Maximizing Rover and Instrument Mission Performance with Advanced Autonomy and Operations Tools: Overview of Upcoming Flight Demonstration and Future Activities.

K. Raimalwala[1], M. Cross[1], A. Higginson[1], C. Dubois[1], M. Pitropov[1], B. Bonham-Carter[1], L. Chavier[1], A. Pascual[1], T. Heydrich[1], A. J. Macdonald[1], K. Mewhort[1], T. Farley[1], J. Enns[1], Y. Brown[1], M. Faragalli[1], [1]Mission Control, kaizad@missioncontrolspace.com, 162 Elm St W, Ottawa, K1R 6N5 Canada

Introduction:

The development of advanced autonomous capabilities is essential to maximize scientific output amidst significant bandwidth, power, and communication limitations, particularly under challenging terrain and lighting conditions at the lunar south pole. These factors necessitate autonomous decision-making onboard with minimal human intervention. Mission Control has developed autonomous technologies that enable robotic platforms to identify scientific targets, assess operational hazards, and direct instruments, with minimal operator input. These capabilities will be presented first in the context of an upcoming rover-based technology demonstration at the lunar south pole, and second in the context of an ongoing Phase 0 study for a science instrument that would be integrated onto the Canadian Lunar Utility Vehicle.

BEACON: Technology Demo at the Lunar South Pole:

Mission Control and Astrobotic Technology, Inc. are collaborating on a joint lunar rover mission demonstration known as BEACON (Benchmark for Engineering and Autonomous Capabilities in Operations and Navigation). The mission will integrate Astrobotic's CubeRover® mobility platform with Mission Control's Spacefarer™ mission operations software. CubeRover will be delivered to the lunar south polar region aboard Astrobotic's Griffin-1 lander, scheduled for launch no earlier than July 2026. Once deployed, rover operations will be jointly conducted from Astrobotic's facilities in Pittsburgh and Mission Control's facilities in Ottawa. The collaboration aims to showcase how commercial partnerships can accelerate advancements in lunar exploration technologies.

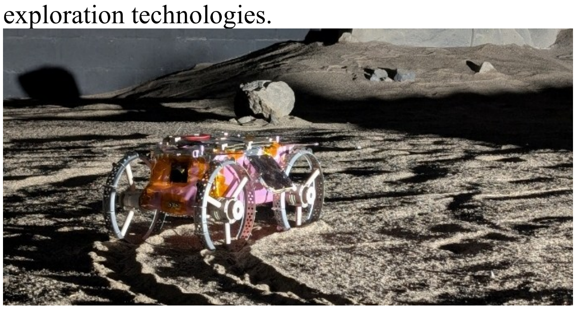

Figure 1: Development model of CubeRover in Mission Control's Moonyard undergoing integration and operations testing with Spacefarer™.

*Mission Objective and Profile***.** BEACON's primary objective is to demonstrate CubeRover's performance on the lunar surface and validate Spacefarer™ as a capable ground-operations platform. After deployment and egress from the Griffin lander, CubeRover will undergo up to 120 hours of surface operations near Nobile Crater. During this phase, the joint operations team will execute mobility tests, including driving in shadowed regions, and collect imagery for AI model retraining and panoramic stitching. Initial drive segments will establish baseline performance metrics that will be compared against several experimental operational modes. Figure 2 shows a high-level concept for the joint surface operations and demonstration activities.

These advanced operational modes include semi-autonomous navigation, VR-based teleoperation, and hazard assessment powered by the rover's onboard AI payload. Together, they will be used for the remainder of the mission to evaluate novel methods for efficient and safe rover control. Mission Control's contributions focus on demonstrating cutting-edge operator tools within Spacefarer™ (an example operator console layout shown in Figure 3) and validating technologies that support future autonomous and human-directed lunar missions.

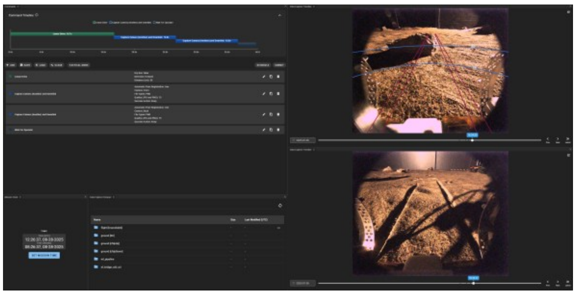

Figure 2: Example of Spacefarer™ operator console that includes the command builder, data explorer, and image viewers of both front and back cameras.

Technology Demonstration. The technology demonstration showcases how Astrobotic and Mission Control are using the Spacefarer™ mission operations platform to command and control CubeRover during lunar surface operations. Spacefarer's Common Operating Picture (COP) and Live Planning tools provide operators with synchronized 3D visualization, imagery integration, and waypoint-based planning both through a web interface and virtual reality. These tools enable operators to visualize rover pose, review images linked to location data, plan traverses interactively, and iterate seamlessly between planning and situational awareness. Semi-autonomous navigation reduces operator workload by automatically generating and sequencing complex command stacks, breaking long traverses into safe, reviewable segments and enforcing multi-operator approval for uplink.

To support localization on a rover without onboard navigation sensors, Mission Control developed a georeferencing application that allows operators to refine the rover's position by selecting tie points across images in Spacefarer™. Using camera models, rover pose estimates, and a ground-plane assumption, the system computes survey points and updates the rover's world-frame position after each drive step, with error reduction techniques such as RANSAC improving reliability. While this operator-assisted localization is inherently approximate, testing shows it is sufficiently accurate for short drive steps and effectively supports mission objectives by compensating for wheel slip and other accumulated errors.

An onboard AI payload enables real-time hazard assessment by running neural-network inference on images captured during rover operations. Activated by ground controllers and constrained by power availability, the system generates two key outputs for each image: segmentation masks and an overall hazard assessment. One model identifies lighting hazards such as darkness or saturation, while another detects terrain features including regolith, rocks, sky, and spacecraft components. These results, along with an estimated distance to the nearest hazard, are downlinked and visualized in Mission Control's Spacefarer™ platform, an example shown in Figure 4, where segmentation overlays enhance situational awareness.

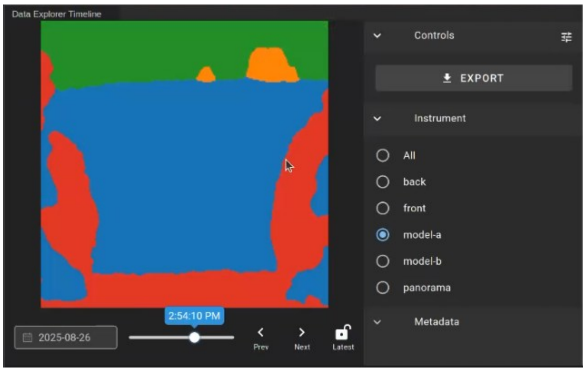

Figure 3: Ground segment visualization of the onboard AI software payload data product. [Green: 'sky', red: 'spacecraft' elements (CubeRover's wheels), orange: 'rocks', blue: 'regolith'.]

To support this capability, Mission Control developed a machine-learning pipeline centered on data curation, model training, and flight-ready deployment. Training used a mix of public lunar imagery and private datasets from the Moonyard analogue site, with careful attention to camera representativeness and the domain gap between Earth analogues and lunar south-pole lighting conditions. Validated models underwent hardware-in-the-loop testing on CubeRover's development platform and were integrated with NASA's core Flight System for autonomous operation. Because no real imagery from the landing site existed during development, the system was architected to allow in-mission model updates, enabling adaptation as new data becomes available despite the inherent operational risks and bandwidth limitations.

Autonomous Instrument Targeting:

Mission Control's autonomous targeting concept leverages panoptic segmentation and explainable anomaly detection to allow science instruments to independently locate and analyze areas of interest. Using convolutional neural networks, the system classifies features from camera images, identifies and then prioritizes targets based on anomaly scores with explainability metrics for operators. Tests in Mission Control's Moonyard showed a 3x increase in science acquisition efficiency over human teleoperation.

In late 2025 Mission Control was chosen by the CSA to develop the iSPI+ (intelligent Sensing and Perception in Infrared) instrument for the LUV. iSPI+ integrates autonomous targeting with infrared spectroscopy to detect fine-scale temperature variations and identify micro cold traps that may contain water ice, enabling opportunistic data collection even when science is not the primary mission focus. This maximizes science return during routine operations such as construction, resource utilization, or astronaut support. An overview of the instrument concept and how onboard autonomy enables maximizing mission objectives will be presented.

Conclusion: In summary, the integration of Astrobotic's CubeRover and Mission Control's Spacefarer™ platform demonstrates a significant leap forward in lunar mission operations. The technologies showcased—including advanced planning tools, operator-assisted localisation, and onboard AI for hazard assessment collectively enhance autonomy, efficiency, and scientific return on the lunar surface. The BEACON mission's achievements will validate the potential for commercial innovation to address complex challenges in planetary exploration. Mission Control is continuing to further advance onboard autonomy use cases for science instruments as well through development of the iSPI+ instrument in a Phase 0 study and prototyping activity. These advancements lay the foundation for future robotic and crewed missions, enabling more resilient and adaptable operations on the Moon and beyond.

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