Canadian Space Agency
Lunar Ice Cave Explorer (LICE) Project
Project Requirements Document

6 September 2024

Background

NASA's Moon Mineralogy Mapper and China's Chang'E-5 have found evidence of water and hydroxyl radicals on the moon.

Last year, India's Chandrayaan-3 mission to the Moon's south pole has landed the Vikram lander, and its Pragyaan rover has found a series of caves that might contain ice.

This past summer, NASA's Lunar Reconnaissance Orbiter (LRO) found evidence of a series of caves on the moon.

It will be up to future Moon missions to search these caves for signs of ice and to determine if the caves are habitable.

In response to these discoveries, the Canadian Space Agency (CSA) has established the Lunar Ice Cave Explorer (LICE) program. The purpose of LICE is to map the caves and search them for evidence of water (in the form of ice). The LICE program relies on the LICE Rover (LICER).

The Rover (LICER) is being built by CSA. The software to control LICER is to be designed, implemented, and tested by a crack team of Computer Engineers. LICER is to operate autonomously under the control of the LICE software (LICES).

The Artemis 3 mission will carry three LICER's aboard SpaceX's HLS Starship. Only one LICER will be operated at a time, although a LICER can be sent to rescue another LICER that has, for example, run out of energy. More information about the LICER is described in this Project Requirements Document.[1]

Caves

Using data from the LRO and the Pragyaan rover, and studies of terrestrial caves occurring in places such as Iceland, CSA's astronomers and lunar experts have concluded that the best way to explore the caves is to divide them into 10-metre-long cells. It is assumed that the mapping of the caves would take place in an area 10-kilometres-by-10-kilometers. There is a potential for one million (1,000-by-1,000) 10-metre-by-10-metre cells. The cave entrance is assumed to be in the middle of the map.

Each cell has the following characteristics:

- An elevation relative to zero (at the mouth of the cave). The elevation is expressed in metres. The examples given in this document assume elevations ranging from -4 to +4 metres above the cave entrance. These are conservative values, and the range will probably exceed these values.

[1] This is a preliminary design document. Some information may change as more data becomes available and the project evolves.

- A roughness or friction factor from 1 to 9. A roughness increases from 0 (friction → 0) to 10 (friction → ∞). The ideal roughness is 5.
- The radiation level of the cell, measured in becquerels.
- The cell type: R (rock); P (powder of unknown depth); W (ice).

A cave might not lead to ice, it can have loops, join to other caves, and have branches.

For example, the following is a cave leading down to water:[2,3]

0/5/R/1	-1/4/R/1	-2/4/R/1	-2/5/R/1	-2/1/W/1	

The cave system can also have loops:

		-1/5/R0/1	0/0/P1/0	-1/4/R0/0				
		0/5/R1/3		-2/3/R0/2				
0/6/R0/1	+1/5/R0/1	0/4/R0/1		-1/2/R1/0	0/3/R0/0			
	+1/6/R1/1				+1/4/R0/1		-4/1/I0/0	
	+2/5/R2/1	+3/7/R0/1	+4/6/R0/1	+3/5/R0/6	+2/4/R1/0	+1/5/R0/0	+1/1/R2/1	

Lunar Ice Cave Explorer Rover characteristics

The Lunar Ice Cave Explorer Rover (LICER) is an electrically powered vehicle designed to traverse the caves discovered at the lunar south pole. The LICER has sensors to check left, forward, and right. The sensors determine the elevation of any non-wall cell, the friction of the surface of the cell floor, the contents of the cell's floor, and the radiation level of the cell.

Battery

The LICER is electric. Its energy is supplied by a 150-kWh battery.

Power consumption

The LICER's basic, non-motive power consumption is 0.05 kWh for each 10-metre cell it traverses; this is for its on-board systems and sensors.

When ascending a slope (for every one-meter increase in height), an additional 0.25 kWh are consumed.

When descending a slope (one-meter decrease in height), 0.1 kWh are produced.

In a cell with no slope, 0.05 kWh are consumed.

---

[2] Colour codes are as follows (rock is any other color and is indicated by its elevation):

Cave wall	Ice	Powder

Elevation	-4	-3	-2	-1	0	+1	+2	+3	+4

[3] Cell codes should be interpreted as Elevation/Friction/Cell type/Radiation Level. For example, +3/4/P/10 means 3 metres above the cave mouth, a friction of 4, powdery material, and a radiation level of 10 becquerels. A cell code of 9/9/R9/9 indicates a solid wall that cannot be entered.

Cells with rock floors (R#, see below, Ritterbarium) can be travelled with no power penalty; however, a powdery floor has a penalty of 0.25 kWh.

Power consumption also depends on the friction of the cell. More power is consumed as friction decreases (from 4 to 0, becoming increasingly smooth) or increases (from 6 to 10, becoming increasingly rough). There is no penalty for a friction of 5.

The friction factor penalty (in kWh) is:

$$Penalty = \frac{|Friction - 5|}{5} kWh$$

For example, a friction of 2 increases consumption by $|2 - 5|/5$, or 3/5, or 0.6 kWh. This is over-and-above the other energy requirements of the LICER for the cell it is currently in.

Radiation

The LICER will cease operating when its cumulative radiation exposure exceeds 100 becquerels. Radiation exposure also drains the battery. Every becquerel absorbed reduces the battery's energy by 0.25 kWh. The amount of radiation varies from cell to cell in the cave system.

An irradiated LICER can be decontaminated by a second LICER carrying a decontamination unit. The decontamination unit is described below.

A LICER cannot decontaminate itself.

Ritterbarium

In addition to lunar dust and radiation, a cell can contain *Ritterbarium*, a previously unknown mineral that increases the battery's energy while the LICER is in the cell. The increase in energy depends on the quality of the Ritterbarium (RB):

Cell type	RB content	Chemical name	Increase in energy
R0, P0, I0	0%	-	0.0 kWh
R1, P1, I1	1%	RB-MC	0.5 kWh
R2, P2, I2	5%	RB-DC	2.5 kWh
R3, P3, I3	10%	RB-DCH	5.0 kWh

The Ritterbarium energy boost (some say it is akin to a chocolate high), instantly boosts the LICER's battery while it is in the cell. The level of Ritterbarium can vary from cell to cell; it can also change within a cell over time.

Bridge

The LICER should not enter cells when the penalty associated with the cell means it will be unable to return to the Starship. This includes cells that require it to descend or ascend more than one metre. If the LICER is "in a hole" and is unable to get out it remains there "forever", a testament to human drive and ingenuity (or poor software design on someone's part).

The LICER carries a bridge that can be used to span a single cell that should not be entered. The bridge is directable in that it can be instructed to span a cell to the left, right, or in front of it. The bridge can be left behind or retrieved.

For example, if the LICER is in the highlighted cell, it cannot cross the next cell because of the change in elevation (+2 to -4), but the bridge can be directed to connect to any allowable cell with acceptable elevations (+2 and +3, but not -1, in this case).

	+2/6/R0/2	
+2/4/R0/2	-4/9/R3/2	+3/4/R0/2
	-1/5/R2/2	

Before the bridge can be deployed, the LICER needs to know which cell to enter. The LICER is equipped with a Canadarm Jr. robot arm that can be extended over the unenterable cell to sense the cells that are adjacent to the unenterable cell. In the above example, Canadarm Jr. would indicate that the adjacent cells have characteristics +2/6/R0/2, +3/4/R0/2, and -1/5/R2/2. The level of Ritterbarium does not affect the LICER's battery.

Opening the bridge consumes 1 kWh to open and 1 kWh to retrieve. Operating Canadarm Jr. consumes an additional 0.25 kWh.

The bridge can be left behind after spanning an unenterable cell or it can be retrieved for subsequent use. Bridges that are left behind remain in place until they are retrieved. The LICER can carry up to two bridges.

Payloads

A LICER can carry two payload units (PUs), PUs include:

- A 150-kWh battery. The Canadarm Jr. can replace an existing depleted battery with the spare. Full or depleted batteries can be placed in cells along a cave route. The Canadarm Jr. consumes 0.25 kWh when replacing a battery. Depleted batteries can be retrieved.

  When retrieving a depleted battery, it can be picked up by Canadarm Jr. and stored on the LICER if there is space. The cost of retrieval is 0.1 kWh.

  Retrieval is important, because the mission is only supplied with 25 batteries.

- A second bridge. This can be a bridge stored on the Starship or one that has been retrieved.

- A decontamination unit. The decontamination unit can be used on a second LICER that has exceeded the 100 becquerel limit. Operating the decontamination equipment consumes 0.25 kWh.

Carrying one or two PUs do not drain the rescuing LICER's battery.

LICER rescue

A LICER that is stranded because of power loss or radiation over-exposure can be rescued by another LICER. The stranded LICER is to be pulled out of the caves by the rescuing LICER. The cost of moving the stranded LICER is 0.01 kWh per cell. The cost of connecting to the stranded LICER is 0.01 kWh. There are no additional energy costs for moving the stranded LICER, regardless of the contents of a cell.

No more than one LICER can be rescued at a time.

A LICER cannot rescue itself.

A contaminated LICER must be decontaminated before it is moved.

A LICER stuck in a hole cannot be rescued.

Other requirements

As LICER moves through the cells, it is in constant contact with the Starship, returning route information as it trundles along through the caves, dreaming of electric sheep.

If the LICER abandons a search because of low power, it can return to the Starship for a new battery to resume its search.

The astronauts aboard the Starship can review the route as it is displayed on a Viewport. The Viewport can be "moved" over the route to inspect the cave system.

As maps are created, LICERs are expected to use the map to pick the best possible routes through the cave system in search of ice.

All cells in a cave system need to be visited as part of the mapping process.

LICE Software

The LICER is controlled by software. The LICE Software Package (LICES) is responsible for navigating the cave cells successfully in the search for water. It is responsible for deciding which cells to enter, creating cave route maps, maintaining sufficient battery capacity to allow a return to the Starship, and not putting the LICE in an unsafe state (i.e., into a cell hole, becoming overly irradiated, or depleting the battery).

LICE Data

The LICE software navigates by reading the LICER's sensor data.

The LICER's sensor data indicates what lies in the cell to the left, forward, or right of the LICER. The sensor data is read and data for the three directions is returned as a single binary-formatted record. Each direction (left, forward, right) is expected to contain the following:

Cell Number (CN): An unsigned integer to be used by the LICE software to specify the next cell (left, forward, or right) to visit. The LICE can move from cell-to-cell using the CN.

Elevation (EL): The elevation at the far end of the cell as determined by the LICE. This is a signed integer value.

Friction (CF): An unsigned integer indicating the roughness of the cell.

Type (TY): The type of material in the cell represented as an unsigned character.

Radiation Level (RL): The radiation level of the cell, stored as an unsigned short.

Cell Contents (CC): Up to three different minerals, each represented by a signed-integer code and a quantity. A negative value is used to specify the end of the mineral list if the cell contains less than three minerals.

Your job

Your two-person team must design, implement, and test your LICE software to search the south pole caves for ice and map a cave system. The LICE system can be used in any cave system. Since maps of the caves do not exist yet, it will be necessary to produce your own maps for testing purposes.

Your solution is to build the route to the ice if it exists or indicate that a route is not possible.

Visual representations of the cave system are to be produced as the LICER moves through the caves showing a bird's eye view of the caves explored showing the various cells.

The routes are to be recorded in a file for subsequent examination or use. Route information can include information such as elevations, cave contents, friction, location of batteries, bridges, and stranded LICERs.

It will be necessary to do extensive testing of your LICE software by creating different scenarios. For example, caves longer than a single battery charge; LICERs requiring to be rescued; caves requiring the use of the bridge. It might also be necessary to record what is found in different cells for future trips into the caves.

Some of the specifications in this document could change as the LICER development team implements it.

Questions will be answered by your CSA-LICE liaison officer.