HOW ASTRONAUTS WOULD CONDUCT A SEISMIC EXPERIMENT ON THE PLANET MARS

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ABSTRACT. During the Summer 2001 Flashline Mars Arctic Research Station (M.A.R.S.) campaign in Devon Island, Nunavut, Canada, the crew of the second rotation conducted a geophysics experiment aiming at assessing the feasibility of an active seismology method to detect subsurface water on Mars. A crew of three deployed a line of 24 sensors. Reflected and refracted signals produced by mini-quakes generated by a sledge hammer were recorded by a seismograph. The experiment was conducted three times, once in a dry run and twice during simulated Extra-Vehicular Activities (EVA) on the edge of the Haughton crater, allowing a three dimensional characterization of the subsurface ground to a depth of several hundred meters. Data were recorded for later detailed processing. A third EVA attempt inside the crater had to be aborted because of the poor weather and terrain conditions. Despite this failed attempt, a large amount of results were collected. Several operational lessons were learned from conducting this experiment under simulated EVA conditions. This paper presents the experiment and the methodology used, reviews the experiment performance and summarizes the results obtained and the operational lessons learned.

1. INTRODUCTION

The Mars Society [1] is a non-profit private organization whose purposes are "to further the goal of the exploration and settlement of the Red Planet by broad public outreach to instill the vision of pioneering Mars; by supporting ever more aggressive government funded Mars exploration programs around the world; and by conducting Mars exploration on a private basis." In this framework, The Mars Society has established the Flashline Mars Arctic Research Station (M.A.R.S.) in Devon Island, Nunavut, North of Canada, at a latitude of 75 degrees North, well in the Arctic Circle. The Flashline MARS station is situated on the edge of the Haughton crater [2] which was formed by the impact of a large meteorite 23 millions years ago. The strange geology and ecology of this site and the harsh climatic conditions make this part of the Earth surface as close as one could expect to a Martian environment, except for the presence of a breathable atmosphere. Arctic wild life, including polar bears, is the only sign of life on this island. The interest in using this Mars analog on Earth was recognized by NASA several years ago. Several research programs were initiated by the NASA Ames Center and the SETI Institute under the umbrella of the NASA-Haughton Mars Project (HMP) [3].

During the Summer 2001, the MARS Flashline Research Station supported an extended international simulation campaign of human Mars exploration operations. Six rotations of six person crews spent from four to ten days each at the MARS Flashline Research Station. International crews, mixed in gender and in professional qualifications, conducted various tasks as a Martian crew would do including scientific experiments in several fields (Geophysics, Geology, Biology, Psychology, ...). One simulation campaign goal was to assess the operational and technical feasibility of sustaining a crew in an autonomous habitat, while conducting a field scientific research program. Operations were conducted as they would be during a Martian mission, including Extra-Vehicular Activities (EVA) with specially designed unpressurized suits.

Water on the surface of Mars exists in its solid form in the polar caps, but can not exist in its liquid form due to the low Martian atmospheric pressure. However, it is suspected that liquid water could exist under the surface possibly as underground pockets or trapped in rocks. Detecting liquid water under the Martian surface at a depth accessible to a human crew (from several to a few hundreds meters) is important for two main reasons. First, under the adage "Find the water, and you may find life", detecting liquid water would increase the chances of finding evidence of past or present life, possibly in a bacterial form somehow similar to terrestrial extremophile bacteria. Second, water detected close to first human settlement on Mars could help to sustain the human crew presence and operations in terms of consumption and fuel generation.

To prepare for this kind of operation, one of the experiments during the Flashline MARS Summer 2001 campaign was proposed by Dr P. Lognonné (*Institut de Physique du Globe de Paris*, IPGP), Dr V. Dehant (Royal Observatory of Belgium, ROB) and Dr V. Pletser (ESA). This experiment "Subsurface water detection by seismic refraction" aimed at assessing the feasibility of conducting an active seismology experiment to detect the potential presence of subsurface water. It can, together with a Ground Penetrating Radar, provide a sounding of the subsurface allowing to identify conductive liquid (e.g. salty water) from rocks or non conductive liquids (e.g. liquid CO_2).

A line of 24 seismometer sensors was deployed in several directions on the surface of the edge of the Haughton crater to record seismic signals generated by a mini-quake, somehow similar to experiments conducted on the Moon [4]. The seismic instrumentation was provided by the IPGP. Signals were recorded for later analysis to extend the characterization of the Haughton crater structure by supporting Scientists of the IPGP and the ROB.

This experiment can be seen as a possible continuation of the future automatic Seismology and Gravimetry experiment (SEIS) aimed at characterizing the deep internal structure of Mars and of its direct subsurface, to search for the presence of water. This SEIS experiment [5] will be conducted by teams of IPGP, ETHZ (Switzerland), JPL (USA) and ROB Scientists during the NETLANDER mission, a cooperative program between France, Germany, Finland, Belgium and the USA, to be launched in 2007.

2. METHOD, INSTRUMENTATION AND PREPARATION

The proposed geophysics experiment relies on the general principle of the seismic refraction method, in which a wave generated by a seismic event and propagating in the ground is reflected on and refracted along the interface between two underground media. Reflected and refracted signals are recorded by a set of seismic sensors connected to a seismograph. The analysis of the recorded signals allows to separate the signal reflected and refracted components. To characterize the underground media, only the refracted components are considered for detailed analysis, providing information on the propagating speed, the depth and geometry of the interface and the nature of the encountered media. More details can be found in [6-8].

24 seismic sensors, called geophones, were installed every four meters in linear array, called a geophone flute. The geophone line was connected via data cabling to a Seismograph Acquisition System (SAS) (Terraloc Mark 6 Seismograph [9]). Mini-quakes were generated by using either a sledge hammer on a metallic plate or a geophysical thumper gun.

The experiment was conducted in several steps, involving ten successful test shot recording in stacking mode for each of six test configurations in the selected area. SAS recordings were started by a trigger geophone installed close to the source seismic event. Three test configurations required the line of 24 geophones to be installed in one direction, the other three test configurations required the geophone line to be installed in the perpendicular direction. The three test configurations differed by the location of the trigger geophone and the quake source:
- Test 1 : trigger geophone and quake source placed in the middle of the geophone line,
- Test 2 : trigger geophone and quake source placed at one extremity of the geophone line, and
- Test 3 : trigger geophone and quake source placed at the other extremity of the geophone line.

Recorded signals were viewed on the SAS screen display between the shots to assess the acquisition and the quality of the recorded signals. After completion of the tests, data were transferred to floppy disks for later detailed analysis.

All seismic equipment was lent by the IPGP Laboratory. One of the Investigators, who lead the field operations at the Flashline MARS Station, was trained in using the instrumentation at the Geophysical Research Centre of Garchy, France, one month prior the Flashline MARS campaign. Step-by-step nominal and off-nominal troubleshooting procedures were prepared and rehearsed. The instrumentation was packed in three containers and shipped to Canada for delivery to the NASA HMP Base Camp on Devon Island. A GPS system and shot shells were available at the Flashline Mars station. The equipment total mass of 130 kg however could be reduced to a few tens of kg and is therefore compatible with payload constraints of future Mars missions.

3. CONDUCTING THE EXPERIMENTS

The experiment program conducted by the second rotation crew is summarized in Table 1.

TABLE 1: EXPERIMENTS CONDUCTED BY THE ROTATION 2 CREW (10 - 17 July 2001)

Geophysics:	Subsurface water detection on Mars by active seismology *Dr P. Lognonne, M. Diament (IPGP, Paris Univ., F), Dr V. Dehant (Belgium Royal Observatory, Brussels, B), Dr V. Pletser (ESA)*
Biology:	Search for fossils and evidence of microbial life *Dr C. Cockell (British Antarctic Survey, UK)*
Radio-Biology:	Deployment of radiation dosimeters, during 1 EVA *Dr C. Cockell (British Antarctic Survey, UK)*
Human Factors	Time dependent occupation of habitat volume by a human crew of six in isolation *Dr W. Clancey (NASA Ames, USA)* Human factors and habitability assessment *Drs J. Novak, E. Morphew, J. Connolly (NASA-JSC Crew Station Branch, USA)* Needs assessment of psychosocial support to individuals in a space simulation in an extreme environment *Pr. J. Lapierre (Quebec Univ., CDN)* Assessment of water consumption of a Mars human crew of six *Mr R. Zubrin (The Mars Society)*

Regarding the geophysics experiment, the operations of geophone line deployment and quake generation with a sledge hammer are mildly physically demanding in normal conditions. However, it was not known a priori whether the experiment would be feasible under EVA conditions and with operators wearing simulated Martian EVA suits.

A first dry run was conducted in the afternoon of Tuesday 10 July, before the rotation 2 crew entered into the Flashline Mars Habitat. The three instrumentation containers were transported in a trailer pulled by an All Terrain Vehicle (ATV). A three person team deployed the 24 geophone flute line in the Haynes Ridge plain, on the edge of the Haughton crater, a few hundred meters away from the Mars Habitat. This deployment direction was approximately perpendicular to the

crater rim. This dry run was to verify the instrumentation and to train the other crew members who would be involved in the experiment during future EVA's. A single point was measured with the trigger geophone and the seismic source located in the middle of the geophone line.
During the second EVA, a three member EVA crew conducted the seismic experiment during a four hour EVA in poor weather conditions (rain and wind); see Figure 1. The 24 geophone flute line was deployed in the Haynes Ridge plain, in front of the Flashline MARS Habitat. The geophone flute was laid in a South-South-East direction, approximately parallel to the Haughton crater rim. This direction was chosen perpendicular to the direction of the flute laid in the previous dry run trial. Three tests were conducted with the trigger geophone triggered by quakes created by sledge hammer shots. . Three tests were conducted with the trigger geophone and the sledge hammer shots at the middle of the geophone flute (Test #1) and at the flute both extremities (Tests #2 and 3). Locations were measured using a hand-held GPS receiver. The geophones were tested individually and automatically prior to conducting the first Test and were found in functioning conditions. In order to improve the signal to noise ratio, tests were conducted in a stacking mode with ten hammer shots for each test. Data were recorded and logged in the SAS for later data treatment and assessment in the Flashline MARS Habitat to obtain first results.

Figure 1: EVA crew member K. Quinn hits the sledge hammer under the rain during the second EVA on 12 July, while V. Pletser operates the SAS under monitoring of R. Zubrin; the Mars Habitat is visible in the background (Photo V. Pletser).

The third three hour EVA took place on Saturday 14 July to deploy radio-biology dosimeters at Breccia Hill and Trinity Lake inside the Haughton crater. While on EVA with the ATV's, four other potential locations for deployment of the seismic experiment were visited, respectively close to Trinity lake, at the bottom of a small valley at the intersection of two small rivers, on the inside rim of the crater, and on the crater external rim. The fourth EVA expedition on Sunday 15 July was a scouting EVA to find other potential locations to deploy the seismic experiment into the Von Braun Planitia, a few km away from the Flashline Mars Habitat and the NASA-HMP Base Camp. It was hoped to conduct the geophysical sounding of a pingo (a mass of water ice in the ground), but it was not sure if there were any at a reachable distance with ATV's. Two potential locations were found which were not too muddy nor covered by too many loose pebbles and rocks. After assessing the merits and disadvantages of the several locations visited, taking into account the potential seismic interest, the access possibilities of ATV's with the 130 kg instrumentation trailer, the terrain conditions (rather muddy in some places due to severe rains in previous days and weeks), it was decided that the fifth EVA of Monday 16 July would take place in the Haughton crater. It would be the most ambitious EVA planned, with deployment of the geophone flute in two perpendicular directions in the Haughton crater, and with six series of measurements, including ten shots with the sledge hammer in stacking mode and one with the geophysical thumper gun at each of the six locations. Four EVA crewmembers left for the crater in the morning. While inside the Haughton crater, the trailer with the 130 kg instrumentation got stuck in the Arctic mud to a depth of half a meter. More than one hour was spent pulling the trailer out with the other ATV's (see Figure 2). In view of the exhaustion of all crew members and the degrading terrain conditions, it was decided to abort the EVA and to return to the Habitat. On the way back, the instrumentation trailer got stuck a second time in the mud and was salvaged again only after quite some time. This EVA lasted eventually three and half hours, unfortunately without any results.

Figure 2: EVA crew members R. Zubrin and V. Pletser pushing the instrumentation trailer out of the mud in the Haughton crater during the fifth EVA of 16 July (Photo Discovery Channel).

The sixth and last EVA took place on Tuesday 17 July and lasted two and half hours. It was again a three person EVA to deploy the geophone flute in the Haynes Ridge plain, in front of the Flashline MARS Habitat, at the same location of the deployment during the second EVA. The geophone flute was laid in a direction perpendicular to the one of the second EVA, approximately perpendicular to the Haughton crater rim, i.e. the same direction as for the dry run of Tuesday 10 July. Three tests were again conducted as previously and locations were measured using a handheld GPS. This final series of measurements allowed a complete characterization of the three dimensional underground structure of the Haynes Ridge plain in front of the Mars Habitat. After completion of the test, data were recorded and transferred to diskettes for later analysis. All equipment was packed into the transport containers, for the return shipment on the evening return flight of the same day.

4. FIRST RESULTS

The location of the geophone flute laid down during the second EVA of Thursday 12 July were as follows (within GPS precision and related to the WGS84 ellipsoid):

4 m mark at N 75 deg. 25.871, W 89 deg. 50.067, 240 m elevation
96 m mark at N 75 deg. 25.847, W 89 deg. 49.894, 242 m elevation
Shot (Test #1) at N 75 deg. 25.859, W 89 deg. 49.976, 253 m elevation
Shot (Test #2) at N 75 deg. 25.872, W 89 deg. 50.075, 260 m elevation
Shot (Test #3) at N 75 deg. 25.846, W 89 deg. 49.881, 256 m elevation

A first analysis in the Mars Habitat of data obtained for this run with a sampling interval of 100 micro-s and a number of samples of 2048, showed the following results:

1. For all test configurations, the average underground velocity of the signal was approximately 2600 m/s. (See Figure 3)

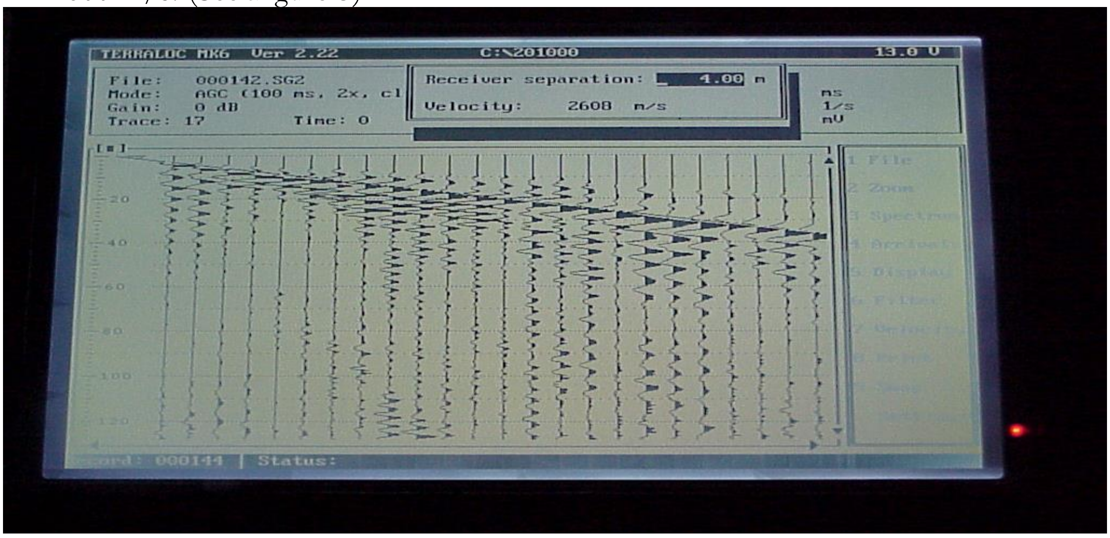

Figure 3: View of the SAS screen during first data analysis in the Habitat. An average velocity of 2600 m/s is found (Photo V. Pletser)

2. The spectrum analysis for each geophone signal for the three tests showed the following ranges of maximum frequency peaks :
   Test #1: 135 Hz (channel 18) to 405 Hz (Channel 17)
   Test #2: 121 Hz (channel 22) to 443 Hz (Channel 7)
   Test #3: 67 Hz (channel 3) to 409 Hz (Channel 17)
3. Sounding extended to vertical depths in excess of 550 m, a depth likely greater than drill which might be foreseen on Mars in the few next decades. A deeper sounding could easily be reached by using safe explosive sources, either shot shell or binary storage explosives.
4. The first refracted signal recorded in Test #1 was returned after 70 milliseconds, consistent with an approximate position of an interphase at a depth of 90 m.

No underground water was detected in the Haynes Ridge plain, despite the rainy conditions prevailing at the surface. Average velocities of wave transmission for water are catalogued between 1450 and 1500 m/s for liquid water and between 3300 and 3800 m/s for ice. The average velocity deduced from test results is consistent with Calcium Carbonate and Dolomite (catalogued range: 1200 to 7000 m/s), which is commonly found in this area [10]. A more detailed analysis of the results is in process to further characterize the underground structure of the Haughton crater rim.

5. OPERATIONAL LESSONS LEARNED

During the three EVA's dedicated to the deployment of this seismic experiment, and two other scouting EVA's to search for potential experiment locations, several observations could be made from an operational view point. These are believed to be important lessons learned that should be considered when planning future missions to Mars and preparing scientific expeditions on the surface of Mars by the first human crews.

5.1 OPERATOR SKILLS

To successfully conduct a field scientific experiment requires among other things expert knowledge, training, adequate and working instrumentation and favorable weather and terrain conditions. This is an obvious statement. However, a multidisciplinary crew, like those who would eventually be sent to Mars, would be composed of scientists and engineers in different scientific and technical fields. Being an expert in his own field, a crew member needs also to be trained at an adequate field working level in other disciplines. In this respect, the dry run conducted before entering the Mars Habitat on Tuesday 10 July proved to be more than helpful in reviewing the instrumentation and in training other crew members to use the instrumentation and to follow the experiment procedures.

This specific experiment required the installation of 24 geophone sensors, the deployment of more than hundred meters of cabling, more than 50 data electrical connections in the appropriate order, the keying in of the appropriate settings in the SAS computer, and the testing of all sensors and connections before eventually conducting the experiment itself. All the installation, laying out and preparation of the instrumentation took more than 80% of the time, with the remaining less than 20% of time needed for the experiment performance itself. It is therefore of paramount importance to properly prepare, optimize and discuss all operations during briefing prior to starting the EVA. It means also that in the field, the location of the experiment needs to be properly assessed and decided by the relevant discipline experts having the necessary scientific and field know-how. It is therefore crucial for the relevant scientific and technical disciplines to be represented among the crew members and for properly qualified scientists to be selected as part of the human crews for these planetary missions.

The experiment performance under EVA conditions was very physically demanding. Crew members at the end of EVA's were quite exhausted, not only due to physical activities while wearing EVA suits, such as transporting heavy equipment, walking over long distances carrying part of the instrumentation, handling the sledge hammer, and so on, but also due to riding the ATV's with EVA suits and overheating despite the ambient Arctic Summer conditions (with temperatures ranging between 5 and 10 deg. C). This has a direct consequence on the choice of conditions for the several month interplanetary travel between Earth and Mars. An interplanetary flight under microgravity conditions would have well-known debilitating effects on the musculo-skeletal system to a point where a human crew after landing on Mars could no longer be engaged in physically demanding scientific activities like this seismic experiment. Therefore, the Mars mission scenario should foresee either some sort of artificial gravity system in the design of the interplanetary spacecraft for the Earth-Mars leg of the mission, even at a partial earth gravity level, e.g. a Martian gravity level of 0.38 g, or appropriate counter-measures to delay or minimize the microgravity debilitating effects on the human body.

5.2 EVA AND SUPPORTING TECHNICAL EQUIPMENT COMMUNICATIONS IN DEGRADED MODE

During field operations, communications among EVA crew members and between EVA crew members and the base (the Mars Habitat in this case) are of paramount importance, for safety reasons first, but also to properly conduct the experiment. A portable radio system allowed communication among EVA crew members themselves and with the Habitat base. Unfortunately, this portable radio system failed regularly and on nearly all EVA's due to either battery problems (insufficiently charged, or loosing their charge because of cold temperatures), or accidental disconnection of cabling due to falls or arm movements, or stuck buttons, or to improperly set or shifting gain. When this happened, communications between crew members were conducted either verbally through helmets when in close range, or with hand signals at further range. During the experiment performance, at more than one instance, arm signals were also nominally used between the SAS operator and the sledge hammer operator to signal stand-by for acquisition (one arm raised) and ready for acquisition (both arms raised).

• Impaired vision

When wearing the EVA suit helmet, vision was impaired in particular conditions in three cases. The first one occurred while setting up the SAS on the second EVA of Thursday 12 July in poor weather conditions (rain and wind). The SAS screen visibility was impaired by straylight and multiple reflections inside the spherical helmet, further aggravated by rain drops on the helmet. In normal conditions, the screen brightness is sufficient to neglect straylight and multiple reflection, but this incident showed the importance of improving the visibility of the helmet material and shape. A flat transparent surface in front of the face (or at least a portion with a larger curvature radius) could be considered to improve the helmet in this respect.
The second case was mud partially covering the helmet impairing sometimes drastically the vision. During the fifth aborted EVA, nearly all EVA crew members fell several times in the mud. Their helmets were covered to various extents by mud. Wiping them with gloves (also covered in mud) was obviously ineffective. This was also true to a lesser extent during other EVA's while raining; wiping helmets with dirty or dusty gloves resulted also in muddy strains across the helmet vision field. This could have resulted in safety issues, especially while riding ATV's at the end of EVA's. Rain and mud would obviously not be a problem on the surface of the planet Mars. However, this situation experienced several times is relevant for Martian wind and dust, that could eventually cover the helmet of a Martian EVA suit. A system should be designed such as to allow cleaning of the external surface of the helmet in the vision field of the EVA crew member, either with a special brush mounted on the arm of the EVA suit, or a system of several transparent layers adherent to the helmet external surface that could be peeled off by the EVA crew member.
The third case, more common, was fogging of the inside surface of the helmet due to perspiration or exhalation. Ejection of water by the mouth after taking a sip from the drinking outlet valve was effective to wash out the helmet inside surface. For further EVA's, a fine layer of liquid soap was smeared on the helmet inside surface prior to EVA's, which was sufficiently efficient.

• Downward vision in the sagittal plane

The helmet design provided a nearly 180 deg. vision in the horizontal plane and a more than 90 deg. vision angle in the sagittal plane, from slightly below the horizontal plane upward. This angle meant that it was impossible to look at one's own chest, where some of the controls for the radio were mounted. It was also difficult to look at the suit pockets. Although difficult to be implemented, the design requirement for an EVA helmet should be to provide a larger downward vision angle in the sagittal plane as close as possible to that of normal vision.

• Rear vision

Rear vision was also extremely difficult, especially while riding ATV's. To look behind oneself while walking or standing, an EVA crew member had to turn the torso, which was not easy with bulky EVA suits, or to turn completely on himself. This obviously is not possible while riding ATV's. The situation could be improved by mounting rear view mirror(s) on the ATV's, or, better, installing a mirror on the arm of the EVA suit, like it was done with a handheld mirror and some sticky tape. The design of arm mirror actually exists on orbital EVA suits used by Russian cosmonauts and US astronauts on the Mir and the ISS space stations.

• A Martian GPS system ?

For the purpose of this seismic experiment, the use of a handheld GPS system proved to be very useful. A similar GPS system could be considered for future Mars missions. The installation of piggyback GPS systems on presently considered Martian spacecrafts that once in orbit around the planet, would create a simplified Martian GPS constellation. This would greatly enhance the safety of the first human crews and ease their field operations and expeditions.

5.3 ERGONOMY OF INSTRUMENTATION WITH EVA SUIT COMPATIBLE INTERFACES

The instrumentation (geophones, data cabling, SAS, handheld GPS) used for this seismic experiment was designed to be used on earth in normal field conditions and not adapted for use with EVA suit gloves. Several ergonomic problems were encountered, although these have most likely already been foreseen and solved by space mission managers and designers.
The use of bulky gloves caused difficulties for the following categories of operations:
(1) pushing keys on SAS keyboard and on handheld GPS, activating switches, activating radio push button, opening and closing locks and manipulating handles on transport containers;

(2) plugging and unplugging certain connectors (requiring turning a security ring on the connectors), adjusting rotating radio gain buttons;
(3) unrolling and rolling data electrical cables;
(4) writing with pens, manipulating diskettes for data back-ups, holding procedure booklets and turning pages (especially when raining).
Turn-around solutions were found each time and implemented, but often at the cost of carrying extra equipment and extending the operation time. The obvious solution to category 1 operations was to use an extra tool (e.g. screwdriver) to activate keys on keyboards and switches. One crew member improved the idea by taping a small screwdriver on her index finger to push keys on her handheld GPS. Radio push buttons were too small to be properly activated with one gloved finger and resulted often in a two hand operation to bring the button box in the vision field to ascertain that the button was properly depressed.
The solution for category 2 operations was to use another tool (pliers) to turn connectors, especially those not having space around them, being too close to other connectors or box edges to allow manipulation with gloved fingers. Adjusting the rotating radio gain button was found difficult and resulted often in a loss of radio contact; no solution could be found.
Regarding the third category, the rolling of several tens of meters of electrical cables was difficult as the cables would get entangled and create knots. No specific solutions were found, other than patience and the extra time needed to undo knots in the cables.
No solution was be found for the fourth category, other than avoiding these operations and relying on logging data and results either by radioing to base (but not often possible due to radio contact failures) or copying them in memories of the SAS and the handheld GPS computers.
It was found also that it was easier to have the tools that one crew member would need carried in another crew member's suit pocket, as vision of the own suit pockets was very limited.
Finally, it was found that the time allocated for each sequence of steps was longer than anticipated, even with an EVA correction factor of 2 or 3. However, certain sequence of steps were found shorter than anticipated while others were much longer than expected, e.g. for those operations involving EVA operators walking to install instrumentation. Furthermore, certain sequence of settings on the SAS could have been automated or implemented as default choices.

6. CONCLUSIONS

This simulation campaign was extremely productive scientifically and technically. The multidisciplinary and multicultural aspects of the crew members were definitely an enrichment and it was extremely rewarding to work and interact in such a high level environment.
The goal of the proposed experiment was achieved, i.e. to demonstrate the feasibility of conducting a seismic experiment in extreme conditions. It was proven possible to conduct this physically demanding scientific task under EVA conditions similar to those that human crews would encounter on the planet Mars. Despite the one failed attempt due to specific terrestrial weather conditions, it was shown also that the implementation of the seismic refraction method is feasible by EVA crew members in an extreme environment such as the Arctic and that it could be envisaged for future human missions to the planet Mars to detect subsurface water.
Water was not found in the area chosen for measurements, but a large amount of data on the underground structure of the Haynes Ridge plain at the Haughton crater rim was obtained and is still under analysis. A first assessment of the recorded data showed results consistent with the already known underground structure, i.e. mainly Calcium Carbonate and Dolomite rocks.
From an operational viewpoint, several lessons were learned and were presented above in order to improve design of EVA suits and of instrumentation to be used by crew members. Based on observations during the simulated EVA's, suggestions were also made regarding Martian mission concepts and scenarios. It is hoped that these comments and suggestions would be considered for further simulation campaigns and eventually for the first human Mars mission.

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