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SURFACE EXPLORATION METRICS OF A LONG DURATION POLAR ANALOGUE STUDY: IMPLICATIONS FOR FUTURE MOON AND MARS MISSIONS

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ABSTRACT

To prepare for the return of humans to the Moon by 2020 and the eventual human exploration of Mars, it is important to gain a better understanding of the logistical requirements for living, working, and exploring on the surface of another planet. Given humanity's limited experience with human planetary surface research (i.e., the Apollo missions), high fidelity simulations in analogue environments on Earth offer important insights in learning how to explore on other planets. During the summer of 2007, an "exploration metrics" study was conducted during the Flashline Mars Arctic Research Station's (FMARS) 100-day Long Duration Mission (F-XI LDM) in the Canadian High Arctic. Crew members timed and recorded their daily activities, including field excursion preparation, travel, sample collection, sample triage, lab work, and time spent on house-keeping and leisure activities. Preliminary results show that during the 100-day simulation, crew members conducted 88 EVAs, traveled a total distance of 1074 km, and spent 12% of the mission time conducting scientific exploration, and 5% in the laboratory. It is proposed that findings from this study may be used towards developing a baseline strategy for scheduling and logistics planning of planetary field excursions for the Moon, Mars, or any other planetary surfaces.

INTRODUCTION

With the expected return of humans to the surface of the Moon by 2020 and the eventual human exploration of Mars, it is pertinent to place more emphasis on the logistical requirements of planetary surface operations for living, working, and scientific exploration. Given humanity's limited experience with human planetary surface research (i.e., the Apollo missions), high fidelity simulations in analogue environments on Earth offer important opportunities to learn about how to explore on other planets. In addition to data from Apollo, Osinski et al. [1] and Eppler [2] have collected data based on Arctic and Antarctic expeditions. This study differs in that exploration metrics data were collected continuously during a long duration Mars simulation specifically for future mission planning. Here, "exploration metrics" may be defined as data that quantifies the basic logistical requirements of field exploration excursions, referred to throughout this paper as extra-vehicular activities (EVAs; time spent outside of the habitat collecting scientific data), with emphasis on time, distance, and mass. Times were consistently recorded over a 100-day period for pre-EVA preparation and briefing, travel to and from study sites, duration at study sites, post-EVA activities, and de-briefing, as well as many other activities at the research station, not directly related to exploration. Distances and number of samples were also recorded for each EVA.

This paper summarizes preliminary results from an exploration metrics study conducted during the Flashline Mars Arctic Research Station's (FMARS) Long Duration Mission (F-XI LDM) at the 23 km diameter Haughton crater, in the summer of 2007. During F-XI LDM, seven scientists and engineers took part in a 100-day simulated Mars mission on Devon Island, Nunavut, Canada, where they conducted a rigorous field research program, and collected data on the logistics and metrics of daily activities, including EVAs. Data from this and similar future studies will be valuable to the planning of human planetary missions, as the current knowledge-base of human planetary exploration is minimal. In particular, as long duration Moon/Mars missions are planned that will require more sustainable workloads compared to those of the short Apollo missions, the F-XI LDM due to its long duration nature will prove as a very valid reference point. Additionally, the crew's activities were much more aligned to future Moon/Mars surface stay activities compared with other terrestrial studies as they included such activities as communication with mission support, daily report generation, and on-site laboratory analyses.

LUNAR/PLANETARY DATA

The six Apollo surface missions from 1969 to 1972 remain as humankind's only extra-terrestrial experience with surface exploration. In total, the Apollo missions lasted less than 65 days, with only 12.5 days spent on the lunar surface, and only 81 hours spent on a total of 14 EVA's on the lunar surface (1 to 3 per mission) [3]. During the 14 EVA's, Apollo astronauts traveled less than 100 km, collected 378.8 kg of samples [3], and were directed strictly by Mission Control on Earth. In comparison, the F-XI LDM crew was able to spend more time conducting surface exploration and sample analysis, with a more flexible schedule (see Table 1).

Apollo	F-XI LDM
Short duration (few days)	Long duration (100+ days)
Sampling-based exploration	Detailed surveying; hypothesis driven exploration; generation of results, manuscripts in the field
Samples returned to Earth for analysis	In situ and lab-based field sample analysis
Highly orchestrated and scheduled EVAs	More flexible "open" schedule by crew
1 scientist *(geologist)*, 11 non-scientists	4 scientists *(2 geologists, 1 biologist, 1 computer scientist)*, 3 engineers

Table 1: Profiles of Apollo surface missions compared to F-XI LDM.

PREVIOUS ANALOGUE DATA

To date, analogue research involving human subjects has been completed at several locations around the world, but very few long-duration mission-scale simulations have been conducted. In addition, most simulations have been based around psychological studies on the effects of isolation and confinement, rather than field research (e.g., Antarctic winter-over stays, submarine missions, Skylab, ISS). A few limited studies related to surface exploration have been conducted, including two at the Haughton Mars Project (HMP) research station; one on field science ethnography [4], and another on short-duration operations focused on astrobiology laboratory requirements [5]. Two of the more in-depth studies that are most similar to F-XI LDM were conducted by Osinski et al. [1] in the Canadian Arctic, and by and Eppler [2] in Antarctica. The Osinski et al. study was used as a baseline for the F-XI LDM study, and hence the two utilize similar data collection methodology. The Osinski et al. study was carried out at HMP, uses data collected over a ten year period, (each field season lasted roughly one month, up to a maximum of approximately 40 days), and while some activities involved varying degrees of Moon/Mars simulation, research was typically not conducted under full simulation. The Eppler study took place in Antarctica during the Antarctic Search for Meteorites (ANSMET) 2002-2003 austral summer season (mid-December to mid-January), and included logistical data for getting to and from Antarctica as well as operations in the field, with a focus on the masses of supplies and samples, and time spent on various activities. The Eppler study did not intentionally include any form of simulation; however Antarctic operations have many innate similarities to operations on another planet.

F-XI LDM ANALOGUE DATA

In contrast to previous studies, F-XI LDM focused on long term Mars analogue field exploration and related logistics, under nearly full-time Mars simulation conditions. Field studies include more than ten geology, biology, and environmental parameter studies, with secondary emphasis on human factors and psychology. F-XI LDM represents an extremely high-fidelity simulation, as the crew members lived in a simulated Mars habitat; wore simulated surface suits while exploring; faced dangers due to their isolated location; operated on Martian sols (24 hr 39 min "days"), facilitated by the polar 24-hour sunlight; carefully mapped out each excursion, and briefed other crew members according to strict protocol; followed strict 20-minute delayed communication protocols "with Earth"; managed operations nearly autonomously, with secondary input from Mission Support; and recorded waypoints and tracklogs of each EVA. Six of the seven crew members timed and recorded their daily activities for 63 days (37 of which were sols), including EVA preparation, travel, sample collection, sample triage and archiving, and time spent on house-keeping, communication, and leisure activities.

EVA PROCEDURES

In order to collect consistent data, one crew member was assigned as EVA Commander (CDR) for each field excursion party, and one crew member remaining at the research station was assigned as Habitat Communications Officer (Hab Comm). Before, during, and after each EVA, the EVA CDR and Hab Comm worked together to collect data according to this protocol:

EVA Planning:

a) EVA CDR and EVA team discuss specific science goals, equipment needed, and route for EVA; EVA CDR programs route into GPS, and records start and end time of planning meeting, as well as all other details of the EVA, into EVA database (typically the night before)

EVA Briefing:

b) Hab Comm records start and end time of all-hands briefing meeting (including locations of study sites, proposed route, and expected check-in times, just prior to departure) in EVA database

EVA Preparation:

c) Hab Comm records time that EVA team begins to prepare for excursion (including gathering science gear and personal supplies, and donning surface suit simulator) in EVA database

Departure from FMARS:

d) Hab Comm records time of departure in EVA database (including time in/out of simulated airlock)
e) EVA CDR turns on GPS, to record tracklog and waypoints

Arrival at first study site:

f) EVA CDR reports time of arrival to Hab Comm, via radio. This serves both as a safety check-in, and an opportunity to record the time interval between departure from FMARS, and arrival at the study site. EVA CDR records time in EVA database
g) EVA CDR saves study site waypoint in GPS
h) EVA team conducts research, collects samples, etc. EVA CDR records number of samples collected with voice recorder (meanwhile, the EVA science specialist records all other scientific data in a separate voice recorder)

i) EVA CDR reports time of departure from study site to Hab Comm; Hab Comm records this in EVA database

Arrival at second study site:

j) Follow same steps as for first study site; repeat at each study site

Return to FMARS:

k) EVA CDR reports time of return to Hab Comm; Hab Comm records time in database
l) EVA CDR turns off GPS

Post-EVA processing with MapSource software:

m) EVA CDR downloads waypoints/ tracks from GPS
n) EVA CDR selects all tracks and calculates total distance traveled

Post-EVA processing in Excel EVA-database:

o) EVA CDR inputs data from voice recorder (number of samples) and MapSource (distance traveled)

Post-EVA Debriefing:

p) EVA CDR discusses EVA outcome/lessons learned with the crew, and records start and end time of debriefing meeting in EVA spreadsheet (usually after supper)

RESULTS

Preliminary results show that during the 100-day simulation, crew members conducted 88 EVAs, and traveled a total distance of 1074 km. It is proposed that study findings be used towards the development of a baseline strategy for scheduling and logistics planning of planetary field excursions (EVAs), or an entire planetary surface exploration plan for the Moon, Mars, or any other planetary surface. More statistics are shown in comparison to Apollo data, in the section to follow.

COMPARISON OF FXI-LDM vs. APOLLO DATA

During the 100 mission days of F-XI LDM, the crew conducted more than six times the number of EVAs than did all of the Apollo surface missions combined, and traveled more than ten times further. Table 2 compares various statistics from F-XI LDM against the Apollo surface missions.

	Apollo 11,12,14-17	**F-XI LDM**
Total mission days (surface)	**12.48**	**100**
Total EVAs	**14**	**88**
Avg total EVAs per crew member	2.33	39.14
Avg EVAs per day	1.12	0.88
Total hours on EVA	80.57	288.33
% surface hours on EVA	**26.9**	**12.0**
Total hours in science lab	n/a	123.35
% surface hours in lab	**n/a**	**5.1**
Total distance traversed	**< 100 km**	**1074 km**
Avg total distance per crew member		518.39 km
Avg distance per day	< 8 km	10.74 km
Total mass of samples collected	**378.8 kg**	**roughly 100 kg**

Table 2. F-XI LDM EVA data compared to Apollo surface mission statistics.

As demonstrated in Table 2, in 100 days, the F-XI LDM crew completed, on average, 0.88 EVAs per day, and traveled on average approximately 10 km per day. In 12.5 surface days, the Apollo astronauts completed on average 1.12 EVAs per day, but traveled a much smaller distance. It is not surprising that the F-XI LDM crew spent only 12% of the mission on EVA, and 5% in the lab whereas the Apollo astronauts spent 27% of surface time on EVA. This difference arises from the facts that: a) the much longer duration F-XI LDM mission required that more time be spent on logistics and other non-science activities, and also that the crew maintained a sustainable pace; (whereas the shorter duration Apollo missions required for as many EVAs as possible to happen as quickly as possible) and b) the F-XI LDM spent a large portion of mission time processing samples in the lab, documenting preliminary science results, and planning for the day's exploration activities (whereas all samples taken by the Apollo astronauts were shipped back to Earth for study by specialists). This 17% (EVA time plus science lab time) is consistent with Eppler's [2] suggestion that less than 20% of the crew's time should be spent on science operations, due to the "logistical requirements that staying alive on a hostile planetary body may impose on any surface exploration" [2]. In addition, the Apollo astronauts collected more than three times the mass of samples as the F-XI LDM crew. This difference is due to the facts that: a) the F-XI LDM crew included four scientists, who were able to identify optimal samples, thereby down-selecting and minimizing the number of samples to return to FMARS (whereas only one out of twelve Apollo astronauts was a geologist); and b) the F-XI LDM crew ran many preliminary analyses in the field or lab, whereas the Apollo astronauts returned all samples to Earth for analyses.

FUTURE DATA PROCESSING

The authors will continue processing data to determine totals for additional categories (leisure time, sleep time, etc.), averages per crew member, gender averages, and scientist vs. engineer crew member time spent per day and over the total mission on: planning EVAs; preparing for EVAs; out on EVAs; at study sites; processing samples in the lab; writing reports; doing other work; daily leisure activities; exercising; and sleeping. Ultimately, this data will be helpful to use as a baseline for planning future human missions to the Moon and Mars.

CONCLUSIONS

It is clear from comparing percentages of time, as well as distances and sample masses, that the Apollo missions were conducted very differently from F-XI LDM. It is likely that future long duration human Moon or Mars missions will need to adopt an intermediate style of exploration, or a style more similar to F-XI LDM, pending sufficient laboratory equipment. In conclusion, more analogue studies are needed to better constrain the parameters for exploration, and to thereby identify technological and logistical requirements for future human Moon or Mars missions, and to ultimately maximize time efficiency while on the surface of another planet.

FUTURE STUDIES

The authors from the University of Western Ontario are actively conducting geological and astrobiological field research projects at numerous Moon and Mars analogue locations. They intend to build on previous studies conducted by Mars Society Canada, and also to take this study one step further by comparing the efficiency of field exploration and sample collection using more traditional field techniques (notebook, maps) with more advanced Moon/Mars human exploration analogue techniques (voice recorder, PDA with digital maps). In addition, other colleagues are using data from this study to design more advanced analogue surface suits, to increase efficiency of data collection and exploration [6].

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