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OPERATIONAL MONITORING AND ANALYSIS OF SPACE, TIME, AND SCHEDULE AS PART OF A SPACE ANALOGUE MISSION ON DEVON ISLAND

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ABSTRACT

Human factors research is a critical element of space exploration as it provides insight into a crew's performance, psychology and interpersonal relationships. Understanding the way humans work can help improve mission efficiency and safety, and lead to an optimal design for a habitat. Long duration analogue studies, such as those being conducted at the Flashline Mars Arctic Research Station (FMARS) on Devon Island, Canada, offer an opportunity to study mission operations and human factors, and contribute to the design of missions to explore the Moon and Mars. FMARS 2007 was the first four-month analogue Mars mission ever conducted, and thus provides a unique insight into human factors issues for long-duration space exploration. However, on FMARS 2007 and similar missions, both simulated and space-based, human factors studies have been considered as time-consuming contributing to the crew workload. In reality, human factors research should be treated as part of a comprehensive global science program for the crew. Here we examine the time required for the crew and support team of conceiving, managing and participating in human factors studies the FMARS 2007 expedition.

First, we will describe the selection of the four primary human factor studies by the FMARS Science Advisory Group, with assistance from the crew. These include studies on support measures based on distance communication technologies and physical training, group dynamics and the perception of situational factors, station environment habitability, and sleep disruption. Two additional studies were added during the mission, including a Mars Time study (using a 24.6 hour day) and a comparison of various food preparation strategies. Second, we will describe the administration and planning phases, including the role of the remote science team. The execution of the projects will be discussed in terms of accomplished tasks with respect to space in terms of conditions needed to perform the studies, crew time to complete the tasks, and schedule in terms of study requirements. Included in this analysis is a post mission survey of the crew and the Remote Science Team on the perceived relevance and effectiveness of each study. The operations are compared to the planned science objectives and how thoroughly they were completed. The objective of this analysis is to maximize the scientific return from the four-month mission by discussing the challenges associated with conducting human factors research, and to provide recommendations for the selection and management of human factors studies on future long duration missions.

The analysis from monitoring the six primary human factors studies will provide useful design information for mission architecture planning, as it gives both the crewmembers' and the remote scientists' perspectives in a relevant analogue environment. This will allow human factors researchers to plan effectively and avoid confounding factors, thus maximizing the success of their studies so that they yield more valuable results.

INTRODUCTION

Human factors research and data from spaceflight missions and from relevant space analogue stations are essential for gaining an understanding of human performance on long term missions to optimize mission efficiency and success. The research conducted for human factors needs to be integrated into a comprehensive global science program so that the crew is able to participate without feeling that different tasks are time intrusive. The 2007 four-month simulated Mars mission on Devon Island, Nunavut, offered realistic mission constraints and operational scenarios, similar to those that a real Mars crew would experience. The time spent on human factor tasks by the crew was recorded for all of the human factors studies. Because the simulation was realistic and the human factors studies were typical of those carried out on such missions, this data will be important input into the design of schedules for future missions. This paper assesses the time demands for preparing and execution of various human factors studies in a Mars exploration simulation, so that future researchers can plan their studies effectively.

BACKGROUND

Human Factors is an area of research that includes human performance, human-technology interactions, human-design interactions (such as habitable volume layout), and human-computer interactions in a task orientated environment [adapted from Seymour, 2002]. For the purposes of this paper, the crew physiology projects such as exercise and sleep monitoring are considered as human factors projects as they involve interactions with equipment that directly relate to crew performance. Seven human factors projects (including this paper) were carried out at the Flashline Mars Arctic Research Station (FMARS) during the 2007 long duration mission (LDM), located in the high Canadian Arctic on Devon Island, Nunavut (see fig. 1). FMARS is one of two Mars analogue stations used by the Mars Society to investigate how to live and work under Mars mission constraints. The other station is the Mars Desert Research Station (MDRS) located in Utah, USA. FMARS sits on the rim of 39 million year old Haughton Impact Crater on Devon Island (see fig. 2). The 2007 crew at FMARS was composed of seven researchers, including university graduate students and faculty (three females and four

males), and was the longest simulated Mars mission to date. The FMARS (F) 2007 crew was the 11th (XI) crew at the Arctic station, and the mission was named F-XI LDM.



Fig. 1: FMARS is located at the top of North America in the Arctic Circle (image created in Google Earth).

The F-XI LDM crew's objectives were to:

1. Survive harsh conditions and psychological challenges of isolation,
2. Prepare for eventual human missions to Mars,
3. Focus on scientific exploration, by
 - a. Investigating field exploration techniques relevant to the scientific exploration of Mars
 - b. Pursuing a suite of relevant science goals in a Mars analogue environment
 - c. Conducting scientific exploration under nearly all constraints that Mars astronauts will one day face, and
4. Generate public interest, and educate as to the importance of space exploration.

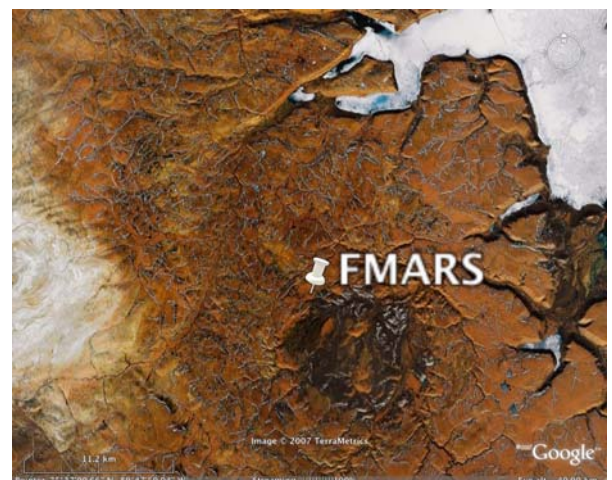


Fig. 2: FMARS location on Devon Island on the North rim of Haughton Impact Crater (image created in Google Earth).

ANALOGUE RESEARCH

Human factors research is a critical element of space exploration as it provides insight into a crew's performance and interpersonal relationships. The studies conducted with the F-XI LDM crew looked at the psychological, physiological, and sociological changes that occur over a long duration mission. The station has many constraints and operational guidelines to make the simulation as close to a Mars mission as possible. These imposed constraints are reinforced by the remoteness of Devon Island and the isolation that the crew experiences there. The closest town is an hour away by small plane, and flights are not readily available. The weather conditions vary rapidly and may delay any rescue by weeks. Devon Island is the largest uninhabited island on Earth and visible life is rare. These many similarities to Mars make FMARS one of the best Mars analogue locations on Earth. With temperatures reaching as low as negative forty degrees (Celsius or Fahrenheit) the harsh conditions simulate hardships that a crew would experience during a real Mars mission.

The simulation is further strengthened by the level of confinement, which is defined by how closely the crew follows protocols such as wearing spacesuits every time they leave the habitat. The layout of the habitat lends some visual privacy in limited crew quarters, but the walls are not soundproof. The 24 hours of daylight are analogous to that of a polar Moon or Mars mission, where the crew's schedule would be conducted in the absence of visual cues for the time of day (see fig. 3). These conditions make FMARS an ideal location for hosting human factors research and an excellent analogue for human exploration of the solar system.

Analogue research's critical role in human exploration is supported by NASA's planned use of the Moon as an analogue station for learning how to prepare for Mars. In addition, workshops have been conducted at NASA headquarters and Johnson Space Center [McKay, 2007] on the topic of using Earth analogues to prepare for space missions. The Canadian Space Agency recognizes the importance of analogue research, which is apparent from their continued funding of the Canadian Analogue Research Network (CARN) program and their funding allocation to the FMARS 2007 project.



Fig. 3: FMARS surrounded by a rocky terrain and lit by the midnight sun in late August.

METHODOLOGY

The data collected for this study can be put into four categories: direct observations by this study's Principal Investigator (PI) who was also one of the crew members; indirect observations from the Science Advisory Group (SAG) Human Factors lead; records of time spent on tasks; and responses to the questionnaire distributed to the crew and the survey distributed to the human factors Remote Science Team (RST). The crew questionnaires were divided into two types of questions: a set of scaled response, and a set of free-text feedback questions on potential improvements to the human factors program. The RST survey asked about time spent before and during the mission, and intended goals for the data collected were in terms of publications. The summary of responses from the crew is presented in Table 4 of this paper. The additional feedback received was incorporated into the lessons learnt and recommendation sections.

FMARS HUMAN FACTORS STUDIES (FHFS) OVERVIEW

The six FMARS human factors studies (FHFS) are described in this section. This paper was designated as study FHFS-05.

Study FHFS-01: Countermeasures to stress and isolation related to long term working in extreme environments during Mars Analogue Missions in the Canadian Arctic: Measure and evaluation of support interventions based on distance communication technologies and of physical training on relevance, feasibility and perceived efficacy.

This study included Telecommunication & Support Sessions (TCSS), a personalized exercise program, personal history surveys and critical incident logs. The TCSS consists of a set of questions delivered using various types of electronic communications media, including emails and video chat. Six sessions were conducted with a different medium every other week. The questions and answers provide insight into daily routines and communication patterns. Traditional and systematic approaches were used to help with relationship strategies. The formation of this study was based on data collected previously from the PI on the "Terre Adélie" mission in Antarctica, and during a 110-day confinement mission simulation in Russia. After each session the crew would fill in a technology evaluation survey and submit it to the PI.

The personalized exercise program includes the use of a stationary bike, free weights, an exercise ball, and elastics for resistance training. The bike was positioned for a scenic view of Haughton Impact Crater out the larger downstairs window. The three goals of the exercise protocol are to increase the volume of oxygen transported by the cardio respiratory system (VO₂max, a standard measure of fitness), to improve aerobic endurance, and to improve muscular endurance and flexibility (see fig. 4).

The critical incident log was filled out at the end of each third of the mission. The log had no specific structure, but asked the crew to write down any events, positive or negative, that they felt influenced their personal feelings during the mission.



Fig. 4: F-XI LDM Crewmember exercising while looking out window at crater

Study FHFS-02: Analysis of group dynamics - perception of situational factors (heterogeneous and international) and its impact on crew interaction and perception of behavior and performance of crewmembers.

This study included several online surveys to be filled in during various parts of the mission using SurveyMonkey.com. The surveys included: the Personal History Questionnaire (PHQ) at the beginning; the Deep Freeze Opinion Survey (DFOS) taken at the beginning and end; the Profile of Mood States (POMS) taken monthly; and the Group Environment Scales (GES) taken monthly. The purpose of these measurements is to evaluate the effects of personality characteristics, multicultural interactions, group dynamics and environmental stimuli on the psychological adjustment and performance of individuals working in a multicultural environment. This data will be used in combination with data from other analogue missions to develop optimal psychological selection criteria and appropriate training and countermeasures for individuals and teams working and living in multicultural extreme environments such as the Polar Regions, the International Space Station, future Lunar and Mars missions, multinational project teams, and others [Lasslop, 2007].

Study FHFS-03: Analysis of the station environment habitability, of crewmember cognitive performance and changes in group dynamics.

This study included computer based cognitive software (WinSCAT), an initial personal assessment, a monthly survey called Assessing Mars Habitat Group Dynamics, Personality, Subjective Stress and Coping (AMPS) taken online (using SurveyMonkey.com), and a end of mission survey called the Planetary Habitat Analog Design Efficiency Survey (PHADES).

The Mars Analogue Station Cognitive Testing (MASCOT) is conducted using computer-based software called WinSCAT (Spaceflight Cognitive Assessment Tool for Windows). WinSCAT is a computer-based battery of neuro-cognitive assessment tests design by researchers at NASA JSC and Wyle Laboratories (see fig. 5). It has been validated in various clinical settings and on the International Space Station. Its purpose is to evaluate the crew's brain functions objectively [Flynn, 1998].



Fig. 5: F-XI LDM Crewmember during WinSCAT training

WinSCAT evaluation criteria includes: Code Substitution Delayed Response Time; Code Substitution Delayed Accuracy; Running Memory Response Time; Running Memory Accuracy; Running Memory Lapses; Match to Sample Response Time; Match to Sample Accuracy; Mathematics Response Time; and Mathematics Accuracy [Bishop, 2007]. The F-XI LDM crew was also able to talk with International Space Station crewmember Clay Anderson [Anderson, 2007], who informed them that he have been using WinSCAT once every three or four weeks.

The AMPS survey was also taken online, and asks stress management strategy questions, to be answered on a relative increment scale. PHADES is an end-of-mission survey that allows the crew to give feedback on a relative scale about the layout and design of the habitat. It asks about space use within the structure and other aspects of habitat design.

Study FHFS-04: CASPER (Cardiac Adapted Sleep Parameters Electrocardiogram Recorder): The use of cardiac autonomic activity as a surrogate marker for sleep in a space analogue environment.

CASPER provides a portable, lightweight method of monitoring and cataloging incidents of disturbance during a crew members sleep period, based primarily upon an assessment of cardiac autonomic activity from an electrocardiogram (ECG), augmented by other physiological parameters [O Griofa, 2007]. This study is important for collecting data on crew sleep patterns for long duration missions that have analogue conditions such as high noise levels, isolation and non-standard day-night cycles, which can lead to disruption of the crew's circadian rhythm. For five consecutive nights, two

crewmembers wore ergonomic physiological monitoring systems called LifeShirts (made by Vivometrics). Another two crewmembers wore the monitoring equipment for the next five consecutive nights. Since we only had two sets of equipment, only those four crewmembers wore the LifeShirts. All crewmembers participated in the study by filling in a sleep diary during the testing nights and for the duration of the Mars Time study (see FHFS-06). The PIs on this project have previously conducted similar experiments with astronauts on the International Space Station as part of the European Space Agency (ESA) Astrolab.

Study FHFS-06: Sleep quality and cognitive/behavioral changes associated with a Martian sol sleep-wake cycle on a long-term space exploration simulation mission.

The Martian day, or 'sol', is 24.6 hours long, and during the surface exploration phase, a Mars crew would have to operate on Martian time (unless the landing site is in a polar region). This slightly longer day has psychological, physiological, and operational repercussions. We already know that astronauts are influenced by and suffer from disruption to their sleep patterns and circadian rhythm from being in Earth orbit [Santy et al 1988, Monk et al 1998]. This may be due to a combination of factors, including cardiovascular changes and exposure to microgravity. However, there is also the significant impact of disruption to the circadian rhythm to be considered, which is intrinsically linked to many of the body's other functions. NASA has even identified sleep and circadian rhythm disruption in their Bioastronautics Critical Path Roadmap as one of the key areas that must be researched and addressed before the advancement of long duration human spaceflight can occur. Risks #29 & #30 specifically address sleep, circadian, alertness and performance as key space human factors areas [Charles, 2005]. In addition to the pre-planned projects, the crew opportunistically added a "Mars Time" study for the entire month of July operating on 24.6 Earth hours per day. The PI directed the Mars Time study and monitored the crew daily with performance aptitude tests for reaction time and decision speed, both before and after sleep. Two online programs were used and the crew filled out a daily sleep log. A study of this nature has never been conducted using an analogue station and

mission. This study could only be conducted in an environment such as the FMARS station for several compelling reasons, including:

- The Arctic summer's 24 hours of sunlight offers no natural visual cues for a 24-hour day. Window shades are required for any darkness, and can be drawn at any time to simulate 'night'.
- The simulation conditions make the study realistic for a Mars journey, with respect to work load, noise levels, lack of privacy, etc., all of which can affect sleep cycles
- The long duration of the mission allows time for the crew to adapt to Mars time, and re-adapt to Earth time, giving the opportunity to study this adaptation.
- The 24-hour daylight allows the crew to safely conduct fieldwork at any time.

No direct diurnal cycle measurements were taken for this study, such as measuring enzymes excretion cycle changes, due in part to the opportunistic nature of the study, which did not allow for the level of ethics review required for medical samples to be taken.

Study FHFS-07: Food choice, preparation and satisfaction on a four-month planetary exploration simulation.

Although pre-prepared food is nutritional and requires minimal effort, there are well documented [Stuster 1996, Smith et al 2004], albeit largely anecdotal, psychological advantages to being able to prepare at least some foods from scratch. It allows the crew to prepare special dishes for particular occasions (e.g. birthdays and other milestones). It also allows the crew to eat foods that would be difficult or impossible to preserve long-term (e.g. breads and other baking, cultured dairy products, etc.).

During F-XI LDM, we found certain food-related technologies (e.g. sprout grower, yogotherm, breadmaker) to be invaluable, even though the enjoyment of food preparation as such varied widely from crewmember to crewmember. Based on this observation, we began an opportunistic study on food choice, preparation and satisfaction. Crew food choices, use of kitchen equipment, and overall satisfaction were recorded, using a daily inventory tracking system and an end-of-mission questionnaire, and are being analyzed to determine the relative value of various food preparation strategies in this context.

FHFS: PROJECT SELECTION

The study selection process included four main steps: 1) the Mars Society internal call for proposals by human factor investigators; 2) an initial feasibility assessment of by the Scientific Advisory Group; 3) Identification of a Human Factors PI lead to pursue the initial assessment and submit a proposed selection of projects to the SAG and crew; and 4) Final selection based on SAG and crew recommendations.

The feasibility criteria included an assessment of crew time constraints, availability of required facilities (e.g. storage), the innovativeness of the research, the crew's interest and motivation to participate and the integration of the studies into the general scientific program objectives.

Ethics approval

All principal investigators confirmed having obtained a 2007 ethics approbation from their institution. This ensures that all future publications respect international ethics guidelines in terms of confidentiality, informed consent, minimizing risks, providing support as necessary, respect for participants, and finally the prioritization of human health and protection over the scientific goals of the experiment.

MDRS TRAINING

Before the four-month Arctic expedition, there was a two-week crew training rotation at MDRS in Utah. The training program included a handover of human factors project information from the SAG lead to the crew lead. At that point there were only the first five human factors projects, including this study. The projects were reviewed and the approximate schedule was designed. Early issues were identified, such as difficulty of obtaining a VO₂max value on a treadmill with limited monitoring equipment. A highlight of the MDRS human factors training was with a visit from CASPER PI who gave presentations on his research and spent time with the crew lead explaining proper donning instructions for the LifeShirts (see Fig. 6). In addition Clay Anderson reinforced the need for crew training by saying: "important... to become as close as you can on the ground and that you do as much of your training as possible together" [Anderson, 2007].

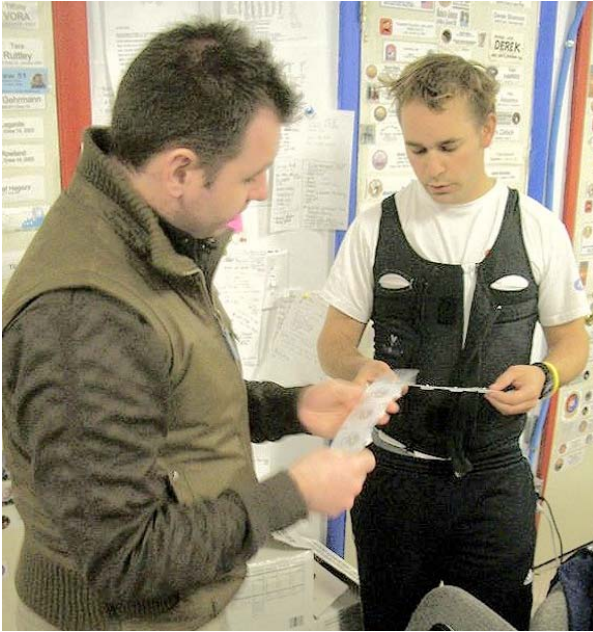


Fig. 6: CASPER PI (FHFS-04) working with human factors crew lead.

PRE-MISSION ORGANIZATION

During the two months prior to the mission, due to the widespread home locations of the SAG and crew, the planning and coordination of the projects had to be conducted via emails and the weekly teleconferences. A few additional one-on-one phone calls were made to clarify some of the study objectives. Some modifications had to be made to the projects. For example, saliva testing was removed from the coping with stress aspect of study FHFS-03 due to crew objections. The bulk of preparation time was spent on designing a schedule for the crew to follow while in the Arctic, and collecting ethics certificates for all the projects. All human factors studies at FMARS received ethics approbation from the PI's respective universities.

MISSION OPERATIONS

The largest difficulty faced by a human factors program is having a crew that is willing to cooperate and endure the sometimes-repetitive tests. The highly motivated F-XI LDM crew fully participated in all the studies with the common inspiration that the data would be used to help to improve future exploration space missions. Moreover, having a crewmember as human factors manager, with the responsibility of facilitating the studies and maintaining the weekly task schedule, helps the crew feel invested in the studies as they help their teammates carry out their duties.

Schedule changes were required during the mission due to issues such as Internet outages, and changes in programs like the addition of Mars Time.

During the mission, communication between SAG and crew was via emails and an online collaboration tool developed and hosted at the University of Hawaii called Prometheus. Prometheus provided 'workgroups', which served as discussion areas for posting messages, data, observations and files during the mission. The primary use of Prometheus for the F-XI LDM human factors studies was for posting a record of issues encountered during the CASPER sleep study. This feedback will help PIs further enhance their research program for future missions.

CREW TIME RESULTS

Crew time is a valuable commodity on a space exploration mission. Even on a long duration mission, it is important to have projects planned out and a time slot dedicated to completing that task. The schedule for human factors was arranged so that most tasks fell on Wednesdays, in the middle of the workweek. This prevented any tasks from being neglected at the end of the week. Table 2 shows a summary of time requirements from the original four projects. Table 1 summarizes the average time spent by the crew on each study. Some training time was required for the use of WinSCAT including practice sessions that averaged 45 minutes total per crewmember. Only six subjects were used for the exercise data as one withdrew from the program early in the summer. Four crewmembers participated in the CASPER sleep study by rotating the two sets of equipment over 53 nights in total. The Mars Time study (FHFS-07) was averaged over the 37 days that the experiment was conducted. This data is not directly compared to the requirements since not enough data was included in pre mission. Additionally, the tasks carried out by the crew post mission were not accounted for but include a post debriefing sessions (approximately 45 minutes per crewmember). For the averages, 100 days was used as the total mission time. The two most significant blocks of required crew time were for participation in the Mars Time study and in the exercise program. The Mars Time tasks included morning and night cognitive and reaction time tests, totaling 20 minutes a day. The exercise duration for the crewmembers was between two and four

times a week, averaging one hour per workout. Fig. 7 shows the accumulated minutes of exercise by the six participating individuals. It should be noted that the crew continued to exercise as much as possible, even when their Extra-Vehicular Activities (EVAs) increased in the middle of the mission to collect data during the permafrost transition phase. More laboratory work commenced mid-June and exercise cycles for some crewmembers became less frequent.

PROJECT	TIME SPENT [mins/CM/week]
FHFS-01 Comm.	43.8
FHFS-01 Exercise	152.1
FHFS-02 Group Dyn.	13.3
FHFS-03 Cog.+Hab.	32.6
FHFS-04 CASPER	15.8
FHFS-06 Mars Time	140.0
FHFS-07 Food Prep.	1.1
TOTAL	398.6

Table 1: Crew time spent on human factors (units are minute per crewmember per day).

STUDY #	TITLE	REQUIREMENTS
FHFS-01	Measure and evaluation of support interventions based on distance communication technologies and of physical training on relevance, feasibility and perceived efficacy.	<ul style="list-style-type: none"> *Brief questionnaire/20 min./pre; *TCSS (support sessions)/45 min. X 6; *Evaluation (cam-email-chat)/15min.X6; *Physical fitness;BMI/pre/post; *Polar watch training; *Personalized training program/3X-week; *Critical incident log/diary *Debriefing session/45 min./ post.
FHFS-02	Analysis of group dynamics- perception of situational factors (heterogenous and international) and its impact on crew interaction and perception of behavior and performance of crewmembers.	<ul style="list-style-type: none"> *PHQ/30 min./pre; *DFOS/20 min./pre-post; *POMS/10 min./pre-Xmonth-post; *GES/10 minutes/6 X.
FHFS-03	Analysis of the station environment habitability, of crew member cognitive performance and changes in group dynamics	<ul style="list-style-type: none"> *PHADES/once last day mission; *MASCOT/once a week; *AMPS/pre-once/month-post.
FHFS-04	CASPER The use of cardiac autonomic activity as a surrogate marker for sleep in a space analogue environment.	<ul style="list-style-type: none"> *5 nights baseline data/pre; *15 nights Lifeshirt/3blocks-5; *5 nights post-mission/post *PDA diary

Table 2: Time requirements matrix for original four human factors projects

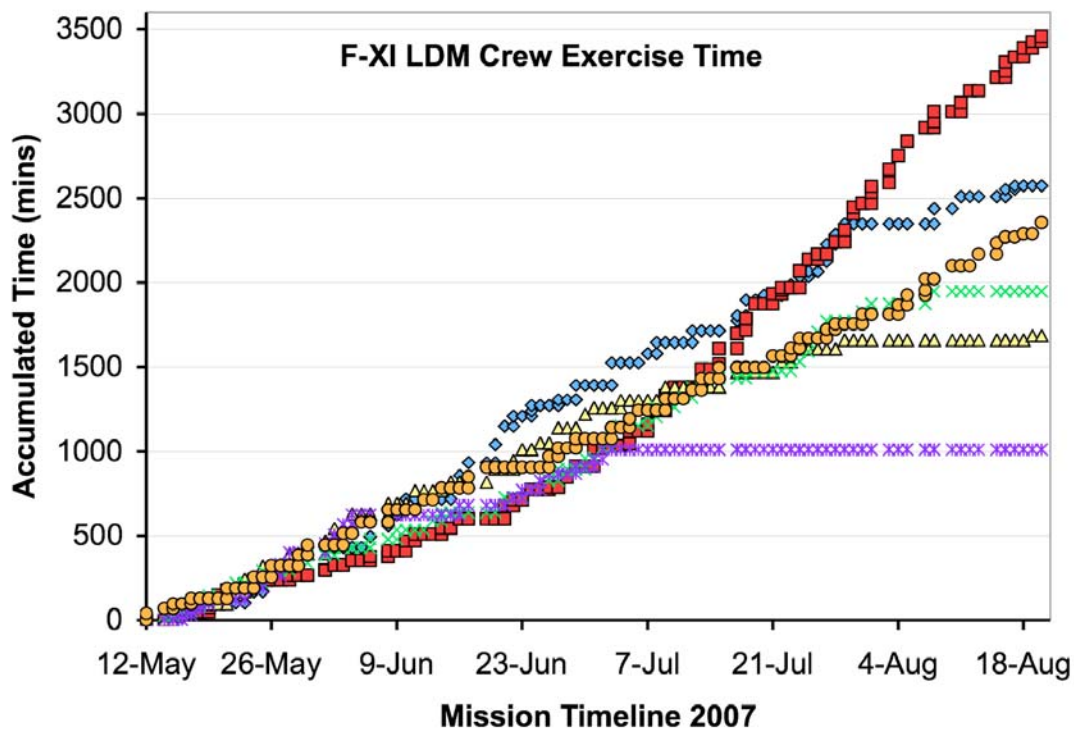


Fig. 7: Accumulated exercise minutes by six subjects on F-XI LDM crew.

HUMAN FACTORS MANAGEMENT & RST COLLABORATION RESULTS

Equally important to crew time for the human factors studies is the amount of time spent on the planning and management of the program. The following time estimates come from a survey administered to the PIs (or RST) of each human factors project and from tracking emails. These numbers are provided to give insight to the workload involved in conducting a human factors program on a long duration mission.

The lead PI and the SAG spent approximately eight hours in meetings for the initial human factors program selection. This included a one-hour from the combined weekly SAG teleconferences, as well as the time spent on reading proposals and gathering PIs contact information. The SAG meetings were weekly for the four months leading up to the mission, with good attendance. During the mission, the teleconferences were poorly attended and all collaboration was done via emails and Prometheus.

The lead and crew PIs worked together before and during the mission to coordinate the human factors program. At MDRS, approximately 3 hours were spent together transferring information about the program. An estimated 9 hours were spent on pre-mission planning each, after MDRS and before FMARS. Approximately 80 emails were sent between the two investigators during March and April.

An estimated 20 hours were spent working together during the mission to coordinate issues and maintain the program. Over 400 emails were sent between the two investigators during the four-month mission using direct email and by using Prometheus.

The crew and SAG interaction was critical for making maintain the human factors program. From June 22 until August 18th, one crewmember collected data on crew time usage, allowing the crew PI to track daily hours spent on human factors. The crew PI spent an average 1.7 hours per day on facilitating the human factors program and preparing status reports for the RST.

Prometheus was also used to communicate with the RST of all of the studies. However, most of the human factors PIs preferred to communicate by email. The only significant use of Prometheus was for the CASPER sleep study, and daily updates of issues encountered by the sleep subjects were posted there. Table 3 includes workload estimates provided by the PIs of each study. Categorizing hours from the work conducted by the PIs was difficult to breakdown since the projects varied. Some projects took little front-end time because they have been in progress with other crews for many years, while others are brand new and required significant development time. All PIs expressed intent to publish their results in various reviewed journals such as the *Journal of Human Performance in Extreme Environments* and the *Aviation, Space, and Environmental Medicine*.

END OF MISSION CREW QUESTIONNAIRE RESULTS

At the end of F-XI LDM, the crew and RST were given questionnaires to offer feedback on the human factors program. The results of the crew's questionnaire are tabulated anonymously in Table 4 with mean values and standard deviations.

	TIME SPENT [Hours]					
	FHFS-01	FHFS-02	FHFS-03	FHFS-04	FHFS-06	FHFS-07
Proposal	30	2	2	16	8	1
Training	16	0	0	8	2	0
Ethics Approval	15	2	1	8	2	2
Team Meetings	6	8	1	12	4	0
During Mission	56	9	7	16	2	1
Transcription	210	***	0	20	***	10
Analysis	30	*	6	40	***	10
Papers	24	24	24	32	24	24
TOTAL TIME	387	45	41	152	42	48

Table 3: Hour work breakdown from principle investigators of human factors studies (*Ph.D. analysis in progress, ***not available).

		FHFS-01	FHFS-02	FHFS-03	FHFS-04	FHFS-06	FHFS-07		
QUESTION	Q1	How effective do you feel this study was? (1 = very effective, 5 = not effective at all)		2.7 ± 0.6	3.3 ± 0.8	2.4 ± 1.4	1.6 ± 0.8	1.4 ± 0.8	1.7 ± 0.8
	Q2	How much did this study interfere with your daily routine? (1 = not at all, 5 = a lot)		2.4 ± 0.8	2.1 ± 0.9	2.3 ± 0.5	3.1 ± 1.3	3.7 ± 1.3	2.9 ± 1.1
	Q3	How relevant is this study for human exploration of space? (1 = very relevant, 5 = not relevant at all)		1.7 ± 0.5	2.1 ± 0.7	1.7 ± 0.5	1.3 ± 0.5	1.0 ± 0.0	1.3 ± 0.5
	Q4	How relevant is the FMARS location for conducting this study? (1 = very relevant, 5 = not relevant at all)		1.5 ± 0.8	1.7 ± 0.8	1.6 ± 0.8	1.4 ± 0.8	1.0 ± 0.0	1.7 ± 1.1
	Q5	Did this study offer insight to your own routine/psychology? (1 = very insightful, 5 = not insightful at all)		3.3 ± 1.4	3.4 ± 1.2	3.1 ± 1.3	2.0 ± 1.0	1.4 ± 0.5	2.4 ± 1.4
	Q6	Did this study influence or change your daily routine/ psychology? (1 = Changed a lot, 5 = did not change at all)		3.4 ± 0.7	3.7 ± 1.3	3.7 ± 1.1	2.4 ± 1.1	2.0 ± 1.2	3.0 ± 1.4
	Q7	Will your participation in this study influence your routine/ psychology at home? (1 = definitely, 5 = not at all)		3.3 ± 1.4	4.0 ± 1.2	3.6 ± 1.5	3.4 ± 1.5	3.6 ± 1.6	3.1 ± 1.6

Table 4: Evaluation of FMARS human factors studies by crew including mean value and standard deviation.

ANALYSIS OF FEEDBACK

Table 4 shows the mean values and standard deviations from the crew questionnaire for each human factors study. Looking at the overall program, the crew rated the Mars Time study as most relevant, effective, and insightful, but it took significant time in their daily routine. This is an example case where high crew time investment pays off in a high impact study.

For all studies, the crew found that studies were relevant for human space exploration and that the FMARS environment was a relevant location for conducting the studies. This shows that the selection of projects was appropriate and recognized as such by the participants.

Except for the Mars time study, the crew gave diverse answers as to whether or not these studies offered insight to their own routine. This corresponds with the informal comments reported in lessons learnt section, suggesting that the crew prefers to view a record of their progress in the tests/tasks they perform.

In order to compare results for each study compared to the overall project averages, the calculated means and standard deviations are presented in Table 5.

LESSONS LEARNT FROM THE CREW

The following lessons learnt are a combined set of observations from the PIs and feedback from the crewmembers.

FHFS-01: Support Interventions & Exercise

Sending additional personal feelings communications to a support PI can feel like

a time intrusive task (since issues are usually sent to family and friends), but time spent filling out answers to specific questions offers the crew an opportunity to reflect on the mission and support received. The crew all felt that this study offered an opportunity to stop and think about their mission and the goals they were working towards.

The initial session for TCSS (out of six conducted) included a survey for the crew to answer. It was not clear to the crew that this session was for the project PI to gain insight about the crew and therefore they were expecting feedback. It was later understood on that the session was not to be two-way communication but intended method for the PI to determine where to best use support interventions.

		ALL STUDIES		
QUESTION	Q1	How effective do you feel this study was? (1 = very effective, 5 = not effective at all)		1.9 ± 0.7
	Q2	How much did this study interfere with your daily routine? (1 = not at all, 5 = a lot)		2.4 ± 0.8
	Q3	How relevant is this study for human exploration of space? (1 = very relevant, 5 = not relevant at all)		1.3 ± 0.4
	Q4	How relevant is the FMARS location for conducting this study? (1 = very relevant, 5 = not relevant at all)		1.3 ± 0.6
	Q5	Did this study offer insight to your own routine/psychology? (1 = very insightful, 5 = not insightful at all)		2.2 ± 1.0
	Q6	Did this study influence or change your daily routine/ psychology? (1 = Changed a lot, 5 = did not change at all)		2.6 ± 1.0
	Q7	Will your participation in this study influence your routine/ psychology at home? (1 = definitely, 5 = not at all)		3.0 ± 1.3

Table 5: Evaluation of overall FMARS human factors studies by crew including mean values and standard deviations.

The second and third sessions offered a form of interactive feedback with a video chat and an email chat. The crew particularly enjoyed the video sessions, although we know that on Mars this would not be possible with the large time delay from Earth. Telemedicine could progress to the point where a virtual psychologist AI system could interact and ask critical questions like "How are you Dave?", but the crew suspects that it would still lack a human touch. The third session used emails to discuss questions about issues and empowerment and even though the sessions took longer than expected, the discussion was insightful and productive. The following three sessions repeated the previous modes of communication but the sixth mode was improved by using a chat program instead of emails. The crew preferred the faster communication modes as it prevented them from attending to other duties while waiting for a response. Some of these sessions were difficult to schedule with many different mission and non-mission circumstances. The timing should have been refined after the mission started. Regardless of the mode of communication, the crew enjoyed having a friendly and known person outside of the simulation to relay important issues and the comfort of knowing that they could provide support interventions.

One crewmember mentioned that they were disappointed to be missing the hockey playoffs and the PI was able to have the crew watch one of the games. The PI worked very hard to try and have the game viewed with a delay and in the end the crew was able to enjoy watching the game. Another example of a support intervention included the PI sending a package of favorite foods, books, and a movie, which was a pleasant surprise for the crew. Some crewmembers had family members pack surprises in their bags to be opened throughout the mission. For a long duration mission to Mars it would be a good idea for crew psychologists to ask family and friends to help prepare surprise packages. Small surprise packages are often sent to the International Space Station crews.

It was also particularly beneficial to have a support PI that was bilingual (French and English) so that crewmembers could have discussions in their native tongue.

Crewmembers also favored the fact that there was a set time limit for the TCSS sessions so that they knew how much support they were going to receive and made sure to get

important issues relayed. It would also be best if the PI had more training or experience on the technology systems used to avoid any issues. To help with these issues the PI and human factors crew lead were able to conduct test sessions, but earlier in the mission they were time consuming. By the end of the mission they were running very smoothly. The crew also enjoyed discussing the sessions together, which helped with group dynamics.

The crew was eager to participate in the personalized exercise program. The personal target heart ranges did not arrive until almost one month into the mission. Data such as resting heart rate, resting blood pressure, average heart rate during exercise, and duration were collected in a spreadsheet and sent periodically to the PI as the software for the polar watches was inadequate for downloading the data locally (only the last 12 exercise sessions could be transferred to an internet site). In addition, there was no feedback offered to the crew from the PI about their personal progress. It was difficult for a remote PI to be able to work with the crew and their training program. In the beginning month, the crew exercised three times a week, including approximately 30 minutes on a stationary bike and then 30 minutes of free weights. The elastic bands and exercise ball arrived late in the mission and were useful additions to the program. The intensity level of the program was also raised after one month. The frequency of exercise dropped to about two times a week in the last month of the mission because of increased number of EVAs and increased laboratory work. A proper VO₂max test should have been conducted with the crewmembers at the beginning (and end of mission) in a proper facility, as the equipment at MDRS for the training was not adequate. The physical changes would have offered useful data for planning appropriate countermeasures for long duration surface missions. In the crew feedback, several crewmembers commented that having a program that was being monitored and recorded helped to motivate them to continue to participate.

The critical incident log was initially difficult for the crew to fill out. A rough template for the crew to use with examples would have been useful. Making notes of the important events during a long duration is a good idea because when reflecting on the mission the

crewmembers can see what events influenced their attitudes and work dynamics during the mission.

A Physiology Needs Questionnaire was designed for a more personal look into how crewmembers are affected by their environment. This study was removed since baseline data was not available prior to the mission and the crew felt that the study did not provide enough anonymity, since age and gender alone was sufficient to identify individual crewmembers. Questions included frequency of sexual thoughts on a daily basis for comparison. Very strict privatization of the data would have to be ensured in order to conduct this study. Another issue was that the final survey was not ready until one month into the mission, which had already missed capturing important transition data. In retrospect the questions that were asked were so personal that the crew did not even discuss these items after spending four months together in close quarters.

FHFS-02: Group Dynamics

The surveys for this study were easy for the crew to complete and were well spaced throughout the mission to see how our opinions change over time. The web interface was simple to use but the major roadblock that the crew experienced upon arrival at Devon Island was that we did not have sufficient bandwidth to use the online service. The first survey was to be filled out by the crew on their first full day on the island to capture their first impression (not the first day of simulation, which was one week later). The crew filled in Excel files and submitted the data when a better communication link was established. Another issue was that the first crewmember arrived two weeks ahead of the rest to help prepare the habitat with critical engineering systems. They were not able to fill in the initial questionnaire on their first day so their answers were not perfectly reflective of their first impression of being on the island. A similar Internet related error occurred after one month, potentially from bad weather, and the same issues were encountered. Even though internet based surveys give PIs data in easy manageable quantitative form for statistics, it would be more realistic for a Mars simulation to collect the data without the dependence of the internet and submit the answers in a "data dump" back to Earth. Some questions were gender specific and time should be taken to

edit surveys before administering. In addition, some questions were asked about leadership but it was not clear which leader should be referred to while providing answers. For example, the commander of the mission is considered the leader for the crewmembers, but for the commander it was not clear if they should answer questions about themselves or about Mars Society personnel. Other questions were not fitting with the mission circumstance, for example "does the leader make an effort at introducing new people to the group".

Another issue encountered for this study and FHFS-03 surveys was that certain English words had to be translated to French by a crewmember. This added a lot of time and difficulty because of the synonymous nature of the words. Some felt that these tests took a lot of time and had a lot of repetition and overlap (the crew actually performed GES twice in the first few sessions but their feedback is referring to the same question being asked multiple times within the same survey). One suggestion was to make the surveys shorter and do them more often. Another issue that applies to most human factors studies was that the crew had difficulty finding a quiet area to work on the tasks. In addition to survey modifications, it would be best of the heading bar of available responses would scroll down in long surveys so that the crew could remember the scale being used (or it could be repeated often enough to be seen on the screen).

FHFS-03: Habitability, Cognitive Performance & Group Dynamics

The MASCOT practice sessions for using WinSCAT were compressed into the week leading up to the Mars simulation, meaning crewmembers performed the 20-minute test 2 to 6 times. This was frustrating for some crewmembers as the program can be monotonous. After approximately two weeks with only performing WinSCAT once a week, the crew was more than happy to comply with performing the test especially since that it only takes 10 to 15 minutes without the training instructions. The task was felt to be boring and if the test was more enjoyable the users would be more inclined to fully focus on their participation. This is a good example of how a human factors task can be integrated into a mission without interfering with crew operations. The issue of not being able to find a quiet work area made the WinSCAT testing

variables increase. If all members could use headphones it would be easier to control interference variables. Since the WinSCAT noises came from the computer and not the audio system it would have to be upgraded, if the noises are considered to be an important part of the testing. An additional variable was the time of day the test was taken. This time was not consistent with each crewmember and a set time schedule would have been more ideal to maintain as many variables as possible. The crew found WinSCAT to be a good "brain exercise" and some mentioned continuing to use it after the mission.

The AMPS survey was also taken online and the crew experienced the same issues as with FHFS-03. There was some confusion while taking these studies as the GES appeared within the AMPS survey as well. The PIs collaborated to make sure the crew only needed to fill out the GES once between the two surveys.

PHADES was relatively simple to fill out but there were sections that did not apply to FMARS (since it was designed for MDRS). This was not a big issue since N/A could be selected but there was some confusion on what certain terms applied to. The crew was told to assume "the garage" was the large storage tent and that there was no greenhouse or common area, since the upstairs area is considered the dining or wardroom.

FHFS-04: CASPER Sleep Study

The CASPER sleep study was a smooth running project, which can be attributed to the MDRS training and the available feedback during the summer from the PIs. The LifeShirts were not a perfect ergonomic fit for the crewmembers and it is possible that they interfered with sleep patterns. Even the crewmembers that were not wearing the sleep equipment were very cooperative with filling out the sleep diary. The batteries for the system could only hold a limited amount of charge and on weekend sleep-ins the initial battery would discharge completely and the user would have to use a secondary battery to fill out the morning diary, sometimes missing a significant amount of sleep hours. Luckily there was a power adapter in the habitat since the plugs that arrived were European and the electrical system at FMARS was standard North American. Some sensors would have to be taped onto the electrodes as a few disconnections were

experienced. Some skin irritations were experienced by from the electrodes. The two modifications to be made in future sleep studies would be to add information about napping and sleep times into the diary so that even none LifeShirt participants can contribute information. The time stamp on the PDA would suffice for the sleep time if all crewmembers were wearing LifeShirts, but with Mars Time the time code would have to be re-calculated daily by the PIs. It was also commented that the sleep study equipment might have caused sleep to be disturbed or worse than normal. The crewmembers that wore the LifeShirts also did not like filling out both the PDA and Excel file, and in some cases different answers were given to questions. The equipment needs to be non-intrusive to avoid affecting sleep results. The crewmembers did feel like they were productive even while sleeping as the CASPER study provided important mission data.

TCSS6: Mars Time

Conducting this study with a new circadian cycle, the crew has experienced what future Mars explorers would. The insight to living on a longer day will be sought from future investigators to tailor additional Mars time studies. Common observations made by the crew included that in the first week the crewmembers were getting hungry earlier than the meal times were set at, similarly to when someone is jet lagged and hungry on their old time zone. After a week the eating cycle reached equilibrium, but snacking was increased. It was noticeable that the crew went to bed earlier in the first two weeks of Mars Time. During the first week one crewmember commented "It feels like I pulled 3 all nighters in a row. I'm just completely exhausted". It was also noted that crewmembers were waking up naturally after 7 hours of sleep even after going to bed early. The crew commented about being out of sync with earth was sometimes difficult when regular business or personal support was needed. One positive aspect to the simulation was that our neighbors at the Haughton Mars Project were active while the crew was sleeping and vice versa. This opposite phased work cycle helped maintain the suspension of disbelief by reducing the chance encounters with other scientists in the field. The two tests taken every morning and every night were time consuming for the

crew. The tests were also taken on personal computers, unlike a common computer being used for the WinSCAT testing, so results varied depending on hardware. This variance caused some frustration for crewmembers because this caused slower results. Also the competitive nature of the crew made having lower results to be bothersome for some crewmembers. The tests themselves were simple and effective, but the quality of test could be improved. They should also be independent of an Internet connection. Crewmembers missed nights that the power was shut down or days when Internet outages occurred. The crew was highly motivated by participating in an experiment so novel that could only be conducted in an Arctic setting with the 24 hours of sun and isolation. Before the study crewmembers were worried that the study would interfere with their research or lower the quality of results, but all were satisfied once adjusted to the longer day. Fieldwork was commented to be more inspiring and a motivating challenge because of the different lighting and shadows. The Polar Continental Shelf Project safety check-ins were daily at 7:30am and 7pm, so on Mars Time some member of the crew had to wake at bizarre hours to perform their normal duties. The crewmembers involved were able to go back to sleep but it did interfere with sleep patterns. The mission support team was able to program a Mars Clock that all members used during the 37-day experiment. These were critical to keeping on track and scheduling meals and bedtime. Mars Time wristwatches would be the preferred for future studies. Reminding the crew also became a task since most nights the crew were tired and most mornings the crew were trying to get the day started. It was also suggested to try and conduct Mars Time for as long as possible during the simulation. With sunlight being a factor in early May and late August it would be suggested to try and conduct a two month experiment over the middle of the summer.

TCSS7: Food Prep.

Food variety was not an issue for the crew by rotating the daily chores including cooking lunch and dinner. One crewmember also took personal challenges to make favorite dishes out of the available ingredients. This study only included a short survey so it was simple to administer. Cooking is an essential daily life task and the crewmembers were able to

learn new techniques and new dishes from each other. Some crewmembers were not as keen to prepare meals so they would trade their “task” for alternative work. Since a few members preferred cooking, trading was easy to accommodate and no conflicts arose from food preparation. The crewmembers enjoyed trying each other’s dishes and creativity. In general, the crew did not like the Textured Vegetable Protein (TVP), but it was a useful supplement to different sauces prepared. If future study could look at pre-design meal plan versus a “make it yourself” plan and investigate how crew morale and performance are affected. Food selection and planning should be conducted for future missions included feedback obtained from this study.

LESSONS LEARNT FROM THE SAG HUMAN FACTORS LEAD PI

To improve the whole program of human factors research at FMARS the following are general guidelines suggestions:

- Make an external request for proposals (RFP) sufficiently ahead of time to allow for researchers to submit proposals;
- Make the RFP in major human factors journals, Mars Society websites, through space agencies, and universities;
- Create a human factors scientific group within the Mars Society that would also act as review committee for the research program;
- Create an email group of all human factors scientists with research proposals;
- Have the SAG human factors lead submit the group of research protocols to FMARS participants;
- Transmit discussion issues relevant to the studies to PIs, maintain same criteria but add one for comprehensiveness of the program;
- Promote sharing of data when possible to lower workload on participants; and
- Add all lessons learnt from each mission to the program.

CONCLUSION

The human factors research conducted during the F-XI LDM on Devon Island will help contribute to future programs of analogue and space research. Ongoing investigations for development of human spaceflight and exploration will be critical for learning how to keep astronauts alive, healthy, and happy.

HUMAN FACTORS RECOMMENDATIONS FOR FUTURE ANALOGUE AND SPACE PROGRAMS

Tasks must be designed so that the crew is comfortable fulfilling the requirements and if possible make the crew part of the process of looking at their own data to maintain their interests. FMARS and MDRS are excellent locations to do pilot human factors studies and they should be used in the future.

Monitoring personal statistics is very helpful for crewmembers to maintain interest in human factors studies. Humans are naturally curious about how their brain and body works and when they can see their performance change it can be helpful for regulating work load. For future studies, access to personal data should be available throughout the mission.

Exercise is a critical element to any space mission, especially for a crew experiencing a significant duration of reduced or microgravity. A more interactive program with future analogue crews on long duration missions should be investigated for relevant terrestrial environments. This data would be valuable since the crew is very restricted in physical activity in their daily lives with the only activity being EVAs or going down the ladder to use the laboratory or bathroom. All space studies are focused on microgravity bone and muscle reduction but further investigation is required for mission operations with surface EVAs. An interactive program would keep the crew motivated and also return the significant data. This methodology of interaction would also apply to all human factors research, as participants would be more willing to learn about themselves versus being someone else's guinea pig.

For future communication studies, the Mars signal delay should be observed. Every synchronous session of support takes away the sense of isolation. Alternative methods could be investigated using recorded video and audio messages.

Integrated into the planning and training of future crews, it is important to have pilot data and crew training time for all human factors studies. Having two RST PIs at MDRS to present their research and train the human factors crew lead on using the equipment is a perfect example of how to properly prepare a crew for a mission. This point is inherently obvious but has not been practiced

previously for all studies conducted in human factors or field sciences in analogue research.

A human factors support member to meet crew before and to speak with them during the mission can provide continuity of managing the human factors program. A crewmember does not need to take the lead in managing tasks but since the crews schedule was flexible it was important to have someone on the inside reminding everyone of deadlines and daily tasks.

Using a project organization tool for data like Prometheus should continue and be further developed so that all users are comfortable with the interface. This program proved to be a useful way to organize data and was easy to navigate while looking for data.

For further validation of data, control groups should be used where applicable. Crew alternates could be used as test subjects as they may want to help with the mission. They could potentially help manage the human factors program as well since it was observed to be a 1.7-hour daily commitment. By allowing them to test the different protocols, it gives them the opportunity to find issues before the prime crew experiences them.

A follow-on survey might be administered to the crew to gain retrospective data on the project and how their lives may have changed from the experiences learnt while on their mission. Example changes could include exercise regime, cooking variety or diet, and work output.

The human factors tasks not only need to be scheduled in advance for the day performed, but for tasks such as exercise, it would help to observe a schedule with predictable time slots. In the beginning of the mission the crew picked their preferred exercise times, but with EVAs and other chores the schedule was not used after one week.

The crew did prefer that all the human factors studies were scheduled before the mission and spread out to fit into the daily routine. The data collection strategies in combination with the schedule made it relatively simple to complete all of the tasks during the mission.

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