Autonomous Architecture Proposal for Summit Science Station in Greenland.

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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. A design project has been initiated in response to growing international scientific research interest at Summit Station in Greenland and a requirement for better accommodation and support. Research at IMAC involves the study of intelligent cable-strut structures that are adaptable and self repairing. An architectural and engineering development approach as well as conceptual proposals for the Summit Station in Greenland for science research and operational support is proposed.

The proposed facility in Greenland supports 50 people during the summer season and 25 people during the wintertime. Primary elements of the modular configuration include a triangular platform with two upper floors that is supported by three jacking columns. This approach means that structure can be adjusted to accommodate differential settlement of supports. An adaptable apron structure around the primary platform is used to modify the form of the underside of the platform to maintain predetermined clearance criteria between the structure and level below, thereby avoiding excessive snow accumulating around the building and minimizing drifting and scour underneath it (on Mars, dust storms might be the difficulty). A separate structure for a mechanical shop and power support is added to complete the initial configuration. Important priorities are to provide a high quality environment and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy and human factors.

Testing of a plywood model of the primary facility that was installed in Summit in May 2005 and a wind tunnel model at EPFL confirmed that if the structure was not sufficiently elevated, drifting could bury it. Important parameters are the shape of the building, the form of the bottom of the platform, snow accumulation points, snow drift distribution, wind direction, wind speed and distance between the structure and the snow surface.

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 (Harrison et al, 1990).

Summit Camp is an ideal place for scientific activities, especially those related to climate change and snow chemistry research. The Summit facility needs to accommodate many users while maintaining a clean sampling environment in order to satisfy a growing demand for scientific research. The year 2007-08 is the 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 the Arctic specifically (GeoSummit Science and Facilities Planning Meeting, 2004).

The goal of this project is to provide a high quality environment for scientific research and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy and human factors and the maximum use of renewable energy. Program specifications and design assumptions are grouped into the following categories:

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

Polar Experience. Numerous research stations in Antarctica were constructed after the first International Geophysical Year in 1957-58. There is a long history of Antarctic and Arctic exploration and the notion of using elevated structures in polar environments is not a new idea. Traditional construction techniques in cold regions are not sufficient for polar environments because of constant generation of snow deposit around buildings and anything else that is located near the surface. Various structures have been tested through the years, and elevated structures prove to be the most reliable and life-cycle operable for inland polar conditions and especially under conditions of severe snow drifting. 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 1) have demonstrated the usefulness of raised structures compared with those on the surface. However, they also revealed important challenges.

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

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” (Brooks, 2000).

Project Background

Greenland environment and conditions. 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 (Figure 2).

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 2).

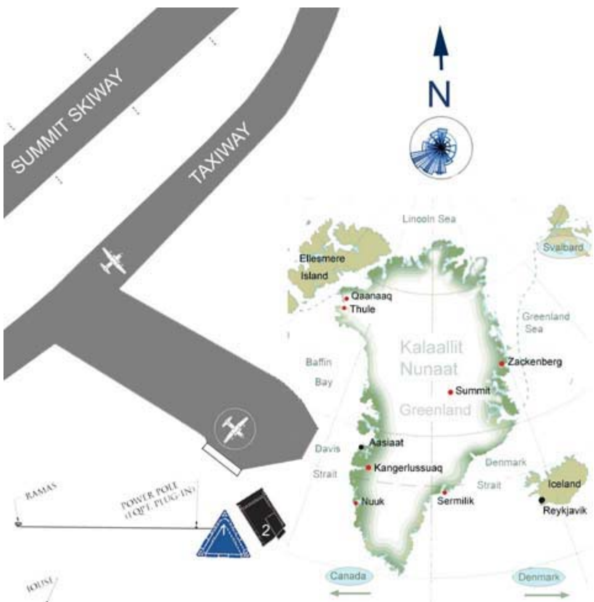

Figure 2. New Summit Station site map (1-main building; 2-secondary structure) and its location in Greenland.

Summit Greenland is a site of expanding scientific interest by both U.S. and European scientists. Current topics of projects include evaluation of characteristics of ice-cores in relation with environmental change, investigation of upper and middle atmosphere phenomena for improving understanding of the global climate system, evaluation of atmospheric conditions in the troposphere and in the boundary layer contacting the Greenland permanent ice sheet and studies of the radiation, energy, and water balances which occur on the ice-pack (International Arctic Research Center (IARC), 2003; Geosummit winter, 2004–2005).

Proposed Architectural Design

Site influences. Skiway location and the existing taxiway were considered key-elements in the choice of the location of the new structure. The exact orientation of the buildings is under study. The prevailing wind direction (S-W with seasonal changes of the wind speed from 21 m/sec to 0.2 m/sec) is a key factor in this study and for using wind turbines for power generation. Finally, the building was positioned to avoid pollution produced by airplane exhaust.

Facility planning considerations

Building systems:

- All elements are designed for transport by ski equipped LC-130 airplane to the site.

- System conceived to avoid heavy construction and transportation equipment needs.
- 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 snow drifting 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 (Table 1). 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. According to NREL (National Renewable Energy Laboratory) report, total cost of energy in Summit will be approximately $0.35 per liter equivalent of gasoline (compared with approx. $2/l now) when 80% of energy will be produced by renewables (Baring-Gould, 2004).

Table 1 Renewable energy sources.

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

Facility elements (Figure 3). *Living accommodations:*

- 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:

- 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.

Support structures

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

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 (a productivity factor of 2.16 was determined for construction work in Polar Regions) (Marty,, 2000).

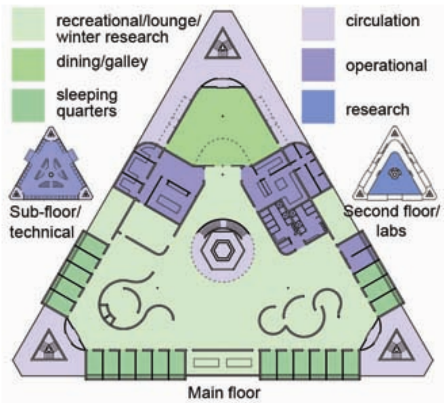

Figure 3. Facility Elements.

Summer Testing

The purpose of this mock-up testing.is to guide design adjustments. The mock-up model was tested at 2 different heights from the surface: 50 cm (1’6”) and 25 cm (10”). An important problem is related to scale. At this scale, it is as if each grain of snow were the size of a softball. Also, the entire model is down in the thickest part of the snowdrift, while the real building would largely be placed above it. Although there is scale incompatibility, the testing demonstrated a significant difference between snow drift accumulation at different heights above the ground and indicated model surfaces where drift is forming by prevailing winds. (Figures 4-6).

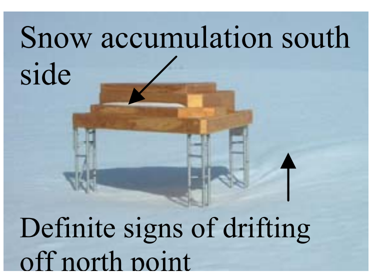

Figure 4. Installation at 1’6” height. June 2005.

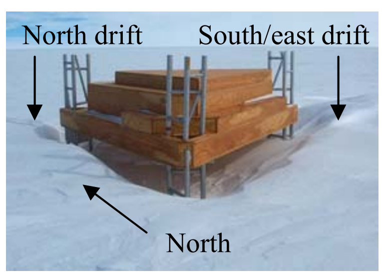

Figure 5. Installation at 10” height. End of July 2005**.**

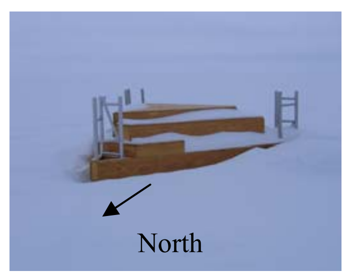

Figure 6. Installation at 10” height. Sept. 2005.

Design Adjustments

Shape and structure. The triangular shape with 3 legs support was compatible with Summit conditions. No inclining was indicated during the summer testing. The model remained leveled and stable.

External walls and structures. Testing showed that most of the 90 degrees corners (both vertical and horizontal) accumulated snow (depending on their orientation to wind direction) (Figures 7 and 8). Testing also demonstrated that the snow accumulation diminishes with increasing of elevation from the snow surface. Therefore adjustments more likely should be done only on the first level of the structure.

Many factors (wind speed, temperature, humidity, type of snow, period of time since surface snow was deposited, air density, etc.) influence snow transport. Another possible adjustment is the scaling whole structure down to serve for 25 people during the summer and 6-10 people during the winter time. This design is easy scalable to satisfy various occupancy levels and functions and does not require complicated layout rearrangements (Figure 9).

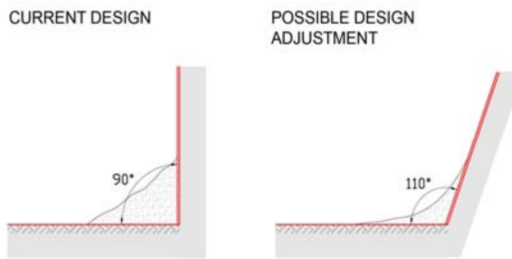

Figure 7. Vertical wall adjustments.

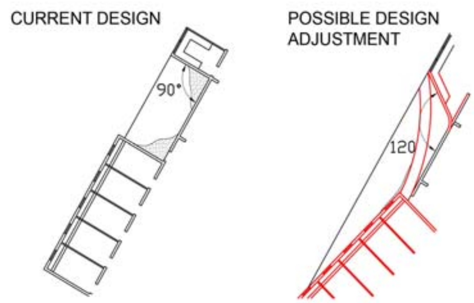

Figure 8. Horizontal wall adjustments.

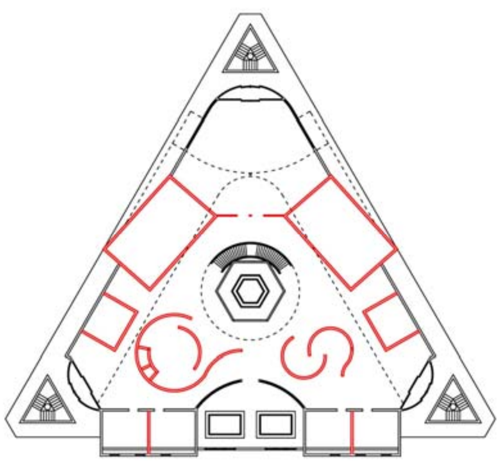

Figure 9. Scaled down design for lower occupancy.

Wind Tunnel Studies

Wind tunnel studies were carried out at EPFL in a boundary layer facility, Figure 10, using a 1:150 scale model, Figure 11. Over 50 tests were carried out with a wind velocity of 3-5.5 m/s. The duration of each test was 12 minutes and this is equivalent to approximately 17 hours in a full scale situation.

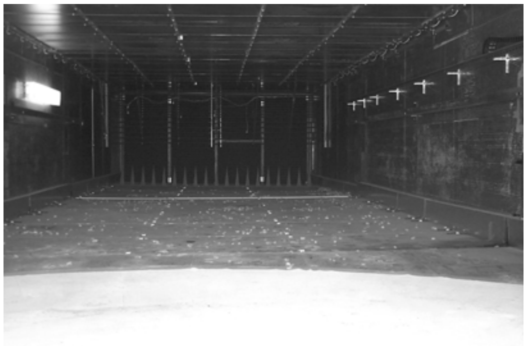

Figure 10. Interior of the wind tunnel at EPFL. Vortex generators and roughness elements produce a turbulent boundary layer.

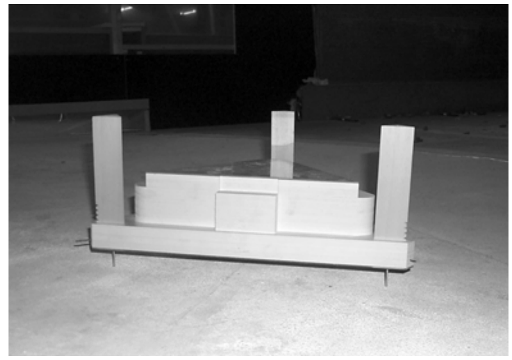

Figure 11. Model (scale 1:150) used for qualitative parametric studies.

Special tiny glass spheres are used to simulate snow in the wind tunnel. Spheres have to be heated in an oven before running the experiment. Otherwise they are not dry enough and remain on the bottom of the wind tunnel during testing. The spheres are weighed before and after running the experiment. Tests were carried out using 1.5-2.5 kg of spheres. These glass particles are the finest that can be used for wind tunnel studies. Nevertheless, in relation to the dimensions of the real building they would have the diameter of a tennis ball. Therefore results, as is the case with the site testing of the scale model, must be interpreted with caution. Trends, rather than precise numerical values, are of greatest relevance. Such trends are discussed below.

Tests were carried out to examine the qualitative influence of the following parameters on snow transport.

- Height of platform above the glacier
- Wind speed
- Test duration
- Wind direction
- Presence of aprons making the underside of the platform rectangular
- Angle of aprons
- Aprons with reduced size
- Initial position of glass spheres

Space limitations do not allow a full discussion of all results in this paper. A detailed description of findings are contained in a report (Landschulz et al, 2005). Results of the wind tunnel studies show that an adjustable, elevated structure has potential to help avoid buildings becoming buried under snow drifts in polar environments. Since it is certain that snow will accumulate under the structure, tests where snow transport was observed indicate favorable design conditions.

Snow accumulation under the structure can be reduced by increasing the distance between the glacier and the underside of the building. A distance of 4.6 m results in promising behavior for a self-cleaning structure for conditions in the wind tunnel. At greater distances, snow transport under the structure can not be guaranteed. Smaller distances lead to an increase of snow accumulation under the structure. Therefore, at Summit, an optimum height needs to be established.

A wind direction of 180° creates the most active snow transport under the building. The real building should be oriented according to this observation. A triangular shape of the building is attractive for jacking with three supports to various heights. Nevertheless, in the wind tunnel tests demonstrate that a triangular shape of the underside of the platform is not ideal regarding snow accumulation. For the construction of the new advanced Summit Camp a more rectangular shape (on three supports) should be considered.

Snow transport can be improved with a triangular shape through the use of aprons that make the underside shape of the platform rectangular. These aprons increase wind speeds a critical positions under the elevated building and therefore decrease snow accumulation. Aprons should be inclined at positive angles less than 10°. The best angle depends on wind speed and direction. The apron size can reduced to lower construction and maintenance costs. Aprons with 75% of the size of those that create a rectangular shape ensure snow transport under the structure. The aprons with reduced surface should also be inclined at various angles. Finally, it is possible that a longer test duration would lead to more pronounced results.

Conclusions

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. The following benefits are offered:

- 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 structures help 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.

The International Polar Year is an excellent possibility for multi-national and interdisciplinary US-European cooperation in Summit. The European Polar Board, which represents 22 countries, is interested in encouraging further research at Summit station (Albert, 2004).

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