

MOON/MARS SCIENCE AND EXPLORATION IN PRESSURIZED ROVERS: EARLY LESSONS FROM ANALOG STUDIES AT THE HAUGHTON-MARS PROJECT SITE, DEVON ISLAND, HIGH ARCTIC.

Pascal Lee^{1, 2, 3}, Michael Gernhardt⁴, Andrew Abercromby⁴, Stephen Braham^{1,5}, Tom Chase⁶, Jean-Marc Comtois⁷, Matt Deans³, Rainer Effenhauser⁴, Terry Fong³, Charles Frankel⁸, Brian Glass³, Ed Hodgson⁶, Stephen J. Hoffman⁴, Jeffrey A. Jones⁴, Jonathan Nelson¹, John W. Schutt¹, Marcelo Vasquez⁹. ¹Mars Institute (NASA Research Park, Moffett Field, CA 94035-0006, USA, pascal.lee@marsinstitute.net), ²SETI Institute, ³NASA Ames Research Center, ⁴NASA Johnson Space Center, ⁵Simon Fraser University, ⁶Hamilton Sundstrand, ⁷Canadian Space Agency, ⁸Middlebury College, ⁹National Space Biomedical Research Institute.

Introduction: An important option in Moon/Mars human exploration architectures considered in NASA's Project Constellation is the use of pressurized rovers for conducting long-range (tens of km), multiple-day excursions or *traverses*. Since 1997, practical operational experience with planning and implementing Moon/Mars-relevant science-driven long-range vehicular traverses across unprepared rocky terrain has been accumulated at the Haughton-Mars Project (HMP) site on Devon Island, High Arctic, in particular using (since 2003) the HMP's *Mars-1 Humvee Rover*, a modified High Mobility Multipurpose Wheeled Vehicle (HMMWV) serving as a low-fidelity analog for a *small pressurized rover* (SPR) (Fig 1).



Figure 1: The *Mars-1 Humvee Rover* on a small pressurized rover (SPR) analog traverse on Devon Island. (Photo NASA/HMP-2003-P07160032).

The HMP site is particularly well-suited for Constellation lunar SPR analog studies because of the following unique *combination* of relevant attributes [1]: a) *Science*: Haughton Crater offers a rich array of well-developed, well-preserved, and well-exposed lunar-relevant impact features and materials not present at small impact structures (e.g., Meteor Crater, AZ) or not well-preserved at other large impact sites; b) *Scale of Exploration*: Shackleton Crater on the Moon (D=19km) and Haughton Crater (D=20km) are similar in diameter + Devon Island offers open access to ~30,000 km² of barren rocky terrain dissected by lunar-rill-like valleys (in form, not in nature); c) *Operational Environment*: Isolation, remoteness, extreme climate, permanent insolation (Summer), and lack of scale references in the landscape (e.g. trees, buildings) are real and of relevance as operational constraints.

Objectives: During the recent HMP-2008 field campaign, the use of two SPRs working in tandem – a mode of vehicular exploration currently examined by Constellation – was investigated, with the following two primary objectives: 1) to understand better the planning and implementation requirements (including remote ops support) for long-range science-driven SPR and dual-SPR traverses, including SPR-based EVAs; 2) to test and mature quantitative metrics for evaluating the productivity of science and exploration SPR traverses and EVAs.

An immediate goal of the HMP campaign (Jul-Aug 2008) was to develop critical experience that would inform the first field test (Oct 2008) of NASA Constellation's SPR concept vehicle at the Black Point Lava Flow site near Flagstaff, AZ (Desert RATS-2008 analog campaign). A longer term goal was to begin identifying early, the processes and tools that will ensure safe, productive and cost-effective exploration of the Moon using pressurized mobility systems. Lessons learned from HMP typically fall in one of two categories: lessons for lunar (or Mars) exploration, and lessons for conducting simulations at analog sites. Both are critically important for achieving our goals. The present paper focuses lessons learned from HMP-2008 that will enhance lunar science return.

Methods: *Objective 1* was approached using an iterative process involving *planning and executing* an actual science-driven dual-rover traverse following specific "*flight rules*" (e.g., provisions for *targets of opportunity*, optional "*get ahead*" tasks, periodic comms check intervals, daily end-of-day rendez-vous required between rovers, return legs via "known paths" only, EVA times limited by weekly EVA budget of 24 hrs and daily limit of 8 hrs, Apollo procedures for rock sample collection, etc.), *analyzing* in the field the main difficulties encountered in the planning or execution of the traverse, then *planning and implementing* a new traverse with the benefit of previous lessons learned.

Objective 2 was met by evaluating the performance of two distinct experimental quantitative productivity metrics: an unweighted task-based metric developed at Pavilion Lake, BC, and a weighted science return-based metric developed at HMP (*Lee-Braham Index*).

Traverse and EVA Planning: Multiple day traverses and EVA planning include the following sequence of steps: 1) *Identification of prioritized science objectives, tasks, and sites of interest* for drivebys and EVA stations. In the case of field work at an analog site, establishing *traceability* between science investigations at that site and their (scientific or operational) equivalent on the Moon is a critical additional step; 2) *Development of a traverse plan* with a detailed timeline with a resolution of ~15 min, including alternate routing options at approximately hourly intervals, that weighs safety, productivity, and cost-effectiveness (minimal use mission resources). This step was aided at HMP by the use of a *Traverse Management System (TMS)* developed at the Mars Institute (the TMS is currently a traverse and EVA planning, replanning, and tracking software tool) that helped identify viable excursion paths that excluded specified above-threshold conditions (e.g., terrain roughness, slope); 3) *Readiness review* of crew, vehicle, and ops support systems, including updates to checklists.

Traverse and EVA Execution: Two dual-SPR traverses were implemented at HMP-2008: *Expedition 1* on 6-7 Aug, and *Expedition 2* on 8 Aug. *Expedition 1* focused on impact geology and geophysics, and headed SW and S of the HMP Research Station. Expedition 2 focused on country rock and glacial geology, and reached to the North coast of Devon Island (Fig 2).

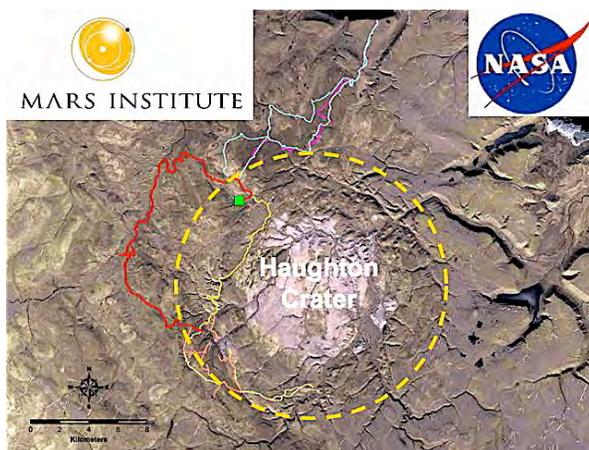


Figure 2: Map of analog SPR traverses conducted around Haughton Crater, Devon Island, during HMP-2008. Each colored path represents one day of traversing by one SPR. The yellow hatched line is a circle the size of Shackleton Crater on the Moon (19 km). Background: ASTER image.

Each expedition entailed two supposedly identical SPR vehicles, each occupied by a crew of 2 and following separate but proximate paths: a *Humvee* and a *Mule* (smaller 2-person all-terrain vehicle or ATV). For safety and logistical reasons, each SPR was fol-

lowed by an “invisible” support team of 3 on ATVs. An additional person acting as a data-logger rode non-interferingly inside the Humvee with its crew. EVAs out of the Humvee were conducted in lightweight mock spacesuits developed by Hamilton Sundstrand. EVAs out of the Mule were in shirtsleeves but time-constrained to reflect suited EVAs. Donning and doffing times were limited to 15 and 10 min, respectively, which proved adequate. Cameras and Apollo-style tools and sample bags were available to each crew.

Important Lessons or Reaffirmations:

- Scouting via robotic rovers would have provided important, at times critical, data for traverse and EVA planning, for both pathfinding and science return enhancement.
- Science planning for extended traverses and EVAs over complex or “science-rich” terrain is a time-consuming task, making any substantial unforeseen replanning on-the-fly of uncertain benefit. Meanwhile, sufficient *open* time must be built into traverse timelines to allow crews to explore *targets of opportunity*.
- Waypoints in a traverse plan (including for an EVA station) need to be qualified by radius of required proximity: over open smooth terrain, it may be sufficient to reach a waypoint or site to within 100 m, whereas wheelbase-scale accuracy may be needed over complex or extremely rough terrain.
- Over complex or extremely rough terrain (actual threshold depends on vehicle’s capabilities), return legs may take significantly longer than outbound legs if known path cannot be traced back to within the scale of the vehicle’s wheelbase. Even so, traverses over complex or extremely rough terrain may difficult to reproduce in reverse.
- Vehicle *bearing* information is critical on map displays, not just *location*, particularly when landscape features are poorly visible (adverse lighting).
- Positioning, navigation and tracking are substantial (time-consuming) tasks, particularly over terrain lacking mappable distinguishing features, unless robust solutions are in place for assisting with vehicle position, navigation, and tracking.
- Drive-by investigations in SPRs can be productive.

References: [1] Lee, P. & G. R. Osinski (2005) *Meteoritics & Planetary Sci.*, 40, 1755-1758.

Acknowledgements: This research was supported by NASA (Coop Agreement NNX08AO59A) and by the Mars Institute. Development of the TMS was supported in part by NASA and the Canadian Space Agency, with contributions by N. Wilkinson. Special thanks are owed to the US Air National Guard, AM General LLC, Hamilton Sundstrand, and SETI Institute. We also thank First Air, Indian & Northern Affairs Canada, Nunavut Research Institute, Qikiqtani Inuit Association, Polar Continental Shelf Project, and the Communities of Grise Fiord and Resolute Bay.