Crew Experience at the Mars Desert Research Station

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ABSTRACT

Preparing for manned space exploration missions beyond Earth orbit requires precursor activities in the form of integrated mission simulations at dedicated Earth-based analog facilities such as the “Mars Desert Research Station”, a Mars-analog planetary surface base operated by the Mars Society in the deserts of southern Utah. Based on the author’s experience as executive officer, station engineer and medic during the first closed crew rotation at the “Mars Desert Research Station”, this paper documents some lessons learned for the design and operation of the next generation of analog bases and for actual future planetary outposts.

INTRODUCTION

Today, the Earth’s frontiers may be settled, but a new frontier on a new world awaits mankind’s pioneering spirit. Sending the first human expedition to Mars, while definitely feasible ([41], [15]), still poses a formidable challenge to mission and systems engineering due to the inherent complexity of manned space exploration missions beyond Earth orbit. Planning such missions requires precursor activities in the form of integrated Earth-based simulations at dedicated analog facilities [14]. These facilities allow the operational, hardware, and human side of all mission-related elements to be combined, and therefore permit the capturing of interactions among those elements in order to derive design requirements, identify potential system- and subsystem-level integration problems, and generate invaluable “lessons-learned” data. Their mission objectives thus go beyond those of traditional closed-chamber life support system testing facilities [25] or isolation experiments [36], and just like actual future planetary bases, their design requires thorough integration of the human crew and technological environment ([1], [26], [28]). In addition, the unique context of such facilities can motivate all contributors and provides a focal point for related volunteer and outreach activities.

With human expeditions to Mars expected to take place in the next few decades [15], such integrated simulation facilities are already in place ([8], [12], [33]). Among the first is the “Mars Desert Research Station” (MDRS; [20]), a Mars-analog planetary surface base operated by the Mars Society in the deserts of southern Utah, where the author served as executive officer, station engineer and medic during the first closed MDRS crew rotation in April 2002 [21]. Based on the first-hand experience gained during that mission, this paper will document some lessons learned and suggest improvements related to the design and operation of the next generation of analog bases and actual future planetary outposts. The focus will be on station design features, equipment, procedures, and operational support.

Certain caveats need to be kept in mind, however. By necessity, first-hand field reports are anecdotal to a certain degree since they relate to one specific example or experience, and subjective insofar as the authors/crewmembers determine what lessons are worth reporting and what recommendations seem important from their own perspective. Issues covered thus range from crucial to the seemingly mundane, but by spanning the whole range, each such report contributes to the initial documentation of a crew’s overall experience. Strictly objective approaches will also increase a simulation mission’s cost and complexity, and may be too specific to capture the unexpected [9].

Distilling lessons and generating recommendations from just one simulation mission – or even one simulation facility – is also fraught with the danger of drawing conclusions that are not generally applicable and thus might prove counterproductive. Field reports must therefore be integrated among various analog sites and correlated with spaceflight experience and research results.

Another limitation relates to extrapolating from short-duration to long-duration missions, especially with respect to the impact of habitability and crew dynamics. In this context, it is also important to keep in mind that the perceived and actual risk of a simulation

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environment on Earth is never as high, opportunities for discovery are never as plentiful, and isolation is never as complete as during an actual space mission.

THE MARS DESERT RESEARCH STATION

The Mars Society [38], an international association of space scientists, engineers and others interested in advancing the case for sending humans to Mars, has started building and operating a number of Mars-analog stations in remote environments:

- Flashline Mars Arctic Research Station, FMARS, built in 2000, is located on Devon Island in the Canadian Arctic close to Resolute Bay ([12], [33]);
- Mars Desert Research Station, MDRS;
- European Mars Analog Research Station, EuroMARS, to be built in 2003 in Iceland [11];
- Australian Mars Analog Research Station, planned to come on-line in 2004, located in Australia’s red center [2].

Below is a brief description of MDRS; further information is available at the MDRS website [20].

SITE

MDRS is located in the deserts of southern Utah near Hanksville [13], about five hours by car south of Salt Lake City (Figure 2). Figure 1 shows the site’s very Mars-like look and gives a first impression of the station’s exterior. Its design reflects current thinking about the first Mars bases ([15], [41]). In addition to the large habitation module (“hab”) described in the subsequent section, the base consists of an experimental greenhouse, several unpressurized rovers (All-Terrain Vehicles, ATVs), a power plant with gasoline-powered generators, an external water storage tank, and an “Earth Return Vehicle” (minivan) for crew transfer to and from the Salt Lake City airport.

PHYSICAL LAYOUT AND EQUIPMENT

MDRS was built by a team of Mars Society volunteers led by Frank Schubert. Its layout is based on that of FMARS, which was designed by Architect Kurt Micheels and his team. Two floors accommodate research-related (lower floor) and crew habitation space (upper floor). Figure 3 shows the lower floor's layout. It features a primary and backup airlock, a room for EVA suit and equipment storage, a large work area with laboratory equipment for biology and geology research, a small workshop area for the station engineer, and crew hygiene facilities. A central column provides support for the upper floor. Small circular windows are provided in the airlock doors, in the EVA preparation room, and above the laboratory work table. A steep set of stairs next to the primary airlock leads to the upper floor.

Figure 4 shows that the upper floor is divided into two main areas. The northern half contains six crew quarters (CQs) of approximately equal size, each providing a bunk and a shelf/desk for crewmembers to work and store their personal belongings. The southern half contains a galley for food storage and preparation (Figure 5, left), a long work table for crewmembers to set up their personal computers, and a communications desk with the main computer, Starband satellite receiver, and a low-power radio base station for communication with EVA crews. The wardroom table, large enough for the entire crew to sit at, is located in the center of the floor. It is used for meals, meetings, and individual projects (Figure 5, center and right). Two large circular windows are located on the south and east
ORGANIZATIONAL STRUCTURE

The Mars Society owns MDRS, it finances its operation and provides general organizational support and mission rules within which the crews operate. The Mars Society also coordinates public outreach and pre-selects crew volunteers. This framework provides broad latitude to the individual crews for defining their own mission objectives and management styles. Commanders are tasked with the final selection of their crews, as well as with preparing and executing a crew rotation.

During an MDRS mission, all communications between the crew and the "outside world" are done by e-mail via the Starband satellite link. It is routed through an off-site Mission Support center staffed by Mars Society volunteers. Mission support for Crew Five’s rotation was provided by the Northern California chapter of The Mars Society under the guidance of Mark Klosowski and Frank Crossman.

Local support (replenishing of fuel and water tanks, ATV maintenance, waste disposal) is done through a local contractor. A motel in Hanksville, about four miles from MDRS, accommodates crewmembers for occasional pre-/post-mission overnights and also serves as a base for Mars Society support staff upgrading MDRS systems or performing major repairs between crew rotations (regular maintenance and repairs are each crew’s responsibility).

CREW FIVE

MDRS crewmembers are unpaid volunteers with suitable professional and personal backgrounds. The current MDRS crews have been selected from a pool of over 500 applicants who responded to the Mars Society’s open calls for volunteers [6]. Crew Five included the following members:

- Dr. William J. Clancey, Commander and Human Factors Researcher. Dr. Clancey is Chief Scientist for Human-Centered Computing in the Computational Sciences Division at NASA’s Ames Research Center, where he manages work systems design and evaluation for Mars exploration missions and the International Space Station. He is also a Senior Research Scientist at the Institute for Human and Machine Cognition at the University of West Florida in Pensacola.
- Andrea N. Fori, Geologist. Ms. Fori is a planetary geologist with a background in Martian geology; she works for Lockheed-Martin as an aerospace systems engineer tasked with instrument design, payload integration and missile development.
- Dr. Jan Osburg, Executive Officer, Health and Safety Officer, Station Engineer. Dr. Osburg is an aerospace systems engineer specializing in human integration and life support issues; at the time of Crew Five's mission, he worked as researcher and...
lecturer at the University of Stuttgart’s Space Systems Institute in Stuttgart, Germany.

- Dr. Vladimir Pletser, Geophysicist and Botanist. Dr. Pletser’s background is in Geo- and Astrophysics. He manages the European Space Agency’s parabolic flight program and is involved in instrument development for ISS. He is also an astronaut candidate for Belgium and has done two months of astronaut training.

- David Real, Public Affairs Officer. Mr. Real is an editor and writer for Belo Interactive which runs the web sites and provides content for the Dallas Morning News and other major newspapers and TV stations.

- Dr. Nancy B. Wood, Microbiologist. Dr. Wood is an experimental scientist with expertise in chemistry and microbiology. Her interests include the adaptation of microorganisms, especially human-associated microflora, to novel environments.

SCOPE OF SIMULATION

Crewmembers are subject to strict mission rules aimed at making the operation of MDRS as similar to a real Martian surface habitat as possible ([3], [4]). One of Crew Five’s objectives was to be the first MDRS crew to run a “closed simulation”, meaning that no crewmember left the station without donning a “Marsuit” and following EVA protocol (Figure 7), and no external visitors were allowed inside the hab.

The station’s design, however, required some compromise: handling gasoline for the ATVs and the generators, for example, had to be performed without an EVA suit for safety reasons. Also, due to the fact that all crewmembers were volunteers who for the most part had to take personal time off from work for the duration of their mission, joint pre-mission training and post-mission debriefing had to be cut from the schedule, and mission duration was limited to two weeks.

On the other hand, the facility provided for an accurate simulation of everyday station operations, mission support procedures, EVAs and field science. Due to the remote location of MDRS, confinement, isolation and risk also affected the crew, which added to the authenticity of the simulation.

The crew investigated the following issues during their stay [7]:

- If there is life on Mars, how can crewmembers best take a soil or rock sample that contains it?
- How can “expedition memory” be improved? Can a geologist, for example, fully understand the work performed by previous crews and develop a geology primer of the region?
- What is the effect of chores like cooking, cleanup, waste management system maintenance, etc. on science team productivity?
- What are the psychosocial benefits of growing plants in the hab?
- How do plans develop and change during the mission? How do individual and group activities affect one another?
- How can Earth-based mission support understand and assist Mars surface exploration? Can mission support suggest possible EVA targets and routes by using data such as reports from previous crews?
- How is public and private space used? How can the hab’s layout be improved?
Several reports have been published by Crew Five members covering those and other issues ([7], [31], [32],
[34], [35], [39]).

OPERATIONS

Crew Five structured its days according to the following schedule:

- 08:00h: wake/wash/breakfast
- 09:00h: crew meeting
- 12:30h: lunch
- 14:00h: EVA (until 18:00h or 19:00h)
- 20:00h: dinner
- 21:30h: movie (occasionally)
- 02:00h: sleep

The unscheduled time was taken up by research, maintenance work, report writing, etc. Lunch and dinner were welcome group activities, as was jointly viewing the occasional Mars- or space-themed movie (the crew had brought DVDs to run on personal laptops, as well as a computer projector and a screen). Housekeeping chores rotated daily: generator maintenance and water tank refilling required two crewmembers, while the cook/janitor role, appropriately titled “DGO” (Director of Galley Operations), was performed by one crewmember.

Overall, Crew Five’s rotation lasted fifteen days, with twelve days of closed simulation, one “open house” day for media visitors, and one handover/travel day before the simulation and one after. More detailed information about daily activities and statistics on time use are provided by Clancey [7].

LESSONS LEARNED FOR FUTURE PLANETARY BASES

Representing the first generation of analog Mars bases, MDRS turned out to be extremely well suited for the task. No major problems occurred that would have forced Crew Five to cut short its simulated mission.

However, as expected, many issues were identified that now can serve as valuable lessons for future planetary bases. These will be discussed in this section, while the next section will summarize those lessons that are specifically applicable to the next generation of analog bases. Lessons learned are categorized into useful procedures, useful design features, and additional recommendations. Issues are consecutively numbered for easy referencing.

USEFUL PROCEDURES

1. Final crew selection by commander after extensive telephone interviews of candidates from a shortlist led to mutual compatibility of crewmembers’ personalities and increased crew coherence
2. Crew roles that covered all important aspects: Commander, Executive Officer, Engineer, Health and Safety Officer/Medic, Microbiologist, Biologist/Botanist, Geologist, Human Factors Specialist, Public Affairs Officer
3. Rotating chores among crewmembers (according to a schedule generated by the crew itself) was efficient and sustained crew morale
4. Crewmembers cross-training each other during the mission also increased morale
5. Assigning a name to every established waypoint helped EVA routing and communication, since it is much easier to remember names than waypoint numbers or coordinates [23]; naming geographic features is also a traditional prerogative of explorers and thus increases crew motivation
6. Posting all daily reports and pictures on a public website [22] enabled rapid-turnaround documentation and feedback; it also supported the outreach effort and therefore encouraged crewmembers to write reports
7. Encrypting personal e-mail between crewmembers and family/friends with PGP software [30] assured complete privacy and therefore reduced perceived degree of isolation and confinement

Figure 5: MDRS upper floor (from left): galley area, with Dr. Pletser officinating as DGO; wardroom table used for lunch by Crew Five (author, Dr. Pletser, Mr. Real, Ms. Fori, Dr. Wood; Dr. Clancey took the picture); wardroom table used for project by the author (background shows hab computer/communications area with large porthole)
USEFUL DESIGN FEATURES

8. Spaces most utilized by the crew were (in this order): stateroom (especially those equipped with LAN access), workstation, mess table [7]
9. High ceiling on upper floor of hab gave feeling of spaciousness
10. Carpeting on upper floor improves habitability, metal floor on lower floor facilitates cleaning
11. LAN access in crew quarters allowed using CQ as private office
12. High crew quarters bunks acted as work desks during the day
13. Each crewmember definitely needed a personal laptop for daily work, in addition to the PC fileserver installed in the hab
14. Useful galley equipment: bread maker (availability of fresh-baked bread boosted crew morale and improved diet while requiring only minimal effort), crock-pot-style slow cooker (low crew time and power requirements)
15. Using lightweight, compact ATV-type vehicles increased EVA range while allowing for individual mobility of crewmembers, maintaining full immersion into environment, and providing multiple redundancy in case of breakdowns
16. Duct tape, which was available (and used) in large quantities, was a crucial tool for a host of repairs and improvements (Figure 6)

ADDITIONAL LESSONS AND RECOMMENDATIONS

17. Having a rugged mobile computer available for EVAs allows the crew to take the GIS database (containing the list of waypoints and area features) as well as science-related files into the field
18. Inventory and logistics management (what is available, where it is, what needs to be resupplied, what incoming crews can expect) is crucial, as corroborated by ISS experience [37]
19. Each crewmember should be assigned one complete EVA suit (helmet, suit, backpack, gloves, gaiters, boots, radio, GPS) that he/she alone uses and maintains during a mission; this significantly reduces EVA preparation time and increases the likelihood that suits are properly maintained
20. Crew quarters doors should have ventilation slats and “windows”
21. All crew quarters should feature outside windows
22. Lots of shelving and cabinetry is required in crew quarters
23. Providing high-quality kitchen appliances allows for more efficient use of crew time [7]
24. A heavy-duty pressure cooker can be used for efficient food preparation as well as to sterilize instruments for biology lab and medical use
25. The EVA prep room can serve as a private meeting area and should therefore contain two or three chairs [7]
26. An ATV trailer (with trailer hitches installed on all ATVs) increases the amount of equipment available in the field
27. A contingency kit containing tools and emergency supplies should be carried on every motorized EVA
28. A fail-safe backup toilet system is crucial to crew health and morale
29. All liquid pumps must be able to survive running dry, and be redundant
30. Large amounts of H₂O₂, bleach or similar substances are required for disinfection, including periodic disinfection of hab interior surfaces, water tank and pipes
31. Lots of filing cabinets and shelves are needed in work areas
32. Station toolkit should include high-quality multimeters; a soldering station with accessories and associated consumables; bulk materials such as nails, screws, lumber, sheet metal and piping; as well as tool cabinets and organizers
33. Mission planners must realize that chores and seemingly minor technical problems can turn into major time-consumers (cf. ISS experience [24]), and issues affecting key systems (e.g. water and waste management, power supply, communications and IT infrastructure) will impair habitability and productivity

Figure 6: Multiple-use items such as duct tape enable applying the full range of a human crew’s ingenuity (from left: splinting broken equipment, creating a multi-functional EVA glove, improvising flypaper)
34. Due to the long time delay between a Mars base and Mission Support on Earth, the crew needs autonomy (i.e. authority, knowledge and means) to deal with rapidly evolving situations [7].

35. Experience shows that field science is a very iterative process, thus a planetary base requires on-site, rapid-turnaround lab facilities [39].

36. Documentation and debriefing is crucial to maintain continuity during station handover, especially for the engineering and science roles.

All in all, the basic design of MDRS, given some minor improvements, seems appropriate for the support of human operations on a planetary surface. It can therefore be used as a baseline for the next generation of analog facilities.

LESSONS LEARNED FOR FUTURE ANALOG STATIONS

The lessons for actual planetary bases compiled in the preceding section are of course also applicable to analog simulation facilities. In addition, however, Crew Five’s experience resulted in several recommendations that are applicable to simulation facilities. These issues will be summarized in the following, organized under the headings of useful procedures and design features, suggested improvements and additional equipment, and additional recommendations.

USEFUL PROCEDURES

37. Giving individual crews latitude in selecting their own command style, detailed mission objectives, mission support strategies, etc. leads to motivated volunteers as well as to valuable experience with a using variety of approaches.

38. The volunteer system in combination with moderate qualification requirements results in increased diversity of crewmembers.

39. Running mission support from an off-site location is realistic since it introduces e.g. communications delays and restricted bandwidth, limits situational awareness of mission support staff, and forces the crew to deal with mechanical and other problems on their own.

40. Using multiple GPS receivers for recording each waypoint increases positioning accuracy and allows for estimation of positioning error.

41. Hosting dedicated Open House/Media Days before or after closed crew rotations allows for outreach and media integration while preserving isolation during simulation.

42. Outreach benefits greatly from a website presenting daily unfiltered updates and pictures.

USEFUL DESIGN FEATURES

43. Station location in a large (several square kilometers) Mars-like environment (cf. # 62).

44. A Starband®-type satellite link provides sufficient bandwidth for e-mail and low-speed Internet access from remote locations, but it probably provides better connectivity than what will be available on Mars [5].

45. Not having a mattress on bunks in crew quarters improves hygiene, while crewmembers’ personal self-inflating mattresses provide sufficient padding.

SUGGESTED IMPROVEMENTS

46. In the early phase of a simulation facility’s life, on-site technical support is needed to fix mechanical and electronic problems quickly that are frequent during set-up and initial simulations (cf. # 63).

47. On motorized EVAs that leave the established roads, at least three crewmembers/ATVs are required since it is impossible for two people alone to lift an ATV that is stuck in rough terrain.

48. On-site crew training on hands-on topics such as ATV and GPS use, radio use/procedures, and safety drills should be mandatory on the day before a crew rotation starts.

49. A handover period between crews should be mandatory so the new crew can “learn the ropes” from the previous crew in key areas such as hab systems operation, current problems and workarounds, etc.

50. A day immediately after the end of a crew rotation should be devoted to joint and individual post-mission debriefing of all crewmembers.

ADDITIONAL EQUIPMENT


52. Topographical maps of the station’s surrounding area with superimposed UTM coordinate grid, laminated and mounted on 11” x 8.5” boards, to help with navigation and documentation during EVAs.

53. Tyvek® coveralls to be worn over EVA suit during handling of gasoline (ATV refueling), or over IVA.
clothing during activities involving hazardous materials (waste management compartment cleanup etc.), including chemical-resistant gloves

54. Simple smoke hoods (EvacUB® or similar product), to be stored on upper floor

55. Emergency real-time voice communication system (satellite phone, ham radio) in addition to regular time-delayed satellite e-mail/Internet connection

56. Marker panels, smoke grenades and flares to mark landing zone in case helicopter medevac is required

57. Flypaper; scorpion, rodent and ant traps

58. Rechargeable batteries for all handheld devices, plus lots of disposable batteries as spares

59. Sensors for continuous measurement and logging of potable water use

ADDITIONAL LESSONS AND RECOMMENDATIONS

60. A two-week crew rotation does not address long-term habitability issues, therefore expansion of simulation duration to several months (cf. LMLSTP Phase I/II/III, [16], [17], [18], [19]) and ultimately several years is required; simulation facilities must provide sufficient flexibility to accommodate such growth in mission/simulation duration

61. The downside of having volunteer crews of diverse backgrounds (cf. # 38) is that typical analog station crewmembers will probably differ from actual astronauts in personality and abilities; for validation purposes, it is recommended that at least some simulations are run with crews recruited from the astronaut corps

62. A realistic overall environment is important to properly simulate crew dynamics and to maintain crew motivation; it should include the simulation facility being in a location that provides actual isolation, a certain degree of real risk and abundant opportunities for discovery and encountering the unexpected

63. Especially in the early phase of a simulation facility’s life where equipment failures are more frequent, it is difficult to strike a balance between increasing realism by having the crew perform all repairs by themselves, and improving efficiency by using external maintenance staff (cf. # 46)

64. When forced to make trade-offs affecting simulation accuracy for budgetary or other reasons, the focus should be on the facility’s ability to enable an integrated simulation with emphasis on the human element – the most crucial and at the same time most complex mission component

Many additional MDRS-specific recommendations were compiled in a post-mission report to MDRS program management [27]. The web-published daily field reports from MDRS [22] provide an abundant source of detailed information about operational and crew-related aspects. Of course, those desiring to gain first-hand crew experience are encouraged to volunteer for crew duty via the Mars Society’s website [6].

CONCLUSIONS

The first closed simulation at the Mars Desert Research Station has yielded a large amount of valuable experience and lessons learned that have already had a positive impact on the ongoing work there: Recent MDRS upgrades include a custom-designed Geographic Information System, longer crew rotations, and follow-up crew performance investigations [29]. Analog simulation facilities currently under construction (EuroMARS in Iceland, [11][10]) or in various stages of planning (Analog Simulation Facility in Australia [2]; NASA’s INTEGRITY project [14]) will profit as well from the experience gained by the pioneering crews of FMARS and MDRS.

An important final recommendation is to achieve some degree of overall synchronization among those projects, in order to maximize the usefulness of the joint body of knowledge that their operation will yield. Dedicated workshops [40] and sessions at conferences such as ICES are already a step in the right direction. Coordination of simulation approaches and objectives, cooperation in areas ranging from crew selection and training to mission support services, and free exchange of results and lessons learned will benefit all involved.

Such measures are even more important given that many time-consuming iterations of design and integrated testing will be needed before the first crew can be sent with confidence on their historic journey to Mars. The experience gained at MDRS and other analog simulation facilities can make a significant contribution to the success of this magnificent endeavor, which will quite literally open up a new world and thereby move mankind ahead on the sometimes rocky but ultimately inevitable path to the stars.
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ACRONYMS

AIAA American Institute of Aeronautics and Astronautics

ALS Advanced Life Support

ATV All-Terrain Vehicle

CQ Crew quarters

DGO Director of Galley Operations

EVA Extravehicular Activity

FMARS Flashline Mars Arctic Research Station

GIS Geographic Information System

HMP Haughton-Mars Project

ICES International Conference on Environmental Systems

INTEGRITY Integrated Human Exploration Mission Simulation Facility

ISS International Space Station

IVA Intravehicular Activity

JSC Johnson Space Center

LAN Local Area Network

LMLSTP Lunar-Mars Life Support Test Project

MDRS Mars Desert Research Station

MEOW MDRS Expedition One WinSCAT Experiment

NASA National Aeronautics and Space Administration

PC Personal Computer

PGP Pretty Good Privacy

SAE Society of Automotive Engineers

WinSCAT® Spaceflight Cognitive Assessment Tool for Windows