Preliminary Design Review

Ernutet Crater - Millenium 7

Sebastian Garcia
Chelsea Nation
Kathrine Owens
Mathew Wharton
Kevin Alegre
Hannie Pham
Toluwani Ogunyemi
Cameron Godreau
Viganesh Ramachandran
Akhil Abraham

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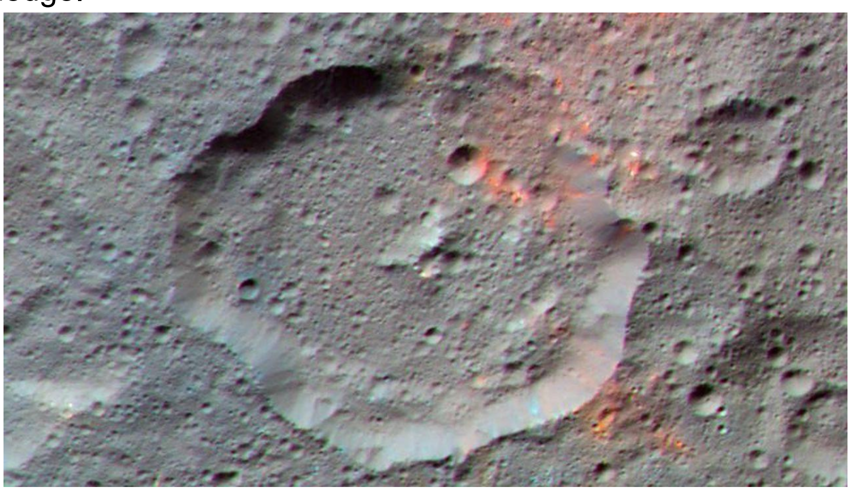
1.1 Mission Statement

The objective of the Ceres Ernutet Exploration Rover (CAESAR) mission is to deploy a rover on Ceres, tasked with analyzing organic compounds and exploring geological and hydrothermal processes within the Erntutet crater. The mission seeks to understand whether these compounds are indigenous to Ceres or imported from beyond, and to determine if these geological activities could foster microbial life. The data from this mission will contribute to priceless insights into the nature of organic materials on foreign celestial bodies and the mechanisms of geological processes in extraterrestrial environments, thereby enriching our understanding of the diverse processes within our solar system. The team will employ two instruments, namely the mass spectrometer and vis/IR spectroscopy, to discern the origin of organic compounds. They will focus on volatile compounds, excluding certain acids and other compounds due to their interactions with the surface matrix. By utilizing the mass spectrometer, the team can identify complex silicon compounds and large chains that would not be volatile under ordinary conditions. This analysis will help determine whether the organic compounds are indigenous to the celestial body or not. Understanding the organic components on different celestial bodies can help determine if they resulted from chemical reactions or have extraterrestrial origins. It offers insights into the formation of our solar system and the potential emergence of life. NASA's investment in this research is crucial as it deepens our understanding of the cosmos and our place in the universe, benefiting humanity's knowledge.



1.2 Mission Requirements

In pursuit of our mission objectives, this report presents a comprehensive overview of the indispensable requirements for the forthcoming exploration mission to Ceres, meticulously documented in Table 1. Each requirement in the table is uniquely identified and accompanied by a detailed description, a rationale for its inclusion, potential parent and child requirements (as applicable), an assigned verification method, relevant subsystem associations, and an indication of its fulfillment status. These requirements encompass a diverse range of vital considerations, including scientific aims, operational capacities, subsystem functionalities, and compliance with regulatory standards. By thoughtfully addressing these requirements, our team aims to ensure the successful design, development, and execution of the mission while diligently adhering to necessary constraints and guidelines.

Table 1 offers an expansive compilation of requirements, certain entries have been designated as "TBD" (To Be Determined). This label signifies that specific details or values pertaining to those requirements are currently undergoing the finalization process. As our mission progresses and additional information becomes available, we will continually refine these requirements to ensure their precise specification, thereby enhancing the overall accuracy and effectiveness of our mission implementation.

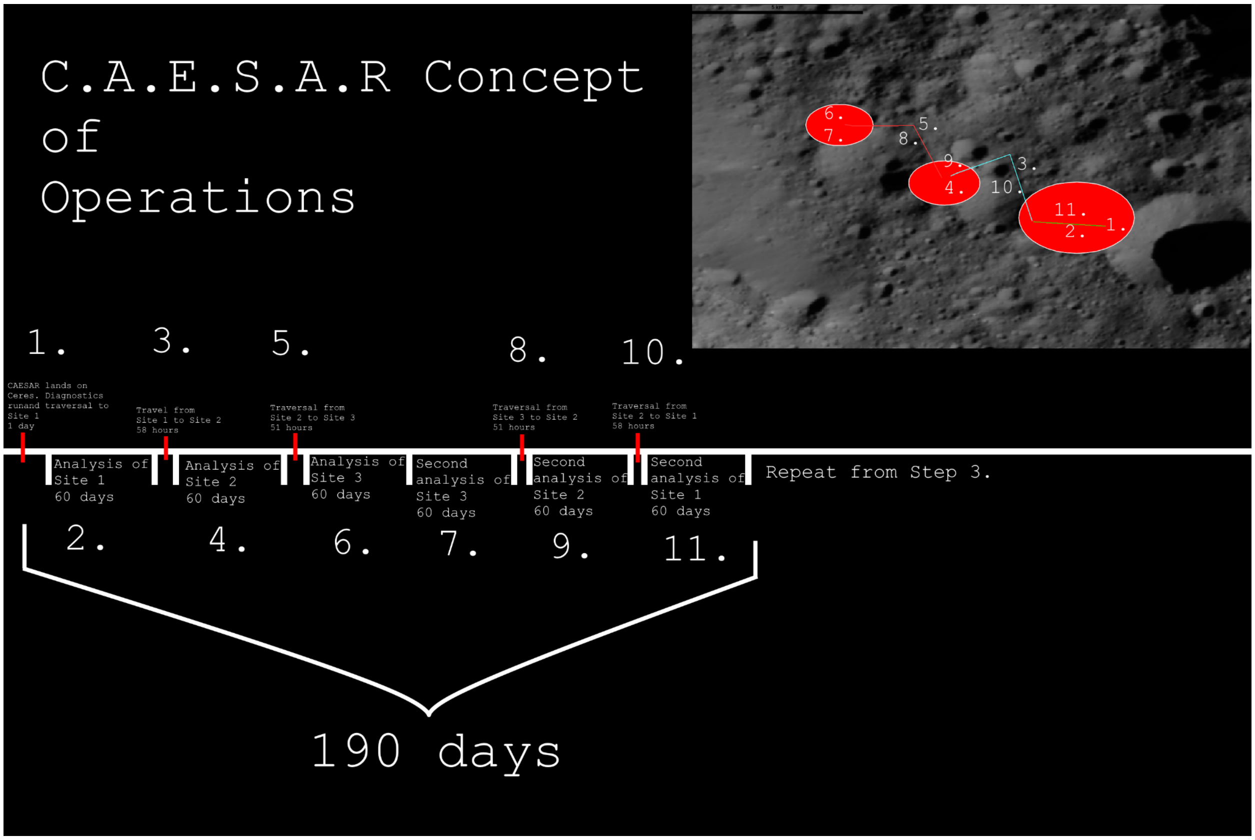
1.3 Mission Success Criteria

We selected this criteria as we felt that it was the most important thing as we needed power for the rover to run. Our Sample collection system has to carry an exact amount of samples in order for correct research to be done. Our water temperature and thermal constraints are necessary for the compounds to stay intact and for the rover to continue running. Our navigation helps the rover get to the necessary places to conduct and bring back research. These criteria help define our mission success.

In order for the rover to be considered a success it must meet these criteria:

Category	Minimum Success	Optimum Success	Stretch Goal
Power/Operations	Remains functional for **30** days Obtains the optimal power shown by requirements.	Remains functional for **90** days	Remains functional for **180** days
Navigation	Successfully travels to designated area in Ernutet Crater	Reaches designated area in Ernutet Crater and is able to travel **10** km	Reaches designated area and is able to travel **15** km
Science (Sample Collection System)	Collect and analyze **1** surface samples	Collect and analyze **10** surface samples	Collect and analyze **20** surface samples
Water Temp. Data Collection	Collects water temperature data over a distance of **1** km Stays in between thermal constraints.	Collects water temperature data over a distance of **10** km. Stays in between thermal constraints.	Collects water temperature data over a distance of **15** km. Stays in between thermal constraints.

1.4 Concept of operations (ConOps)



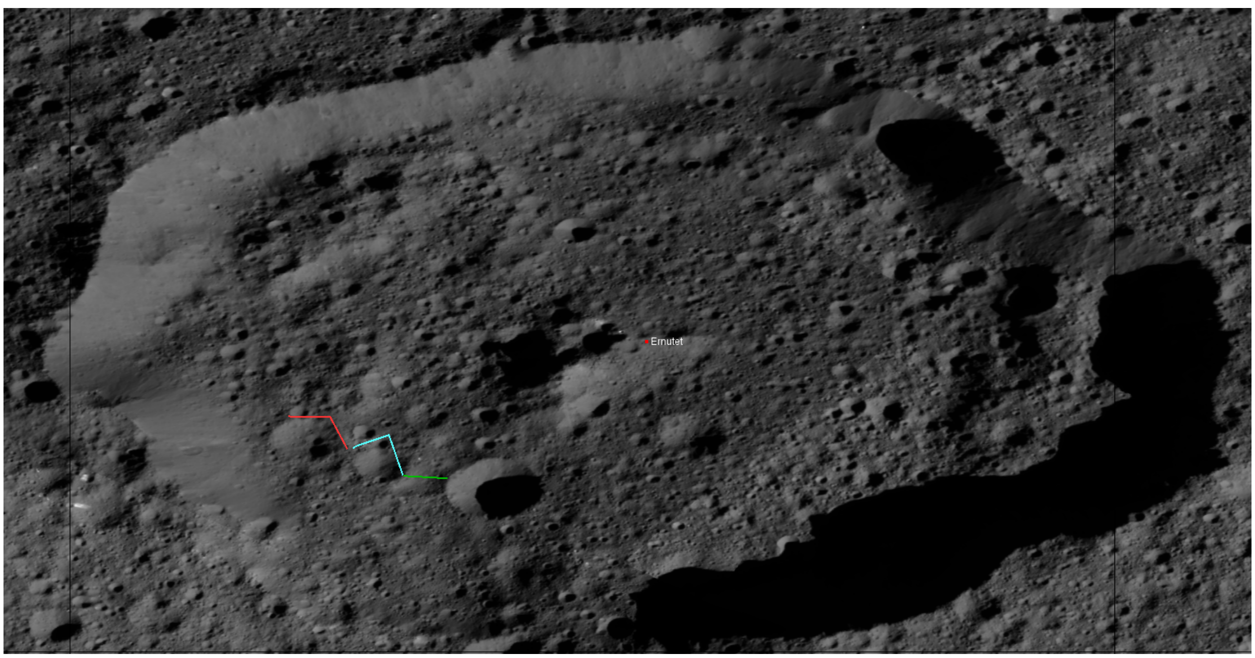
One cycle is approximately half of a year. CAESAR will attempt to do 4 full cycles of analysis. CAESAR will land at Site 1.

In order to examine organic material in Ernutet Crater, CAESAR will land in a region of smaller craters in the southwest of Ernutet that has been shown via NASA's Dawn mission to contain a high concentration of organic material. This region's elevation has been analyzed and it was determined that the terrain allows for ground that is traversable enough for CAESAR's design, with the steepest angles of elevation being approximately 20 degrees, while CAESAR can handle up to 30 degrees.

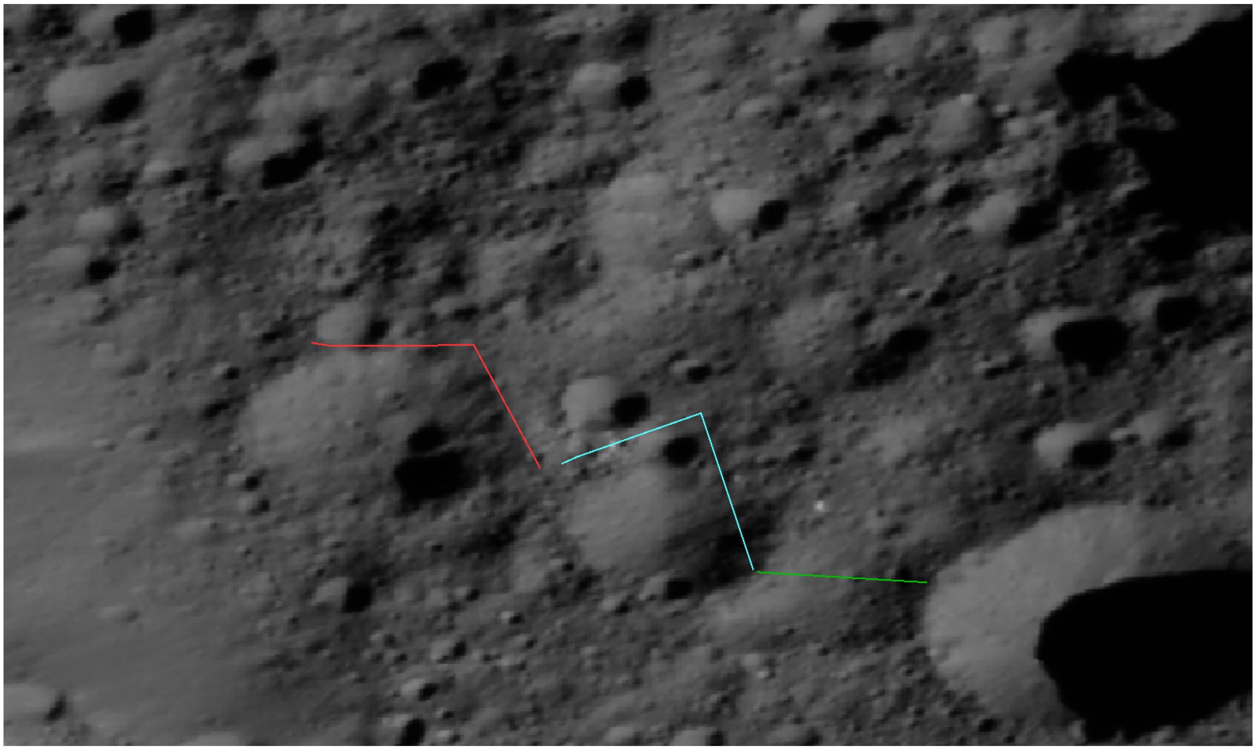
CAESAR will land at Site 1, closest to the easternmost crater. Upon landing, CAESAR will deploy from its compact mode, and perform checks of its various systems, assuring that they are all nominal. These systems are the mobility, thermal, communications, data, power, instrumentation, and analysis systems. Once CAESAR's functionality is ensured, it will begin scientific analysis of Site 1. This will last for 60 earth days. During these 60 earth days, CAESAR will collect small samples and bring them inside of its chassis to perform in-situ analysis, where it will send data to NASA back on earth when possible. CAESAR will additionally periodically slow functions such as movement to recharge and maintain battery life. After 60 days of analysis on site 1, CAESAR will begin the trek to site 2. During the traversal, CAESAR will stop to analyze samples on its path. This will effectively double the travel time between sites. When CAESAR reaches site 2, it will perform the same analysis as it did in site

1, for 60 days as well. From there, it will travel to the final site, Site 3, where it will again perform analysis of samples on its route to site 3. At site 3, CAESAR will perform more analysis for an additional 60 days. When the analysis of each site is completed, it will have been nearly 200 days. Because CAESAR has 2 years for its mission on Ceres, it will begin traveling back to site 1, repeating its processes the same way it did while moving from site 1 to site 3. This, however, will begin with analysis of site 3 for another 60 days, in order to keep the time spent analyzing each site uniform. In the end, CAESAR will likely be able to go from site 1 to 3 and back, and then site 1 to 3 and most of the route back before the mission duration is over.

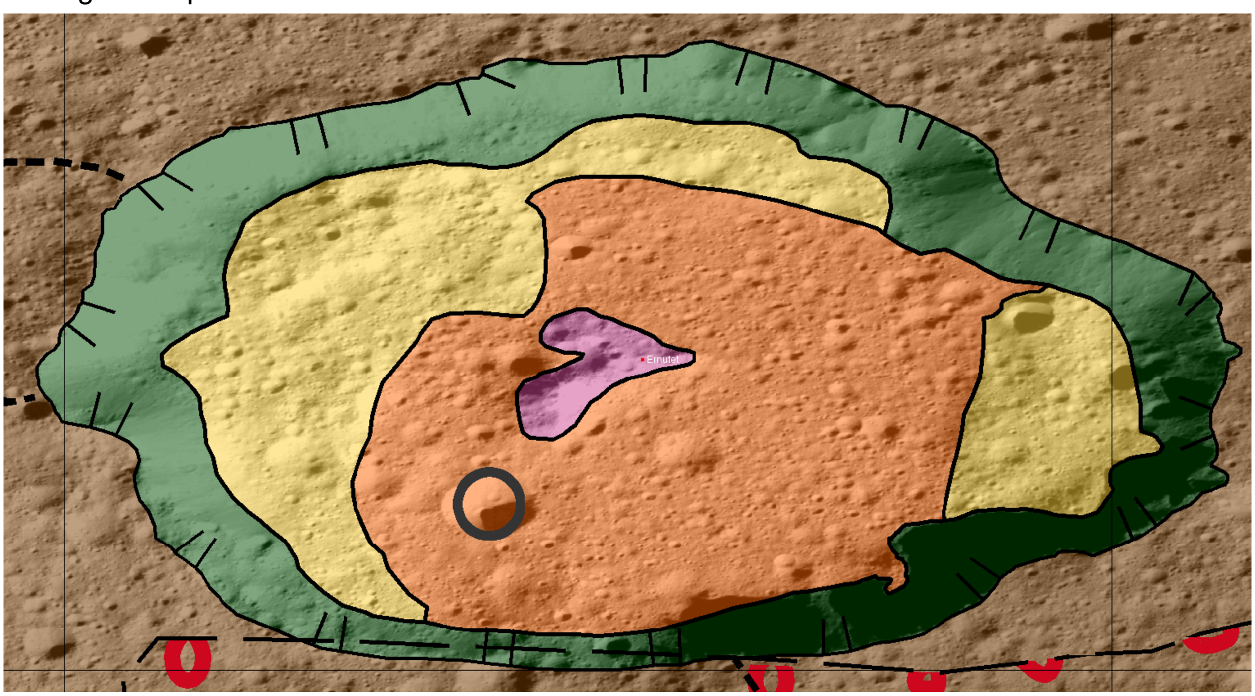
Landing (Site 1) to other side of Site 1:
2 km (22 hours)
Site 1 edge to Site 2:
5.2 km (58 hours)
Site 2 to Site 3:
4.6 km (51 hours)
Speed at day: 0.15 km/h
Speed at night: 0.03 km/h
Avg. Speed: 0.09 km/h
CAESAR routes



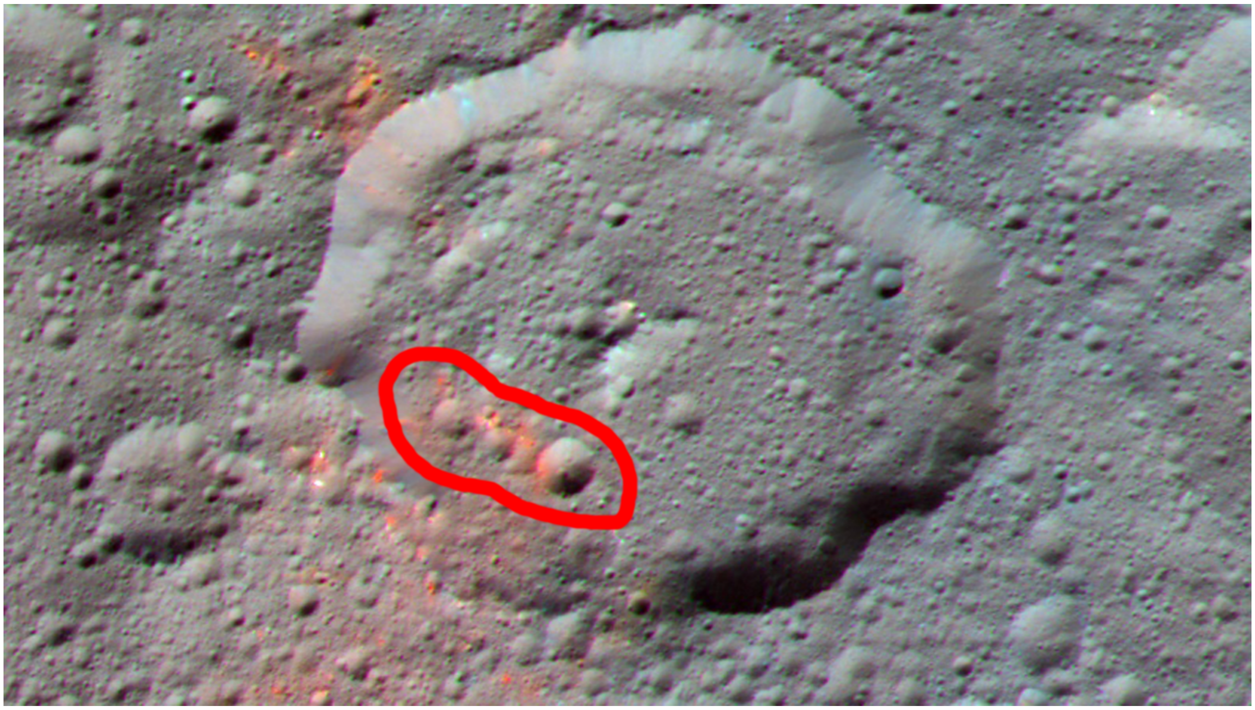
CAESAR routes (zoomed)



Geological Map of Ernutet



Area of Interest (circled in red)



1.5 Vehicle Design Summary

To begin, the CAESAR rover weighs approximately 120 kilograms with every system. In its compact form, it can condense down to 120x125x80 cm. When deployed, It can extend to 200x150x82, including its mechanical arm stretched to its full length. Its maximum power draw is (power) watts. CAESAR makes use of two instruments, a mass spectrometer and an infrared spectrometer. The mass spectrometer analyzes samples using gas chromatography, and the infrared spectrometer analyzes the interaction between visible and infrared radiation. The mechanical system includes the subsystems of the chassis, which houses all internal components, the mobility system, which includes the rocker-bogie and the wheels, and the robotic arm, which acts as a sample collection mechanism. The thermal systems of the rover include white silicone paint for its thermal properties, a 2mm multi-layer insulation blanket, and kapton heaters to keep sensitive components at a proper operating temperature.

1.6 Payload and Science Instrumentation Summary

This Table shows the lower level requirements used to design the payload and instrumentation.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification	Relevant Subsystem	Req Met?
MS.1	Lander shall identify organic compound concentrations in surface	To determine if micelles are present in the Ernutet Crater.	**TBD**	**TBD**	**TBD**	Mass Spectroscopy	YES
IS.1	Lander shall detect infrared peaks of 5128 cm^{-1}, 6896 cm^{-1}, 8333 cm^{-1}, and 10300 cm^{-1}	To determine if subsurface water temperature cycles are suitable to sustain microbial life.	**TBD**	**TBD**	**TBD**	Infrared Spectroscopy	YES

Instrumentation System Overview

To determine the presence of organic compounds, it is important to monitor the environment of the Ernutet crater using different instruments. These instruments need to measure the composition of organic compounds and the temperature of the environment. Using some instruments may also hint whether the environment is suitable for microbial life based on the subsurface water temperature.

Visible and Infrared Spectroscopy is a close range electronics unit which includes a cryocooler with driving electronics. It presents two cameras in which one captures apparent light and the other identifies infrared. The visible channel possesses 96 channels, spanning from 0.35 to 1.07 µm and possesses a field vision of 32x32 mrad. This instrument is able to achieve detection, determination and distribution of organic compounds, minerals, and atmospheric gasses. The TRL-Level for this instrument is a 7 as it has been used for several space missions.

Mass Spectroscopy is able to achieve abundance and detection of organic compounds as well as water. It operates in the range of -40 degrees Celsius to 20 degrees Celsius (233 - 293 K). It can be volatilized by laser desorption which allows the fragments to remain intact, especially larger fragments. The TRL-Level for this instrument is a 7 as it has been used for several space missions.

This Table shows the mass, volume, and power for the instrumentations.

Compounds	Mass (kg)	Volume (m^3)	Power (W)
Visible and Infrared Spectroscopy	3	0.32604	5
Mass Spectroscopy	11.5	0.6534	65

1.7 Programmatic Summary

1.7.1 Team Introduction

- Kathrine Owens

Mechanical Engineering
The City College of New York, New York, NY

Member of the AIAA in the flight test division and a member of the Society of Women Engineers.

- Sebastian Garcia

Computer Engineering
The University of Florida, Gainesville, Fl

Love technology and aspire to make a change in it one day.

- Toluwani Ogunyemi

Mechanical Engineering
Virginia Tech, Blacksburg, VA

Highly enjoy finding new ways of relieving stress either through physical activities or aerobics.

- Cameron Goodreau

Chemistry, Engineering
Brown University, Providence, RI

Researching organic compounds in extraterrestrial materials and engineer on SBUDNIC satellite

- Matthew Wharton

Mechanical Engineering
University of New Hampshire, Durham, NH

Interested in propulsion, Launch ops/Safety officer for college rocketry club

- Viganesh Ramachandran

Aerospace Engineering
Pennsylvania State University, State College, PA

- Kevin Alegre

Computer Science
Virginia Tech, Blacksburg, VA

- Akhil Abraham

Mechanical Engineering
Rutgers University, New Brunswick, NJ

Highly interested in all forms of rocket propulsion, member of college rocketry team

- Hannie Pham

Data Analytics
Dickinson College, Carlisle, PA

I am fascinated by the invisible forces guiding our world and how we are controlling them through technological advancements.

1.7.2 Team Management Overview

Team 7 is well-equipped to handle the rover mission task due to its diverse set of specialists. The team consists of Mechanical, Thermal, and CDH (Command, Data Handling) Engineers responsible for designing and ensuring the rover's functionality in terms of physical components, thermal management, and overall command and data handling. Additionally, there is a team of Scientists contributing their domain knowledge to guide the scientific goals of the rover. The Programmatics Team focuses on mission planning, scheduling, and resource management, while the Project Manager oversees the entire project's execution and ensures coordination among the different teams.

The team works collaboratively, with regular meetings and communication channels set up to ensure smooth interactions among team members. They were structured via when2meet, and through all teams we announced what time and when they would occur. Usually tried to stay in the weekly note of every sunday night and squeeze in others throughout the week. The Mechanical, Thermal, and CDH Engineers collaborate closely to design an efficient and robust rover that can withstand the extreme conditions of its mission. The Scientists Team works hand-in-hand with the engineers to align the rover's capabilities with the scientific objectives. The Programmatics Team ensures that all aspects of the mission are well-coordinated and that the project stays on track.

The team's structure was carefully planned to cover all essential aspects of the rover mission. Each team member has a specific role that aligns with their expertise. The inclusion of mechanical, thermal, and CDH engineers ensures a well-rounded approach to the rover's design and operation. The presence of a dedicated Scientists Team guarantees that scientific goals are at the forefront of the mission. The Programmatics Team and Project Manager provide project management expertise to keep the project organized and on schedule.

Throughout the rover development, challenges arose in different areas, such as engineering constraints, scientific requirements, or project timelines. The team addresses these issues collectively through regular discussions and collaboration. We each delved into the problems and had people work with mentors and feedback on how to fix things. We had established a structure with roles and then this helped manage the team. Each team member brings their unique perspective to find effective solutions.

NASA
MEET THE TEAM
MILLENNIUM 7
L'SPACE Academy
PROJECT MANAGER
LEAD SYSTEMS ENGINEER
Sebastian Garcia
DEPUTY PM RESOURCES
LEAD PROGRAMMATICS
Chelsea Nation
LOGISTICS COORDINATOR
THERMAL ENGINEER
Kathrine Owens
MECHANICAL ENGINEER
CHIEF SCIENTIST
Matthew Wharton
COMPUTER &
MECHANICAL ENGINEER
Kevin Alegre
ASTROBIOLOGIST &
GEOCHEMIST
Cameron Goodreau
PLANETARY GEOLOGIST
THERMAL ENGINEER
Akhil Abraham
MISSION ASSURANCE SPECIALIST
ELECTRICAL ENGINEER
Toluwani Ogunyemi
ASTRONOMER
HYDROLOGIST
Viganesh Ramashandran
PROGRAM ANALYST
RESEARCH SCIENTIST
Hannie Pham

1.7.3 Major Milestones Schedule

Major Milestone	Phase	Date
CDR	C	2/7/2023 - 6/12/2023
CDR Approval	C	6/14/2023
Manufacturing Complete	C	12/14/2025
SIR	D	2/1/2026 - 4/1/2026
Rover Assembly	D	7/19/2026 - 2/10/2027
ORR	D	7/20/2026 - 2/11/2027
Rover testing Complete	D	5/19/2029
MRR	D	5/23/2029 - 10/20/2029
Launch	D - E	12/29/2029
Landing on Ceres	E	2/12/2037
PFAR	E	2/5/2039
Mission Completion	E - F	4/1/2039
DRR	F	5/1/2039
Lessons Learned	F	7/6/2039 - 1/12/2040

Phase C
• Total Time: 2.5 years • The Critical Design Review shall be written which shall further detail the information from the PDR. • Following the completion and approval of the CDR, manufacturing shall commence. Manufacturing • The conclusion of Phase C shall be once the System Integration Review (SIR) has been written, but given that the components are either labeled as COTS or are manufactured by companies who've been hired for previous missions, the

document should not merit additional time.

Phase D
- Total Time: 2.5 years   - Phase D begins with the assembly of the rover, which is named Caesar, at JPL   - Following assembly the Operational Readiness review (ORR) shall be verified to show all validations and required training for rover operations is complete   - Prior to the launch of our rover, a Mission Readiness Review shall be completed. This verifies our vehicles competence for the mission and enables the commencement of the launch.   - The rover shall launch on December 20, 2029 and shall take approximately 7 years to reach Ceres.

Phase E
- Total Time: 9 years   - The rover shall traverse the Ernutet Crater, which is 52 kilometers, for approximately two years. Rovers top speed is approximately 0.152 kilometers per hour based on Mars exploration, so to get through the crater non-stop 342 hours. However, since data and testing shall take place, allocating an additional two years on the crater is vital.   - During this period, the science team shall collect data in the team's points of interest and evaluate whether the current hypotheses are proven correct or need to be revised.   - Following the landing of the rover, a Post Flight Assessment Review (PFAR) shall be conducted to determine whether the payload and operations are adequate for the missions' duration.   - Assuming the mission lasts nine years, and the rover is continuing to collect data, a Decommissioning Review (DR) shall be conducted and the plan for closeout shall be made. Following this, the closeout of the mission in Phase F shall commence.

Phase F
- Total Time: 6 months   - The team shall write up the DRR, the disposal readiness review. This document shall detail the requirements established by NASA, detail the systems and engineering of our rover, and evaluate the performance of our rover post launch   - Following the completion of all Nasa Life-Cycle documentations, the team shall additionally write a “Lessons learned” document. This shall detail all milestones, points of weakness, points of strength, and, most of all, points of improvement.   - Lastly, a wrap up meeting to verbally reflect on the experience shall take place, and the mission shall be officially closed out

1.7.4 Budget Overview

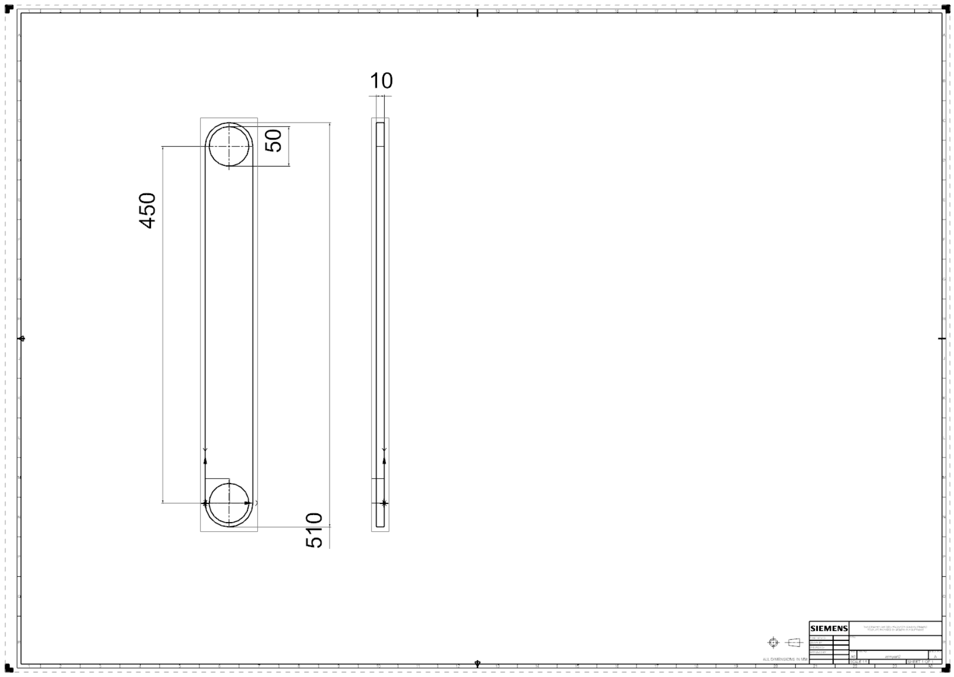
During budget development and forecasting, a number of assumptions were made. Firstly, budgets are prepared with assumptions about the rate of inflation, assuming that it will remain relatively stable throughout the mission. This assumption helps in projecting future costs accurately. Secondly, the budget assumes that the cost of specific resources, such as fuel, raw materials, or labor, will remain constant throughout the mission period. For example, the personnel budget remains the same for all roles, $80,000 for Science and Engineering, $60,000 for Technicians and Administration, and $120,000 for PM. Thirdly, travel costs are estimated based on certain assumptions, such as flights and destinations being located near the headquarters where the model will be launched to facilitate project implementation. For project timelines, the budget assumes that the mission will be completed within a specific timeframe, and costs will be incurred accordingly. In addition, some external factors like weather conditions, regulatory changes, or geopolitical situations might be assumed to remain stable or within a specific range during the mission. Finally, budgets include contingency funds to account for unforeseen events or changes in project scope, with assumptions made about the likelihood and impact of such occurrences.

2. Overall Vehicle and System Design

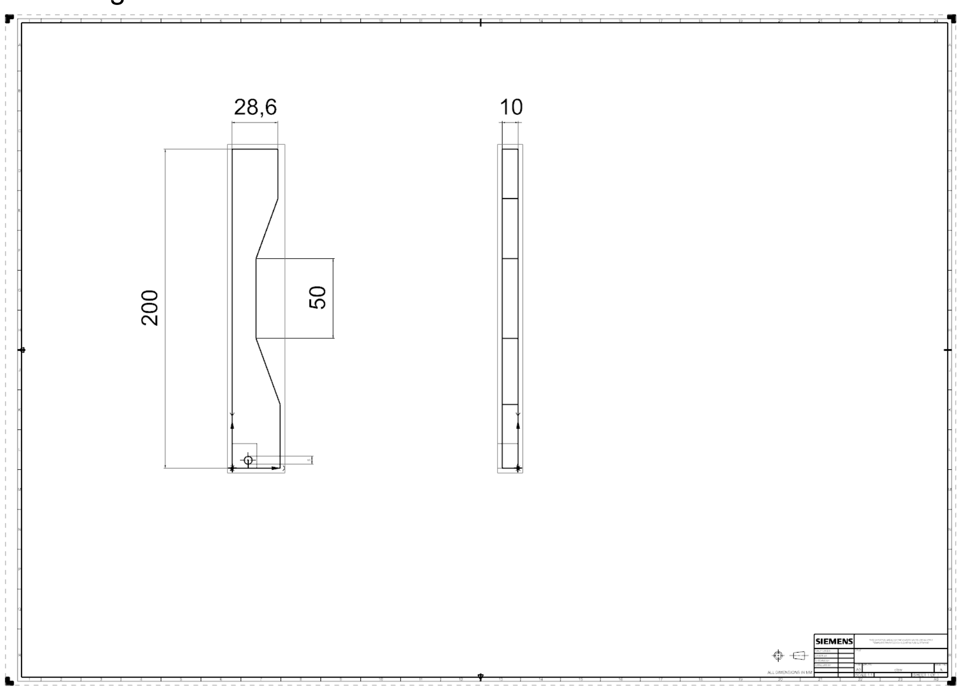
2.1 Vehicle System Overview

Component CAD Diagrams:

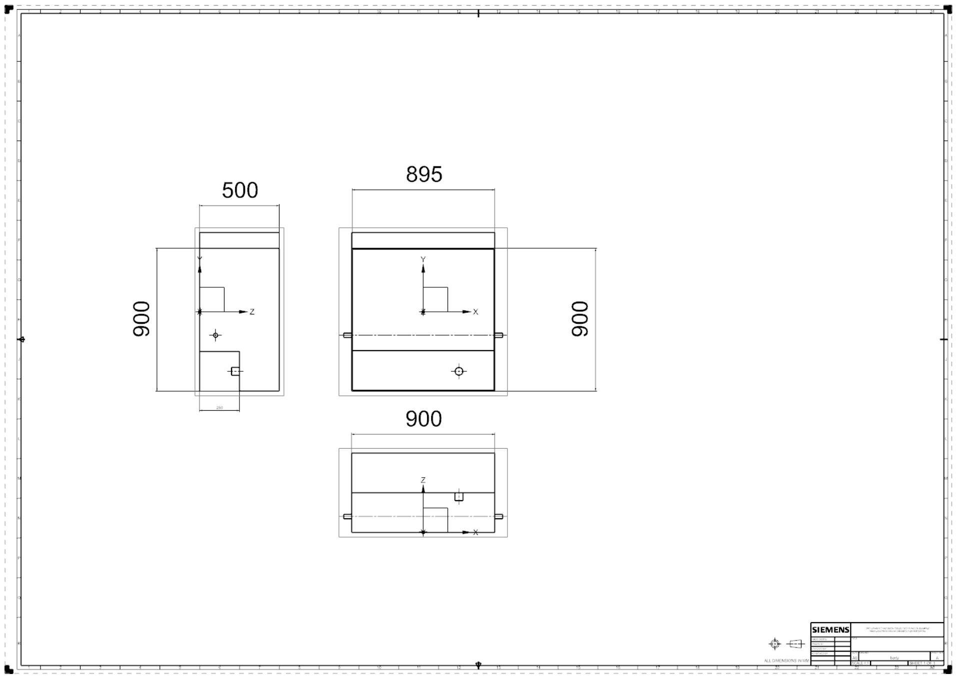
Arm Segment



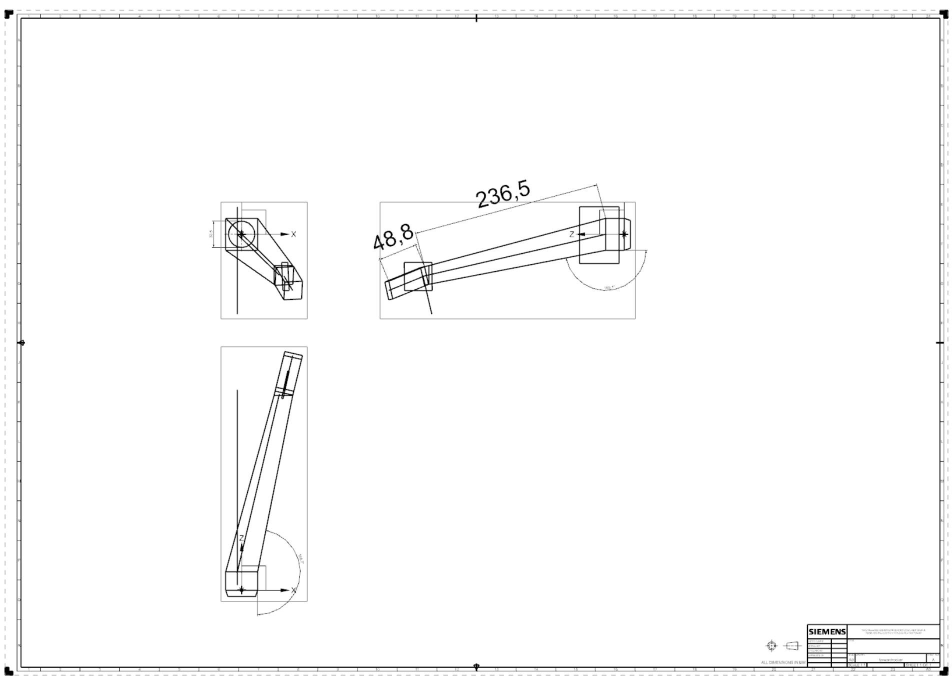
Claw Segment



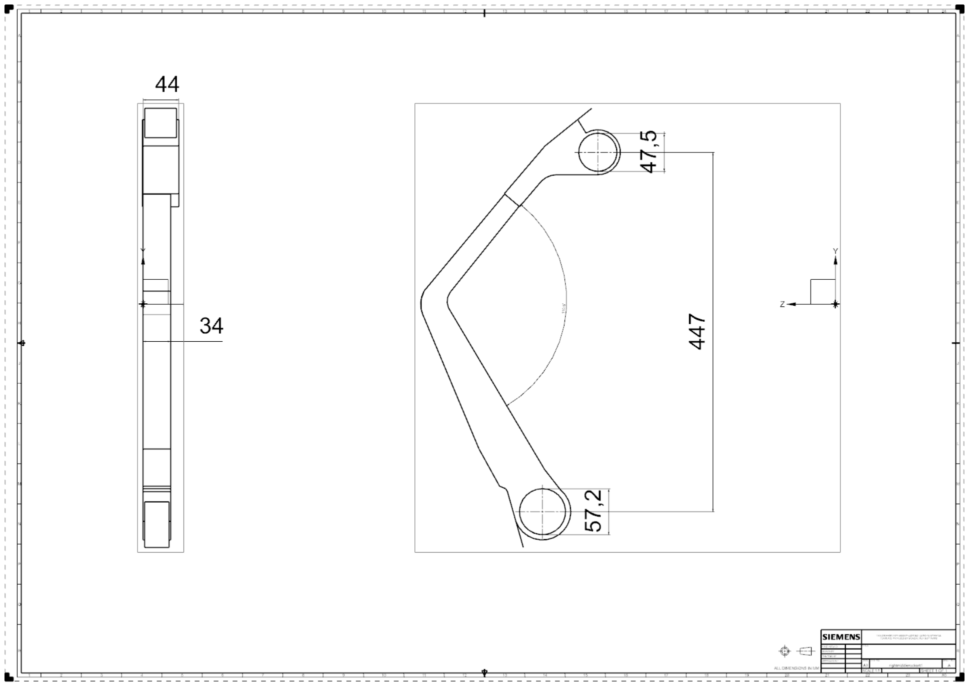
Chassis



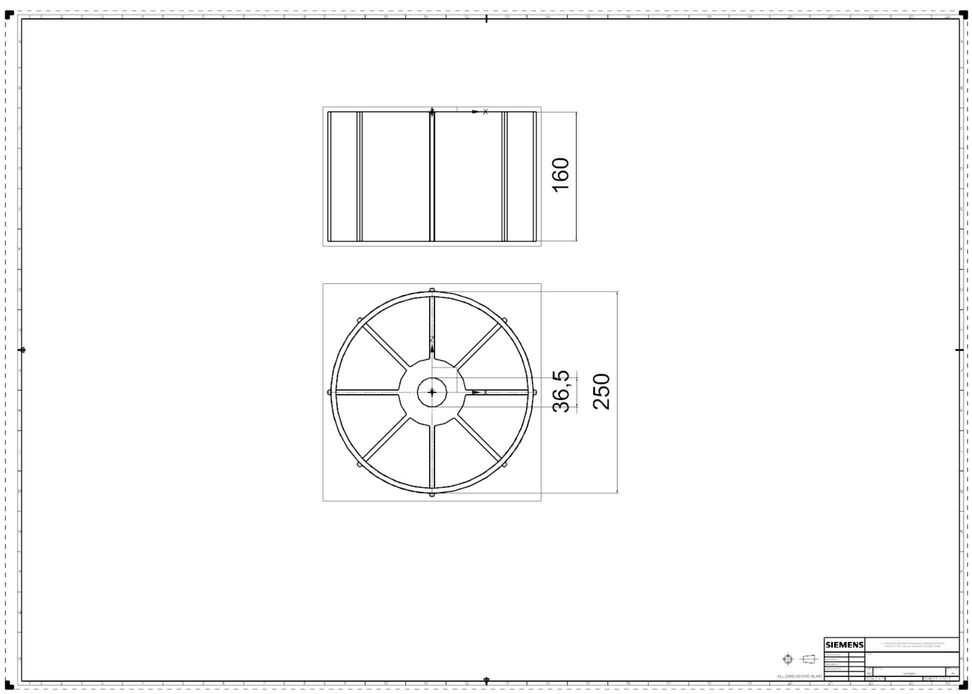
Forward Rocker



Angled Rocker Segment



Wheels



Trade Studies:

Rover Body Material						
Criteria	**Explanation**	**Grade**	**Weight**	**Aluminum**	**Titanium**	**Carbon Fiber**
Cost	The material must be relatively low cost to stay within our price constraints.	10 = The material is very cost effective 5 = The material is median-range price for what it does 1 = The material is very expensive 0 = The material is too expensive	33%	7	4	0
Strength	The material must be relatively high strength to keep the rover together for the duration of the mission.	10 = The material is very strong and not prone to breaking 5 = The material is decently strong 1 = The material is very weak 0 = The material will not hold the rover together.	33%	5	9	8
Weight	The material must be light enough to keep the rover under the weight limit.	10 = The material is incredibly weight efficient 5 = The material is decently weight efficient 1 = The material is incredibly heavy 0 = The material is too heavy	33%	8	3	10
		TOTALS:	**100%**	66.67%	53.33%	60.00%

Rocker-Bogie System						
Criteria	**Explanation**	**Grade**	**Weight**	**Curiosity**	**Spirit & Opportunity**	
Rotational Range	The rocker-bogie system must be able to rotate enough for the rover to crest difficult terrain	10 = Can rotate at extreme angles 5 = Can rotate at a decent angle 1 = Can rotate at very shallow angles 0 = Cannot rotate	28%	7.5	7.5	
Size	The size of the component should be close to the CAESAR rover to avoid changing the component too much.	10 = Fits exactly on our current rover design 5 = Needs moderate resizing 1 = Needs extreme resizing 0 = Resize is so extreme that most functionality is lost	28%	3	7	
Recency	The more recently the rover was made, the more developed the component will be.	10 = System was last used in the most recent NASA rover 5 = System was last used in a moderately aged NASA rover 0 = System was last used on one of the oldest NASA rovers	15%	8	6	

Mission Relevance	The rocker-bogie system should be one used in a somewhat similar mission to the Ceres mission	10 = Rover was used in the exact same mission as the rover we are designing 5 = Rover completed vaguely similar tasks to the rover we are designing 0 = Rover was used to perform unrelated tasks to our rover	28%	8	7	
		TOTALS:	**100%**	64.42%	68.58%	0.00%

Mechanical Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Weight - Mobility	3	5	↓	W	Mobility system fails to stay under weight limit	Active
2	Weight - Chassis	3	5	↓	W	Chassis fails to stay under weight limit	Active
3	Weight - Arm	3	5	↓	W	Robotic Arm fails to stay under weight limit	Active
4	Mechanical - Chassis	2	5	→	W	Chassis is damaged upon travel to Ceres	Active
5	Mechanical - Arm	2	5	→	W	Robotic Arm is damaged upon travel to Ceres	Active
6	Mechanical - Mobility	2	5	→	W	Mobility System is damaged upon travel to Ceres	Active
7	Mechanical - Arm	2	3	↓	A	Claw of robotic arm is damaged when attempting to grab sample	Active
8	Mechanical - Arm	1	5	→	W	Secondary claw is damaged when attempting to grab sample	Active
9	Mechanical - Arm	2	5	→	W	Regolith clogs joints of robotic arm	Active
10	Mechanical - Mobility	2	5	→	A	Regolith clogs wheel motors	Active
11	Mechanical - Chassis	2	5	→	A	Chassis is damaged by Ceres	Active

						environment	
12	Mechanical - Mobility	2	5	→	A	Mobility system is damaged by attempting to traverse steep incline	Active
13	Mechanical - Mobility	2	5	→	A	Mobility system is stopped by a hole on the surface of Ceres	Active
14	Mechanical	1	5	→	W	Rover is flipped over due to weak gravity on Ceres	Active
15	Mechanical - Mobility	1	5	→	W	Mobility system fails to deploy from compact state	Active
16	Mechanical - Arm	1	5	→	W	Robotic arm fails to deploy from compact state	Active
17	Budget	2	5	↓	W	Mechanical system fails to stay under budget	Active
18	Manufacturing - Chassis	3	4	→	W	Manufacturing period of chassis goes overtime	Active
19	Manufacturing - Arm	3	4	→	W	Manufacturing period of arm goes overtime	Active
20	Manufacturing - Mobility	3	4	→	W	Manufacturing period of mobility system goes overtime	Active
21	Testing - Chassis	3	5	↓	M	Chassis fails tests and design needs to be altered	Active
22	Testing - Arm	3	5	↓	M	Arm fails tests and design needs to be altered	Active
23	Testing - Mobility	3	5	↓	M	Mobility system fails tests and design needs to be altered	Active

2.1.1.1: Requirements:

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
1	Mechanical subsystem must not exceed 90 kg	Must be able to fit within the 120 kg limit while allowing room for other systems	N/A	2,3,4	Inspection	All	Met

2	Rocker bogie system must not exceed 50 kg	Must be able to fit other mechanical subsystems	1	N/A	Inspection	Mobility	Met
3	Chassis must not exceed 35 kg	Must be able to fit other mechanical subsystems	1	N/A	Inspection	Chassis	Met
4	Arm must not exceed 5 kg	Must be able to fit other mechanical subsystems	1	N/A	Inspection	Arm	Met
5	Mechanical subsystem must fit inside of the stowed 125 centimeter cubed volume	Must be able to fit in given volume constraints	N/A	6,7,8	Inspection	All	Met
6	Rocker-bogie must be designed to fit in a stowed 125 centimeter cubed volume	Must be able to fit in given volume constraints	5	9	Inspection	Mobility	Met
7	Arm must be designed to fit in a stowed 125 centimeter cubed volume	Must be able to fit in given volume constraints	5	10	Inspection	Arm	Met
8	Chassis must be designed to fit in a stowed 125 centimeter cubed volume	Must be able to fit in given volume constraints	5		Inspection	Chassis	Met
9	Rocker-bogie must be designed with a stowed configuration	Allow the rover to extend past the 125 cm cubed limit while not stowed	6		Inspection	Mobility	Met
10	Arm must be designed with a stowed configuration	Allow the rover to extend past the 125 cm cubed limit while not stowed	7		Inspection	Arm	Met
11	Mobility system must allow the vehicle to rotate at least 30 degrees to climb slopes	Allow the rover to scale most harsh terrain it will encounter on Ceres	N/A	12	Demonstration	Mobility	Met
12	Mobility system must be able to turn wheels 45 degrees each way to allow rover to perform a full 360 rotation in place	Allow the rover to have more dynamic movement in order to change course when needed	11	N/A	Demonstration	Mobility	Met
13	Chassis must allow clearance on all dimensions to allow for 30 degree tilt and proper terrain scaling	Allow the rover to scale most harsh terrain it will encounter on Ceres	12	N/A	Demonstration	Chassis	Met
14	Wheels must be large enough to allow for full 30 degree tilt and proper scaling of terrain	Allow the rover to scale most harsh terrain it will encounter on Ceres	12	N/A	Demonstration	Mobility	Met

15	Chassis must be designed to fit other subsystems	The chassis will house most components from other systems, and thus must be able to house all of their components.	N/A	16,17,18,19	Inspection	Chassis	Met
16	Chassis must be designed to fit scientific instruments	The chassis must be able to house instruments for in-situ analysis	15	N/A	Inspection	Chassis	Met
17	Chassis must be designed to fit CDH system	The chassis must be able to house CDH system for things like the software and communication system of the rover	15	N/A	Inspection	Chassis	Met
18	Chassis must be designed to fit power system	The chassis must house the relevant power systems that provide energy to all electronic components	15	N/A	Inspection	Chassis	Met
19	Chassis must be designed to fit thermal system	The chassis must house all of the thermal components that regulate all internal parts that operate at a specific temperature range outside of Ceres' temperature.	15	N/A	Inspection	Chassis	Met

2.1.1.2: Overview Section 1: Design Intent:

Chassis:
The design intent of the chassis is to maintain all vital systems of the rover in a safe position to ensure that no harm can be done to any other subsystems. The chassis is also used to provide the main structure for the rover to give it strength and allow it to withstand forces. To fit every subsystem and provide a strong frame, the chassis was designed to be approximately 90x90x50 centimeters

cubed in volume. Because the rover utilizes the rocker-bogie system of the spirit rover, the chassis was designed to be approximately 30 centimeters off of the ground. Due to inspiration being drawn from Spirit, chassis proportions were also kept similar to Spirit in order to maintain geometry that has been proven in space.

Rocker-Bogie:

A rocker bogie is chosen for the rover because it allows the rover to travel smoothly over rough terrain. A differential inside of the rover allows for automatic balancing between both sides of the rover, making it much more stable. The rocker-bogie was also designed to be able to compact to a smaller volume in order to match travel volume constraints. The design of the rocker-bogie is the exact same design as the spirit rover - this is due to two main reasons. One, the spirit rover is a very similar size to the Ceres rover. This means that any necessary resizing of structural components will be minimal and thus have minimal to no impact on functionality. The other reason is because Spirit's mission was very similar to CAESAR's mission. Both rovers are tasked with analyzing areas to find out its history and any potential signs of life.

Wheels:

The wheels were designed with the intent to withstand the harsh environment and thermal properties of Ceres. This meant that conventional wheel materials like rubber tires could not be used, as it would not be able to withstand the harsh temperatures of Ceres. To drive the design of CAESAR's wheels, previous rovers were analyzed. To deal with the environment of Ceres, the wheels are made out of titanium and were additionally given titanium cleats for traction on the rough terrain. The wheels also must be able to turn in order to rotate the rover when necessary, so motors used on the Spirit rover were given to each wheel so that the rover is capable of turning in place.

Robotic Arm:

The robotic arm of the rover needed to be designed to collect samples from the surface of Ceres for in-situ analysis. These samples come in the form of solid material of a specific size. The rover also needs the capability to grab these samples without any difficult maneuvering, and therefore requires the arm to extend from the chassis to grab them, and then retract to bring the sample inside of its chassis to perform the required in-situ analysis. Because of the inspiration the mechanical system draws from Spirit, the functions of the arm (folding, extending, and rotating) are all done in a very similar fashion to Spirit.

2.1.1.2: Overview Section 2: Capabilities:

Chassis:

The chassis is intended to be made out of aluminum 6061, a widely available, cost-effective, and relatively light material with a density of around 2.7 grams per cubic centimeters. This material gives the chassis a tensile strength of 310 megapascals.

Rocker-Bogie:

Being the same as Spirit's rocker-bogie, it is capable of climbing angles of up to 45 degrees (though is programmed to be limited to only 30 degrees to avoid any unnecessary risk) The system also allows the rover to move at five centimeters per second. The reason why the rover moves so slow is to, like the limit on climbing angles, mitigate risk. There are no repair stations on or near Ceres, so anything breaking would have dire consequences, especially for systems where there are no redundant systems in place. The rocker-bogie is also able to compact, using an actuator and a telescoping aft-bogie, down to under 125 centimeters cubed. The structural components of the rocker-bogie will be made out of titanium, giving it an average density of 4.5 grams per cubic centimeter. Since the rocker-bogie has to support the weight of the entire chassis and consequently every other subsystem, it must be made out of a material that is safe and reliable. Being made out of this material, the titanium parts of the rocker-bogie have a tensile strength of anywhere from approximately 862 to 1200 megapascals.

Wheels:

As mentioned previously, the design of the wheels allow the rover to traverse a variety of harsh terrain on Ceres. It can go through holes that are larger than the size of the wheels, which are 25 centimeters, and its traction allows it to grab onto rough terrain, which can be anywhere from sand to rocks. The wheels are made out of titanium, which has a density of 4.5 grams per cubic centimeters, because of their structural nature. They have a tensile strength of anywhere from approximately 862 to 1200 megapascals.. The motors on each wheel of the rover also allow it to turn 360 degrees in place, like previous rovers. The individual motors on each wheel can turn up to 45 degrees in each direction. The motors utilized to turn and drive the wheels are the same used on the Spirit rover, permanent magnet brushed D.C motors. These motors have a continuous torque from 0.25 to 0.48 Newton-meters and can spin up to 3000 RPM.

Robotic Arm:

To meet the science requirements, the arm was designed with a grasping mechanism that can grab samples with a diameter of approximately 5 to 25 centimeters, allowing it to grab samples that are up to the size of a baseball. The arm is also capable of grabbing samples that are up to 90 centimeters from the front of the rover when fully extended, meaning it can reach the entire length of its own body.

2.1.1.3: Redundancy:

Chassis:

The chassis does not have a redundant system accompanying it. This is because of a multitude of reasons. Firstly, the risk of the chassis failing is incredibly low. It is one of the least complex areas of the rover, as well as one of the strongest, making its potential risks incredibly unlikely. The rover also does not have a redundant chassis because another chassis would not fit due to mass and volume constraints.

Rocker-Bogie:

The rocker bogie does not have an accompanying redundant system. This is because it has a low likelihood of failure, it is not as delicate or complex as other systems on the rover, and the mass and volume constraints of the rover do not allow it to have an extra mobility system.

Wheels:

Because of how the rocker-bogie system works, the rover is designed to have six wheels in total, with three on each side. This amount of wheels gives some amount of redundancy - if a wheel were to completely fall off of the rover and leave 2 wheels on one side, there would be a sizeable impact to its performance, but it would still be able to traverse across Ceres, albeit with a much more limited amount of terrain it has the ability to travel on.

Robotic Arm:

Because the grasping mechanism at the end of the CAESAR rover's arm is going to be put in many potentially harmful situations, it was designed to have two layers of claws in the event that one layer breaks. The rover is designed to utilize only one of these layers at a time, meaning that it will only utilize a backup pair when needed.

2.1.1.4: Manufacturing and Procurement

Because of the Jet Propulsion Laboratory's history of manufacturing five successful Mars rovers, and in particular the Spirit rover, which inspired much of this rover's design, they were chosen to manufacture the mechanical subsystem of the rover. Each subsystem of the mechanical system that requires specially-made parts will be made in-house at JPL. In total, the manufacturing, assembly, and testing of the mechanical subsystems will take around 32,500 people-hours. Once the mechanical system is assembled successfully at JPL, it will be combined with the other systems and shipped to Marshall Space Center, where it will proceed to go through all of its tests prior to launch.

System	Subsystem	Primary Component Supplier	Place of subsystem assembly and V&V	Lead time	Details
Mechanical	Body	In-House	Jet Propulsion Laboratory	7 month manufacturing time, 4 months assembly, 5 months test	The chassis of the rover is to be constructed out of Aluminum 6061, and machined and created specifically to match the rover's requirements. JPL was chosen because of their expertise in the creation of previous rovers.

	Rocker-Bogie	In-House	Jet Propulsion Laboratory	7 month manufacturing time, 4 months assembly, 5 months test	The rocker-bogie of the rover is a complex system that requires many specialized components for the environment it will be used in, like the wheels. Therefore, the rocker-bogie will be made in-house. JPL was chosen as the manufacturing place because of the same reasons as the chassis.
	Collection System	In-House	Jet Propulsion Laboratory	7 month manufacturing time, 4 months assembly, 5 months test	The collection system of the rover is complex, much like the rocker bogie, and must be tailored to the rover's size and the environment of Ceres. Therefore, it will be manufactured at JPL with the rest of the mechanical subsystems.

2.1.1.5 Mechanical System Verification and Validation

Chassis:
Being the main structure and one of the strongest parts of the rover, the chassis will need to be tested rigorously. It will have to go through a vibrational test to ensure that it can withstand traveling to Ceres and it will need to withstand thermal and vacuum tests to make sure that it can survive the harsh environment of Ceres. In addition, it will need to be tested with g-forces to ensure it can survive a large amount of force when launching from a rocket.
Rocker-Bogie:
As the rocker-bogie needs to be one of the strongest parts of the rover, it will need to be tested rigorously. It will have to go through a vibrational test to ensure that it can withstand traveling to Ceres and it will need to withstand thermal and vacuum tests to make sure that it can survive the harsh environment of Ceres. In addition, it will need to be tested with g-forces to ensure it can survive a large amount of force when launching from a rocket.
Wheels:
Being the part of the rover that contacts the ground and one of the strongest parts of the rover, the wheels will need to be tested rigorously. It will have to go through a vibrational test to ensure that it can withstand traveling to Ceres and it will need to withstand thermal and vacuum tests to make sure that it can survive the harsh environment of Ceres. In addition, it will need to be tested with g-forces to ensure it can survive a large amount of force when launching from a rocket.
Robotic Arm:
In addition to the list of tests that all other parts of the rover must pass (vibrational, thermal, vacuum), the claw will be tested with a wide range of materials of varying diameters, along with varying grip forces to find the optimal

grip strength without harming the sample or the claw, while also maintaining a firm grasp on important samples.

2.1.1.6: Confidence and Maturity

Chassis:
To meet the external requirements of the rover, the mechanical system took inspiration from the Spirit rover, a rover of a similar size and with a very similar mission to the rover on this mission. The internal requirements of the rover meant that it must be designed to allow proper use of the mass and infrared spectrometers. The chassis changed size throughout its development, as it was given more volume when it was discovered that there must be more space for other subsystems than originally anticipated. Since the chassis is a new design, and it has only been tested in simulation, it is only at a Technology Readiness Level of around two. However, by the end of the long list of tests it must go through in order to be considered safe for travel, landing, and use at Ceres, the chassis should be at a TRL of around six.
Rocker-Bogie:
Being a heritage component, this mechanical subsystem has a large advantage in Technology Readiness Level. However, minor changes in design compared to the Spirit rover will reduce the Technology Readiness Level from nine to around eight. Both internal and external constraints allow for Spirit’s rocker-bogie to be used on the CAESAR rover. CAESAR is designed to be around two-thirds of Spirit’s mass, and therefore the risk of the rocker-bogie being too weak to handle the rest of CAESAR's mass is very small.
Wheels:
The wheels of the rover are a part that had its design driven mostly by external requirements. Because of the volume and mass constraints, the wheels had to be large enough to allow the rover to traverse harsh terrain without damage, but also small enough that they fit within the mass and volume constraints. The current design of the wheels are at a Technology Readiness Level of around 2, but the scheduled tests and checks will ensure that the wheels launch at a technology readiness level of around 6.
Robotic Arm:
Many rover arms have been designed prior to CAESAR's arm, and thus have inspired the design of this rover’s arm. The TRL of the arm is currently around 4 or 5 because of this reason. However, with the tests that the arm will have to pass, it will eventually be at a TRL of around 6 before launch.

2.1.2 Power System Overview

2.1.2.1 Power System Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
PS-1	The system shall generate enough power to last the duration of the mission	Mission success is dependant on the system having power	customer	TBD	All	Power	Not Met
PS-2	The system must support a peak power	To meet the			Test	Power	Not Met

	demand between 1000- 15000 MW	maximum load requirement					
PS-3	System must have a voltage range of 20-50V	To accommodate various electrical devices			Inspection	Power	Not Met
PS-4	System must provide a backup power source	To ensure uninterrupted power supply during outages			All	Power	Not Met
PS-5	System must comply with safety regulations	To ensure the protection of users and equipment			Analysis Inspection	Power	Not Met
PS-6	System must have a power factor of 1-1.5 GW	Analyze the efficiency of how the power system distributes energy,			Test	Power	Not Met
PS-7	Battery shall be able to hold power until the end of the mission.	The battery keeps the rover operated and moving at all times.	customer		All	Power	Not Met

2.1.2 Power System Overview
2.1.2.1 Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
PS-1	The system shall generate enough power to last the duration of the mission	Mission success is dependant on the system having power	customer	TBD	All	Power	Not Met

PS-2	The system must support a peak power demand between 1000- 15000 MW	To meet the maximum load requirement			Test		Power	Not Met
PS-3	System must have a voltage range of 20-50V	To accommodate various electrical devices			Inspection		Power	Not Met
PS-4	System must provide a backup power source	To ensure uninterrupted power supply during outages			All		Power	Not Met
PS-5	System must comply with safety regulations	To ensure the protection of users and equipment			Analysis Inspection		Power	Not Met
PS-6	System must have a power factor of 1-1.5 GW	Analyze the efficiency of how the power system distributes energy,			Test		Power	Not Met
PS-7	Battery shall be able to hold power until the end of the mission.	The battery keeps the rover operated and moving at all times.	customer		All		Power	Not Met

2.1.3 Systems Overview (CDH)

2.1.4 Thermal Management System Overview

Before being able to design an effective thermal control system, we first had to create a first level heat flow map for both the extreme hot and cold cases. As a side note, conduction between the wheels of the rover and Ceres' surface is not included in the calculations under the assumptions that the heat flow as a result of conduction will be relatively insignificant and that thermally isolating the wheels will not be a complicated task. Additionally, a target internal temperature of 279 K was chosen because it falls under the mass spectrometer's operating range of 233 to 293 K and this temperature minimizes the heating required after all the future calculations are completed. Finally, all of the calculations in this section regarding electronic parts assume a 1 Watt used : 1 Watt of heat ratio.

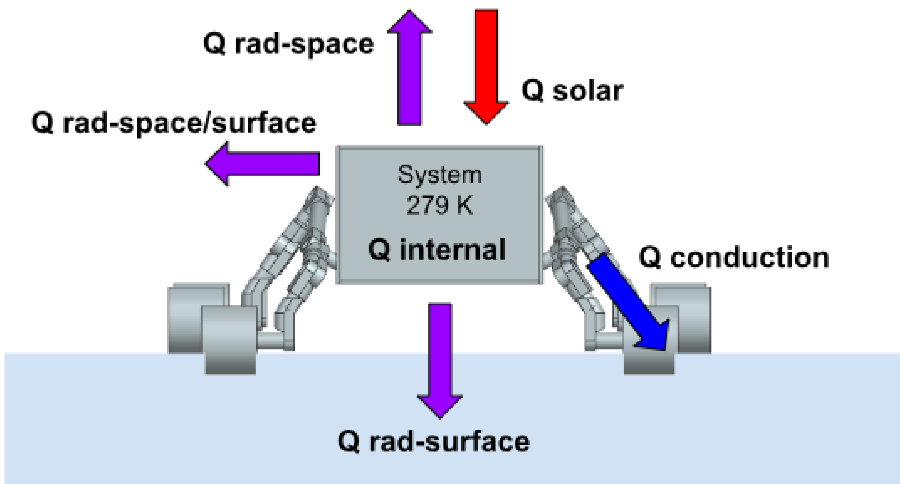


Diagram illustrating the heat flow processes occurring on the rover

2.1.4.1 Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Verification	Relevant Subsystem
TSC-1	System should be able to withstand the magnitude of weather and temperature changes.	Ensure systems function optimally	SYS-1 SYS-2 SYS-3	TSC 1.1	Test and Analysis	All

TSC-1.1	The system must maintain an internal temperature of or between 276 - 282 K for the entire mission	Ensure systems function optimally	TSC-1	TSC 1.1.2 TSC 1.1.3	Test and Analysis	All
TSC-1.1.2	The system shall maintain a temperature between 233 - 293 K for the mass spectrometer instrument	Ensure the mass spectrometer instrument function properly	TCS- 1.1	-	Test and Analysis	TCS
TSC-1.1.3	The system shall ensure that the solar panels maintain a temperature of around 278 K	Ensure Solar panels work properly	TCS- 1.1	-	Test and Analysis	TCS
TSC-1.1.4	All components of the TCS should be able to withstand the environment they will face on Ceres	Ensure all TCS components function properly	TCS - 1.1	TSC 1.1.4.1 TSC 1.1.4.2	Test and Analysis	TCS
TSC - 1.1.4.1	The system shall maintain an appropriate temperature to preserve functions of the heaters	Ensure all heaters work properly	TSC - 1.1.4	-	Test and Analysis	TCS
TSC- 1.1.4.2	The MLI shall be able to withstand solar radiation as expected on Ceres with minimal degradation.	Ensure proper function	TCS - 1.1.4	-	Test and Analysis	TCS

2.1.4.2 Subsystem Overview

Knowns & Assumptions	
Space temp. (K)	3
Ceres surface temp., cold (K)	180
Ceres surface temp., hot (K)	240
System temp. (K) (will change) -->	279
q solar flux (W / m^2)	174.36
Base emmisivity	0.4
Base absorptivity	0.3
Surface area - top (m^2)	0.48
Surface area - bottom (m^2)	0.48
Surface area - sides (m^2)	1.12
Boltzman Constant	0.0000000567

Chart showing the known values and assumptions
on which the initial calculations were made

Hot Case (no TCS)	
Q solar (W)	25.11
Q internal (W)	120.00
Q rad-space (W)	65.96
Q rad-space/surface (W)	111.78
Q rad-surface (W)	29.84
Q in (W)	145.11
Q out (W)	207.58
Q net (W)	-62.48

Chart showing the heat flow calculations without
any thermal control system

As seen above, assuming the rover's body is made out of Aluminum 6061, the rover would be experiencing a net heat load of around 62.5 W exiting the system without any form of thermal control system.

The first design choice is designating the top surface of the rover's body as a radiator, painting it with white, silicone based MAP SG122FD paint. This specific paint has an absorptivity constant of 0.2 and an emissivity constant of 0.90. Then, the bottom surface of the rover would be wrapped with a 2 millimeter multi layer insulation (MLI) blanket, made out of aluminum coated PET. The blanket will be purchased from Sheldahl. After applying these changes and re-doing the calculations, we end up with the following result for the hot and cold cases.

Hot Case (w/ TCS)		
Q solar (W)	16.74	Paint white: a = .2
Q internal (W)	120.00	
Q rad-space (W)	125.33	Paint white: e = .9
Q rad-space/surface (W)	9.78	
Q rad-surface (W)	2.61	MLI: e = .035 sides & bottom
Q in (W)	136.74	
Q out (W)	137.72	
Q net (W)	-0.98	~1 of heating required

Cold Case (w/ TCS)		
Q solar (W)	0.00	
Q internal (W)	120.00	
Q rad-space (W)	125.33	
Q rad-space/surface (W)	12.30	
Q rad-surface (W)	4.77	
Q in (W)	120.00	
Q out (W)	142.40	
Q net (W)	-22.40	~25 W of heating required

Charts showing heat flow calculations for the
hot and cold cases respectively after applying the thermal control system

In order to heat the rover, we will make use of Kapton heaters. The Kapton heaters provided by Thermo Heating Elements, LLC have a maximum watt density of 7.75 W/cm^2 (50 W/in^2). To provide the full amount of heating required, along with accounting for the heaters not operating at maximum efficiency, a total of 6.45 cm^2 (~ 1 in^2) of Kapton heaters will be required. The heaters will be divided and installed onto or near electronic components. They will be connected to and regulated by a thermostat that will in turn be connected to the main power supply of the rover. It will also transfer heat via conduction specifically to the solar panels (if they are not at the optimal temperature) and the mass spectrometer.

Trade Studies:
While most of the decisions regarding what materials would be used were easy to make due to only one product providing an effective solution (such as the thermal coating, and MLI material choice), there was one decision that required a trade study. Both aerogel and MLI were suitable choices for insulation on our rover, and so the following trade study was conducted. Based on the criteria of cost, effectiveness, and mass, it was determined that an MLI blanket would be the best insulator for our rover.

Spacecraft Insulator Material					
Criteria	**Explanation**	**Grade**	**Weight**	**MLI**	**Aerogel**
Cost	Relative unit price	1 - most expensive 10 - least expensive	15%	7	4
Effectiveness	How high is its emissivity value (lower is better)	1 - highest emissivity 10 - lowest emissivity	70%	10	2
Mass	How heavy is it	1 - heaviest 10 - lightest	15%	4	10
		Total:	100%	86.50%	35.00%

2.1.4.3 Redundancy Plans

Extra Kapton heaters will be attached to all critical parts and wired in parallel in the case that one of the heaters malfunctions. Other than the heaters, all other parts in the thermal control system are Single Point Failures (SPFs).

As for recovery, cryocoolers in conjunction with a pumped fluid loop will be used for emergency purposes when a part overheats. This system will be activated by thermostats that can detect the temperatures of all critical parts.

2.1.4.4 Manufacturing and Procurement Plans

Thermal	Heating	In-House	Ames Research Center	4 month manufacturing, 2 month assembly, 2 month test	This subsystem utilizes off-the-shelf components because components matching the specifications required were commercially available, but the rest of the system requires mostly in-house and specially made parts. Will be assembled and tested at Ames Research Center due to their development in advanced thermal protection.
	Cooling	In-House	Ames Research Center	4 month manufacturing, 2 month assembly, 2 month test	This subsystem must be made specifically for the rover, as a cooling system needs to be made to match the rover's size and power requirements. Will be assembled and tested at Ames for the same reasons as the heating subsystem.
	Insulation	In-House	Ames Research Center	4 month manufacturing, 2 month assembly, 2 month test	This subsystem must be made specifically for the rover because of factors like the rover's unique geometry, power requirements, and constraints. Will be assembled and tested at Ames for the same reasons as the heating subsystem.

2.1.4.5 Verification and Validation

Component testing, per NASA's request, shall be performed at Ames Research Center so that all advanced thermal protections are in place. The MLI insulation blanket and thermal coating will be tested for the correct absorptivity and emissivity values when first bought. Additionally, the Kapton heaters will be tested to verify that they are working at the correct efficiency and have no deficiencies that will prevent them from working for long hours – at least 4.5 hours, or the length of night on Ceres.

After all the parts have been verified and assembled, one final test will be conducted, placing the rover under the extreme hot and cold cases of Ceres to confirm that all thermal elements will act as expected as well as to confirm that the internal temperature of the rover remains at a safe level.

2.1.4.6 Confidence and Maturity

Most of the main components of the thermal control system–MLI blankets and white thermal coatings–have been used on numerous prior missions, including the International Space Station, Hubble Space Telescope, and Mars Reconnaissance Orbiter. Because these specific materials may not have been used before, but the general system has, the team has placed the Technology Readiness Level (TRL) of the MLI blankets and thermal coatings at 6. The same applies for the Kapton heaters being used.

The overall design of the thermal control system has changed slightly, with the main change being how components are heated/cooled. At first, the Kapton heaters were placed together. However, after feedback from a mentor, it was pointed out that the heaters actually have to be applied to the component that they are responsible for heating. As a result, the change was made to attach heaters to all the vital components. Additionally, there was not a cooling system prior to the feedback, but after considering the redundancy and recovery of the thermal system, it was determined that a cooling system would be put in place for emergency purposes.

3. Payload design and Science Instrumentation

3.1.1 Science Payload Objectives

3.2 Payload & Instrumentation

To determine the presence of necessary energy and nutrients to support microbial life, it is important to analyze the conditions of the environment using different instruments. Some of the instruments need to identify the organic compounds present within the surface or measure the water temperatures within the environment. To do this in the Ernutet crater, gas chromatography-mass spectrometry and Vis-IR spectroscopy will be used.

3.2.1 Instrumentation Overview

Gas chromatography-mass spectroscopy is an analytical technique that will be used to identify volatile aliphatic hydrocarbons present within samples by measuring the mass-to-charge ratios of ions. Surface samples of the Ernutet crater will be collected and contained within a sealed vessel. The sample will be crushed to release compounds within the material. Using laser desorption up to 200°C, the sample will then be released through the gas chromatograph capillary for separation for 30 minutes before going to the mass spectrometer.

It operates in the range of -40°C to 20°C (233-293 K). The compounds will be volatilized by laser desorption which allows the fragments to remain intact, especially larger fragments.

Visible and Infrared Spectroscopy measures the interaction between visible and infrared radiation with matter through the absorption, emission, or reflection of specific wavelengths. It is a close range electronics unit which includes a cryocooler with driving electronics. It has two cameras: one to capture apparent light and the other for infrared. The visible light channel possesses 96 channels, spanning from 0.35 to 1.07 µm and possesses a field vision of 32x32 mrad. This instrument is able to achieve detection, determination, and distribution of various organic compounds, minerals, and atmospheric gasses, but will be used for water detection on Ceres. Water interacts with different wavelengths depending on its form, allowing us to detect the natural form of water and infer its temperature.

This Table shows the mass, volume, and power for the instrumentations.

Compounds	Mass (kg)	Volume (m^3)	Power (W)
Visible and Infrared Spectroscopy	3	0.32604	5
Mass Spectroscopy	11.5	0.6534	65

3.2.2 Recovery and redundancy

Mechanical system: Redundancy: The mechanical system may require redundancy for critical components to ensure mission-critical requirements can still be met in the event of a failure. Redundant components can be considered for systems where failure could have severe consequences. For example, critical structural elements, such as load-bearing members, may have redundant counterparts to provide backup support. However, it is essential to perform a risk assessment to determine the need for redundancy in each specific case. Components that are too expensive, large, or do not pose significant safety risks may be designated as Single Point Failures (SFPs) and may not have redundant counterparts.

Recovery: In the event of a system error in the mechanical system, a recovery plan should be established to return to a safe configuration. The recovery plan should be designed to be autonomous, driven by the spacecraft's software. For example, if a thermal sensor detects a component operating at an unsafe temperature, the recovery plan could involve activating cooling mechanisms or adjusting ventilation systems to bring the component back to a safe operating temperature. Collaborating with the software team is crucial to ensure that the recovery plan is seamlessly integrated into the spacecraft's software architecture and executed autonomously without direct control from mission control.

Command and Data Handling (CDH) System: Redundancy: The CDH system may require redundancy for critical components involved in data processing, communication, and command execution. Redundant processors, memory modules, and communication interfaces can be considered to provide backup capabilities and fault tolerance. However, the level of redundancy implemented should be carefully evaluated, considering factors such as mission criticality, cost, and complexity. Non-critical components or subsystems may not require redundancy if their failure does not significantly impact the system's overall functionality or safety.

Recovery: The CDH system's recovery plan should be focused on returning to a safe and operational state autonomously through software-controlled actions. In the event of a system error, the recovery plan may involve error detection and isolation, failover mechanisms to switch to redundant components or alternate processing paths, and error recovery protocols to restore normal operation. It is crucial to collaborate with the software team to ensure that the recovery plan is well-integrated into the CDH system's software architecture and can be executed autonomously without direct control from mission control.

Thermal System: Redundancy: Redundancy within the thermal system can be considered for critical components such as temperature sensors, heaters, or cooling systems. Redundant components can provide backup capabilities and ensure the system maintains thermal control in the event of a failure. However, the need for redundancy should be evaluated based on the criticality of the components and the consequences of thermal system failure in relation to mission objectives and safety.

Recovery: The recovery plan for the thermal system should focus on maintaining safe operating temperatures for critical components. It may include monitoring and diagnostics to detect thermal system failures, failover mechanisms to switch to redundant components or alternative cooling methods, and protocols for system reboot, error recovery, and data restoration. It is crucial to have well-defined procedures for responding to thermal system failures and ensuring efficient recovery to prevent damage to sensitive components.

Verification and Validation (V&V) should be applied to each of these systems to ensure their reliability and performance. Verification ensures that the mechanical, CDH, and thermal systems are built according to predefined requirements, while validation confirms that the systems will function as intended in the operational environment. Detailed testing plans should be developed for each system, outlining the necessary steps and tests to verify the design against the system requirements and validate its performance in relevant conditions.

3.2.3 Manufacturing and Procurement Plans

The gas chromatograph-mass spectrometer instrument was previously used in the Rosalind Franklin, Viking, Philae, and Curiosity rovers. It was developed by the Max Planck Institute for Solar Systems, LISA, and LATMOS, which would be contracted to design the system for this mission as well.

The Visible and Infrared Spectrometer was previously used in the Mars 2020 Perseverance Rover, also known as SHERLOC. It was developed by the Jet Propulsion Lab in Pasadena, California, which will be contracted to design another for this mission.

3.2.4 Verification and Validation

The GC-MS should fit within power, mechanical, etc. constraints for the entire mission. It should also be able to detect aliphatic hydrocarbons in a controlled environment within temperature conditions, sample sizes, etc. This verification will be completed in close partnership with the companies in their design of the instrument, which includes working with engineers on this mission for validation.

The Visible and Infrared Spectrometer should also fit within mission constraints and requirements. It should be able to identify water peaks and work within environmental conditions of Ceres. This verification will be completed in close partnership with JPL, including working closely with mission engineers for validation, during the design of the instrument.

3.2.6 Testing & Calibration Measurements

To test the GC-MS instrument, a sample of aliphatic hydrocarbons will be used to test the instrument for its recognition of the compounds and to determine if any changes to the method must be changed. The sample will include some of the basic hydrocarbons expected to find on Ceres, including methane, ethane, etc. The focus of this mission is on aliphatic hydrocarbons, so no further tests need to be performed for compound identification, but a baseline should be taken in case of contamination of the column with environmental compounds. Using a known concentrated sample can also lead to an estimation of the concentration of aliphatic hydrocarbons present on Ceres, though this value might not be accurate.

To test the Visible and Infrared Spectrometer, water at different temperatures should be measured to determine whether the device is able to accurately depict water temperature due to differences in wavelength interactions. This should be used as a standard for when on Ceres, as it also allows for calibration of the instrument. Water at 0°C, 20°C, 30°C, and 100°C should be used, plus more if possible, to get a full range of possibilities of what might exist on Ceres.

3.2.7 Precision & Accuracy of Instrumentation

Many factors can affect the precision and accuracy of the GC-MS, leading to missing data. The concentration of aliphatic hydrocarbons must be >10ppb so not to be confused with background noise. If there is less concentration, that doesn't disprove their existence but just that the sensitivity of the instrument cannot detect them. As the volatile organic compounds on Ceres are relatively unknown, there is no indication for the background noise that will be present. The concentration of other compounds, especially in relation to aliphatic hydrocarbons, may lead to being unable to detect the compounds desired. Contamination to the column and column degradation as a result of exposure to organic compounds may also affect the precision and accuracy of the results, leading to more background noise.

Visible and Infrared Spectroscopy can also have factors that affect its precision and accuracy. The presence of other compounds can lead to water peaks being drowned out, especially if other compounds interact with the same wavelengths. The peaks also might provide accurate readings on the temperature, but more of an estimation that could help determine if the water present could serve as a resource for microbial life.

3.2.8 Expected Data & Analysis

The GC-MS should produce chromatograms of the compounds found in the samples. These mass-to-charge values should be able to be compared with the NIST Mass Spectrometry Data Center Library, for identification of compounds. All chromatograms should then be compared to one another to determine best results. The chromatograms should vary, as they will be a result of different samples from different locations. They should have various concentrations of different compounds as a result. Therefore, finding common volatile aliphatic hydrocarbons is one of the key results from these.

The Visible and Infrared spectroscopy should produce peaks that illustrate wavelengths at which there was an interaction with compounds. These should be identified and associated with compounds, with the emphasis to identify which could relate to water. These results should be compared with the standard for water taken during the testing and calibration stage to estimate temperatures of water found.

4. Mission Risk Management

4.1.1 Risk Analysis

Through a scale-based evaluation, the team assessed the potential impact of each risk, allowing for a comprehensive understanding of their significance. Regular risk review meetings are conducted, ensuring ongoing evaluation, updating, and incorporation of new risks into the summary. This iterative approach ensures that risks are consistently monitored throughout the project's lifespan.

As the project progresses, the team acknowledges that certain risks may possess a higher probability of occurrence than desired. To mitigate these probabilities, particular emphasis will be placed on risk reduction by the Preliminary Design Review (PDR) stage. Recognizing that subsystems with lower Technology Readiness Levels (TRLs) may carry higher inherent risks, the team diligently tracks and investigates these risks to minimize their likelihood and impact on the overall mission.

In addition to risk mitigation efforts, the team will prioritize the selection of technologies with higher TRLs for each subsystem whenever feasible. Rigorous verification and validation processes will be employed to ensure the reliability and functionality of mission components, further reducing potential risks and enhancing the mission's likelihood of success. Critical systems, such as power, thermal, and communication, will be given meticulous attention due to their crucial role in mission operations and the potential consequences of failure.

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Vehicle Review	2	2	↓	A	Failure to counter all of system's risks to fix on time	Active
2	Mechanical System	3	5	→	R	Failure for maintenance may result in equipment failure, reduced performance, or potential safety hazards	Actice
3	Power System	3	4	↑	R	Inadequate power management, including improper load distribution, excessive power demands, or short circuits, can overload the power system	Active
4	CHD System	2	4	→	W	Inadequate cooling leads to overheating and system failure, but can be prevented through proper airflow and maintenance.	Active
5	Thermal Management	1	5	→	W	Failures lead to increased temperatures in sensitive areas, posing safety risks such as fire hazards, electrical malfunctions, or thermal runaway events	Active
6	Payload and Instrumentation	2	3	→	M	Failures result in the loss or corruption of critical data. Inaccurate or incomplete data collection can hinder scientific research, hinder mission objectives, or compromise the accuracy of navigation, communication, or remote sensing capabilities.	Active

7	Communication	4	4	↓	R	Failure to connect signals between different parts	Active
8	Budget	3	4	↑	R	Failure to stay within a cost cap for a project	Active
9	Schedule	3	3	→	R	Failure to meet deadlines for each criteria	Active
10	Safety	3	5	→	W	Hazardous material release while fueling during ground operations	Active
11	Recovery and Redundancy	3	2	↑	W	Inadequate recovery and redundancy measures lead to extended system downtime, impacting operations, service availability, and productivity, which result in financial losses, customer dissatisfaction, or reputational damage.	Active
12	Interface Control	2	3	→	W	Inadequate interface control between system components may lead to compatibility issues, data loss, system malfunctions, or operational inefficiencies.	Active

4.1.2 Failure Mode and Effect Analysis

4.1.3 Personnel Hazards

Related System	Hazards	Mitigations/PPE
Mechanical/Instrumentation	• Improper use of machinery/lack of care can lead to injury • Improper handling of a heavy rover • Sharp edges can cut body • Pinch points can injure body if not careful • Exposed mechanisms can injure body if not careful	• Ensure that proper care is taken when moving/adjusting rover • Follow all proper safety procedures when handling machinery • File down sharp edges or take care to not run a body part across a sharp edge • Do not bring hand near pinch points and exposed

		mechanisms ● Stay far away from rover while testing
Power/CDH	● Improper use of batteries can cause a fire or leak of toxic materials ● Exposed wires present a danger of electric shock/electrocution ● Toxic materials can cause severe damage to body if not dealt with properly	● Handle batteries with care ● Wear gloves when handling batteries in case there is a leak ● Follow proper safety procedures if there is a fire or toxic spill ● Ensure that all wires are fully plugged in and that no parts are exposed
Thermal	● Contact with extreme hot or cold surfaces can lead to burns and skin damage respectively ● Heaters may catch on fire if used haphazardly ● Toxic materials can cause severe damage to body if not dealt with properly	● Allow extreme hot/cold surfaces to return to normal temperatures after testing ● Wear gloves when handling materials such as thermal coatings ● Never leave heater unattended

5. Activity Plan

5.1 Project Management Approach

Mission Team Structure:

Project Manager/Director: Responsible for overall mission planning, coordination, and execution. Manages the entire project, including budgeting and reporting to higher authorities.

Mission Scientist: Leads the scientific objectives of the mission, defines research goals, and ensures that the mission's scientific goals are met.

Systems Engineering Team: Responsible for the overall design and integration of mission systems, ensuring that all components work together seamlessly. This team might include:

- Systems Engineer
- Integration and Testing Engineer
- Verification and Validation Engineer

Mission Operations Team: Responsible for the day-to-day operations of the mission. This includes mission control, scheduling, and monitoring. Roles may include:

- Mission Operations Manager
- Flight Controllers
- Ground Station Operators

Payload Team: For the mission’s scientific instruments, this team can include:

- Instrument Scientists
- Engineers for each instrument

Flight Dynamics and Navigation Team: Responsible for the trajectory and navigation of the spacecraft. Key roles may include:

- Flight Dynamics Engineer
- Navigation Specialist

Communication Team: Manages communication between the spacecraft and Earth, including data transfer and telemetry. Roles may include:

- Communication Specialist
- Ground Station Engineers

Data Analysis and Research Team: Analyzes data collected during the mission and conducts scientific research. This team might include:

- Data Analysts
- Researchers

Quality Assurance and Risk Management: Ensures that the mission meets quality standards and manages risks associated with the project.

Finance and Budgeting: Manages the budget, financial planning, and resource allocation for the mission. Includes roles such as:

- Finance Manager
- Budget Analyst

Legal and Regulatory Compliance Team: Ensures that the mission complies with all relevant laws and regulations.

Public Relations and Outreach Team: Manages public relations, outreach, and education efforts related to the mission.

Nutrient Analysis Team: for the research we collect.

- Geochemists
- Biologists
- Analytical Chemists

The degree of autonomy and budgeting authority for each team or subteam would be the project manager/director who would have the ultimate budgeting authority, while team leads might have some autonomy within their areas of responsibility, which would be subject to project-wide financial constraints depending on each team.

5.2 Outreach Summary

Outreach is required to promote the importance and significance of the CAESAR mission to the general public. Millennium 7 will enhance the appreciation and public awareness of the field of the CAESAR mission in a few ways. Utilizing social media as a mode of communication to reach mass audiences can be extremely effective. Whether sharing breaking news or promoting a message, the implementation of media communications is a vastly growing field as technology and AI continue to advance. Outreach through the media and educational and promotional events to show, will increase public awareness of the CAESAR mission and the design of mission-specific products.

As personal devices are rapidly becoming more widespread around the world, people are increasingly using social media as a method to connect and acquire information. Large social media platforms in the United States include Instagram, TikTok, Facebook, Twitter, Reddit, YouTube, Twitch, and LinkedIn. The team will first post regularly about current projects, goals, and accomplishments through media platforms to raise awareness and appreciation about the CAESAR mission within online communities. Here, team members can connect with as many people as possible throughout STEM and Non-STEM communities to learn about and help with mission goals.

The team will create social media profiles with a name appropriate for the mission. Members will be assigned to different social media platforms to ensure the team's message is reaching audiences of all demographics. A profile will be created on each platform with the name of the CAESAR mission. On the platforms that are more focused on short-form and image-related content (Instagram, TikTok, Facebook, Twitter, Reddit, and LinkedIn), the social media team will regularly post about the current progress of the mission, including short and exciting descriptions and images/videos. Additionally, the scientific goals and their potential impact on humanity's understanding of life and the solar system will be emphasized.

Accomplishments will also be shown whenever possible. On the platforms that are more focused on long-form video-related content (YouTube, Twitch), the social media team will showcase Ceres-related media, including videos on the science behind organic matter, geologic processes on Ceres, and the formation of the solar system and asteroid belt. Videos will also be made that demonstrate the engineering behind the rover, showing the robotics aspects and manufacturing process. Furthermore, interviews will be conducted with the engineers, scientists, and management working on the mission. Content creators with strong followings and suitable NASA aligned brands will be contacted to share information about the mission or science/engineering behind it.

Each member of the social media team will collaborate with one another for peer review and with the social media managers for final approval before posting. The goal of the social media promotion campaign will be to popularize the mission and simplify the goals and achievements to promote a positive image to a wide population around the world. News-focused media organizations provide news to large audiences, and news articles are often spread through the social media platforms previously discussed. Similar to the strategies for spreading information through social media, the news-focused media team will work to ensure that news highlights the scientific goals, engineering achievements, and potential the CAESAR mission has to advance our understanding of science and technology.

The promotion of students will not be limited to first and second-world countries. Underrepresented communities will be a group that outreach will focus on. Communities that suffer from a lack of resources, whether equal education opportunities, funds, or support, will be given resources to hold career-based STEM workshops. The workshops will share information about the CAESAR mission and will give the communities opportunities to improve their skills in subjects related to the mission. People will be able to partake in these workshops in person or virtually. For those who may not have access to phones or laptops, fundraisers will be created with the help of NASA mission partners to ensure equal access to education and opportunity for all.

The team will create an email list of schools and STEM-focused organizations around the world to send weekly updates to. Team leads running the various media platforms or social media managers (SMM), will be grouped with other teammates to help manage their media outlets. Each SMM will designate someone to comment and message responses, adding and connecting with people of all backgrounds and ages, photography, and content creation. Each member will collaborate with one another for peer review and with the SMM for the final approval before posting. It will also be essential that teams reach out to content creators with strong followings whose messages align with the STEM and NASA L'SPACE brand in order to increase visibility during the outreach process. Oftentimes this involves paying creators if they are well established. However, Millennium 7 will try to find student creators that are looking to establish themselves in the media, to brand themselves within the space industry, and/or who are pursuing journalism who would like to work in those roles for free or as unpaid internships.

Regarding outreach at educational institutions, the team will create an email list of K12 schools and higher education universities to send weekly updates to. Two additional teammates will be assigned telecommunications and email management roles. Each teammate will have one area of specialization but will be trained to perform professional outreach and professional response through both modes of communication. This will ensure that if one member is caught up on their duties, then they can continue to assist with outreach and response within the other area. At a K12 level, members of the outreach team will visit schools and engage in activities that are related to the science or engineering being done for the CAESAR mission.

These activities will include science experiments about microbiology, organic compounds, or the physical environment on Ceres, as well as small engineering projects that can be done during class. K12 school officials and communities will be a primary focus in outreach via social media, telecommunications, and email correspondences as this is the prime window to promote the CAESAR mission as well as STEM topics to students who are considering majors they might pursue in college. At a university level, members of the outreach team will give talks, presentations, and visit university design teams. Design competitions will also be created that encourage student teams and individuals to create robotic components, learn about microbiology and geologic processes, and design art for the mission.

K12 school officials and communities will be a primary focus in outreach via social media, telecommunications, and email correspondences as this is the prime window to promote students that are involved in the CAESAR mission in order to attract those who may be interested in working on the CAESAR mission. Volunteers from all backgrounds will be essential for outreach across the country. Volunteers and students will be selected through a public application process. The volunteer application will be promoted at the start of the campaign. There will also be a designated videographer, video editor, and a primary content host for some of the content. Multiple members will be cross-trained in various roles for risk management purposes. Over time, the YouTube team will look for sponsors to help fund the channel so they may travel to various locations where different aspects of the CAESAR mission can be applied like field training or trips to various engineering, programmatic, and science sites of other companies we hope to collaborate with.

Costs and travel could include launching test rockets and going on NASA tours to see different forms of science, engineering, mathematics, and technical roles in action. It could also include showcasing pilots in action during their training or test flights with GoPros, interviewing astronauts, providing media feed of live testing rovers, as well as showing STEM students and subject matter experts in action as they do things like comparing ionic propulsion to other propulsion types, applying scientific methods towards surviving in environments like Ceres, courses on proper mission planning processes, and more. The designated videographer and SMM will also travel to different NASA sites to network with prospective sponsors and to showcase the work that the team is doing as a whole.

Activities will vary for all ages of K12 and college students. Science experiments will showcase the most exciting concepts of engineering to draw the attention of all audiences. Once audiences are engaged, then leads will coordinate the sending of educational videos via email for schools and communities to share with students based on the designated age group. Activities could include students attending, participating in, or virtually watching anything from combining baking soda and vinegar in a volcano to discussing chemical reactions, robotics events, and glider flying lessons for older students. More expensive activities would be partially funded by sponsors. In exchange, the Millennium 7 team would promote that organization or independent sponsor/donor if desired, and how they are helping students grow their passion for STEM as well as to grow awareness of and participation in the CAESAR mission.

Underrepresented communities will be additionally focused on in the team's outreach efforts. Communities that suffer from a lack of resources, whether equal education opportunities, funds, or support, will be notified of the team's goals to make STEM accessible and desirable to all. Students from communities locally and globally will be invited to activities and virtual events to partake in learning and resources to help them move towards the educational future of their goals. For those who may not have access to phones or laptops, fundraisers will be created with the help of current and prospective sponsors to ensure equal access to education and opportunity for all. The team will additionally create awareness within local communities that are underrepresented of local school needs in order to get volunteers and donors to help with these ambitions. The team will promote local community members who are helping with these efforts by showcasing their work and support in an online website. A website will eventually be made to create easier access to all of the team's social media pages, a way to sign up for the email list, educational sessions, donation portal, merchandise, and exclusive updates. When this occurs, a site manager will be brought on to manage and update the site when needed.

At this point, an LLC will be created as a risk management strategy to mitigate liability and increase the credibility of the team and community efforts. Once the website and LLC are formed, a registered agent will be hired to update the LLC annually, a student web designer will be brought on to update the website when needed, and a team member will be assigned to help with the website based on their specific areas of experience. The team may also reach out to students who are going to school to become lawyers to review questions about copywriting laws as the team continues to build the CAESAR mission brand, website, and content.

In an effort to help mitigate the costs of these endeavors, the team will recruit a student product designer who is interested in helping build a product line that promotes STEM and the CAESAR mission. A few examples of these products include model rovers or Ceres geology kits. The products will be designed through a two-year public competition that encourages individuals to create art, clothing, models, toys, and other goods. After the competition closes, the products will be reviewed and chosen by a designated member of the outreach team. The individuals who create the chosen products will be given compensation of $1000. Products will be submitted via an online portal, and people will be encouraged to share their designs online. Chosen products will be displayed on the mission website.

5.3 Schedule

<u>Schedule Assumptions</u>

Phase C, the team estimates, shall take approximately two years. Based on feedback given for the PDR, an additional four months will be required to update and implement necessary revisions for the Critical Design Review (CDR). The CDR is a document that finalizes the budget and schedule, confirms all science and engineering system designs, and outlines the design objectives. Considering the significance of this document and the numerous revisions the PDR underwent, the team estimates it will take approximately four months to complete the CDR.

Approval by NASA takes place at a primary site such as the Marshall Space Flight Center and is presented to the whole team, as well as sub-teams and team specialists. This process usually only lasts a few hours since NASA consistently follows up throughout the CDR revisions. The first manufacturing stage will commence immediately after getting the CDR signed and approved.

The first significant step in manufacturing is getting all the components to the main base, the Marshall Space Flight Center. The Gantt chart illustrates that the team has 2.5 years set for Phase C with an additional three months of margin to account for any shipping delays or manufacturing errors. However, for the sake of time and budget, each engineering section shall have overlaps and the individual teams should begin making their orders to companies as soon as possible. This shall allow all sections to arrive punctually and meet all inspection needs from NASA.

The team of mechanical engineers have designed components made of Aluminum 6061. These components are intended for assembly and will be tested at the Jet Propulsion Laboratory in California, which has extensive research and experience with rovers. The mechanical engineering team have used design inspirations from the 2003 Spirit Mars Missions. The designs for Caesar's body, rocker bogie, and collection systems were revised and finalized.

The body of the rover takes seven months for manufacturing, four months for assembly, and five months for testing; the rocker bogie takes seven months of manufacturing, four months for assembly, and five months for testing; and the collection system takes seven months for manufacturing, four months for assembly, and five months for testing. Given that all these sections are independent of each other, the team allocates 16 months for all mechanical system manufacturing.

Thermal components shall be designated as commercial–off-the-shelf (COTS) from outside manufacturers, including the MAP SG122FD paint from MAP Space Coatings; the Multi-Layer Insulation (MLI) Blanket purchased from Sheldahl, based in New Mexico, and the Kapton heater and the thermostat, purchased from Thermal Heating Elements LLC. The thermal systems shall primarily be tested once the rover is entirely built; however, the component testing, per NASA's request, shall be performed at Ames Research Center so that all advanced thermal protections are in place.

The thermal engineering team specifically references past satellite missions that have used MLI and various thermal coatings, such as the International Space Station and the Hubble Telescope. While a satellite is not a rover, it replicates an environment similar to it since Ceres has almost no atmosphere.

The team predicts that the heating shall take four months for manufacturing, two months for assembly, and two months for testing; cooling shall take four months for manufacturing, two months for assembly, and two months for testing; insulation shall take four months for manufacturing, two months for assembly, and two months for testing.

The electrical and power system shall be collected from outside manufacturers such as Lockheed Martin, which manufactured parts for the Artemis program, and the Human Research Laboratories, which manufactured parts for some of NASA's satellite missions.

Parts from Lockheed Martin include the metal frame and the glass casing and the parts from HRL include the batteries, the solar panels, and the distribution system. Given that additional missions such as the Rosa and iRosa mission used the electrical systems manufactured by these companies, the electrical engineering team has confidence that using the given information, that six months for all parts shall suffice.

The computer/hardware systems shall be made primarily in-house and undergo a series of function/accuracy testing, meaning the model shall understand and respond appropriately to a wide range of user inputs. However, these tests are pivotal and are conducted after the manufacturing stage begins.

Some additional items manufactured in Ames include a space-grade mass spectrometer, an infrared spectrometer, and a camera. These instruments are vital for the teams' data analysis and collection by the science team. This equipment shall be manufactured in the Ames warehouse and does not need complex testing due to being used on previous missions.

With the understanding that mass spectrometers have been made for previous missions, the team predicts that with the mission's specific constraints it shall take five months for manufacturing, three months for assembly, and two months for testing. It is for this same reason the infrared spectrometer shall take the same amount of time. Finally, the camera, also collected in-house at the Ames Research Center, shall take five months for manufacturing, three months for assembly, and two months for testing.

Following the approval and accounting for the arrival of all parts, the System Integration Review (SIR) shall be written.The engineering and science team shall be responsible for writing this and the document shall be approved by the whole team so that the confidence for manufacturing to commence is high.

As stated previously, most of the material collecting and testing overlap due to time constraints; nevertheless, time shall not trump safety, so given that this phase takes 2.5 years, the team has at least a two-month schedule margin for any unforeseen issues or delays.

In equivalence to phase C, phase D, the manufacturing stage, shall take approximately 2.5 years. Unlike phase C, each test must be completed in succession. As assigned, the team base is the Marshall Space Center in Huntsville, Alabama. It houses the team's state-of-the-art technology that will be most beneficial towards the end of the testing stages. In addition, the location and connections throughout NASA help quickly get replacement parts due to the center's site.

Following all crucial inspections, the team shall be ready for the assembly stage in Phase D. The team allocates seven months for the assembly of the full rover to ensure all internal and external components fit with precision and have no damages in the coming stages. This time also allows the science and engineering teams to write the Operational Readiness Review (ORR). In this document, the team will present updates on the project, system overviews, operational readiness, and an evaluation of success criteria. The ORR acts as a comprehensive guide that details every essential aspect of the project at this stage. This document's primary purpose is to demonstrate the team's plan for correcting project errors, the plans for communication and outreach, and most importantly, the budget and schedule plans for testing. By providing such an exhaustive review, the ORR ensures all stakeholders are aligned and informed about the project's current status and future trajectory.

Following the completion of this document and approval from NASA to proceed, the rover, which as previously mentioned is named Caesar, will be taken to the Neil Armstrong test facility to begin the instrumentation testing.

For quick reference, members of our team came up with the name Caesar to stand for the acronym Ceres Accretional Environment Searching Autonomous Robot. The rest of the team liked the names creativity, making it the official name of our rover.

Returning to the current topic, the various science tests include ambient testing, which assesses air contamination that could hinder the rover's performance; analysis testing, which is integrated into our environmental testing; and laboratory hazard testing.

Tests performed for instrumentation include, but are not limited to, Ambient vibration testing and Analysis testing. Ambient vibration testing assesses the Caesar's abilities to stand extreme pressures by observing the vibrations collected with sensors such as accelerometers or seismometers. Testing ambience takes about 3-7 days to complete, however retrials shall be made for assurance.

Environmental degradation testing is used to evaluate performance, durability, and resilience of the rover. The specific tests that shall be performed are the chemical exposure test and the accelerated aging test.

The accelerated aging test exposes the rover to extreme temperature conditions and fluctuations, ultraviolet radiation (UV), and high humidities. Given that the UV radiation and humidity is close to zero, the variable tested is extreme temperatures.

The test proceeds in a temperature chamber which is equipped with a heating and cooling system that can change to extreme temperatures rapidly. Then a fractional sample is collected and tested if its properties shall withstand temperatures on Ceres. However, having the assurance that all possible environmental hazards have been tested shall increase the confidence in the team's outcomes.

During the entirety of science testing, the rovers' structural integrity shall be monitored and the data collected, shall be an indicator if the rover shall proceed to the more intense engineering tests.

Given that these tests could overlap and multiple rounds of testing shall be performed, the team allocates 2.5 months to ensure consistency in the results and to set aside time for travel to the next test center.

Due to Ceres' low atmospheric pressure, weak gravity, and extreme temperature, the team believes that the Space Environment Simulator at the Goddard Space Flight Center will be adequate for environmental and potentially some power testing. The Vacuum Chamber A and the 15 ft Chamber at the Johnson Space Center are suitable for comprehensive systems and structural tests. Finally, the Sunspot Thermal Vacuum and other flight/ground tests at the Marshall Flight Center's main base should complete all the required testing.

The rover is shipped in a truck for the seven hour trip from instrumentation testing in Armstrong to the environmental testing in the Goddard Space Flight Center. Here the rover shall be tested in ultra-low pressures and undergo a wide range of thermal condition testing. The rover enters a chamber that evacuates air using mechanical pumps and cryopumps. The test is analyzed using a thermoelectric quartz crystal microbalance (TQCMO) and residual gas analyzer (RGA), which provides monitoring of molecular contamination and quantitative and qualitative monitoring.

Following the environmental testing, the rover flies the three hour trip from Goddard down to the Johnson Space Center, where the engineering-based testing commences.

The first test the rover shall endure is Vacuum Chamber A. The chamber can simulate the low pressures and the extreme temperatures that Ceres can reach and lower. This test, in addition, validates spacecraft components, instruments, and systems including the mass spectrometers, infrared cameras, and television cameras.

Examples of missions that used this chamber for testing Apollo 11 which housed astronaut Neil Armstrong, in 1969, the Skylab Apollo telescope Mount prototype in 1971, and the James-Webb telescope in 2017. These missions all conducted tests in the chamber twice and each lasted approximately 4-6 months each.

Even though it's a long process, the success of this test, shall validate a vast majority of the systems competencies. Given this information the team uses the upper side of the statistic and allocates 12 months for the testing in vacuum chamber A.

Since both Vacuum Chamber A and the following test, the 15-Foot Chamber, have temperatures ranging down to -300* F, they surpass Cere's nighttime temperatures, which can hit -225* F. This increases the team's confidence that if all thermal systems and power testing are successful, the rover shall technically be exceptional.

Speaking of it, following the Chamber A testing, the team moves on to the 15-Foot Chamber, specially designed to test battery-power systems, actuators, and auxiliary power units. In this Chamber, all the power and software systems are put under pressures of approximately 760 torrs; since the atmosphere on Ceres is almost non-existent, putting our power systems to testing of this intensity is vital so the team has confidence it shall survive on Ceres. During this test, the thermal systems keep the power systems at a functional temperature.

This testing equipment was used for Nasa's spacecraft for the Artemis Program, Orion. And during testing, Orion went through two phases in the 15 ft chamber which lasted around 60 days each. Given this information, the team predicts that five months for this test should be adequate to cover any unforeseen complications.
Concluding the tests in Johnson, the rover takes an hour flight to the base, the Marshall Flight Center, for final tests and inspections.

Throughout the conduction of quality assurance tests, if additional mechanical, weld, nondestructive, and failure analysis testing needs to be evaluated, this is the stage it's done. Following the assurance checks, evaluations done by the programmatic team are performed primarily with the representatives in project management to verify that all data calculations are fulfilled, all signatures of team leads are present, and the rover is in perfect condition. Under the quality assurance mission, the ISO, International Organization for Standardization, the customer is confident that all operations are consistently under scrutiny. Inspections and signing of documentation should be done in earnest.

In conclusion of the inspections, the Mission Readiness Review (MRR), is written.The MRR should be detailed and should ensure utmost confidence in order for the mission to be approved for launch. The document details all pre-flight assessments completed such as flight hardware, software, and other essential resources. Given this document includes verifications from the quality assurance tests, it shall be written as the quality assurance tests are in progress. With that being said, the team allocates five months for both the verification of the rovers functions and the MRR document completion.

Although it's not explicitly mentioned in the notes, the team reviews for a two-month margin between the completion of the MRR and the launch to guarantee product performance excellence.

After the testing and evaluation successes, the team prepares for launch. Like the rover attached to the Atlas V rocket, our rover is mounted to a rocket and secured in the rocket's nose cone.

At this stage, all coordinates and mappings have been verified, and all final safety checks have been accounted for—finally, the rover launches on December 20, 2029

Following the successful rocket launch, and the 30 day margin, Phase E has come into effect. The team is unable to estimate a time for how long Caesar the rover shall last on Ceres however given that the duration to travel to Ceres is 7 years and the time to get around the Ernutet crater is approximately a year without pause, the team shall allocate 9 years for the time Caesar is in space.

Once Caesar lands on Ceres, the science and engineering teams shall be responsible for ensuring proper recharging times, data collection and analysis, and writing updates on Caesars performance.

Earth takes 24 hours to make a full cycle around its orbit, around 12 of those hours are at night. Given that Ceres takes approximately nine hours to cycle around its orbit, the team concludes that Caesar shall recharge every night around four hours, to have sufficient power for the remainder of the mission.

During the two years allocated for Caesar to be on Ceres, the science team shall perform numerous data assessments and chemical testings that have been specified in the PDR as well as other, more recent, documents. The testings that commence have been utilized in missions such as Viking, Philae, and Curiosity, for Mass Spectroscopy, and Dawn and Cassini, for Infrared Spectroscopy.

Organic compounds such as volatile aliphatic hydrocarbons shall be sampled using chromatography-mass spectroscopy, by measuring mass-to-charge ratios of ions. Given previous mission test performance times, each sample shall be collected and observed for 60 minutes to ensure all low weight compounds release.

Infrared spectroscopy shall be used to measure interactions between visible and infrared ration through matter. Common forms include absorption of water, reflections of wavelengths, and emission. Primary form used on Ceres is water.

From NASA’s Dawn spacecraft mission, which orbited Ceres, bright spots such as salts, water that's been erupted, subsurface reservoirs of water, and ice. Being able to traverse the crater and collect actual specimens of data shall broaden the possible capabilities of future missions.
The science team shall collect samples and perform the tests numerous times during the entire time on Ceres, so the allocated time for science does not end until the rover dies .

While the science team does its duties, the systems engineering team shall update all system performances and use remote software updates if troubleshooting is needed. The engineering teams shall be responsible for collecting data from telemetry (TLM)/ digital data, which measure the temperatures of the rover, downloading data using DSN Downlink tracking, and, best of all, sending data back to Earth spacecraft engineering support if needed. This ensures all system control repairs shall be made promptly, not costing the healthy function of the rover.
The DSN delivers all information to the TLM to collect all analysis and data, sends it back to our systems in the Flight Center, and shall be used for publication post-launch.

Following the science and engineering tasks, the programmatic team shall complete the Post- Flight Assessment Review (PFAR). Based on the NASA Procedural Requirements document, the team has concluded the programmatic team shall be able to complete majority independently, and the science and engineering team shall fill in the remaining portions if necessary.

Following the disappearance of our rover, the team shall write up the DRR, the disposal readiness review. This document shall detail the requirements established by NASA, detail the systems and engineering of our rover, and evaluate the performance of our rover post launch. The gist of the DRR is spelling out all the fine-line details in all stages of the mission including the success criteria, figures, and procedures.
Given that most of this information shall be taken and/or reformatted from previous success criteria documents, the team allocates two months to complete this requirement.

The team shall be responsible for writing a “Lessons Learned Document” which shall culminate all the many successes and setbacks the team faced. This document shall be a tool for the team to reflect, as well as, a tool for future mission teams to learn from our mishaps. Given that this document shall detail the whole mission from phase A to phase F, the team is confident that six months should be sufficient time for completion.

The conclusion of the project shall result in a wrap-up meeting which includes the entire team and additional members of NASA who have played a role on the side.

This gives the team a chance to decompress and to further gain connections with others who may participate in future missions on Ceres.

Schedule

The following includes the breakdown of the Millennium 7 mission schedule.
This timeline goes from the approval of the Preliminary Document Review following Phase B all the way to Phase F when the operation has been completed.

Major Milestone	Phase	Date
CDR	C	2/7/2023 - 6/12/2023
CDR Approval	C	6/14/2023
Manufacturing Complete	C	12/14/2025
SIR	D	2/1/2026 - 4/1/2026
Rover Assembly	D	7/19/2026 - 2/10/2027
ORR	D	7/20/2026 - 2/11/2027
Rover testing Complete	D	5/19/2029
MRR	D	5/23/2029 - 10/20/2029
Launch	D - E	12/29/2029
Landing on Ceres	E	2/12/2037
PFAR	E	2/5/2039
Mission Completion	E - F	4/1/2039
DRR	F	5/1/2039
Lessons Learned	F	7/6/2039 - 1/12/2040

Now that the team has completed Phase B, the Preliminary Design Review (PDR) is written and approved, so it starts the manufacturing stage. This means organizing a list of components needed to build the rover and accounting for all sections that the Engineers shall make in-house and those that outside vendors are manufacturing.

Due to testing being of individual components, the dates slightly overlap for time and money.

Before moving into Phase D, the team ensures that all parts have been delivered or collected by our engineers and confirms that they have been tested and approved by the manufacturers and Nasa.

In addition, the locations for assembly and the dates for the assembly process shall be accounted for so that the time for travel is allotted.

Due to the operation of testing taking approximately 2 years, our margin between Phase C and Phase D shall be 2 months.

4	**Phase C**		0%	10/1/23	4/1/26	914	2
4.1	PDR Revisions	Everyone	Not complete	10/1/23	2/3/23		
4.2	CDR Draft	Everyone	Not complete	2/7/23	6/12/23		
4.3	CDR Approval	Everyone	Not complete	6/14/23	6/14/23		
4.4	Mechanical Manufacturing	Mechanical Engineers					
*	Jet Propulsion Laberatory	Mechanical Engineers					
	Body	Mechanical Engineers	Not complete	6/20/23	11/1/24		
	Rocker-Bogie	Mechanical Engineers	Not complete	6/21/23	11/2/24		
	Collection System	Mechanical Engineers	Not complete	6/22/23	11/3/24		
4.5	Thermal Manufacturing	Thermal Engineers					
*	MAP Space Coatings	Thermal Engineers	Not complete	6/25/23	3/10/24		
*	Multi-Layer Insulation	Thermal Engineers	Not complete	6/26/23	3/11/24		
*	Limited Liability Company	Thermal Engineers					
	Kapton Heater	Thermal Engineers	Not complete	6/27/23	3/12/24		
	Thermostat	Thermal Engineers	Not complete	6/28/23	3/13/24		
4.6	Electrical System Manufacturing	Electrical Engineers		6/29/23	3/14/24		
*	Lockheed Matin	Electrical Engineers					
	Metal Frame	Electrical Engineers	Not complete	7/1/23	1/10/24		
	Glass Casing	Electrical Engineers	Not complete	7/2/23	1/11/24		
*	Human Research Laboratories	Electrical Engineers					
	Batteries	Electrical Engineers	Not complete	2/2/24	12/20/24		
	Solar Panels	Electrical Engineers	Not complete	2/3/24	4/11/25		
	Distribution System	Electrical Engineers	Not complete	2/4/24	2/1/25		
4.7	Instrumentations	Science Team					
	Mass Spectrometer	Science Team	Not complete	2/5/25	12/10/25		
	Infrared Spectrometer	Science Team	Not complete	2/6/25	12/11/25		
	Camera	Science Team	Not complete	2/7/25	12/12/25		
4.8	CDH	Systems Engineers					
	Communications	Systems Engineers	Not complete	1/5/25	12/10/25		
	Data Storage	Systems Engineers	Not complete	1/6/25	12/11/25		
	Software	Systems Engineers	Not complete	1/7/25	12/12/25		
4.9	Evaluation for Manufactored Parts	Science, Engineering Team	Not complete	12/14/25	1/25/26		
	Plan for Assembly - SIR	Everyone	Not complete	2/1/26	4/1/26		
4.1	Schedule Margin					2	
4.11	◆ Milestone - SIR		Not complete	10/1/23	4/1/26	914	

For phase D, the assembly of the mechanical, computer/hardware, thermal, and electrical systems shall be accounted for. Given that Ceres shall reach temperatures as low as minus 143 degrees C, the team shall test the full rover in the Marshall Space Flight Center, which supports testing such as the Sunspot Thermal Vacuum and the 20-ft Vacuum Chamber. Testing must cover all bases, such as temperature, power, data analytics, and all general system functions.

Once all tests are accounted for, the project manager and programmatic team review and revise all requirements that may not have been covered or need further evaluation. Once this stage has been approved, it's time to send this rover into space.

5	Phase D		0%	7/1/26	12/29/29	1278	2
5.1	Verify and Evaluate materials	Everyone	Not complete	7/1/2026	7/8/2026	8	
5.2	Assemble the Rover	Engineering, Science Team				1	
	Ames Research Center	Engineering, Science Team	Not complete	7/19/2026	2/10/2027		
5.3	ORR	Engineering, Science Team	Not complete	7/20/2026	2/11/2027		
5.4	Instrumentation Testing	Science Team					
*	Ambient Testing	Science Team	Not complete	2/13/2027	7/7/2027		
*	Analysis Testing	Science Team	Not complete	2/14/2027	7/8/2027		
*	Laboratory Hazards Testing	Science Team	Not complete	2/15/2027	7/9/2027		
5.5	Engineering Performance Testing	Engineering Team					
*	Space Enviornment Simulator	Engineering Team	Not complete	7/11/2027	11/20/2027		
*	Vacuum Camber A	Engineering Team	Not complete	11/22/2027	11/24/2028		
*	15 Ft Chamber	Engineering Team	Not complete	11/26/2028	5/18/2029		
5.6	Qualiity Test Assurance	Everyone	Not complete	5/22/2029	10/19/2029	151	
	MRR	Everyone	Not complete	5/23/2029	10/20/2029		
5.7	Launch	Everyone	Not complete	12/29/2029	12/29/2029	1	
5.8	Schedule Margin					2	
5.9	◆ Milestone - Launch		Not complete	7/1/2026	12/29/2029	1278	

As the launch commences, all teams double and triple-check that all requirements, systems, and data collection resources are in exceptional condition. The team allotted 7 years for phase E since this is the time required to get to and from Ceres from Earth, including a month or two of actual exploration on Ceres.

Assuming that all measurements and collections are successful and the power in our rover handles the environment, our mission shall conclude successfully.

6	Phase E		0%	2/1/2030	4/1/2039	3347	1
6.1	Vehicle Assurance - Throughout	Engineering Team	Not complete	12/29/29	3/1/2039		
6.2	Trouble Shooting - Throughout	Systems Engineers	Not complete	12/31/29	3/3/2039		
6.3	Recharging Time	Electrical + Systems Engineers	Not complete				
6.4	Data Collection - On Ceres	Science Team				1	
	Infrared Spectrometer:	Science Team					
*	Water Testing	Science Team	Not complete	2/12/37	3/17/2039		
	Mass Spectrometer:	Science Team					
*	Volatile Alliphatic Hydrocarbons	Science Team	Not complete	2/12/37	3/17/2039		
6.5	PFAR	Programmatic Team	Not complete	2/5/39	4/1/2039		
6.6	Schedule Margin					1	
6.7	◆ Milestone - Mission Completion		Not complete	2/1/2030	4/1/2039	3347	

The team shall write a "Lessons Learned" document detailing the progression from revising our PDR to the end of the launch. The team shall include points of weakness, mistakes made, and times that the team dynamic could be improved. Reflection makes the team better industry workers, and having this information shall help in future missions so that all mistakes shall be mitigated.

In addition, the team must have an end-of-mission meeting, as it helps the team dynamic if everyone has a chance to reflect verbally and have a moment to speak about their individual experience throughout. With all that being said, our launch to Ceres has concluded, and hopefully, a return mission with so much acquired knowledge shall lead to more and more success.

7	Phase F			0%	5/1/39	1/13/2040	258	1
7.1	DRR		Everyone	Not complete	5/1/39	7/3/39		
7.2	Lessons Learned Document		Everyone	Not complete	7/6/39	1/12/40	191	
7.3	Meeting to wrap up		Everyone	Not complete	1/13/40	1/13/40	1	
7.4	Schedule Margin						1	
7.5	◆ Milestone - Lessoms Learned			Not complete	5/1/39	1/13/40	258	

5.4 Budget

The total estimated cost of the mission would be around $300 million. This includes personnel budgets, travel budgets, outreach budgets, and direct costs.

Additional Information

	Phase B	Phase C	Phase D	Phase E	Phase F
# People on Team	FY 1	FY 2	FY 3	FY 4	FY 5
Science Personnel:	8	10	12	12	10
Engineering Personnel:	8	10	12	12	10
Technicians:	7	8	10	10	8
Administration Personnel:	8	8	6	5	6
Management Personnel:	5	5	4	4	4

Here is a table of the number of people our team needs for each position through each phase. In general, the number of people in the Management position is the smallest and most of the human resources are focused on technology positions, especially during project development. Administration and management positions are often emphasized in the early stages of conceptualization and planning because they are the ones who will have to cover the overall project.

NASA L'SPACE Mission Concept Academy Budget - *Ernutet Crater*

Mission Phase	Phase B	Phase C	Phase D	Phase E	Phase F	
Year	Year 1	Year 2	Year 3	Year 4	Year 5	Cumulative Total
PERSONNEL						
Science Personnel	$ 80	$ 80	$ 80	$ 80	$ 80	$ 400
Engineering Personnel	$ 80	$ 80	$ 80	$ 80	$ 80	$ 400
Technicians	$ 60	$ 60	$ 60	$ 60	$ 60	$ 300
Administration Personnel	$ 60	$ 60	$ 60	$ 60	$ 60	$ 300
Project Management	$ 120	$ 120	$ 120	$ 120	$ 120	$ 600
Total Salaries	$ 400	$ 400	$ 400	$ 400	$ 400	**$ 2,000**
Total ERE	$ 112	$ 112	$ 112	$ 112	$ 112	**$ 558**
TOTAL PERSONNEL	$ 512	$ 512	$ 512	$ 512	$ 512	**$ 2,558**

This section includes 5 key roles in the project: Science Personnel, Engineering Personnel, Technicians, Administration Personnel, and Project Management. For the initial phase, personnel will mainly be focused on Administration and Project Management because the initial steps require a lot of work in creating ideas, plans, and specific timelines to work throughout the project. These are the main professional tasks that the Administration and PM will be in charge of, so for the position of administration, there will be 8 people in charge and the PM will have 5 people. The remaining 3 positions related to scientific and technical expertise will require at least 6 members in each role. All play a role in building a project idea of what the model will look like and how long it will take to complete, as well as the cost required. Through the development phase and moving to model building, more human resources will be added to more specialized scientific and technical teams. At this point, the leadership team will be reduced to about 4 people for PM and 5 people for administration. In the technology and engineering team, there will be at least 8 people for each role. The reason for this change in human resources is that in the process of building a model when there is a specific outline, the steps need a lot of people with expertise to be able to draw as well as understand the parts of the model related to the technical aspects so that the model when presented in reality does not make unnecessary mistakes.

As for the budget for each position, the PM will have the highest level of $ 120k because they are the ones who have to work the most to cover the entire project and take the longest time to connect and organize between teams. Then comes to Science and Engineering Personnels, positions that require highly specialized skills and are active during project construction but only need to be coordinated mainly within a certain team, so will have the second highest budget at $80K. Finally, there are the Technicians and Administration, teams that I think will be a useful source of support for the mainstream teams mentioned above, so it should take up a budget as low as $60k. Assume budget levels are stable so they will stay at those prices throughout the phases.

- **Scientists** for the design of your experiment and analysis of data - $80,000 salary/year
- **Engineers** for designing, building, and testing your mission concept and for mission operations - $80,000 salary/year
- **Technicians** for assisting engineers and scientists with manufacturing, assembly, and testing of instruments and systems of the mission concept - $60,000 salary/year
- **Administration** for tracking schedule and mission costing - $60,000 salary/year
- **Managers** for organizing mission personnel, budgets, and schedules - $120,000 salary/year

These salaries will be assumed to be constant to ensure that the budget does not fluctuate unpredictably.

Expense	**Persons**	**Per Person (USD)**	**Total (USD)**
*Airplane Cost**	5	678	2790
*Shuttle (Uber to LAX if needed)***	5	80	400
Shuttle (Uber to hotel)	5	150***	350
*Hotel****[1]*	5	144/night = 864	4320
Shuttle (Uber to KSC)	5		60
Meals[1]	5	500	2500

*Taking into the assumption that the trip occurs on December 17th 2023 to December 23, 2023, from LAX (Los Angeles) to MCO (Orlando) for important personnel. We have decided to include five people: the program manager, chief scientist, chief engineer, and two others that may be deemed necessary.

** This is assuming personnel cannot find their own rides. This cost may be reduced. This is based on estimated Uber costs.

*** Including tip into all shuttle costs

****Each personnel will receive their own room for the trip.

Lead Engineer, lead scientist and astrobiologist will travel to Ames Research Center. This location is where the thermal and payload subsystems are manufactured. This research center was chosen in order for both scientists and engineers to be able to see their aspects of the rover being manufactured.

Expense	**Persons**	**Per Person (USD)**	**Total (USD)**
Airplane Cost to SFO	3	1000	3000
Car Rental	3	N/A	400
Gas	N/A	N/A	50
Hotel	3	110	1980
Meals	3	500	1500

Project Manager and Deputy PM will travel to attend the Standing Review Board (which can take place at any NASA center). For calculations, JPL is used in order to budget for the longest distance travel.

Expense	**Persons**	**Per Person (USD)**	**Total (USD)**
Avg. Airplane Cost to LAX	2	850	1700
Car Rental	2	N/A	240
Gas	N/A	N/A	50
Hotel	2	100	1800
Meals	2	500	1500

Personnel will be added from the phase C to the end. Other members recruited will move to the NASA center to support the project in the same time.

Expense	**Persons**	**Per Person (USD)**	**Total (USD)**

Airplane Cost	15	700	10500
Shuttle (Uber to LAX if needed)	15	100	1500
Shuttle (Uber to hotel)	15	150	2250
Hotel	15	144/night = 864	12960
Shuttle (Uber to KSC)	15	15	225
Meals	15	500	7500

The airline that will be prioritized for members to travel is Delta Airlines. And the hotel was chosen as Holiday Inn Express because it is close to Ames Research Center, in Mountain View to facilitate the movement of team members.

TRAVEL						
Total Flights Cost	$ 50	$ 50	$ 50	$ 60	$ 60	**$ 270**
Total Hotel Cost	$ 28	$ 38	$ 35	$ 30	$ 30	**$ 161**
Total Transportation Cost	$ 28	$ 38	$ 35	$ 30	$ 30	**$ 161**
Total Per Diem Cost	$ 8	$ 15	$ 15	$ 12	$ 12	**$ 62**
Total Travel Costs	$ 114	$ 145	$ 142	$ 142	$ 146	**$ 689**

At each phase, an amount will be added to each category to make a reserve fund for incurred expenses such as shuttle transportation not available and having to change or add meals, etc.

OUTREACH						
Total Outreach Materials	$ 80	$ 80	$ 70	$ 70	$ 55	**$ 355**
Total Outreach Venue Costs	$ 50	$ 40	$ 40	$ 45	$ 40	**$ 215**
Total Outreach Costs	$ 130	$ 123	$ 116	$ 124	$ 105	**$ 598**

The outreach portion of the CAESAR mission will be allocated $598,000 accounting for inflation of 2.6% per year, or approximately 0.6% of the total budget. Supplies will be purchased and sent to locations such as schools and underrepresented communities as needed. Funds allocated for venues will be used as needed.

During year 1, social media accounts will be set up, email lists will be created, and outreach to K12 schools and higher education institutions will begin. Talks will be given at venues at different universities and conferences such as the American Astronomical Society. Members of the outreach team will reach out to news organizations as well. The CAESAR mission website will be created and public competitions to design products for the mission will start. Promotional videos and images will be taken at various NASA and NASA partner sites where work on the CAESAR mission is being done.

During year 2, work from Year 1 will continue, including operating social media accounts, outreach to K12 schools and higher education institutions, and the creation of promotional videos and images. Design competitions will take place at universities. Talks will be given at universities and conferences throughout the United States.

During year 3, work from Year 2 will continue. Social media accounts will be operated, outreach to schools and universities will be done, and promotional videos and images will continue to be taken at various stages of the development of the rover. The competition to design promotional products will conclude and products will be chosen.

In year 4, social media operations and educational outreach will take place. Videos and images will be produced, including videos of the manufacturing process and associated achievements.

In year 5, outreach operations will conclude. Work from previous fiscal years will be finalized and promotion toward the launch and start of the mission will take place.

The cost of the material also includes online tools such as cameras, laptops and school supplies such as books and minutes to announce the news in that year. Also, the expenditure of marketing agency service and email marketing will be covered. Materials will be priced at the local market price of the project site. Venue costs are determined based on the number of project members and the city's consumption costs. For this term, our team chose schools, colleges, public centers, and online platforms. In addition to, the team will have additional outreach events in industry conferences, space centers, and research institutions in order to gather community. This can take more venue cost than the first event.

DIRECT COSTS						
|> Science Instrumentation	$ 7,000	$ 8,000	$ 10,000	$ 9,000	$ 9,000	**$ 43,000**
|> Other Payload Costs	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	**$ 5,000**
Total Payload Costs	$ 8,000	$ 9,234	$ 11,572	$ 10,780	$ 11,040	**$ 50,626**
|> Mechanical Subsystem	$ 2,000	$ 6,000	$ 6,000	$ 1,000	$ 1,000	**$ 16,000**
|> Power Subsystem	$ 2,500	$ 4,500	$ 4,500	$ 4,500	$ 5,000	**$ 21,000**
|> Thermal Control Subsystem	$ 1,500	$ 3,000	$ 3,000	$ 3,000	$ 3,000	**$ 13,500**
|> Comms/Data Handling Subsystem	$ 1,000	$ 1,500	$ 2,500	$ 3,000	$ 3,000	**$ 11,000**
Total Vehicle Costs	$ 7,000	$ 15,390	$ 16,832	$ 12,397	$ 13,248	**$ 64,867**
|> Manufacturing Facility Cost	$ 4,000	$ 4,000	$ 4,000	$ 2,600	$ 2,600	**$ 17,200**
|> Test Facility Cost	$ 4,000	$ 4,000	$ 4,000	$ 3,000	$ 3,000	**$ 18,000**
Total Facilities Costs	$ 8,000	$ 8,208	$ 8,416	$ 6,037	$ 6,182	**$ 36,843**
Manufacturing Margin	$ 11,500	$ 16,416	$ 18,410	$ 14,607	$ 15,235	**$ 76,168**
Total Direct Costs	$ 34,500	$ 49,248	$ 55,230	$ 43,821	$ 45,706	**$ 228,504**
Total MTDC	$ 7,500	$ 12,312	$ 14,202	$ 11,589	$ 12,144	**$ 57,747**

The amounts we estimate are within the MCA task's recommended amount (attached here).

Component	Estimated Cost (in millions)
Chassis and Mobility System	$40 - $60
Power System	$20 - $40
Communication System	$10 - $20
Scientific Instruments	$50 - $80
Avionics and Control System	$30 - $50
Thermal Control System	$10 - $20
Sample Collection System	$20 - $30
Data Storage and Processing	$10 - $20
Navigation System	$10 - $20
Integration and Testing	$30 - $50
Mission Operations	$40 - $60
Contingency	$20 - $30
Total	$280 - $440

Combining and using the calculation formulas included in the MCCET form, we have obtained the above estimates with TotalMass = 110 kg and TotalMaxPwr = 100W, MechMass = 11.5 kg. As for other data such as related to DsgnLife, MechMass, ThermMass, we are still discussing and will update. As for the current figures, we are just making an estimate for now.

6. Conclusion

The mission at hand is dedicated to the rigorous exploration of Ceres, an opportunity to unravel the intriguing mysteries shrouding this celestial body. Our mission's core purpose is to deepen our comprehension of the solar system's history and contribute vital insights to the realm of space exploration, inspiring current and future generations. The PDR serves as a pillar supporting our purpose-driven endeavor. It ensures that our mission objectives remain steadfastly aligned with the profound significance of Ceres. The PDR connects the future plans to progress in our organic findings which would progress the research on Ceres, as this document moves towards the revised phases, refinements, and etc.

The PDR assesses potential challenges, assuring that every facet of the mission serves our purpose with precision. With our commitment to our mission's purpose, the guiding influence of PDRshows the path ahead. Through thorough analysis and strategic refinement, PDR enables us to optimize resources, mitigate uncertainties, and navigate a well-defined course towards Ceres. The PDR continues to be an instrumental force in shaping our mission. Building upon the foundation set by the PDR, the later stages evaluates the feasibility and technical soundness of our preliminary design. It ensures that our proposed solutions and systems are in perfect harmony with the mission's established purpose and objectives.The PDR’s requirements and information will help us set up for our mission. This document has resulted in a summation of all things that would achieve our science goals of organic compound research. This document shows how all the elements are in alignment. As we embark on our journey to Ceres, our mission speaks volumes about human ingenuity. It's a testament to how far we've come as a species! With the guidance of PDR, we're equipped with the knowledge and professionalism to tackle this cosmic challenge. We're not just here to make history; we want to leave a lasting legacy that'll impact generations to come. We're a bunch of young engineers with a passion for space and a whole lot of determination. Our hearts are set on pushing the boundaries of cosmic understanding. So, with heads held high and unwavering commitment, we're diving headfirst into the wonders of Ceres. Let's show the world what we're made of! Onwards, towards the cosmos!

Appendix

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NASA Systems Engineering Handbook
https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook_0.pdf

Basics of Space Flight - Solar System Exploration: NASA Science https://solarsystem.nasa.gov/basics/chapter18-1/

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https://deepspace.jpl.nasa.gov/files/Intro_4_Mar20151.pdf

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https://environmentaltest.gsfc.nasa.gov/5494web/facility/fac290.htm

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