Soil Composition and LiDAR Detection (SoCoLD) in Martian Lava Tubes

Team 26
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Agenda

- Mission objectives/requirements/constraints
- Science objectives/main design drivers
- Mission design
  - Systems
  - Subsystems
- Science instrumentation/plan for data collection
- Overall cost
- Summary and next steps

Timeline

Table 1: Mission Timeline

Phase	Start	End	Tasks
Pre-Phase A	05/31/22	06/13/22	Concept Studies
Phase A	06/13/22	06/20/22	Concept and Tech Development, STM and Risk Matrix creation
Phase B	06/20/22	09/02/22	Preliminary Design and Tech Completion, ConOps and Milestone Schedule creation
Phase C	09/09/22	10/07/24	Final Design and Fabrication, CDR, SIR
Phase D	11/06/24	01/30/27	System Assembly, Integration & Test, Launch & Checkout, PLAR
Phase E	02/07/27	09/20/27	Operations, CERR, DR
Phase F	10/22/27	12/13/27	Checkout, DDR

Mission Requirements and Constraints

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem
0.1	The system shall not exceed 50kg	The system must remain within the mass constraint provided by the mission task	NASA L'SPACE Academy	POW-0.1 CDH-0.1 NAV-0.1 COMM-0.1 MEC-0.1 THM-0.1 PAY-0.1	Inspection	All
0.2	System shall have a volume constraint of (1.5 X 1.5 X 1.5)m	System must accommodate into launch vehicle size restriction	NASA L'SPACE Academy		Inspection	All
0.3	The total cost of the mission shall not exceed $300M	Budget constraint	NASA L'SPACE Academy	POW-0.3 CDH-0.3 NAV-0.3 COMM-0.3 MEC-0.3 THM-0.3 PAY-0.2	Inspection	All
0.4	The system shall investigate the Martian cave	The system must have adequate time to gather data within the cave	NASA L'SPACE Academy	SYS-0.1 SYS-0.2 SYS-0.3	Demonstration	All
0.5	The system shall communicate with earth via the primary lander	The data collected from the system must be retrievable and readable	NASA L'SPACE Academy	COMM-0.4	Demonstration	COMM
SYS-0.1	System shall maintain operation within allowable operating temperatures within Martian cave, within [-40C, +40C]	The system must be regulated at operating temperatures to ensure mission operation	0.4	THM-0.4	Demonstration	THM
SYS-0.2	The system shall have the mobility to navigate the Martian cave	Necessary for operation of mission	0.4	CDH-0.4 NAV-0.4, 0.5 MEC-0.5	Test	MEC CDH NAV
SYS-0.3	The system shall provide enough power for operations for ≥3 days	All systems need power to operate and perform tasks	0.4	POW-0.2	Demonstration	POW
SYS-0.4	The system shall provide a method of entering into cave formation from deployment site	The system upon deployment must be able to enter cave formation through Martian cave ceiling	0.4	MEC-0.4	Demonstration	MEC
SYS-0.5	The system shall provide mapping of the cave formation	STM Science Objective	0.4	PAY-0.3	Test	PAY CDH NAV COMM
SYS-0.6	The system shall search for olivine within the Martian cave	STM Science Objective	0.4	PAY-0.4	Demonstration	PAY
SYS-0.7	The system shall analyze soil composition within the Martian cave	STM Science Objective	0.4	PAY-0.5	Test	PAY
SYS-0.8	The system shall provide images of soil/rock samples within the Martian cave	STM Science Objective	0.4	PAY-0.6	Demonstration	PAY

Figure 1: Mission Requirements

Science Goals

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
Conducting reconnaissance to expand the knowledge known about the Martian cave environment	Determine the terrain of the lava tube located at CC0769	Take geographic scans of the Martian lava tube to a depth of 20m	Completion of a map indicating the characteristics of the structure within the lava tube	Range	30 m Min	40- 100 m	Innoviz360 LiDAR	SYS-0.5: The system shall provide mapping of the cave formation
				Accuracy	±10 cm	±10 cm		
				Spatial Resolution	(0.5 - 1.0) ° x (0.5 - 1.0) °	(0.25) ° x (0.50) °		
				Update Rate	5 - 20 fps	10 fps		
	Capture images of the inside of the lava tube	Take a minimum of 2 high resolution images inside of the lava tube	Take a long-range image when LiDAR scan is complete (300-500 μm), and close-range images of sample sites (minimum 60 μm)	Range	1.4 m - 100 m	1.4-100 m	SuperCam: Remote Micro-Imager (RMI)	SYS-0.8: The system shall provide images of soil/rock samples within the Martian cave
				Calibration Target	1 - 3 cm	3 cm		
				Resolution	60 μm minimum	100 μm		
				Data Return	15.5 megabits	15.5 megabits		
	Determine if the presence of the mineral olivine is present within the Martian lava tube.	Identify the amount of olivine within the soil found within the Martian lava tube	Detect the presence of olivine at a range of 7 meters	Range	5-10 m	7 m	SuperCam: Raman Spectroscopy	SYS-0.7: The system shall search for olivine within the Martian cave
				Calibration Target	10 - 15 mm	12 mm		
				Wavelength Range	535 - 855 nm	535 - 855 nm		
				Data Return	15.5 megabits	15.5 megabits		
	Determine the mineral composition of the regolith within the Martian lava tube.	Identify the 3 most common minerals within the soil found within the Martian lava tube	Detect the presence of minerals found at a range of 7 meters	Range	5-10 m	7 m	SuperCam: Laser Induced Breakdown Spectrometer (LIBS) and Visible/Near-Infrared Spectroscopy (VISIR)	SYS-0.6: The system shall analyze soil composition to an accuracy of TBD
				Calibration Target	10 - 15 mm	12 mm		
				Wavelength Range	245 - 835 nm	245 - 835 nm		
				Data Return	15.5 megabits	15.5 megabits		

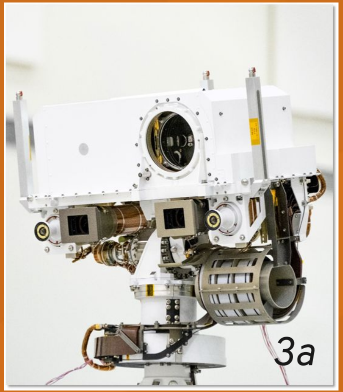
Figure 2: Science Traceability Matrix (STM)

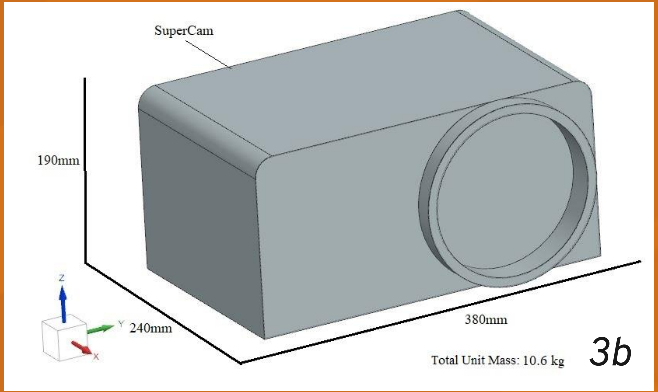
Science Instrumentation Summary

In order to conduct this important science, our Rover will utilize two instruments, the SuperCam and a Commercial-Off-The-Shelf (COTS) LiDAR sensor.

The SuperCam suite is a legacy instrument used on the Perseverance Rover with the ability to take pictures and laser sample rocks and soils from up to 7m away.

The LiDAR sensor chosen is the Innoviz360 LiDAR sensor.





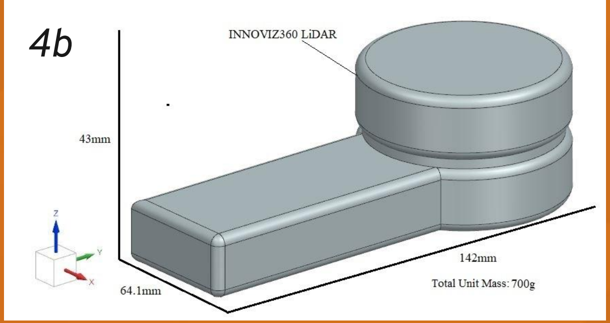


Figure 3a and 3b: SuperCam
Figure 4a and 4b: Innoviz360 LiDAR sensor

Mission Success Criteria

Success Level	Description	Performance Criteria
Complete Mission Success	Investigate and analyze the regolith within the Martian cave using all of SuperCams' instruments: Remote Micro-Imager (RMI), Remote Raman Spectroscopy, Visible/Near-Infrared Spectroscopy (VISIR), Laser Induced Breakdown Spectroscopy (LIBS). Utilize RMI to capture images of selected sample sites Conduct spectroscopy of minerals using Remote Raman Spectroscopy and VISIR Identify elemental composition of regolith using LIBS Utilize VISIR to identify molecular composition of regolith and detect presence of minerals such as olivine, phosphates, carbonates, sulfates, and metal oxides	- RMI spatial resolution of at least 55 μm [1] - Remote Raman Spectroscopy pixel resolution < 4 cm^{-1} and a full width half maximum (FWHM) resolution < 12 cm^{-1} [2] - VISIR instrument should be conducted at an absolute radiometric calibration better than 10% and relative calibration better than 1% [14]. - LIBS instrument should observe and determine the presence of elements to at least 300 parts per million (ppm) [3]
Minimum Success	SuperCam must at least capture images using RMI and identify minerals using VISIR	- VISIR instrument should be conducted at an absolute radiometric calibration better than 10% and relative calibration better than 1% [14]. - RMI spatial resolution of at least 55 μm [1]
Associated Failure Mode	SuperCam is unable to conduct any spectroscopy analysis and only RMI is able to capture images for analysis	- RMI spatial resolution of at least 55 μm [1]

Figure 5: SuperCam success criteria table

Success Level	Description	Performance Criteria
Complete Mission Success	Utilize Innoviz360 LiDAR to provide detailed 3D mapping of the terrain and geography inside the Martian cave. The 3D mapping should be accurate enough to allow for the Rover to safely traverse the cave and for adequate analysis of the cave's macroscopic features.	- LiDAR should be able to map up to a range of 200 meters
Minimum Success	LiDAR is not accurate enough for analysis of macroscopic features but it is still able to aid in mapping a route for the Rover	- LiDAR should be able to map up to a range of 200 meters
Associated Failure Mode	LiDAR is very limited in mapping and only large objects can be identified. SuperCam's RMI would then have to be used to aid in navigation	- N/A

Figure 6: LiDAR success criteria table

Mechanical System Design

Success Level	Description	Performance Criteria
Complete Mission Success	Rovers body must be able to withstand environmental conditions and protect all contents within the body. Anchoring component of egress system must firmy attach itself to Martian surface and allow for safe descent into the cave. Tether must be able to support Rover during descent into the cave. The tether must also be long enough to allow for the Rover to reach the bottom of the cave. Wheels and suspension must allow Rover to traverse over obstacles within lava tube	- Rover's body must give a yield and tensile strength of 2500 MPA and 4000 MPA respectively - Tether must withstand up to 750N of force [27] - Spool component of egress system must be able to deploy all 60 meters of tether if needed - Wheels and suspension must allow Rover to travel at least 20 meters inside cave

Figure 7: Mission success criteria table for mechanical system

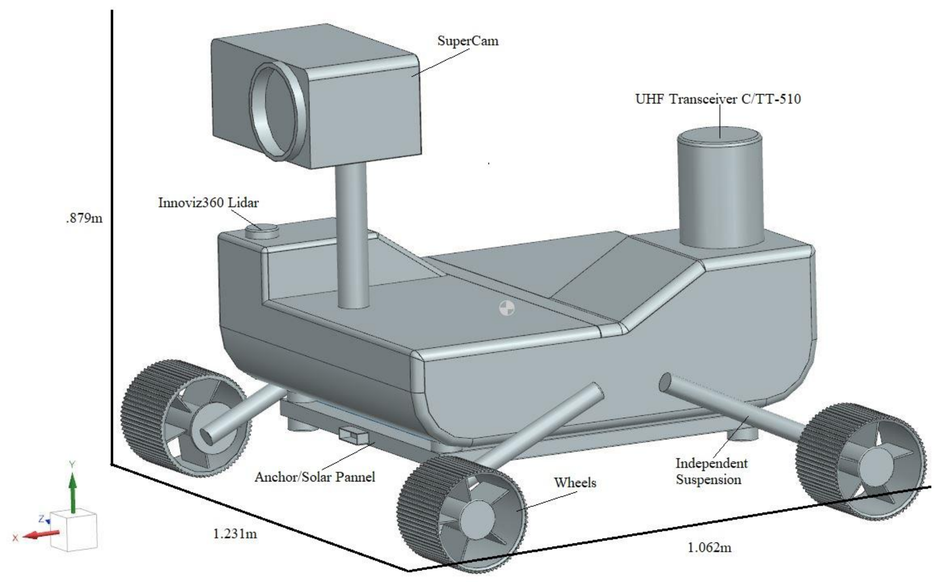


Figure 8: Fully assembled CAD model of the Rover.

System Design / Mechanical / Egress

- Main purpose: Control descent into Martian cave and ascent from it.
- Spool: incorporates electric motor to control descent while guiding the tether
- Tether: Incorporates power cables and structural cables attached to spool and anchor.
- Tether Length: 60m
- Tether Strength: 750N

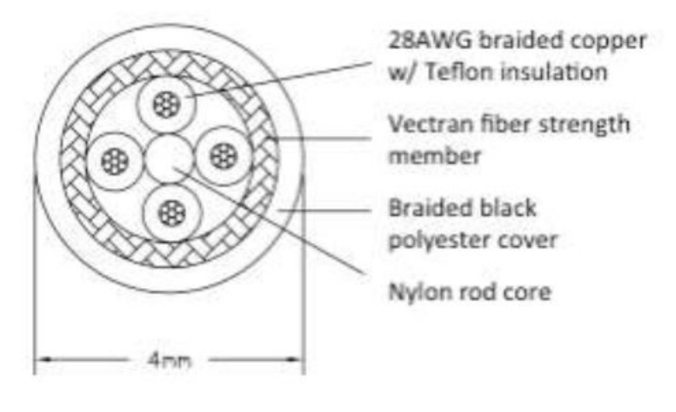


Figure 9: Details of tether design, such as materials and diameter.

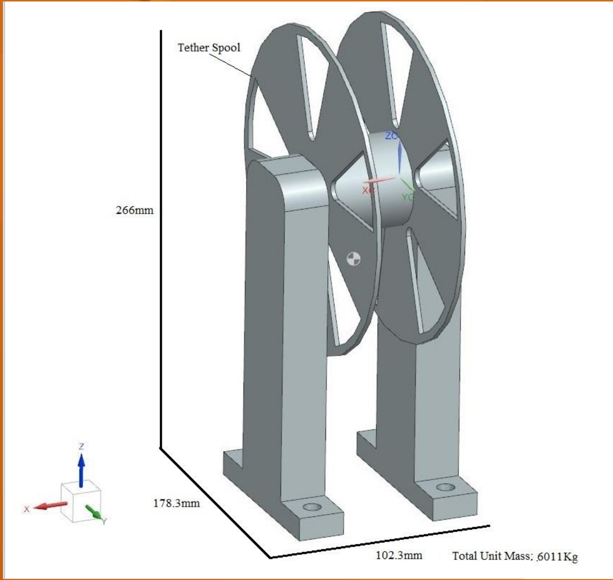


Figure 10: Tether spool design with dimensions and mass.

(178.3 x 102.3 x 266)mm and 0.6011 kg.

System Design / Mechanical / Anchor

- Tether: At the other of the tether, the structural cables within will be attached to the body of the anchor.
- Tether: The power cables will be soldered onto the solar panel leads in order to transfer power to the Rovers onboard batteries.
- Anchor: Uses powered charges to drive anchor rods into ground
- Anchor: Will utilize a solar panel to generate backup power. When the Rover is in the cave, it will store that power in batteries placed within the anchor body.

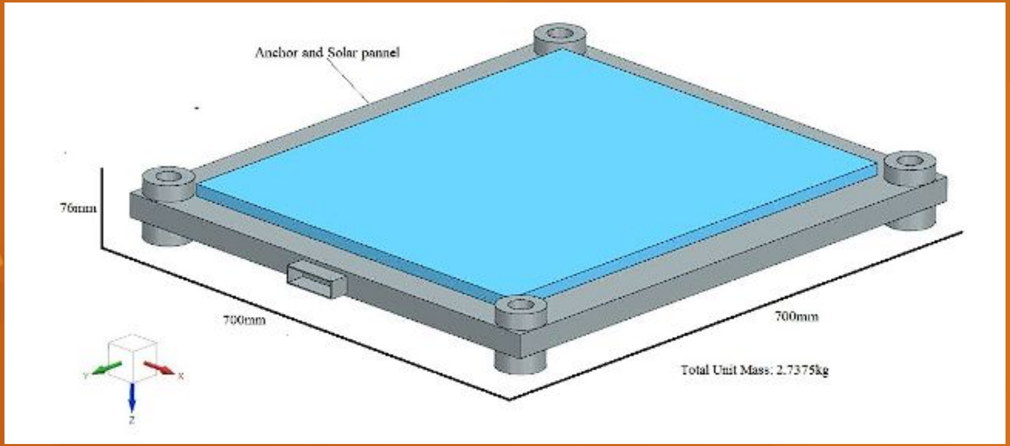


Figure 11: Anchor design with dimensions and mass.

(700 x 700 x 76)mm and 2.7375 kg.

System Design / Mechanical / Mobility

- Wheel and Independent Suspension Material: Aluminum and carbon fiber
- Wheels: Powered by electric Maxon 108828 motors.

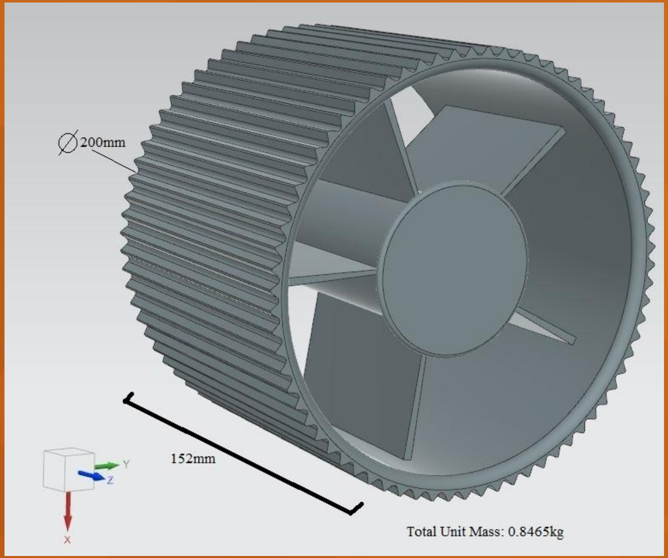


Figure 12: Wheel design with dimensions and mass of 0.8465kg each

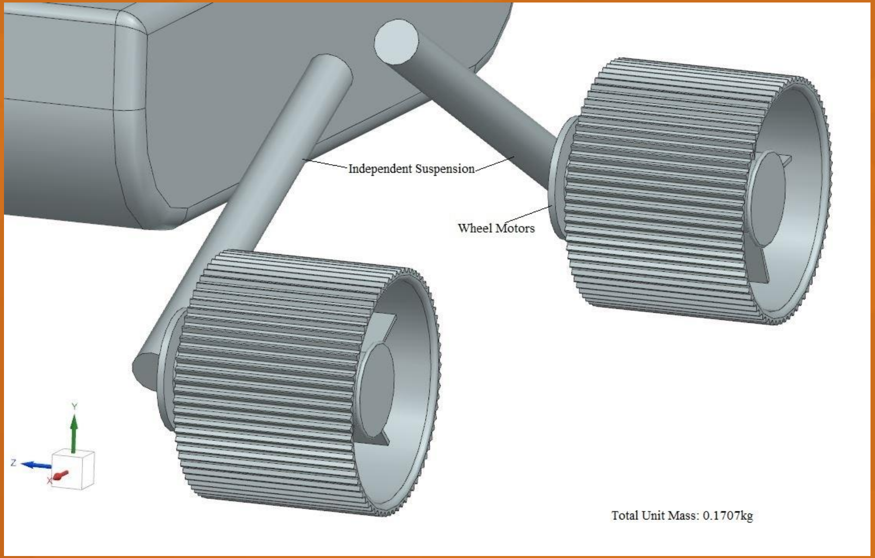


Figure 13: View of wheel and suspension design, with an individual mass of 0.170 kg per section.

Mechanical Manufacturing Plan

Table 2: Mechanical manufacturing parts information

Product Name	Material	COTS / In-House	Manufacturing Company	Start Manufacturing Phase	End Manufacturing Phase
Rover Body	Carbon Fiber	In-House	GSFC	C	D
Anchor Base	Aluminum 6063	In-House	GSFC	C	D
Tether Stand	Aluminum 6063	In-House	GSFC	C	D
Tether Spool	Carbon Fiber	In-House	GSFC	C	D
Tether	Multi-	In-House	JPL	C	D
Independent Suspension	Carbon Fiber	In-House	GSFC	C	D
Wheels	Multi-	In-House	GSFC	C	D
Motors	Multi-	COTS	Maxon	C	D

System Design / Mechanical / V&V / Integration Plan

Req #	Requirement	Verification Success Criteria	Verification Method	Facility	Phase
MEC-0.1	The mechanical system shall not exceed a weight of 15 kg	1. Aggregate mass of system does not exceed indicated limit	Inspection	GSFC	B-D
MEC-0.2	The power consumption of the mechanical system shall not exceed 100 Watts	1. Driving motors consume 96 Watts	Test	GSFC	C-D
MEC-0.3	The cost of the mechanical system shall not exceed 5% of the total budget	1. Aggregate cost of components does not exceed indicated limit	Inspection	GSFC	B-C
MEC-0.4	The mechanical system shall provide a way of entering the cave	1. Egress system incorporates an anchor teether system to safley lower rover into cave.	Demonstration	GSFC	C-D
MEC-0.5	The mechanical system shall provide a way of traversing the cave's terrain	1. Wheels powered by electric motors provide mobility of the rover.	Demonstration	GSFC	C-D
MEC-0.5.1	The mechanical system shall have adequate traction to traverse sandy, rocky, and loose terrain	1. Wheels constructed from materials to provide traction to the rocky surface. 2. wheels are widened to provide additonal surface area.	Demonstration	GSFC	C-D
MEC-0.5.2	The mechanical system shall provide a method to maneuver over and around potential obstructions	1. Independent suspension provides the ability to increase/ decress ground clearance . 2. Suspension maintains contact with ground and maintains the body parallel to the ground.	Demonstration	GSFC	C-D

Figure 14: Verification and Validation Integration Plan Table

System Design / Communication System

1. Ultra High Frequency Transceiver C/TT510

2. Point to point communication

3. Operating frequency: 390 - 450 hz

4. Data transmission rate: 1 to 10 Mbps

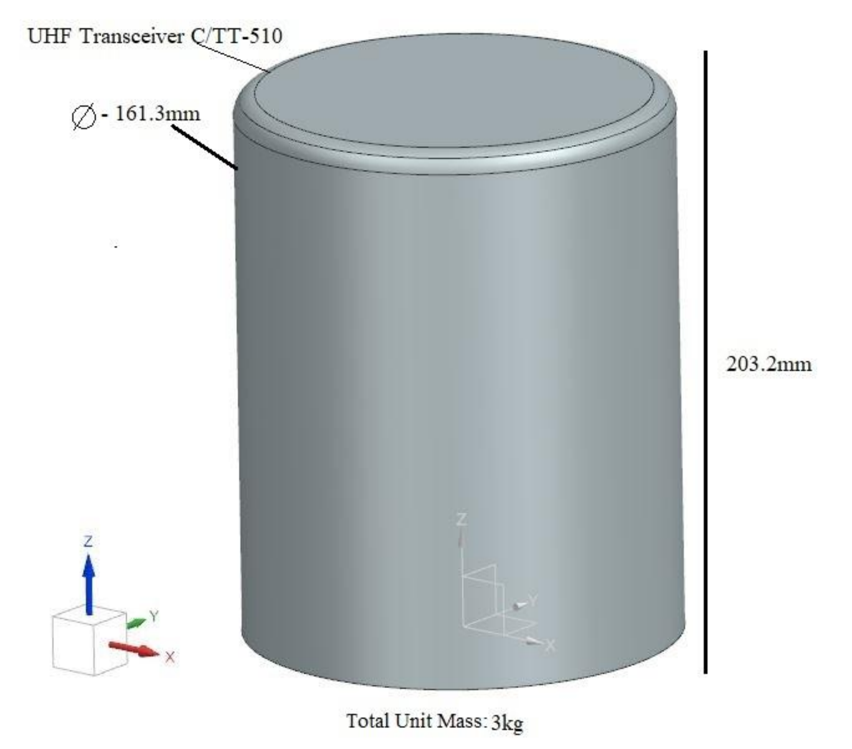


Figure 15: UHF Transceiver C/TT510

System Design / Communication / Manufacturing Plan

Table 3: Manufacturing Plans

Product Name	COTS / In-House	Manufacturing Company	Start Manufacturing Phase	End Manufacturing Phase
(C/TT-510) ELECTRA-LITE UHF Transceiver	COTS	L3HARRIS	C	D

System Design / Communication / V&V / Integration Plan

Req #	Requirement	Verification Success Criteria	Verification Method	Facility	Phase
COMM-0.1	The Communication system shall not exceed 4kg	1. Aggregate mass of system does not exceed indicated limit	Inspection	GSFC	B-D
COMM-0.2	The power consumption of the Communication system shall not exceed 75 Watts	1. UHF transceiver consumes 65 Watts in operational mode 2. UHF transceiver consumers 15 Watts in standby mode	Test	GSFC	C-D
COMM-0.3	The cost of the Communication systems shall not exceed 8% of the total budget	1. Aggregate cost of components does not exceed indicated limit	Inspection	GSFC	B-C
COMM-0.4	The Communication system shall maintain contact with the primary lander	1. Tranceiver communicates with responder from a minimim distance of 150m	Test	GSFC	C-D
COMM-0.4.1	The Communication system shall provide a method of communicating with the primary lander while inside the cave	1. Transeiver produces A high frequency data wave to overcome signal loss.	Test	GSFC	C-D
COMM-0.4.2	The Communication system shall deliver instrument data to the primary lander	1. Transeiver must have upload data rate of <5 mbps	Test	GSFC	C-D
COMM-0.5	The Communication system shall receive instrument data from the CDH system	1. Transeiver must have download data rate of <5mbps	Test	GSFC	C-D

Figure 16: Mechanical parts information table

System Design / Data Handling / Controller System

- RAD750 3U CompactPCI
- Radiation shielded for space mission
- Legacy part used to control past rovers

Figure 17: RAD750 3U CompactPCI

System Design / Data Handling / Manufacturing Plan

Table 4: Data handling manufacturing plans

Product Name	Material	COTS / In-House	Manufacturing Company	Start Manufacturing Phase	End Manufacturing Phase
RAD750 3U CompactPCI	Circuit board	COTS	BAE Systems	C	D

System Design / Data Handling / V&V / Integration Plan

Req #	Requirement	Verification Success Criteria	Verification Method	Facility	Phase
CDH-0.1	The Command & Data Handling system shall not exceed 1 kg	1. Aggregate mass of system does not exceed indicated limit	Inspection	GSFC	B-D
CDH-0.2	The power consumption of the Command & Data Handling system shall not exceed 15 Watts	1. Command & Data Handling does consume more than 15 Watts	Test	GSFC	C-D
CDH-0.3	The cost of the Command & Data Handling system shall not exceed 8% of the total budget	1. Aggregate cost of component does not exceed indicated limit	Inspection	GSFC	B-C
CDH-0.4	The Command & Data Handling system shall allow the vehicle to operate autonomously	1. The component must be self evaluating in cases of no communication	Demonstration	GSFC	C-D
CDH-0.4.1	The Command & Data Handling system shall have the ability to receive and act on teleoperated commands	1. The component must have communciation between Navigation instruments and process data based on software guidance	Demonstration	GSFC	C-D
CDH-0.4.2	The Command & Data Handling system shall communicate the navigation plans to the mechanical system	1. The component must have communication between itself and the machanical system	Test	GSFC	C-D
CDH-0.5	The Command & Data Handling system shall be able to send commands to each major subsystem	1. The component must have communcation between all major subsystems	Test	GSFC	C-D
CDH-0.5.1	The Command & Data Handling system shall send commands to the PAY system as needed by operational procedures	1. the component must have communcation to the PAY systems for data collection	Demonstration	GSFC	C-D

CDH-0.5.2	The Command & Data Handling system shall send the cave mapping from PAY to NAV system	1. the component must have communcation and process the data from PAY for deliverance to NAV system	Demonstration	GSFC	C-D
CDH-0.6	The Command & Data Handling system shall collect data and other telemetry from each subsystem	1. The component must be able to performe telemetry checks for each system	Test	GSFC	C-D
CDH-0.6.1	The Command & Data Handling system shall gather telemetry from the instrumentation	1. The component must be able to performe telemetry and calibration of instruments	Test	GSFC	C-D
CDH-0.6.2	The Command & Data Handling system shall collect data on the thermal state of each subsystem	1. The component must act as a thermal managment system to verify internal temperatures and control heating and cooling operations	Test	GSFC	C-D
CDH-0.6.3	The Command & Data Handling system shall receive navigation plans from the NAV system	1. The component shall have communcation from the NAV system	Test	GSFC	C-D
CDH-0.7	The Command & Data Handling system shall have the ability to send telemetry to other subsystems	1. The component shall be able to send data to all subsystems that requires inputs from other systems	Test	GSFC	C-D
CDH-0.7.1	The Command & Data Handling system shall deliver instrument data to the COMM system	1. The component shall be able to send data collected from instrumentation to the COMM system for data send back	Test	GSFC	C-D
CDH-0.7.2	The Command & Data Handling system shall communicate the thermal state of each subsystem to the Thermal system	1. The component shall be able to verift internal temperatures and report system health to thermal system	Test	GSFC	C-D

Figure 18: Integration plan for data handling

System Design / Power System / Components

- Solar Panel
- IMM Solar Cells (same as Ingenuity)
- Ingenuity solar panel: 0.07m^2, 350 W/day
- Rover solar panel: 0.348m^2, 1736W/day

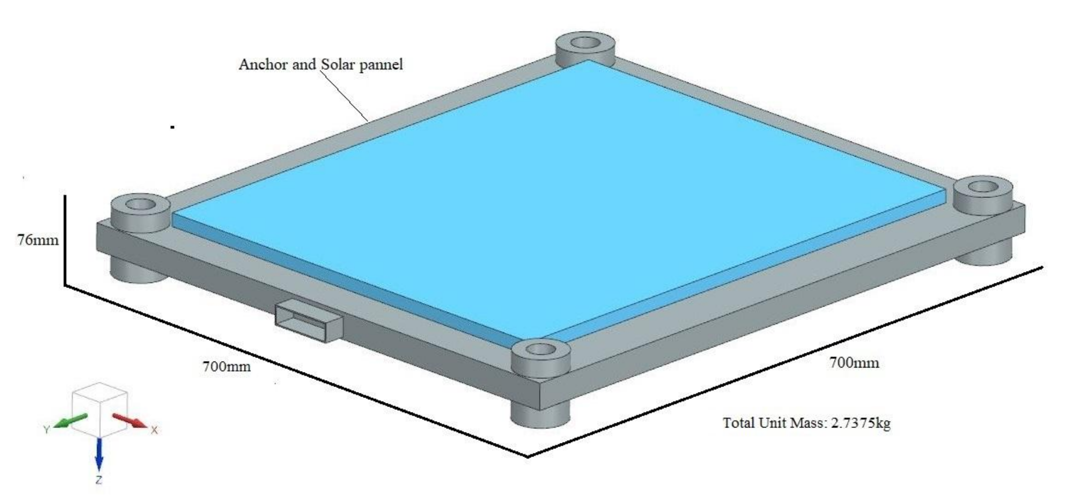


Figure 19: Anchor and solar panel

System Design / Power System / Components

- Lithium ion LP 33037 60Ah 4.1V battery (provides 246Wh each)
- 4 batteries allocated to rover (984Wh)
- 3 batteries allocated to solar panel (738Wh)
- 7 batteries total (1722Wh)

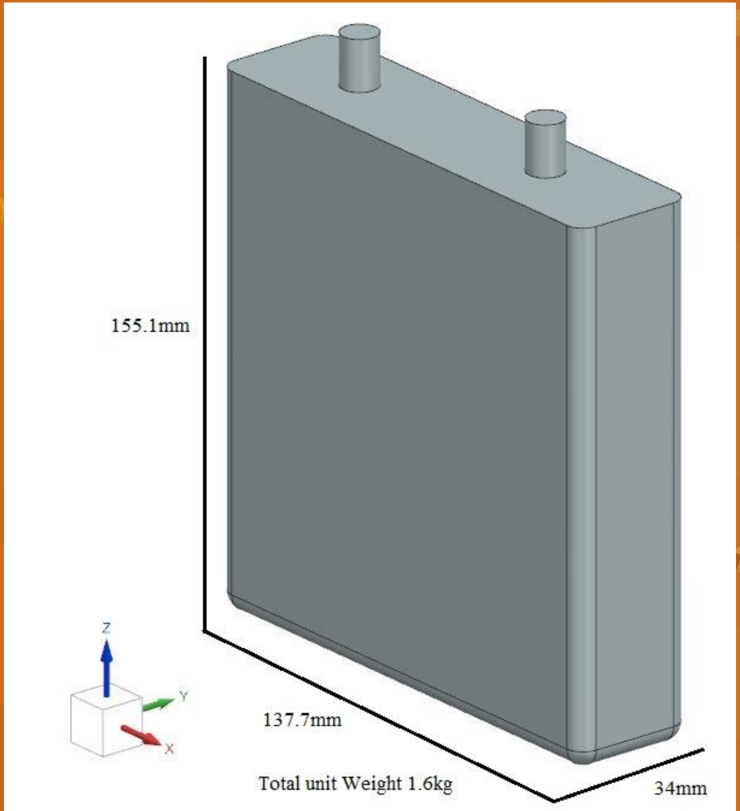


Figure 20: Lithium ion LP 33037 60Ah 4.1V battery

System Design / Power System / Power Consumption

Three modes of power consumption:

- Data Collection (Day: 242.3W, Night: 165.9W)
- Sending Data (Day: 27W, Night: 75.6W)
- Full Rest (Day: 77W, Night: 77W)

Rover Modes

Data Collection Mode (**Day**)		Data Collection Mode (**Night**)	
Component/System	Power Consumption (W)	Component/System	Power Consumption (W)
Supercam	17.9	Supercam	17.9
LiDAR	25	LiDAR	25
Motors (x16)	96	Motors (x16)	96
UHF (**standby**)	15	UHF (**standby**)	15
Thermal System	76.4	Main Computer	12
Main Computer	12	**Total**	**165.9**
Total	**242.3**		

Rest Mode (Sending Data, **Day**)		*Rest Mode (Sending Data, **Night**)	
Component/System	Power Consumption (W)	Component/System	Power Consumption (W)
UHF (***active***)	65	UHF (***active***)	65
Main Computer	12	Main Computer	12
Total	**77**	**Total**	**77**

Rest Mode (Full Rest, **Day**)		Rest Mode (Full Rest, **Night**)	
Component/System	Power Consumption (W)	Component/System	Power Consumption (W)
UHF (***standby***)	15	UHF (***standby***)	15
Main Computer	12	Thermal System	48.6
Total	**27**	Main Computer	12
		Total	**75.6**

Figure 21: Table showing power consumption during different modes

System Design / Power System / Timeline

Rover activity after entry:

- Data Collection and Sending Data during night hours

- Resting to replenish power supply during day hours

Rover Activity After Entry					
Time (hr)	Rover Status	Power Consumption (W)	Rover Battery Level (Wh)	Solar Battery Level (Wh)	Day/Night
1:00:00	Data Collection	165.9	130.7	738.0	Night
2:00:00	Sending Data	77	176.7	615.0	Night
3:00:00	Resting	75.6	224.1	492.0	Night
4:00:00	Resting	75.6	271.5	369.0	Night
5:00:00	Resting	75.6	318.9	246.0	Night
6:00:00	Resting	75.6	366.3	123.0	Night
7:00:00	Resting	27	462.3	0.0	Day
8:00:00	Resting	27	580.0	0.0	Day
9:00:00	Resting	27	697.8	0.0	Day
10:00:00	Resting	27	815.5	0.0	Day
11:00:00	Resting	27	933.3	0.0	Day
12:00:00	Resting	27	984.0	0.0	Day
13:00:00	Resting	27	984.0	117.7	Day
14:00:00	Resting	27	984.0	235.5	Day
15:00:00	Resting	27	984.0	353.2	Day
16:00:00	Resting	27	984.0	471.0	Day
17:00:00	Resting	27	984.0	588.7	Day
18:00:00	Resting	27	984.0	706.4	Day
19:00:00	Resting	75.6	908.4	738.0	Night
20:00:00	Data Collection	165.9	742.5	738.0	Night
21:00:00	Sending Data	77	665.5	738.0	Night
22:00:00	Resting	75.6	589.9	738.0	Night
23:00:00	Data Collection	165.9	424.0	738.0	Night
24:00:00	Sending Data	77	347.0	738.0	Night
24:40:00	Resting	75.6	296.6	738.0	Night
	Total	1556.7			

Figure 22: Power system timeline

System Design / Power System / Time Plots

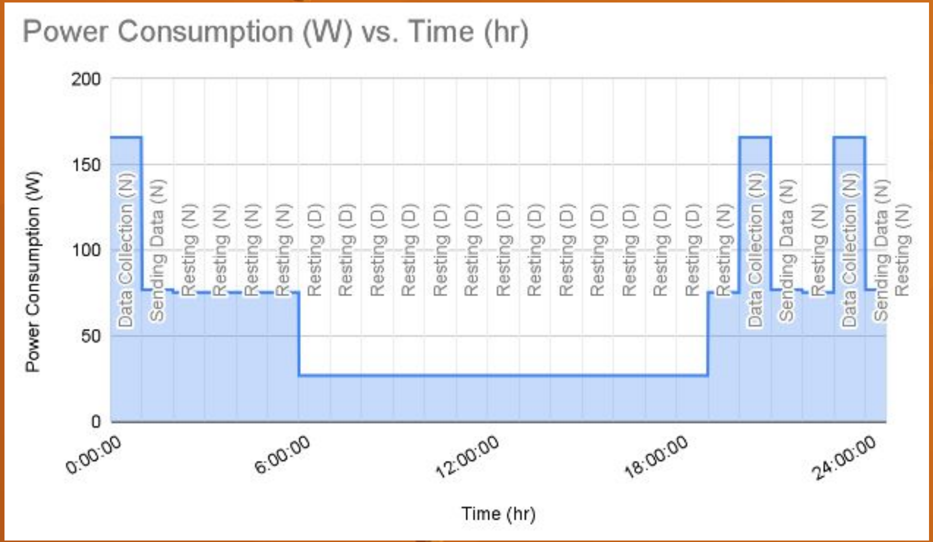


Figure 23: graph displaying power consumption over time

Figure 24: graph showing battery level over time

System Design / Power System / Manufacturing & Integration Plans

Table 5: power system manufacturing plans

Product Name	Material	COTS / In-House	Manufacturing Company	Start Manufacturing Phase	End Manufacturing Phase
Lithium-ion Cell 60Ah Space Cell	Lithium-ion	COTS	EaglePicher Technologies	C	D
Space Solar Cell	Metamorphic N on P	COTS	SOLAERO Rocket Lab	C	D

System Design / Power System / V&V

Req #	Requirement	Verification Success Criteria	Verification Method	Result	Facility	Phase
POW-0.1	The total mass of the power system shall not exceed 7.0 kg	1. Aggregate mass of system does not exceed indicated limit	Inspection		GSFC	B-D
POW-0.2	The power system shall provide energy to each subsystem	1. Battery bank provides <200 Watts	Test		GSFC	C-D
POW-0.2.1	The power system shall provide enough energy to sustain the system for a minimum of 3 days	1. Battery bank shall have a energy capacity of < 200 Watts 2. Battery charging system produces 180W/hr	Test		GSFC	C-D
POW-0.2.1.1	While in active mode, the power system shall provide sufficient energy to each subsystem	1. Battery Bank shall have a capacity of <200 Watts 2. Battery cells shall have a max discharge rate of 200A	Test		GSFC	C-D

Figure 25: power system verification and validation

System Design / Power System / V&V (cont.)

POW-0.2.1.2	While in rest mode, the power system shall provide sufficient energy to maintain the vehicle's operating temperatures	1. Battery bank shall provide power to CHD and Thermal distribution system to maintain operational temperatures.	Test		GSFC	C-D
POW-0.3	The cost of the power system shall not exceed 10% of the total budget	1. Aggregate cost of components does not exceed indicated limit	Inspection		GSFC	B-C

Figure 26: power system verification and validation, continued

System Design / Thermal System / Components

RAD750 3U compactPCI

- Monitor component temperatures via thermoresistors
- Control heating and cooling

Silicone Rubber Heaters

- Temperatures up to 200°C
- Heat output of 9.30 W/cm^2

Dedicated Cooling Panel

- Contact cooling via copper air cooling channels.

Figure 27: RAD750 3U CompactPCI

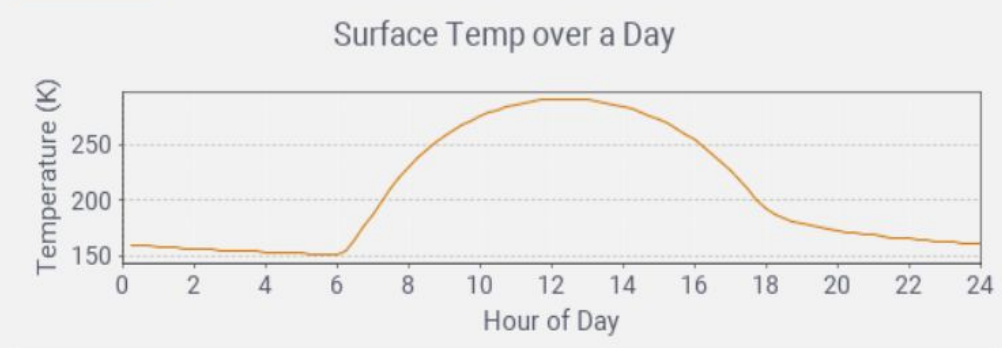
System Design / Thermal System / Expected Conditions

Average Surface Temperature

- Day: 250K
- Night: 160K

Average Subsurface Temperature

- Day: 240K
- Night: 150K



Name	Color	Temperature (K)	Hour	Ls
CC0769		160.184	24	180

Figure 28: graph displaying the change in surface temperature

System Design / Thermal System / Expected Conditions

- Operating Temperature Range: [233K, 313K]
- Stable:
  - Day: Sending Data, Full Rest
  - Night: Data Collection, Sending Data
- Unstable:
  - Day: Data Collection
  - Night: Full Rest

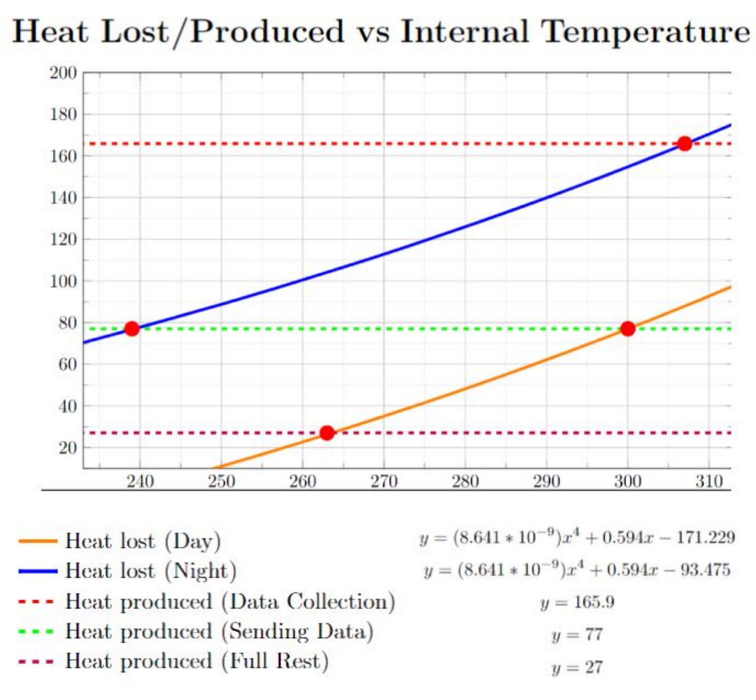


Figure 29: graph displaying heat lost or produced verses internal temperature

System Design / Thermal System / Expected Conditions

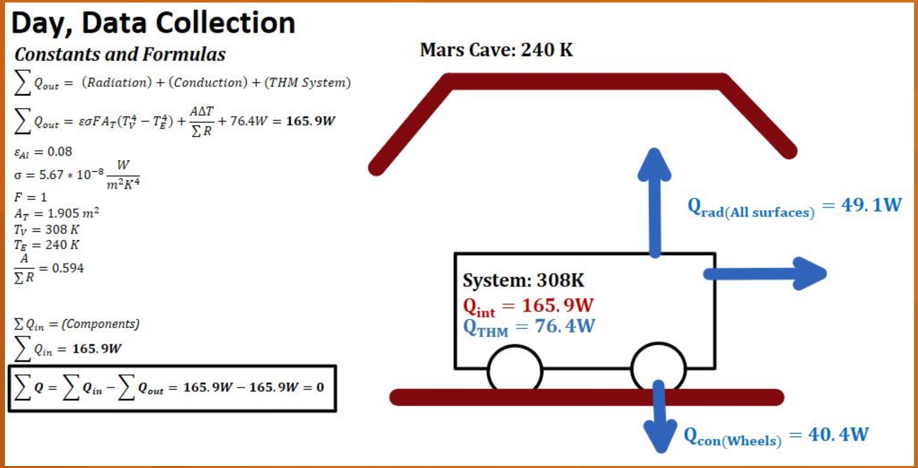


Figure 30a: heat flow map for data collection mode

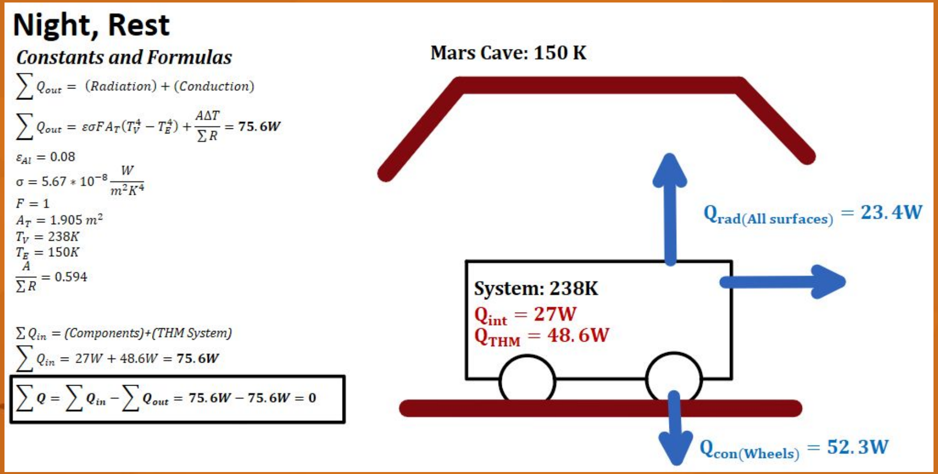


Figure 30b: heat flow map for rest mode

System Design / Thermal System / Manufacturing & Integration Plans

Table 6: Thermal system manufacturing plans

Product Name	COTS / In-House	Manufacturing Company	Start Manufacturing Phase	End Manufacturing Phase
Silicone Rubber Heaters	COTS	Thermo Heating Elements LLC	C	D

System Design / Thermal System / V&V

Table 7: V&V table for thermal system

Req #	Requirement	Verification Success Criteria	Verification Method	Result	Facility	Phase
THM-0.1	The thermal system shall not exceed a weight of TBD kg	1. Aggregate mass of system does not exceed indicated limit	Inspection		GSFC	B-D
THM-0.2	The power consumption of the thermal system shall not exceed TBD Watts	1. Thermo-Electric heaters consumes 15 Watts	Test		GSFC	C-D
THM-0.3	The cost of the thermal system shall not exceed 5% of the total budget	1. Aggregate cost of components does not exceed indicated limit	Inspection		GSFC	B-C
THM-0.4	The thermal system shall maintain vehicle's operating temperatures throughout the duration of the mission	1. Thermal-Electric heaters maintain internal temperatures with +-5 degrees Celsius of operation temperatures.	Demonstration		GSFC	C-D
THM-0.4.1	The thermal system shall maintain a temperature within the range [-40 C, 40C]	1. Heaters add heat to the system increasing or maintaining temperature 2. Coolers remove heat or maintain temperature	Demonstration		GSFC	C-D
THM-0.4.2	The internal temperature of any given subsystem shall not deviate from its operating temperature by more than +-5 degrees Celsius	1. Thermal distribution system shall monitor internal system temperatures and accurately indicate temperature and systems thermal needs.	Demonstration		GSFC	C-D
THM-0.4.3	The thermal system shall generate heat to sustain operating temperatures during operations	1. Heaters shall be able to increase internal heat when exposed to lowest possible temperature of -113 Celsius.	Test		GSFC	C-D
THM-0.4.4	The thermal system shall receive telemetry on the thermal state of each subsystem from the CDH system	1. Communication verification CDH system and Thermal system	Demonstration		GSFC	C-D

System Design / Thermal System / Risk Analysis

Table 8: thermal system risk analysis

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention
Thermal management system (TMS) is unable to keep all instruments and other systems in their respective operating temperature.	Power is depleted.	Mission timeline would be decreased.	100	More than expected power is used.	90	Reduce power consumption of components when they're not needed.
	TMS is damaged	Internal components and science instruments will reach extreme temperatures and become inoperable.	95	TMS is damaged	20	Ensure TMS is durable.

Mission Cost

Table 9: breakdown of mission cost

Name	Cost
Personnel	$17,216,686.00
Travel	$286,000.00
Outreach	$210,000.00
Direct Costs	$92,158,895.00
Other Costs	$34,407,026.83
Total Project Cost	**$144,278,607.83**

Summary & Next Steps

- SoCoLD's goal is to investigate the subsurface conditions on Mars by exploring the Martian lava tube CC0769

- Science goals
  - Map terrain and geography of skylight and lava tube
  - Determine abundance of olivine within lava tube
  - Determine mineral composition of regolith inside lava tube

- Data will be collected through SuperCam and the Innoviz360 LiDAR sensor

- Next steps
  - Prepare for CDR
  - Focus on further research into instruments and hardware
  - Refine V&V plans, risk mitigation, budget, and schedule

Thank you & Questions