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# BASE – Bubble Architecture Space Environments

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ABSTRACT

As we make the transition from space visitor to space inhabitant, with an anticipated opening up of Earth orbit to space tourism, and in the lead up to a return to the Moon and a manned mission to Mars, the many unanswered questions surrounding sustaining human life in space prompts the question of how we plan for the success of these endeavors. Earth based simulations do not truly represent the intricate factors of isolation in space. BASE is proposed as a 'workshop' or 'hangar', devised to accumulate data in-situ in-orbit, in its mission to develop and test ideas for new orbital habitats (research and recreational configurations), and capsule 'mock-up' habitats for interplanetary travel. An on-board centrifuge would replicate the gravity fields of the Moon and Mars to give a crew prolonged exposure to conditions at destination arrival. The next question is how to achieve a large pressurized enclosure for this multi-purpose application? It seems reasonable that one of the next evolutionary steps in space architecture will utilize inflatable technology. The cylindrical modules of the ISS have reached natural limitations in size, flexibility and the quality of space utilized by the astronauts. NASA's Transhab module provided a promising alternative in the form of an inflatable enclosure deployed about a central service core. The inflatable has to perform to design parameters imposed by the extreme environment of space, including pressurization, radiation shielding, micrometeorite shielding and thermal control. The resultant heavy multi-layered enclosure imposed limitations on the geometry and volume achievable. BASE asks the question; given the current technologies available, what are the possibilities when exploring a hybrid approach, combining inflatable and shell enclosures? In this way the primary function of the inflatable skin is pressurization, protected by 'armadillo' shell segments providing radiation & micrometeorite shielding, in addition to thermal control. BASE explores interior planning and comments on what configuration might lead to the best utilization of the space by astronauts. As we move towards sustaining a long term human presence in space, it is essential that new ways are found to interact and stimulate the senses within encapsulated spaces. BASE explores the concept of transforming the inside of the enclosure into a media skin providing sensory input. In assessing the quality of the interior living spaces, this paper investigates the link between a sensory rich environment and notions of ephemeral design. Since the space shuttle is scheduled for decommission within the next decade, BASE also looks towards alternative vehicles for delivery to orbit. The author has been involved in the development and realization of pod architecture across a number of projects. As a terrestrial spin-up, the author comments on the quality of these spaces as possible references for space habitats.

## I. Living in Space – The unanswered Questions

This section borrows heavily from the seminal book 'Living Aloft' [Connors, Harrison, Atkins, 1985], which comprehensively pulled together, organized and synthesized data from many research studies, both from terrestrial studies and space based missions.

Habitats of early space flight were sized to sustain an individual for a brief period of time. Cabin volumes for Mercury were 1.53 M3 per person, Gemini provided 1.25 M3 per person and Apollo provided 3.03 M3 per person. Subsequently, space stations were sized to maintain 2, 3 or more individuals for several months up to a maximum recorded stay of 1 year (Vladimir Titov and Musa Manarov spent 366 days in space from December 21, 1987, to December 21, 1988 on board Mir). The explorable volume on Skylab was 120 M3 per person, Mir: 126.7 M3 per person and the ISS: 170 M3 per person (on assembly completion). The future challenge will be to provide not only a sufficient, but an enriching environment for groups of people for periods of up to 3 years, for a mission to Mars and Lunar outposts.

Volume Per Person Per Crew Size:
We have a limited understanding of what constitutes adequate space per person over long durations. Nor do we understand how an increase in crew size affects each individual's requirement. To date there is no agreement on whether larger crews require more or less volume per person than small crews. Research studies by Davenport, Congdon, Pierce (1963), supported by Smith and Haythorn (1972), suggested an increase in volume per person is necessary as crew size increase. However, Breeze (1961) implied the opposite, that less space is required per person with an increase in crew size. Whichever may be the case, it is natural to anticipate a requirement for larger single volumes as meeting forums for congregation to cater for larger crews. Private enterprise will open up low earth orbit to space tourism (Bigelow Aerospace test flight of Genesis-1). It is anticipated that the initial low volume 'millionaires club' will eventually fund a new infrastructure that will put the 'dream ticket' within the reach of more and more people. <u>These space hotels will require larger single volumes for congregations engaged in recreational and entertainment pursuits</u>.

Group Behavior:
Crew sizes have historically been small and predominantly male. Almost nothing is known about mixed sex groups interacting under extended conditions of isolation in a microgravity environment. The best way to gather information to establish a sound criteria for crew selection is through in-flight experience. This will shed more light on the benefits of crew diversity in terms of age, nationality, gender, personality and hierarchy structure. Earth based isolation studies do not accurately simulate the conditions of space. A 'performance laboratory' in space could provide the opportunity to explore the complexities of performance, unhindered by the requirements of mission control. The prospect of initiating a program of on-board learning should be considered.
<u>A large space based environment, equipped with a centrifuge to replicate Lunar and Mars gravity fields, and dedicated to the research of group behavior would prove invaluable ahead of a proposed Lunar outpost and a mission to Mars</u>.

| Space Station | Crew Size | Habitable Volume | Volume / Crew Member | Maximum Diameter | Comments |
|---|---|---|---|---|---|
| International Space Station (1998 – 2020?) | 7 max | 1200 M3 on completion | 171.4 M3 | 4.3M diameter | Civilian (non military) International partnership research platform, 1 bar environment, orbit: 389KM |
| Mir (1986 – 2001) | 3 max | Core: 90 M3 Extended: 380.2 M3 | 126.7 M3 | 4.15M diameter | Civilian (non military) Materialsprocessing, Atmospheric studies, Astronomical observatory, 1 bar environment, orbit: 300-400KM |
| Salyut 7 (1982 – 1991) | 3 max | 100 M3 | 33.3 M3 | 4.15M diameter | Civilian (non military) Occupation 812 days by 10 crews, Orbit: 474KM |
| Skylab (1973 – 1979) | 3 | 361 M3 | 120.3 M3 | 6.6M diameter | Civilian (non military) Solar observations, Endurance 600 days, 340 mbar environment, Dry 3rd stage of Saturn V Rocket, Orbit: 435KM |
| Table 1, Space Station Volume Analysis | | | | | |

Table 1: With the exception of Salyut, volumetrically, the 'explorable' environment per crew member has increased in size over the last 30 years, for long stay missions in low earth orbit. Increasing from 120M3 per head on Skylab in the 1970's, up to 170M3 per head on the ISS (on assembly completion), an increase of 42% per head. The maximum dimension of the explorable environment has decreased in size, from the 6.6M diameter workshop in Skylab, to the standardized 4M diameter modules of the ISS.

The diversity of the spaces (spaces varying in size and shape) has decreased over time, from the days of Mir and Salyut, in favor of repetition and uniformity. The Transhab Module, with its 6.7M diameter deployed envelop, had it been implemented as an expansion module to the ISS, would have broken this trend, and provided a different spatial experience.

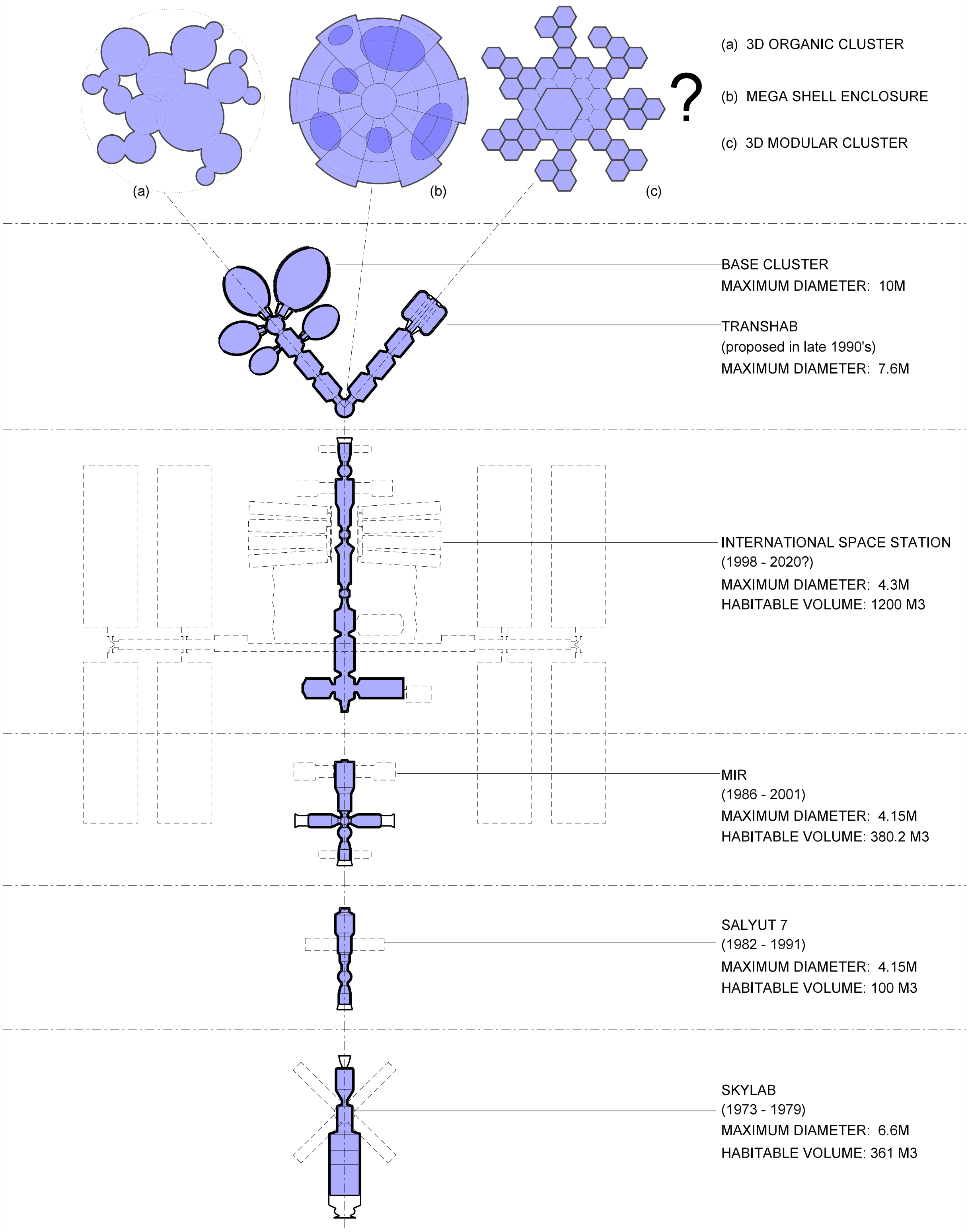


Figure 1, Space Station Spatial Comparison

Space Environment Interior Design & Planning:
Fraser (1968a) suggested 4 functional units for space habitation as follows:

1 Work Unit (operational tasks, vehicle management)
2 Public Unit (dining, recreational, exercise)
3 Personal Unit (sleeping, personal privacy, personal storage)
4 Service Unit (toilet, laundry, public storage)

Allocation of private space to allow a crew member to retreat from the group during a long duration mission, is widely accepted. The Transhab inflatable habitat proposal from the late 1990's provided a 'Crew Personal Unit' for each crew member. These 7.3 M3 compartments incorporated a computer entertainment center, a storage space for personal items, in addition to a sleeping restraint area.

The relationship between private and public areas needs to be further explored. An adaptable design allowing the personal unit to open up into a semi-enclosed arrangement, with visual sightlines to activities beyond, is thought to have psychological benefits. Research also indicates a preference for shared spaces (whether working or public spaces) that are configured to allow a person to withdraw, but at the same time still retaining line-of-sight contact with the other group members (perhaps akin to work alcoves within an open plan office). Rogers (1978) found that this preference for shared space over private space extends to mixed group crews. Being in line-of-sight contact with others seems to comfort the confined individual, probably by keeping him or her current on what is happening in the group. It is generally accepted that the interior design of a spacecraft should have built in flexibility. Such flexibility could include the use of adjustable partition elements and re-locatable working surfaces, adapting to evolving needs or a desire for change. Well considered terrestrial interior design makes use of complimentary color schemes. Color change could be introduced over time through subtle colored lighting washing the enclosing surfaces, or through projectible designs. Touching surfaces of contrasting texture is a familiar experience on Earth and one we would undoubtedly miss if it were absent from space habitats. A study by Jackson, Wamsley, Bonura and Seeman (1972), suggested that the working and living areas be made sharply distinct from each other by virtue of design – color, style, lighting and acoustics.

Skylab astronauts reported that the sameness of color within their station was disturbing (Berry, 1973a). Russian investigators have looked at the visual environment of a spacecraft and have proposed ways that changes in décor could be employed not only to relieve visual monotony but to maintain the space traveler's link to the home planet [Petrov, 1975]. It seems self evident that people will desire greater environmental complexity with the passage of time [Dember and Earl, 1957]. We should therefore continue to explore how to design stimulating 'layered' environments for long duration flights (refer to section II Sensory Environments).

Since work in space is likely to become progressively less demanding during long duration flights, one might expect a shift towards more enriching recreational pursuits. It is likely that individuals in space will develop interests in movements unique to space. Astronauts on Skylab were enthusiastic about the possibilities of tumbling and acrobatics in space, and suggested that all future space stations include facilities for acrobatics. Over time, crew members loose their motivation to condition their bodies through a repetitive exercise regime, such as a treadmill [Oberg, 1981, p.213]. As an incentive, new ways should be found to combine conditioning with fun activities, such as acrobatics.

There is an emerging need for a space based workshop facility with the purpose of testing interior design mock-ups in micro-gravity, including the investigation of adaptable / demountable spaces, lighting effects, materials, emitted odors, acoustics, noise levels from lift support systems etc.

Local Vertical:
Weightlessness permits astronauts to use a volume more efficiently than on Earth [Berry, 1973a]. One of the biggest questions that needs to be addressed is whether space travelers are able to learn to adapt through familiarity to a multi-directional world in weightlessness, or, if their need for Earth conditioned cues of 'up' and 'down' persist. This fundamentally influences how we design space habitats for long duration flight in the future.

Contradictory accounts have not yet clarified this question and further research is required into the relationship between familiarization training on the ground or in space, and adaptation behavior in space.
Astronauts of Skylab reported that they preferred those areas where there was a local vertical, to give a sense of up and down. Astronauts felt least comfortable in the larger upper deck of Skylab where, because of size and lack of architectural cues, orientation was difficult (Life in a space station, new Yorker magazine, 8/30/76 and 9/6/76). Astronaut Gibson (1974) of the Skylab 4 Crew reported:
''Being upside down in the wardroom made it look like a different room than what we were used to. When I started to rotate back and go approximately 45 degrees or so off the attitude which we normally call 'up' the attitude in which we had been trained, there was a very sharp transition in my mind from a room that was sort of familiar to one which was intimately familiar. It all of a sudden was a room in which we felt very much at home and comfortable with. It wasn't a gradual thing, it was a sharp transition''.

On the other hand, Story Musgrave, mission control specialist who participated in an extravehicular activity on STS 6 has reported that he felt no need to identify a particular direction as 'up' or 'down' (personal communication, June, 1983). He further raised the interesting possibility that the presence of a defined vertical within the vehicle might cause conflict with outside perceptions (during EVA), possibly contributing to space sickness.

Some research suggests that to avoid 'sensory conflict' (conflicting information transmitted by the Otoliths and the semi-circular canals of the ear), that which can lead to spatial disorientation and space sickness, we should create environments with an Earth like orientation, to retain an impression of an 'up' and 'down', through spaces defined by floors, walls and ceilings. Other research suggests less literal measures, such as architectural cues for orientation such as colored strips on the interior surfaces (study of Soviet cosmonauts by Leonov and Lebedev, 1975). However, other research suggests that by defining local verticals within differently orientated modules, we could exacerbate the problem, if the crew member has to by necessity reorientate themselves, for example carry out an EVA outside the vehicle or space station, or take evasive action in an emergency situation (decompression of the Spektr module, Mir Space Station, Tsibliyev, Lazutkin, Foale, 1997, evasive action to sever cables and seal the hatch, Space Exploration edited by Russell Lawrence).

Lynch (1960) has used the term 'legibility' to describe how parts of a scene can be organized into a coherent pattern. The desire of astronauts to define direction in space can be thought of as an attempt to establish a metal reference of their local position relative to the whole. It may be that the effects of spatial disorientation can be offset by visual architectural cues that signpost each habitable space relative to the whole vehicle or space station complex. For example, color coding parts of the interior surfaces of every module to represent port, starboard, aft, stern, nadir and zenith (nadir and zenith being borrowed from earth orbit, as a substitution for up and down during interplanetary travel). In this way there is no conflict between the interior and exterior as the 3 axis color coding applies to the whole complex.

For this reason, further research needs to be carried out into the benefits of preflight familiarization of spaces experienced in different orientations, through training in rotating simulators [Abbott and Duddy, 1965, Adams and Bulk, 1967]. A more forward looking and authentic scenario would be to construct a simulator 'workshop' in low earth orbit, in the form of a large pressurized volume, inside which mission to Mars mock-up capsules can be tried, tested and thoroughly familiarized by the crew.

Artificial Gravity:
The effects of weightlessness on human physiology is reasonably well understood – including de-conditioning of the cardiovascular system, demineralization of bones and decreased muscle tone and strength. The goal therefore is to find effective and practical countermeasures that will probably include replicating gravity by means of a centrifuge for cardiovascular and muscular conditioning, and through use of pharmaceuticals to replace mineral loss in bones [Nicogossian and Parker, 1982; Dietlein and Johnston, 1981]. Artificial gravity, either in the form of a rotating vehicle or on-board centrifuge device, needs to be tested in space. The use of an on-board centrifuge is probably a practical near term solution. A spacious pressurized 'workshop' in low Earth orbit would facilitate the testing of an adjustable centrifuge, exploring the relationship between rotational acceleration and radii distance, to ascertain what fraction of 1G would adequately stabilize the human physiology during a mission to Mars, and simulating the Mars gravity field of 0.4 G on arrival .

Mobility & Restraint:
Mobility and restraint systems have been advanced since the days of Skylab, where restraints were either too difficult to slip in and out of, or, those that were easier to engage were too loose to hold a person in place to be of any effective use. Vogler, Andreas, ''Design for an astronaut's workstation'' (SAE 2005-01-3050), developed an effective seating frame for micro-g, tested on parabolic flight. Further research should be carried out to devise mobile versions of these devices, for example, transferring the frame onto a sliding rail to facilitate a researcher to easily interface with a larger working surface, such as a wall of modular experiment racks.
Welsh, Chris, (2002), ''Study for a personal mobility unit'' Kingston University, London, tested mobility aids in parabolic flight. These comprised of battery powered fans strapped to the users arm. The development of these and other yet to be conceived of devices is important to enhance mobility in space. Therefore an ergonomics and product development 'workshop' for space application, developing and testing devices in-situ in low Earth orbit is a sensible scenario.

## II. Sensory Environment

Jorgenson, Jesper, ''Restricted Sensory Stimulation in Space Environments, implications for a necessary cooperation between architecture and psychology in designing for coming missions'' (SAE 2005-01-2912), put forward a clear argument for the integration of psychological research with the design of habitats for living in space. One consistent outcome exhibited by individuals subject to sensory deprivation during isolation is depression and regression [Natani and Shurley, 1974; Natani et al., 1973; Strange and Klein, 1973; Serxner, 1969; Ruff, Levy, and Thaler, 1959; Lug'', 1973; W. Smith, 1966].

On earth we take in sensory information we are not even aware of, from random cloud formations fleeting across our peripheral vision to shifting rhythms in background noise experienced in everyday life. Without these sensory inputs, psychological unease sets in, becoming more and more apparent the longer one is isolated.

Media screens are becoming a more familiar backdrop to city life. These can be based on plasma screen technology or an LED matrix. More recently, fluorescent tubes that can finely adjust their light emission have been developed and used as media pixels (example: media screen on HVB building in Potsdammer Platz, Berlin).

BASE explores the idea of transforming the interior surface of the enclosure into a media screen. An ephemeral skin of 'moving images, a reflection of the everyday world we have become accustomed to if not conditioned to. The skin becomes a canvas onto which we can project color for the eyes to feast on, like an aquarium of tropical fish that mesmerizes and has a calming effect. The images can be familiar – wind blowing through a meadow of long grass or completely abstract renderings that ripple across the interior like ripples in a pond. The background 'performance' can be anything the astronauts wish to program. (Note; media pixels are proposed to be fixed to a carbon fiber grid shell, erected inside the pressurized bladder. A fire proof cloth separates the grid shell from the bladder).

It would also be interesting to simulate a 24 hour night and day cycle by manipulation the level of ambient light emitted by the media skin, perhaps helping to offset the effects of the 90 minute light and dark cycle of low earth orbit, and associated sleep disorders experienced by astronauts trying to adjust.

On a double curvature surface, a media screen can comprise of a matrix of LEDs or fluorescent tubes. The higher the pixel density the higher the image resolution, but high resolution is not necessarily the object of the exercise. The 'moving' images can be an abstracted representation of reality. Astronauts are instinctively keen to peer out through porthole windows to survey their surroundings. The media skin could project in real time, panoramic views relayed from cameras positioned externally around the ISS.

A color pattern language could be developed to communicate information from life support sensors on temperature, humidity and CO2 levels.

## Ⅲ. Terrestrial Spin-Up

The author has been involved in the development and realization of pod architecture in Europe and the Far East. Their purpose derive from a desire to create encapsulated spaces for multimedia presentations, or respond to a desire to animate a much larger public realm by inserting pod objects that appear to float within the space. These pods are usually formed in one of two ways:

1 Shells - cast materials such as glass reinforced plastics (GRP), glass reinforced gypsum (GRG), and pressed materials such as metal alloys

2 Membranes & Fabrics – tensile supported PTFE, ETFE, reinforced Polyurethane & Nylon.

These objects often generate a sense of excitement in people, attracting them to venture upward and explore their interiors. The observer often senses that the interiors feel unfamiliar, without the usual references of walls and ceiling, the pods create an interesting and ambiguous depth of field, spacious, and at the same time concentrated.

On a much larger scale, this optical illusion is demonstrated by the currently vacant Millennium dome in London. The perception at the perimeter is that a journey to the center is within a relatively short range. Only when setting out on the journey does it become apparent that our eyes have deceived us and the distance is considerably longer.

The wrap around space is therefore unique from the more commonly experienced extruded spaces that generate linear perspectives.

Part of this paper investigates whether any lessons learned from terrestrial pod architecture can be applied as a spin-up to space based habitats. In the absence of gravity, there are opportunities to utilize the volume in many new and different ways.

The geometry and expression of the pods illustrated come from many sources, from soft organic to hard crystalline geometries, all of which can be found in nature. The process undertaken has included the following stages, involving reiterative loops before a final design emerged:

1 Form Finding - an architectural intent establishing form and volume in response to purpose.
2 Materials - engineering of a hard or soft enclosure in response to form and environment.
3 Patch Finding - subdivision of enclosure into manageable modules or patches.
4 Transportation - modules checked in response to carrier – road / rail / sea container.
5 Fabrication - consideration of erection sequence in response to site conditions and crane loads.

The same process and equivalent design considerations are applicable to the development of BASE.

## IV. Next Step Technologies

Question: what technologies will allow us to realize large bubble environments in low earth orbit, in the short term? NASA's Transhab module provided a promising alternative to the cylindrical modules of the ISS. The inflatable has to perform to design parameters imposed by the extreme environment of space, including pressurization, radiation shielding, micrometeorite shielding and thermal control. The resultant wall is 300mm thick, comprising of 17 layers of ceramic fabric, polyurethane foam, polymer film and Kevlar, (coping with collisions from space debris up to 1.8 centimeters in size moving seven kilometers per second). However, this combined accumulation of layers imposes limitations on the deployable geometry and volume attainable.

In analyzing the problem, it seemed advantageous to separate out the two functions of a bubble enclosure, leading to the idea of a two skin assembly:

1. Inner pressure bladder: a reinforced polymer designed for a 1 atmosphere pressure differential.
2. Outer protective layer: a hard or soft shell (ceramic, Kevlar and polyurethane foam layers), providing radiation and micrometeorite shielding, and thermal control.

Next step is to consider the options for achieving this assembly, addressing the issues of transportation to and deployment in orbit.

<u>Option 1 Exoskeleton</u>:
Combining inflatable bladder inner layer, with hard shell exterior. An 'Armadillo' tile pattern of shell segments are assembled and mechanically fixed together to provide overall structural rigidity. Once in place, the inner pressure bladder is inflated. This sequence ensures that the inflatable remains protected during deployment into its final shape. Further research revealed some difficulties with this approach. The smaller the segments, the more in-orbit assembly results. The larger the segments, the more reliance there is on a Herculean carrier such as the space shuttle. The shuttle with its 18M long cargo bay is scheduled for decommission within the next decade. A more flexible approach is required, which lead to consideration of Option 2.

<u>Option 2 Deployable Overcoat:</u>
Inflatable bladder inner layer combined with deployable protective outer layer. In this option, an analogy can be made with petals on a flower. The outer layer becomes a series of unfurling and overlapping patches, deploying in the same way as solar arrays. The petal segments could be made of solid hinged panels. Alternatively, it may be more beneficial to form the petals out of a layered quilt material. A high level of dimensional tolerance is not required with this approach – upper and lower level petals unfurl and overlap, requiring one EVA to fasten where they come together. This design suggests that the petals incorporate inflatable ribs along the edges, that facilitate deployment and hold the petals into the final curved profile (like an inflated segment of tube in a bicycle wheel), before they are fastened together at the ends. An interesting comparison can be made with the activities of a Californian based company named

L' Garde, which specialize in the manufacture of inflatable structures designed for space. Much of the designs incorporate inflatable ribs for deployment and stiffening of the elements.

Once the outer protective layer of petals are deployed, next the inner bladder deploys. L'Garde film footage of inflatables deploying in space capture a fluid and sometimes erratic motion. For a gradual and symmetrical inflation, a series of release straps (threaded through loops on the membrane wall), uncoiling uniformly from release winches at the base, would guide the 'Iris Window' (integrated with the inflatable wall) towards the aperture in the petals. Figure 2 shows 'work in progress' illustrations of a Base I version, and Figure 3 illustrates a BASE II version. The ellipsoid form was chosen (over say a spherical or torus form) as the preferred geometry that the petals could deploy and 'conveniently' configure around. BASE I, with petals attached prior to launch, fits snugly within a carrier such as the space shuttle, deploys to achieve an internal volume of 360 cubic meters. BASE II explores a much larger deployed volume of 700 cubic meters, and requires in-orbit attachment of the petals. To simplify the assembly of BASE II, a collar on the docking segment, containing the petal anchorages, rotates to align the anchor points towards the orientation of the shuttle or ISS robotic arm. A camera on the robotic arm would enable remote assembly, guiding a simple 'push and click' pinion and socket connection for each folded petal cassette. Although involving more assembly steps, the way is now reasonably clear for envisaging a much larger bubble environment - an enclosure suited to the intended application of BASE as a generously sized in-orbit 'workshop'.

An attachment site to the ISS is considered, located near the center of mass underneath and aft of the ISS truss (ISS final stage). The shuttle as a delivery vehicle, and in the docked position, is in a good orientation to attach the module, and subsequently attach the petals using its robotic arm. The illustration suggests a cluster of 3 modules, all docked to a spherical node module. The cluster arrangement means that each module is inclined at 50 degrees relative to Nadir, and would receive excellent views of the earth – the curvature of the earth crossing the center of the Iris windows, when looking out from within

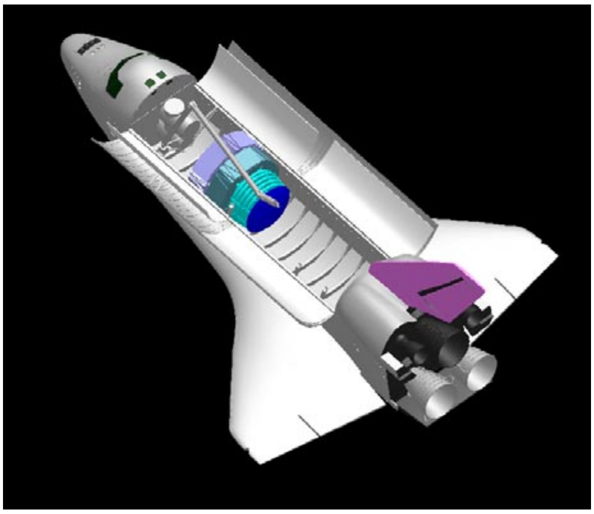

Fig. 2.1 Delivery to Orbit

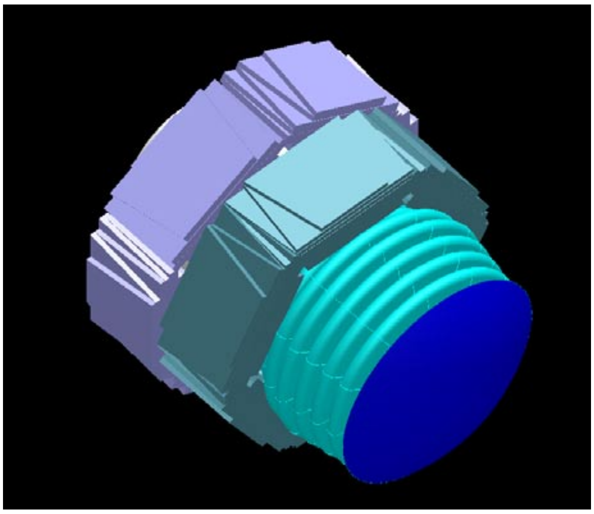

Fig. 2.2 Petals pre Attached

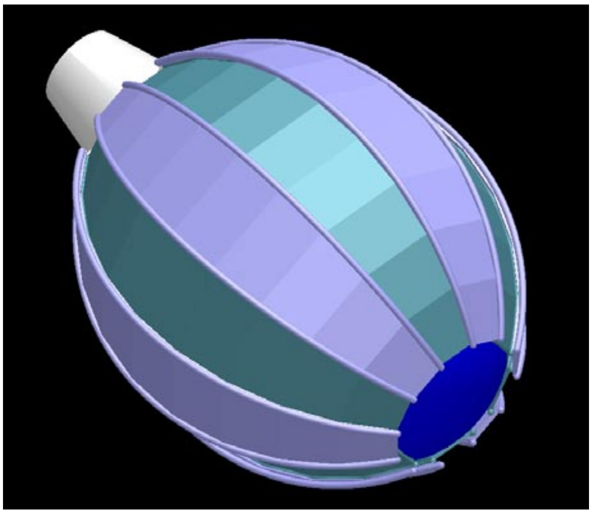

Fig. 2.3 Deployment Complete

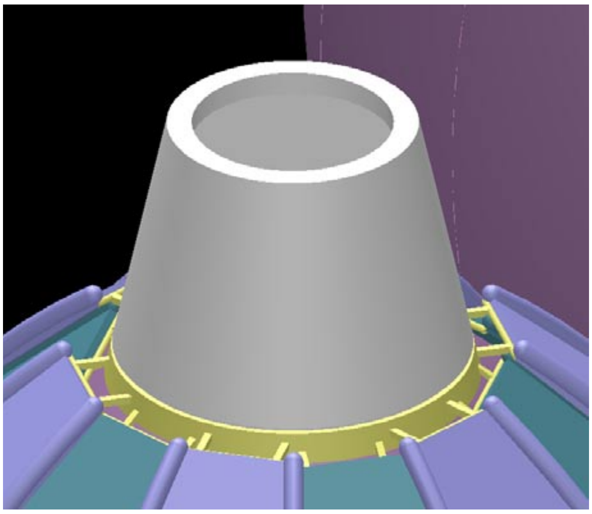

Fig. 2.4 Petal Attachment Collar

Figure 2, BASE I, Deployment VOLUME 360 $M^3$

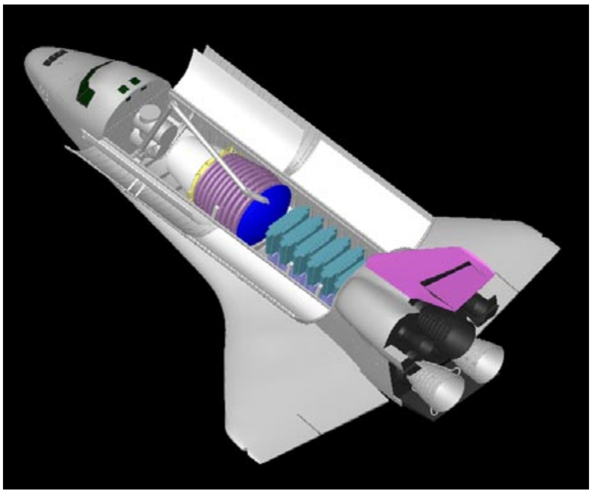

Fig. 3.1 Delivery to Orbit

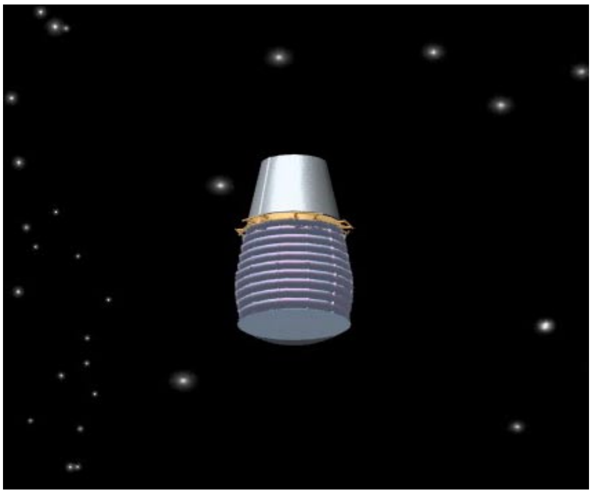

Fig. 3.2 Inflatable Module

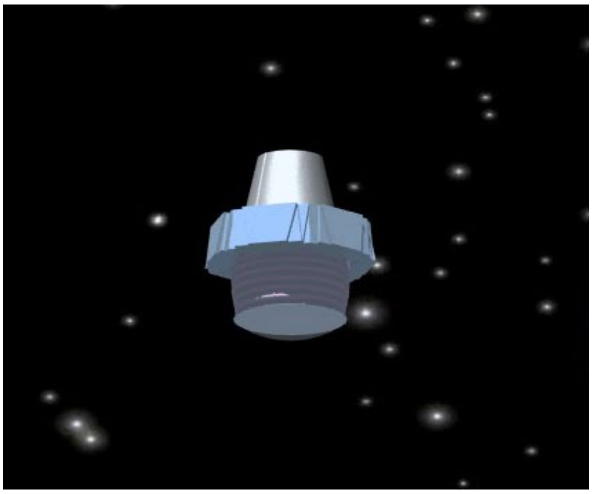

Fig. 3.3 Attach Lower Petals

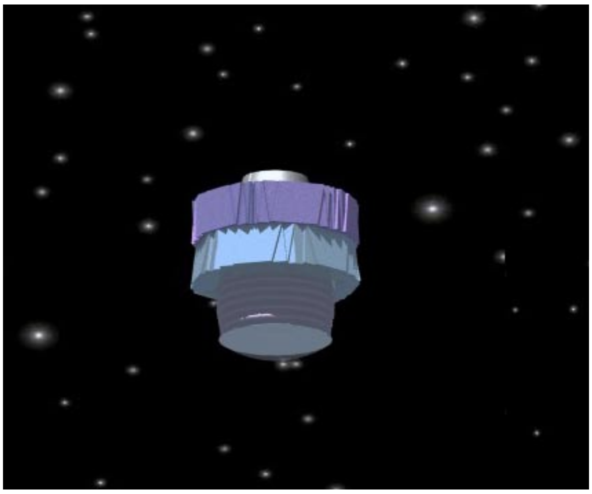

Fig. 3.4 Attach Upper Petals

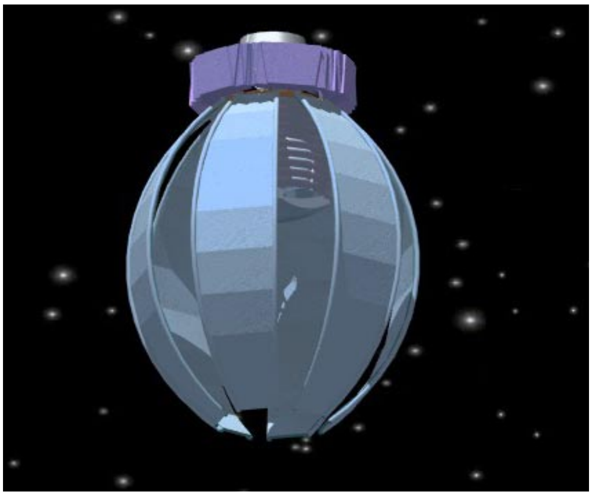

Fig. 3.5 Deploy Lower Petals

Fig. 3.6 Deploy Upper Petals

**Figure 3, BASE II, Deployment** VOLUME 700 $M^3$

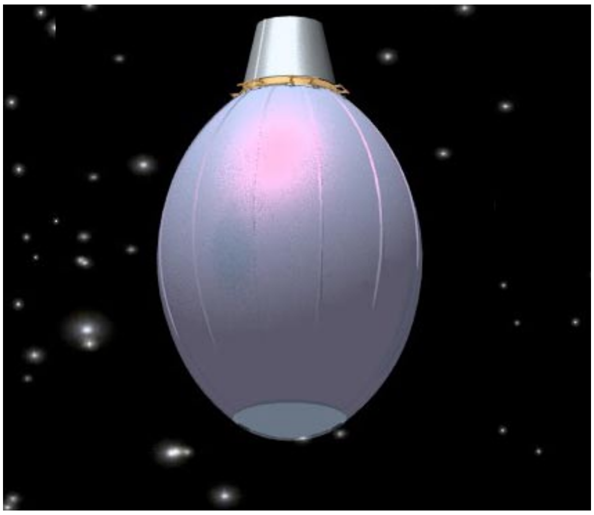

Fig. 3.7 Deploy Inflatable within Petals

Fig. 3.8 Base II Complete

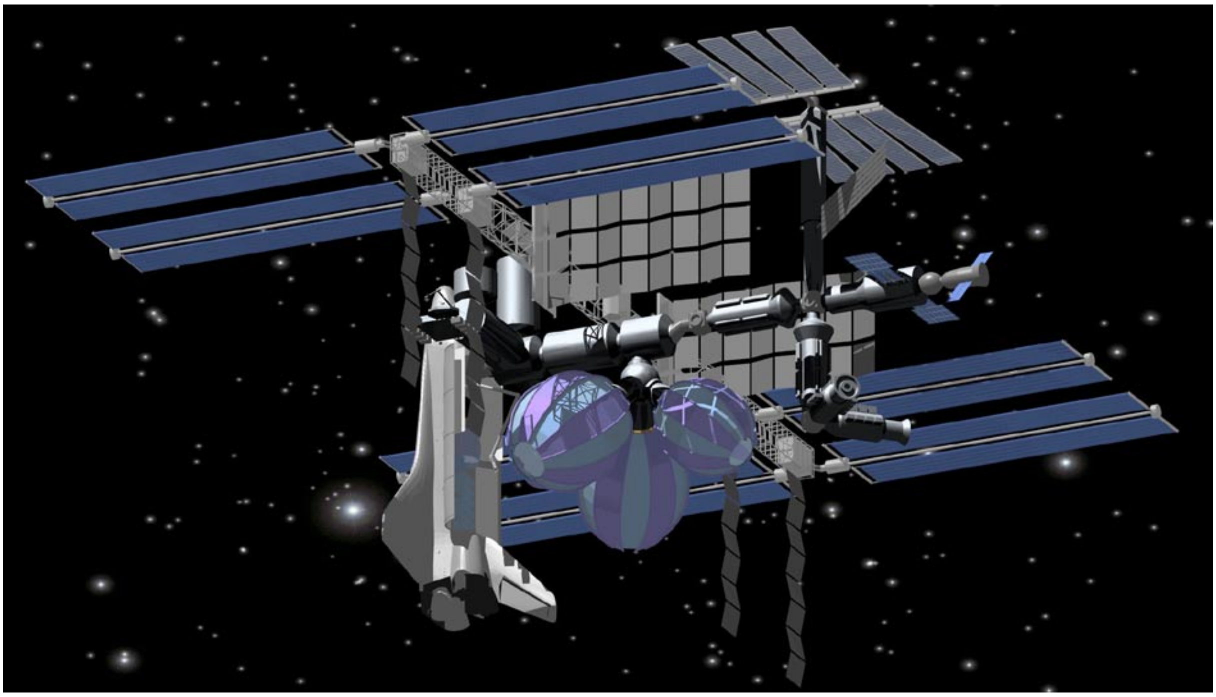

Fig. 3.9 ISS Attachment Site

Figure 3, BASE II, Deployment VOLUME 700 M$^3$

## V. Research & Recreational Environments

Transhab follows a perfectly valid and efficient configuration for its interior space planning. The 7.6M diameter by 12.2M tall torus is compartmented into 3 habitable levels (Galley + Wardroom, Crew Quarters and Crew Health Care).

In considering the space planning of Base II, this paper explores a configuration that tries not to completely compartmentalize the volume. Working surfaces are configured like floating elements within the excitement of experiencing a larger volume. Compartmented spaces must also be considered (for say personal and service units), and these would be incorporated along the central stem structure.

Figures 4 and 5 illustrate a Research Configuration; a modular carbon fiber structural stem is erected after the envelope has deployed, extending from the docking segment through the center of the volume, connecting to the rim of the Iris window at the other end. Modular experiment racks extend radially from the structural stem (also containing services distribution). For the 10M diameter volume, a radial arrangement of 4, 5 and 6 walls were tested. The 4 wall arrangement seemed to underutilize the space, and the 6 wall arrangement made the 60 degree habitable segments slightly too narrow at the base for back to back movement of 2 astronauts interfacing with the experiment racks. The pentagon arrangement of 5 radial walls achieved a good balance between efficiency (41.25 cubic meters of experiment rack space) and free and unhindered movement of astronauts. The radial walls occupy the central zone of the ellipsoid, all having a dynamic orientation towards the Iris window, offering views of the earth and stars beyond. A circular seating frame, accommodating meetings and science write-up is poised directly underneath the Iris window - visual connection to the outside world. A micro-g life science research zone wraps round the stem near the docking end of the module.

Figure 6 illustrates a Recreational Configuration, with a possible application as an ‘acrobatics’ arena (as expressly desired by the Skylab crews), or a ‘space sports’ or ‘dance performance’ arena to entertain future space tourists. The object of the exercise is to create a completely open interior volume for these activities to take place. Whether on Earth or in space, an audience will continue to surround the spectacle in the middle. For this reason the central stem shown in the research configuration is replaced with a perimeter light weight skeleton in carbon fiber, in the pattern of connected ‘hoops’ (offset from the pressure bladder and separated from it by a protective fire proof cloth). The entire assembly is comprised of ‘stick’ components that can be passed through the main access hatch (3 tubular sticks forming each triangular region between the hoops). Inflatable ‘lily pads’ on stems are attached radially to the perimeter skeleton, each lily pad seats 6 to 8 people, in a reclined position, all orientated towards the center of the arena. Of course safety considerations relating to emergency evacuation and capacity of life support systems etc will limit the permitted maximum audience size (an area for future research). At this stage, the author simply wants to test the ellipsoid volume as a possible public performance / assembly area. For smaller group events, engaged in sports or acrobatics, the surrounding soft lily pads double up as surfaces to rebound off or grab hold of.

The next exercise will examine how BASE operates as an in-orbit R&D ‘workshop’ containing capsule mock-ups and centrifuges relating to future interplanetary missions.

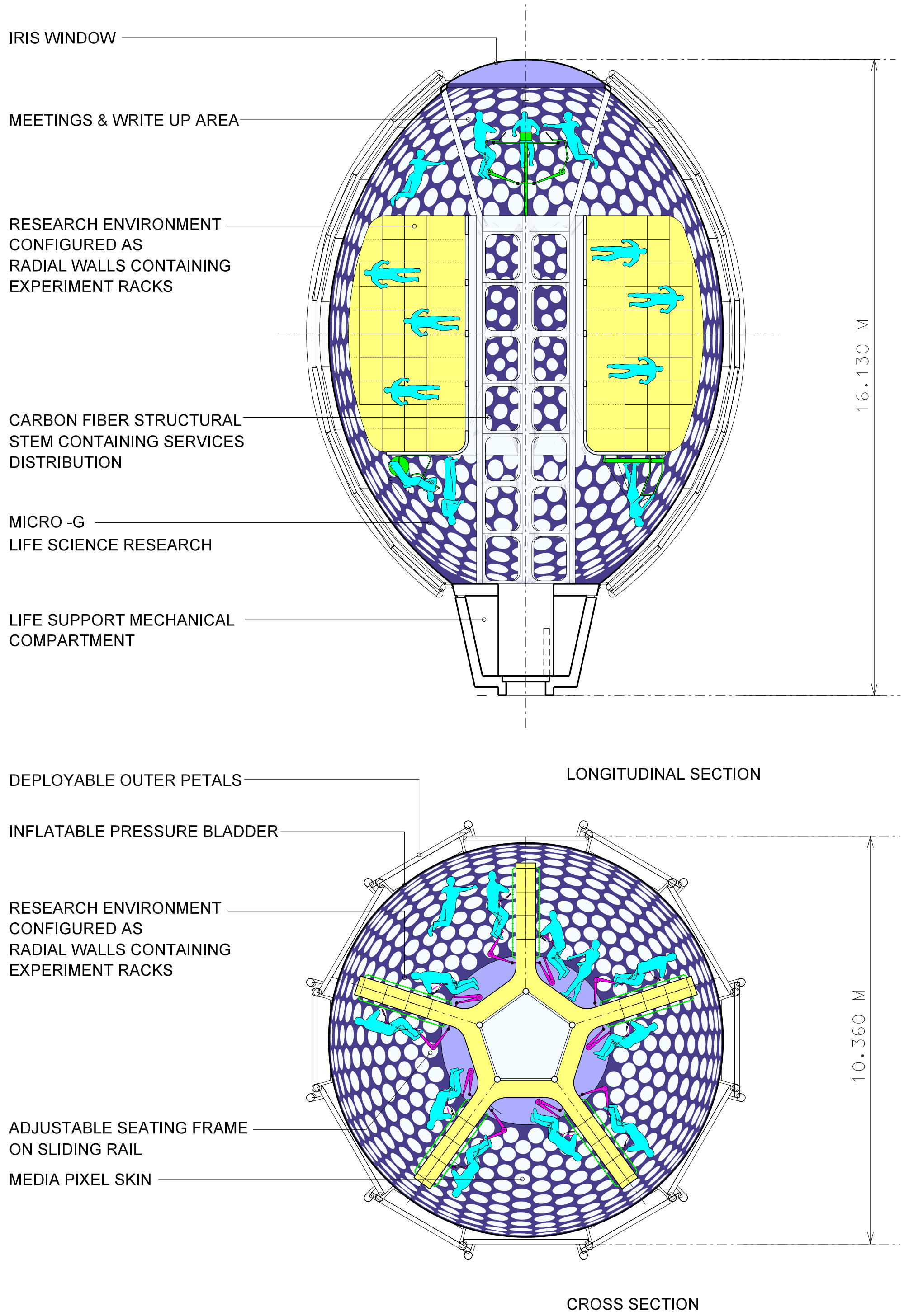


Figure 4, BASE II, Interior Planning,Research Configuration

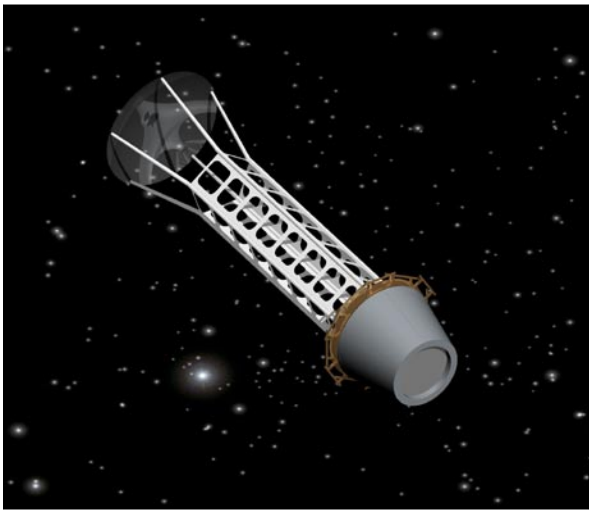

Fig. 5.1 Structural Stem

Fig. 5.2 Radial Walls

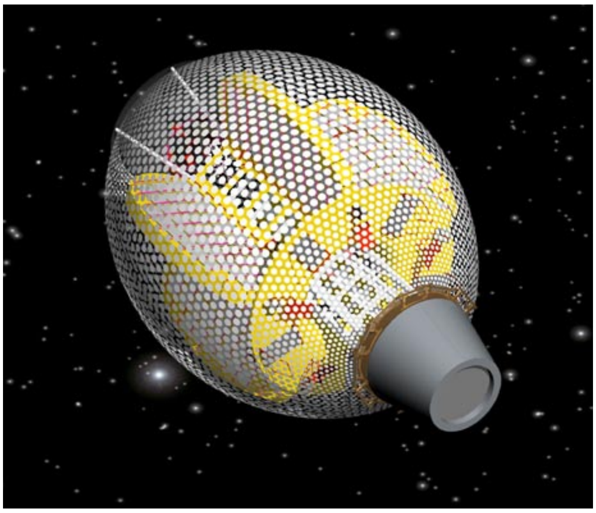

Fig. 5.3 Media Skin Pixels

Fig. 5.4 Interior View

Figure 5, BASE II, Interior,Research Configuration

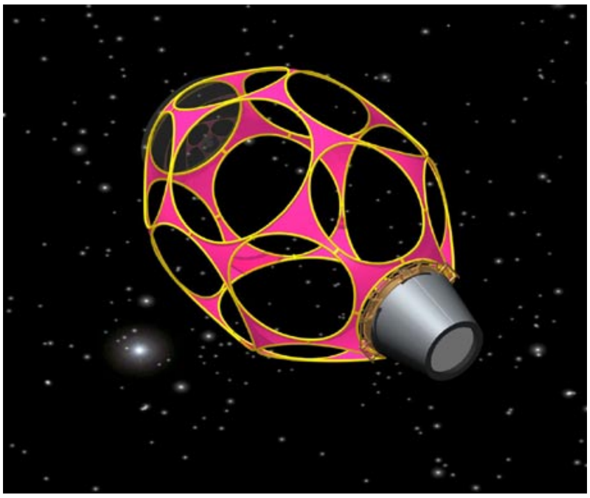

Fig. 6.1 Perimeter Skeleton

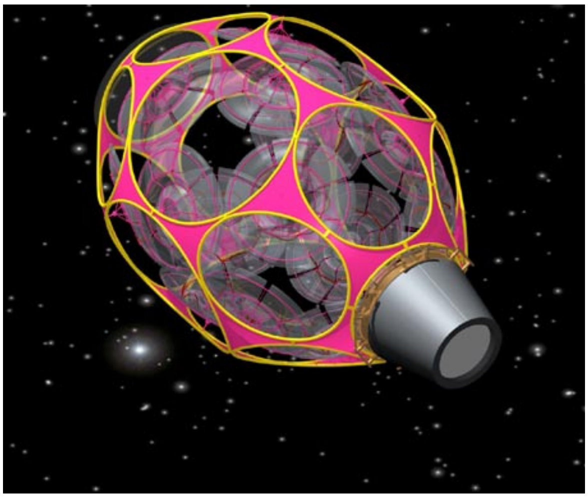

Fig. 6.2 Perimeter Seating

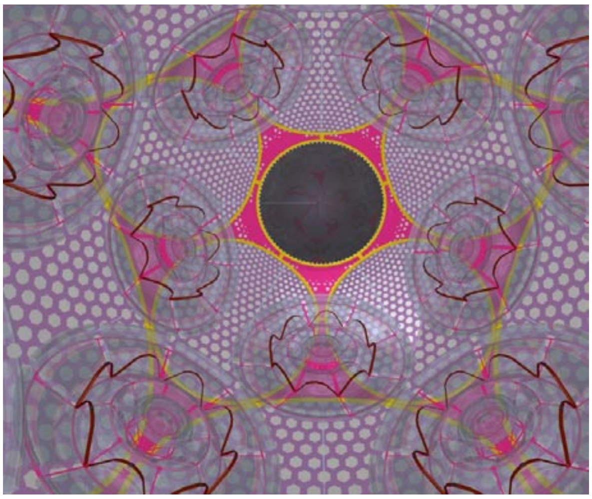

Fig. 6.3 Interior view

Figure 6, BASE II, Interior,Recreational Configuration

## VI. Conclusion

This paper begins with the premise that it is reasonable to anticipate that in time, designs for microgravity will include remarkable bubble enclosures, that offer new experiences beyond the 'extruded' enclosures we see today. BASE – Bubble Architecture Space Environments, explores and appraises some possibilities for inflatable enclosures, assigning a value to the 'quality' of the spaces formed within.

If one is an advocate of continued human exploration of space, and if we are to move from short term to long duration missions, and if space is to be opened up to space tourism, then getting a better understanding of the factors affecting human psychological wellbeing becomes paramount.

The history of civilization is said to be a history of celebrating the visual arts, it is what make us human. So why should it be any different as civilization ventures into space? That is to say, in time greater acknowledgement is given to the 'function of beauty'. That an environment rich in sensory inputs actually addresses our basic fundamental need for an emotional sense of wellbeing, leading to greater efficiency in carrying out the tasks at hand, especially applicable to the isolated conditions of an extreme environment.

In assessing the 'quality' of the interior living spaces, this paper investigates the link between a sensory rich environment and notions of ephemeral design (changing / interactive environments).

More inventive and experimental bubble architecture is appearing across our globe, from large scale environments in a landscape, such as the 'Eden Project' in Cornwall in the UK, to smaller pod objects animating our cities. BASE explores how to translate the sense of excitement generated by these objects into new environments for research and eventually space tourism.

Visualization:
In considering how to achieve larger volumes, this paper concentrates on an inflatable technology. A double skin approach is looked at, offering advantages over integrating all functions into one less flexible skin. A solution evolves combining an inflatable bladder protected by deployable 'flower' petals. An ellipsoid geometry emerges as the common form both layers can conveniently deploy into. Two versions, BASE I and BASE II are illustrated:

BASE I : deployed volume 360 cubic meters, ellipse major axis 11.5M, ellipse minor axis 8M
BASE II: deployed volume 700 cubic meters, ellipse major axis 14.3M, ellipse minor axis 10M.

BASE I has outer protective petals attached, prior to launch, fitting within a cargo envelope of 4.3 M diameter, suitable for a carrier such as the space shuttle or other vehicles listed in Table 2. By scaling up the ellipsoid by 25% to create BASE II, the volume is nearly doubled at 700 cubic meters. BASE II pre-deployed inflatable fits within a cargo envelope of 4.3M diameter, however, in achieving a larger deployed volume, the outer protective petals are stowed separately and attached in-orbit.

Delivery to Orbit:
The payload is tested using the space shuttle as delivery vehicle. Table 2 lists alternative vehicles with a similar payload envelop, range and lifting capacity.

Sensory Environment:
As we move towards sustaining a long term human presence in space, it is essential that new ways are found to interact and stimulate the senses within encapsulated spaces. BASE explores the concept of transforming the inside of the enclosure into a media skin providing sensory input.

Next Step Technologies:
BASE looks towards the integration of existing technologies – inflatable membranes, structures and deployable Solar arrays.

Illustration:
Attached to the ISS, the deployment of BASE II will be further investigated using computer animation. This will also capture movement through the interior spaces, illustrating research, recreational and workshop configurations.

| LAUNCH VEHICLE | PAYLOAD ENVELOP / PAYLOAD FAIRING | PERFORMANCE | PRINCIPLE USES |
|---|---|---|---|
| Space Shuttle Orbiter<br>US (1981 – 2010+?) | Cargo Bay:<br>4.57M diameter x 18.3M long | LEO: 24,990 KG<br>(OV - 103/104/105) | US manned missions to beyond 2010, payload delivery to LEO, ISS assembly & servicing. |
| Ariane 5<br>European (1996) | Payload Envelop:<br>4.57M diameter x 12.7 or 17M long | LEO: 18,000 KG | Future convergence with ISS activities (ATV), payloads to GTO, sun synchronous orbit, lunar transfer, shared GTO mission. |
| Atlas V, 500 series<br>US (2003) | Payload Fairing:<br>5.4M diameter x 20.7 or 23.4M long | LEO: 20,520 KG | Delivery of single or double payloads to LEO or GTO. |
| Delta IV, heavy<br>US (2004) | Payload Fairing:<br>5M diameter x 19.8M long | LEO: 21,892 KG | Delivery of single or double payloads to LEO or GTO / GEO. |
| Titan 4<br>US (1989) | Payload Fairing:<br>5.09M diameter x 23.2M long | LEO: 21,900 KG | Large military payloads to LEO, GEO, sun synchronous orbit, NASA deep space launches, no plans for commercial use. |
| Ares V CaLV<br>US (2017?) | Payload Envelop:<br>7.47M diameter x 12M long | LEO: 124,340 KG | Large payloads to LEO and the moon. |
| Table 2, Alternative Payload Delivery Vehicles | | | |

Table 2: BASE has been sized to fit within the Space Shuttle's cargo bay, on which there is considerable data available. Following the Columbia tragedy in 2003, and after a long safety review period, the Space Shuttle has returned to service (Space Shuttle Discovery, STS 121). However, there is a critical backlog of payloads waiting to fly, increased pressure to finish the ISS and a desire to end the Shuttle program early. Reliance on the Shuttle as a medium or long term delivery vehicle is therefore not feasible. Table 2 compares a number of alternative delivery vehicles with payload capabilities similar to the Space Shuttle - payload envelop and mass delivered to low earth orbit. Medium term options could be Ariane 5, Atlas V (500 series) or the Delta IV heavy lift vehicle. A long term option could be the proposed Ares V cargo lift vehicle (2017). This preliminary investigation simply demonstrate that the required payload envelop of BASE II (4.3M diameter x 14M long) can be transferred to other vehicles. Obviously, If the ISS is considered to be the host for BASE, then a different solution for ISS rendezvous and attachment would need to be developed for each scenario.

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