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SYMPOSIUM ON STEPPING STONES TO THE FUTURE: STRATEGIES, ARCHITECTURES, CONCEPTS AND TECHNOLOGIES (D3)

Infrastructures and Systems to Enable International Future Exploration and Utilization of Space (3)

Design and Construction of an Inflatable Lunar Base with Pressurized Rovers and Suitports.

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As part of a recently awarded 3-year NASA grant titled "Integrated Strategies for the Human Exploration of the Moon and Mars," a group of faculty and students from the Department of Space Studies at the University of North Dakota (UND), United States is designing and building an inflatable lunar habitat. Once completed, the prototype will be tested together with two electric rovers and the recently developed NDX-2 space suit on an analog simulation at the Badlands of North Dakota.

The habitat will consist of a rigid frame covered by an inflatable bladder. This arrangement will allow both tensile and compressive loads to be transferred from the soft fabric to the rigid frame avoiding punctures or penetrations. The inflatable material must be malleable and retain strength during folding. It also needs to be lightweight and be able to stow into a significantly smaller volume. An expandable soft goods structure offers a lower mass solution with increased volume than using metal or rigid composite materials.

The UND lunar habitat will be built for a crew of four, for a six-month mission period. The interior will consist of four sleeping compartments where the astronauts will be able to rest and stow their personal belongings, a small galley/dining room, a bathroom and laboratory space. The habitat will be about 12 meters long, 3 meters wide and 3 meters high and will be completed by the end of the three year grant with a 30-days analog simulation which will include full pressure suits and pressurized rovers performing scientific and operational tasks.

Introduction

This paper provides an early progress report on a design study presently being led by the Department of Space Studies at the University of North Dakota. This 3-year NASA-funded study, entitled "Integrated Strategies for the Human Exploration of the Moon and Mars," is directed at advanced inflatable architectural concepts. The study is aimed at concurrently studying the habitat as well as other pressurized elements, including airlocks, pressurized connectors, pressurized rovers. and space suits, all of which must be tightly integrated.

In this study, the main element of a planetary outpost, the habitat, is based on a hybrid inflatable design concept in which it may be possible to maximize the commonality of technologies used in several different pressurized subsystems (namely the habitat, airlocks and connecting structures, spacesuits, and pressurized rover interfaces). The technology concept for the habitat involves an inflatable structure that is stiffened and constrained by an internal rigid frame. A feature of the internal frame is that it is a spaceframe composed of a kit of parts that are palleted within the inflatable bladder package for transport to the planetary surface. It is believed that this approach allows the structurally robust parts to be most effectively transported to the planetary surface.

Once in place on the surface, the bladder is inflated to partial pressure whereupon astronauts enter the interior pressurized volume. Working within this pressurized volume they are able to erect the frame without the encumbrance of spacesuits (Fig.1).

It is an essential objective of this study to develop an inflatable structure that can support itself intact during periods of depressurization — a problem made all the more difficult if the structure is supporting the load of heavy regolith shielding.

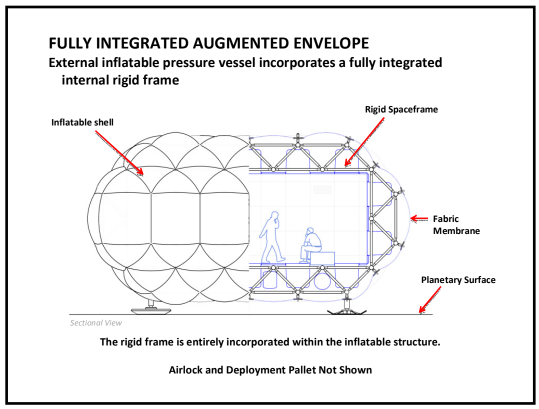

Fig. 1 Preliminary design of inflatable habitat.

It is a further objective of this study to maximize radiation protection measures. For this reason, the design is intended to include a means by which heavy regolith shielding may be incorporated into the architecture. The use of regolith shielding has been considered by many authors over the years, and we are working to develop a system which will be conducive to its use namely by making the physical form of the habitat, and the structure, capable of supporting the loose soil and weight of this material. Doing so in the context of an inflatable structure is especially difficult as the doubly-curved morphology of such structures tends to shed loose regolith coverings. Additionally, the use of aluminum and other structural metals is deliberately avoided to reduce secondary radiation.

At this juncture, the specific geometry of the internal spaceframe is the subject of continuing study. However, we are illustrating here a common square-pyramid type space truss which we have determined will meet the structural loading, low mass, and ease-of-erection requirements. This internal spaceframe, which is composed of interlocking hub and strut elements, is constructed within the bladder by the astronauts (Fig.2). Once erected the frame provides support for mounting interior architectural elements, such as floor and wall panels, life support equipment, and storage racks. A unique node connector is used to marry the pneumatic bladder to the frame, thereby allowing substantial structural loads to pass through the pneumatic bladder without penetration.

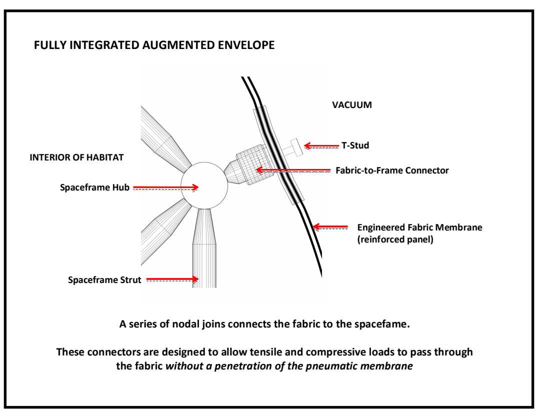

Fig 2. Interlocking hub and strut element.

We have also deliberately avoided mixing rigid monocoque shells with intermediate inflatable bladder sections in order to reduce long seal lines and differential skin behavior under varying temperature and dynamic conditions.

Background

Our work is being conducted in North Dakota and by researchers located in Pennsylvania. Florida, and in Spain, with disciplinary expertise in space architecture, space suit design, vehicle design, space life sciences, radiation protection, structural, systems and aerospace engineering. We begin with an extensive understanding of the history of space architecture, a working knowledge of many Earth-based habitat analogs, the technology of orbital space missions including the International Space Station, and working knowledge of engineered fabric structures.

Hybrid Inflatable Concept

There are two basic approaches to building a hybrid rigid/inflatable structure in the context of lunar and Mars base design. The first is by composing discrete sections that are each either predominantly rigid or inflatable. This is problematic because it tends to require long seal lines at the joining interfaces of each component. Within each component. one tends to suffer the same limitations that attend to each - namely the inability to support concentrated loads, as well as the tendency for the inflatable section to collapse when deflated.

The approach we are following involves placing one type of structure within the other in order to gain the maximum benefit of each. In our proposal, we take advantage of the large volumetric capacity of an inflatable as well as its capacity to self-deploy under pneumatic pressure, and augment this soft structure with an internal rigid frame. Unlike a monocoque rigid shell. a frame can be palleted for shipment and then erected from a kit of parts, so it is possible to create a frame that is dimensionally commensurate with the inflated section.

In the development of this approach. we place the rigid frame within the bladder so as to allow the bladder to unfold and deploy first, and then. in sequence, to use astronaut labor to erect the frame within the partially pressurized bladder. In this way, we believe it is feasible for the astronauts to enter the low-pressure bladder structure initially and to work within it without the encumbrance of full space suits.

In order to create a very strong and low-mass frame, we utilize a modular three-dimensional spaceframe. This type of structure is composed of two basic parts, namely a plurality of tubular struts and connecting hubs.

This is a system that provides a very strong structure with low mass and one that has been well studied in terrestrial practice in terms of structural performance and constructability.

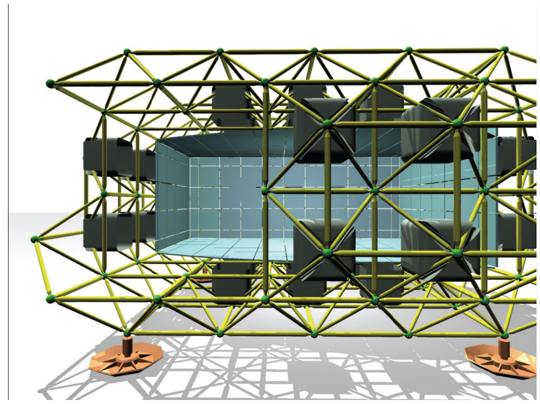

Figure 3 shows the relationship of the panels and the interstitial storage racks to the frame. Note that this structure can be located very close to the surface to improve access and mobility.

The prefabricated parts can be assembled without tools very rapidly, and the hubs and struts can be packaged for shipment very efficiently on a pallet. In order to meet the requirement for high strength and low mass, and that the structure be non-metallic, we are studying the use of CFRP for this part of the structure (Fig.3). The actual geometry of the spaceframe remains under study.

To connect the inflatable fabric structure to the rigid frame, the team is developing a connector that attaches to the outboard hubs in the manner of a strut. The connector provides a slotted capture mechanism that slides over and holds a projecting T-stud that is embedded into reinforced panels of the inflatable fabric membrane. By this device, we avoid the need for penetrations at the connections, and provide a simple means by which the two structures can be made to cooperate, allowing both tensile and compressive forces to be passed through the membrane.

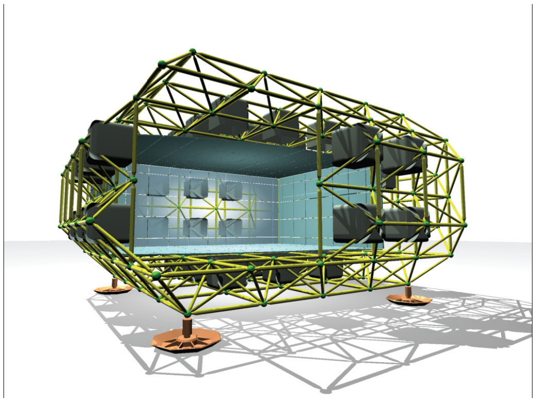

Fig. 4 provides a better perspective of the system views as a cut-away from the corner.

The purpose of the internal frame is to provide support for each of the requirements listed, namely to provide connection points along the interior and exterior of the habitat for equipment and fixtures, to support these gravity loads and the weight of external radiation shielding; and to do so in a such a way as to support the loads and the integrity of the habitat during periods of deflation.

The frame is located on the interior of the bladder to allow for inspection of the structure, potential future repairs, and to prevent degradation due to exposure to ultraviolet radiation and dust abrasion. Additionally, the tubular struts themselves may be given additional purpose by utilizing their internal voids.

Basic Description of the Interior of a Hybrid Inflatable Habitat

In order to overcome the challenges of human settlement in planetary environments, it is necessary to gain a deeper understanding of numerous system-wide and operational regarding habitation techniques. As part of the current project one of the goals is to build an proof-of-concept of the inflatable habitat and associated elements such as rover and suitports. For this, is necessary to determine the basic interior requirements of the so-called hybrid Inflatable Terrestrial Habitat (HITH) for an analog lunar base.

The habitat is being built at the University of North Dakota (UND); and will be tested in the Western part of the State at the end of the grant period. The HITH will interact with two electrical rovers, a pressurized tunnel that will connect the rovers to the habitat, and the NDX-1 and NDX-2 space suits.

The habitat will include 4 sleeping compartments, where the test subjects will be able to rest and stow their personal belongings, a small galley/dining room, a bathroom with a small shower and laboratory space. It will be approximately 13 m long, 3 m wide and 3 m in height.

Interior Volume

The required volume is a function of the crew size, layout efficiency, mission duration and objectives. The prototype shall then be designed according to the maximum usable volume and floor area for the associated structural mass.

Private compartments

The sleeping compartments will consist of 2 modules that will be subdivided into 2 private cabins each. The access to the upper private cabins shall be by means of a small ladder attached to the wall of each compartment. Each private cabin will be equipped with one single bed and the space below will be used as storage.

The cabins shall be isolated by closing the door to offer privacy to the crew members.

Galley and Meeting Area

The galley will have a U-shaped fixed table and chairs and will be used for eating and recreation such as games, drawing, laptops etc.

The galley will also be equipped with a food preparation area. The remaining space will be used as food storage compartments. Meals will be heated up in a convection oven or on a hot plate.

Laboratory

The HITH laboratory will be used to conduct experiments similar to the ones that could be done on the lunar surface. Some of the research areas that will be applied are geophysics and geology, as well as closed-loop technologies such as physic-chemical or biological research.

The laboratory will consist of a fixed table, a foldable table placed opposite to the fixed table, a projector for teleconferences and video and a small greenhouse. The space below the fixed table will be used as storage compartments, while the foldable table will be for laptops and other temporary activities.

Space will be provided for special equipment such as microscopes for geological or mineralogical sample research, tools and such. The laboratory shall also be used for recreational activity, while not conducting experiments. It will also be used as a gym with machines such as a fixed bicycle, rope or weights.

Bathroom Area

The bathroom will be very similar to the ones found in motor homes or boats, where the toilet seat-sink-shower distribution allows saving space.

Since the bathroom and the kitchen will both have a water supply system, these two compartments will be placed next to each other to avoid the use of two separate water pump systems. Usually these equipments tend to be noisy so in order to prevent vibrations and uncomfortable sounds for the crew, the bathroom will be placed next to the laboratory.

The internal design process will present several challenging aspects that are being studied and analyzed, such as volume saving, ways of stowage and furniture distribution.

Lunar Pressurized Rover

Under this project two electrical wheeled vehicles are being developed, one of them pressurized.

The pressurized rover design contemplates accommodation for a crew of two astronauts during missions and two additional members in an emergency/rescue situation. It will also contain a suitport interface allowing the space suits to remain outside and to enter the rover and habitat unsuited, while maintaining fairly constant the pressure values and containing dust penetration.

The vehicle was built by UND students with the cooperation of Cirrus Co. in Grand Forks, ND. The rover's basic structure consists of a re-shaped commercially available electric vehicle, enclosed with a composite shell of fiberglass and epoxy resin.

Composite materials, such as the employed fiberglass, were chosen because they are easily molded into complex and double-curved shapes. They can create very strong structures tolerant to wide variations in temperature and requires little maintenance.

The rover will be equipped with communication systems and experimental hardware to store soil samples for transportation back to the habitat. The 1G testing of the vehicle will show the feasibility of the common airlock system, its ability to safely and reliably conduct experiments and easily transport the crew across rough terrain.

Space Suits

A new suit system, termed the NDX-2 (North Dakota eXperimental 2) is in development at the University of North Dakota (UND) Space Suit Laboratory under a NASA grant. The NDX-2 has incorporated the improvements achieved during the NDX-1 Mars Space suit prototype demonstrator program. After the numerous lessons learned during the development of the NDX-1 Program, new advanced systems were undertaken that, due to time and budgetary constraints could not be applied to the NDX-1. Also, after careful examination of the methods devised for lunar exploration, it is clear that some (if not all space suit systems needed) will require a specific donning/doffing capability and method that was not contemplated by the NDX-1.

Fig.5. Donning the rear entry NDX-2 suit.

Rear-entry (for don/doff), as opposed to the Shallow Dual-Planar type entry (as was used on the NDX-1), would have most likely been employed as part of the Constellation Extravehicular Activity (EVA) lunar missions, if that mission had materialized. The development of an improved and enhanced follow-on to the NDX-1 using Rear-entry (as the Russian Orlan spacesuit does, for example) will allow a higher fidelity suit demonstrator. Enhanced shoulder, arm, hip, knee, and ankle joints and new glove designs have provide advanced dexterity. The NDX-2 was designed to focus more on lunar scenarios and techniques to mitigate dust inside joints and mechanisms since this was, at the time of its design, a more urgent need in NASA mission planning.

Fig 6. NDX-2 suit during preliminary human-rated testing.

The NDX-2 is now undergoing human-rated testing and will be incorporated trough a suitport, to the pressurized rover.

Conclusions

A mixed discipline team based at the University of North Dakota was able to study a novel approach to a hybrid inflatable habitat structure.

The approach to the habitat design involves a hybrid inflatable structure that bears many similarities to prior work conducted by Adams and Petrov, particularly in its development of an endoskeletal rigid frame. However, our approach is to construct a more robust internal frame that is capable of supporting substantial gravitational loads and holding the habitat Intact during periods of decompression. In a manner similar to TransHab, we allow the rigid frame to be fully encapsulated within the fabric structure. This approach allows the flexible fabric to be constrained to form by non-penetrating nodal attachment points. The advantage of this approach is that the fabric and the rigid systems are allowed to cooperate with minimal interference and the volume of the habitat can be maximized relative to the launch shroud. The use of an integrated rover/airlock/suitport system will permit exchange of the crew without the use of pressurized suits, maintaining a dust-free environment inside the habitat. After testing, all hardware will be made available to other researchers to perform experiments in analog environments.

Acknowledgement

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