Mission control team structure and operational lessons learned from the 2009 and 2010 NASA desert RATS simulated lunar exploration field tests

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Abstract
The NASA Desert Research and Technology Studies (Desert RATS) is an annual field test of advanced concepts, prototype hardware, and potential modes of operation to be used on human planetary surface space exploration missions. For the 2009 and 2010 NASA Desert RATS field tests, various engineering concepts and operational exercises were incorporated into mission timelines with the focus of the majority of daily operations being on simulated lunar geological field operations and executed in a manner similar to current Space Shuttle and International Space Station missions. The field test for 2009 involved a two week lunar exploration simulation utilizing a two-man rover. The 2010 Desert RATS field test took this two week simulation further by incorporating a second two-man rover working in tandem with the 2009 rover, as well as including docked operations with a Pressurized Excursion Module (PEM). Personnel for the field test included the crew, a mission management team, engineering teams, a science team, and the mission operations team. The mission operations team served as the core of the Desert RATS mission control team and included certified NASA Mission Operations Directorate (MOD) flight controllers, former flight controllers, and astronaut personnel. The backgrounds of the flight controllers were in the areas of Extravehicular Activity (EVA), onboard mechanical systems and maintenance, robotics, timeline planning (OpsPlan), and spacecraft communicator (Capcom). With the simulated EVA operations, mechanized operations (the rover), and expectations of replanning, these flight control disciplines were especially well suited for the execution of the 2009 and 2010 Desert RATS field tests. The inclusion of an operations team has provided the added benefit of giving NASA mission operations flight control personnel the opportunity to begin examining operational mission control techniques, team compositions, and mission scenarios. This also gave the mission operations team the opportunity to gain insight into functional hardware requirements via lessons learned from executing the Desert RATS field test missions.

Abbreviations: 2XComm, Twice a day Communication; ATHLETE, All-Terrain Hex-Limbed Extra-Terrestrial Explorer; Capcom, Capsule Communicator; CC, Continuous Communication; DC, Divide and Conquer; EAMD, Exploration Analogs & Mission Development; EVA, Extravehicular Activity; ISS, International Space Station; LOS, Loss of Signal; L&F, Lead and Follow; MCC, Mission Control Center; mMCC, mobile Mission Control Center; MMT, Mission Management Team; MOD, Mission Operations Directorate; OpsPlan, Operations Planner; PEM, Pressurized Excursion Module; PUP, Portable Utility Platform; RATS, Research and Technology Studies; SciCom, Science Communicator; SEV, Space Explorations Vehicle; SEV A, Space Exploration Vehicle Alpha; SEV B, Space Exploration Vehicle Bravo; SimSup, Simulation Supervisor; TD, Traverse Director; TD1, Traverse Director 1; TD2, Traverse Director 2

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This paper will detail the mission control team structure that was used during the 2009 and 2010 Desert RATS Lunar analog missions. It will also present a number of the lessons learned by the operations team during these field tests. Major lessons learned involved Mission Control Center (MCC) operations, pre-mission planning and training processes, procedure requirements, communication requirements, and logistic support for analogs. This knowledge will be applied to future Desert RATS field tests, and other Earth based analog testing for space exploration, to continue the evolution of manned space operations in preparation for human planetary exploration. It is important that operational knowledge for human space exploration missions be obtained during Earth-bound field tests to the greatest extent possible. This allows operations personnel the ability to examine various flight control and crew operations scenarios in preparation for actual space missions.

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1. Introduction

The 2009 and 2010 NASA Desert Research and Technology Studies (Desert RATS) field tests were conducted at Blackpoint Lava Flow, near Flagstaff Arizona as simulated two week lunar rover missions. Desert RATS is an annual engineering field test that originated in support of advanced spacesuit design and has since evolved to support field testing of a variety of surface based human space exploration hardware and lunar geologic science field operations concepts (Ross et al.) [8]. The hardware in these tests included advanced surface spacesuit designs, various surface exploration extravehicular activity (EVA) equipment and tools, as well as conceptual lunar rover designs, and other potential hardware for use during future human planetary space exploration (Ross et al.) [8].

The 2009 and 2010 NASA Desert RATS field tests incorporated a number of activities into a mission operations style timeline using advanced hardware, tools, software (Lee et al.) [7], and lunar surface field geology concepts (Horz et al.) [4]. Multiple NASA centers, universities, and science organizations provided both hardware and personnel for the exercises. The field test was organized and executed in a framework that was based on the current Space Shuttle and International Space Station (ISS) mission operations [5] (JSC-26843) [6] (JSC-29229) with allowances for the fact that this was an Earth based analog conducted in support of engineering field test evaluations of both hardware and concepts of operations.

For the 2009 field test, the executed mission scenario was a simulated two-week lunar exploration with continuous communications with the mission control team, using a single two-man rover, called a Space Exploration Vehicle (SEV). During the test, the crew of one astronaut and one geologist, lived and worked in and around the SEV 24 h a day for the entire two week mission duration (Abercromby et al.) [1].

In 2010 the field test mission scenario evolved into a more elaborate two-week lunar mission using multiple crewed assets in two major modes of communications (Ross et al.) [8]. The first was continuous communications, where assets were required to support a communications link with the mission control team. The second mode was twice-a-day communications where, after receiving a morning prebrief, the crew worked autonomously through the day, and then setup their communications hardware to re-establish communications with the mission control team (Abercromby et al.) [1]. The major components included two SEVs, a Portable Utility Platform (PUP) that contained the communications relay station, a Pressurized Excursion Module (PEM) mockup, and a large unmanned cargo transport robot (All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE)).

Fig. 1. Two Space Exploration Vehicles (SEV) preparing to dock with the Pressurized Excursion Module (PEM) during the NASA Desert RATS 2010 field test.
PUP is a small pallet that was carried on the aft of the SEVs, and was able to be deployed as a communications relay station between the SEVs, and provide high bandwidth communications to the control team. The PEM is essentially a small habitable module that theoretically would be relocated across the Lunar surface by the ATHLETE robot. It provides an airlock, several workstations, and a compact geology glovebox laboratory for in-situ analysis of samples collected during EVA (C.A. Evans et al.) [3]. Once again as in 2009, each SEV housed a crew of one astronaut and one geologist. Both SEVs docked at the PEM twice during the mission (Fig. 1).

2. Field test teams, hardware, and facilities

The infrastructure required for the 2009 and 2010 Desert RATS field tests included mission operations, communications, and engineering support teams, a base camp, and a chase team convoy in the field with the SEVs (Ross et al.) [8].

The overall leadership team for Desert RATS consisted of personnel from the advanced suit development organization (Ross et al.) [8]. This team has been conducting field tests for many years, beginning with studies on advanced spacesuit concepts. This team provides the management oversight and field test experience necessary for incorporating the growing number of objectives and hardware.

With respect to the simulated mission architecture, the base consisted of the mobile Mission Control Center (mMCC) (Fig. 2), and several engineering backroom support trailers. In 2009 the mMCC contained approximately twenty positions, and in 2010 expanded to approximately thirty positions in both the mMCC and co-located science backrooms to support the second SEV and the PEM. Several positions were supported by the facilities and communications team, the science backroom team (Eppler et al.) [2], and the data collection research team (Abercromby et al.) [1]. The primary engineering teams for the SEV, PEM, and ATHLETE were each also provided a console area in the mMCC, as well as additional locations within their specific support trailers. In 2009 the mission operations team consisted of four positions within the mMCC: Traverse Director, Assistant Traverse Director, Capcom, and Operations Planning. A second Traverse Director position was added in 2010 to accommodate the second SEV. These will be further discussed in Section 3.

The mission operations team was critical to the execution of the activities on the daily plans in a simulated mission environment. Key to the functioning of teams and the execution of the mission plan, the communications team maintained the data and audio link between all the SEV crews, base camp, chase team, and the test hardware engineering support teams. Engineering teams provided support for the various hardware and vehicles such as the SEVs, the PUP, EVA tools, the PEM, ATHLETE, and an EVA navigation system. Because this mission focused the majority of daily operations on simulated lunar geological field operations, an entire science team was in place at the mMCC to support the mission (Eppler et al.) [2]. Additionally, there was significant recording of human factors research data by several researchers for determining the livability of the SEV for 14 consecutive days, as well as the efficiency for the various modes of operation that were tested (Abercromby et al.) [1]. All of these teams supported not only positions within a miniature mission control style and simulation control environment at base camp, but also supported positions on the SEV traverse chase team.

The chase team consisted of several positions for each SEV, including those for the mission management team, medic, SEV and PUP engineering support teams, science team, cameraman, public affairs outreach lead, and a field Traverse Director from the mission operations team.

3. Mission profile and field test mission operations structure

The Desert RATS engineering field test mission plan design for 2009 was a simulated two week lunar traverse using a two person pressurized rover, the SEV. The SEV is a small rover containing a simulated pressurized volume

Fig. 2. NASA Desert RATS field test mMCC console operations.
in which the crew lives and sleeps, drives the rover, and prepares for EVA. The EVAs in this conceptual vehicle are performed via two suitports located in the aft pressure bulkhead. The suitports give the crew the capability to egress the SEV directly to the lunar surface, without the use of an airlock. For 2010 the primary simulated mission was again a two week lunar traverse, but this time extended to include a second crewed SEV and the PEM.

Crew activities during these two week missions revolved around the primary objective of conducting simulated lunar geological fieldwork from the SEVs. These included EVAs via the suitports, PUP berthing and unberthing, SEV docking, crew control of the ATHLETE robot in 2009, and crew activities in and around the PEM in 2010. Fig. 3 is the overview of the daily modes of operation for 2010, and Fig. 4 shows examples of overview timelines of three of the modes for the fourteen day mission (Ross et al. [8]).

To support the mission timeline activities the mission operations team used current and former NASA Mission Operations Directorate (MOD) flight controllers with varied backgrounds with respect to their specific disciplines. Areas of expertise included EVA, robotics, onboard systems and maintenance, and timeline planning (OpsPlan).

During the simulated missions, all teams were integrated into a pseudo-flight control team, working out of the mMCC facilities at base camp and within the chase team Fig. 5.

The primary mMCC console positions at base camp and their associated responsibilities follow.

- Traverse Director: This position, also known as TD1, was essentially equivalent to the combination of Space Shuttle or Space Station Flight Director and a Simulation Supervisor (SimSup) in charge of a training simulation. The TD1 was the point of coordination between the various teams and the crew, and the progress of the daily simulated mission activities was this person’s responsibility.
- Capcom (Capsule Communicator): The Capcom, just as in actual spaceflight missions, at the direction of the Traverse Director, relayed information from the control team to the crew for non-science activities within the simulation. If a non-flight like hardware issue arose, the sim communication would pause, and the engineering teams would work directly with the crew to resolve the problem before returning communications to the Capcom.
OpsPlan: This position was responsible for creating and updating the timeline for the crew and coordinating with SEV Support to get various electronic files uplinked and downlinked from the SEV. Additionally, this person captured the actual timeline execution of the activities for comparison with the pre-mission plan.

Opslink: This was a science team position co-located with the Traverse Director and was responsible for coordinating the realtime updates to the daily traverse plan with the Traverse Director, as well as maintaining situational awareness of the crew's activities between the Science Team Lead in the science backroom and the Traverse Director (Eppler et al.) [2].

SciCom (Science Communicator): Similar to Capcom, this position was held by a geologist who was responsible for communication between the control team and the crew for all science activities. They discussed with the crew the geology of the areas they were traversing in the SEV, as well as the science activities the crew was conducting during the field geology EVAs.
● SEV Support: The SEV engineering team had up to two engineers filling this position. Their role was to provide SEV systems monitoring of the health and configuration of the vehicle and relay SEV status to the Traverse Director. Additionally, the SEV command, uplink, and downlink support functions were performed by this position.

● ATHLETE Support: This support was provided by up to two people, and was similar to the SEV Support roles. One engineer was co-located with the Traverse Director, with the other located in the ATHLETE support facility backroom. Their role was to monitor ATHLETE systems and relay the vehicle status to the Traverse Director. Additionally, commanding to the ATHLETE robot was able to be performed from this console position if needed during the activities.

● PEM Support: Similar to the SEV Support and ATHLETE Support roles, this position’s expertise was in the PEM systems and operations being conducted onboard. They provided PEM procedure expertise and timeline inputs to the rest of the operations team for the activities to be performed during days the SEVs were docked to the PEM, and provided PEM status to the Traverse Director.

● Facilities Support: These positions were essentially equivalent to the Space Shuttle or Space Station MCC Ground Control console position which is responsible for the building and network infrastructure during actual space missions. These personnel were responsible for the communications infrastructure, mMCC facility, and internet interfaces. From an mMCC perspective, they provided the Traverse Director with input on the health of the simulation infrastructure, in particular the communications assets.

● Human Factors and Exploration Analog and Mission Development (EAMD) Research: The purpose of the field test was to obtain data for review and analysis, and then apply that to future testing. A large part of the data collection for 2010 was determining the ideal modes of operation and the habitability potential of the SEV for a long duration traverses. To meet this objective, researchers coordinated at regular intervals with the Traverse Director for appropriate times to obtained feedback from the crew on items such as workload and fatigue.

● Mission Management Team (MMT): During the 2010 field test this position was included in the mMCC to allow management to observe the operations and provide management direction to non-technical, ‘out-of-sim’, questions. This position gave management good situational awareness of the day’s activities which would then be discussed at the evening group meeting. The health of the simulation infrastructure, including the communications assets.

The chase teams, one per SEV, had similar, but fewer positions. These positions and their responsibilities were as follows:

● Mission Management: The mission management positions were a key part of the chase team as they had eyes on the actual proceedings. They had the ultimate call on any changes with major impacts to the objectives of the field test, such as vehicle malfunctions, weather delays, or system issues that arose.

● Field Traverse Director: Also known as TD2, this position provided the eyes in the field for the Traverse Director at mMCC, and helped coordinate the activities and plans between the Traverse Director in mMCC with the chase team. Additionally, when communications were lost to mMCC the TD2 assumed all responsibilities of the mMCC Traverse Director, TD1, and Capcom.

● SEV Support Team: This team was responsible for monitoring the health of the SEV systems, coordinating SEV requirements with TD1, via SEV Support in mMCC, and TD2. The team provided the repair capability for non-flight like (out of sim) SEV malfunctions.

● SEV Emergency Stop: The primary responsibility of this position was to activate the SEV emergency stop switch if an unsafe condition arose for either the hardware or the crew. They would also secure the SEV while the crew was conducting EVAs. This position would normally work directly with the crew to clear an unsafe condition or to verify the SEV was properly configured to move.

● Science Field Team: From an operations perspective this position’s responsibility was to fill in as SciCom during unexpected loss of communications between the crew and the SciCom at basecamp. These positions had other responsibilities of collecting data for the Science Team for post-test comparisons, but these responsibilities were not considered to be within the simulation.

4. Mission operations lessons learned

Although Desert RATS is specifically an engineering field test of prototype hardware and modes of scientific operations, the inclusion of flight controllers from the NASA human spaceflight Mission Operations Directorate (MOD) provided many benefits, such as the skills to support the test within a realistic mission scenario. It allowed MOD to begin examining the mission control techniques, team compositions, and various realtime scenarios for lunar exploration. This also provided MOD the opportunity to gain early insight into potential future hardware, modes of scientific exploration of the Moon, and become integrated with the teams developing the functional requirements and testing conceptual designs. Through these tests, there have been a number of lessons learned that are key to conducting space mission analogs, as well as to future space exploration missions.

Prior to the 2009 Desert RATS field test, mission operations had had minimal involvement, and the tests had been largely an engineering evaluation of prototype human space exploration hardware, systems, and vehicles [8]. By 2009, these prototypes had sufficiently matured to warrant evaluation within a simulated mission operations structure. A key lesson learned was that the inclusion of a Mission Operations Team in the Desert-RATS
engineering field test provided the benefit of adding flight-like mission procedures, flight rules, timelines, and activities for the engineering and research teams to test integrated systems objectives within. The examination of mission control techniques, team compositions, and various realtime scenarios that were used for these tests are applicable to future manned lunar exploration missions. By including mission operations flight controllers in these tests, operations personnel were able to gain insight into potential future lunar hardware and to begin providing input into the functional requirements of the conceptual hardware used in these field tests. This allows for early investigation of concepts as well as examination into the applicability of current realtime mission operations. The mission operations personnel were able to provide the skills to integrate the objectives from various science, engineering, and hardware groups, basic flight rules and ground rules, and hardware testing into a coordinated scenario with significant interaction between these various groups.

The 2009 and 2010 Desert RATS field tests examined several modes of operation that included both single SEV operations, as well as dual SEV operations (Abercromby et al.) [1]. From the organization of the Mission Operations team console positions that were fielded for these tests there are several recommendations for future console teams that were determined. This includes a recommended number of TDs, Capcoms, and OpsPlanners. The suggested console positions per SEV for field tests: TD1 (mMCC), Assistant TD (mMCC), TD2 (chase team), Capcom and OpsPlanner. If using multiple SEVs, it may be possible to share the assistant TD and the OpsPlanner between them. This is not all inclusive, as it is recommended that each SEV also have an Opslink, SciCom, vehicle support console positions, as well as other systems positions. For actual space missions the console position requirements would need to be examined based on the modes of operations of the mission. For example two SEVs working in conjunction may be able to operate with a single mission control team, whereas for two SEVs working independently in different areas it may be prudent to split into two separate, but coordinating, mission control teams.

As with actual spaceflight, unexpected adjustments were required throughout the field tests, due to weather or hardware issues, which highlights that pre-mission planning, familiarization, and training are very important to the execution, and accomplishing of test objectives. Therefore it’s important to define and agree to clear, prioritized objectives so that when issues and hardware failures occur in the field, the teams have a clearly defined hierarchy of objectives to guide replanning.

The teams should plan early and thoroughly. This includes the details of the training products, timeline, procedures, flight rules, ground rules, and protocols. Additionally, through this process, repeatedly offer all teams the opportunity to provide feedback. This allows for good interaction between teams to help build understanding and confidence between the various teams prior to getting to the field.

It’s recommended that teams create a flexible test plan for the unexpected adjustments that will need to be accommodated. This includes the simulation timelines as well as the software used to update the plan (Lee et al.) [7]. Integrated tools and planning products used between mMCC, the SEVs, and PEM need to facilitate replanning and uplinking of current products to the crew.

Thorough crew training on hardware is a necessity. This includes maintaining a certain level of proficiency on tasks such as SEV driving, and operation of hardware and controls. This removes the learning curve from the field exercises and provides for less likelihood that the crew will exceed the operational constraints of hardware. Along with the crew, it is very important for the operations team, including the Traverse Directors, Capcoms, and OpsPlanners to have hardware and science familiarization training. This provides a basic level of knowledge on the hardware and the science being conducted that will provide a more fluid integration of the activities into realtime replanning. Similarly, the crew should have mission operations training. This includes training on both nominal and off-nominal procedures and protocols including loss of communication, ground control approach techniques, and procedure execution. Additionally, the crew should receive basic training on the flight rules and ground rules under which the field test is being executed. This provides for maintaining the testing of desired objectives. To facilitate smooth realtime replanning during the field test, the Operations, Engineering, and Science teams should all receive training on test objectives, flight rules, ground rules, and operations protocols, including communication loop protocols. This ensures each team is aware and has an understanding of the interaction of various objectives and of the plan to achieve all teams’ objectives.

It was found that conducting fully integrated dry runs prior to executing the simulated mission timeline is necessary to help facilitate a smoother execution of the field test. This also provides for a smoother transition between personnel as various people rotate through the chase team, and mMCC and Science team console positions.

As part of defining of the test objectives, it is very important that there be early definition of the communications concepts to be simulated, which will allow for better planning of how to manage test assets according to the concept. This is significant, as the simulation plan really hinges on what capabilities for communication are to be tested, including planned loss of signal, bandwidth, and if any delayed transmission, simulating deep space missions, is to be tested.

As with actual spaceflight, for analog missions it is important to have created the necessary procedures, flight rules, and a list of priority of objectives to accomplish, prior to beginning the field test. For procedures, the use of nominal and off-nominal cue cards and a procedures book which all teams can reference helps to maintain situational awareness among all teams. For the field test, a well defined list of maintenance and malfunction procedures that can be executed by the crew should be defined. This agreed to list will help define the line between what activities the Operations Team will coordinate within the simulation for the crew to conduct, and
what repairs and maintenance is required to have the engineering support teams to conduct. By defining this list of activities prior to the field test it will help to get all teams in agreement with how the field test will be executed. Finally, an overall review prior to the field test, with representatives from all teams, will help to formalize agreements on the priority of objectives, flight and ground rules that will govern the activities, and protocols that will be used in the field.

With respect to communications, there are two major areas for lessons learned that are recommended to be applied to future analog field tests. The one deals with the stability of the communications system used for the field test. The other has to do with the number of simultaneous communication loops that are available, and is also applicable to actual spaceflight operations. Both highlight that communications is a critical key to successful mission/test execution.

With respect to the stability of the communications system, unexpected, intermittent, or complete loss of communications presents significant difficulty in executing the test simulation plan, and unexpected communication outages significantly slow test operations and reduce the number of objectives that are able to be tested. To alleviate some of the impact to test objectives from unexpected loss of communications, it is suggested to have preplanned Loss of Signal (LOS) protocols for crew and mMCC to execute in order to maintain a coordinated understanding of the test activities to be performed in these cases. These protocols need to cover various cases, including planned LOS periods, unplanned LOS periods, SEV traverse, and EVAs.

Science discussions during intermittent communications become very cumbersome. The overhead associated with attempting to apprise the mission operations team of information, or with the operations team providing direction to the crew, drastically reduces the efficiency of accomplishing the tasks being performed. This in turn adversely affects the realtime replanning of subsequent tasks and reduces the ability to meet test objectives. It is recommended for future analogs to invest in a robust communications system with the capability to, on cue, provide degraded, delayed, or loss of communication periods as planned for within the test objectives.

It was noted by the Operations Team, during the test debrief, that an inadequate number of communications loops between the mission control team and the crew can slow the coordination and reduce overall situational awareness between separated teams. In 2009, with the field test using only a single SEV, this issue was not as apparent, as there was only a single two person crew, who were always working either the same tasks, or within the same area in a coordinated manner. However, 2010 with the addition of a second SEV, and modes that included both coordinated and independent operations between the SEVs crews, the number of communication loops between the mission control team, and the SEV crews or PEM became a limiting factor for partitioning the transmission of information in a coordinated effort between all parties. The reason for this was the infrastructure provided the capability for two communication management options. These were either an individual communication loop to each SEV, or a single simultaneous communications loop to both SEVs. The recommendation for future analogs is that the number of communication loops should be increased to provide capability matching or exceeding the number of simultaneous loops available on docked Shuttle-Station missions. This will increase the fidelity of the field test to provide accurate results when examining various modes of operation that are dependent on communications, and remove this from being an unintended limiting variable. At a minimum, the recommended communication loops would include:

- An individual loop to each crewed asset (including vehicles, habitats, and EVA teams).
- A single combined loop including all assets (including vehicles, habitats, and EVA suits).
- Capability for each asset to communicate with any one or more of the other assets at any time (similar to a conference call).
- Capability for each asset to be able to monitor any desired communication loop simultaneously. This will provide increased situational awareness to all parties, as well as allow direct discussions between two parties, while still monitoring for calls on the other loops.
- Also, there may be a need for individual science loops to separate vehicle operations from science operations.
- Additionally, for the analogs, sufficient loops between the simulation team and the chase team engineers should be provided to work the ‘out-of-sim’ issues that arise, which is similar to how training simulations are conducted now for Space Shuttle and International Space Station missions.

Since analog mission simulations are utilizing prototype vehicles and hardware, there is invariably a significant number of support personnel and infrastructure that is required, with significant logistics planning to facilitate a smooth execution of the field test. To this end, a logistics support team that provides services, such as food, facilities, etc. for the basecamp would allow the engineering, science, and operations teams to focus on their systems and the execution of the field test. Vehicles to taxi spare parts, personnel, and other necessities between the base camp, and the chase team are necessary to support smooth simulation execution. Although the science traverse dictated the overnight positions, it was found that having the SEV(s) overnight near roads, a non-flight-like constraint, was necessary to provide the overnight chase teams access to the hardware and crews in order to service the vehicles, and to provide the needed level of safety for both the crews and vehicles (Abercromby et al.) [1], (Horz et al.) [4]. A final note on hardware is that it was found that the low fidelity suits/backpacks provided for more overlapping of test objectives and allowed greater chase team distancing from the test subjects. This results in less interaction between the chase team and analog crew, which therefore provides for a more realistic simulation environment for the analog.
5. Future application of lessons learned

There are several areas to which the knowledge gained from the 2009 and 2010 NASA Desert RATS field tests can be applied. These areas include future NASA Desert RATS field tests as well as other space analog field tests, the design of future human space exploration missions, and the planning for the complement of mission control flight controller positions for these missions.

For instance, the planning for the 2010 NASA Desert RATS field test incorporated many of the lessons learned from 2009. The major lessons incorporated included the development of training material and training flows for all of the various operations, engineering, and science positions prior to deploying to the field for the annual test. Additionally, the required mission operations flight controller positions and required communication loops to execute the simulated mission timeline and coordinate with the other console positions was used in defining the team for the 2010 field test.

With respect to future human space exploration, these field tests provide the opportunity for the operations team to understand some basic requirements for the complement of flight controller positions. They also provide for the early examination of control center protocols between the science, engineering, and operations teams for coordinating with the crew during different communication modes for executing planetary surface exploration. This includes exercising methods for realtime adjustments to the plans, as well as replanning for the subsequent days, and in future tests will extend to exercising realtime operations under a delayed communication scenario.

6. Conclusion

The annual NASA Desert RATS field test provides not only an engineering evaluation of potential planetary surface exploration hardware, but also provides a relevant simulation for obtaining operational knowledge and protocols for human surface exploration missions beyond Earth orbit. This knowledge was gained during the field tests themselves and also from the interaction of the mission operations team with the multiple engineering and science teams during the months of preparation leading up to the execution of the field tests. During these Earth-bound simulations, operations personnel had the ability to examine various flight control and crew operations scenarios in preparation for actual space missions. The lessons learned are being put into practice on future NASA Desert RATS field tests and other space analogs, and can be applied to future human space exploration.

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