

# Lunar Base Micrometeorite Inspection Robot(s)


NASA HUNCH Project Requirements Document

## Picture

## Credits:

Nancy Hall NASA	- Ideator
Michael Hayes -MASA HUNCH	- Author
Xxxxxxxxxxxxxx - Contributor	- TBD

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Hall, Nancy R. (GRC-MSIO) <nancy.r.hall@nasa.gov>.....	4
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Thu, Mar  
5,  
8:31 AM

## Overview

Hall, Nancy R. (GRC-MSIO)  
<nancy.r.hall@nasa.gov>

to Glenn,  
Glenn, me,  
Michael,  
Cody

Glenn, Michael

I have this cool idea for a project. I did discuss this with Michael and want to now expand upon it and share with Glenn and get your feedback.

**Overview:** You are on the moon and there happens to be a micrometeorite shower as without an atmosphere to burn up space debris, they just fall straight through. The meteorite shower occurred at your moon base and you want to be able to inspect your lunar habitat to determine if there has been any damage to your habitat. You can use your autonomous lunar rover to crawl onto the sides and roof of your lunar habitat to inspect it. With this is happening, the details the robot sees on the surface of the habitat is fed into a system that maps what it sees. The rover “camera” or “optics” utilizes a recognition system to identify the normal features of the lunar habitat and highlight any new features such as micrometeorite hits. It also needs to be able to discern sizes of any “hits” by micrometeorites.

I see this project could potentially be both a D&P and Software/AI project.

-The Software/AI version is also the VR portion, where you are remotely controlling a rover, moving it across the lunar habitat, using facial recognition to map what it sees and point out any damage. It might be good for the software to determine how bad is the “hole,” how deep it is, can it cause decompression in the lunar habitat, etc. I think we might need the student to also

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design their habitat?

-The D&P portion is designing a rover that can crawl across the sides of a lunar habitat and detect holes of varying sizes. They would need to design a habitat and have it include holes of several sizes that the robot can detect. Do we want them to build a habitat or not?

The above is just a start and probably needs more discussion but wanted to pass this along.

Nancy

216-385-6302

--



### **Nancy Rabel Hall**

**GRC HUNCH and XMIPT Project Manager  
STEM Engagement**

ISS and Human Health Office MSI

NASA Glenn Research Center

21000 Brookpark Rd, 77-7

Cleveland, OH 44135

216-385-6302

[nancy.r.hall@nasa.gov](mailto:nancy.r.hall@nasa.gov)

# User Requirements

## Overview and Mission Scenario

### Mission:

The Lunar Base Micrometeorite Inspection Robots(s) project challenges students to design, build, and program a robotic system capable of autonomously and remotely inspecting a **lunar base** to detect micrometeorite impacts and structural damage. The Robots(s) must traverse a **1-kilometer-radius circular lunar base** and inspect its structures, including a **500-meter diameter rocket landing pad located 1 kilometer away from the base center**.

### Scenario:

Micrometeorite showers pose a critical risk to lunar habitats and infrastructure due to the lack of an atmosphere to burn up space debris. Following each meteorite event, the Robots(s) will autonomously or remotely inspect the lunar base, identifying and analyzing damage to structures, landing pads, and surrounding surfaces.

### Key Features:

- The Robots(s) will collect data using modular sensors such as RGB cameras, LiDAR, and IR sensors.
- AI software will process the data, detect anomalies (e.g., pits, cracks, fissures), and assess damage severity.
- A management system will store, analyze, and visualize the collected data in real time or near-real time.

## Updated Lunar Base Scope

The lunar base is modeled to simulate a realistic environment for testing the Robots(s).

### 1. Base Layout

- **Lunar Base:**

- A **circular base** with a **1-kilometer radius** (diameter: 2 kilometers).
- Includes habitat modules, solar arrays, and storage areas, out building, Robots and Robots(s) Garage.

- **Rocket Landing Pad:**

- Located **1 kilometer away from the base center**.
- Circular with a **500-meter diameter**.
- Designed to simulate a flat, debris-free landing zone for rockets.

### 2. Inspection Area

The Robots(s) must inspect:

1. **Habitat Structures:** Cylindrical or dome-shaped modules with smooth or textured surfaces.
2. **Landing Pad:** Flat surface with potential micrometeorite pits and cracks.
3. **Other Areas:** Solar arrays, storage tanks, and connecting pathways.

### 3. Environmental Conditions

- **Gravity:** Lunar gravity (~1/6th of Earth's gravity).
- **Surface Texture:** Smooth and curved surfaces for habitats, flat surfaces for the landing pad.
- **Light Conditions:** Simulated lunar lighting, including shadows and dark areas.

**See Video - What they don't want you to see ( 10 Mins ) - Add**

## System-Level Requirements (SYS-xxx)

### Logical Function:

The system must enable comprehensive, reliable, and repeatable inspection of the lunar base, including habitat structures, landing pads, and surrounding infrastructure.

### ID Requirement Statement

SYS-0 01	The system shall transmit inspection data in real time or near-real time (latency <2 seconds).
SYS-0 02	The system shall support modular sensor payloads, including RGB cameras, IR sensors, and LiDAR.
SYS-0 03	
SYS-0 04	The system shall provide a management interface for data storage, visualization, and AI-driven analysis.
SYS-0 05	
SYS-0 06	The system shall operate under lunar environmental conditions, such as low gravity and low light.
SYS-0 07	The system must provide internal measurements for heat, temperature, humidity, vibrations. Visual clarity and other sensors that might indicate performance of robot(s).
The system shall enable the Robots(s) to inspect at least 110% of the lunar base surface area, including habitat structures and the rocket landing pad( Note: There may be overlap)	
The system shall support both autonomous and remote-controlled operation.	

## Section A — Software / AI Requirements (SW-xxx)

### Logical Function:

Software and AI subsystems provide data processing, mapping, damage detection, visualization, and reporting capabilities.

Refer to the [original software specifications](#) with **expanded scope** to support larger inspection areas and multiple inspection zones (base and landing pad). Key updates include:

- **AI Damage Detection:** Detect pits, cracks, and fissures across larger surface areas.
- **Inspection Zones:** Map and differentiate data from the habitat and landing pad.
- **Localization:** Track Robots(s) position across a 2-kilometer diameter inspection area.

## Section B — Hardware / Electronics Requirements (HW-xxx)

### Logical Function:

Hardware subsystems provide power, sensor integration, communication, and computing for real-time operation.

Refer to the [original hardware specifications](#), with updates to reflect:

- **Increased Range:** Communication and telemetry must function reliably over a **2-kilometer distance**.
- **Extended Power Requirements:** Battery life must support at least **1 hour of operation** over the expanded area.

## Section C — Mechanical Engineering Requirements (ME-xxx)

### Logical Function:

Mechanical subsystems ensure the Robots(s) can traverse diverse surfaces, maintain sensor stability, and operate under low gravity.

Refer to the [original mechanical specifications](#), with additional updates:

- **Long-Distance Traversal:** The Robots(s) must handle a larger inspection area, including the landing pad.

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- **Terrain Adaptability:** The Robots(s) must transition between smooth, curved, and flat surfaces (habitats to landing pad).

## Section D — Lunar Base Model Requirements (HAB-xxx)

### Logical Function:

The base model provides a realistic, testable environment for Robots(s) traversal and inspection.

| HAB-001 | The lunar base model shall represent a 1-kilometer radius base with habitat modules, solar arrays, and connecting pathways. |

| HAB-002 | The model shall include a 500-meter diameter flat landing pad located 1 kilometer away from the base center. |

| HAB-003 | The model shall include micrometeorite impacts (pits: 0.1 mm–20 mm diameter) on habitats and the landing pad. |

| HAB-004 | The surface material of the model shall simulate lunar regolith and smooth habitat surfaces. |

## Section E — E File Layout for Data Streaming

Refer to the [detailed file layout](#) previously

provided. Updates include:

- **Inspection Zone Identifier:**
  - Add `zone_id` to differentiate between the base (`HABITAT`) and landing pad (`LANDING_PAD`).
- **Expanded Position Tracking:**
  - Add Robots(s)'s global position relative to the base center.

This updated document reflects the expanded scope of the **Lunar Base Micrometeorite Inspection Robots(s)** project, incorporating the new **rocket landing pad** and **file layout** requirements. It provides a comprehensive framework for students to design, build, and test their systems while addressing real-world lunar exploration challenges.

# Appendix

## Section A — Detail Software / AI Requirements (SW-xxx)

### Logical Function:

Software and AI subsystems provide data processing, mapping, damage detection, visualization, and reporting capabilities.

Refer to the [original software specifications](#) with **expanded scope** to support larger inspection areas and multiple inspection zones (base and landing pad). Key updates include:

- **AI Damage Detection:** Detect pits, cracks, and fissures across larger surface areas.
- **Inspection Zones:** Map and differentiate data from the habitat and landing pad.
- **Localization:** Track Robots(s) position across a 2-kilometer diameter inspection area.

## Section B — Detail Hardware / Electronics Requirements (HW-xxx)

### Logical Function:

Hardware subsystems provide power, sensor integration, communication, and computing for real-time operation.

Refer to the [original hardware specifications](#), with updates to reflect:

- **Increased Range:** Communication and telemetry must function reliably over a **2-kilometer distance**.
- **Extended Power Requirements:** Battery life must support at least **4 hour of operation** over the expanded area.

## Section C — Detail Mechanical Engineering Requirements (ME-xxx)

### Logical Function:

Mechanical subsystems ensure the Robots(s) can traverse diverse surfaces, maintain sensor stability, and operate under low gravity.

Refer to the [original mechanical specifications](#), with additional updates:

- **Long-Distance Traversal:** The Robots(s) must handle a larger inspection area, including the landing pad.

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- **Terrain Adaptability:** The Robots(s) must transition between smooth, curved, and flat surfaces (habitats to landing pad).

## Section D — Detail Lunar Base Model Requirements (HAB-xxx)

### Logical Function:

The base model provides a realistic, testable environment for Robots(s) traversal and inspection.

| HAB-001 | The lunar base model shall represent a 1-kilometer radius base with habitat modules, solar arrays, and connecting pathways. |

| HAB-002 | The model shall include a 500-meter diameter flat landing pad located 1 kilometer away from the base center. |

| HAB-003 | The model shall include micrometeorite impacts (pits: 0.1 mm–20 mm diameter) on habitats and the landing pad. |

| HAB-004 | The surface material of the model shall simulate lunar regolith and smooth habitat surfaces. |

## Section E — E File Layout for Data Streaming

Refer to the [detailed file layout](#) previously provided. Updates include:

- **Inspection Zone Identifier:**
  - Add `zone_id` to differentiate between the base (`HABITAT`) and landing pad (`LANDING_PAD`).
- **Expanded Position Tracking:**
  - Add Robots(s)'s global position relative to the base center.

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## Section A — Management Software / AI Requirements

### (SW-xxx) Logical Function:

Software/AI subsystems provide remote control, mapping, damage detection, impact analysis, visualization, data management, and reporting, leveraging AI/ML for anomaly detection and user-friendly interfaces.

#### LF-SW-1: Remote Control Interface

| SW-001 | The software shall provide a GUI or VR interface for remote control of the rover, displaying real-time visual feeds. |

#### LF-SW-2: Surface Mapping and Baseline Capture

| SW-002 | The software shall capture and store baseline images and 3D maps of the undamaged habitat surface. |

#### LF-SW-3: Change Detection and Damage Identification

| SW-003 | The software shall use AI/ML algorithms to detect and highlight new features (e.g., micrometeorite impacts) compared to the baseline. |

#### LF-SW-4: Impact Analysis

| SW-004 | The software shall measure and classify impact sites by length, width, and depth in 3D. |  
| SW-005 | The software shall assess the severity of each impact and estimate decompression risk. |

#### LF-SW-5: Fracture and Fissure Analysis

| SW-006 | The software shall detect and classify micro and macro fractures or fissures on the habitat surface. |

#### LF-SW-6: Visualization and Overlay

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| SW-007 | The software shall provide visualization modes for RGB, IR, and LiDAR/depth data, with overlay capability. | | SW-008 | The software shall generate impact maps and allow top-view and close-up inspection down to 1 cm<sup>2</sup> resolution. |

### LF-SW-7: Data Management and Version Control

| SW-009 | The software shall store all inspection data with timestamps, dates, and version IDs. | | SW-010 | The software shall generate periodic change logs at intervals of 1 minute, 60 minutes, 24 hours, and 7 days. |

### LF-SW-8: Clutter Elimination and AI Anomaly Detection

| SW-011 | The software shall filter out irrelevant data and use AI to flag anomalies for review. |

### LF-SW-9: Reporting and Logging

LF-SW-10 Please use common File Specification

## Section E — E File Layout for Data Streaming

| SW-012 | The software shall automatically generate and store periodic impact reports, prioritizing the top X% largest impacts. |

## Section B — Hardware / Electronics Requirements

### (HW-xxx) Logical Function:

Hardware/electronics subsystems provide onboard computing, sensor integration, power, communication, and control interfaces to support robust, real-time operation and modularity.

#### LF-HW-1: Onboard Computing and Processing

| HW-001 | The rover shall include an onboard computer capable of autonomous navigation and sensor data fusion. |

#### LF-HW-2: Multi-Modal Sensor Payload

| HW-002 | The rover shall support a modular sensor bay for at least RGB camera (min 1080p), IR sensor, and LiDAR/depth camera. || HW-003 | The sensor suite shall detect surface pits  $\geq 0.1$  mm in diameter and measure depth to at least 0.05 mm. || HW-004 | The rover shall include proximity sensors for edge detection and collision avoidance. |

#### LF-HW-3: Power System

| HW-005 | The rover shall operate for at least 30 minutes on a single battery charge. || HW-006 | The power system shall provide regulated voltage to all subsystems. |

#### LF-HW-4: Communication and Data Transmission

| HW-007 | The rover shall transmit video and sensor data via Wi-Fi with latency  $< 2$  seconds. || HW-008 | The system shall be compatible with ROS for data logging and remote control. |

#### LF-HW-5: Control Interface Electronics

| HW-009 | The rover shall include electronics for remote control signal reception and autonomous/manual mode switching. |



## Section C — Mechanical Engineering Requirements

### (ME-XXX) Logical Function:

Mechanical subsystems ensure the rover can physically traverse the habitat model, maintain sensor line-of-sight, and support modular payloads, with robust structure and reliable adhesion.

#### LF-ME-1: Rover Chassis and Structural Robustness

| ME-001 | The rover chassis shall withstand a drop from 0.5 meters without functional damage. | |

ME-002 | The chassis shall be lightweight and rigid, supporting all payloads. |

#### LF-ME-2: Locomotion System

| ME-003 | The rover shall traverse flat, curved, and vertical surfaces (sides and roof) of the habitat model. | | ME-004 | The rover shall use a tracked or hybrid wheel-track system for mobility.

| | ME-005 | The rover shall traverse inclines up to 90° using an appropriate adhesion mechanism.

|

#### LF-ME-3: Adhesion Mechanism

| ME-006 | The rover shall use vacuum suction cups or magnetic adhesion, compatible with the habitat model surface. | | ME-007 | The adhesion system shall maintain attachment during all

traversal maneuvers. |

#### LF-ME-4: Path Coverage and Navigation

| ME-008 | The rover shall follow a programmable path covering at least 105% of the habitat exterior

surface. | | ME-009 | The rover shall support both scheduled and on-demand traversal. |

#### LF-ME-5: Sensor Mounting and Articulation

| ME-010 | The sensor bay shall include articulation or gimbal mechanisms to direct optics for clear surface observation. |

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LF-ME-6: Modular Payload Interface

| ME-011 | The rover shall include a mechanical quick-change interface for swapping sensor modules. |

Section D — Habitat Model Requirements (HAB-xxx)

## Logical Function:

The habitat model provides a realistic, testable environment for rover traversal and damage detection, with features representing micrometeorite impacts. | HAB-001 | The habitat model shall represent a simplified lunar habitat (cylindrical, dome, or modular). | | HAB-002 | The model shall include at least four holes of different diameters (1 mm, 5 mm, 10 mm, 20 mm) to simulate micrometeorite impacts. | | HAB-003 | The surface material shall be compatible with the rover’s adhesion mechanism. | | HAB-004 | The model shall be dimensioned for full rover traversal in a classroom/lab setting. | | HAB-005 | For Software/AI track, a virtual 3D habitat model may be designed and used. |

### Requirements Verification Matrix

Requirement ID	Requirement Summary	Verification Method	Notes/Acceptance Criteria
SYS-001	105% surface coverage	Test/Demonstration	Full traversal observed
SW-003	AI detects new impacts	Test/Analysis	Correctly flags simulated damage
HW-002	Modular sensor bay	Inspection/Test	Sensors swapped in/out successfully
ME-003	Traverse vertical surfaces	Demonstration	Rover climbs sides/roof
HAB-002	Four impact holes	Inspection	All sizes present and
...	...	...	detectable ...

Export as CSV

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## Project Tracks Summary (D&P vs. Software/AI)

Track	Focus	Required Deliverables
D&P	Physical rover, habitat model, sensor integration, mechanical and electronics design	Physical prototype, engineering notebook, test results, demonstration video
Software/AI	Remote control, AI/ML for damage detection, VR/GUI, data management, virtual habitat (optional)	Software code, documentation, AI models, virtual demo, presentation

Export as CSV

**Teams may pursue one or both tracks, collaborating as needed.**

## Recommended Deliverables for Students

- Engineering notebook (design process, iterations)
- Requirements document (adapted from this baseline)
- Design drawings or CAD models (rover, habitat)
- Software documentation and code repository
- Test results log (with photos/videos)
- Final presentation (PowerPoint or similar)
- Demonstration video (physical or virtual)



## Section D — Habitat Model Requirements (HAB-xxx)

## Section E — E File Layout for Data Streaming

Here is the **extracted file specification** based on the updated **Lunar Base Micrometeorite Inspection Rover** requirements document.

## File Specification: Robot ↔ Management System Data Exchange

**Current Time:** Thursday, May 21, 2026, 05:16 UTC

### File Format

- **Format:** JSON (preferred for readability) or Protobuf (for high efficiency).
- **Structure:** Hierarchical, with distinct sections for metadata, sensor data, telemetry, and inspection results.
- **Timestamps:** All data packets include timestamps in **ISO 8601 format** for synchronization.

# File Layout Specification

## 1. Header Information

Field Name	Description	Type	Example
	Unique identifier for the rover		
<code>robot_id</code>	Unique identifier for the current inspection session	String	"SESSION-20260521-001"
<code>session_id</code>	String		"RVR-001"
	Timestamp of the transmitted data (UTC)	ISO 8601 String	16:00Z "2026-05-21T05:16:00Z"
<code>timestamp</code>	longitude of the lunar base center	Object {	"longitude": -158.2 }
<code>base_location</code>	Latitude and	"latitude": -89.9,	

### 3

## 2. Inspection Zone Information

Field Name  
Description Type Example

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inspected Enum (String)

zone\_id Identifier for the  
current inspection zone  
String "HABITAT" or "LANDING\_PAD"

## 3. Sensor Data

"Habitat", "Landing Pad", "Solar Array"

zone\_type Type of zone being

Field Name	Description	Type	Example
<code>sensor_type</code>	Type of sensor transmitting	Enum (String)	data (e.g., "LiDAR")
<code>sensor_id</code>	Unique identifier for the sensor	String	"LIDAR-01"
<code>raw_data</code>	Raw data captured by the sensor (e.g., image, point cloud)	Base64 String	
<code>resolution</code>			
<code>frame_rate</code>			
<code>data_format</code>			

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PCD)

Float 30.0

`data_size`

Size of the raw data in bytes

`sensor_position`

String "PCD"

Resolution of the sensor data (if applicable)

Position of the sensor on the rover (e.g., front, top)  
String "1920x1080"

Integer 204800 String

Frame rate for video or image capture (if applicable)

"Front"

Format of the raw data (e.g., PNG, JPEG,

## 4. Rover Telemetry

Y, Z in meters relative to base center)  
Object { "x": 500.0, "y": 300.0, "z": 0.0 }

**Field Name**

**Description Type Example**

position Current position of the rover (X,

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<code>orientation</code>	Orientation of the rover (pitch, yaw, roll in degrees)	<code>10.5, "yaw": 45.2, "roll": 2.3 }</code>
<code>velocity</code>	Current level	
<code>battery_</code>	Remaining battery percentage	<code>Float 85.3</code>
<code>adhesion</code>	<code>_status</code> Status of the adhesion system (e.g., suction, magnetic)	<code>Enum (String) "Active"</code>

## 6

<code>path_cov</code>	<code>erage</code> Percentage of the inspection area covered (%)	<code>Float 56.5</code>
-----------------------	--	-------------------------

## 5. Inspection Results

Field Name	Description	Type	Example
damage_detected	Boolean flag indicating whether damage was detected	Boolean	true
damage_location	Position of detected damage (X, Y, Z in meters relative to base center)	Object	{ "x": 520.0, "y": 310.0, "z": 0.0 }
damage_size	Size of the damage (length, detected damage (e.g., pit, fissure)	Enum (String)	"Pit"
damage_type	Type of	level for damage detection (%)	Float 92.1
confidence_level	AI confidence		
structure_id	Identifier for the structure		being inspected (e.g., habitat, landing pad)

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Description Type Example

6. Data Integrity and Logs  
String "HABITAT-001"

Field Name

String "PKT-20260521-001"

packet\_id Unique identifier for the data packet

String "5f4dcc3b5aa765d61d8327deb882cf99"

checksum Checksum for validating data integrity

for the data packet Enum (String)  
(INFO, ERROR, "INFO"  
WARNING)

log\_level Log level

error\_code Error code if applicable Integer 0

7. Commands Received by the Rover

8

Field Name Description Type Example command\_id Unique identifier for the command

String "CMD-20260521-001"

command\_type Type of command issued (e.g., MOVE, SCAN, STOP) Enum (String) "SCAN"  
 command  
 Object { "path": "ZIGZAG", "speed": 0.5 }

parameters Parameters associated with the COMPLETED Enum (String) "COMPLETED"

execution\_status Status of the command execution (PENDING, IN\_PROGRESS, 8. Retransmission Capability)

To enable retransmission of specific time periods of data, the following fields are required:

Retransmission Request Fields

Field Name Description Type Example

# 1 NASA HUNCH Project Requirements

retransmission request  
String "REQ-20260521-00 1"

request\_id Unique identifier for the

## 9

retransmission request (HIGH,  
MEDIUM, LOW)

start\_time Start timestamp of  
the requested data period

Enum  
(String)  
"2026-05-21T05:00: 00Z"

### Retransmitted Data Fields

end\_time End timestamp of the  
requested data period

ISO 8601 String  
"2026-05-21T05:10: 00Z"

data\_type Type of data  
requested (e.g., ALL,  
SENSOR, TELEMETRY)

ISO 8601 String  
"SENSOR"

Enum  
(String)  
"HIGH"

priority Priority of the

The retransmitted data will follow the same structure as the **real-time data fields**, with an additional field indicating retransmission status:

Field Name Description Type Example

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	<code>session_id</code>	String "RT-20260521-001"
<code>retransmis</code>	Unique identifier for the retransmitted data	

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	<code>timestamp</code>	packet	"2026-05-21T05:06:30Z"
<code>original_t</code>	Timestamp of the original data	ISO 8601 String	

### Example JSON Structure (Real-Time Packet)

```
{  
  
  "robot_id": "RVR-001",  
  
  "session_id": "SESSION-20260521-001",  
  
  "timestamp": "2026-05-21T05:16:00Z",  
  
  "base_location": { "latitude": -89.9, "longitude": -158.2 },  
  
  "inspection_zone": { "zone_id": "HABITAT", "zone_type": "Habitat" },  
  
  "sensor_data": {
```

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"sensor\_type": "LiDAR",

"sensor\_id": "LIDAR-01",

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## 1 NASA HUNCH Project Requirements

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This file specification ensures robust, real-time data exchange between the **Lunar Base Micrometeorite Inspection Rover** and its management system, supporting both live and retransmitted data for enhanced reliability.

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## Appendix — Technical Reference Notes for Students

### Locomotion Mechanism Options

- **Magnetic adhesion:** Simple, robust, but only for ferromagnetic surfaces.
- **Vacuum suction:** Effective for smooth/curved surfaces; needs power and sealing.
- **Tracked/hybrid systems:** Best for variable surfaces; combine with adhesion for vertical traversal.

### Sensor Options

- **RGB camera:** High-res ( $\geq 1080p$ ), e.g., Raspberry Pi Camera, Intel RealSense.
- **LiDAR/ToF:** 3D mapping, e.g., Garmin LIDAR-Lite V3, Intel RealSense L515.
- **Thermal IR:** Detects heat anomalies, e.g., FLIR Lepton.
- **Depth camera:** Real-time 3D, e.g., Intel RealSense D435.

### Micrometeorite Impact Characteristics

- **Pit diameter:** 0.1 mm to several mm; design detection for  $\geq 0.1$  mm.
- **Visual features:** Central pit, radial cracks, glassy lining.

### Communication Options

- **Wi-Fi:** Real-time video/data, easy integration.
- **ROS:** Middleware for sensor integration and logging.

## 1 NASA HUNCH Project Requirements

- **Bluetooth:** For short-range, low-bandwidth telemetry.

### AI/ML Tools for Students

- **TensorFlow, PyTorch:** For training AI models.
- **OpenCV, YOLO:** For image processing and object detection.

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#### **Summary:**

This requirements document provides a clear, structured foundation for student teams to design, build, and document a lunar habitat inspection rover for the NASA HUNCH program, with logical functions and requirements split by subsystem and aligned with professional engineering standards.

# Enhanced Requirements Document & Professional Presentation

## NASA-Inspired Lunar/Martian Habitat Inspection Project

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### Key Findings & Deliverables

- **Comprehensive requirements document:** Formal, numbered, and fully referenced, covering both Software/AI & VR and Design & Prototyping (D&P) tracks.
  - **Professional slide deck:** 17 slides with technical depth, presenter notes, and authoritative NASA/ESA data.
  - **Incorporates real micrometeorite flux, Artemis/Mars habitat context, robotic/AI inspection analogues, and structural health monitoring standards.**
-

# 1. Enhanced Requirements Document

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## NASA Lunar/Martian Habitat Inspection Project

**Version 1.0**

**Date:** June 4, 2026

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### 1. Version History

Version	Date	Author	Description
1.0	2026-06-04	Project Team	Initial requirements document

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### 2. Definitions & Acronyms

Term/Acronym	Definition
EVA	Extra-Vehicular Activity (spacewalk)
ISRU	In-Situ Resource Utilization
MMOD	Micrometeoroid and Orbital Debris
SHM	Structural Health Monitoring
D&P	Design & Prototyping
VR	Virtual Reality
AI	Artificial Intelligence
NASA	National Aeronautics and Space Administration
ESA	European Space Agency

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## 3. Executive Summary & Project Vision

NASA's Artemis and Moon-to-Mars programs are pioneering permanent human habitats on the Moon and Mars. A critical challenge is the ongoing threat of micrometeoroid impacts and space weather, which can compromise habitat integrity and astronaut safety. This project aims to develop a dual-track solution:

- **(1) Safety Mode:** Real-time, autonomous inspection and alarm systems to ensure astronaut safety.
- **(2) Research Mode:** Longitudinal, data-driven analysis of habitat surface degradation for scientific study and material improvement.

The solution leverages robotic inspection (rover-based), advanced AI/computer vision, and VR teleoperation, drawing on NASA/ESA analogues and standards.

---

## 4. Background & Problem Statement

### 4.1 NASA Artemis & Moon-to-Mars Habitat Programs

- **Artemis Base Camp:** Fixed lunar South Pole habitat for 4 astronauts, up to 1-month stays, with robust pressure vessels and micrometeoroid shielding .
- **Lunar Gateway:** Modular lunar-orbiting station supporting surface missions and Mars transit .
- **Mars Surface Habitats:** Scalable, pressurized modules with radiation shielding and ISRU integration .

### 4.2 Micrometeoroid & Space Weather Hazards

- **Lunar Micrometeoroid Flux:** ~10 impacts/m<sup>2</sup>/s (particles >10<sup>-18</sup> g), avg. velocity 20 km/s; peak flux at ~200 μm diameter .
- **Impact Effects:** Microcraters, melt zones, deformation, potential penetration or catastrophic failure .
- **Material Strength:** Regolith-based concrete (48 MPa) vs. commercial (27 MPa); hypervelocity impact tests at 7 km/s .

## 1 NASA HUNCH Project Requirements

- **Mars:** Lower micrometeoroid flux due to thin atmosphere, but larger particles still pose risk .
- **Space Weather:** Solar flares and radiation cause long-term material degradation .

### 4.3 Inspection Challenges

- **Manual EVA Limitations:** Hazardous, time-consuming, incomplete coverage, no longitudinal baseline.
  - **Need for Autonomous, Robotic, and AI-Driven Inspection:** Inspired by Perseverance, VIPER, Astrobee, and ESA METERON projects .
- 

## 5. Project Scope

### 5.1 Tracks

- **Software/AI & VR Track:**
    - Remote VR rover control
    - AI/computer vision for surface mapping and anomaly detection
    - Longitudinal/time-series analysis
    - Digital habitat model design
  - **Design & Prototyping (D&P) Track:**
    - Physical rover design for habitat traversal
    - Sensor/optics suite for damage detection
    - Physical habitat model with pre-defined damage sites
- 

## 6. Functional Requirements

### 6.1 Software/AI & VR Track

1. **Remote Rover VR Control**
  - VR interface for teleoperation, inspired by ESA METERON .
2. **AI/Computer Vision Surface Mapping**

## 1 NASA HUNCH Project Requirements

- Semantic segmentation and anomaly detection (NASA MMOD deep learning analogues) .
  - Highlight new features (e.g., micrometeoroid hits).
3. **Impact Severity Assessment**
    - Quantify hole size, depth, and decompression risk.
  4. **Longitudinal/Time-Series Analysis**
    - Archive and analyze surface data over time.
  5. **Digital Habitat Model Design**
    - Students must design a digital model of the habitat for simulation and mapping.

## 6.2 Design & Prototyping (D&P) Track

1. **Physical Rover Design**
    - Capable of traversing sides and roof in lunar/Martian gravity analogue.
  2. **Sensor/Optics Suite**
    - Detect holes from sub-mm to cm scale (stereo cameras, structured light, LIDAR analogues).
  3. **Physical Habitat Model**
    - Includes pre-defined damage sites of varying sizes and materials.
  4. **Data Integration**
    - Real-time data transmission to analysis system.
- 

## 7. Non-Functional Requirements

- **Real-Time Performance:**
  - Alarm/event detection latency <30 seconds (Safety Mode).
- **Reliability & Safety:**
  - Compliance with ECSS-E-ST-10-03C and NASA SHM guidelines.
- **Data Storage & Security:**
  - Secure, redundant archiving for longitudinal studies.
- **System Robustness:**

## 1 NASA HUNCH Project Requirements

- Fault-tolerant operation in simulated lunar/Martian environments.
- 

## 8. System Architecture Overview

- **Sensor Networks:**
    - Analogous to NASA SMART Layer (piezoelectric/fiber optic sensors) for real-time crack, strain, and impact detection.
  - **AI/Computer Vision Pipeline:**
    - Deep learning models for anomaly detection, semantic segmentation, and severity assessment.
  - **VR/Teleoperation Layer:**
    - Real-time control and feedback, haptic integration optional.
- 

## 9. Operational Modes

- **Safety Mode:**
    - Real-time alarm, preventative maintenance scheduling, astronaut evacuation protocol integration.
  - **Research Mode:**
    - Longitudinal study of virgin construction, data archiving, material degradation analysis.
- 

## 10. Acceptance Criteria & Success Metrics

Requirement	Metric/Threshold
Damage Detection Accuracy	≥95% for holes ≥1 mm
Alarm Latency (Safety Mode)	<30 seconds from impact detection

## 1 NASA HUNCH Project Requirements

Longitudinal Data Completeness	≥90% surface coverage per inspection
Rover Traversal Reliability	≥95% successful traversal attempts
AI Severity Assessment Accuracy	±10% of ground truth (hole size/depth)

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## 11. Student Deliverables

### Software/AI & VR Track

- VR rover control interface
- AI/computer vision pipeline (code + documentation)
- Digital habitat model
- Longitudinal analysis report
- Demo video and technical presentation

### D&P Track

- Physical rover prototype
  - Sensor/optics integration
  - Physical habitat model with simulated damage
  - Test results and analysis report
  - Demo video and technical presentation
- 

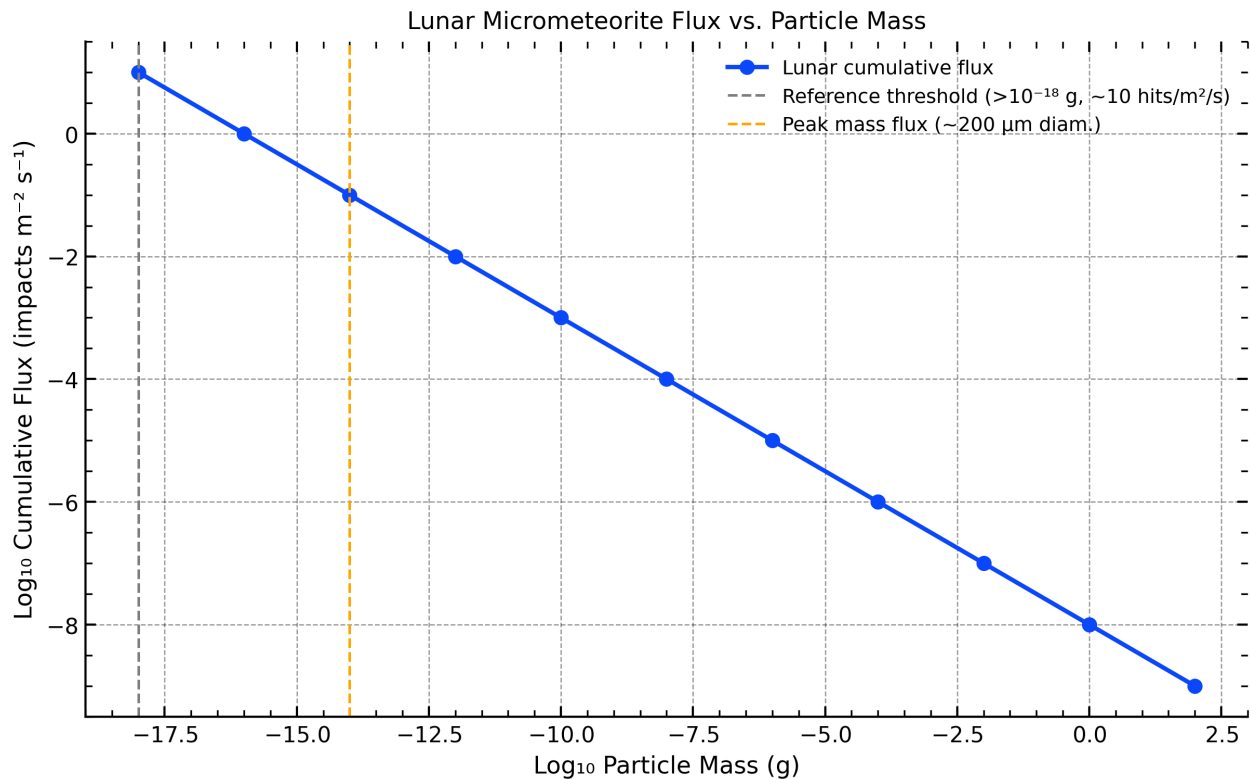
## 12. References

1. NASA Artemis Base Camp Concept
2. NASA Gateway Program
3. NASA Technical Reports on Lunar/Mars Habitats
4. Micrometeoroid Flux Data
5. Hypervelocity Impact Studies
6. NASA Perseverance, VIPER, Astrobee, ESA METERON
7. NASA SMART Layer, SHM Standards



## Visuals & Figures

### Example: Micrometeoroid Impact Frequency



Estimated micrometeoroid impact frequency on lunar surface.

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## 2. Professional Presentation Slide Deck

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### Slide 1: Title Slide

**NASA-Inspired Lunar/Martian Habitat Inspection Project**  
*Autonomous Robotic & AI-Driven Structural Health Monitoring*  
June 4, 2026

**Presenter Notes:**

Welcome to our presentation on the NASA-inspired Lunar and Martian Habitat Inspection Project. Today, we'll explore how advanced robotics, AI, and VR can safeguard future space habitats from micrometeoroid and space weather threats.

## Slide 2: The Challenge: Life on the Moon and Mars

- NASA Artemis Base Camp: 4-astronaut lunar South Pole habitat
- Lunar Gateway: Modular orbital station
- Mars: Scalable, pressurized modules with radiation shielding
- Long-duration missions require robust, maintainable habitats

### Presenter Notes:

NASA's Artemis and Moon-to-Mars programs are establishing permanent human presence beyond Earth. Habitats must withstand harsh environments and support long-term missions, making structural integrity and maintenance critical.

---

## Slide 3: The Micrometeorite Threat

- Lunar flux: ~10 impacts/m<sup>2</sup>/s (>10<sup>-18</sup> g), avg. 20 km/s velocity
- Peak flux: ~200 μm diameter particles
- Larger meteoroids: rare but can excavate meter-scale craters
- Impact effects: microcraters, deformation, potential decompression

### Presenter Notes:

Without an atmosphere, the Moon is bombarded by micrometeoroids at high velocities. Even tiny particles can cause significant damage, while larger impacts pose catastrophic risks to habitat safety.

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## Slide 4: Space Weather Hazards

- Solar flares: intense radiation bursts
- Long-term material degradation from cumulative exposure
- Mars: thin atmosphere, lower micrometeoroid flux but still hazardous
- Need for continuous monitoring of surface and material health

### Presenter Notes:

Space weather, including solar flares and cosmic radiation, accelerates material degradation. Both lunar and Martian habitats must be monitored for cumulative damage to ensure long-term viability.

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## Slide 5: Problem Statement

- Manual EVA inspections: hazardous, incomplete, time-consuming
- No longitudinal baseline for surface degradation
- Need for autonomous, robotic, and AI-driven inspection
- Critical for astronaut safety and scientific research

### Presenter Notes:

Traditional manual inspections are risky and inefficient. Autonomous systems can provide comprehensive, repeatable, and safe monitoring, enabling both immediate safety and long-term research.

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## Slide 6: Project Overview

- Two-track solution:
  - Software/AI & VR Track
  - Design & Prototyping (D&P) Track
- Two operational modes:
  - Safety Mode (real-time alarms)
  - Research Mode (longitudinal analysis)
- Inspired by NASA/ESA analogues

### Presenter Notes:

Our project is structured into two tracks and two operational modes, ensuring both immediate safety and scientific value. We draw on proven NASA and ESA technologies for inspiration.

---

## Slide 7: Safety Mode Deep Dive

- Real-time alarm system for impact events
- <30 sec detection latency requirement
- Preventative maintenance scheduling
- Astronaut evacuation protocol integration

### Presenter Notes:

Safety Mode prioritizes astronaut protection. The system must detect and alert for dangerous impacts within 30 seconds, enabling rapid response and maintenance planning.

---

## Slide 8: Research Mode Deep Dive

- Longitudinal/time-series analysis of surface degradation
- Virgin construction baseline methodology
- Data archiving for scientific study
- Supports material improvement and mission planning

### Presenter Notes:

Research Mode enables in-depth study of how habitats degrade over time, providing valuable data for future habitat design and mission planning.

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## Slide 9: Software/AI & VR Track Overview

- VR interface for remote rover control (ESA METERON-inspired)
- AI/computer vision for surface mapping and anomaly detection
- Digital habitat model design requirement
- Longitudinal data analysis tools

### Presenter Notes:

The Software/AI & VR Track combines immersive teleoperation with advanced AI for automated inspection, leveraging digital models for simulation and analysis.

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## Slide 10: AI/Computer Vision Pipeline

- Semantic segmentation and anomaly detection
- NASA MMOD deep learning analogues
- Highlight new features (e.g., micrometeoroid hits)
- Quantify hole size, depth, and risk

### Presenter Notes:

Our AI pipeline uses state-of-the-art computer vision to identify and assess surface anomalies, drawing on NASA's deep learning models for MMOD impact detection.

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### Slide 11: Severity Assessment & Decompression Risk

#### Analysis

- Measure hole size and depth
- Model pressure differential and decompression risk
- Prioritize repairs based on severity
- Integrate with alarm and maintenance systems

#### Presenter Notes:

Beyond detection, the system must assess the severity of each impact, modeling potential decompression events and guiding maintenance priorities.

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### Slide 12: D&P Track Overview

- Physical rover design for habitat traversal
- Locomotion for curved and vertical surfaces
- Sensor/optics suite: stereo cameras, structured light, LIDAR analogues
- Real-time data transmission

#### Presenter Notes:

The D&P Track focuses on building a physical rover capable of navigating complex habitat surfaces and detecting damage with high precision.

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### Slide 13: Physical Habitat Model Requirements

- Includes pre-defined damage sites (sub-mm to cm scale)
- Simulated lunar/Martian materials (e.g., regolith concrete)
- Supports rover traversal and sensor testing
- Enables controlled, repeatable experiments

#### Presenter Notes:

A physical habitat model with known damage sites allows for rigorous testing and validation of both the rover and AI systems.

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## Slide 14: Real-World NASA/ESA Analogues

- Perseverance: HazCams, Navcams, robotic arm
- VIPER: stereo cameras, 10 cm feature detection
- Astrobee & Robonaut 2 (ISS): autonomous caretaking
- ESA METERON: VR + haptic teleoperation
- NASA SMART Layer: embedded SHM sensors

### Presenter Notes:

Our approach is grounded in real NASA and ESA technologies, ensuring feasibility and alignment with current best practices in space robotics and monitoring.

---

## Slide 15: Student Deliverables & Assessment Criteria

- **Software/AI & VR Track:**
  - VR rover control interface
  - AI/computer vision pipeline
  - Digital habitat model
  - Longitudinal analysis report
- **D&P Track:**
  - Physical rover prototype
  - Sensor/optics integration
  - Physical habitat model
  - Test results and analysis report
- **Assessment:** Detection accuracy, alarm latency, coverage, reliability

### Presenter Notes:

Clear deliverables and assessment criteria ensure that student teams can demonstrate both technical achievement and scientific rigor.

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## Slide 16: Impact & Future Vision

- Pathway to real NASA/ESA deployment
- Enhances astronaut safety and mission success
- Advances AI, robotics, and SHM for space habitats
- Foundation for future lunar/Martian infrastructure

# 1 NASA HUNCH Project Requirements

## Presenter Notes:

This project not only prepares students for real-world space engineering but also contributes to the future of human space exploration and settlement.

## Slide 17: Q&A / Conclusion

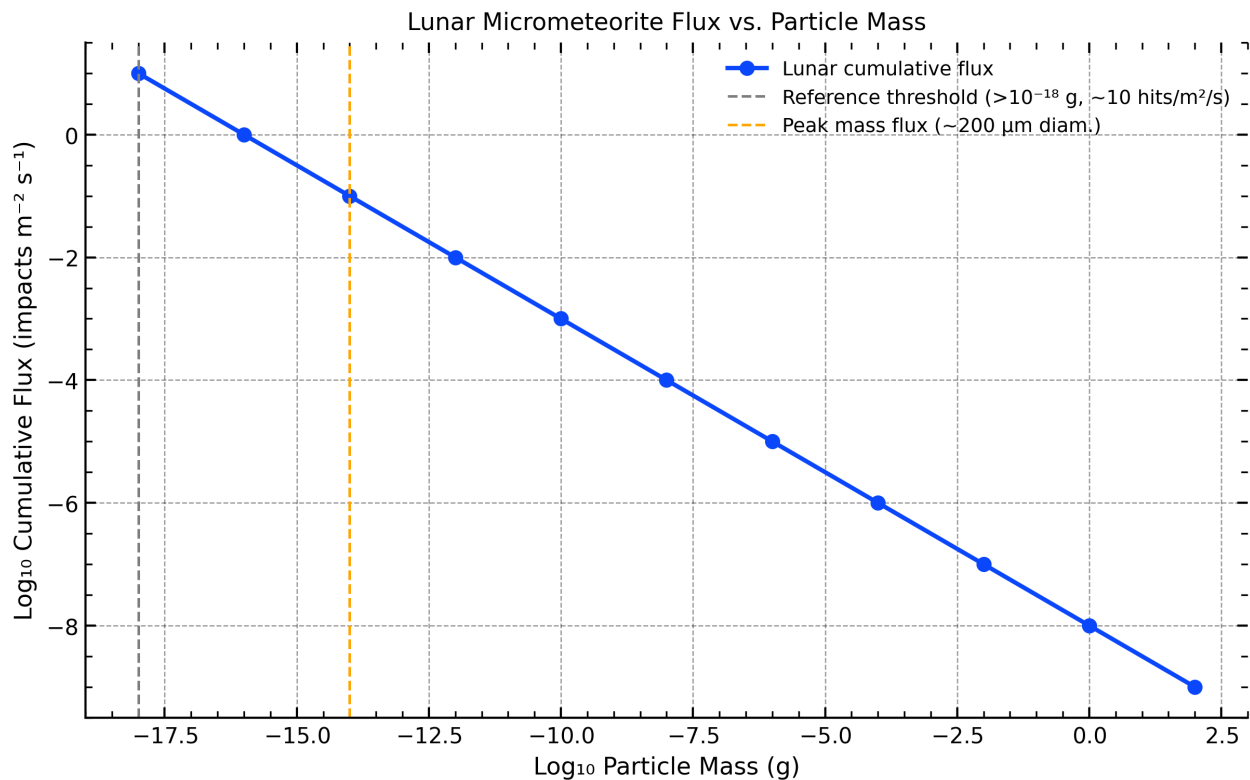
- Questions?
- Thank you for your attention!

## Presenter Notes:

Thank you for joining us. We welcome your questions and look forward to discussing how this project can shape the future of space habitat safety and research.

## Visuals & Figures (Sample)

### Micrometeoroid Impact Frequency



Estimated micrometeoroid impact frequency on lunar surface.

## 1 NASA HUNCH Project Requirements

### **Key Takeaway:**

This dual-track, standards-driven project leverages the latest NASA/ESA research and technology to address the scientific advancement.

# Lunar Base Micrometeorite Inspection Robots

## A NASA HUNCH Engineering Challenge

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### Picture this.

You're living on the Moon. There's no atmosphere to burn up incoming space debris, so when a micrometeorite shower hits, the particles slam straight into your habitat at speeds around 20 kilometers per second. A single impact you can't see could mean a crack, a slow leak, or a dangerous loss of pressure. How do you find the damage before it finds you?

That's the problem **you** get to solve.

**This just happened.** In April 2026, NASA's Artemis II crew — the first astronauts to fly around the Moon in over fifty years — looked down during a solar eclipse and watched **at least five micrometeorites slam into the lunar surface**, each one a flash of light from a tiny rock hitting at cosmic speed. NASA scientists reportedly cheered out loud; they hadn't expected the crew to see so many. Humans have now witnessed, with their own eyes, the very threat your robots are being built to detect.

### The Mission

Your challenge is to design, build, and program a robotic system that can inspect a lunar base for micrometeorite damage — autonomously or by remote control. Your robot has to crawl across the curved walls and roof of a habitat, scan the surface, and spot the difference between a normal feature and a brand-new impact. Then it has to answer the questions that actually matter: *How big is the hole? How deep? Could it cause the habitat to lose pressure?*

It's the kind of work real space agencies are racing to figure out right now — and it's the kind of work that could one day keep astronauts alive on the Moon and Mars.

### Choose Your Track

This is a project with room for every kind of builder and thinker. Teams can take on one track or both:

## 1 NASA HUNCH Project Requirements

**Design & Prototyping (D&P)** Build a real rover that can climb vertical and curved surfaces using suction, magnets, or tracks. Outfit it with cameras and sensors, then design a habitat model with impact "holes" of different sizes for your robot to discover.

**Software / AI & VR** Develop the brains. Train computer-vision models to detect pits, cracks, and fissures. Build a VR or graphical interface to pilot the rover, map what it sees, and flag damage in real time. Estimate impact severity and decompression risk — and design your own digital habitat to test it all.

## What You'll Learn

This isn't a worksheet. It's a genuine engineering project that mirrors how NASA and ESA actually work — drawing inspiration from real missions like *Perseverance*, *VIPER*, *Astrobee*, and ESA's METERON teleoperation experiments.

Along the way, students get hands-on with:

- Robotics, mechanical design, and surface adhesion
- Sensors like RGB cameras, LiDAR, and infrared
- Artificial intelligence and computer vision
- Real-time data streaming and management systems
- Virtual reality and remote operation
- The full engineering process — from requirements to a working demo

## Why It Matters

NASA's Artemis and Moon-to-Mars programs are building toward a permanent human presence beyond Earth. Keeping those habitats safe from impacts and space weather is one of the great unsolved challenges of long-duration spaceflight. The skills students build here — robotics, AI, systems thinking — are exactly the skills that will carry the next generation of explorers forward.

**Ready to protect a Moon base? Let's get building.**

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*A project of the NASA HUNCH program — engaging students in authentic engineering challenges for human spaceflight.*

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