Fall Test Plan

Lunar ROADSTER

Team I

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September 16, 2025

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1 Introduction

This document details the test plans for the Lunar ROADSTER system throughout the fall semester, aimed at validating compliance with functional requirements. The testing framework follows a structured, incremental approach, beginning with fundamental assessments and progressively advancing in complexity as subsystem development progresses. Additionally, this document outlines a timeline for achieving each key functionality, ensuring systematic evaluation and refinement. Test results will be reviewed during scheduled progress reviews. By the fall validation experiment, the system will demonstrate a minimum viable product, showcasing autonomous crater grading in the Moon Yard. A milestone schedule is also provided to track progress toward key objectives.

2 Logistics

The equipment and test sites required for Lunar ROADSTER are listed below:

2.1 Equipment

1. **Lunar ROADSTER Rover:** The CraterGrader Workstation was modified to the project's requirements. The improvements include a front-mounted dozer, an improved sensor stack, and wheels suited to the Lunar Terrain.
2. **Leica TS16 Total Station:** An external sensor which will be used for localization of the robot's position.
3. **VectorNav VN-100 IMU:** An onboard Inertial Measurement Unit which will be used for localization of the robot's orientation.
4. **Zed 2i Depth Camera:** A stereo depth camera will be used to validate the environment manipulation being performed.
5. **Wheel Prototypes:** A series of 3D-printed wheel designs will be tested until the optimal design is decided.
6. **Dozer Assembly:** An actuated assembly that will be mounted to the front of the rover and used to manipulate the Lunar environment.
7. **NVIDIA Jetson Orin:** The onboard central compute for the robot.
8. **Arduino Due:** The onboard microcontroller interfaces the motor controllers and fans.
9. **Operations Terminal:** The main control centre of the Lunar ROADSTER mission. This is used to tele-operate and monitor the rover during all tests.
10. **Jetson TX2 Relay:** As a part of the external infrastructure, the Jetson TX2 board will connect to the Leica TS16 Total Station and obtain the measured data.
11. **TP-Link Router:** A personal LAN network will be created to connect the Jetson Orin on the rover, the Jetson TX2, and the Operations Terminal.

2.2 Testing Sites

1. **Planetary Robotics Lab Moon Yard:** The sandbox is the primary test site for most tests and the Fall Validation Demo.

2. **CIC LL67 Lab:** Our primary working area and the site for all small-scale unit tests.

3. **MRSD Project Lab:** Site for presentations and for testing any MRSD project course-related assignments.

3 Schedule

Date	Event	Capability Milestones	Tests	Requirements
09/10	PR7	• Hardware and software refinement	T01	M.F.2 M.F.3 M.F.4 M.F.5 M.F.7 M.F.9
09/24	PR8	• Validation stack setup • Navigation stack setup • Obtain Gradable Craters Location	T03	M.F.6
10/08	PR9	• Perception stack detects craters accurately and provides waypoints • Validate grading • Rover navigates to goal location accurately	T02 T04 T05 T06 T07	M.F.1 M.F.2 M.F.3 M.F.4 M.F.6 M.F.8 M.F.9
10/29	PR10	• SkyCam-based localization for improved global positioning • Ensure compute usage is below orin limits • Tool Planner stack completed and integrated with necessary subsystems	T08 T09	M.F.3 M.F.7
11/12	PR11	• Full system integration • Conduct quality assurance testing	T02 T06 T09 T10 T11	M.F.1 M.F.6 M.F.2 M.F.7 M.F.3 M.F.8 M.F.4 M.F.9 M.F.5
11/17 & 11/24	PR12 (FVD and Encore)	• Final system demonstration involving autonomous grading of multiple craters	T02 T06 T07 T12	M.F.1 M.F.6 M.F.2 M.F.7 M.F.3 M.F.8 M.F.4 M.F.9 M.F.5

4 Tests

4.1 T01: Rerun Spring Validation Demonstration

Rerun Spring Validation Demonstration	
Objective	Test and validate that the ROADSTER is in working condition by re-running SVD
Elements	Full ROADSTER system
Location	Planetary Robotics Lab MoonYard
Equipment	Lunar ROADSTER rover, Dozer assembly, ZED 2i Depth Camera, Leica TS16 Total station, VectorNav IMU, Operations terminal laptop, Communication setup
Personnel	Bhaswanth, Ankit, Deepam, Boxiang, Simson
Procedure	
1. Attach and connect all the components and subsystems of the rover.	
2. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router, and the Jetson TX2 relay.	
3. Prepare the Moon Yard with a suitable crater and dune.	
4. Place the rover in the Moon Yard and calibrate its localization.	
5. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop.	
6. Switch the rover to autonomous mode and run the start-up procedure.	
7. Observe the rover autonomous grade the crater and level the dune. If anything unexpected occurs, press the emergency stop button.	
8. Record system rosbags to use for analysis and GUI development.	
Verification Criteria	
1. The rover will climb gradients up to 15° and have a contact pressure of less than 1.5 kPa.	
2. The rover will fill craters of up to 0.5 meters in diameter and 0.1 meters in depth.	
3. The rover will localize itself and follow the planned path to a maximum deviation of 10%.	
4. The rover will operate autonomously and communicate the robot state and mission status to the user.	

4.2 T02: Global Path Planner Accuracy Test

Global Path Planner Accuracy Test	
Objective	Test that the global path planner can plan a path with $< 25\%$ cumulative deviation from the reference latitude
Elements	Navigation Subsystem
Location	Planetary Robotics Lab MoonYard
Equipment	FARO Laser Scanner, Jetson Orin, Operations Terminal
Personnel	Simson, Bhaswanth
Procedure	
1. Take a new map of the MoonYard using the FARO Laser Scanner	
2. Use the navigation pipeline to create a grid-based cost map	
3. Plan a path using the custom path planner with a circular reference (latitude), treating gradable craters as traversable and ungradable ones as obstacles.	
4. Use the RMSE metric to calculate and validate path planning.	
Verification Criteria	
1. Cumulative deviation RMSE between reference latitude and planned path is $< 25\%$	

4.3 T03: Filtering and Selection of Gradable Craters

Filtering and Selection of Gradable Craters	
Objective	Validating the methodology for selection of gradable craters
Elements	Navigation subsystem
Location	Planetary Robotics Lab MoonYard
Equipment	FARO Laser Scanner, Jetson Orin, Operations Terminal
Personnel	Simson, Bhaswanth
Procedure	
1. Prepare the MoonYard with multiple craters placed randomly with varied sizes.	
2. Use the FARO Laser Scanner to obtain a map of the MoonYard.	
3. Run the filtering and selection pipeline on the generated costmap.	
4. Physically measure each crater's diameter and depth to obtain ground truth.	
5. Compare ground truth with the pipeline's results	
Verification Criteria	
1. The pipeline should mark all craters $> 0.5m$ in diameter as ungradable.	
2. The pipeline should mark all craters $> 0.1m$ in depth as ungradable.	

4.4 T04: Navigation planner maximum deviation test

Navigation planner maximum deviation test	
Objective	Validate that the navigation planner ensures rover follows planned path with maximum deviation ≤ 10%.
Elements	Navigation subsystem, Localization subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Leica TS16 Total Station, Jetson Orin, Operations Terminal, Communication setup
Personnel	Simson, Bhaswanth
Procedure	
1. Initialize rover localization using Total Station and IMU.	
2. Generate a reference path in the Moon Yard using the navigation planner.	
3. Command rover to autonomously follow the planned path.	
4. Record rover's actual trajectory using localization logs.	
5. Compute deviation between planned path and executed trajectory.	
Verification Criteria	
1. Maximum path deviation ≤ 10%.	
2. Rover completes the planned trajectory without manual intervention.	

4.5 T05: Perception Stack Crater Geometry Extraction Test

Perception Stack Crater Geometry Extraction Test	
Objective	Check that the perception stack can accurately extract crater geometry parameters (depth, diameter, rim size, sand volume)
Elements	Perception subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	ZED 2i Depth Camera, Jetson Orin, Operations Terminal
Personnel	Deepam, Ankit, Boxiang
Procedure	
1. Prepare the Moon Yard with multiple craters of varying depth, diameter, and rim shapes.	
2. Use measuring tools like rulers and tapes to obtain ground truth dimensions of the craters' geometry (diameter, depth, etc.).	
3. Run the perception stack with the ZED 2i Depth Camera to autonomously detect and extract crater geometry parameters.	
4. Compare extracted values against measured ground truth to measure accuracy.	
Verification Criteria	
2. Perception stack successfully detects craters in the scene	
1. Perception stack successfully extracts geometry of the craters in scene	

4.6 T06: Repeatability Test of Local Navigation Controller

Repeatability Test of Local Navigation Controller	
Objective	Validate that the local navigation controller produces consistent results when executed multiple times under identical conditions.
Elements	Navigation subsystem, localization subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Operations terminal laptop, Communication setup (LAN router, TX2 relay), Leica TS16 Total Station, VectorNav IMU
Personnel	Bhaswanth, Simson
Procedure	
1. Power on rover and establish SSH connection to onboard compute.	
2. Initialize localization stack and verify position accuracy.	
3. Send identical goal points for the rover to reach via the local navigation controller.	
4. Repeat the same test at least 5 times under identical environmental conditions.	
5. Record trajectory logs, timing, and deviations.	
Verification Criteria	
1. The rover follows consistent local paths across repeated runs.	
2. Maximum trajectory deviation between runs is $\leq 10\%$	
3. Controller performance is deterministic and reliable.	

4.7 T07: Trail Grooming Slope Validation

Trail Grooming Slope Validation	
Objective	Verify rover's ability to autonomously groom a trail to ensure a maximum traversal slope of $5°$.
Elements	Dozer assembly, navigation subsystem, tool planner
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Dozer assembly, ZED 2i Depth Camera (for crater detection), Leica TS16 Total Station, VectorNav IMU, Operations terminal laptop, Communication setup
Personnel	Ankit, Deepam, Boxiang
Procedure	
1. Prepare a testbed trail in the Moon Yard with irregular slopes $> 5°$.	
2. Initialize rover's localization, navigation, and perception stacks.	
3. Command rover to traverse the circular trail autonomously while grooming it.	
4. As rover progresses, the ZED 2i camera evaluates trail slopes at the end of each grooming operation.	
5. If slope $\leq 5°$, then proceed to next section. If slope $> 5°$, then repeat the grooming process for that section until slope $\leq 5°$ is achieved.	
6. At the end of the trail, validate slope and crater filling results with the ZED 2i camera.	
Verification Criteria	
1. Groomed trail slope $\leq 5°$ at all tested sections, confirmed via the perception stack.	
2. Grooming is repeated automatically where slope criteria are not initially met.	
3. Rover completes the entire circular path autonomously without getting stuck at grooming just one crater.	

4.8 T08: SkyCam Localization Validation

SkyCam Localization Validation	
Objective	Validate whether SkyCam-based localization provides accuracy comparable to the Total Station.
Elements	Localization subsystem, navigation subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, Leica TS16 Total Station, Jetson TX2 Relay, LAN Router
Personnel	Boxiang
Procedure	
1. Power on the rover with the NVIDIA Jetson Orin.	
2. Set up the Total Station and track the prism mounted on the rover mast.	
3. Run the localization stack using the Total Station and IMU, localize the rover, and record its pose.	
4. Repeat the localization process using the SkyCam method and record the rover pose.	
5. Execute navigation tests with both localization methods.	
Verification Criteria	
1. The rover pose estimates from SkyCam and Total Station should closely match.	
2. SkyCam localization should demonstrate reduced latency compared to the external Total Station, resulting in smoother navigation performance.	

4.9 T09: CPU/GPU Usage of Autonomous Stack is Below Orin Compute Limits

CPU/GPU Usage of Autonomous Stack is Below Orin Compute Limits	
Objective	Validate that the computational load of the full autonomous stack does not exceed the processing capacity of the NVIDIA Jetson Orin.
Elements	Localization subsystem, navigation subsystem, validation subsystem, tool planner subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, NVIDIA Jetson Orin (onboard)
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Power on the rover with the NVIDIA Jetson Orin.	
2. Launch the complete autonomous stack.	
3. Use system monitoring tools (`htop`, or equivalent) to record CPU and GPU utilization continuously during operation.	
4. Conduct a task (e.g., waypoint following, grading) in the Moon Yard while monitoring usage.	
Verification Criteria	
1. Average CPU and GPU utilization remains below 80% during nominal operation.	
2. No subsystem causes prolonged spikes that exceed Orin compute limits and degrade real-time performance.	
3. Navigation and Validation tasks are executed smoothly without delays or dropped frames due to computational overload.	

4.10 T10: Maintenance, Reliability and Quality Assurance Test

Maintenance, Reliability and Quality Assurance Test	
Objective	Evaluate the maintainability, reliability, and overall quality assurance of the hardware and autonomous stack under real operational conditions.
Elements	Hardware Integrity and Software system
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, NVIDIA Jetson Orin (onboard), Spare parts for maintenance
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Perform a pre-operation inspection of rover hardware and connectors.	
2. Power on the rover and launch the full autonomous stack.	
3. Execute a set of operational tasks (e.g., waypoint navigation, grading, obstacle avoidance) in the Moon Yard.	
4. Monitor software logs, sensor health, and communication between subsystems throughout the tasks.	
5. Document any maintenance actions required, including software resets, recalibration, or hardware adjustments.	
Verification Criteria	
1. Rover completes all assigned tasks without critical failures or crashes.	
2. CPU/GPU usage remains within safe operating limits, ensuring no performance degradation.	
3. All subsystems function properly.	
4. Maintenance actions are minimal, indicating high reliability and ease of service.	

4.11 T11: Fall Validation Demo Preparation Test

Fall Validation Demo Preparation Test	
Objective	Conduct a full dress rehearsal of the Fall Validation Demonstration, verifying rover performance in navigation, grading, and validation tasks.
Elements	Navigation subsystem, localization subsystem, validation subsystem, tool planner subsystem, external environment
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, Leica TS16 Total Station, Jetson TX2 Relay, LAN Router
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Prepare the Moon Yard terrain with multiple representative crater and dune.	
2. Perform a FARO scan of the environment and preprocess the scan to generate a map used for identifying gradable crater poses and for navigation planning.	
3. Set up external infrastructure: place the Leica total station in the corner of the Moon Yard, configure the LAN router, and connect the Jetson TX2 relay.	
4. Position the rover in the Moon Yard and perform localization calibration.	
5. Switch the rover to autonomous mode and launch the full software stack.	
6. Observe the rover autonomously grade multiple craters and dunes along a circular path while performing validation. Monitor the job status through the GUI, and use the emergency stop button if any unexpected behavior occurs.	
Verification Criteria	
1. Plan a path with cumulative deviation of $\leq$ 25% from chosen latitude's length.	
2. Follow planned path to a maximum deviation of 10%.	
3. Have a contact pressure of less than 1.5 kPa.	
4. Avoid craters $\geq$ 0.5 meters.	
5. Fill craters of up to 0.5 meters in diameter and 0.1 meter in depth.	
6. Groom the trail to have a maximum traversal slope of 5°.	

4.12 T12: Fall Validation Demo Test

Fall Validation Demo Test	
Objective	Conduct the Fall Validation Demonstration, verifying rover performance in navigation, grading, and validation tasks.
Elements	Navigation subsystem, localization subsystem, validation subsystem, tool planner subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, Leica TS16 Total Station, Jetson TX2 Relay, LAN Router
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Prepare the Moon Yard terrain with multiple representative crater and dune.	
2. Perform a FARO scan of the environment and preprocess the scan to generate a map used for identifying gradable crater poses and for navigation planning.	
3. Set up the external infrastructure by positioning the Leica total station at the corner of the Moon Yard, configuring the LAN router, and connecting the Jetson TX2 relay.	
4. Position the rover in the Moon Yard and perform localization calibration.	
5. Switch the rover to autonomous mode and launch the full software stack.	
6. Observe the rover autonomously grade multiple craters and dunes along a circular path while performing validation. Monitor the job status through the GUI, and use the emergency stop button if any unexpected behavior occurs.	
Verification Criteria	
1. Plan a path with cumulative deviation of $\leq$ 25% from chosen latitude's length.	
2. Follow planned path to a maximum deviation of 10%.	
3. Have a contact pressure of less than 1.5 kPa.	
4. Avoid craters $\geq$ 0.5 meters.	
5. Fill craters of up to 0.5 meters in diameter and 0.1 meter in depth.	
6. Groom the trail to have a maximum traversal slope of 5°.	

5 Appendices

5.1 Mandatory Requirements

5.1.1 Mandatory Functional Requirements

Table 14: Mandatory Functional Requirements

Sr.No.	Mandatory Functional Requirement (Shall)
M.F.1	Perform **trail path planning**
M.F.2	Operate **autonomously**
M.F.3	**Localize** itself in a GPS denied environment
M.F.4	**Navigate** the planned path
M.F.5	Traverse **uneven terrain**
M.F.6	Choose craters to **groom and avoid**
M.F.7	**Grade** craters and **level dunes**
M.F.8	**Validate grading** and trail path
M.F.9	**Communicate** with the user

5.1.2 Mandatory Performance Requirements

Table 15: Mandatory Performance Requirements

Sr.No.	Performance Metrics (Will)
M.P.1	Plan a path with **cumulative deviation of** $\leq 25\%$ from chosen latitude's length
M.P.2	**Follow planned path** to a maximum deviation of **10%**
M.P.3	Have a **contact pressure of less than 1.5 kPa**
M.P.4	**Avoid craters** ≥ 0.5 **meters**
M.P.5	Fill craters of **up to 0.5 meters** in diameter and **0.1 meter** in depth
M.P.6	Groom the trail to have a **maximum traversal slope of** 5°

5.1.3 Mandatory Non-Functional Requirements

Table 16: Mandatory Non-Functional Requirements

Sr.No.	Parameter	Description
M.N.1	Weight	The rover must weigh **under 50 kg**
M.N.2	Cost	The cost for the project must **be under $5000**
M.N.3	Computing Capacity	The onboard computer should be able to **run all required tasks**

5.2 Desirable Requirements

5.2.1 Desirable Non-Functional Requirements

Table 17: Desirable Non-Functional Requirements

Sr.No.	Parameter	Description
D.N.1	Technological Extensibility	The system will be **well documented** and designed so that future teams can easily access and build on the work
D.N.2	Aesthetics	Requirement from sponsor, the rover must **look presentable and lunar-ready**
D.N.3	Modularity	To enable **tool interchangeability**, the tool assemblies must be modular and easy to assemble/disassemble
D.N.4	Repeatability	The system will **complete multiple missions without the need of maintenance**