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Autonomous Architecture: Summit Station in Greenland Design Proposal as a Test-Bed for Future Planetary Exploration.

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ABSTRACT

This paper reports results of collaboration between the Sasakawa International Center for Space Architecture (SICSA), Houston, USA and the Applied Computing and Mechanics Laboratory (IMAC), Lausanne, Switzerland. Research at IMAC involves the study of intelligent cable-strut structures that are adaptable and self-repairing in an autonomous regime. An architectural and engineering development approach and conceptual proposals for the Summit Station in Greenland for science research and operational support is proposed. The purpose of the project is to:

- Introduce the theory, requirements and design concepts for autonomously adjustable architectural elements of the structures and systems in extreme and special environments, including outer space and terrestrial architecture;
- Attain understanding of these structures and systems through design, research, and analysis of specific projects;
- Identify design solutions for the Greenland Summit Station to be applicable to other extreme environments such as those on the Moon or Mars (a test-bed capability);
- Perform a modularity study for future station expansion in Greenland as well as extensions for creating settlements on the Moon, Mars and beyond.

The project is undertaken as a response to the GEOSummit and Facilities Planning Meeting, which took place in January 2004. During this meeting a growing interest in polar research was observed and the necessity for a new station at Summit with better research and accommodation conditions was recognized.(1) This station is also proposed to be a place for NASA and related research for space missions.

INTRODUCTION

Psychological, social, and cultural aspects of life in Arctic and Antarctic remote areas, outer space and other environments have similar isolation, confinement, deprivation, and risk factors that building designers must consider. There are direct analogies related to symptoms, time lines of missions, and research goals, opportunities and risks.(2)

The goal of this project is to create green architecture design with convenient spaces for science research and operations and the maximum use of renewable energy. That is one of the most critical issues for research at Summit.

Program specifications and assumptions fall into the following categories:

- Identification of requirements for client/user support;
- Major activities and relationships between them;
- Site influences;
- Facility planning;
- Budget and schedule.

The proposed facility in Greenland will support 50 people during the summer season and 25 people during winter. Primary elements of the modular configuration include a triangular platform with two upper floors, which is supported by three jacking columns that maintain the facility at a preset average distance from the surface. Extra 2.4 meters (8 foot) truss elements can be added by crane incorporated in one of the legs to provide a possibility of raising the structure above the initial height of the supporting legs. The proposed crane structure is self-climbing and can be adjusted to the necessary height. (Figure 1)

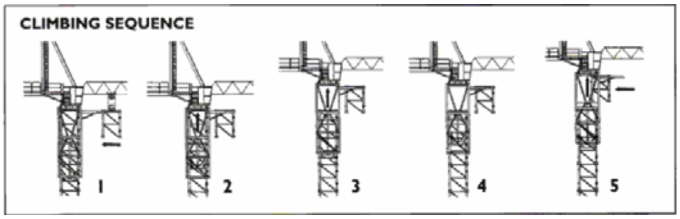


Figure 1: Climbing sequence for crane and legs structure extending.

This approach enables the structure to adjust to differential settlement of supports. An adaptable bottom floor structure is used to modify the form of the underside of the platform to avoiding excessive snow drifting (on Mars, dust storms would be the difficulty). Even though there most likely no such thing as a dust drift problem exists in Mars environment, jacking columns and adjustable structures may be in use to provide a safety gap between habitable facilities and a potentially hazardous unknown surface below. A separate structure for a mechanical shop is added to complete the initial configuration. Important priorities are to provide a high quality environment for research and science experiments and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy and human factors.

POLAR EXPERIENCE

ARCTIC AND ANTARCTIC STATIONS

Numerous research stations in Antarctica were constructed after the first International Geophysical Year in 1957-58. There is a big history in Antarctic and Arctic exploration and the notion of using elevated structures in polar environments is not a new idea. Traditional techniques for constructing in cold regions are not sufficient for polar environments because of constant generation of snow deposit around buildings and anything else that is located on the surface. Different types of structures have been tested through the years, and elevated structures prove to be the most reliable and long-term operable in inland polar conditions and especially under severe snow drifting circumstances. Stations such as the first elevated structure, Australian Casey Station, the German Filchner Station, the British Halley Research Station, and most recently the Amundsen-Scott South Pole Station (Figure 2) demonstrate the usefulness of raised structures compared with those on the surface. However, they also revealed important challenges. William D. Brooks in his paper “The Rationale for Above-Surface Facilities” provides a review of the history of Antarctic exploration and describes advantages and disadvantages. Specifically, he emphasized that “no matter how well snow drifting could be controlled, at some point the station would need to be raised”.[3]

Figure 2: Antarctic Elevated Stations. (1-Filchner station, 2-Halley station, 3,4-Atmospheric Research Observatory, 5-Amundsen-Scott Station)

SICSA’S ANTARCTIC PLANETARY TESTBED (APT) PROPOSAL [4]

SICSA has a long history of projects that involve the design of extreme environment architecture and space structures, including habitats for low-Earth orbit (LEO) and planetary applications. One of its major initiatives was the Antarctic Planetary Test-bed (APT) project, which started in 1987. An important APT function was to serve as a controlled psychological and social research laboratory. Space mission simulations provide opportunities for crew training and selection. Based on this research a genuine justification for the planetary test-bed facility was established. However, in the opinion of the SICSA team, analogs for space could be equally well served in other locations such as remote desert sites or underwater – thereby eliminating the increased expense a dedicated Antarctic facility such as the APT. Nevertheless, the team emphasized that it is the added terrestrial benefits of Antarctica that make it superior and merit serious consideration (Figure 3). However, the absence of a capability to adjust the height of the structure above the surface was considered to be a disadvantage and this is reviewed in the proposed project.

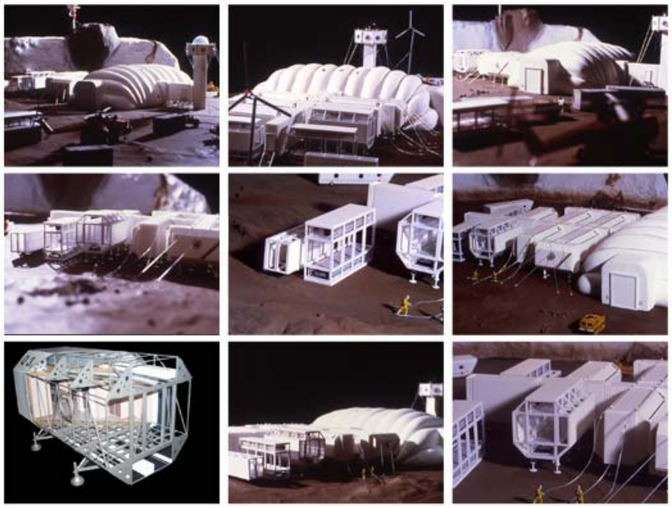


Figure 3: SICSA's Antarctic Planetary Testbed (APT) project.

PROJECT BACKGROUND

GREENLAND ENVIRONMENT AND CONDITIONS

Permafrost covers about 20-25% of the Northern hemisphere open land surface. Soil, covering even larger areas, is seasonally frozen. Variation in permafrost and frozen soil indicates important climate changes, and is particularly useful in testing modeling results. Permafrost is a natural basis for Arctic ecosystems and infrastructure. Permafrost is also recognized as an important matter for the trace gases and the atmosphere exchange.(5)

Greenland is the world's largest non-continental island. It is approximately 81% ice-capped and its center is positioned at 72 00 N and 40 00 W. The Greenland terrain includes a flat to gradually sloping icecap covering all but a narrow, mountainous, barren, rocky coast.

Over three quarters of the country is constantly under the ice. The total weight of this ice has caused the middle of the country to sag and form a curved in basin, which reaches a depth of 360m (1180ft) below the sea level. Above the ground rising crystal columns of ice spot the landscape, glaciers push huge icebergs into the sea. If it thaws any time in the future, the amount of ice would be enough to put coastal cities around the world under the water.

SUMMIT STATION BACKGROUND

Summit Camp, located at the peak of the Greenland ice cap, is a scientific research station sponsored by the US National Science Foundation (NSF). The camp is situated atop 3200m (10498 feet) of ice and is nearly 400km (248.5 miles) from the nearest point of exposed land. (Figure 4)

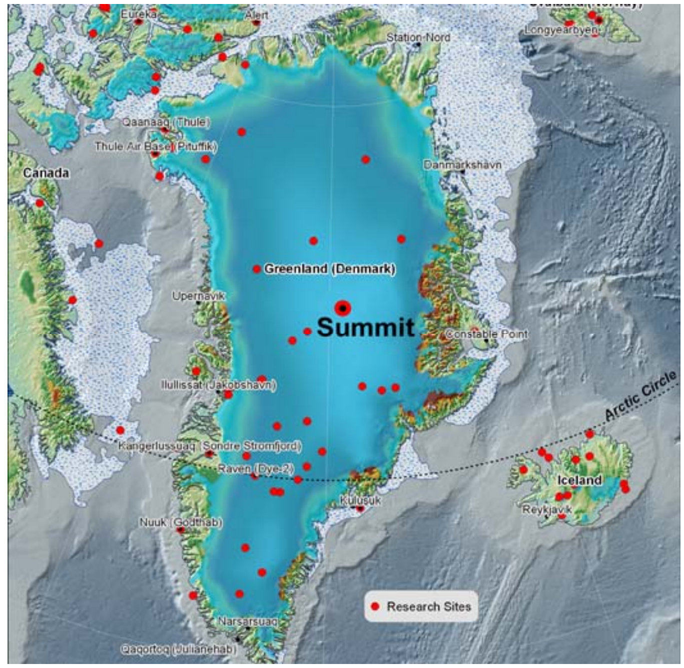


Figure 4: Summit Station location in Greenland.

A number of science operations have been carried out at Summit Camp during the past decade. It is practically an ideal place for climate change and snow chemistry research. The GEOSummit facility will need to accommodate a larger number of users while maintaining a clean sampling environment to satisfy growing science demand. The year 2007-08 is announced to be an International Polar Year and there are already a number of activities planned for this event. The new advanced Summit Station is a response to increasing research needs in Polar Regions and in Arctic specifically. (6)

Summit Greenland is a site of expanding scientific interest by both U.S. and European scientists. Current U.S. projects are: evaluating ice-core characteristics related to environmental change, investigating upper and middle atmosphere phenomena as a basis for understanding the global system, evaluating atmospheric conditions in the troposphere and in the boundary layer contacting the Greenland permanent ice sheet, and establishing the radiation, energy, and water balances which occur on the ice-pack. A Science Coordination Office was established for more effective coordination of the different communities using this environmental observatory and its goals are to:

1. coordinate data between researches and the sharing of station facilities and personnel,

2. present scientific requirements to NSF, its operational support team and European partners through the facility development,

3. encourage data sharing between science projects.

<u>Current station problems</u>

Site plan

Multiple structures are scattered on the site and they are widely separated, which amplifies snowdrift, requires individual heating for each building and jeopardizes safety during hazardous weather conditions. Only a couple of buildings are currently elevated at a fixed height and there is no capability to adjust the distance to the surface below. Most buildings are constantly buried under the snow and need to be dug out several times during a year. (Figure 5)

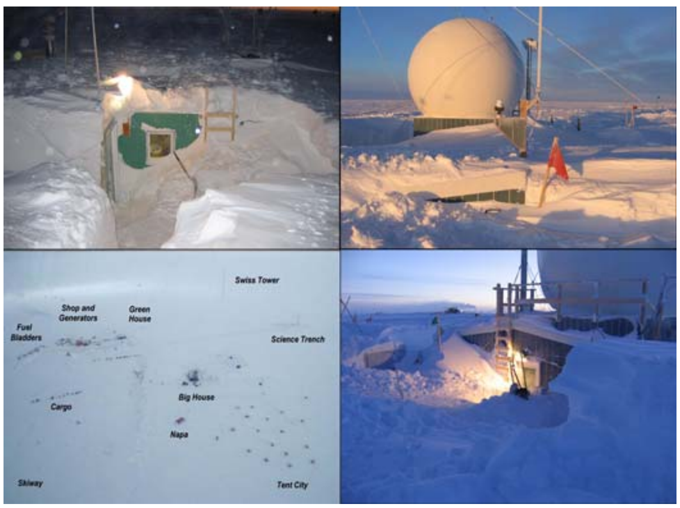


Figure 5: Current pictures of Summit Station.

Power

There is one diesel generator in Summit now and the entire station is heated year around regardless of its occupancy. Pollution from the diesel generator hinders scientific research such many activities require a clean environment. This type of power is also expensive in Greenland and especially at Summit. Diesel fuel can be delivered there only by air, making its cost at Summit at least $2 per litre or $8 per gallon and this significantly increases the total operational cost of the station.

Operational capacity/volume

Lack of the dedicated lab space on the station complicates and limits research possibilities. Also, the station does not have enough flexibility for seasonal changes in station population.

CLIENT-USER SUPPPORT REQUIREMENTS

Extreme polar conditions effect many aspects of life and work in the cold environment at Summit. Important aspects are:

1. transportation;

2. occupancy (summer/winter);

3. life support and emergency;

4. work requirements.

<u>Transportation</u>

The only transportation available to Summit 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. These circumstances may prolong the construction period to two seasons (2 years) before the first stage of the station can start operating. 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 are designed to fit the payload size; therefore all dimensions of the elements are divisible to 2.4 meters (8 feet). Summit Station remoteness thus creates access problems which are similar in principal to circumstances encountered in planning future planetary bases.

<u>Occupancy</u>

The new facility is proposed for 50 people occupation during the summer seasons and 25 – during the winter. Accommodation within the building is proposed for 25 winter shift personnel. Scientists who come for temporary research projects during the summer stay on the field outside of the building in personal tents. It was observed through years of Summit's existence as a science base that the most people who visit the station for a short period of time prefer to sleep outside in tents because temperatures at Summit during the summer are not particularly cold.

<u>Life support and safety requirements</u>

Apart from the periodically bad weather conditions and depending on flight availability, links between Summit and the coast are good during the summer. However, there are no regular flights offered during the winter (August-April). These conditions present another challenge for design: the station should be operable autonomously and should provide all necessary support for 25 people for 9-months without re-supply. The renewable energy approach that is proposed in this paper can meet all power requirements and excess of the accumulated energy can be stored in batteries for later utilization. The storage area is a part (sub-floor) of the main structure and equipped with containers, which makes it easily accessible and simplifies supply deliveries. In emergency situations on the main structure a mechanical shop (secondary structure) can be used as a temporary shelter.

Safety

- Provide a safe haven with food and shelter.
- Design structures and select materials to reduce fire hazards.
- Design structures to withstand lateral loads caused by high winds.
- Provide backup power and communication systems.
- Design systems for reliability, easy maintenance and repair.
- Provide means for emergency crew evacuation.

<u>Work requirements</u>

The purpose of the project is to create a clean, pollution free green energy environment to provide optimal conditions for good scientific research. The research topics which can be investigated both at Summit and during space missions include human factors research, hydroponics study, psychological factors and physical factors and conditions for people during a long stay in isolation, and finally, snow drifting (in case of a Mars mission this would be dust storms).

CLIENT-USER MAJOR ACTIVITIES AND RELATIONSHIPS

Summit Station supports a wide range of scientific research on a year-round basis. Represented fields are: meteorology, glaciology, atmospheric chemistry, and astrophysics. In addition, the station serves as a base for long-term environmental observations. This multiplicity of purpose demonstrates the significance of Summit Station as a research base, but also creates some specific operational challenges. Sometimes research projects can involve contradictory methodologies, and even the operational requirements of the station itself can have negative influence on performing some of the research. There are two fundamental types of activities at Summit: scientific (research) and logistic (support). Population of the station is divided approximately half and half between scientists and support crew and this provides good conditions for scientific experiments. The main structure is separated into several zones and has dedicated areas for both: science and support operations.

DESIGN APPROACH

PROPOSED ARCHITECTURAL SOLUTIONS

<u>Site influences</u>

Skiway location and existing taxi way were considered key-elements for new structure's location. To avoid extra site work and snow removal and minimize construction time, both buildings are placed as close as possible to the taxiway. The exact position of the buildings is based on the wind tunnel study and also depends on prevailing wind direction (South-West with seasonal changes of the wind speed from 21 m/sec to 0.2 m/sec) as a key factor for using wind turbines for power generation and for avoiding pollution from the skiway that is produced by airplane exhaust. (Figure 6) The shape of the main building was influenced by aerodynamics and, with 3 supporting jacking legs, provides maximum structural determinacy to avoid stresses due to differential settlement.

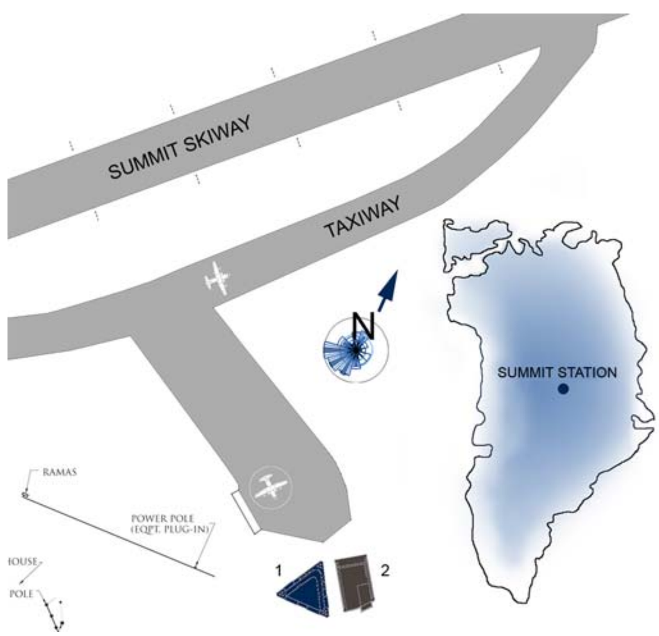


Figure 6: New Summit Station site map (1-main building; 2-secondary structure).

Facility planning considerations

Building systems (Figure 7)

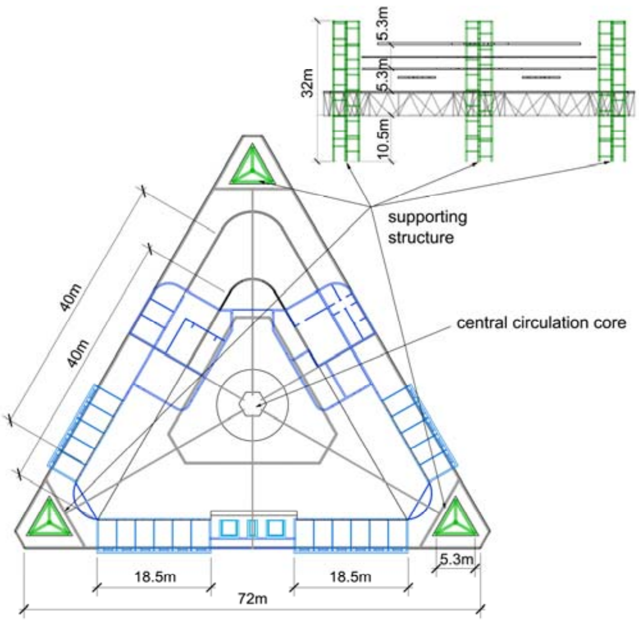


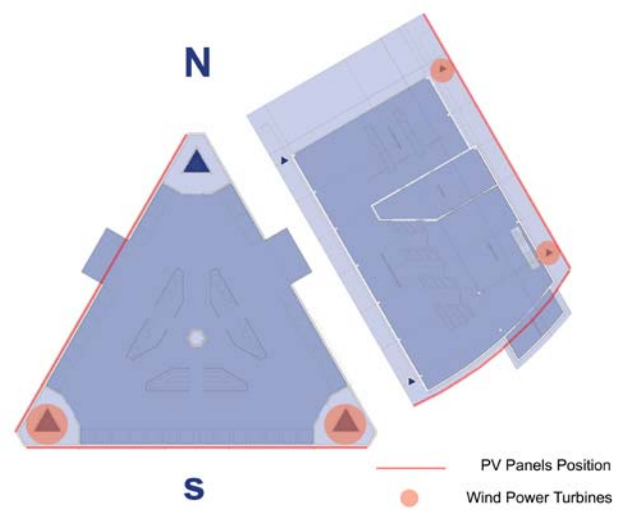
Figure 7: Plan and section of the main building.

- All elements designed for transport by ski equipped LC-130 airplane to the site.
- System design to avoid the need for very heavy construction and transportation equipment.
- Construction planned to minimize impact on environment.
- Balanced weight distribution to avoid differential settlement.
- Modular interior design to enable easy and versatile expansion, reconfiguration and equipment change outs.
- Design by zones with possibility of temporary seasonal shut downs by sections, reconfiguration and flexibility of interior arrangement.
- Incorporating an active structure into the main facility platform to minimize snowdrift around the facility and a negative drift crater underneath it.

Utility systems

- Use of renewable energy.
- Modern systems to collect and recycle waste materials.
- Utility interfaces to accept standardized space facilities such as experiment racks and functional units.
- Automation and robotic systems to reduce labor and demonstrate space applications.
- Databases and computing systems to control and monitor diverse experiments.
- Communication and telemetry systems.

A minimum of 200 kW of power is necessary for station operation, is achieved by 4 up-wind power turbines and 1085 m^2 (11678.8 ft^2) of Photovoltaic (PV) panels incorporated on both structures. Each wind turbine is 12m (40') diameter and produces 55 kW of power. The rest of the necessary energy is proposed to come from solar panels located on the south and east elevations of the main building and south and west sides of the secondary structure. (Figure 8) According to NREL (National Renewable Energy Laboratory) report, total cost of energy in Summit will be approximately $0.35 per liter (compare to approx. $2/l now) when 80% of energy will be produced by renewables.(7)



	Wind Power (KW)	PV Panels (KW)
Main Structure	110	≈600
Secondary Structure	110	≈400
Total	220	≈1000

Figure 8: Renewable energy sources locations.

Facility elements (Figures 9 and 10)

Living accommodations (Figures 9 and 10)

- Crew quarters
- Cafeteria and kitchen to seat 50 people in shifts with similar menu provisions to space stations.

- Exercise, toilet, shower and laundry equipment.
- Small health maintenance facility for routine and emergency medical care.

Research accommodation (Figures 9 and 10)

- Facilities for environmental, biological, human, animal and plant life science research.
- Open-plan laboratory space with movable workbenches, experiment racks and storage.
- Maintenance and parts room with basic tools and calibration equipment.
- Wet lab with separate exhaust duct system and temperature control areas.

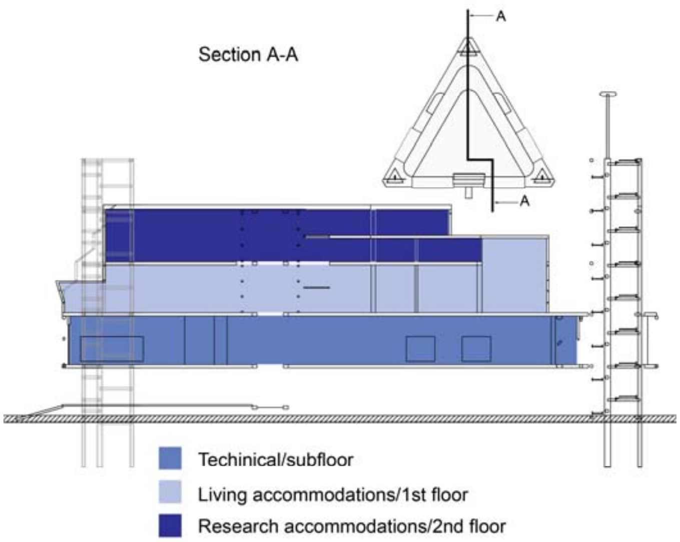


Figure 9: Main facility vertical zoning.

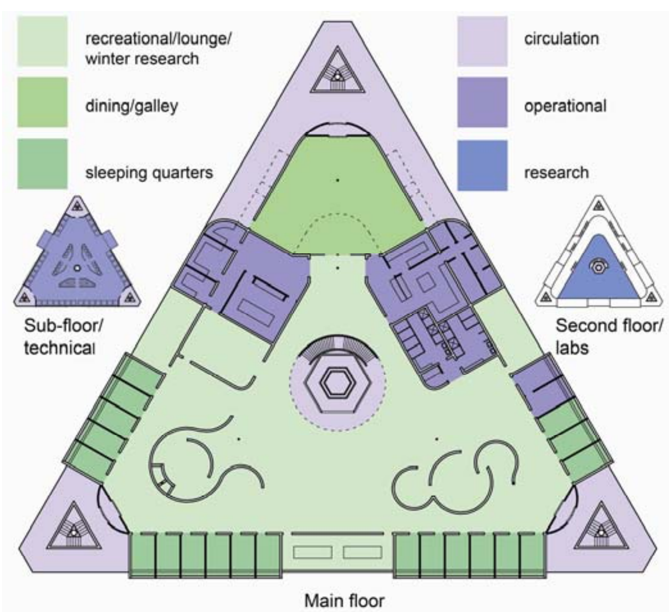


Figure 10: Main facility horizontal zoning.

Support structures (Figure 11)

- Greenhouse/biosphere for plant growth and hydroponics research (main structure).
- Vehicle repair and temporary emergency shelter (secondary structure).
- Storage facilities (both structures).

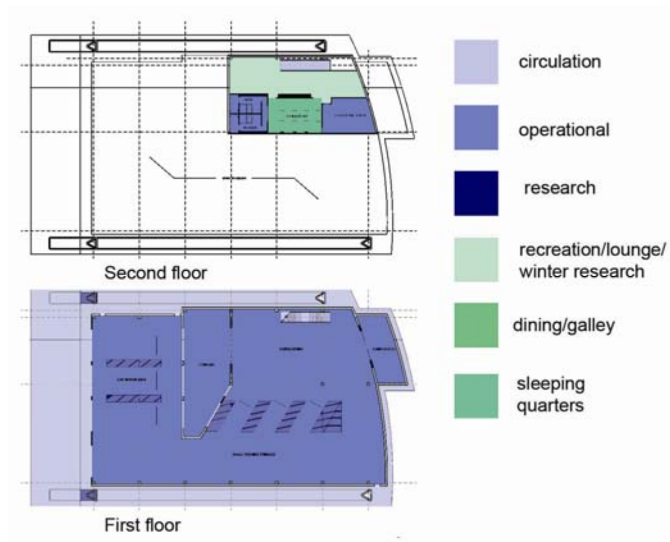


Figure 11: Secondary structure horizontal zoning.

Economic considerations and schedule

- Provide well-insulated, tight construction to minimize heat loss.
- Provide economical, nonpolluting energy sources for heating and power systems.
- Size and package payloads for efficient airplane transport.
- Construction delivery schedule according to flight availability from May to August with maximizing number of flights per month during this period.
- Construction assembly on a year-round basis.

The extreme environment at the South Pole is similar to conditions at Summit Station with respect to aspects such as altitude (2851 m above sea level at the South Pole and 3200 m at Summit), additional clothing for work in extreme temperatures, isolation, living conditions and remoteness. According to statistical research, a productivity factor of 2.16 was determined for construction work at South Pole stations. It means that time to accomplish construction work in such an extreme environment takes 2.16 times longer than under normal circumstances.[8] Even though productivity factors are not expected to be as bad at the Summit Station such reductions in productivity may delay construction.

Construction materials and methods

The initial phase will be built by a crew of approximately two dozen people during the Arctic summer and half of the group – through the winter.

Most common and economical construction today makes use of steel frames covered with laminated aluminum-fiberglass panels and these are proposed for walls structure of both facilities.

The intent of the project to utilize materials and methods, which bear resemblance to those, proposed for extra-terrestrial bases. The materials and methods were studied in light of the following criteria:

- Weight;
- Strength and durability;
- Economics;
- Insulation value;
- Ease of fabrication;
- Ease of erection/assembly;
- Ease of maintenance;
- Flexibility;
- Deformation under temperature variation;
- Availability.

Based on the review and evaluation done by criteria described above, the following materials are recommended for the uses indicated in Figure 12.

Material	Recommended use
Steel alloy tubing	Structure trusses, framing members and supporting legs
Honeycomb "sandwich" panels with Kevlar reinforced lamination	Modular skin panels
Triple glazed, laminated and coated glass	Windows
Aluminum alloy tubing	Floor structures
Lightweight tubular steel or steel lattice	Wind towers
Laminate flooring system and Mateflex	Floor surfaces
PV PolyCrystalline	Solar panels

Figure 12: Materials and recommended uses.

WIND TUNNEL STUDIES OF AN ACTIVE STRUCTURE

Several tests have been run in the wind tunnel at EPFL to analyze the effects of snow accumulation under this elevated structure. The most effective way to ensure that excessive snow accumulation is avoided is through the use of aprons that vary their angle according to wind speed and direction. The objectives of this study are to:

- vary the distance between the glacier and the building to see when snow accumulation disappears;
- determine the influence of fixed aprons on the snow accumulation;
- investigate different angles of the aprons;
- reduce the surface of the aprons to find the most economical solution.

Figures 13 and 14 below show the interior of the wind tunnel and the model used for the studies.

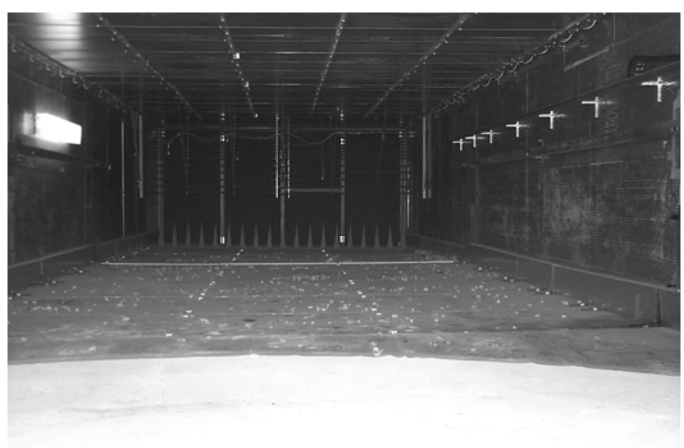


Figure 13: Interior of the wind tunnel at EPFL

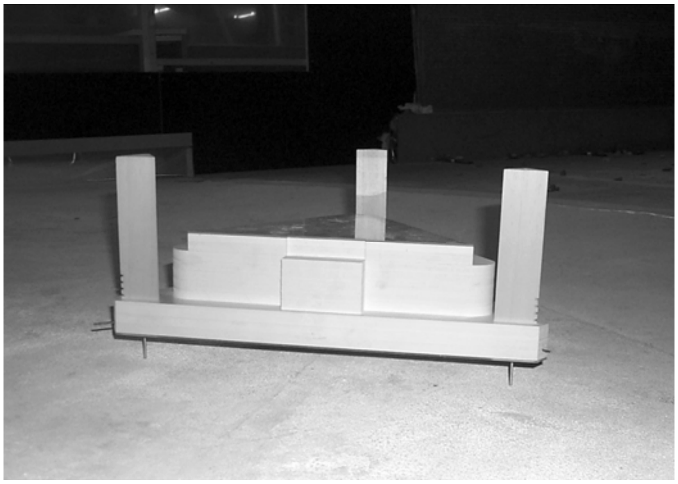


Figure 14: Model used for the wind tunnel studies

For the design distance between the glacier and the building (4.575 m) different wind directions (0°, 30°, 60°, 90°, 120°, 150°, 180°) were studied. The wind direction of 180° has been found to be the most critical. For this wind direction, snow accumulation under the structure and snow drifting around the columns was observed. (Figure 15)

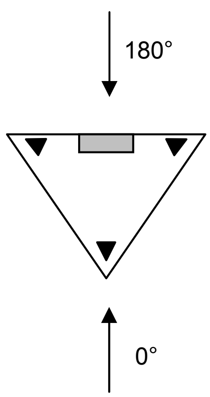


Figure 15: Definition of the wind direction

With the critical wind direction, four additional heights (6.86 m, 5.72 m, 2.29 m and 1.14 m) were tested. In the case of 6.86 m the effect of snow accumulation under the building disappeared. Nevertheless, snow drifting around the columns remained. In the case of 1.14 m height, snow accumulation achieved the greatest depth. A phenomenon of snow transport up to the top of the building was also observed. This phenomenon also occurred for a height of 2.29 m. For a height of 5.72 m the effect of snow accumulation was less than for a height of 4.575 m, but more than for a height of 2.29 m. These results lead to the conclusion that the effect of snow accumulation under the elevated structure can be reduced only partially by increasing the distance between the glacier and the building. An increase of the height of the building causes an enhanced and more uniform wind speed under the elevated structure.

In future studies, the influence of fixed aprons on the snow accumulation under the building will be tested. The concept involves transforming the shape of a triangle into a rectangular shape. In a next step aprons at various angles will be tested (Figure 16). For the real structure, aprons with variable angles would be designed as active structures along the edges of the building.

In addition, future studies include the examination of a reduced surface of the aprons (Figure 16). The goal is to identify the most economical solution.

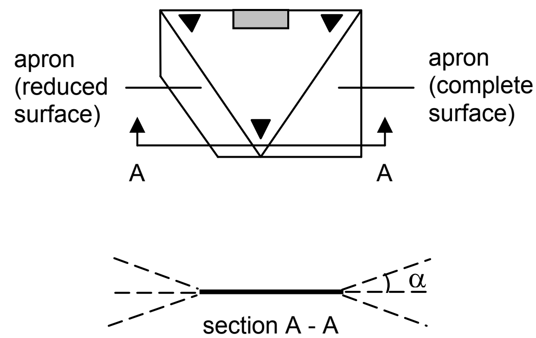


Figure 16: Aprons with complete and reduced surface that are inclined at various angles according to wind speed and direction

PLANETARY TESTBED APPLICATION

Activities and personnel on small arctic bases have many attributes in common with astronauts on space missions. Highly motivated crews cut off from outside resources and services perform important roles under challenging, sometimes dangerous conditions. Such circumstances are difficult to recreate in an artificial simulation environment in order to carry out for example, psycho/social research and crew training.

ENVIRONMENTAL AND GEOLOGICAL SIMILARITIES

- Summit, which is 3200 meters above sea level, is one of the earth's highest and driest environments with a relatively low atmospheric pressure most like Mars.
- Temperatures are as low as –50°C during the wintertime has similarities to the Moon and Mars.
- Wind range can reach 21 meters per second. Snowstorms in these locations have similarities to dust storms on Mars and may create similar to snow drifting difficulties.

- Arctic environments and the Moon experience long days and nights, thereby affecting surface operations. The Arctic has almost 5 months of darkness and extreme cold while the Moon has 14 days of darkness (1 Moon day lasts 27 Earth days).

- Greenland terrain contains sterile areas that are devoid of any life form and this is similar to conditions found on the Moon and Mars.

- The permafrost environment in Greenland is similar to surface conditions on Mars.

PERSONNEL PROFILES AND ACTIVITIES

- Arctic and space crews are typically well motivated and educated. Their devotion to mission goals distinguishes them from subjects in contrived laboratory simulation settings.

- Crew who are cut off from outside resources and services for long periods of time are forced to adapt and become self-reliant. They must confront difficult problems with determination, innovation and teamwork.

- Remoteness imposes space-like restrictions on living and work facilities, amenities and operations. Construction activities, for example, are constrained by seasonal weather conditions, limited available equipment and small labor crews.

- Environmental safety and conservation is a high priority for planetary exploration and activities in Greenland.

POSSIBLE STRUCTURAL ADJUSTMENTS

Several parameters can be adjusted for space mission (planetary exploration) applications. Figure 17 presents a comparison table between design for Summit and its extra-terrestrial utilization.

ASPECTS	SUMMIT	MOON/MARS
Main platform	Modular steel trusses for the support structure	Modular aluminum/steel trusses for the support structure (1/6 of the Earth gravity on Moon and 1/3 on Mars allow to build lighter structures)
Supporting legs	Jacking legs for adjusting necessary clearance between bottom of the structure and surface below and for counteracting differential settlement	Jacking legs for adjusting a desirable clearance between bottom of the supporting structure and surface below and for counteracting differential settlement if any occurs
Apron	Self cleaning of snow drifts and low erosion around supports	Self cleaning of dust and lower erosion around supports (Mars only)
Outer shell	Modular aluminum skin panels	Inflatable structures to minimize payload weight
Interior	Movable, lightweight partitions; racking systems for lab equipment	Movable, lightweight partitions; racking systems with plug & play capabilities for lab equipment
Interior Circulation /EVA	Vertical and horizontal zoning. Main circulation is concentrated in the central core, additional access through the legs.	Vertical and horizontal zoning. Main circulation is concentrated in the central core; EVA operations are carried out through pressurized airlocks.
Power	Mainly renewable energy resources (wind and PV panels)	Mainly nuclear power generators and some of renewable energy (wind and PV panels)

Similar Some differences Different

Figure 17: Comparison table.

GLOBAL RESEARCH AND COOOPERATION

The year 2007-08 is announced to be the International Polar Year and researchers will address important science issues in both Polar Regions, involve multi-national and interdisciplinary collaboration. Such activity should attract and develop the next generation of scientists, engineers and leaders. [9]

There is an excellent possibility for US-European cooperation in Summit. The European Polar Board, which represents 22 countries, is interested in encouraging further research at Summit station. There is a particular interest in the potential for comparisons between the "poles". Concordia in the Antarctic and Summit in the Arctic are excellent examples for such comparisons.

CONCLUSION

The research carried out during the work on this project focused on creating an elevated structure with centralized and minimized station operations through building one main facility with dedicated living, research and operational areas and a secondary structure for a mechanical shop and a temporary shelter for emergency situations.

Building a new advanced science station in Summit is important for the international scientific community since it offers the following benefits (Figure 18):

- A modular station structure design satisfies C-130 payload restrictions with maximum utilization of payload capacity.
- Use of renewable energy helps minimize operational costs and impact on Greenland's environment.
- Energy accumulation during the summer could lead to an autonomous power supply during winter.
- Adjustable support structure helps maintain the necessary clearance between structure and snow surface and corrects for differential settlement.
- Active structures along the edges of the buildings may minimize snow drifting and erosion around supports, thereby reducing energy requirements for snow removal and simplifying facility operation.
- Experience gained during construction and operation of the station will be valuable for future planetary exploration missions.

Figure 18: Perspective view of the proposed station

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