UNMANNED EXPLORATION IN ANTARCTICA; AN EXTRATERRESTRIAL ANALOGUE LABORATORY ON PLANET EARTH

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Abstract

This paper introduces the possibilities of Antarctica as an extraterrestrial planetary analogue site under the viewpoint of unmanned exploration. Furthermore, possible unmanned exploration systems and -challenges are investigated with respect to the problems of planetary exploration already existing.

1. MOTIVATION

There are two different kind of people working on planetary space exploration. On one hand the engineers, on the other hand the scientists. Both have a different way to look at the planetary exploration and its related analogue sites. A geologist might be fascinated by the similarity of the planetary surface of earth and mars with their volcanoes, craters and signs of the (former) presence of liquid mediums. An engineer might have a bigger focus on the problems that might result from those phenomenons and how they influence the design of his hardware. This paper mainly focuses on the engineer's point of view and his requirements to an analogue site to have the hardware operating in an environment as close as possible to that on a surface of an extraterrestrial body.

2. WHY PLANETARY ANALOGUES

The exploration of extraterrestrial bodies is an expensive and resource binding undertaking. There are mutual reasons why, 40 years after the first manned landing on the moon, space flight is still not fully established in the normal industrial processes and the open markets. Some main cost drivers having emerged in space hardware development are listed below:

Launch costs

One reason is the high cost of a rocket launcher. Most launchers never reach a serial production and keep bonded in a constant development and implementation phase. In addition to that, planetary exploration launched from earth requires a high escape velocity and with increasing mass, the list of suitable launchers decreases rapidly.

Complexity

A spacecraft is a very complex system and each individual subsystem mutual influence the others which results in an exponential increase of the overall complexity. For the special case of extraterrestrial exploration, the whole mission persists of multiple extra systems like Launcher, interplanetary stage, orbiter, lander and the exploration craft itself. The lack of serial production is an additional cost driver for the exploration craft itself.

Lack of serial production

Nearly all spacecraft for exploration use are unique specimen and all the development costs are bound to a single product.

Reliability

Due to the high costs of the launcher and the exploration craft (probe, lander, orbiter, rover, etc.) development, it is important that no failure occurs to any mission critical part of the spacecraft. In fact nearly every part is a mission critical one; otherwise the part could have been cancelled for weight reasons or to increase the reliability of the element.

Optimization

To make a mechanism reliable and to keep the launch costs as low as possible, simulation became very important and most parts have to undergo several iteration processes before ever realized in hardware. These optimization processes take a lot of work in computation, simulation, material and design variation. For each individual problem, there are numerous ways to solve it. To safe weight, the applied design factor of safety is less high than on terrestrial applications. This is mandatory to keep the spacecraft weight limited and to safe launch costs. To compensate the reduced safety margin with the high requirement of reliability, the work load of the design optimization is increased.

Qualified Material

Space qualified materials are mostly special developed and qualified for the application in the extreme environments where they shall operate. Even commercial materials have special quality requirements on purity and manufacturing methods to avoid uncalculateable variations in the materials properties.

Testing

To fall back on the requirements of reliability, it is useful to focus on the testing. Each single part needs to be tested and qualified for the harsh environment in space, during launch, assembly on earth and eventually on the planetary body to land on. When assembled to a mechanism, this has to withstand several tests to verify its function for any worst case scenario which might occur. Now this needs to be implemented in an overall system and to be tested again. There it needs to be shown that all subsystems and mechanisms work harmonically together without endangering any single aspect of the overall system.

Several of these problems are currently on their way to be solved. Commercial developers are rapidly reducing launch costs and an ongoing serial production of rocket launcher will reduce the costs even more. With a commercial background, the target to have a final developed hardware and to launch the serial production phase might have a bigger focus as nowadays. Another big thing is the development of modular systems which can be combined in multiple ways, to solve a big bandwidth of different science tasks with a variation of hardware components. This can increase the re-use frequency of once developed hardware and reduce the development costs of the space craft infrastructure. In addition to that, the ongoing standardization and knowledge growing of hardware and material application in space helps the hardware developer in terms of interfaces, standard parts and applicable materials.

Due to the increasing complexity of aeronautical and space systems, the new field of system engineering was created and established in engineering science and industry. Thereby a systems engineer was firmly established in hardware development teams and helps to keep the overview of the individual subsystems. Within this field, several new techniques were developed to keep the problem of growing complexity and a confusing number of requirements low.

The use of analogue sites for field testing came up already during the Apollo program. Thereby the astronauts were sent to remote areas for hardware, equipment and operations tests. These remote areas were selected with respect to their similarity to lunar surfaces and expected geological characteristics of the moon, found on earth. Nowadays, these so called analogue sites are firmly established in the field of manned space flight. So e.g. all ISS astronauts EVA's are preliminary carried out in huge water basins, where all working processes are trained in advance to reduce the accident risk and to optimize the astronauts operations.

The application of analogue sites to unmanned exploration is implemented in the design processes as well. There they are a fundamental part of the concept investigation and verification, as well as operations testing. Mostly this test sites are located by the premises of the developing institution [E.g. Mars Yard JPL]. This approach has shown to be an excellent tool in early phases of concept development, the test of individual subsystems and even whole systems. Without deadlines and deliverables, testing of single elements, optimization calculation and simulating can become a never ending circle. A field test campaign which is fixed on a shipping date is a realistic analogue of a real space mission with its fixed launch date. For interaction tests of multiple element mission concepts like ISRU facilities [G.Sanders] or multi robot interacting exploration missions, a spatially limited test area reduces the test capabilities and lessons learned in mission operation.

Unmanned, multiple element missions are quite complex due to the interaction of multiple, independent units that have to cooperate with each other. Like in real space missions, several of these units and even subunits are developed by different partners who have to cooperate with each other. With an increasing number of collaborating partners it is mandatory to consider that, while overall objectives might be the same, the desired method or hardware to achieve these might be totally different. An analogue field test is a proven method to promote understanding, coordination, and joint development of instruments and operations. Hardware demonstration at an analogue field test is a capable way for evaluation of technologies and operations under partly realistic conditions. They also allow implementation of independent developed instruments and technologies to common operation and mission needs. Technologies and operational procedures from both science and exploration can be added when available on a continuing basis of evolving overall integrated operations and capabilities that can be utilized in future flight missions. Performing analog tests with personnel from engineering and science, working together allows both sides to better tailor their instruments and operations to meet overall mission needs with the minimum of resources. It also demonstrates integration and operational procedures well in advanced of robotic precursor missions. [1 G.Sanders]

A capable analogue test site, selected with the focus on system tests and operations, shall present challenges similar to those that will be faced during the target mission. A challenging environment is mandatory to evaluate mobility, infrastructure and effectiveness in harsh environment. For a multiple element mission with its combined interaction of individual units, data is provided about strengths, limitations and the validity of the operations and helps to find and define processes and requirements.

3. ANALOGUE SITE CHARACTERIZATION

In 2008 at the department of Aeronautics and Astronautics of the Massachusetts Institute of Technology (MIT) a study was made to compare the existing extraterrestrial analogue sites with each other and to rank them with each other with respect to robotic supported, manned exploration [9]. This study was based on a JSC database and its there defined metrics. Based on this ranking, metrics can be varied and defined for robotic exploration.

3.1. Site characteristics

Most analogue sites were established because they represent one or more key elements of the target area. With an increasing number of analogue sites it became mandatory to establish metrics and to compare the individual analogues with each other with respect to their key strengths and weaknesses.

3.1.1. Access with humans and cargo

Nowadays, the worldwide logistic infrastructure is that far established that humans can reach nearly every place on earth within a few days and with acceptable financial efforts. Cargo transportation is already much more challenging due to its higher requirements to the transportation infrastructure. A good accessibility and infrastructure is mandatory for every field test campaign. Because, beside the actual test subject, all the mandatory support and equipment like work shop equipment, replacement parts and the field test crew itself, needs to be brought in the field if not available on site.

3.1.2. Geological characteristics

For most field test equipment, the geology is very important. It has a big influence on mobility systems, way finding autonomy and the gathered data from the soil interacting science instruments. In addition to that, geological similarities to other extraterrestrial bodies are very useful for the scientific output and to deal with eventually unexpected events. The geology influences massively the quality of the analogue site and even the size of an field test area might influence the expressiveness of a test result, especially when its focus is on big systems, long term use and mobile system operations.

3.2. Infrastructure

A good infrastructure in the field replaces a lot of logistical work load. A well established test site with work shops, machinery, standard replacement parts, power supply and communication infrastructure reduces the costs of the field test logistics massively and helps to establish long term test runs. Shelter, medical support, crew canteens and personal transport logistics are mandatory for the field test crew as well.

3.3. Operations

It is a benefit if the test site is operateable the whole year round, it helps to operate the required infrastructure and makes long term tests at all feasible. For operations and system tests, it is useful to have a representative time delay in communication to the test object.

4. ANTARCTICA AS PLANETARY ANALOGUE

Antarctica is already quite a hostile and alien place on Earth that is more comparable to extraterrestrial planets than other places on Earth [1]. The environmental challenges to a long term manned outpost already catch the attention of NASA and several educational and science institutions [2,3]. Most of these activities, studies and hardware developments are focussed on human presence on foreign planets and robotic exploration is just handled as an auxiliary tool for the “Antarctic Astronauts”.

4.1. Key features of Antarctica as an extraterrestrial analogue

- Humidity: Antarctica is in fact a frozen desert and one of the driest places on earth
- Temperature: Coldest place on Earth with temperatures down to -89°C (Mars -85°C)
- Atmosphere: Thin atmosphere, approx. 65% of normal atmospheric pressure

- Radiation: Increased UV-Radiation due to ozone depletion
- Night time survival: Extremely long day/night periods
- Dust coverage: Adhesive and cohesive snow
- Vegetation: The absence of any visible vegetation is realistic to Moon and Mars
- Visual appearance: The snow coverage and the resulting absence of colourful landmarks creates a challenging environment for autonomous navigation
- Science data: Antarctica is one of less known places on Earth, so gathered scientific data are extremely valuable to scientists, working on this field
- Terrestrial analogue to extraterrestrial phenomena: Antarctic dry valleys as analogue to Mars
  - extremely low humidity and the fact that they are water and ice free since approx. 13,8 million years [5]
  - multiple geological similarities to planet Mars [7]
  - living microbes under mars like conditions [8]

4.2. Comparison

In a direct comparison to the best known extraterrestrial bodies (Table 1-1), Antarctica has several similarities, especially to planet Mars.

	Antarctica	Earth moon	Mars
Humidity	Frozen desert, 50mm precipitation / Year	-	-
Temperature	+5/-32 °C Coast -35/-95 °C Interior continent	+111 °C (Daytime equator); -193 °C at night	+20 °C equator daytime / -85 °C at night; average -55 °C
Atmosphere	884,4 hPa at high plateau (65% of norm. pressure)	-	6,36 hPa Wind velocities up to 650 km/h
Radiation	Increased UV radiation due to ozone depletion	Heavy radiation; lack of atmosphere and magnetic field	Heavy radiation, thin atmosphere and absence of global magnetic field
Day/Night time	1400h day/night at coast; 6 month day/night at southpole	Approx. 330h day/night	1 Sol (Martian day) = 24h 37min; similarity to earth
Dust	Adhesive and cohesive snow	Adhesive, ionized dust (abrasive)	Adhesive dust (abrasive)

Table 1-1: Direct comparison of Antarctica and ectraterrestrial planets

4.3. Infrastructure

A big benefit for Antarctica as an analogue test site to extraterrestrial bodies, is that there highly autonomous human outposts already exist and field activities can be hosted, assisted and coordinated right in the field. Normally people don't want to travel half way round the earth for a field test. Against that, the key element of field tests is to have the hardware readily developed and as close as possible to a full working system. A nearby home-laboratory and the expert-colleague right around the corner would lead to a degradation of the test preparation and would not mirror the efforts of a real mission. Human presence is still mandatory because the goal is to learn from the test and all available information about the system and the ongoing operations need to be gathered. The infrastructure challenges in Antarctica are similar, if not the same, as on extraterrestrial planets. In addition to the extreme environment, this creates a holistic analogue to Moon and Mars in a lower scale.

Infrastructure challenges:

- Ease of access with humans: Possible but expensive by plane
- Ease of access with cargo: Possible and easy to Antarctic coastal stations, expensive for the interior continent
- Challenge new technologies in everyday life test under harsh conditions
- Communication: low data transfer due to low satellite coverage
- Commanding: Remote operation by satellite communication, time delays possible
- Energy Supply: Autonomous energy support required for long term operations
- Autonomous navigation for long traverse travel and multi seasonal use
- Science autonomy: communication efficiency, data compression and science output can be increased, system operator time can be reduced

5. POSSIBLE SCIENCE ACTIVITIES

A lot of high valuable science goals for planetary Exploration can be investigated and tested in Antarctica. Beside single tool, concept and system tests, whole multi - unit exploration campaigns, as well as remote controlled semi - autonomous base build up for human presence can be done there and being tested for a proof of concept. Some hot spots of the planetary exploration technology development are:

- Autonomous traverse exploration
- Remotely operated deep drilling campaign
- Science autonomy
- Science ergonomy
- Instrument development
- Environmental hardening
- System tests / optimisation
  - Reconfigurability
  - Modularity
  - Mobility
- Remotely controlled / autonomous build-up of infrastructure
  - ISRU
    - Consumables for life support
    - Propellants
    - Fuel cell reactants
  - Site preparation
  - Base build up
- Resource prospection
- Excavation
- Transport
- Interaction of orbital and ground based systems
  - Landing site characterization
  - Path planning
- Access to surface and subsurface

Another big benefit is that most problems, occurring at planetary exploration, exist for the exploration of the Antarctic continent as well. Covering huge areas with scientific measurements are binding resources and thus extremely expensive. An autonomous operating system for big scale geological measurements, designed for the Antarctic use, will create worthy experience for development and operation of space systems as well as it creates high valuable science data for the Antarctic research. Especially in long term operations, the pure gathering of scientific data might legitimate an development of an unmanned exploration system for the exploration of Antarctica.

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