The Surface Endoskeletal Inflatable Module [SEIM]

Constance M. Adams[1] and Georgi Petrov[2]

[1]Architect / Space Architect / Operations Integration Engineer, Futron Corporation, NASA-JSC, code OC ; e-mail: constance.adams1@jsc.nasa.gov

[2]Space Architect, Synthesis International; e-mail: gpetrov@alum.mit.edu

Abstract

With the development of the TransHab hybrid inflatable habitat, a team at NASA's Johnson Space Center broke with historical paradigms by developing the first endoskeletal space module. The value of this design was cost-effectiveness, efficiency, and the possibility for new forms to support human-rated vehicles and modules for exploration missions.

The "TransHab Paradigm" is a complex, semi-inflatable vehicle whose two basic configurations - launch and deployed - are each optimized for their respective environments while retaining fundamental system integration for autonomy and efficient deployment. In this study, the architecture team has undertaken to adapt the paradigm in two ways: first, by designing a module with similar operations concept, but operating in a different environment - that of a planetary surface; and second, by streamlining the relationship between the hard and membranous structures that make up this type of module's principal components.

Introduction

The new NASA vision for the human exploration of space calls for a crewed return to the Moon by 2020 in a roadmap that channels toward the subsequent human exploration of Mars. In both the establishment of a lunar outpost and of a Mars exploration base camp, the development of robust, flexible housing units that meet all launch and activation criteria while supporting optimal safety, comfort and performance of the crew is a critical-path technology. One recent innovation, the hybrid inflatable habitat module originally developed for the Mars crew transit (TransHab) mission, was declared by NASA's top spacecraft engineers in their September, 1999 Technical Review to be "a major enabling technology" for human exploration of the solar system. TransHab uses mechanical connections to join a reinforced carbon composite end structure with the woven pressure shell. The authors, who previously proposed a design for a surface optimized habitat of this same type, are now hypothesizing a new method for joining the pressure shell typical of a TransHab-type hybrid inflatable directly to the core structures. This integrated assembly method offers to simplify the total assembly, thus reducing risk associated with construction and load transfer, and improving optimization of the mass-to-habitable volume ratio for orbital and surface habitats defined in the Exploration Vision.

As the first and most advanced test article for human-rated space inflatable modules to date, TransHab represents the state of the art in hybrid inflatable structures (Adams, Kennedy 2000) (Kennedy 2002). Hybrid inflatables are deployable structures that combine a hard, skeletal structure with an inflatable outer pressure shell to optimize load distribution for transit as opposed to static phases of deployment. In so doing, they are capable of supporting the habitable volume necessary for long-duration human exploration with several advantages:

1. a greatly reduced mass penalty over hard-shelled spacecraft at comparable volume;

2. reduced radiation risk to crew due to minimized metallic elements in vehicle;

3. lower risk of depressurization at launch phase due to in situ deployment.

Because of its many benefits, the hybrid inflatable structure would also address many of the requirements for long duration Lunar-Mars habitation, but to accomplish this task would need to be adapted in form to support partial-gravity crew operations. In a previous study (Adams, Petrov 2005) the authors proposed a design concept for a "Surface Endoskeletal Inflatable Module" (SEIM) that basically adapts the hybrid structure to the surface mission requirements (Fig. 01).

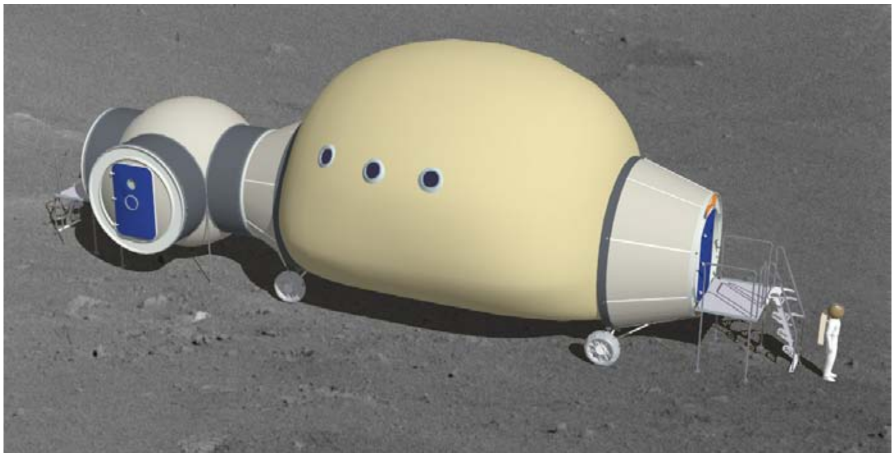

Figure 01. Surface Endoskeletal Inflatable Module

Requirements

The surface habitat requirements for a lunar or Mars expedition include the ability to launch, deliver and deploy the module and subsequently to support positive and efficient operations for a period of up to two years (NASA 1992, 1998). Cost-effective responses to issues of propulsion, assembly method, environmental shielding and surface access are major design drivers. A set of requirements for the SEIM design includes the following: ability to launch on a single flight of any large-size operational launch platform; ability to activate and inflate autonomously at the destination; support of main systems via pre-integrated elements; passive and active bulkheads to enable flexibility of docking configuration; reconfigurability.

Structural Design

Adapting the hybrid inflatable paradigm for the surface mission requires fairly radical changes in form and appearance. The structure is comprised of a rigid core from which a structural membrane is inflated to provide a double story space. The rigid core, which is formed by eight longerons supporting two endcones, remains fixed in both configurations. Flat modular panels are packed around the longerons to provide shear and torsional stiffness during launch and landing and are subsequently deployed to form floors and partitions. The structural shell on the other hand is stowed in around the core in the launch configuration and is activated only after deployment to contain the atmosphere.

The surface inflatable has four operational modes – launch, transfer, landing, and deployed. Each operational mode has different loading requirements. The launch, transfer and landing stages are dominated by axial and shear dynamic loads and can be grouped together. In contrast the deployed stage is characterized by static loads stemming form the need to contain a habitable atmosphere. These conditions lead to two distinct configurations of the module – transfer and deployed.

The Rigid Frame

The frame is be made from carbon-fiber reinforced epoxy composites. It has four primary components – endcones, longerons, movable modular panels and one static panel at the bottom of the Hab (Fig. 02). Two endcones, manufactured as single pieces of lay-up composites, serve as connection points between the inflatable shell and the frame; they provide a means to attach to the launch platform and serve as airlocks after Hab deployment. Eight longerons made of pultruded composites hold the endcones apart and provide the primary load resisting elements of the frame, resisting both launch and pressure loads. In the launch configuration the longerons act as axially loaded members that are braced laterally by the modular panels. In the deployed configuration the longerons serve as beams resisting the gravitational loads of the occupants and the tension load of the internal pressure. Reconfigurable panels allow the core structure to be optimized for the two different loading conditions. In the launch configuration the panels are packed between the longerons to provide lateral restraint (Figs. 03). After the inflation of the shell the panels can be detached and reconfigured to serves as floors and partitions. They can be made of either honeycomb sandwich panels or they can be pultruded like the longerons. Finally, in order to provide the ability to make rigid connections between internal and external equipment, the panel between the two bottom longerons will remain in place in both operational configurations (Fig. 02) and create a chase for preintegrated systems and utilities.

The Inflatable Shell

The SEIM shell design is composed of the following elements starting from the inside. An inner liner provides fire retardant and abrasion protection. Three bladders form redundant air seals, with four layers of felt providing evacuation between bladder layers. The internal pressure is resisted by woven straps of fiber material (Kevlar, e.g.) that form the structural restraint layer. Micrometeoroid, Debris and Radiation shielding will be incorporated into the outer layer. In the transfer configuration the shell is folded and compressed around the core (Fig. 04). It is inflated into the deployed configuration after landing and final positioning on the planetary surface (Fig. 05).

The horizontal deployed configuration of SEIM dictates the most significant revision to the shell design. The use of the static longerons as horizontal beams to support floors results in a non-circular and non-radially symmetrical cross-section of the habitable volume. The most affected element is the structural restraint layer, whose weave pattern will have to be redesigned to accommodate the new shape while keeping a constant stress gradient. The addition of the bottom rigid panel means that the fiber woven straps can no longer be complete circles in the hoop direction, but will be connected at each end to the bottom two longerons.

The partially-solid horizontal geometry creates a structure that is substantially different from the microgravity TransHab version in three principal ways:

1. internal and secondary structures must be more robust;
2. bladder seals must be much longer; and
3. more than twice as many shell-to-core joints.

In order to address the mass penalty issues associated with strengthening of the primary and secondary rigid structures and to reduce risk and complexity in the now considerable shell-to-core connections, the authors propose a new “fused fiber” concept that would integrate the fiber straps of the shell’s primary restraint layer with the composite layup of the core panels.

Currently, the TransHab type structure joins the main pressure shell (a woven layer of fiber straps) to the core structure through a complex mechanism of clevises and mechanical attachments (Raboin 2003). This mechanism adds mass to the total system, reduces the efficiency of load transfer and poses a potential threat to the pressure shell during the folded launch configuration.

Structural Innovation

The innovation currently proposed by us involves streamlining the load path at the joint between shell and core structures by bypassing metal structures and mechanical connectors and joining the restraint layer straps directly to the core (Fig 07). The baseline version of this innovation is a design that embeds short sections of the Kevlar straps into the carbon fiber structure of the endcone during composite manufacture in a fashion that leaves the ends of the straps free of resin and therefore flexible (Fig.08). Leaving sufficient length of the straps free from the hard structure enables the shell main restraint straps to be stitched directly to the embedded, flexible webbing elements (Fig.09). Mechanical connectors such as clevises and other bulkhead-to-core structure components are thus eliminated from the total structural system.

If successfully developed, this hypothesized design represents an ideal structural transition from the rigid composite end frame to the flexible fabric shell of the inflatable space habitat. A critical element of our baseline concept is an embedded strap that transitions from the fully rigid, resin-infused layers in the core of the composite end frame, to a completely dry fabric strap to which the flexible shell is sewn.

Forward Work

There are several technical challenges related to this concept, including the need to develop a technique for transitioning from the strap's rigid resin infused region to the dry uninfused region. This may be accomplished by coating the transition portion of the fabric strap with a nonstructural flexible sealant. This sealant prevents the structural matrix from wicking up the strap, causing a potential failure site. A second concern is the added complexity (and associated risk of manufacturing error) that results from making the transition region as an integral part of the composite structure.

Conclusion

Nearly six years ago, at the conclusion of the TransHab Independent Technical Review, the review board's chairman Dr. Chris Kraft proclaimed the space inflatable habitat an "important enabling technology" for the future of human spaceflight. Since that time, ever-present funding challenges have limited the Agency's ability to further iterate, develop and test this concept internally. While one private aerospace company is proceeding in development and proposed flight testing of the original TransHab structure, the need remains for development of advanced engineering concepts that will enable the next generation of hybrid inflatable structures for long-duration missions to evolve.

In a recent interview with space.com, Apollo 11 astronaut Neil Armstrong noted that the human exploration of Mars will demand the development of better spacecraft technology, including improved comprehensive strategies for radiation shielding. Protecting a long-duration crew against the effects of Galactic Cosmic Radiation (GCRs) is an important part of this effort for systems architects and materials specialists, involving inclusion of hydrogen-rich materials and exclusion of metallic materials from the vehicle's construction (Wilson 2000). One of the benefits of the proposed structural innovation represented in this brief is its ability to support a wholly nonmetallic vehicle structure without compromise of capability. In addition, this innovation may enhance flexibility of design for habitable hybrid inflatables, particularly for surface habitat applications.

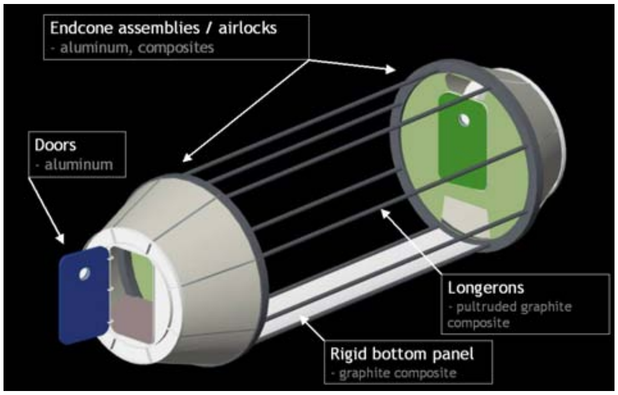

Figure 02. Rigid frame of SEIM

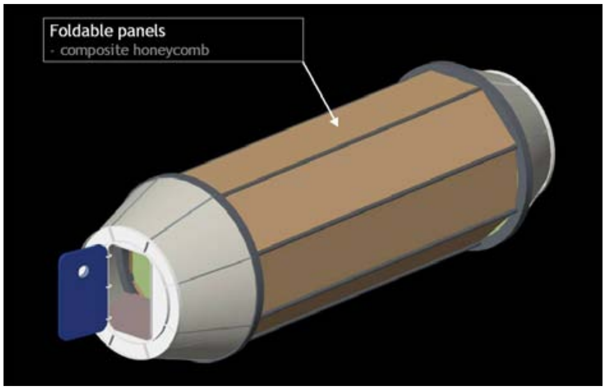

Figure 03. Modular panels in the transit configuration

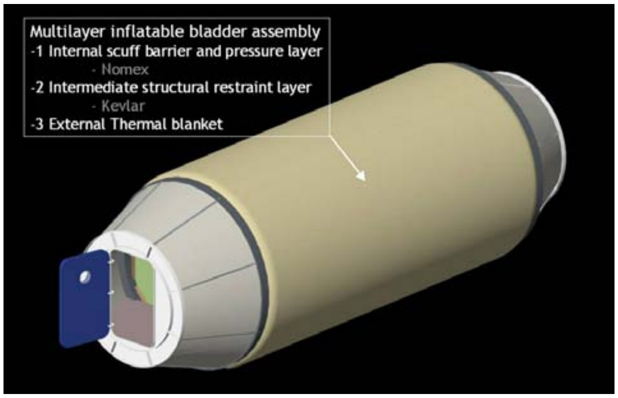

Figure 04. Rigid frame and folded bladder in the transit configuration

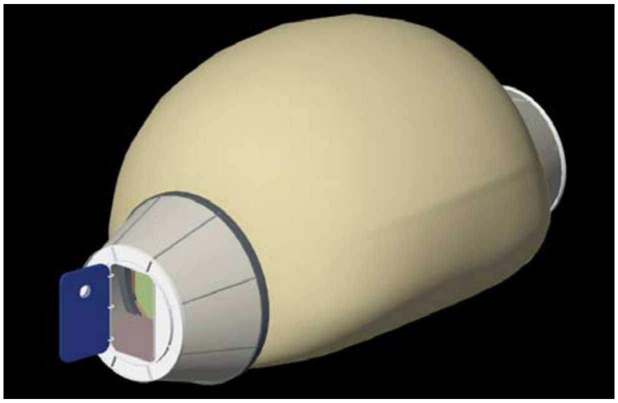

Figure 05. Rigid frame and inflated bladder in the deployed configuration

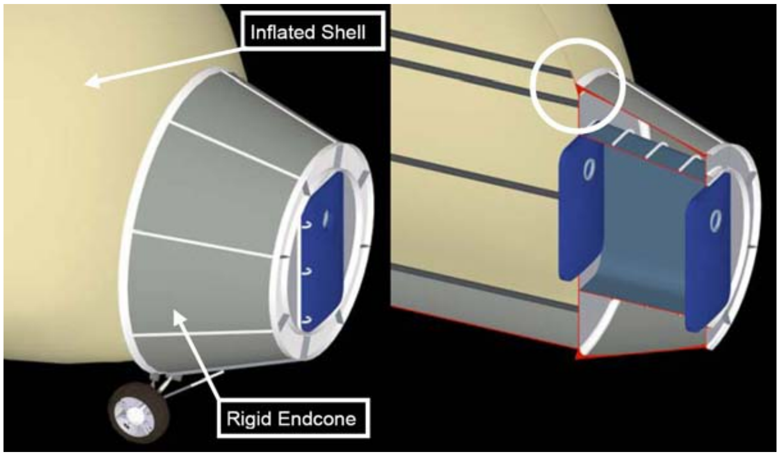

Figure 06. (left) Detail of the endcone of the surface inflatable module.
Figure 07 (right): Section of the endcone of the surface inflatable module showing location of critical connection.

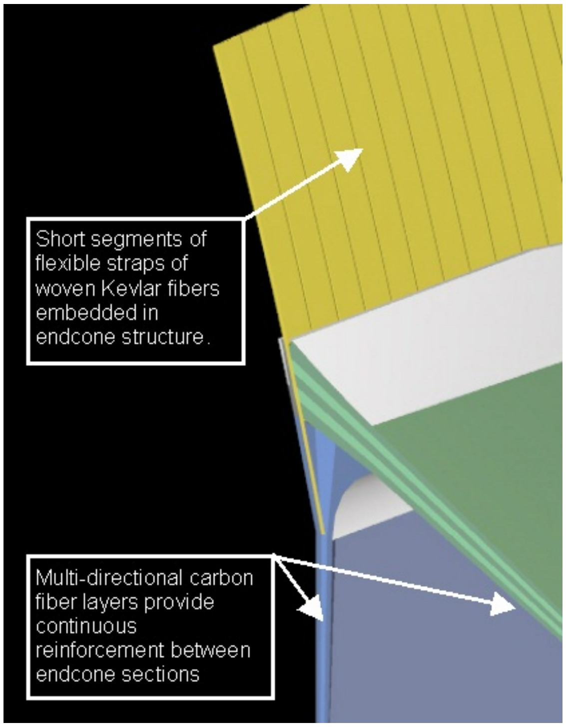

Figure 08. Connection detail

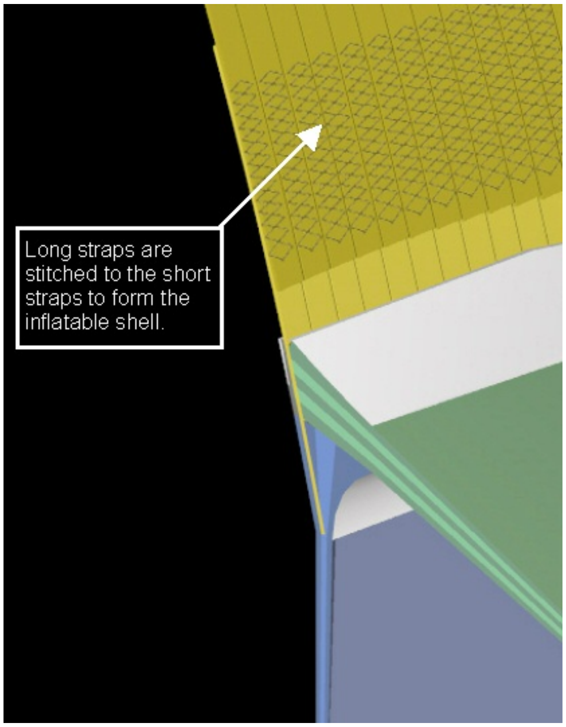

Figure 09. Connection detail

References

Adams, Constance, James Horn et al. A Human Factors Evaluation of the BIO-Plex Habitation Chamber, Volume III: Architectural Evaluation. LMSMSS-32517. Lockheed Martin Space Mission Systems and Services Houston, TX July, 1997.

Adams, C.M. TransHab Schematic Design Phase-Design Evaluation and Trade Study: Human Factors, Ergonomics and Anthropometry. Lockheed Martin Space Mission Systems and Services Report LMSMSS-32618, Houston, TX, Oct., 1997.

Adams, Constance and Kriss J. Kennedy. “ISS TransHab: A Space Inflatable Habitation Module” in Proceedings of Space 2000: The Seventh International Conference and Exposition on Engineering, Construction, Operations and Business in Space (2000); American Society of Civil Engineers, Reston VA

Adams, Constance, Riegel McCurdy. Habitability as a Tier One Criterion in Advanced Space Vehicle Design: Part One—Habitability, ICES 1999-01-2137.

Adams, Constance, Jasen Raboin et al. NASA Tech Brief MSC 23090: Design Concepts for the ISS TransHab Module, 2002; NASA Johnson Space Center, Houston Texas

Adams, Constance, Georgi Petrov (2005 July). ‘Variants on the TransHab Paradigm (2): The Surface Endoskeletal Inflatable Module (SEIM)’ (SAE 2005-01-2847). Proceedings of the 35th International Conference on Environmental Systems (ICES), Society of Automotive Engineers, Warrenburg, PA

Kennedy, Kriss, “Lessons from TransHab: An Architects Experience” AIAA Space Architecture Symposium, 10-11 October 2002, Houston, Texas, AIAA 2002-6105.

Melanie Bodiford. Survey on Lunar/Mars Habitat Structures, AIAA-2005-2704 and NASA report number NASA-00382.

NASA. Human Exploration of Mars: The Reference Mission of the NASA Exploration Study Team. NASA Special publication 6107, 1992.

NASA. Reference Mission Version 3.0 Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team. NASA Special publication 6107-ADD, 1998.

Raboin et al.: United States Patent US 6,547,189 B1, “Inflatable Vessel and Method”. April 15, 2003

Wilson, J. et al. “Improved Spacecraft Materials for Radiation Protection: Shield materials optimization and testing” *Microgravity Materials Science Conference*, Huntsville, Alabama, June 6-8, 2000.