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Special Design Project Issue

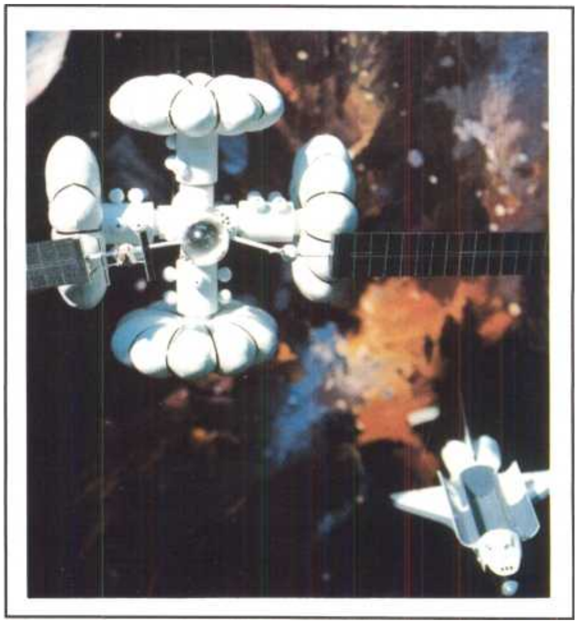
SICSA OUTREACH
Sasakawa International Center for Space Architecture

Inflatable Space Structures

Inflatable space structures include single and multiwalled bladders made of pliable composite materials. Such construction offers an attractive alternative to more conventional rigid metal systems for certain specialized uses. A key advantage is the ability to transport large habitats and other structures for use in low-Earth orbit and on planetary surfaces in a compact, launch-efficient, easy to deploy form. Realization of this benefit will require further development and demonstration of new material technologies. Some new materials show real promise but will require additional testing to ensure long-term safety and reliability under harsh environmental conditions posed by space applications.

Space habitats must provide means to contain internal gases and maintain constant purity and atmospheric pressure to sustain life. Pressure vessel walls must afford a reasonable degree of resistance to micrometeorites, space debris and radiation, yet must be as light and compact as possible to maximize launch efficiency. Exterior surfaces must be able to withstand long-duration exposure to molecular oxygen, ultraviolet rays and temperature extremes. Interior surfaces must be nonflammable and must not offgas toxic or noxious materials.

Recent advancements in nonmetallic material technology warrant optimism that these requirements can be accommodated. SICSA staff and Experimental Architecture graduate students have undertaken conceptual studies which have explored uses of composite nonmetallic inflatable structures for advanced space missions.



LIH Spacehab Concept

Representative Applications

Large habitable environments in low-Earth orbit and on planetary surfaces.

Supplemental storage and waste containment for the Space Station.

Airlocks and connecting tunnels for orbiting and planetary surface facilities.

Means to deploy antennas and other mechanically-rigidized structures.

A Publication of the University of Houston's College of Architecture

Background

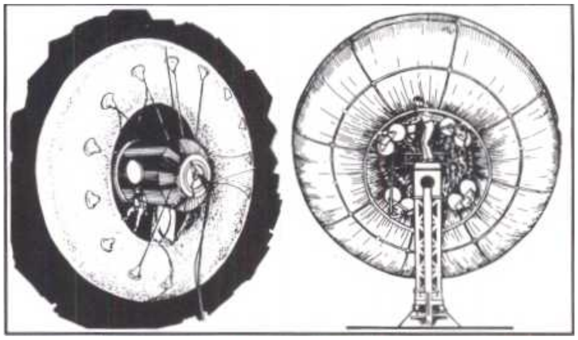
Many innovative inflatable space structure concepts have been proposed during the last three decades. A few have resulted in full-size mockups and working prototypes. The Goodyear Aerospace Corporation (GAC), now part of the Loral Systems Group, has been responsible for the detailed design and fabrication of the majority of these systems. Unfortunately, GAC has discontinued this activity due to diminished government sponsor interest and funding.

GAC designed and developed three pressurized module prototypes under contract with the NASA Langley Research Center. The largest was a 24 foot outside diameter toroidal space habitat structure created in 1960 to demonstrate inflation, repackability, gas retention, thermal performance and structural characteristics. In 1965 GAC developed a lunar shelter to support two people for periods of 8-30 days with necessary radiative thermal control and micrometeorite protection. A 12.8 foot diameter, 37.5 foot long "Moby Dick" structure was developed in 1968 as a prototype for a 110 foot long space habitat.

GAC also fabricated two expandable crew transfer tunnels for space. The first (12 feet long), designed in 1966 by the Air Force Propulsion Laboratory, was developed to connect a Gemini capsule to Skylab's Manned Orbital Laboratory (MOL) crew quarters. The second, in 1979, produced a 14.2 foot long flexible section of a tunnel between the Orbiter's crew cabin and the Spacelab module under contract with the McDonnell Douglas Services Company for the NASA Marshall Space Flight Center.

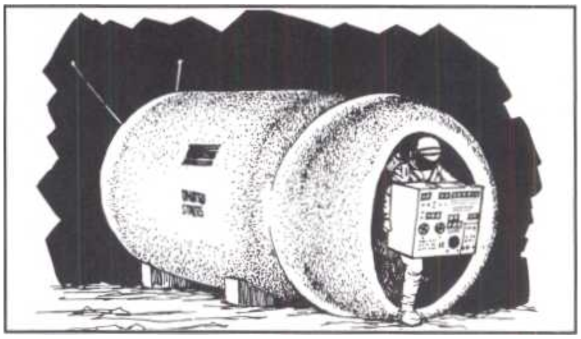
Inflatable airlock technologies have been demonstrated by the U.S. and Soviet Union. A 5.2 foot diameter, 6.2 foot long airlock developed through a joint NASA-Department of Defense venture and constructed by GAC in 1967 was designed to be mounted on a Skylab-type vehicle.

The U.S.S.R. demonstrated an inflatable airlock on its Vostok 2 spacecraft in March, 1985. A miscalculation in the pressurized size of a cosmonaut's EVA suit nearly resulted in tragedy when he experienced great difficulty reentering through the airlock's small hatch.



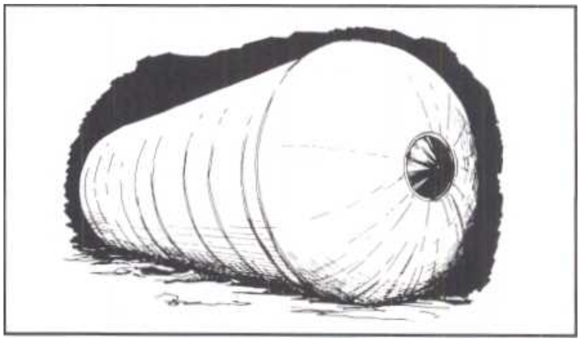
24 Foot Diameter Toroidal Structure

Construction: meriodonally-wound Dacron filaments with a Butyl rubber binder and internal bladder of Butyl-impregnated nylon for gas retention packaged in an 8 foot diameter hub for launch with deployed volume 2,300 cubic feet. Weight approximately 4 oz./ftz of surface area. Designed for 5 psi pressure.



7 Foot Diameter, 15 Foot Long Lunar Shelter

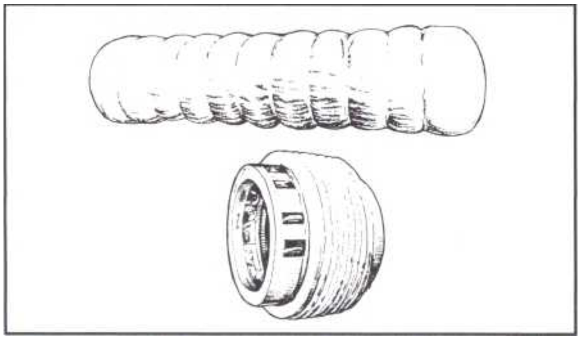
Construction: 3-layer laminate consisting of nylon outer cover, closed-cell vinyl foam, and inner nylon cloth bonded by polyester adhesive layers. Internal volumes of shelter and airlock were 410 cubic feet and 105 cubic feet, respectively. Weight 126 pounds/fl-2(total, 326 pounds). Designed for 5 psi pressure.



12.8 Foot Diameter, 37.5 Foot Long "Moby Dick"

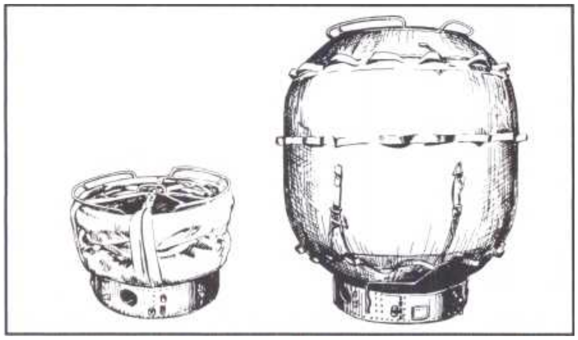
Construction: 1/6 inch thick gas bladder made from 2 inch wide Dacron 52 yam dipped in a polyester resin bath. The bladder was sealed by a polyvinyl chloride (PVC) foam and the entire structure was covered by a 1-3/4 inch flexible polyurethane foam, over which was pkiced a nylon film-fabric laminate painted with a thermal control coating. The 1,622 pound structure was designed for 5 psi pressure.

Illustrations on this page by LI Hua based upon GAC data.



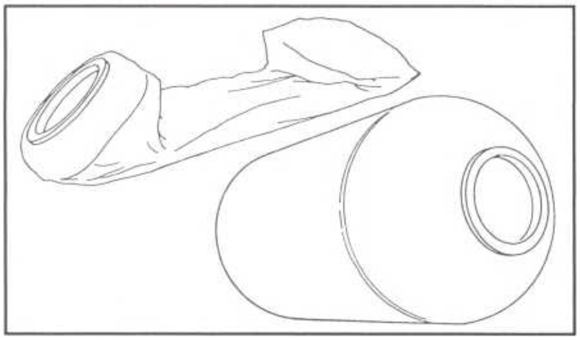
4 Foot Diameter, 14.2 Foot Long Spacelab Tunnel

Construction: 2 plies of Nomex unidirectional cloth fabric coated with Viton B-50 elastomer wrapped around steel beads made from wraps of 0.0307 inch diameter wire. Debris shields constructed of Kevlar 29 covered the surface. The 170.5 inch length compressed to 20.5 inches. Total weight 756 pounds.



5.2 Foot Diameter, 6.2 Foot Long Airlock

Construction: Multilayered expandable material consisting of a composite bladder, filament-wound 3.6-mil steel wire structural layer; flexible polyurethane foam micrometeorite barrier; and fabric-film laminate thermal coat. The unit weighed 185.6 pounds and fit into a 4 foot diameter, 2.5 foot tall cylinder.



"Necking Down" Folding Technique

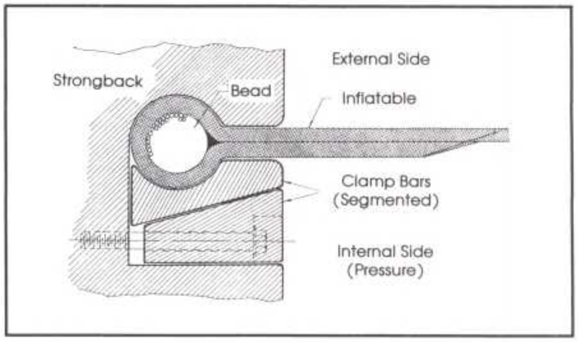
The filament-wound ribbon construction used for Moby Dick enabled the structure to be twisted and compressed through a reduction procedure called "necking down". Longitudinal wraps of Dacron 52 yarn tape were looped around aluminum circumferential rings spaced along the pressure hull to ensure uniform folding. The entire structure could be packaged in a 12.5 foot diameter, 2 foot high cylinder.

GAC has been by purchased by the Loral Systems Group.

Packaging and Connections

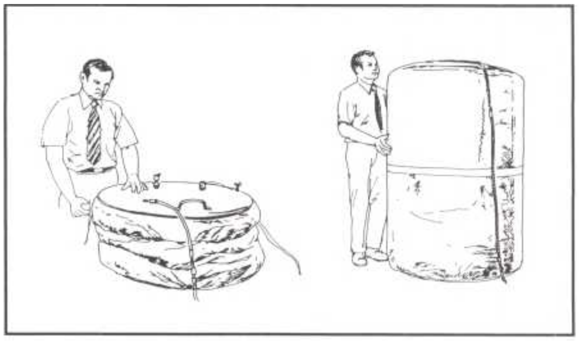
The degree of compactability of inflatable structures for efficient space transportation depends upon the thickness and pliability of wall materials. Large structures packaged in wide diameter containers that minimize folding requirements generally offer the greatest deployed-to-packaged volume ratios.

Experimental tests demonstrated packaging ratios of 12:1 for the 5,000 cubic foot Moby Dick structure and the Skylab Transfer Tunnel. Tests also showed that such structures can undergo repeated inflation-compaction cycles while maintaining high physical integrity with low leak rates.



Illustrative Hardware Attachment Technique

Pliable materials can be attached to hardware elements such as airlocks and berthing systems using a deformable cluster of wire beads at wraparound junctures. Outer edges of receptacle structures should be rounded to avoid damage to the flexible material during folding and deflections while inflated.



"Accordion" Folding Technique

The flex section for crew transfer between the Orbiter crew cabin and Spacelab module used unidirectional fabric plies wrapped around rings of steel wire to minimize interface section loads resulting from axial, lateral, torsional and rotational displacements caused by installation, thermal gradients and maneuvering. Fillets added to outer diameters of the wire rings ensured a smooth transition and avoided fabric abrasion.

Illustrations on this page are by Li Hua based upon GAC data.

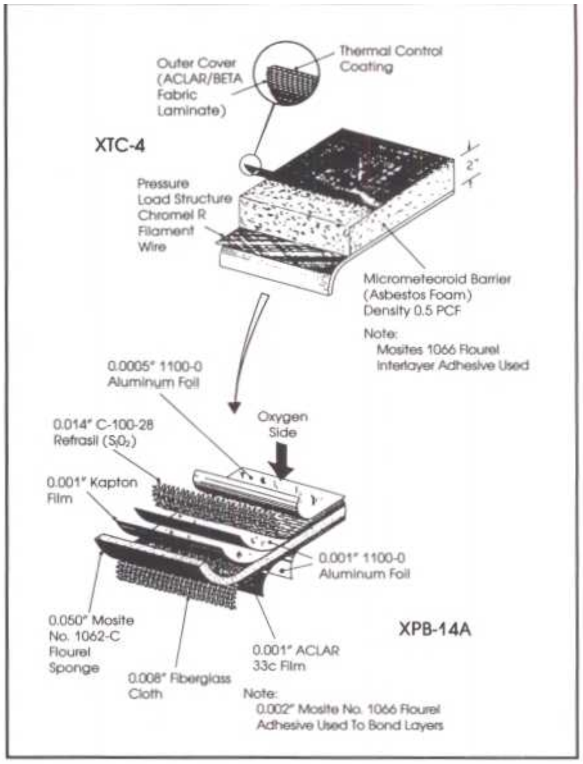
Material Technologies

Experimental tests associated with GAC's lunar shelter, Moby Dick habitat and proposed Skylab airlock demonstrated that design requirements for compact packaging, easy deployment, low leak rates and structural integrity could be achieved. It was not until later in 1970 however, that inflatable material technologies were demonstrated which could meet upgraded crew fire safety requirements established by NASA.

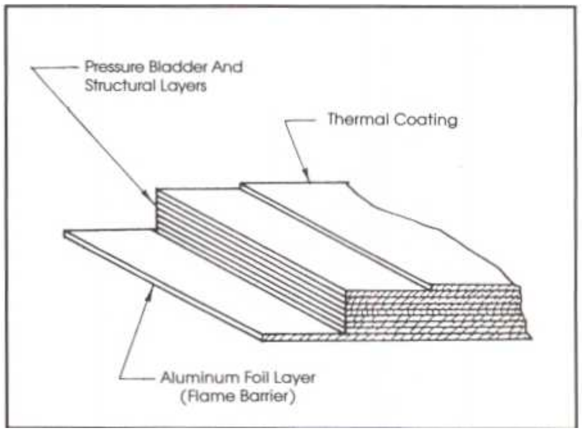
A program conducted by GAC under contract with the NASA Langley Research Center was aimed at developing a nonflammable composite material for a 5 psi, 100 percent oxygen atmosphere. After exploring and testing many materials and laminate combinations, a two inch thick "XTC-4" composite wall construction incorporating an "XPB-14A" flame/gas barrier was selected, which met the rigorous new standards. A 3 foot diameter, 5 foot high inflatable cylinder was constructed which was compactible to fit in a 1.5 foot high cylinder of the same diameter.

GAC qualified a flexible fabric consisting of Nomex unidirectional cloth coated with Viton B050 elastomer for Orbiter-Spacelab tunnel construction. This combination also offers potential applications for inflatable habitats. Nomex/Viton structural layers can be laminated together to obtain desired strength, and a flexible cable can serve as a bead to ensure structural integrity during deployment and fully inflated operational conditions. An asbestos foam micrometeorite shielding outer layer can be added, along with an inner, aluminum foil, flame barrier.

A variety of new materials warrant careful consideration and test evaluation for inflatable space structure applications. Kevlar 29, a fabric commonly used for bulletproof vests, is stronger than stainless steel, comparable in weight to nylon and Dacron, and has higher temperature limits than Nomex. NicalonR and NextelR are advanced flexible materials suited for very high temperature applications. NicalonR, a silicone carbide fiber produced by the Nippon Carbon Co., Ltd. of Japan, remains flexible at temperatures up to 3,000°F. NextelR, a ceramic fiber produced by the 3-M Corporation, becomes rigid at temperatures in the 2,500-3,000°F range.



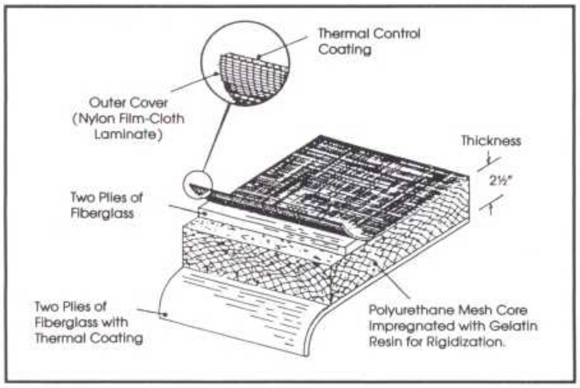
XTC-4 Nonflammable Wall System



Orbiter-Spacelab Tunnel Construction

Nomex/Viton Properties (Per Ply Average Values)	
• Strip tensile strength	1,074 lb/inch
• Weight after cure	46.13 oz/yd^2
• Thickness after cure	0.040 inch
• Peel adhesion after cure	29.7 lb/inch

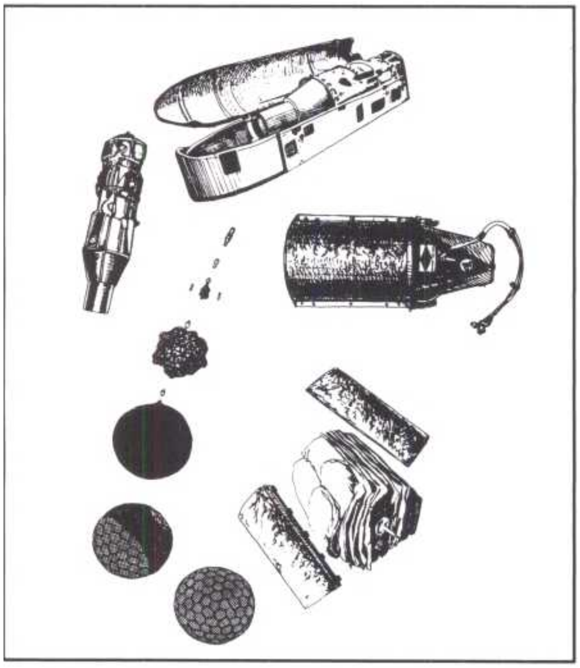
Data and illustrations provided by the Loral Systems Group.



Example Foam-Rigidized Wall System

Material Weight (Pounds/Foot^2)	
Outer cover and thermal coating	0.068
4 Plies of fiberglass	0.142
3 Adhesive interlayers	0.030
Mesh core and gelatin resin	0.750
Inner thermal coating	0.040
Total system weight	1.030

The outer cover in this example is a film cloth laminate base cloth is Stern and Stern A4787 nylon at 0.84 oz./square yard; film is Capron type 77C 1-mil at 0.42 oz/square yard.



Deployment of a Wire Structure

Foam-Rigidized Structures

It may be necessary in some inflatable space structure applications to provide means to rigidize the systems so that overall forms are retained after inflation gases are gone. Examples are hangars and other storage facilities that open directly to the space environment, and stiff elements such as beams and trusses which must be designed to retain structural integrity following micrometeorite penetrations.

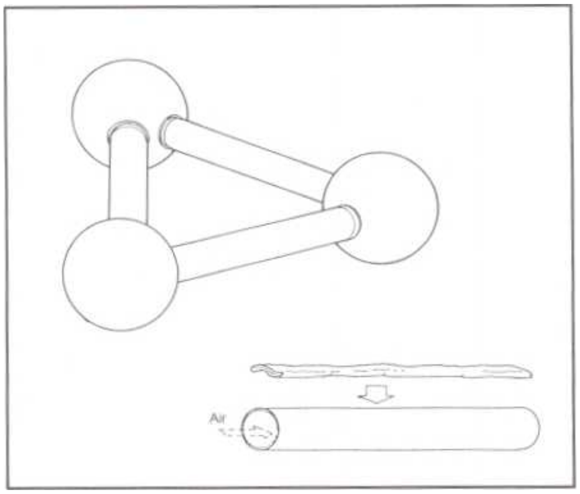
Rigidization can be accomplished by predistribution of inactivated foams on deployable surfaces. This approach involves incorporating a flexible mesh core material impregnated with a gelatin resin between membranes of a sealed structure during the fabrication process. The system remains pliable during the packaged configuration. When the structure is deployed and the wall cavity is vented to vacuum, the gelatin-resin moisture escapes causing foam to expand and harden the mesh core. GAC investigated twelve chemical systems for this process and selected a reversible-type gelatin with a Scott foam mesh core as the most promising material combination.

Mechanically-Rigidized Structures

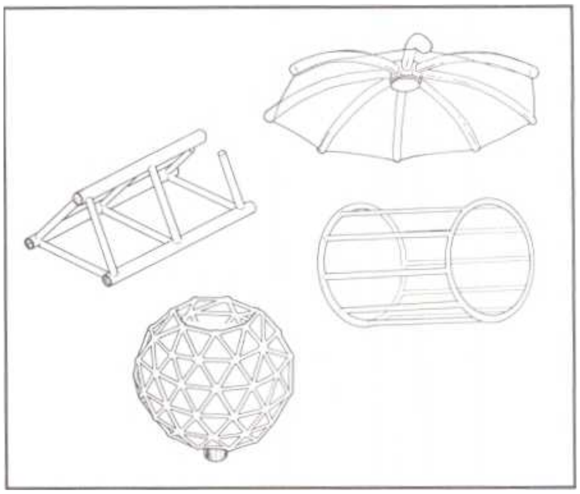
Rigidization through overpressure/yielding of a wire matrix has proven very effective for deployment of such thin skinned space structures as balloons, antennas and reflectors. An inflated pressure bladder is typically used to stress a wire net surface material beyond its yield point through controlled overpressurization. The surface material then retains its shape after pressurization is lost.

GAC has demonstrated a variety of mechanically-rigidized system applications, A 30 foot wire-grid satellite reflector had a photolyzable film bladder that photodegraded and evaporated under the influence of space vacuum and temperatures. An aluminum wire-grid torus was deployed as a planar space target. A 10 foot long, 30 inch high fan beam deployable antenna used overpressurized wire tubes. GAC aslo created a 14 foot diameter balloon of .25-mil aluminized Mylar and 5-mil aluminum wire to serve as a location marker on the lunar surface.

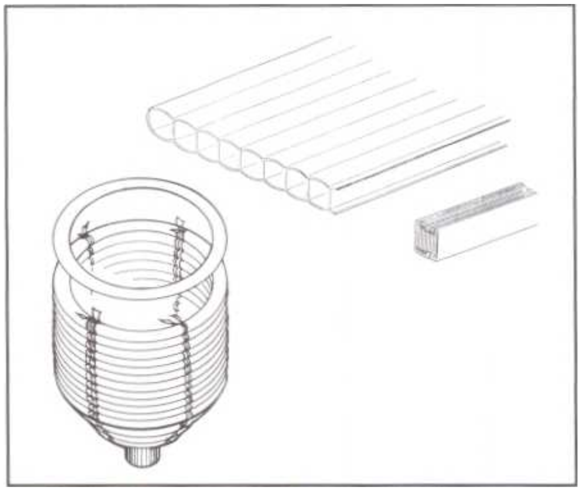
Data and illustrations provided by the Loral Systems Group.



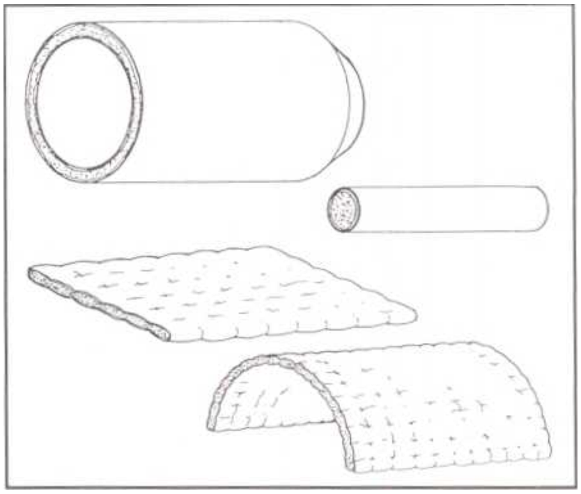
A. Simple Tubes/Bladders



B. Tubular Frame Structures



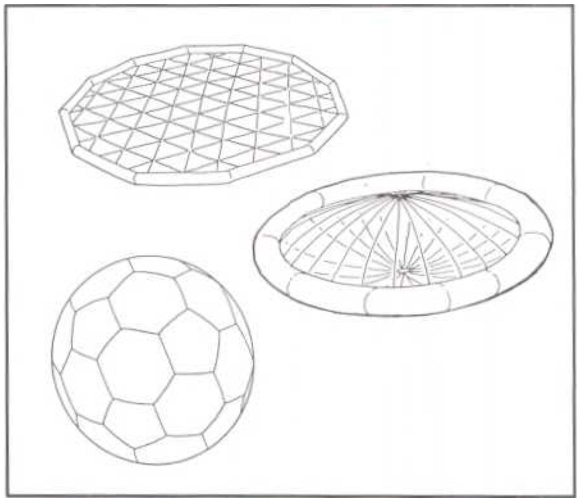
C. Cocoon/Ribbed Structures



D. Foam-Rigidized Tubes/Bladders

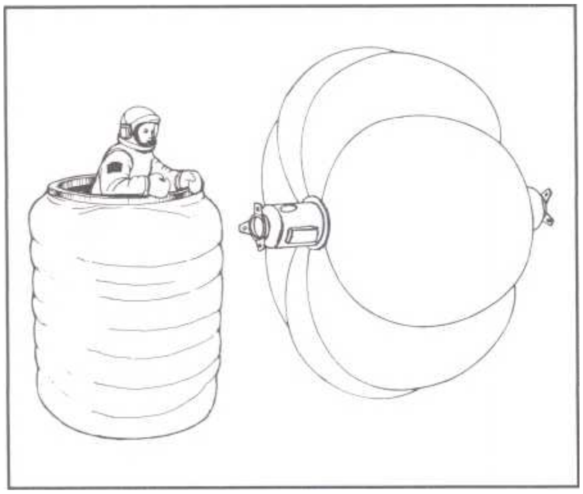
Types of Forms

Inflatable and inflation-deployed structures can be formed in a wide variety of shapes and sizes to meet specific application requirements. Large structures most advantageously exploit the inherent benefit of this technology They potentially afford means to put expansive systems into operation in a very launch volume, time and labor-efficient manner. Spacious, potentially habitable volumes can be created which far exceed size constraints placed upon conventional modules by launch system payload dimensions. Accurate curve profiles for very large antennas and reflectors can be readily achieved.

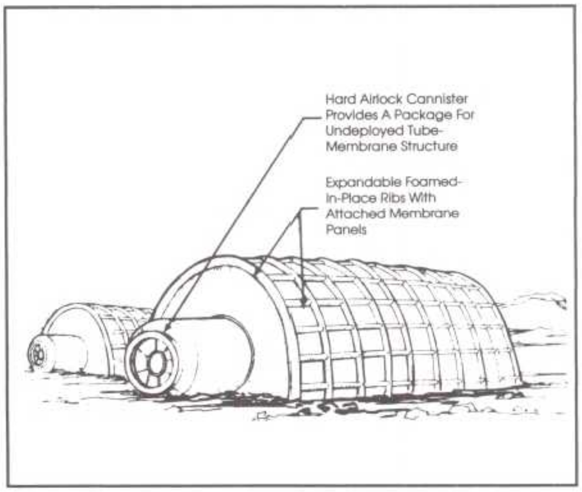


E. Mechanically-Rigidized Structures

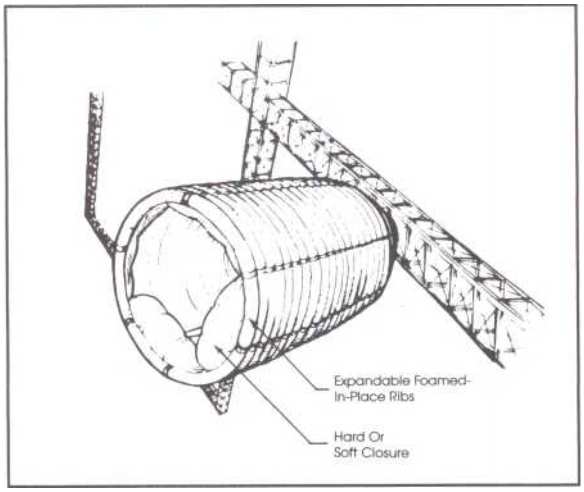
Concepts/illustrations prepared by Larry Bell and Li Hua for wyle Laboratories in support of a NASA-sponsored inflatable structures study.



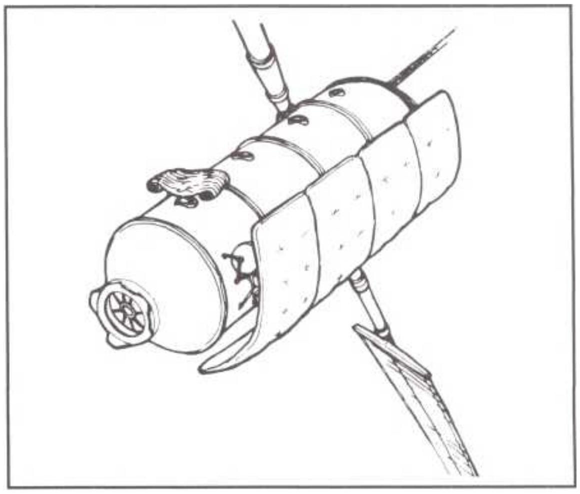
Airlocks and Space Habitats (A)



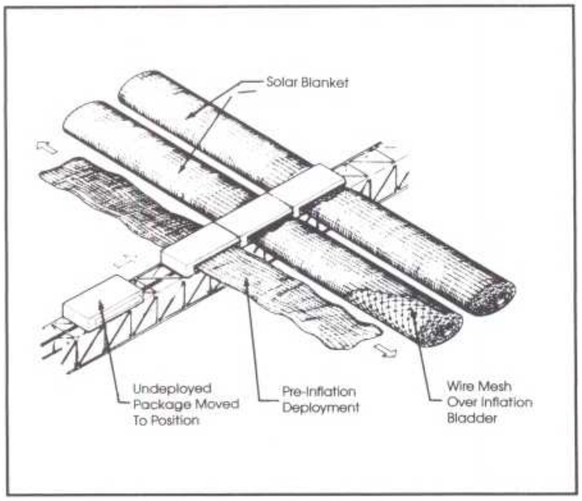
Lunar/Planetary Habitats (B)



Orbital Transfer Vehicle Hangars (C)



Micrometeorite/Debris Shields (D)

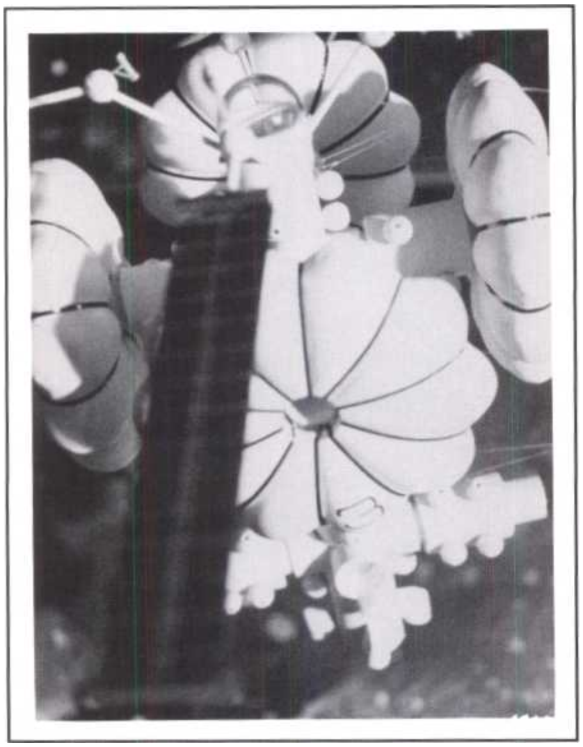


Solar Power Collectors (E)

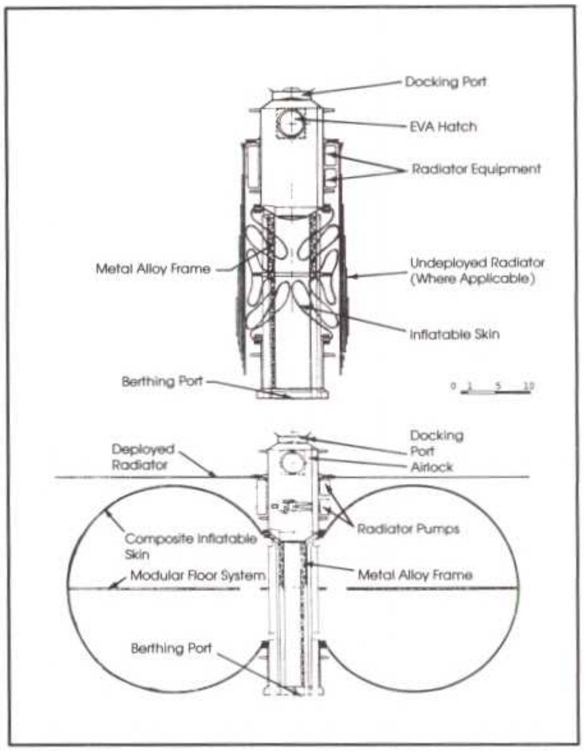
Types of Applications

The broad range of configuration and construction possibilities presented by inflatable and inflation-deployed systems promises a high level of versatility. Tubes, bladders and membranes can be combined and integrated within a common structure in combination with hard elements such as airlocks, hatches and viewports. Wall composition and thickness can be tailored to special operational and safety requirements associated with flame retardancy, thermal insulation, micrometeorite protection and internal atmosphere. The illustrations depicted here represent only a few of the many potential uses.

Concepts/illustrations prepared by Larry Bell and Li Hua for Wyle Laboratories in support of a NASA-sponsored inflatable structures study.



Inflatable Space Station Concept

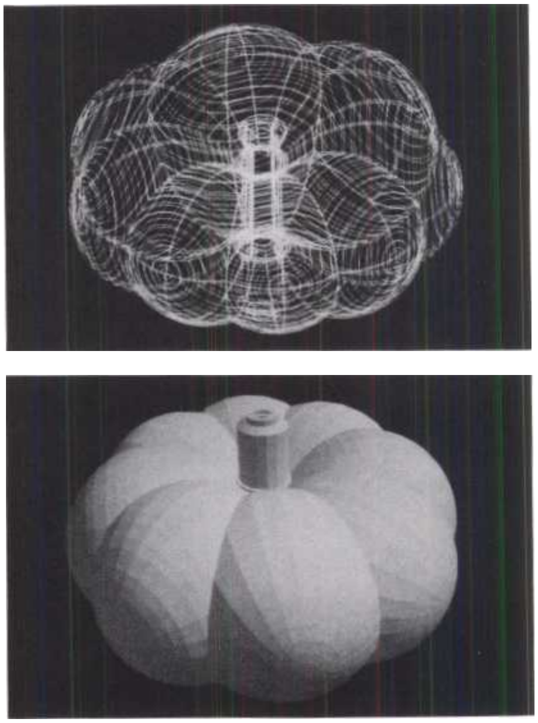


Typical Pod in Packaged and Deployed Stages

Spacehab Project

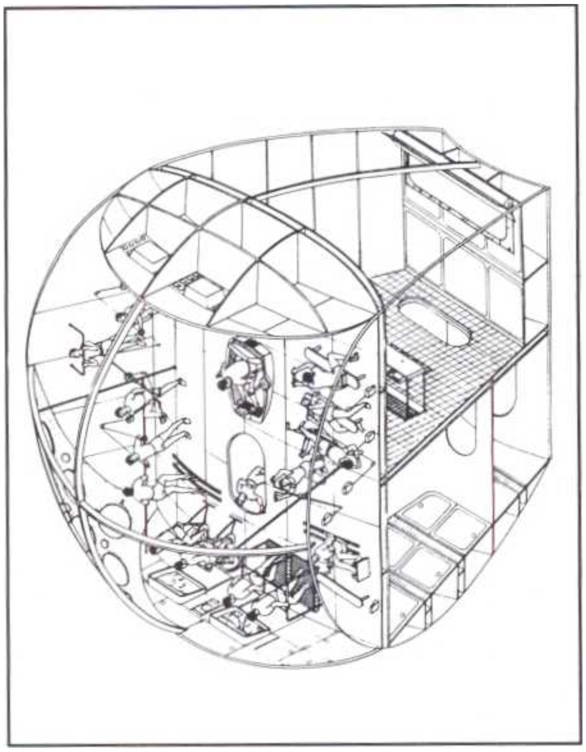
SICSA's predecessor organization, the Environmental Center, investigated ways to construct large (50 persons or more) space habitats under contract with the NASA-Johnson Space Center in the early 1980s. One concept proposed that inflatable 68 foot diameter composite "pods" be sealed around fully integrated utility cores and airlock systems. These pod units would be interconnected by an infrastructure of conventional aluminum modules (not shown).

Spacehab's pods were proposed to be constructed of a net of one inch diameter Kevlar cables spaced 14-16 inches on center that are set between inner and outer layers of Kevlar. Loose layers of thin film Mylar insulation would surround the net to fill grid voids. A single layer of Kevlar (10 oz./yd^2) would serve as a micrometeorite barrier outside the pressure hull and would be covered by a 4-mil film of Tedlar (polyvinyl flouride for ultraviolet and molecular oxygen protection. Kevlar layers totaling 20 oz./yd^2 would form the pressure hull. The inner surface would be silicone-coped in a 40-mil thick matrix to prevent offgassing and offer fire resistance.

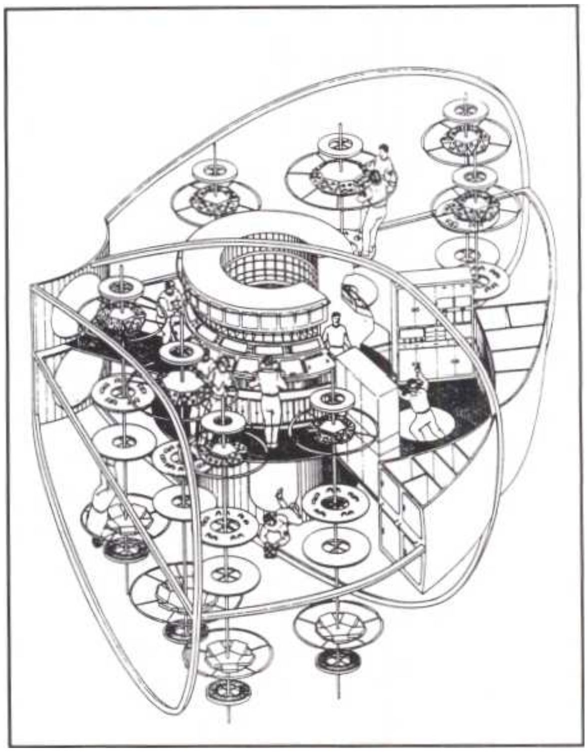


Reinforcement Cables and Composite Skin
Estimated Weight - 16,000 pounds

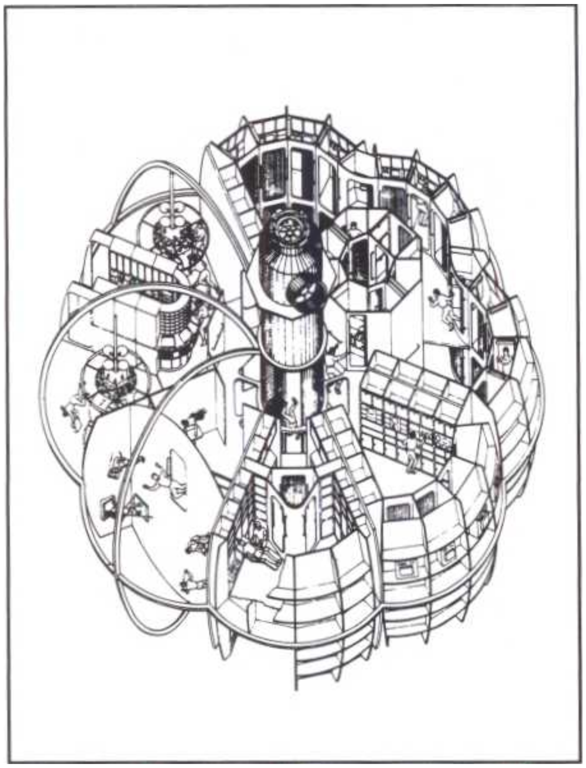
Experimental Architecture concepts for Soacehab by Muhnmmad Siddinui. Frnesto L icen Shirish P ate' and Sandi Susant~



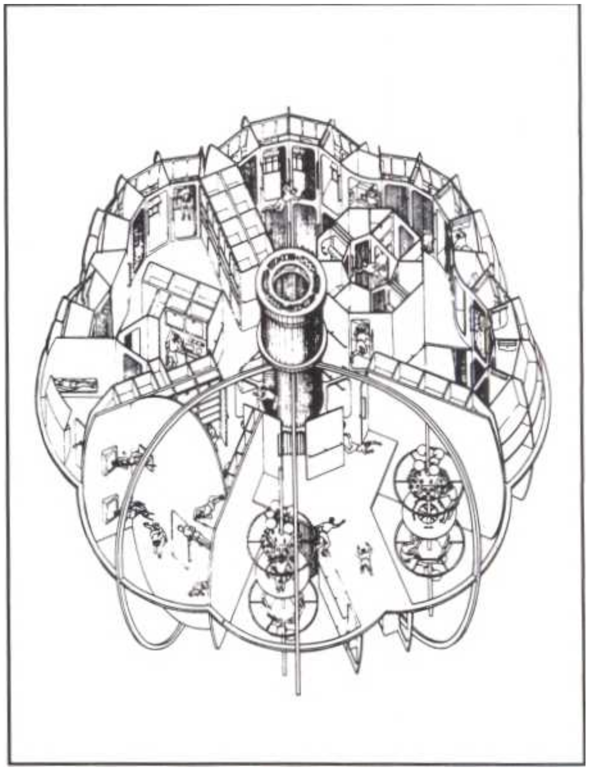
View of Exercise - Recreation Pod Sector



View of Galley - Wardroom Pod Sector

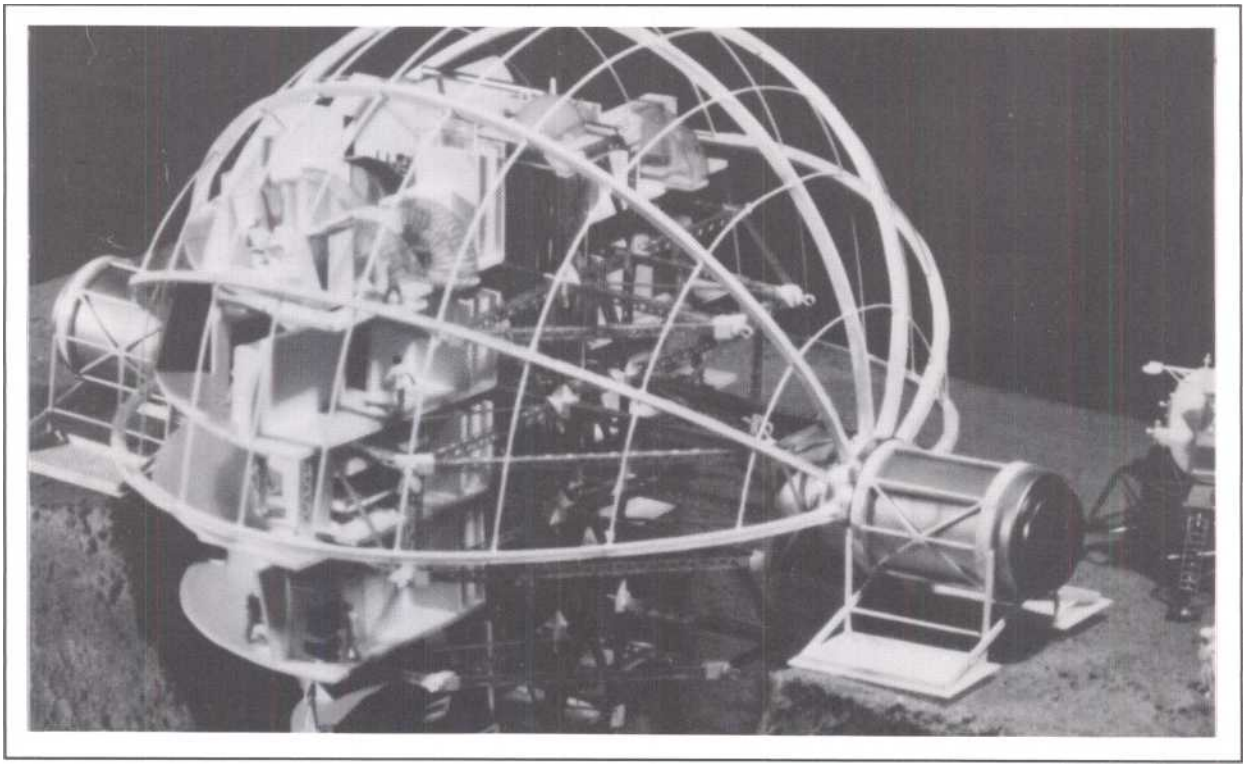


General View of "Upper" Level



General View of "Lower" Level

This "Spacehab" predates and should not be confused with the private "Spacehab" venture involving a Shuttle laboratory module.

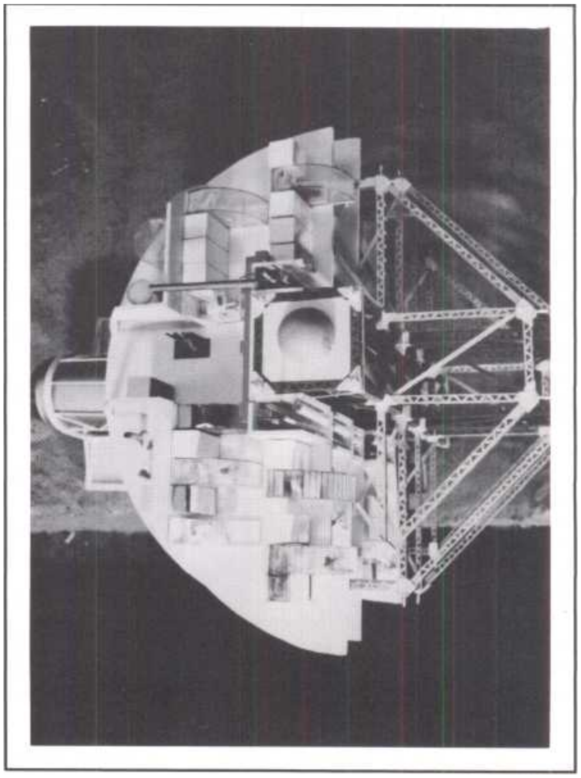


SICSA/Experimental Architecture Inflatable Lunar Structure Concept

Lunarhab Project

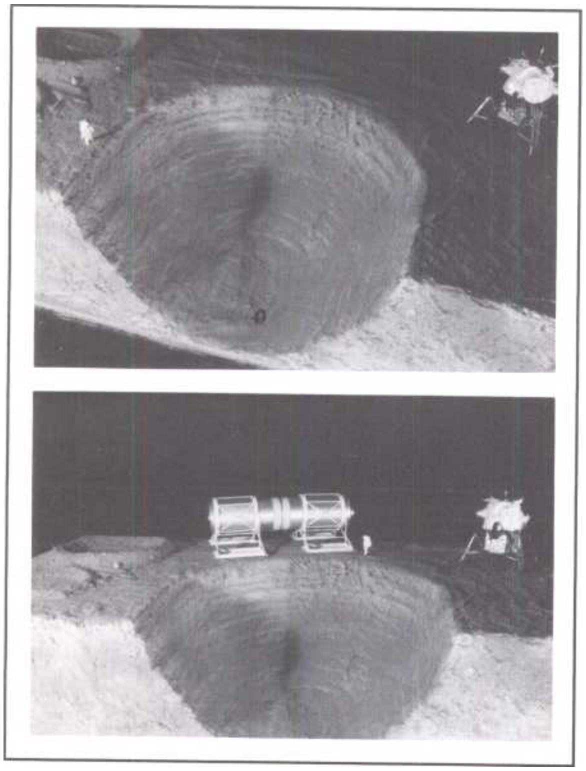
This inflatable structure is proposed for use at a mature stage of lunar base development when mining and industrial production warrant accommodations for relatively large crews. Design goals are to minimize launch weight and erection time. The 70 foot diameter habitat would be comprised of prefabricated aluminum trusses and columns enclosed within a flexible composite pressure bladder similar to Spacehab. These elements would be delivered in a payload carrier containing hatches which separate to provide two independent entry/egress airlocks.

The spherical pressure vessel would be set above a hemispherical surface depression afforded by an existing crater and/or shaped detonation charge. This is important in order to avoid the need for powerful means to anchor the structure in a manner to deform the bladder from a natural circular cross section and resist high inflation lifting forces. The upper hemisphere of the vessel might be covered with a few meters of lunar soil (regolith) to provide a radiation barrier.

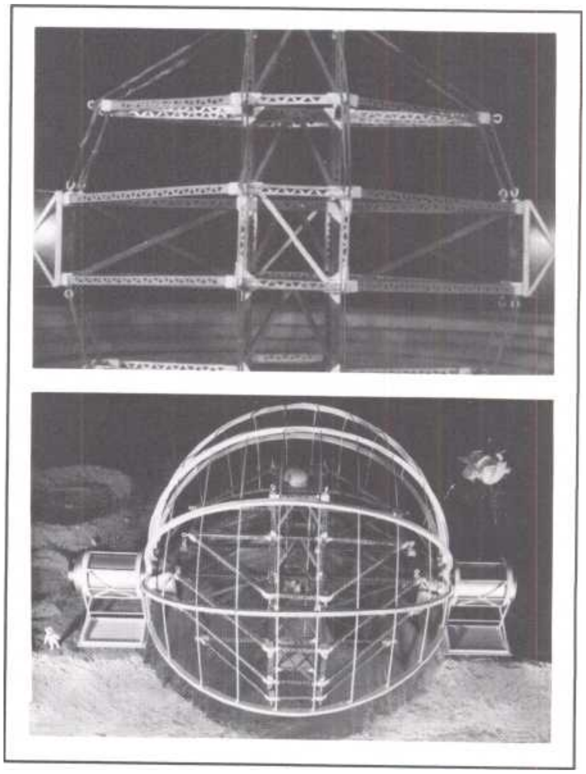


Partial Interior Plan Inside Bladder

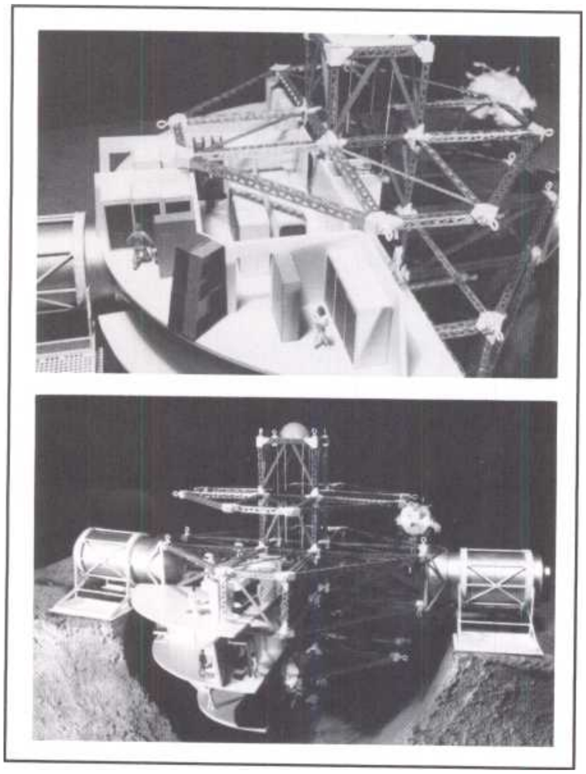
Lunarhab construction concept and models by Warren China,



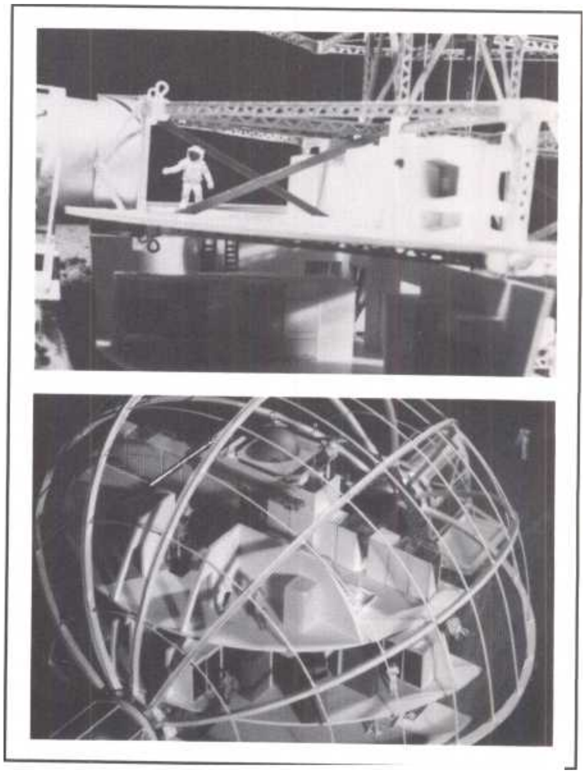
Stage One: Prepare the construction site and offload the habitat structure payload carrier.



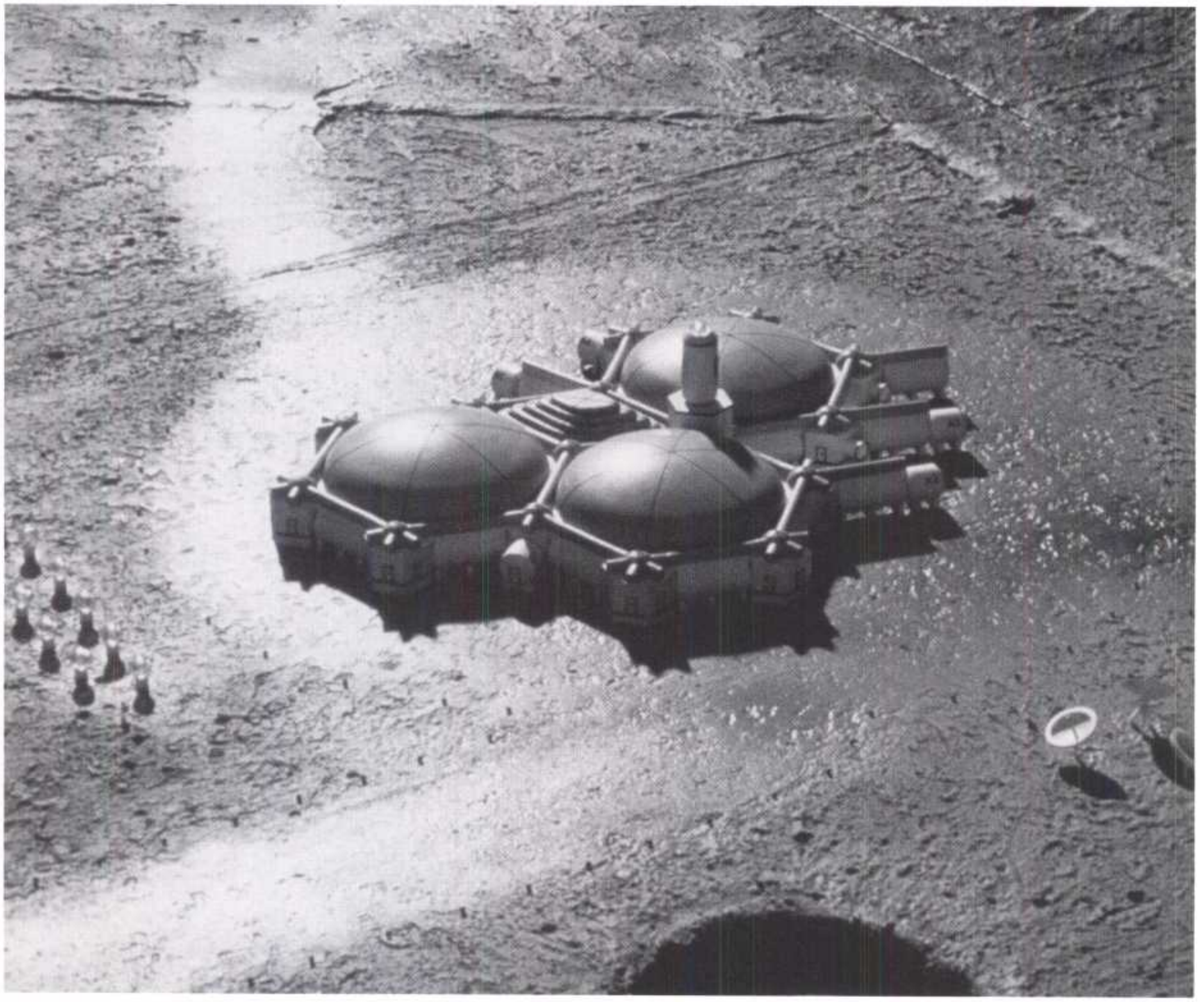
Stage Two: Position and connect the main transverse trusses; then inflate and complete the framework.



Stage Three: Attach floor panels and utility interfaces; then install the life support systems,



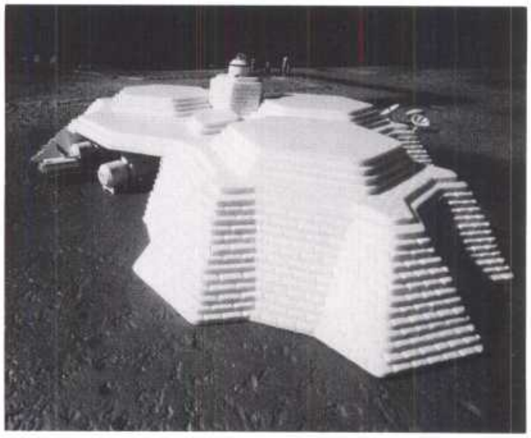
Stage Four: Install the interior partitions, crew system and laboratory facilities.



SICSA/Experimental Architecture Advanced Lunar Base Concept

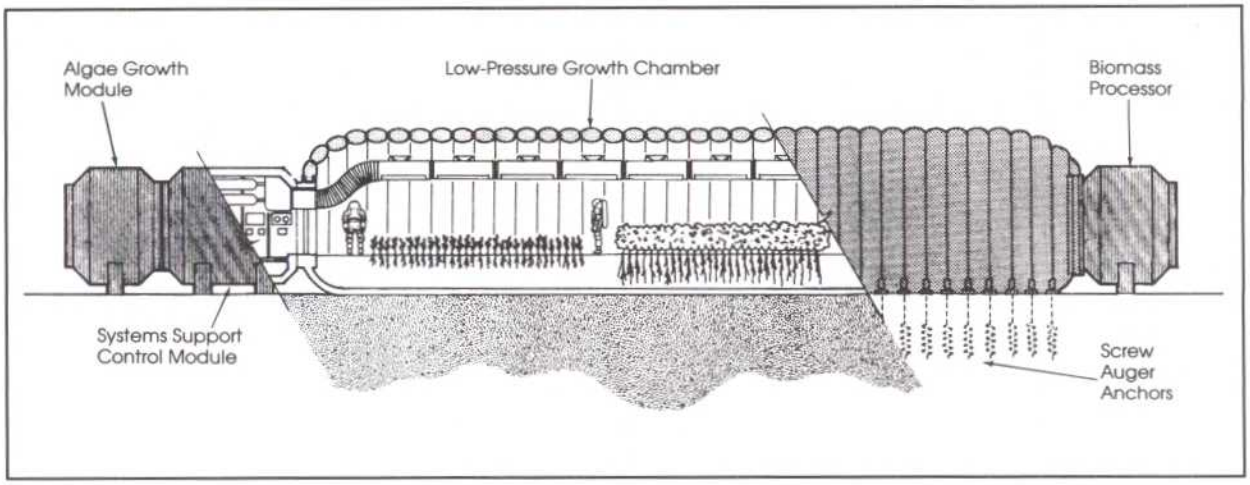
Project LEAP

The Lunar Ecosystem and Architectural Prototype (LEAP) concept featured in SICSA Outreach Vol.1, No. 2 in August, 1987, proposes that large inflatable habitats be added at advanced stages of a lunar development which begins with conventional "hard" modules. This approach assumes that the modules are configured in a ringed arrangement to provide circumferential circulation and multiple access/egress points with respect to the inflatable composite structures. Use of locally produced fiberglass for bladder construction is postulated as a possibility.

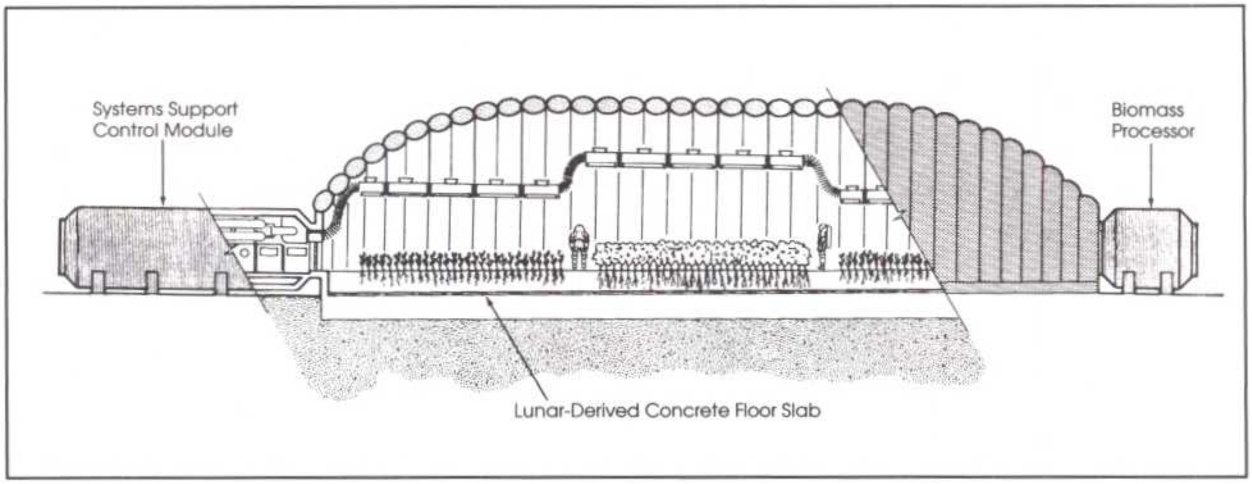


Radiation Shielding by Bags of Lunar Soil

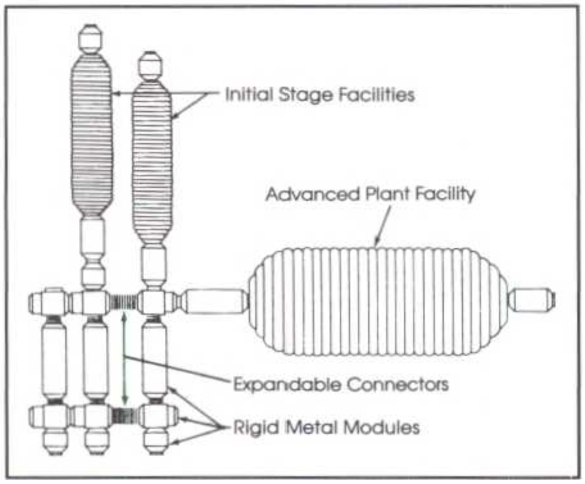
Concept: Jeff Brown, Sam Ximenes and Francis Winisdoerffer



Longitudinal Section Through an Initial Stage Inflatable Facility



Longitudinal Section Through an Advanced Stage Inflatable Facility

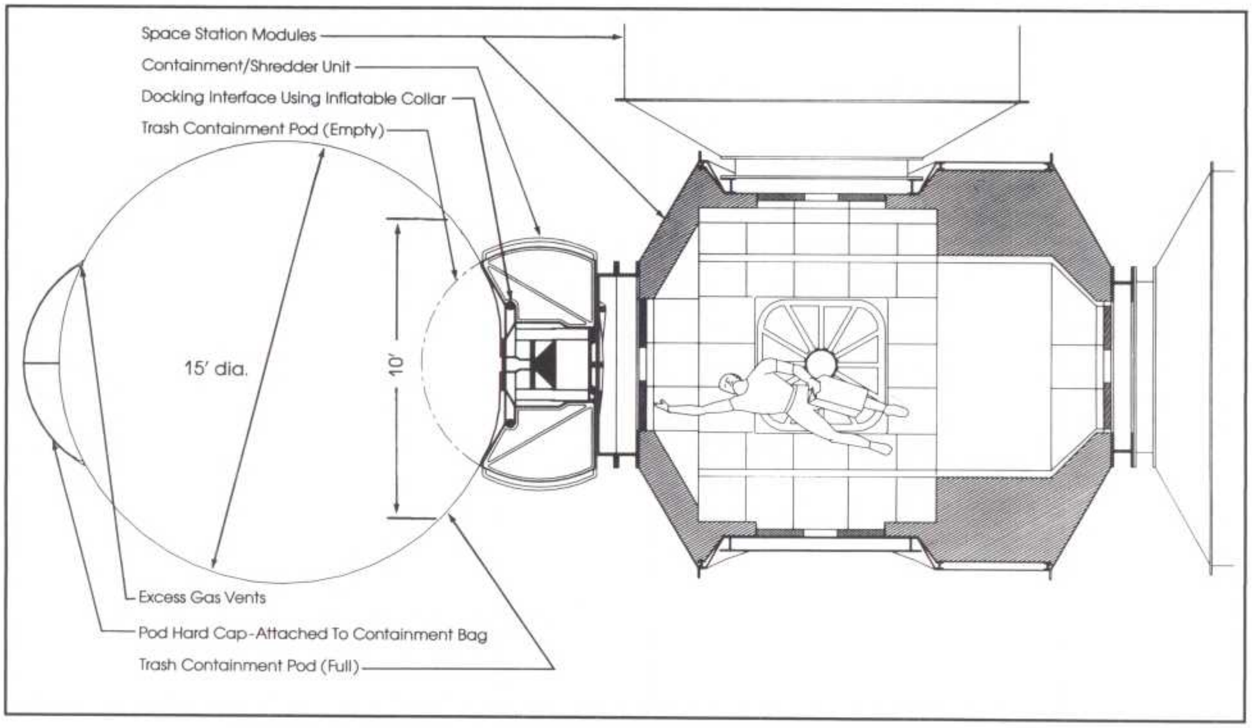


Plan Configuration Concept

Lunar Agriculture Facility

Inflatable structures can offer large plant growth environments to provide food and oxygen for lunar and planetary applications. System elements can include a growth chamber with insulating foam-rigidized ribs; a processor to reclaim nutrients from inedible biomass; a module where algae is grown to produce oxygen; and a module containing all necessary support and control systems. Initial installations might be set directly upon lunar soil and anchored by screw augers. Advanced facilities might incorporate floor slabs made of lunar-derived concrete.

SICSA concepts proposed by Thomas Polette and Larry Toups.



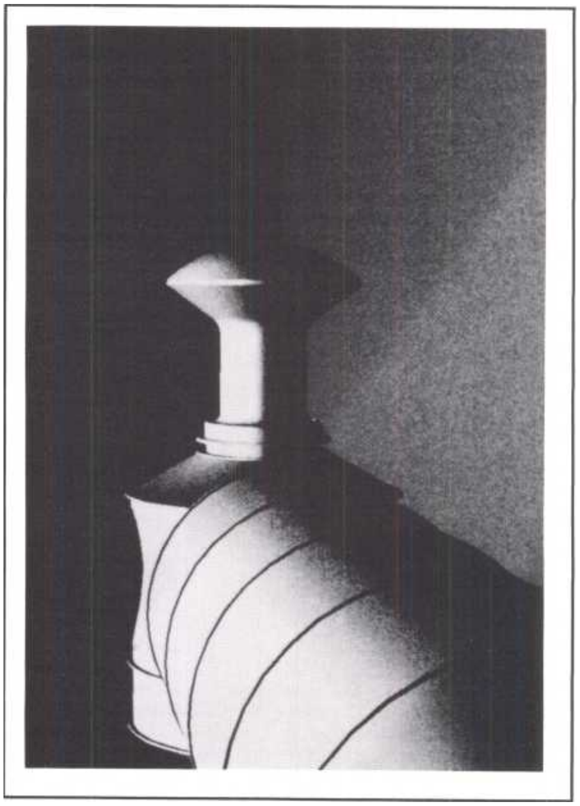
Section Through Trash Management System and Resource Module

Space Station Trash Management

Each Space Station crew mission rotation cycle can be expected to generate hundreds of cubic feet of dry trash which must be stowed until it can be returned to Earth or otherwise disposed of in a safe, clean manner. Expendable bags attached to an external receiving/shredding system offer a promising volume-efficient solution.

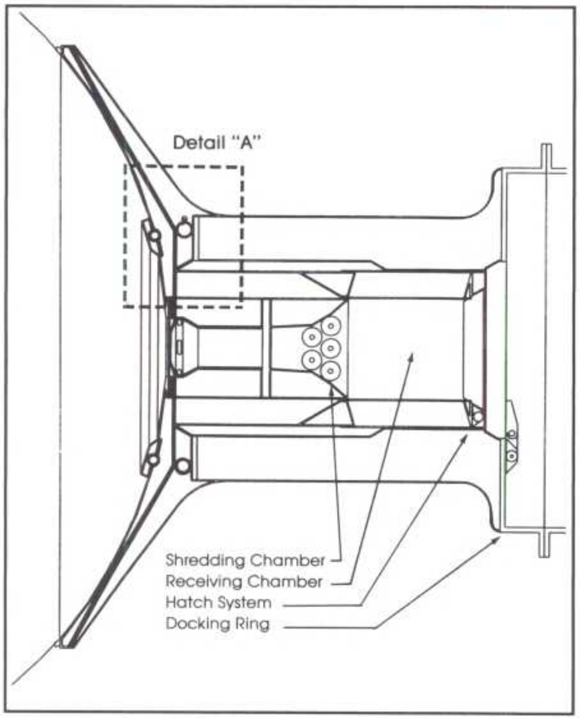
This SICSA/Experimental Architecture concept proposes that a receiving chamber with a shredder be attached to a Space Station berthing port. Expendable bags are sealed into the outermost end of the chamber by inflatable collars that press against a metal outer rim. The 10 foot diameter, 4 foot-3 inch deep bag packages produce a 15 foot diameter, 1,767 cubic foot spherical trash holding area when deployed.

After trash is manually inserted into a 4 cubic foot airlock in the chamber, the material is automatically forced through cutting blades into the attached bag. Vents in the bag allow trapped gases to escape.

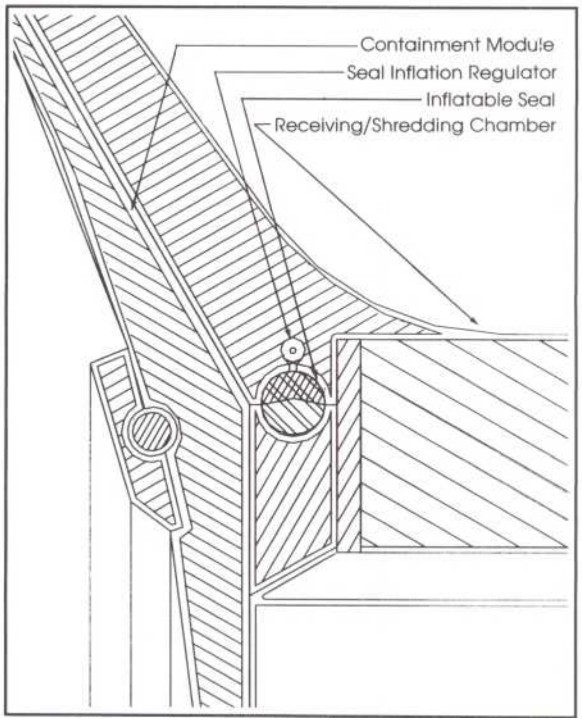


View Showing Bag Package Attached

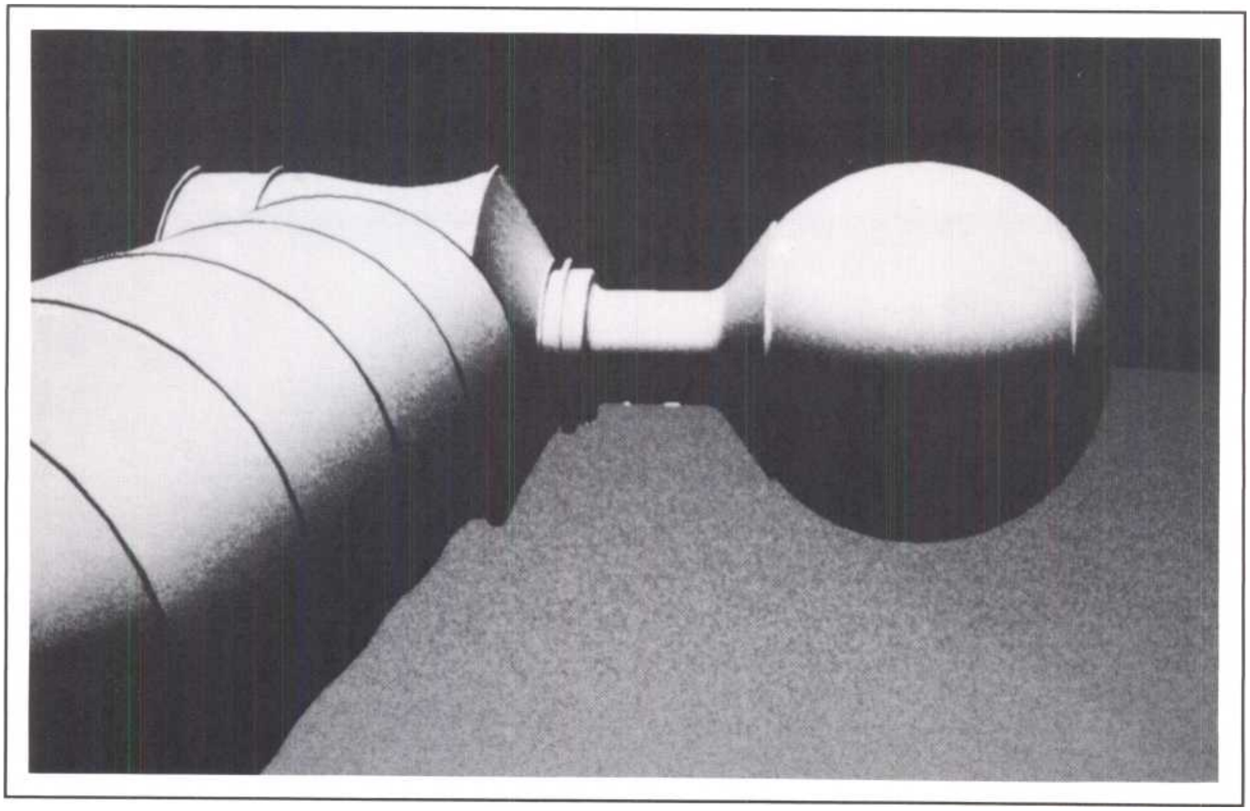
SICSA trash management concept by Rodney Gentry.



Section Through Receiving Chamber



Detail "A" Showing Bag Attachment Seal



View Showing Inflated Bag Attached

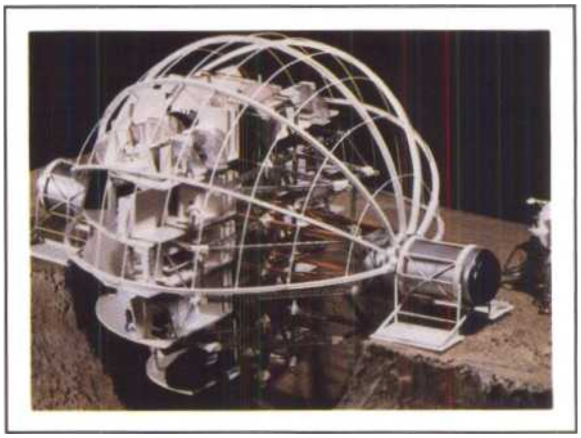
Computer generated SICSA drawings prepared by Rodney Gentry.

SICSA Background

SICSA is a nonprofit research, design and educational entity of the University of Houston College of Architecture. The organization's purpose is to undertake programs which promote international responses to space exploration and development opportunities. Important goals are to advance peaceful and beneficial uses of space and space technology and to prepare professional designers for challenges posed by these developments. SICSA also works to explore ways to transfer space technology for Earth applications.

SICSA provides teaching, technical and financial support to the *Experimental Architecture* graduate program within the College of Architecture. The program emphasizes research and design studies directed to habitats where severe environmental conditions and/or critical limitations upon labor, materials and capital resources pose special problems. Graduate students pursue studies which lead to a Master of Architecture degree.

SICSA Outreach highlights key space developments and programs involving our organization, our nation, our planet and our Solar System. The publication is provided free of charge as a public service to readers throughout the world. Inquires about SICSA and Experimental Architecture programs, or articles in this or other issues of SICSA Outreach, should be sent to Professor Larry Bell, Director.



SICSA Lunarhab Concept

Inflatable composite structures potentially offer a means to create large, environmentally-controlled space facilities which can be packaged in a compact form for launch and easily deployed in a time and labor-efficient manner. SICSA staff and graduate students in the UH Experimental Architecture program have undertaken a variety of studies to determine applications, conditions and design concepts which can optimize these benefits.

This issue of SICSA Outreach highlights some selected inflatable space structure precedents and possibilities to create low-Earth orbit, lunar and planetary facilities.

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