MISSION CONTROL STRUCTURE AND STRATIGIES: LESSONS FROM THE CANMOON LUNAR SAMPLE RETURN ANALOGUE MISSION. G. R. Osinski[1], Z. R. Morse[1,2,3], C. L. Marion[1], J. D. Newman[1], P. J. A Hill[1,4], S. L. Simpson[1], E. A. Pilles[1], and C. M. Caudill[1]. [1]Institute for Earth and Space Exploration, Western University (gosinski@uwo.ca), [2]Howard University, [3]NASA Goddard Space Flight Center, [4]University of Alberta

Introduction: In preparation for the expanded near-future robotic exploration of the Moon and Mars and the return of humans to the lunar surface, the Institute for Earth and Space Exploration at Western University, Canada, has been conducting a campaign of high-fidelity analogue missions at terrestrial analogue sites around the world. In this abstract, we provide an overview of the real-time mission control operations established for the most recent analogue mission dubbed "CanMoon". This builds upon the CanMars Mars Sample Return analogue mission conducted in 2015 and 2016 [1–7].

Mission Overview: The CanMoon lunar sample return analogue mission was funded by the Canadian Space Agency (CSA) as part of its Lunar Exploration Analogue Deployment (LEAD) program. CanMoon field operations were conducted over the span of two weeks in August 2019 at a lunar surface analogue site on the volcanic island of Lanzarote, Spain. Lanzarote hosts several geologically young lava flows that date to the 1700s [8]. CanMoon was designed as a high fidelity simulation of near real-time communication between an Earth-based mission control and an independent scientific rover platform operating on the lunar surface. The scientific objectives of CanMoon were to:

1) Determine the geochemical and lithological diversity of rocks in the landing site region;
2) Identify and collect the best samples for radiometric age dating;
3) Identify and collect the most volatile-rich rocks;
4) Identify and collect any rocks containing crustal and mantle xenoliths in the landing site region.

The operations objectives of CanMoon were to:

1) Explore the mission control operations structure for 24/7 lunar science operations;
2) Compare the accuracy of selecting lunar samples remotely from mission control versus a traditional in-situ human field party;
3) Test the efficiency of remote science operations including the use of pre-planned strategic rover traverses;
4) Evaluate the utility of real-time automated data analysis approaches for lunar surface missions;
5) Test how Virtual Reality (VR) technology can be used to help enhance the situational awareness of a remote mission control team.

Mission Control Team Structure: The CanMoon Mission Control was located on campus at Western University in London, Canada. The CanMoon team was composed of volunteer undergraduate, graduate, and post-doctoral researchers. These participants were divided between the *Planning Team* – responsible for composing and sending specific commands to the analogue rover (see Newman et al. [9] for overview) – and a *Science Team*. The Science Team was broken down into two sub-teams, a *Tactical Science Team* responsible for targeting the individual instruments onboard the analogue rover (see Morse et al. [10] for overview), and a *Science Interpretation Team* responsible for analyzing the constant flow of data being generated and downlinked from the rover platform (see Hill et al. [11] for overview).

Pre-mission team training was critical. This training included lectures from space flight mission and analogue mission veterans, including *Technical Assurance Manager* roles; these persons assisted in the conceptual development of the mission system and the end-to-end implementation strategies and constructs, but critically, developed of training modules for, and gave lectures to, the participants on operational constructs, strategies, instrumentation and data acquisition, and instrument-specific team-building and synergies.

Mission Control Room Structure: The physical space for the CanMoon mission control was divided between two adjacent rooms. All workstations in these open concept rooms faced a central main screen on which information from any individual work station or a live feed from the rover could be shown. One room hosted the *Planning Team* with computer work stations dedicated to rover task and time management as well as issuing commands to the rover. The second room hosted both the *Tactical Science* and *Science Interpretation* teams. One Tactical Science work station dedicated to each of the instruments onboard the rover were located in the front of the room, while shared work stations for data interpretation occupied the back of the room. This loose separation of the Tactical and Interpretation teams allowed members to shift between assisting with instrument targeting when an instrument was in use, or data interpretation when their specific instrument was idle. The Planning and Science Leads were primarily situated in the center of their respective rooms so that they could easily communicate with any of the surrounding stations.

Communication Structure: While the physical separation of the Planning and Science teams allowed for focused discussions in each room, it also presented challenges for clear and efficient communication between the two rooms. Thus, the *Science and Planning Integrator* (*SPI*) roles were introduced. These roles were shared by two individuals, positioned next to the Planning or Science lead in their respective rooms. The integrators had a constant, direct line to each other, and thus, a live audio feed to the other room. The SPI could quickly update their lead on the status of the other room, relaying questions and provide status updates across both rooms in real time. This role was based largely on the Science Engineering Lead (SEL) position as described for participants in the Mars 2020 Rover Operations Activities for Science Team Training (ROASTT) exercise. During CanMoon, this role served as a critical go-between to ensure that activities were planned correctly and that science intent was properly conveyed, and to immediately resolve conflicts and make adjustments to the plan as dictated by mission goals and engineering constraints. In addition to the live communication provided by the SPIs, the Science and Planning team leads could physically visit the other room or meet in the hall to have a discussion or sort out any problems that arose.

All rover commands were issued through a shared modifiable interface called Rover Ops. The structure of “Rover Ops” used multiple sheets that included Rover Command, Command History, and list of activities [9]. Once a command was issued to the rover by the Planning Team, the Field team would acknowledge receipt of the command via Rover Ops, execute the command in the field, and finally note both the activity duration and completion in Rover Ops once the requested command was completed. The Field Team would then share any resulting data through a dedicated file transfer protocol (FTP) site to Mission Control.

Shift Changes During Real-Time Operations: To develop shift handover procedures and documentation templates to be applied to future 24-hour lunar missions, particular attention was given to designing CanMoon’s Mission Control shifts and shift handover procedures. Two different approaches were tested during the two-week mission. During the first week of operations the entire Mission Control team (~40 people) worked the same 10 hour shift (4AM - 2PM EST) during which most roles were double-occupied for the purpose of role and operations training through mentorship. During the second week of operations, the Mission Control Teams were divided into 2 human shifts and one ghost shift, lasting 5.5 hours each, with a 30 minute overlap. Shift A ran from 3:45 AM to 9:15 AM; Shift B from 8:45 AM to 2:15 PM EST. No operations were run during the remaining time called the *ghost shift*. Shift lengths were chosen based primarily on the limitations of daylight at the field site as well as effective use of mission length [12]. Where possible, the rover was given a series of commands to complete during the handover to avoid rover idle time.

Use of Immersive Technologies: Oculus Rift Virtual Reality (VR) headsets were set up in Mission Control to provide members of the Science and Planning teams with a more immersive view of the analogue terrain. The systems were used to visualize two mission datasets: the panoramic images obtained by the rover and a digital terrain model generated using pre-mission remote sensing data [see 13].

Lessons Learned: Some important lessons learned include:

- Open concept mission control rooms enabled greater communications and ease of movement within teams and increased the efficiency of operations;
- The SPI roles were critical for efficient and real-time communication between the Planning and Tactical Science teams; benefits included getting vital information for traverse timing; knowing how many analyses or what instruments could be utilized in a given period of time; enabling adjustments to long term planning based on science decisions made at one area of interest. (i.e. the importance of the LPIs);
- Ground-truthing remote sensing data and applying it to mission operations was important for long-term planning;
- Long-term planning was critical for meeting mission objectives and identifying visit future sites;
- Best results were achieved with a well-documented, in-person shift handover; thorough shift handover documents, completed throughout each shift, rich in annotated figures were the most effective;
- Optimal shifts lengths should be no more than 8 hours to avoid crew fatigue which set in shortly thereafter;
- LiDAR-equipped rovers would enable faster real-time localization, reducing the time wasted on such efforts by the Planning Team during CanMoon;
- The use of VR provided enhanced situational awareness for the Science and Planning teams, in particular providing a better sense of scale, and for orientation and interpretation of the terrain.

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