# A CANADIAN LUNAR EXPLORATION LIGHT ROVER PROTOTYPE


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## ABSTRACT

In 2010, the Canadian Space Agency (CSA) commenced the Lunar Exploration Light Rover (LELR) project as part of its Exploration Surface Mobility program. The LELR project consists of building rovers, integrating them with tools and instruments, and executing representative mission deployments. The LELR is designed for mobility tasks related to science prospecting, in-situ resource utilization (ISRU), and future upgrades for crew transportation. The vehicle is based on a rugged, custom mobility platform built by Bombardier Recreational Products Centre for Advanced Technology. Onboard sensors provide feedback and situational awareness for tele-operation, autonomy, and onboard control (future upgrade). Modular onboard software is used to ensure future upgradeability, and offers such features as localization without external aids and visual teach and repeat software developed by the University of Toronto. Future work may involve adding onboard human control, further integration with payloads and deployments in coordination with the international space exploration community.


## 1 INTRODUCTION

In the context of returning systems to the surface of the Moon, there have been several recent developments in the area of Lunar mobility. The Chariot rover [1] is a large-class system designed to carry astronauts and perform regolith moving tasks such as bulldozing. The Eurobot Ground Prototype (EGP) rover [2] is a medium-class system designed to accomplish both science exploration and transport of a single standing astronaut. The Scarab rover [3] is a small-class rover designed to carry resource prospecting instruments and sensors. The goal of the Lunar Exploration Rover (LELR) program is to develop a mobility solution that can accomplish all of these tasks and thereby provide a flexible and versatile platform for development and testing including integration with exploration tools and instruments. This will then allow development and simulation of analogue mission scenarios. The LELR vehicle is a key part of the Canadian Space Agency (CSA) Exploration Surface Mobility program.

The remainder of this paper will discuss the mission scenarios used to define the LELR requirements, the LELR design, and the current program status and upcoming test plan.

*Figure 1: Artist's Concept of the Lunar Exploration Light Rover*

## 2 MISSION SCENARIOS

The LELR design was influenced by three key operational scenarios.

i. In the <u>Autonomous Science and Exploring</u> scenario the LELR uses a payload suite including a robotic manipulator, microscope, mini-corer and high resolution 3D vision sensor to map, analyze and sample sites of high scientific interest with the option of returning samples to the lander.
ii. In the <u>Tele-operated Resource Prospecting and Construction</u> scenario the LELR uses a payload suite including a drill, bulldozing blade, high energy fuel cell and ground penetrating radar to explore and characterize in-situ lunar resources in

extreme terrain such as craters under limited lunar time latency and bandwidth constraints.

iii. In the Crewed Exploration scenario the LELR carries two suited astronauts, a large suite of EVA tools and remote sensing payloads to transport and assist crewed operations on the lunar surface.

Figure 2 shows the various conceptual mission configurations envisioned for the LELR.

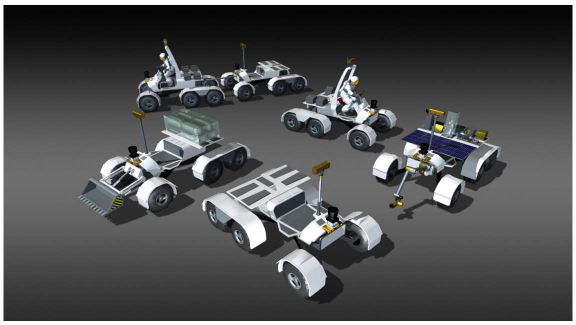

*Figure 2: Artist's Concept of the Lunar Exploration Light Rover's Various Mission Configurations*

# 3 DESIGN

Given the wide range of operational scenarios planned, the system design of the LELR involved a careful balancing of competing priorities and requirements. The autonomous science scenario required a sufficiently large reach envelope for the manipulator, clear viewing for remote sensing and highly accurate localization without external aids. The teleoperated prospecting scenario required centrally mounted drilling systems, high payload mass capability and compatibility with three second lunar latency. The crewed exploration scenario required astronaut accommodation, low vibration transmission and accessible tool storage. The fact that the vehicle needed to be designed and scarred for upgrade to human carrying capability had a fundamental impact on the design. The terrestrial vehicle expertise present on the team ensured that the vehicle was designed around the human and not that the human/machine interfaces were simply bolted on after the vehicle was designed. The large footwell and spacing between wheels have been implemented to ensure a safe and accessible vehicle for onboard operators. This is a critical philosophy required for human rated vehicle developments. Figure 3 shows a stylized view of the LELR without external payloads.

*Figure 3: Stylized View of the Lunar Exploration Light Rover Design*

## 3.1 Chassis and Locomotion

The design of the LELR chassis and locomotion involved a fusion of traditional planetary rover passive-dependent kinematic suspensions with terrestrial vehicle dynamic suspensions. The front wheels are independently sprung to absorb shock and vibration from hitting obstacles at high speed – a critical performance parameter for any human rated vehicle. This is a typical design from commercial all-terrain vehicles [4] (Figure 4). The rear wheel sets are attached via a passive bogie in a manner similar to the Canadian Space Agency's ExoMars-derived rover [5] (top image in Figure 5). The bogie pivots are then sprung on trailing arm suspensions. The bogie allows the vehicle to climb 30cm obstacles and level the body angle while the trailing arm absorbs vibration and keeps levels below 2.5g for onboard operators and sensitive payloads.

*Figure 4: Bombardier Recreational Products' Commander*

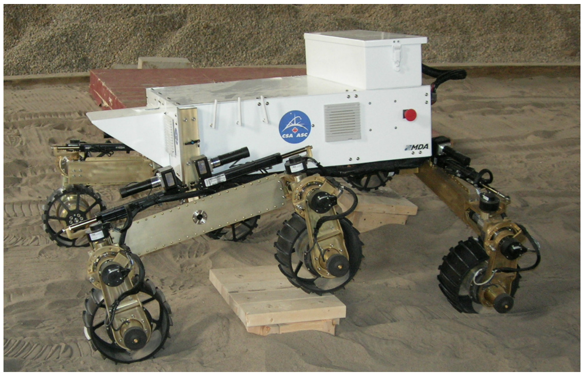

*Figure 5: Canada's ExoMars-derived rover*

## 3.2 Onboard Sensors

The LELR sensor suite provides situational awareness to both remote tele-operators and onboard autonomous controllers. A combination of 2-D and 3-D sensors results in up to 96% ground coverage in the area immediately surrounding the rover. This is illustrated in Figure 6 where the ground coverage of each of the onboard sensors is shown as a different colour. A sensor mast holds a lidar, stereo camera, high resolution camera, sun sensor, tilt sensor and high-intensity driving light. Body mounted sensors include accelerometers, hazard detection sensors, odometer, streaming drive cameras and floodlights for worksite operations. The data from the sensors is available to the onboard computers and remote operators in either real-time or on-demand modes depending on criticality.

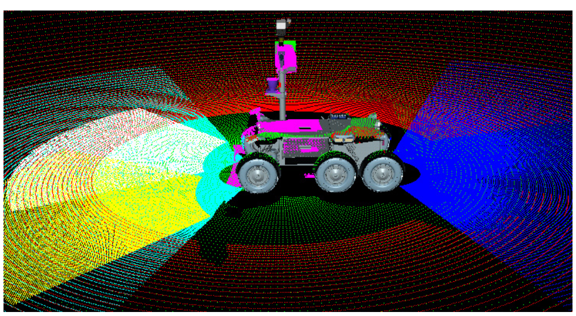

*Figure 6: Simulation of the ground coverage from the LELR onboard sensor suite.*

## 3.3 Control

Multi-mode control is a core design principle for the LELR vehicle. Local and remote tele-operation, precise and high-speed autonomous driving and compatibility for upgrade to onboard control have all been considered in the system architecture. Reliability and path-to-flight has also been considered in the implementation of real-time safety critical hardware and software systems.

Building on previous work [6] and in cooperation with human factors experts, the LELR remote tele-operator station (Figure 7) was designed to enable tele-operation of the vehicle at speeds up to 10km/h while under a 0.7Mb/s communication bandwidth constraint and 3sec roundtrip communication latency. A combination of streaming camera views, 3D terrain plots, telemetry and visual cues provide the situational awareness required to enable safe operations under these difficult conditions. Performance will be verified using lunar analogue scenarios.

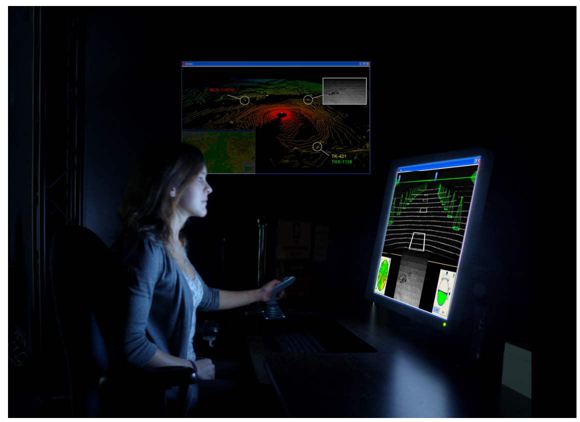

*Figure 7: Artist's concept of the LELR Remote Tele-Operator / Tele-Presence Station*

The LELR autonomous guidance, navigation and control system builds on field validated algorithms [7]. The scanning and planning functions allows for high-level over-the-horizon goals to be identified by remote operators and then executed onboard the vehicle. The precision drive feature allows single-click positioning of targets within reach of onboard sampling instruments. Absolute localization without external navigation aids is also performed. Figure 8 shows an example of consecutive 3D scans which allow the vehicle to find its way out of a dead-end path.

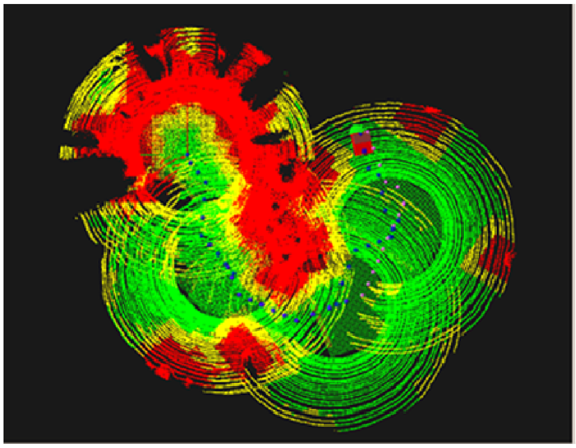

*Figure 8: Example of Consecutive 3D Scans during Autonomous Driving*

In addition to the core autonomy algorithms onboard the vehicle, the LELR also uses visual teach and repeat algorithms developed by the University of Toronto Institute for Aerospace Studies [8]. This allows the vehicle to be taught a path once and then repeat that path (in either direction) in a single command cycle. This could be envisioned for use in a sample return scenario.

The final control mode for the LELR is onboard crew operation. While this mode is not currently implemented, the vehicle and its architecture have maintained compatibility with this as a future upgrade. Mechanical, electrical and software/control interfaces have all been scarred into the system where required to ensure this compatibility.

### 3.4 Payload Accommodation

The LELR payload accommodation was designed to provide a flexible and adjustable interface for a wide range of payloads, which can be attached to any of the following surfaces:

- 1 x 2m top plate
- 0.5 x 1m front plate
- 0.5 x 1m rear plate
- 0.2 x 0.4m mast plate

The maximum payload mass is 300kg while the top payload plate can take a payload as large as 1 x 1 x 1.5m. Electrical accommodation is provided by 10 onboard outlets each capable of providing 24V, 10A service, while communications are provided by 10 onboard wired Ethernet connections.

## 4 PROGRAM STATUS AND TEST PLAN

At the time of writing, the LELR was undergoing final assembly and integration, as shown in Figure 9.

*Figure 9: LELR Assembly and Integration*

Completion of integration will be followed by a rigorous test campaign to demonstrate compliance with system requirements. Testing will be carried out initially at terrestrial vehicle test grounds and other off-road terrain sites and will culminate in extended autonomous and tele-operated traverses across the planetary analogue terrain at the Canadian Space Agency (Figure 10).

*Figure 10: Planetary Analogue Terrain at the Canadian Space Agency*

## 5 FUTURE WORK

The LELR program will result in a rugged, field-tested analogue rover that will be capable of executing a wide range of mission scenarios involving a broad selection of tools, instruments and payloads. Upon completion of the rover system, integration with other CSA payloads developed under the ESM program will commence. These payloads may include: a high resolution lidar sensor, range extending fuel cell, 2m-class manipulator, 1m drill, high bandwidth communications and ground penetrating radar. Following payload integration, the vehicle will be ready for Canadian and International deployments at remote analogue sites. In addition to these deployments, other future work may include integration with additional payloads as well as an upgrade to incorporate onboard human control and accommodation.

## 6 References


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