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Thermal Protection and Gamma Ray shielding on a 60kg Lunar Rover

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Abstract

Water, one of the most important ingredients of life, is present in abundance on the moon's surface. Previous lunar missions like the Apollo Program, Chang'e 1 and Chandrayaan mission have suggested that there is water present on the moon. Although it was believed that water can exist only on the far side of the moon, recent findings by NASA's SOFIA suggest that water can exist even on the sunlit side of the moon. Our paper proposes a sixty kilogram rover proven by preliminary studies at the Wiechert crater in search of water or water ice, extracting and lastly purifying it. This is significant since these ingredients can also be for future human settlers as well to develop economic prosperity and ensure commercial mining of water resources for electrolysis fuel cells. The main payload of this mission is the purification systems and the rocket fuel generator (electrolysis cell) for the moon. The reason why this payload is chosen is because these are 100% INSITU resources and can be drilled from the regolith. This is going to be working when the spectrometer and the hyperspectral imagers are going to be prospecting. The lunar surface. Once the possible chance of water has been found the drill is going to be extracting the water by heating the volatiles in the drill. We will then purify the water by using a hydrogen reduction and ammonia as a scrubber method and scrubbers to remove excess gases from the vapour purifying it from ilmenites and basalts. Then the water will go to the electrolysis cell for further extraction and then for rocket fuel with the help of separating the H from the O. The next science payload is the mass spectrometer which is going to be using a mass magnetic sector and a quadrupole mass spectrometer to separate the ions and the compounds which will then go to the detectors which are both GC or a gas chromatograph. These are going to be working when the lasers have melted the rocks for the gas to come out to be analysed by the electron gun and onto the filters of the RF iron beams and the magnets for separation and then onto the main detector. This type of spectrometer has never been used before since its using a quadruple and a magnetic sector mass spectrometer. These instruments and payloads are all technology demonstrations.

Nomenclature

RDC - Rover Deployed Configuration
RSC - Rover Stowed Configuration

Introduction - Concept of Operation

The main concept of operations for the Wasp Lunar Rover to operate are:

1. The rover will find suitable landing spots using the TRN system and algorithm along with the cameras on the entry descent landing craft. Once the landing spot is confirmed the rover can descend and go to the location desired.
2. The rover will begin its mission at 84 degrees South East of the Wiechert crater. Once it has deployed its components and sent signals to the nearby communications on Earth for double system-checks, it will begin its journey in search of water. It will use its TRN algorithm and navigation cameras to locate possible extraction points on the Wiechert crater for icy-bound or water-bound regolith.
3. The rover will be in contact with the Earth using the relay satellites on the moon like the LRO (lunar reconnaissance orbiter) and lunar flashlight for example. This will be done with the S and the X band antenna systems. We are using the LRO because the antenna sometimes cannot get a complete field of view of Earth and hence the disruptions in the communication can cause the rover to not get complete and vital information.
4. Our speculated mission duration will be 14 days.
5. The rover will start moving and testing out the various systems like the robotic arm, mobility, and the sensors on the rover to verify everything is working perfectly on the moon.
6. The sensors will once again confirm the areas of water using the instruments like cameras, hyperspectral
7. imagers, and mass spectrometers.

8. Once the rover is in the targeted area the rover will collect and vaporise the samples for the mass spectrometers to study the lunar regolith. The drills can start drilling and collecting samples for extraction of volatiles. The drill and the robotic arm will collect samples.
9. The process of drilling should be monitored using sensors to measure the depth using LIDARS. The drills will be using springs as well. The cameras will monitor and use differential algorithms to determine the depth of the drill.
10. Due to the size of the drill, no sensors will be added to the bottom of it.
11. After the regolith is collected using an advanced purification mechanism the unwanted material will be refined and removed from the regolith sample for ease of water extraction using hydrogen reduction. This is going to be done when the heaters are inside the drill. The water will evaporate. Once the water has evaporated the volatiles and water will be vaporised and collected to be condensed at a certain pressure and temperature. After this, the collected ice will be water.
12. We will then start to use electrolysis to use the hydrogen for testing potential fuel for rockets and oxygen for the astronauts. (the water will be checked using the sensors like the spectroscopes and imagers in various spectrums)
13. The drill will check and complete the collection process. After this, the arm will retract and then go back into the rover.
14. The process will repeat and the purification and other discoveries can be done and made. The database is going to be the same which is using the TRN algorithm system.
15. The rover is going to be only operating on the lunar day. We will be putting the rover in hibernation. We hope that the rover will communicate with Earth in the morning .

Detailed Subsystem Analysis

<u>Mechanical subsystem (MES)</u>

Rover body: This is going to be the main structure of the entire rover housing the various components inside.

Wheels: There are going to be 6 rover wheels. They are going to be utilising a new method of wheels with shock absorbers and metal remembering materials to retain the original position with 8 internal shock absorbers. They are also going to be part of the rocker bogie system which will allow the rover to move.

Robotic arm: This is going to be a 4 axis robotic arm meaning it can move in x and y axis 4 ways around. This is also going to be having the drill attached to it.

Drills – This is the main drill that will separate the volatiles and also collect samples of the regolith for the further caching purposes on the moon and for future missions.

<u>Electrical Power Subsystem (EPS)</u>

Solar panels – This is the main power system that will be utilising solar energy. The advantage is that this system can be deployed and folded.

<u>Onboard Computer (OBC)</u>

Drivers - This is the main computer that is responsible for allowing the rover to move wherever it wants us to go. This will contain the resistors and the boards to make sure that the motor does not get burned and also to make sure that the IO pins are perfect for the motors to the main AI, ML, DL computers.

AI, ML, DL boards - This is the main board for decision making when we are not in contact with the Earth. This includes when the rover has travelled to the far side of the moon. This will use various algorithms to adapt to the new environments. This will also contain the system we are building which is going to be the TRN system which will allow the rover to be at least 30% more efficient. In this case they are the single board computers.

Backup computer – This is the main board that will allow the rover to check its subsystems and possibly use backups. This is extremely important in the safety and the entire rover since these anomalies can cause the rover to either crash or do something wrong when the mission could be something else.

Sensor – Interference for the sensors and the components of the entire rover.

Telemetry control – This is very important for the entire rover and is going to be the data of the sensors and is very important.

Communication (COM)

S-band transceiver for TT&TC - This is going to be the main communication system for the rover and is going to be used for low gain antennas

X-band transmitter for payload data downlink – This is going to be the main communication system for the higher range in the spectrum for the payloads.

Payload (PAY)

Mass spectrometer (quadrupole and GC magnetic sector) - This is a special kind of spectrometer that has been designed specifically for this mission since this is combining 2 kinds of spectrometry techniques like the quad and the GC magnetic sector.

Electrolysis cell – A technology demonstration that is going to use electrolysis and is going to be creating hydrogen rocket fuel for the rover.

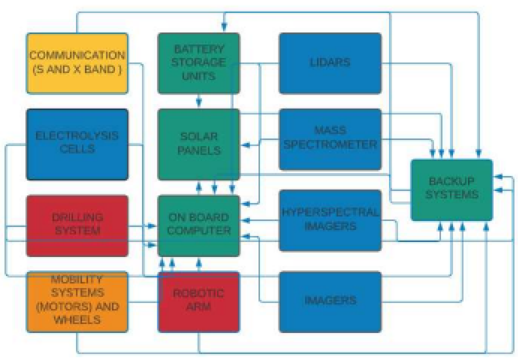
Purification Systems – A second technology demonstration that will purify water for astronauts to drink the water, and purifies the regolith as well as extracts water from the regolith

LIDARS - This is going to be part of the NAV CAMS of the rover and will be also programmed to give information to the TRN system to create realistic images. The specific type of LIDAR we are using is the MM wave LIDARS.

Hyperspectral imagery – This is a kind of imager for the NAV CAMS, SCIENCE CAMS and is used to search for the things in various spectrums depending on the need hence making the rover even more advanced.

Cameras – This is the sensor that is going to be recording a live feed to the mission control with the x and s band antennas and is going to be extremely important for the entire rover.

Rover Subsystems Diagram



Rover Component Mass Budget Calculations

	Component	**Total mass (KG)**	**Dimensions (cm) (length X Width X Height)**
Mechanical	Rover Body	6	75 by 100 when undeployed and when deployed 95 by 100
	Mobility mechanism(Rocker Bogie Suspension + Drive motors)	2.9	90 in length and 18 in sides wheels (25 by 13) and motor
	Robotic Arm	1.3	Rover Stowed Configuration: 10 by 10 by 20 RDC: 20 by 20 by 50
Payload	Mass Spectrometer	6	40 by 30 by 20
	Purification systems	5	60 by 60 by 24

	Drill Mechanism	1.2	100 by 20 (RDC:100)
	Cameras	6.4	9.7 by 9.6 by 6 each. THE LIDAR IS ONLY GOING TO BE 5 BY 4 BY 4 CM
Electronics	Onboard Computer	1.8	39.3 by 32
Communication systems	S-band Transceiver for TT & TC	0.2	40 by 59 (RDC: 59 CM)
	X-band transmitter for payload data downlink	0.3	40 by 59 (RDC: 59 CM)
Thermal Control Systems and Shielding	Polyimide Thermofoil Heaters	1	Thickness: 0.0083 and dimensions 2.24 X 7.3 cm
	Multi-Layer Insulation and Shielding	6	Thickness: 0.3 and with the gamma ray insulation 0.55
Vacuum valves	Pressure pumps	2	14.9 by 17.86
	Mass Flow controllers and shut off valves	1.4	9.23 X 5.25 X 12.5
	Backflow preventer check valves	4	25.4 X 11.7 X 11.1
Power Systems	Rechargeable battery (Li-ion)	2.8	30 X 10 X6
	Solar Panels	11.5	240 X 50 X 2
Total Mass	59.8	Total size	RSC: 77 X 95 100 RDC: 75 by 95 by 100

Rover Component Power Budget Calculations

	Unit Name	Power required (W)	Duty cycle in nominal operation (%)	Nominal power consumption (W)	Duty cycle in emergency operation (%)	In emergency requirement (W)
Mechanical	Drive motors	47	50	23.5	0	0
	Robotic Arm	32	30	9.6	0	0
Payload	Mass	141	5	7.05	0	0

	Spectrometer					
	Electrolysis Cell and Purification Systems	1	5	0.05	0	0
	Drill Mechanism	10	25	2.5	0	0
	Cameras	14	15	2.1	0	0
Electronics	LIDARS	20	50	10	0	0
	Onboard Computer	24	100	24	100	24
	Lasers	5	5	0.25	0	0
	Backup systems	100	10	10	100	100
Communication Systems	S-band Transceiver for TT & TC	60	100	6	20	12
	X-band transmitter for payload data downlink	70	40	28	20	14
Thermal systems.	Polyimide Thermofoil Heaters	46	50	23	0	0
Vacuum Valves	Mass-Flow controller	8	20	1.6	0	0
	Pressure valves	40	20	8	0	0
	Pressure pumps	100	10	10	0	0
Rover safety and mobility	Motor controllers	30	50	15	0	0
	Traction control	40	50	20	0	0
			All components	200		100
Adding			**Rover Power**	230		115

Power budget Margin of 15 %			**Requirement**			

Nominal Power Requirement	**230 W**
Emergency Power Requirement	**115 W**

1.Moon Environment and Thermal Control Systems

1.1 Moon Environment Study and Radiation

1.1.1 Electromagnetic Radiation received from the Earth and sun

The moon produces gamma rays which are dependent mostly from cosmic rays reflected. These rays are of high energy. Cosmic rays can produce kinetic energy at 90 km/h at 50J and 40 million times the energy of the particles from the Large Hadron collider. As these cosmic rays are produced from protons, atomic nuclei, alpha particles, and some electrons. They are similar to X-rays or Gamma rays. On the moon there is an annual exposure that is prominently in a larger range than on Earth due to the lack of the magnetic field on the moon. These ranges are from 380 mSv to 110mSv (GCR or galactic cosmic rays and radiation doses). The cosmic rays are usually defected on Earth and are reflected from the sun.

More results were found from the Indian Chandrayaan Satellite which suggests that most nGy.cm2 from electrons were above Heffner's prediction 0.3-0.35 nGy.cm2 .particle-1 as the analysed dose were located at the inner-radiation scale where mostly protons exist exerting energies at 13MeV. . For shielding against gamma rays we will use an alloy to deflect these rays from affecting our rover's electrical mechanisms.

When the satellite entered a 100 km circular orbit around the Moon the GCR doses fell because of the Moon surface shielding to about 8.8 μGy/h and stayed stable around this value. The flux is 2.29 cm-2.s-1. These were results from the RADOM spectrometer.

This gamma ray division is higher in spectrums than the sun because of the cosmic rays on the moon. This is because the moon has heavier elements than the sun (only helium and hydrogen). Cosmic rays outshine these heavy elements and cause gamma ray diffusion due to nuclear recoil.

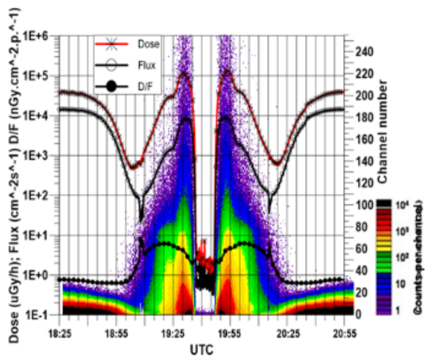


Fig 1. Overlap of 2- and 3-dimensional presentation of RADOM data for 22800 km altitude from Indian INDIAN CHANDRAYYAN-1 SATELLITE. PRELIMINARY RESULTS

1.2 Solar Irradiance, Albedo and Reflectivity

The two types of reflectivity include specular and diffusion reflectivity. Specular reflectivity determines total incoming light reflected in the accrued angle or direction. In the diffused reflectivity the determination is rather the totality for all directions in light reflectivity from the wide angle. For calculating mean solar irradiance, we will find the reflectivity from the diffused, and for the directed solar irradiance we will use the specular reflectivity.

The albedo of the moon is at ranges 12-12.5%. That is the bond albedo of how much light the moon reflects away. If the moon were a blackbody in these terms; it would reflect 0% of the light as it will be absorbed.

1.3 Mean Solar Irradiance

The mean irradiance of the moon is approximate to that of the Earth due to them having the same distance to the Sun of one astronomical unit. To account for the mean radiance variables the only difference would be to use a different albedo value for the moon in terms of accuracy and calculating energy emitted with the Stefan-Boltzmann Law.

$$E_{emitted} = \sigma T^4 \times \pi R_M^2$$

For total solar irradiance we use variables such as the solar luminosity ($L_{sol} = 3.828 \times 10^{26} [W]$) and distance from the Sun's radius to the moon.

$$TSI = \frac{L_{sol}}{4\pi \cdot R^2} \left[\frac{W}{m^2}\right]$$

The total solar irradiance or solar constant is referred to the mean solar irradiance or solar constant which is 1,361 W/m2 and this is regardless to any eccentricity or variation in distances (apogee and perigee) that exists.

1.4 Direct solar insolation

To regard this in accuracy we use the solar insolation or radiant exposure calculation which regards periods of time in the sum of solar electromagnetic radiation per unit area per unit time.

$$I = \int_{t_0}^{t_1} E_{dir}(t)dt\left[\frac{J}{m^2}\right]$$

2. Rover Solar Panel and Battery Design

2.1 Solar Panel Design

Efficiency of solar panel designs is an important factor in determining the useful power of all light that is used to be transferred into electricity. A higher efficiency will convert more sunlight into energy. To calculate the efficiency percentage, we use the equation:

$$E = \left(\frac{Maximum\ Wattage}{Incident\ Radiation\ Flux \times area\ of\ the\ solar\ panel}\right)\times 100$$

In terms of the Lunar rover's solar panel the variables are:

$Maximum\ Wattage\ of\ the\ Solar\ Panel\ =\ 400W ELunar\ Rover\ Solar\ Panel\ =\ 400W$
$Incident\ Radiation\ Flux\ =\ 1361W/m2$
$area\ of\ the\ solar\ panel\ =\ 80cm \times 100cm\ =\ 0.8m2$

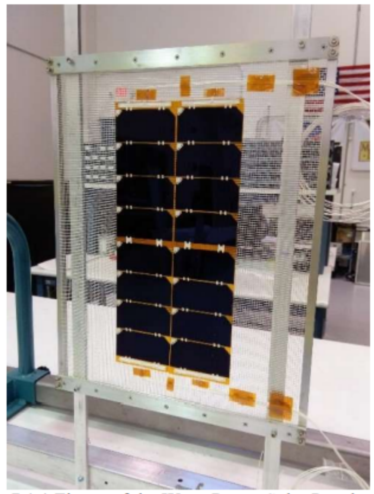
$$E_{Lunar\ Rover\ Solar\ Panel} = \left(\frac{400W}{\frac{1361W}{m^2}\times 0.8m^2}\right)\times 100\ =\ 36.73769287\%$$

The efficiency of one solar panel is 36.74% in the lunar rover.

To achieve this efficiency with regards to the harsh fluctuating temperatures on the moon the Lunar rover will adapt the solar panels that NASA uses which are multi-junctional cells that achieve efficiencies above 30% to meet these requirements

Ga-As multi-junction solar photovoltaic cells have been considered fit for our mission. With current technology these solar cells are 30 % efficient in converting solar energy to electrical energy, which can be used as a power source for our rover.

The mean solar irradiance received on the moon surface during daytime is around 1367 W/m2. Now taking the conversion efficiency of the solar cells to be 28% we get the total power generated by the solar panels as 383 W/m2 .



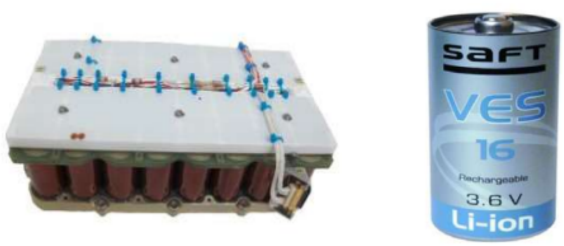
7.1.1 Figure of the Wasp Rover Solar Panels

The nominal Power requirement of the rover is calculated to be 230 W, as given in the Power consumption table. Thus, the area of the solar cells required is = (230 W/ 383 W/m2) = 0.6 m2. This value is calculated assuming a normal incident solar flux. Taking into account the varying angle of incidence throughout daytime we choose the solar cell array size to be 2 * 0.6 m2 = 1.2 m2 .

Ga-As cells have a specific power of 40 W/kg. Thus, the mass of the solar cells required to produce 230 W power is 5.75 kg.

2.2 Battery Design

We propose to use a Lithium-ion rechargeable battery for our rover. Li-ion batteries have a very high specific energy of 150Wh/kg and can go on for 1000 life cycles at 100 % Depth of Discharge. The energy density of these batteries is 350 Wh/litre. It has an average discharge voltage of 3.5 V and has low internal impedance of 1 milli ohms.



7.2.1 Figure of the Wasp Rover Rechargeable Battery

3. 1 Thermal Protection and Gamma Ray Shielding

For Multilayer insulation we have designed an insulation system which prevents electrical conductivity from dust, high doses of gamma rays on the moon and radiation shielding of drinkable water for astronauts and prevents micrometeorite(hypervelocity) impacts. The insulation system will be made of lithium hydride as an equivalent of polyethylene as it reduces distances of particle radiation by 20% and its high hydrogen content. To shield from gamma rays, we have configured alloy layers made of lead (covering 40 cm) which can be used to prevent proximities of solar flares, concrete (covering the whole rover) and water concentrations covering the whole rover as well. We will scale down the lead concentrations to 0.25 mm as used in biomedical uses.

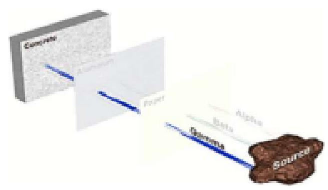


Fig Analysis of gamma ray insulation material
Protection Against Exposure
American Nuclear Society

Aluminized non-metals (Kevlar, Mylar, fibreglass, nylon, Nomex covered by an elastomer layer of VitonB50 and Kapton separated from Mylar by Dacron mesh) will also be mixed with some of the materials mentioned above as they were used on the Shuttle orbiter and were effective in preventing radiations. The entire MLI system will only be 3mm and its mass will be of 0.03 grams per square centimetres of covering the rover. This will be 12 layers of aluminized materials and roughly 5 more layers of the alloy material mentioned above.

Due to its poor electrical conductivity, electrostatically charged dust particles will be deflected and not intrude the systems. Our rover's insulation will be made of aluminized Mylar covering of 1 mm in thickness and has a high tear resistance. Three Kevlar straps will be wrapped around the module system. The Tensile strength is of 185 megapascals internally on the strut material and its thickness is additionally 1.5mm.

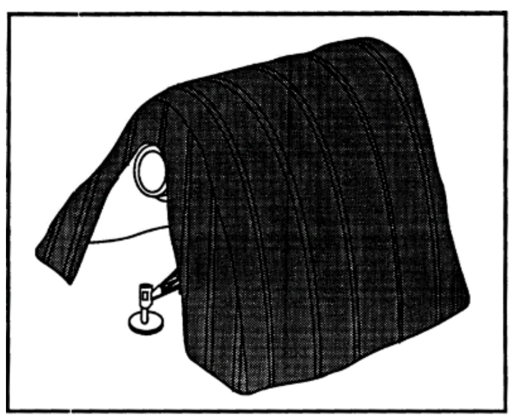


Fig . Apollo Mission Strut MLI

For protection from gas leakages in the pressurised vessels and valves we will use the self-sealing inflatable structures to press and pressurise the gases stored inside with foams. To regulate this, we will use a feedback loop using Machine learning algorithms to keep the pressures at equilibrium. The thermal shield and shock radiation absorber material alloys will be designed to withstand strut rigidity and are fully shielded.

The MLI system in the internal subsystems of the rover (PCB, OBC, purification systems) will also keep a permissible pressure range for 2.3 to 6.7 bar to minimise leakages and will have a redundant system of 2 of each of the components it is covering.

The packaged volume of the insulation blanket will be kept in two adjacent cylinders of radius 28.5 cm and its length will be 14.5 cm in the external part of the rover body.

We will also be using a heat exchanger mechanism which is a process fluid or coolant that is air or water which will be heated in the inlet and outlet temperatures at which the mass flow rates follow linear functions that show that in condensing steam it is puny in terms of static pressure that occurs one the saturates steams is at a high pressure due to the condensing temperature. They will follow cylindrical pipes that are minimized in surface area and small diameters which decrease the heat transfer coefficient. The heat exchanger also adds thermal resistance between the container and the load by sieving as the higher the inlet temperature the gas losses are increased. This will also isolate the circuits and prevent system interruptions. We will be heating the air and vapors by incorporating the excess solar power for heating

3.2 Operating Temperatures of the rover components

	Component	**Operating Temperature (°C)**
Mechanical	Rover Body	-40 to 40
	Mobility mechanism (Rocker Bogie Suspension + Drive motors)	-40 to 100
	Robotic Arm	-40 to 100
Payload	Mass Spectrometer	0 to 50
	Purification systems	0 to 20
	Drill Mechanism	-45 to 75
	Cameras	-20 to 20
Electronics	Onboard Computer	-25 to 70
Communication Systems	S-band Transceiver for TT & TC	-40 to 85
	X - band Transmitter for payload data downlink	-150 to 150
Vacuum Valves	Back-flow preventers	-196 to 816
	Mass-Flow controllers and shut-off valves	Storing temperature: -20 to 80 Operating Temperature: 10 to 50
	Pressure Pumps	-25 to 55
	Pressure Valves	-20 to 50
Power systems	Rechargeable battery (Li-ion)	10 to 45

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