. This includes drop testing at the NASA Glenn Zero Gravity Research Facility and analog research at Black Point Lava Flow in Arizona, which resembles the terrain of lunar pits.

Travel and Logistics ($5M, 1%):

- This budget covers team travel for system testing, reviews, and key decision point (KDP) meetings. Major travel events include system integration at NASA

facilities and participation in the launch readiness reviews at Cape Canaveral, following the NASA City Pair Program for travel and lodging to minimize costs.

Outreach, Education, and Public Engagement ($5M, 1%):

- While a more minor component, this allocation ensures that the mission actively engages the public, provides educational content, and disseminates scientific results. Outreach is crucial for maintaining public interest and support for lunar exploration missions.

Contingency ($63.75M, 15%):

- This category is set aside to address unforeseen technical, operational, or environmental challenges. Given the complexity of pit exploration, a 15% contingency is appropriate to account for potential delays or design changes.

Preliminary Mission Schedule:

The mission schedule is divided into six primary phases, spanning approximately 4 to 4.5 years from initial concept to mission closeout:

1. *Phase 1: Preliminary Design and Systems Engineering (12 months):*
    - Complete preliminary design reviews, select instrumentation, and refine the mission architecture.
2. *Phase 2: Development and Testing (18 months):*
    - Fabricate and integrate the surface vehicle and scientific payload. Conduct environmental testing and analog research to validate the design.
3. *Phase 3: Launch Readiness and Integration (6 months):*
    - Finalize vehicle assembly, conduct pre-launch testing, and integrate with the primary launch vehicle.
4. *Phase 4: Initial Surface Operations (1 month):*
    - Deploy the vehicle, perform initial system checks, and establish communication with Earth.
5. *Phase 5: Primary Science Operations (12 months):*
    - Conduct core science investigations, including geological mapping, environmental measurements, and pit interior exploration.
6. *Phase 6: Extended Science Operations (6 months):*
    - If the vehicle remains operational, expand the mission to additional areas of scientific interest.

Total Estimated Duration: 4 to 4.5 years:

By staying within these cost and schedule constraints, the mission remains aligned with the Discovery-Class framework while maximizing scientific return and minimizing risk. Further refinements will be made as detailed mission requirements become more apparent.

2.10. Conclusion

The Mission Concept Review (MCR) has thoroughly evaluated the scientific objectives, system design, and mission architecture for exploring the Mare Tranquillitatis pit. After analyzing the mission's budgetary and scientific goals, it was decided that the best fit for the system architecture would be a Robotic, All-Terrain Rover due to its mobility and ability to access the critical areas inside the pit. The assessment of alternative mission concepts highlighted the relevance of balancing scientific gains with operational feasibility, ultimately leading the team toward developing a design that maximizes the likelihood of mission success.

With more time for additional concepts and research, the team would implement further studies on markers of habitability in the lunar environment and would be specifically interested in onboard processing capabilities.

The following milestones include developing rover development and testing using Siemens NX. This plan supports the development of the System Requirements Review (SRR) by allowing the team to begin fleshing out initial design ideas and allowing an assessment of the achievability of the outlined mission requirements.

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