Terrestrial Analogs for Planetary Surface Facility Planning and Operations.

Olga Bannova,
University of Houston Sasakawa International Center for Space Architecture,
Houston, TX 77204-4000, USA
obannova@uh.edu

Abstract

This paper will draw parallels and define differences between factors that drive the planning and design of human surface facilities in space and in extreme environments on Earth. Primary emphases will highlight influences upon general habitat requirements, constraints upon delivery and construction, and special provisions for safety and hazard interventions. The overall intent is to identify important lessons that can be applied across different settings which present common priorities, issues and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research and oil/natural gas exploration stations, military desert operations, and natural and man-made emergency shelters.

Important topics of emphasis include the following considerations:

- Design influences driven by transport to remote sites;
- Environmental influences upon facilities and construction;
- Influences of crew sizes, types of activities and occupancy durations;
- Influences of construction methods and support infrastructures;
- Special safety and emergency response requirements.

This presentation will draw upon research and design activities at the Sasakawa International Center for Space Architecture (SICSA). Information is also taken from a SICSA-sponsored conference “International Design for Extreme Environments One” (IDEEA-One) at the University of Houston which attracted more than 400 interdisciplinary participants from 12 countries representing diverse professions and environmental settings.

Background and History

Extreme environments on Earth provide analog experience to support planning of extraterrestrial facilities and operations. Each environment presents special lessons regarding habitat design, crew operations and training, and equipment and logistical requirements for space exploration.

SICSA has extensive experience in research and design for extreme environments, including orbital and lunar planetary facilities, disaster shelters, polar stations and offshore surface and submersible habitats. Investigations have addressed such issues as hardships and challenges posed by harsh climate conditions, remoteness with restricted access and return opportunities, limitations on available equipment and support services, and ever-present safety risks. All of these environments share many kinds of technical and operational priorities. Key among these are needs for appropriate transportation and construction systems, efficient energy, effective and environmentally-responsive waste management and life support systems, maintenance and repair provisions, and emergency accommodations.

It is important to note that needs and priorities in extreme environments also represent some of the most pressing challenges and issues that face our entire planet. Increased difficulties and urgency in addressing human need and requirements in extreme environments often motivates efforts to find new and better solutions. Useful program advancements related to the extreme environment of space, for example, include important contributions to fields associated with computing and information management, material sciences, energy technologies, environmental monitoring and life sciences.

Experiences on US and Russian spacecraft, underwater vessels, and polar stations have revealed a variety of common issues:

• Cut off from "the outside", crews must learn to be resourceful, and to depend upon one another:

- They must work to help crewmates deal with psychological and physical stresses.
- They are required to adapt to limited comfort and recreational amenities.
- They must be prepared for fatiguing work overloads and stimuli deprivations.
- They must be trained and equipped to deal with equipment malfunctions.

• Common types of constraints place stringent requirements and severe restrictions on habitat design and operations:

- Limited internal volumes constrain storage and human activities.
- Limitations on equipment, labor and processes constrain structure assembly/deployment procedures.
- Limitations on maintenance and repairs (people, tools/ spares and methods) constrain maintenance and repair options.
- Safety and operations under harsh environmental conditions and demanding mission schedules pose safety and operational challenges.

Human and Environmental Planning Influences

Human requirements and environmental factors specific to each different type of environment, operation and facility must be correlated with resulting planning needs. Some general considerations are listed below in the Table 1:

HUMAN REQUIREMENTS	ENVIRONMENTAL INFLUENCES
Number of occupants	Structure selection and construction options
Social/cultural influences	Climate/thermal characteristics of the site
Time frame/mission duration	Logistical requirements and scheduling
Special safety hazards	Types and levels of danger
Emergency escape means	Proximity to major transportation modes
Recycling of expendables	Type of surface transportation
Primary mission objectives/purposes	In-situ resource utilization possibilities

Table 1. Planning considerations.

Structure types and architectural forms are typically influenced by similar considerations which include the following:

- Site/environment influences
- Transportation modes
  - Capacity (volume, mass, size)
  - Delivery method
- Mission timeline and crew work schedules
- Site/infrastructure preparation requirements
- Facility evolution/growth projections and requirements
- Special assembly/deployment accommodations and problems

Transportation, Safety and Emergency Response Requirements

As in space, high transportation costs, restrictions on cargo payload volumes, and limitations on periods of site accessibility pose serious constraints for extreme environments on Earth, such as polar and emergency response operations. These constraints impact the design of facilities, applicability and use of large equipment systems, re-supply of consumables, and crew rotation cycles.

For example, the only transportation available for most Greenland science facilities is LC-130 heavy-lift aircraft during the summer. The dimensions of its payload cannot exceed the size of 2.4m x 2.4m x 10.9 m (8 x 8 x 36 ft) and 11340 kg (25000 pounds) in weight. A short Greenland summer and therefore a short period of time when flights are available place additional restrictions on payload mass and size, which can significantly extend any construction period. To simplify construction and to make the most components of the structure exchangeable, all members of the trusses, floor and walls details, and utilities runs must fit the allowable payload size; therefore in this case all dimensions of the elements should be divisible to 2.4 meters (8 feet) (Bannova, O., Smith, I. F. C., 2005) These conditions create delivery and access problems which are generally similar to circumstances encountered in planning future planetary bases.

Logistics and transportation to some disaster areas on Earth can also pose challenging access difficulties. Responses to major disasters require that complex management, training and logistics plans be developed and implemented to deliver services to effected locations quickly and effectively. Special arrangements must be planned to address a broad variety of critical needs. Included are requirements for search and rescue operations; emergency medical accommodations; evacuation and shelters for impacted populations; food and water replenishment; waste cleanup and pollution control; and restoration of power, communications, transportation and other vital support systems.

Terrestrial analog experiences can be useful references to assess and confirm important requirements for space mission planning. It must be recognized, however, that the space environment is very different in many respects from human terrestrial environments:

- There is total dependence on artificial systems.
- Altered gravity conditions influence most activities.
- Extreme radiation, temperature and operational conditions present hazards for people and equipment.
- Stresses related to isolation in close confinement impact crew health and morale.

To accomplish proper planning planners must understand special characteristics of space environments:

- Reduced gravity levels and their implications.
- Radiation hazards and health risks.
- Micrometeoroid/ space protection requirements.
- Special lunar/ Mars surface features and environmental conditions.

Planning scenarios for human planetary exploration missions include short expeditions to the Moon and long-term manned missions to Mars. A mission to Mars will always include a long travel time (potentially 6-9 months each direction) and stay time on the planet surface from 3 months to 2 years. Some of the human factors challenges throughout such expeditions will be different from relatively shorter missions in Low Earth Orbit (e.g., onboard the Space Shuttle Orbiter and ISS). For example, the degree of crew isolation and autonomy during Mars exploration will be extremely high. Lessons taken from long-term stay times in Polar Regions have demonstrated that such isolation can seriously affect and degrade consciousness and somatic and mental health (Barabasz, A.F., 1991). Table 2 (Kanas N. and Manzey, D., 2003) presents some parameters for Polar and space missions that can be tested in extreme Arctic and Antarctic regions on Earth.

MISSIONS / FACTORS	ORBITAL MISSIONS	WINTER-OVER IN POLAR REGIONS	LUNAR MISSIONS	MARS MISSIONS
DURATION (months)	4-6	9-12	6	16-36
DISTANCE TO EARTH (km)	300-400	NA	350-400 thousand	60-400 million
CREW SIZE	3-6	4-100	4	6-8
DEGREE OF ISOLATION AND SOCIAL MONOTONY	Low to high	Medium	High	Very high
CREW AUTONOMY	Low	High	Medium	Very high
EVACUATION IN CASE OF EMERGENCY	Yes	No	Yes	No
AVAILABILITY OF IN-SITE SUPPORT MEASURES				
Outside monitoring	Yes	Yes	Yes	Very restricted
2-way communication	Yes	Yes	Yes	Very restricted
E-mail up/down link	Yes	Yes	Yes	Yes
Internet access	Yes	Yes	Yes	No
Entertainment	Yes	Yes	Yes	Yes
Re-supply	Yes	No	Restricted	No
Visitors	Yes	No	No	No
VISIBILITY OF EARTH	Yes	Yes	Yes	No

Table 2. Comparison between human missions on and close to Earth and future space missions.

Ocean Analogs

Oceans, like space, offer vast and exciting frontiers for science and exploration. The lack of natural life support systems in space and offshore underwater settings force mission planners to provide artificial alternatives with control systems that conserve and protect non-renewal resources. As in space, discharges of toxic wastes can produce harmful consequences. The oceans and other water bodies that constitute a primary part of our natural life support system have a limited capacity to sustain toxic abuse.

Deep ocean diving operations present requirements and constraints that are also similar in many aspects to extra-vehicular activities (EVA) in space. Divers and astronauts depending upon artificial life support systems must perform exhausting, often hazardous work, encumbered by rigid pressure suits that limit body mobility and dexterity. Poor or harsh lighting conditions hamper visibility in performing demanding and potentially dangerous work functions.

Construction Methods and Support Infrastructures

Construction methods in extreme environments must address vital structural safety and reliability requirements and take special environmental influences into account. Included are:

- Lack of onsite equipment and limited labor personnel
- Short construction windows
- Equipment breakdowns with limited tools/spares;
- Hazardous working conditions;
- Extreme temperatures impacting thermal control and structural fatigue.

A common construction priority for extreme environments is to design structures that can be rapidly assembled and deployed under harsh conditions. Modular approaches facilitate deployment and afford immediate occupancy but usually impose internal volume constraints driven by transportability requirements. Erectable structures can overcome volume constraints but add to on-site time and labor required for readiness. Advanced technologies including inflatable and other tensile systems applied to polar and desert environments can have transferable benefits.

Conclusions

Extreme environments offer good opportunities to demonstrate and assess the practical attributes and performance of equipment and operations under rigorous and demanding circumstances. High logistics costs and transportation constraints on allowable volume and weight force designers to create systems that are small and highly efficient. Harsh climates and isolated working conditions impose requirements for ruggedness and dependability. Limited labor resources and available tools place a priority upon ease of equipment deployment and repairs. Planning and design to optimize human safety under normal and emergency circumstances takes on a special urgency.

Operations in extreme environments often place people in small isolated groups where they must learn to depend upon themselves and their team members for social companionship and support ordinarily provided by large and diverse communities. They often experience dangers and stresses that test their ability to adapt, cope and perform. They are forced to work together and be resourceful in dealing with problems and emergencies. By observing experiences in extreme environments, we can learn about fundamental human capabilities and needs that are frequently overlooked or forgotten in modern society.

Different extreme environments on Earth provide venues for testing facilities, diverse issues and influences that apply to space missions. The table below presents some correlative examples:

SETTINGS / FACTORS	POLAR REGIONS	UNDER WATER	DESERTS	DISASTER AREAS
TRANSPORTATION	Maximum	Less	Less	Medium
ENVIRONMENT	Medium	Maximum	Less	Less
CREW: SIZE/ACTIVITIES/ DURATIONS	Maximum	Maximum	Less	Less
CONSTRUCTION METHODS	Medium	Maximum	Medium	Medium
SAFETY AND EMERGENCY REQUIREMENTS	Medium	Maximum	Medium	Maximum

Maximum Medium Less

Table 3. Compatibility and testing abilities of terrestrial analog settings for space applications.

While underwater facilities might be considered most applicable for many space factors, other issues such as transportation and logistics may more closely relate to polar and desert environments. In return, space technology, including easily transportable and deployable habitats using new materials, advanced power and power storage devices, and novel approaches to reduce and reuse waste materials can benefit all settings.

Existing terrestrial facilities such as NASA human-rated test facilities, sub-sea laboratories and polar camps can be used at low-cost as analogs at early stages of mission planning. To increase analog fidelity new terrestrial facilities that are specifically designed for space exploration will be necessary for future mission development. Low Earth Orbit facilities, such as the ISS, can provide a variety of space flight parameters and lunar outposts can provide analogs for future Mars missions.

In every analog, an appropriate mix of systems testing, human research, and mission operations simulation is necessary to achieve early space exploration milestones, both technical and strategic. Earth-based preflight crew training in high-fidelity simulators, geology training at appropriate locations on Earth, new ground facilities including a life support test facility, and life sciences research into human factors including psychosocial issues and habitat design can contribute to planning successful space exploration missions.

Transferable benefits from and between extreme environments can take many forms. Included are advanced technological innovations, significant scientific developments, and probably of greatest importance, enlightenment about ways humans can live and work in harmony with all environments. The ultimate benefit may be to help prevent our entire, fragile, planet Earth from eventually becoming an extreme environment.

References

IDEEA One, The First International Design for Extreme Environments Assembly, Final Conference Report, November 12-15, 1991.

Kanas N. and Manzey, D., Space Psychology and Psychiatry, Kluwer Academic Publishers, London, 2003

Barabasz, A.F., Effects of Isolation on States of Consciousness in: From Antarctica to Outer Space: Life in Isolation and Confinement, ed. Harrison A.A., Clearwater, Y.A., and McKay, C.P. Springer Verlag: New York, 1991.

Bannova, O., Smith, I. F. C., Autonomous Architecture: Summit Station in Greenland Design Proposal as a Test-Bed for Future Planetary Exploration. SAE 2005 Conference Proceedings, July, 2005.

SICSA space architecture seminar lecture series. Part VIII: Shelter Design and Construction. Section A: The Nature of Shelters, www.sicsa.uh.edu, 2006.

Adam, B. and Smith, I.F.C., (2007), "Self-Diagnosis and Self-Repair of an Active Tensegrity Structure", Journal of Structural Engineering, Vol. 133, 1752-1761.