AustroMars – a simulated high-fidelity human Mars analogue mission

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Abstract

AustroMars was the simulation of a crewed expedition on the surface of planet Mars, which took place in April 2006 at the Mars Desert Research Station in Utah. A crew of six carefully selected individuals performed 20 experiments in the fields of robotics, analogue planetary and life sciences as well as human exploration.

1. Introduction

The major European and US space entities have initiated two ambitious exploration programmes culminating in a crewed expedition to planet Mars. Independent of the decision whether to send humans to the Red Planet within the next decade or the next 40 years, first of all, technologies and strategies need to be developed to make such an endeavour a safe and affordable undertaking (Hoffmann 1997).

The Moon, and then Mars, are commonly regarded to be the next logical steps in our exploration programmes[1]. In order to stimulate the necessary technology developments, the US-based Mars Society[2] operates a Mars-analogue station in the desert of southern Utah since the year 2002, where short-duration surface missions are simulated.

The Mars Desert Research Station (MDRS) (Fig.1) is one of the first attempts of a comprehensive integration of planetary field sciences and research schemes, advancing human space exploration beyond Earth's orbit. AustroMars is an interdisciplinary project containing experiments from the area of fundamental research and applied sciences. The spin-off potential is high: Technologies originally developed for Mars research can be applied to non-space related fields, from mobile monitoring of patients to waste management.

This paper summarizes the background, purpose and projects of the AustroMars project.

The Mars Desert Research Station

The Austrian Space Forum as project lead organisation conducted the simulated surface sojourn “on Mars” from 8 to 22 April 2006 at MDRS. The facility (operated by the International Mars Society) is located in the desert of southern Utah near Hanksville. The purposes of analogue stations are learning how to live and conduct science on another planet. Such habitats present a key element in current human Mars mission planning. During AustroMars, the MDRS hosted a total of six “analogue astronauts” as a base for their research activities and exploratory excursions, the latter ones conducted in analogue EVA

[1] Mars is the planet which is most similar to the Earth, it has all the resources to support life and it might be the place where we can find out if life is prevalent in the cosmos or exclusive to the Earth.
[2] The Mars Society, founded in 1998, is a private non-profit space advocacy group which is also conducting research w.r.t the human exploration of Mars.

spacesuits (simulating difficulties real planetary spacesuits will impose on the crewmembers). The two week simulation was carried out in strict isolation of the crew, radio communication to a Mission Control Center (MCC) in Salzburg/Austria being the only link to “Earth”.

Such simulations offer unprecedented opportunities to carry out Mars-analogue field research in a variety of scientific and engineering disciplines that will help humans carrying out a real Mars mission in the decades to come. Therefore, the station serves as a test bed for field operation studies, helping to define key habitat design features, field exploration strategies, tools, technologies and crew selection protocols helping to maximise the scientific output of a real human Mars mission. The facility has been operational since January 2002 and has served 45 expeditions in four field seasons so far, cumulating approximately 80000 “crew hours” of analogue experience – more than any other analogue station in the world.

Table 1: Psychological and medical selection tests

Medical tests	• detailed medical interview & physical examination • spirometry, ergometry under stress • cardio-echography, detailed blood and urinal laboratory analysis • Lower-body negative pressure test[3] (Evens 2004, Hinghofer 2006)
Psychological tests	Performance parameter included (selection[4]) • Ratings to self- and foreign sense, Team capabilities & affect regulation • LVT – line following test (Wagner, 1996) • DT – Wiener Determinationstest (Schuhfried, 1996) • 2HAND – Two-handed coordination (Schuhfried, 1994) • SIMKAP – Simultanous capacity/multitasking (Bratfisch & Hagman, 2000) • 16PF – 16 Personality factors test (Schneewind, Schröder & Cattell, 1986) • DAS – Differential affect scale (Merten & Krause 1993) • SVF 120 – Stress copying questionnaire (Janke, Erdmann, Kallus & Boucsein, 1997) • BSI - Brief Symptom Inventory (Franke 2000) • EER – Questionnaire for emotional regulation (Benecke & Vogt, in Vorbereitung): • AERZ – Questionnaire w.r.t. nuissance copying (Weber & Titzmann, 2003).
	Psychological Interview combined with video analysis (Facial Coding System) using a test battery with highly trained psychologists (Operationalisierte Psychodynamische Diagnostik (OPD[5]; Arbeitskreis OPD 1998))
Other	Background check, language proficiency, technical versatility

2. FLIGHT CREW SELECTION AND MISSION CONTROL CENTER

The AustroMars crew was comprised of six individuals in very good physical condition. The selection process for applicants included a psychological and medical test battery and individual interviews; it lasted three months in total. The selection procedures for the initially 172 applicants included the tests presented in table 1.

[3] This experiment at the LBNP facility of the Institute for Adaptive and Spaceflight Medicine/Graz investigated hormonal reactions of the final 15 Flight Crew candidates as part of the pre-flight tests to determine high susceptibilities to orthostatic intolerances during critical in-flight situations when the air supply of the PLSS might fail. Fig. 2)

[4] The entire psychological test battery included 19 different evaluation methods. (Grömer 2006)

[5] OPD is a reliable and validated system for the evaluation of psychological disorders based on illness, conflict, relation and structure on a structurized clinical Interview.

Modeled after training principles of astronauts and pilots, in simplified and condensed form, the crew underwent a detailed training including education in science and engineering skills as well as physical and mental training. This included various topics ranging from emergency medicine, selected topics in physics, molecular biology, astronomy, spaceflight history and international relations, media training, engineering education, operations procedures, high altitude training, acrobatic flight training, rough terrain ATV-driving training and others (Grömer 2006).

Fig.1.: The Mars Desert Research Station: the central Habitat has a diameter of 8m. In addition a solarpower station, a greenhouse and a small astronomical observatory complement the central infrastructure.

In addition to the flight crew, a trained local support team (On Site Support, OSS[6]) plus other support personnel were available for the on-site training and during the simulation. The OSS realised various planned “mission anomalies” and “invisibly” assisted the crew – without interacting due to the strict application of isolation protocols.

The Utah team comprised 17 members in total (including the crew). The entire AustroMars mission team totaled 145 members (researchers, engineers, physicians, flight controllers, management, media coordinators and many volunteers).

The Mission Control Centre (MCC) for AustroMars was the headquarters of all technical and administrative activities in Austria during the actual simulation phase. The MCC was responsible for the contact to the „Mars“ base and the crew, the on-site support team in Hanksville, Mars Society’s mission support and all science teams. The MCC in Salzburg was staffed 24 hours a day with all critical flight controllers working permanently in shifts.

In addition, the regular Mission Support infrastructure of the Mars Society Headquarters in Denver/Colorado was used; MDRS operations were monitored by ground-based operators. However, in order to ensure that the AustroMars team had a clear and concise picture of events, a Flight Control Team (FCT) consisting of Flight Director, Technical Support and CapCom performed a number of operations support activities, using data from both the down-linked telemetry (habitat environmental

***Fig. 2:** Test subject during the LBNP tests assessing orthostatic in-tolerance behaviour.*

[6] The OSS crew underwent the same selection and training procdure as the main flight crew to allow for a similar sample as a comparison to the flight crew which would not be involved in the flight operations.

conditions), dumps of the various on-board system logs and on-site measurements. These activities occurred both in real-time and non real-time (off-line). The FCT depended on data supplied by the Flight Engineer as well as the on-site technical support team – all relevant data were transmitted via daily Engineering Reports and direct time-delayed[7] communication via Skype®.

MDRS SET-UP

The MDRS central component is the "Habitat" with a diameter of 8 metres; a two-deck structure mounted on landing struts (peripheral external structures). The lower deck includes a laboratory area, two airlocks, hygiene facilities/toilets, EVA-suit storage and a small workshop. The upper deck (command deck) comprises sleep bunks, the kitchen area, the stations computers (including the satellite communication equipment, the remote operation computers for the telescope, etc.), a small library and medical supplies.

In addition to the central habitat structure, a small greenhouse is being used as a bio-regenerative life support system for filtering grey water, a small astronomical observatory and a simulated "nuclear power source" (in reality a diesel generator operated by the OSS but regulated from within the station – similar to a future buried NPS on Mars).

3. Experiments

The AustroMars project included 20 experiments in the fields of geology, astronomy, molecular biology, emergency medicine, human factors research and psychology, robotics, habitability and exploration.[8]

3.1. Life Sciences

BioMars: Track and Trace
During a human Mars mission the contamination of soil samples (especially when looking for traces of life) represents a major microbiological challenge (National Research Council 2006). The BioMars team analysed the magnitude of contamination with putative martian life or forward contamination with "earth" microbes via fluorescent micro-spherules and other microbiological techniques. Sterile filters which were exposed to the environment during repeated EVAs showed persistent contaminations with bacteria. On-site contamination within the habitat was checked by exposed agar plates which were all positive with cultivable strains (Griebler et al., 2001).

Fig. 3: *BioMars sterile suits composed of Mylar-foil were used to track backward contamination under various exploration scenarios.*

BioMars: LiMa
The module *LiMa* ("Life on Mars") simulated sterile procedures to collect samples with subsequent cultivation efforts under simulated spaceflight conditions (Fig. 3). This test focuses on stringent sterile protocols to collect soil samples under harsh conditions by analogue astronauts. Soil samples were

[7] A time delay of 10 min one-way was assumed for all mission communications between the station and the MCC to account for the signal travel time between Earth and Mars.

[8] A more detailed account is given in AustroMars Final Mission Report (Grömer 2006)

mostly obtained in the near surroundings of the Mars Desert Research Station and were cultivated with agar plates growing under in-situ conditions. (Sattler 2007)

BioMars: Human microbiota tests

Due to the fact that no human body is sterile and is thus importing a certain level of microbial background into the station, the amount of terrestrial contamination was assessed by exposing open agar plates with the above mentioned medium in the living space such as dining table, bathroom, glove box, toilet, laboratory space and other neuralgic spots which were likely to be used frequently. Exposure time was 48 hours before visible colonies could be sighted.

Greenhab / Bioregenerative Life support

Project Greenhab is an ongoing research and development initiative to explore life support technologies suitable for the missions at the Mars Society's remote research stations. Evolving from earlier efforts of the Mars Society's life support technical task force, the Greenhab project has developed a low-cost greenhouse that is an analogue of inflatable structures that might be used in an actual manned mission to Mars. (Blersch 2003) The Greenhab was used during AustroMars.

3.2. Engineering/Robotics

Sisi – a satellite controlled rover

The "Sisi"-Rover[9] (Fig. 4) was a rover system controlled by the MCC via a satellite link or, alternatively, by the analogue astronauts via radio link. Besides a GPS-logger, inclination sensors and cameras, the rover also carried a simulated scientific payload to support the crew when on EVA.

Aerobot

To support long-range exploration activities, a small aerial reconnaissance system has been used in addition to satellite remote sensing. This vehicle was a miniaturized paraglider with a remote sensing video system obtaining real-time imagery of areas of interest before dispatching an EVA-team or the rover.

3.3. Physical Sciences

GeoMars

In order to compare the ground truth of the MDRS site and its environment with remote sensing data, a geological sampling procedure has been used similar to the Apollo lunar missions. The characterization of the geological setting was then compared to the data available through standard geological assessments, hence providing an objective measure about the efficiency of the reconnaissance process. (Lenauer 2007)

TeleMars

Operating a small optical/near-infrared telescope under simulated Mars conditions proves to be a significant challenge as standard calibration techniques are only available to a certain extent. The original concept involved determining rotation periods of asteroids. However, due to operational and meteorological constraints, this experiment was not successful.

Fig. 4: *The rover unit "Sisi" during a test run at the MDRS*

[9] Sisi has been built by the Austrian Institute of Technology School in Vienna (TGM) under contract from the Austrian Space Forum (ASF). The ASF acknowledges the financial support of the Austrian Federal Ministry for Transportation, Innovation and Technology.

3.4. Human Factors

MedMars: Rescue operations

Bone loss and muscular atrophy increase the risk for traumatic injury during Mars surface operations significantly. Hence, medical contingency situations were carried out including dealing with accidents of analogue-astronauts in rough terrain. Various modes of transportation were evaluated under emergency medicine viewpoints. (Mauschitz 2006)

MedMars: Treatment procedures

Minor traumatic incidences, such as lacerated contusions, impose a significant challenge for treatment in a spaceflight environment due to sterility requirements. Several high-probability traumata were simulated and the efficiency of the treatment studied (sterility, observance of treatment protocols, etc.). Additionally, various medical baseline data were obtained[10]. (Mauschitz 2006)

Pupillography experiments

Sleepiness during the day and the resulting loss of reactive capabilities is not limited to patients with sleep disorders, but is also likely to happen to healthy individuals in stress conditions like spaceflight situations. The experiment aimed to provide a first quantification of day sleepiness in a spaceflight environment based upon the fact that the Pupillograph measurement is the first clinically proven and easy-to-use method applicable in demanding settings (Danker 2001). The analysis was done by studying the Pupillary Unrest Index (PUI) data from the station crew. In a dark room (in this case, the laboratory deck of the Mars Desert Research Station), the subjects' pupillas were exposed to IR light which was simultaneously filmed by a camera (Bolitschek 2006). The data were correlated with various stress hormonal tests obtained from urine and saliva samples from the PsychoMars-Experiments.

PsychoMars: crew selection

Living under strict simulation procedures in a confined space station creates an inherently stressful environment (e.g. Flynn, 2005). This project evaluated the processes which led to the selection of the six finalists for the flight crew in order to isolate the salient criteria which are essential for a psychological functioning as an individual as well as a crew. The long term perspective is to formulate objective and predictive criteria for future isolation projects including diagnostic, prevention and intervention options prior to a mission.

PsychoMars: crew monitoring

During in-flight situations, a constant psychological crew monitoring is a key in early diagnostics (Manzey 1996). The crew monitoring experiment included a set of reaction and cognitive behavior tests. In addition, a constant psychological monitoring was obtained through near-real time video surveillance and recorded in-flight interviews, and then correlated with daily workload patterns and mission-critical events.

PsychoMars: CogHealth

The flight crew was asked to complete a set of questionnaires dealing with social identity and group organization on multiple occasions throughout the mission, in addition to the AstroPCI personality inventory. Psychometric analyses indicated a stable core of group identity items relating to super-ordinate identity, goal sharing, and organizational behaviour that seems to differ from comparable groups at MDRS and demonstrates a pattern of significant relationships with several key personality factors. The analysis also included objective measures like salivary stress hormone sampling as well as reaction and cognitive performance tests. (Bishop 2004, Bishop 2006)

Famos

Tiredness and exhaustion are two of the major risks for human failure. The fatigue monitory system (FAMOS) is a headset-based system monitoring eye-movements of the crew members. A neurobehavioral test battery was applied consisting of the Karolinska Sleepiness Scale KSS, Karolinska Drowsiness Test KDT, Psychomotor Vigilance Task PVT,

[10] Body weight, total body fat content, total water content, heart reates, blood pressure, sleep duration.

combined with left eye video recordings with an early prototype of the FAMOS Fatigue Monitoring System headset currently being developed by Sowoon Technologies, and Actiwatches[11] that were worn continuously by some crew members. (Wolf 2007A)

Object Tracker
The experiment 'Monitoring of Crew Activity with Object-Tracker' monitored the apparent physical activity of the AustroMars crew inside the Habitat with a video based technique. A camera acquired a video stream of the Habitat work deck and fed the stream to the Object-Tracker system, which is a PC-based platform for motion analysis and target tracking, developed by Object-Tracker in Austria. Activity monitoring with video cameras measures the apparent size (n), displacement (dx), velocity (dx/dt) and acceleration (dx2/d2t) of a moving object or subject. The system analyzed the video stream in real-time and calculated activity measures for each of several regions of interest within the station, in order to determine activity patterns and trends. (Wolf 2007B)

LBNP
The Lower Body Negative Pressure (LBNP) test was a pre-flight selection experiment testing the 15 finalists for cardiovascular fitness. The subjects were put into an airtight container from the waist downwards and subjected to an incrementally decreasing pressure (e.g. Evans 2004). This test was used as a selection tool to screen for applications with an unusually high susceptibility to orthostatic intolerance. In addition, blood samples were obtained to study the hormonal response to pre-syncopal situations[12]. (Hinghofer 2006)

[11] Actimeter watches were worn by 2 crew members at all times during the simulation. These devices have miniaturized accelerometers with a storage function providing precise data on sleep duration and quality as well as movements throughout the day.
[12] In particular the hormonal response with galanin might be an excellent tracker substance for such intolerance reactions which was the main focus of the study,

PhysioMars
The relatively heavy life support system of the Extra-Vehicular Mobility Suit poses a mid-term risk of muscular hardening leading to various detrimental effects like headache, nausea and other disorders. As an in-flight countermeasure, a set of physiotherapeutical techniques was developed and tested. (Lengauer 2006)

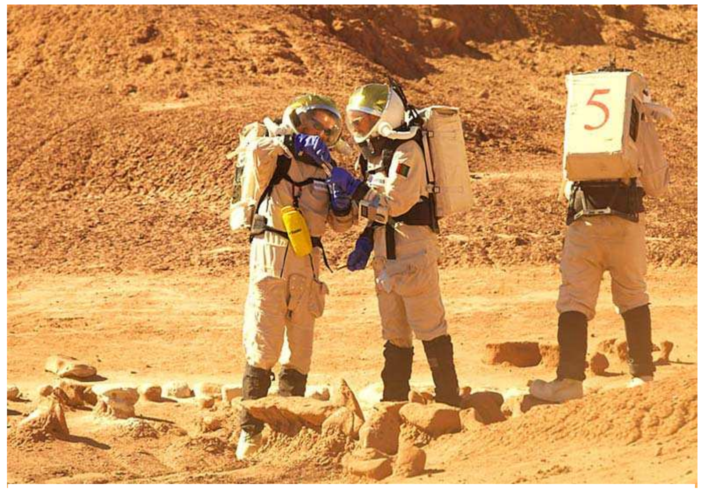

Fig. 5: *Extra-Vehicular Activity strategies were tested using an exploration cascade to choose the optimum sample sites. Here: sampling activity for a local geological survey.*

3.5. Exploration research

Habitability studies
Detailed project debriefs with the crewmembers were made to study space architectural aspects of habitat design. Factors such as habitability (which includes colour, smell, surface material tactility, food and the human-machine interface), socio-psychological factors (which include crew selection and training, heterogeneity versus homogeneity of the crew, coping with stress, group dynamics, cognitive strategies, cultural background of the crew and its implications), culture and therefore the resulting proportion of inhabitable space and it's functionality were topics addressed by the architectural studies. Other issues were cargo-transfer, procedures, storage strategy, trash, training drills, supplies and others. (Imhof, 2007)

Exploration cascade and management studies
The Exploration experiments aimed at optimizing the cooperation between the

scientific teams, simulated satellite data, pictures and measurements of the Aerobot and the rover as well as the crew (Fig. 5). Various workflows, such as the creation of a radiation shielding structures during extra-vehicular activities, were tested. (Grömer 2006)

FoodMars; synergies and education effects

In addition to these experiments, a detailed dietary protocol was elaborated (FoodMars-Project). Also, a strong emphasis was put on involving young researchers as well as choosing experiments which were in line with similar Mars analogue research activities, such as the Haughton-Mars Project on Devon Island in the Canadian arctic.

4. Results[13]

The AustroMars mission was one of the first holistic approaches to study integrated planetary surface expeditions under simulated Martian conditions in order to maximize the scientific output whilst maintaining planetary protection standards and ensuring crew safety in a realistic scenario[14]. Considering planetary protection aspects, up to now no integrated high-fidelity missions have been conducted to our knowledge. In addition, planetary protection has not been considered as a main design driver for planetary surface exploration suits or robotic systems interacting with humans.

5. Acknowledgements

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[13] The individual experimental results are described in the Final Mission Report and in the more detailed Mars 2030 workshop proceeding as well as in the individual researchers papers.

[14] A realistic mission scenario was designed after the current mission reference scenarios of the US-led Vision for Space Exploration (VSE) as well as the European Aurora programme introducing a few keypoints from the Mars Society's "Mars Direct" scenario (Grömer 2006).

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