Two Analogue Test Facilities for Human Planetary Exploration

Triggered by growing solidification of planetary exploration plans e.g., Moon Gateway project by NASA or the "Moon Village" initiative by ESA as well as the ceaseless efforts by Elon Musk, this article looks at two analogue training facilities and their capabilities. First at one of the oldest ones, the Haughton-Mars Project Research Station (HMPRS) and then a new one, planned by ESA, called the LUNA Facility, also known as ESA Surface Operations Laboratory (ESOL).
The first of the two following descriptions (HMPRS) was published by ResearchGate, the second one (LUNA) was presented during the SpaceOps 2016 Conference at Daejeon, Korea .

The discussion of their requirements / capabilities and allows comparison and will shed some light on where we stand and what can be achieved with analogue test facilities rather than using more expensive in orbit / in-situ test exercises.

Haughton-Mars Project Research Station (HMPRS) [1]

Summary: The Haughton-Mars Project Research Station (HMPRS) on Devon Island, High Arctic, is a field research facility dedicated to supporting analog field research in planetary science and exploration. The successful HMP-2016 field campaign marked HMP's 20th expedition already.

Introduction: The Haughton-Mars Project (HMP) is an international planetary analog field research project focused on planetary science and exploration studies at and around the Haughton impact structure on Devon Island, High Arctic. The HMPRS is located at 75^{O} 26 N, 89^{O} 52 W. Devon Island is the largest uninhabited island on Earth. It is part of Nunavut, Canada. Haughton Crater (Diameter ~ 20 km, Age: 21 MYears) is the only terrestrial impact structure set in a polar desert. The HMP has been in operation since 1997, with continuous support from NASA and additional support from the Canadian Space Agency (CSA). The project engages both professional researchers and students (grads and undergrads), and has contributed to many advances in planetary science and exploration. The HMP also supports education and public outreach. Research at HMP is divided into two areas: Science and Exploration.

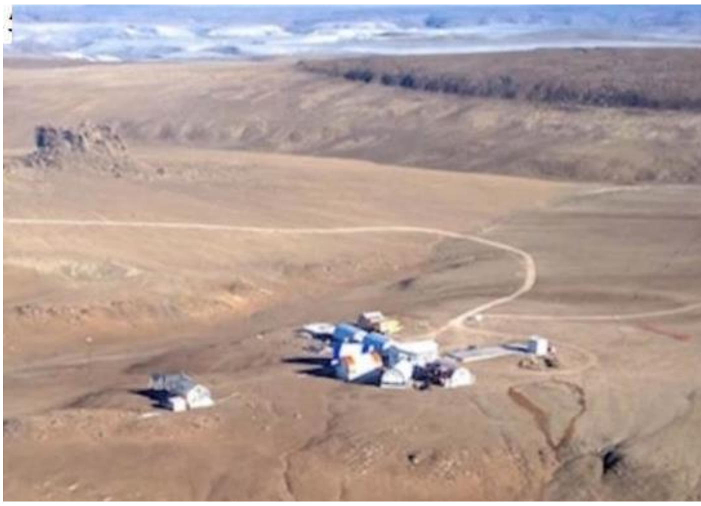

Figure 1: Astronaut at work at HMP

◄ **Figure 2**: HMPRS site with gray impact breccis hills of impact crater in the distance (Photo HMP-2015/P.Lee).

Science research opportunities at the site include the well-preserved medium-sized Haughton impact structure, and a wide range of candidate Mars analog geologic features including small valley networks (subglacial channel networks), canyons (glacial trough valleys), recurring slope lineae and gully systems, rock glaciers, sapping valleys, ground ice, patterned ground, impact-induced hydrothermal deposits, paleolacustrine deposits, polar microbial extremophile biology and ecology, polar desert micro-oases, planetary protection investigation opportunities, etc.

Exploration research opportunities at the site include field studies and tests of robotic and human exploration systems, technologies, and strategies, including aircraft, drills, habitats, rovers, spacesuits, mapping and navigation tools, etc. Investigations in human behavior and exploration practices in remote and isolated environments may also be conducted. Over the next several years, the

HMP plans to conduct dual pressurized rover traverse simulations in support of NASA human planetary exploration planning.

Facilities: The HMPRS is a permanent field research facility established in the northwestern rim area of Haughton Crater. The HMPRS is currently the largest privately-operated polar research station in the world. The station includes a Base Camp, a dirt Airstrip (200 m), a Helipad area, a Satcom area, and a network of connecting trails. Base Camp includes a Core hub, eight WeatherhavenTM-style common tents, and the ACMG (Arthur Clarke Mars Greenhouse).

Structures. The Core is used as a multipurpose common kitchen, pantry, and mess facility. The eight tents serve the following specific functions: Office, Comms, Science, Lab, Medical, Garage/Workshop, Satcom, and Storage (Fig 1). HMP participants need to bring their own (4-season) sleeping tent to be pitched in a designated area ("Tent City", 100 m from Base). Instruments and Tools. The Lab is equipped with an Olympus BX51 polarizing microscope. In addition, a wide range of shared field research gear is available on site, including rock hammers, hand lenses, shovels, mattucks, field markers, tarps, stakes (anchors), handoperated augers and drills, and biological and geological sampling containers.

Assets & Resources: Fuels available at HMPRS include mogas (91 octane gasoline), diesel, Jet-A, Jet-B, and propane. On-demand hot and cold water are available at Base Camp. Water is pumped from a nearby creek. Power is available at the HMPRS 24/7 during normal summer operations. Power sources at Base Camp include diesel generators (7 to 12 kW) with back-up, and several portable 1 to 3 kW gasoline generators. The gasoline generators may be transported for use deep in the field. The ACMG may be powered from Base Camp, and/or autonomously via dedicated solar panels and wind turbines. Plans are underway to augment solar and wind power generation capabilities at Base Camp.

Vehicles. The HMP operates a fleet of 10 all-terrain vehicles (ATVs) or quad bikes that may be used on a shared basis by visiting investigators upon completion of mandatory ATV training at the HMPRS. The HMP also operates one side-by-side (Kawaski Mule) and two Humvees (AM General HMMWV or HighMobility Multipurpose Wheeled Vehicle – modified military ambulance versions) designated HMP Mars-1 (red) and HMP Okarian (yellow). In addition to being means of transport, all vehicles at HMP are considered to be field research tools, as they are critical in allowing access to geologic features, outcrops, and other data sources in the field.

Internet access. Wirelss internet access is available at Base Camp via a Ka band satellite link. Remote internet access from deep field locations may be made available via deployable repeaters linking back to Base Camp. Data rates vary with location and the amount of sharing of the available bandwidth.

Safety is paramount at HMP. HMP field deployments take place in an arctic expeditionary environment, with clear lines of authority, leadership, and reporting defined and agreed upon in advance. Effective safety measures and culture are also in place. After 19 summer and 5 winter field campaigns, totalling close to 10,000 person-days, no serious accident (with irreversible injury) has occurred at HMP. HMP staff usually includes a Medical Officer trained in emergency field medicine, although medical facilities at Base Camp are very limited.
If a serious medical issue arises, a medevac airlift would be called, weather permitting.

After having read the above article I tried to receive more operations-oriented information, however the questions never were answered. Nevertheless, I think it might be helpful to insert the questions here again to keep them in mind while reading the article about the ESA LUNA test facility below.

Q: What was the longest duration period of an "expeditions" so far?
A:

Q: I understand the Haughton-Mars Project Research Station HMPRS) is "catering" opportunities to interested science or research groups which bring their experiment specific equipment – together with trained specialists. However there is a joint pool of common resources the station provides (water, energy, transport, infrastructure, etc.).

How is the planning process for the distribution of those resources (long-, short-term plans and realtime adaptations) and how is the tracking of the actual usage performed?
A:

Q: With respect to “payload operations” you follow a decentralized concept, i.e. the Researchers operate either autonomously or communicate directly with their “home” bases (internet, or via SatCom antennas).
I understand there is an on-site management structure for the infrastructure. How this on-site organization structured and how is the decision process in case of priority conflicts, emergencies, remedial actions and alarms? Do you provide a “safe haven” on-site?
A:

Q: Is the on-site management connected and supervised by a “home” base (like a HMPRS “control center”) on the mainland, on a 24hr basis or otherwise?
A:

Q: What is your experience with the “human factor”? Do you provide social programs?
A:

Q: Is the HMPRS as an institution taking part in the “science” findings? Is there a centralized reporting and archiving system? Is there a information exchange process with other Analogue Simulation facilities?
A:

Q: With Moon and Mars coming more and more into international focus, do you have “bookings” for the coming years? Are you in contact with ESA (Moon Village, Mars program), Russia, China?
A:

Q: For Mars simulations (human or robotic) are you considering communication delays and disruptions?
A:

Q: Last question: Have you been in contact with the “Mars One” people?
A:

LUNA Analog Test Faclity (ESA) [2]

On October 2nd, 2018 representatives from ESA, DLR and Air Liquide Advanced Technologies signed a partnership agreement around energy storage and provision as a first step for the implementation of the LUNA analog test facility. Solar energy has been identified as the most sustainable option for a moon base. During the lunar day, energy from the sun will be used directly via photovoltaic panels, but it will also be used to split water into hydrogen and oxygen. These two elements will be stored separately before being recombined in a fuel cell for used during the two-week-long lunar nights.
The following paper was presented during the SpaceOps Conference 2016, the basic requirements and the description of the planned LUNA Analog Test Facilitiy (also known as “ESOL”) are extracted and repeated here (Ref.: Analogues for Preparing Robotic and Human Exploration on the Moon):

Introduction
In view of lunar exploration, which is foreseen to be one of the next steps in human space exploration, lunar analogues are and will continue to be powerful tools to support the development, demonstration and validation of new technologies and operational concepts. Furthermore lunar analogues will serve as training environment for astronauts and will engage the public with interesting and exciting mission simulations well before actual missions take place. Natural Lunar Analogues have the advantage that they simulate certain aspects of the lunar environment “for free”, i.e. terrain, soil and harsh environment (dust, temperature, psychological effects, etc.). However there are limitations in their simulation capacity and also logistics disadvantages as Natural Analogues are often in remote locations and the deployment of people and equipment is then complicated and costly. Therefore, there is a growing interest in Artificial Lunar Analogues in order to avoid the disadvantages of the Natural

Lunar Analogues. The main benefits of working with Artificial Lunar Analogues are:
1) Ability to control the inside/outside environment (e.g. 'inside' for a lunar habitat or 'outside' for a rover testbed).
2) Standardization of the analogue and tests in order to allow a meaningful comparison between several simulation campaigns. The reduction of noise factors, like weather or climate at the Natural Analogue site, result in improved test quality.
3) Features that are not available in Natural Analogues such as gravity offloading devices, habitats, or highfidelity (even icy) regolith.
4) Significantly reduced logistical preparations and costs compared to simulation campaigns in Natural Analogues.
5) Increased (net) test-time compared to Natural and Mixed Analogues, because reduced logistics (easier access) and independence from weather noise factors (an Artificial Analogue is weather-independent) allow more test runs within a given campaign period.
6) Easier access and lower cost stimulate earlier integrated operations simulation campaigns with different hardware and test communities. This leads to an increased knowledge transfer amongst all involved partners and to more robust hardware and better mission operations concepts.
7) Easier access and higher attraction for the general public, thus higher outreach potential compared to Natural Analogues.

LUNA (ESOL) Technical Concept *(see also Figure 3)*

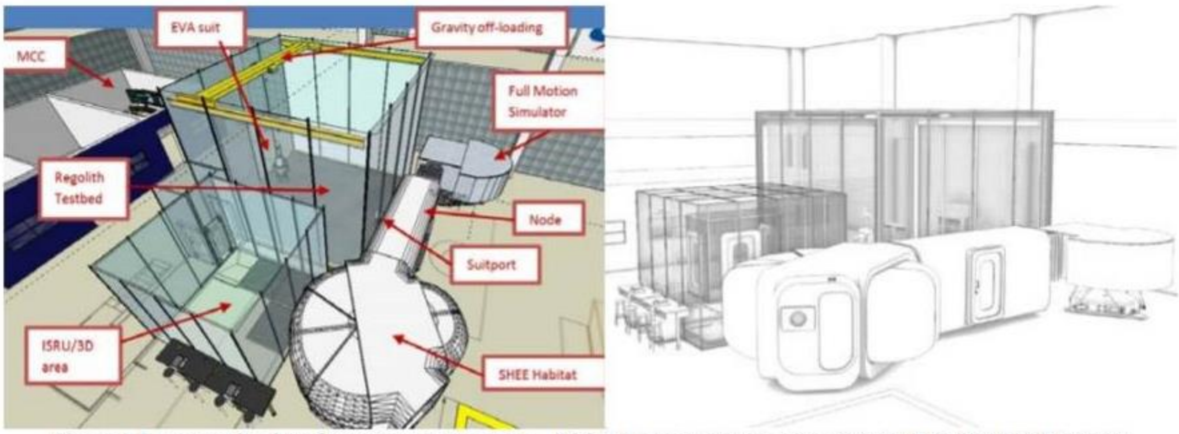

Figure 3 European Surface Operations Laboratory – ESOL Lunar Analogue concept (:envihab, Neutral Buoyancy Facility and big rover testbed are not shown)

The DLR site in Cologne, Germany, contains several existing analogue facilities – facilities at ":envihab" and at the European Astronaut Centre (EAC) – which makes it a good base to implement an Artificial Lunar Analogue facility. The EAC facilities already include the Neutral Buoyancy Facility (NBF), Classroom and Auditorium infrastructure, a Mission Control / Simulation Control Centre set-up and the big Training Hall in which a large area can be dedicated to new components of the Artificial Analogue. Besides the above mentioned on-site facilities, EAC contains a very specific and valuable human capital: directly relevant expertise and know-how from the astronauts, astronaut instructors, flight surgeons and astronaut medical support team, and education & outreach people.

The following components are proposed to be implemented in the EAC Training Hall in order to perform lunar mission simulations: regolith simulant testbed, habitat sized for two to four crew-members for simulations of max. two weeks (the SHEE habitat – Self Deployable Habitat for Extreme Environments, developed in a European FP7 project between 2012 and 2015), two EVA suit mock-ups (usable in dry environment, like in the regolith simulant testbed, but also in water immersion partial gravity, like in the NBF), a gravity off-loading system (for humans, compatible with the EVA suit mock-ups, and for rovers), a system level simulator, full motion simulator (6 degree of freedom lunar rover simulator with a virtual reality rendering of the lunar surface), a Mission Control Centre (MCC), an EVA and MCC information system (chest and wrist displays for the EVA suit and system allowing to introduce communication delays, bandwidth throttling, etc.), a widely compatible robot *control station, and a food growth facility. Furthermore, a ~1000sqm rover testbed, featuring lunar terrain morphology, is proposed to be built in a new greenhouse-type building next to the EAC building. This big testbed would also be valuable for the purpose of testing 3D-printing of larger structures by means of solar sintering of lunar regolith simulant or other techniques.*

This Lunar Analogue facility is mainly intended as a 'Mission-Focused-Analogue', i.e. for highly integrated simulations with robots and humans, to test mission scenarios, stress timelines and operations, examine remote operations and procedures, and to train astronauts for lunar surface operations. However, individual components of the analogue facility can also be used for research or V&V work in a more specific area, e.g. the regolith testbed for testing rovers, ISRU processes or 3D printing, the Habitat for testing ECLSS components and aspects of habitability and Human Factors, etc.

The European Surface Operations Laboratory –ESOL– facility is mainly intended as a 'Mission-Focused Analogue', however, the analogue is also considered a Laboratory, in the widest sense of the word, where research and training can be performed. The acronym ESOL also hints to the Latin name for the Sun "Sol", a term also used to refer to solar days on extra-terrestrial bodies. One of the ESOL Unique Selling Propositions (USP) is that this Artificial Analogue is designed such that the habitat and full motion simulator are completely integrated with the regolith simulant testbed via a suit port module. I.e. astronauts can enter/exit the regolith simulant testbed from/to the habitat or the traverse simulator and perform EVA surface operations activities in their EVA suit mock-ups without having to enter in the 'outside world'. Another USP is the availability of a gravity off-loading device in combination with a regolith simulant testbed, which is covering a worldwide gap in Analogue infrastructure. In the ESOL concept, the ":envihab" facility can be used for doing pre- and post-simulation BDCs (Baseline Data Collection), for isolation studies that leverage the operational fidelity of the analogue at EAC, for simulating crew in a cis-lunar habitat (in the 'living and simulation area' of :envihab) and crew on the lunar surface (in the SHEE habitat at EAC) or for researching the effects of exploration atmospheres on crew

Conclusions
The European Surface Operations Laboratory (ESOL), proposed to be implemented at the DLR/EAC site in Cologne, has been identified as the most promising lunar analogue concept in order to properly address several of the identified gaps in Analogue infrastructure and to enhance Europe's capabilities within the international effort of exploring the Moon. The ESOL facility is designed in first place as a Lunar Analogue facility, however, the concept is extendable to other planetary destinations.
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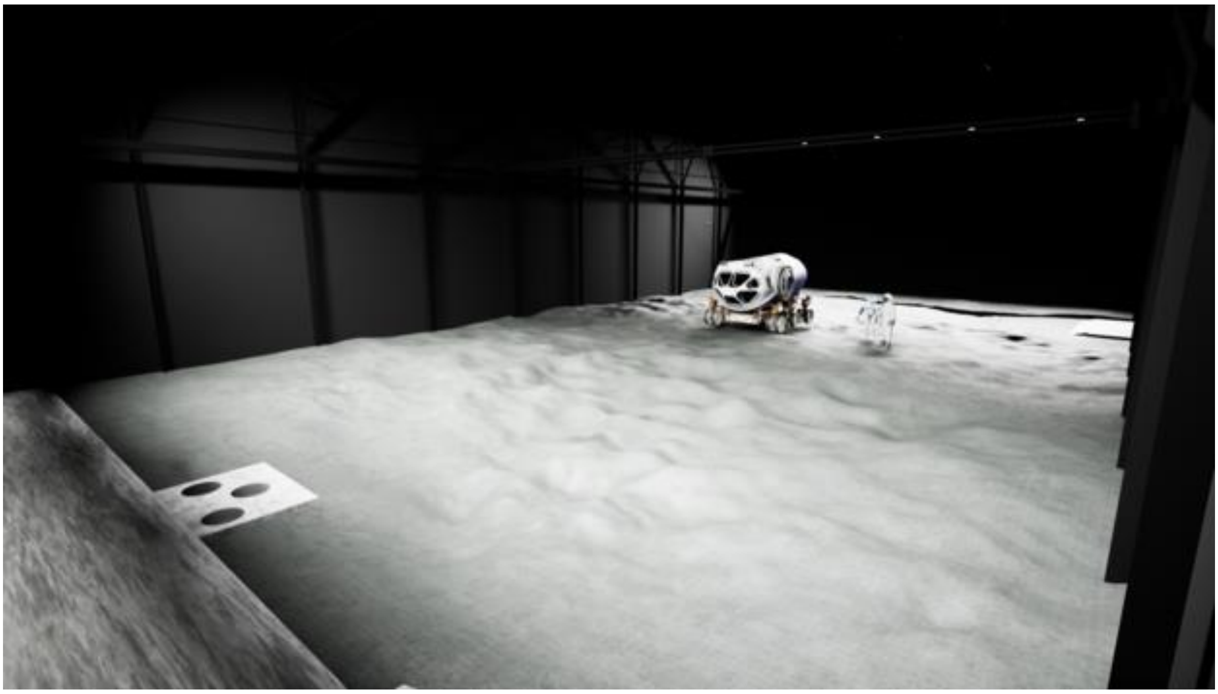

Figure 4: Virtual reality rendering of the LUNA Regolith Testbed (ESA "LUNA Facility brings Moon to Earth", 17 Oct 2018)

There is still a lot to be done, however the concentrated, international approach seems to be on a very good way and the currently established target dates within the next twenty years 2020-2040 seem to be achievable.

References

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[2] LUNA https://arc.aiaa.org/doi/pdf/10.2514/6.2016-2353

November 2018, Joachim J. Kehr Editor SpaceOps News fort he Journal of SpaceOperations & Communicator
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