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DESIGN CONSIDERATIONS FOR EXTERIOR AND INTERIOR CONFIGURATIONS OF SURFACE HABITAT MODULES

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ABSTRACT

Planning for long-duration lunar and Mars exploration missions must provide appropriate human support accommodations to optimize crew comfort, health, morale, performance and safety. This paper presents considerations and concepts for the exterior and interior architectures for lunar and Mars surface habitat modules. The paper addresses two general types of habitat structures: vertical and horizontal. Both types have strictly constrained diameter and length dimensions which must comply with Earth launch vehicles, landing limitations and surface mobility restrictions.

Interior configurations discussed in the paper are based upon a design approach utilizing "inflatable" soft pliable laminated wall structures that can provide large multi-functional interior spaces. A special "pop-out" design concept enables floors and utility interfaces to be pre-integrated in a manner that avoids complex and time-consuming construction on the lunar/planetary surface.

Both of these construction types offer special advantages, and also impose special planning considerations to optimize benefits. Goals are to maximize habitability, crew safety, spatial efficiency, functional versatility and EVA access/egress from the surface. Illustrative concepts are presented showing examples of interior layouts, functional areas and equipment systems.

INTRODUCTION

This paper analyzes vertically and horizontally oriented types of modules that might be considered for lunar and Mars surface applications. Included are conventional "fixed" volume modules, horizontal telescoping "hard modules", and vertical "soft" modules with pliable/foldable sections. Evaluation of these module types is based on potential volumetric capacities, pressurization, surface transportability, growth configurability and outside viewing. Representative schemes are also compared on the basis of equipment mass capacities related to module volumes and useful functional volume capacities. Summary recommendations identify and illustrate recommended schemes for further development.

SICSA has investigated several basic design approaches for creating pressurized surface habitats for Moon or Mars surface applications. These schemes included fixed volume conventional module types similar to modules used in previous international space applications. They can be horizontally or vertically oriented on the surface.

Other examined approaches include modules with telescoping or "inflatable" sections. Telescoping modules expand deployable volume and enable some pre-integration of the equipment and utility systems but such benefits are limited. Inflatables optimize biometric benefits since capacity rapidly expands as a function of diameter. However they also present many challenges. Included are complexities related to envelope stowage and deployment, a reduced capacity for landing with equipment, and the necessity of equipment/utility relocation, outfitting and checkout by surface crews. All expandable schemes present special pressure seal requirements to prevent atmosphere leaks.

Each scheme affects other important design and operational considerations, and is influenced by specific mission tasks and priorities. Examples are inherent differences in requirements for surface landing shock mitigation systems, surface relocation and site configuration possibilities, outside viewing implications, and various operational setup procedures.

KEY DESIGN CONSIDERATIONS

To choose most efficient and appropriate exterior configuration many factors must be taken into considerations, including are: lander types, crew support and mission requirements, equipment needs, and volume/mass of consumables. Impacting factors include nutritional and food preparation influences, radiation protection strategies, characteristics and capabilities of selected ECLSS systems to recycle water and wastes, and many other issues.
Selection and design of any surface module will greatly depend on the means by which it will be landed, transported and deployed on the surface. Factors like risks of damage by surface ejecta from thrusters during landing, the module footprint and its center of gravity influences how it can be moved on the surface. The distance between module living areas and the surface below affect EVA access and egress expediency.

LANDER TYPES INFLUENCES

Three different lander design approaches have been investigated in previous SICSA studies. Figure 1 represents applicability of these lander types to different types of modules [1].

TYPE OF LANDER / TYPE OF MODULE	HORIZONTAL BELOW	VERTICAL BELOW	HORIZONTAL TETHERED
CONVENTIONAL HORIZONTAL	APPLICABLE	NOT APPLICABLE	APPLICABLE
CONVENTIONAL VERTICAL	NOT APPLICABLE	APPLICABLE	CAN BE USED WITH ADJUSTMENTS
TELESCOPIC HORIZONTAL	APPLICABLE	NOT APPLICABLE	APPLICABLE
INFLATABLE VERTICAL	NOT APPLICABLE	APPLICABLE	CAN BE USED WITH ADJUSTMENTS

Fig. 1: Lander Types Applicability to Different Types of Modules.

Based upon comparative assessments, SICSA recommended that use of tethered landers located above either vertically or horizontally-oriented modules/payloads be given special consideration:

- They offer versatility, enabling the same basic system to be used for either vertical or horizontal payloads, including habitable inflatable and conventional modules, logistics carriers, and crew descent/ascent/Earth return vehicles.
- They enable soft landings of vulnerable and costly elements, avoiding free fall damage to fragile pressure hulls and equipment/interface that will be critical for life safety and operational reliability.
- They can afford a symmetrical thruster footprint for landing stability, and can readily accommodate pattern configurations for 1 or even 2 engine-out failures.
- They can minimize or avoid ejecta ballistic hazards to payloads and nearby facilities by placing thrusters higher

above distances between site facilities to be considerably reduced in comparison with other options, minimizing surface transport requirements and thruster/EVA times.
- They can place habitats and logistics carriers directly on the surface, facilitating EVA ingress/egress and rover/cargo deployments.
- By eliminating the need to land with payloads, they can minimize the size and mass elements that must be relocated from surface landing areas, to facilitate transport and positioning.
- They can be used in combination with wheeled modules that do not require lifting and positioning onto maneuverable carriers that would involve special cranes or other complex devices and operations for mounting/de-mounting.

SURFACE MODULES CONFIGURATION CONSIDERATIONS

Comparing different module types on the basis of ease of surface transportability and deployment following conclusions [2, 3] were made:

- Horizontal conventional modules require long carriers or wheel bases which may present difficulties on uneven/rocky surfaces.
- Vertical conventional modules in spite of their compact footprint may be unstable on a rocky/hilly terrain during surface transportation.
- Horizontal telescopic modules may present the same problems as horizontal conventional modules and may also present deployment extension difficulties.
- Vertical inflatable modules present manoeuvrable compact footprint but may be unstable on an uneven/rocky surfaces.

Module types can be also compared by configuration and growth possibilities:

- Conventional horizontal modules can have attachment points varied according to requirements.
- Vertical modules have limited possibilities and will require long transfer tunnels.
- End connections are standard for telescopic modules and axial connections can only occur at telescoping sections, which will reduce the module diameter in these areas.
- In vertically oriented inflatable modules connections are limited to hard shell sections and will require long transfer tunnels (or additional hard modules) between these areas.

The reference patterns presented in figure 2 show two geometric pattern approaches, both providing surface access/egress through suitlocks in the horizontal modules.

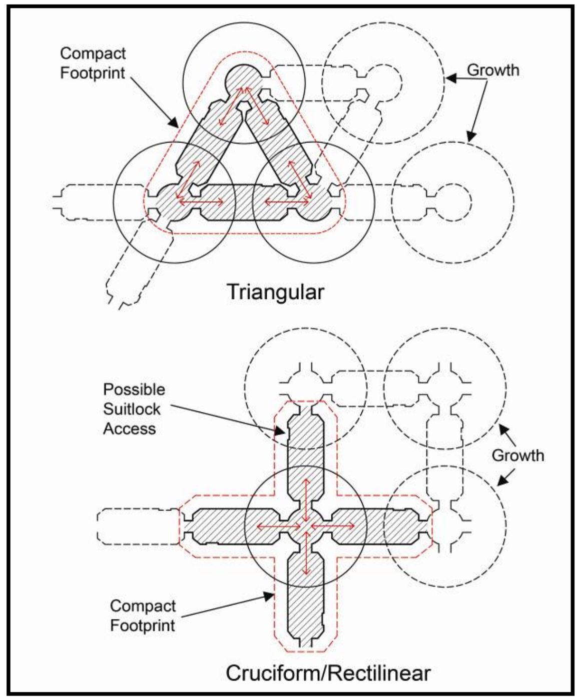

Fig. 2. Module configurations.

The triangular scheme offers such advantages:

- A very compact footprint around the inflatable module support bases minimizing site surface preparation requirements.
- Loop egress is achieved with 3 inflatable modules assembled together.

But this scheme may require more complicated assembling operations and it also presents limited growth variations.

The cruciform scheme also offers some advantages:

- The deployment footprint around the horizontal module is quite small, limiting site preparation.
- The scheme can begin as a cruciform and evolve into a closed-loop plan.

Disadvantage of this scheme is that a dual egress is not achieved until 4 modules are in place.

Combination of horizontal conventional and vertical inflatable modules introduces special advantages of each type (Figure 3):

- EVA access/egress can be provided by suitlocks in each horizontal module.
- The cruciform plan could later be expanded into a closed-loop racetrack.
- Inflatable module greatly increases crew living/working volume.
- All modules have direct connections for emergency egress.
- For module commonality this approach applies 2 module types, each with important functional support benefits.
- Configuration can extend lineally and possible replicate.
- Has a small boundary for level site requirement.
- Does not impose a requirement for more than 2 modules/launches prior to operational configuration.
- Conventional modules with wheels are aligned to interface at a single point.

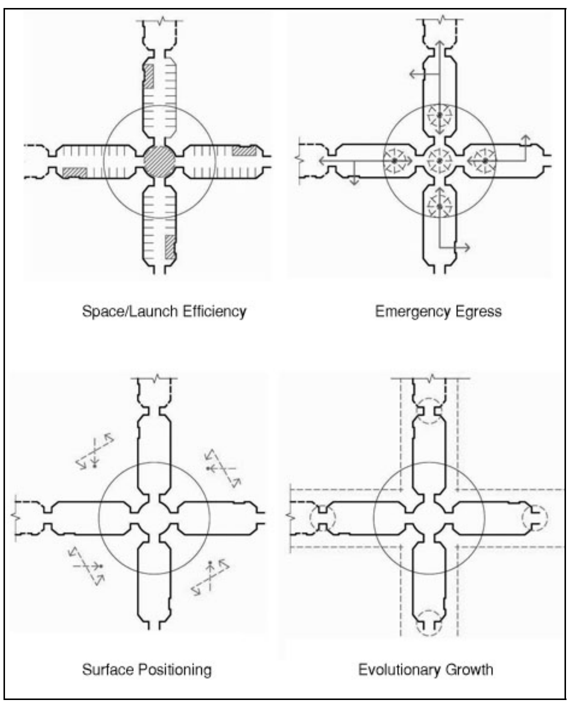

Fig. 3. Considerations for cruciform configuration.

INTERIOR DESIGN CONSIDERATIONS

SICSA has explored interior arrangement options for different surface module types described in the previous chapter. Key factors include volumetric characteristics, outside viewing possibilities, pressurization features and equipments/utilities arrangements [3, 4].
Following figure 4 highlights basic interior design concerns for each of the general concepts that have been investigated.

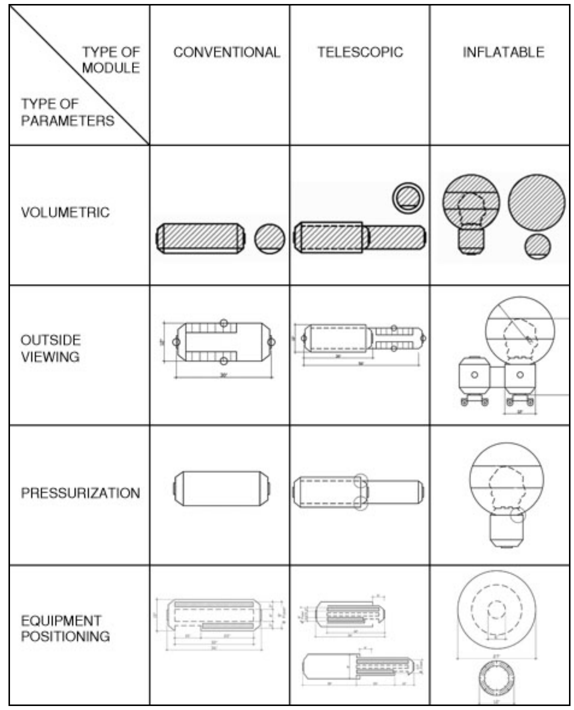

Fig. 4. Interior design parameters.

Volumetric characteristics for different module types are very important for surface module class selection:

- In both types of conventional modules all equipment can be pre-integrated before launch.
- Floor area in telescopic modules can expand at approximately 1:1 ratio with a smaller diameter of a telescoping section.
- In inflatable modules area of the inflatable section expands rapidly with increased diameter as a function of r^2.

This comparison demonstrates that the inflatable modules are the most efficient scheme but in case when the inflatable section stowage is inside the hard part of the module, the relatively large deployment opening and stowage containment areas will be likely to consume much of the volume that would be available for pre-integrated or stowed equipment there. Another approach is to attach the stowed inflatable externally, in-line with the hard module, avoiding the need to deploy the inflatable from within. Stowed equipment volume is quite limited by the small circular floor plan, requiring that the other modules be attached to supplement capacity.

Outside viewing is very important issue for tourism applications but it may be limited due to large amount of required equipment and systems placed along the walls, their possible locations vary for different module types:

- Very limited volume and wall space in both types of conventional modules will prevent windows in areas needed for equipment functions. Viewing can occur at end caps.
- In telescopic modules windows only can be located at the end caps and in telescoping section but only in places free from equipment.
- Windows can be placed in hard sections of inflatable modules and on walls that do not have berthed elements. Axially located windows can provide 360 degree viewing.

Secure modules pressurization is a very important safety issue and depends on sealing characteristics between sections, modules and interfaces:

- Both types of conventional modules use standard module construction, which guarantees no pressurization complications.
- Telescopic module requires a hard seal at the mating connection between the two module sections.
- Vertical inflatable module requires only one seal attachment between hard and soft sections to minimize leak and maintenance problems.

Conventional modules apply relatively simple pressure vessel construction that can accommodate proven means to incorporate penetrations and attachments including viewports, suitlocks and hatches. The modules can potentially be pressurized to dramatically increase stiffness prior to landing, an important consideration for massive cylindrical elements that will experience impacts in their weak (horizontal) orientation.

One of the principal goals of design efforts should be to determine the best approaches to safely and efficiently place the most useful real estate on the surface. Various module approaches afford different capacities against total floor area and volume requirements associated with launch and landing systems, mission goals, number of occupants and operations. These capacities will directly influence the number of launches, orbital transfers, landings and surface manoeuvres.

- All equipment and systems of conventional modules are pre-integrated and checkout before launch; that minimizes necessary preparations for operational promptness by mission crews on the surface.
- Equipment and utilities can be pre-installed only in deployable part of a telescopic module, which volume should also be used for temporary storage for equipment of the stationary section and the crew members have to install it on the surface.
- Equipment arrangements issues in vertical inflatable modules are similar to those in telescopic: utilities and systems can be pre-installed only in the hard shell section of the module and extra installation work is required for the inflatable part.

Conventional “hard” modules afford good pre-integrated equipment capacity along with design simplicity using proven systems. This will be of particular importance for early surface missions to enable rapid operational implementation with the least amount of crew set-up time.

Modules with “inflatable” large diameter sections can offer substantial interior volumes, particularly suitable for living spaces that can optimize crew comfort and performance during extended missions lasting months or even years. They should be designed to minimize deployment and equipment/utility integration requirements, and may be most practical to implement after crew operations have been established using conventional module(s).

Inflatable modules also offer extra space for crew multi-functional activities providing relief from closed and cramped hard module confinement. This is vitally important for good crew morale and performance which significantly influences mission success and safety.

Guided by the configuration option comparisons and interior design considerations, SICSA selected a reference design that combines use of conventional and inflatable (hybrid) modules for further investigation.

Table I presents proposed structures and materials for possible use for interior elements of the soft part of the vertically oriented inflatable module.

MODULE ELEMENTS	STRUCTURE/ MATERIAL
Floor and partitions supporting structures	Tension cords structures
Floor and partitions material	Textile, stretchable and ligh weight materials
Engineering systems (MEP and HVAC)	Light weight materials, plug-n-play systems
Connection tunnels	Inflatable structures
Furniture	Fabric, stretchable materials
Safety heaven	Hard shell section of the facility
Windows and outside viewing	Hard shell section of the facility

Table I. Structures and materials.

SICSA proposed a special design approach for soft sections of inflatable modules. The system includes tension ring supporting floor structure with a web of tension cords for interior partitions installation. It offers benefits of self-deployable light weight structures that contribute less to launch mass and require minimum of crew time for assembling when already on surface. Figures 5 and 6 illustrate special elements designed for "pop-up" type of floor structure with a tension ring interface, attachment of internal partitions to tension cords, inflatable/hard shell interface and typical floor configuration with tension cords supporting structure. Figure 7 presents utilities runs incorporated in floor structures, hard shell section interfaces and expandable connecting tunnels attached to additional conventional horizontal modules.

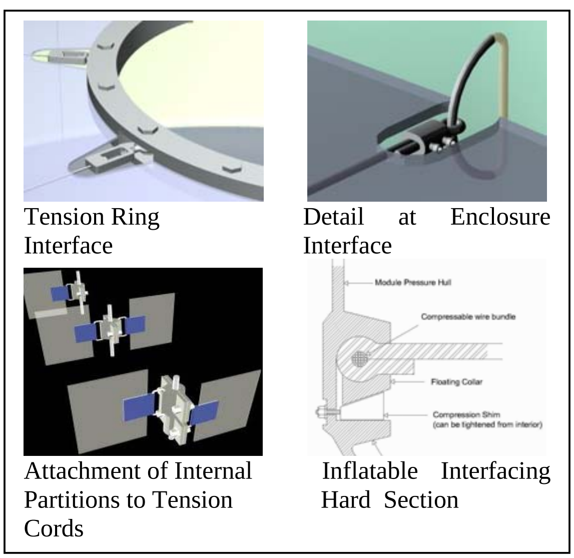

Fig. 5. Partitions and floor details.

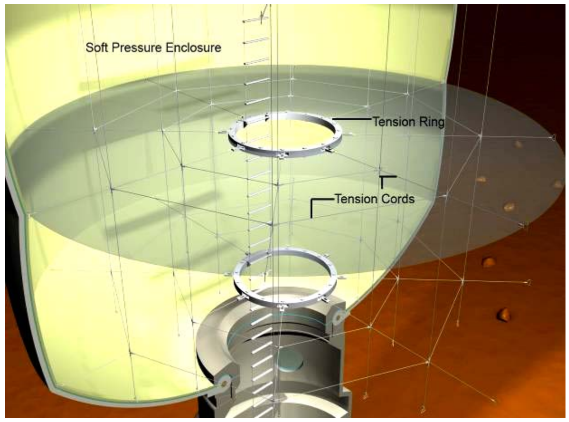

Fig. 6. Typical floor configuration.

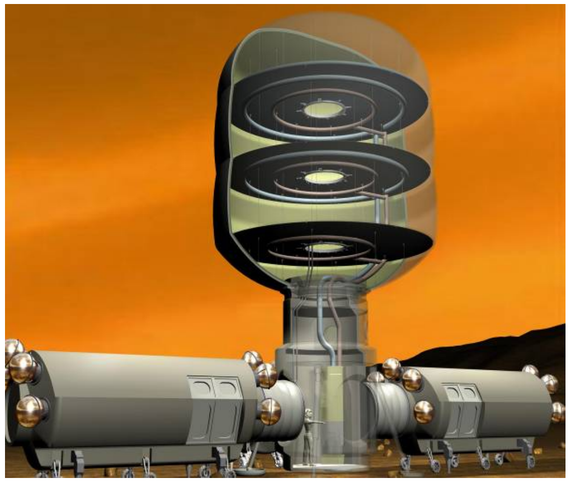

Fig. 7. Utility scheme and hard shell section interfaces.

Illustrations that follow (figures 8 – 12) provide representative concepts to help visualize human scale factors and other important interior dimensional features that may not otherwise be apparent.

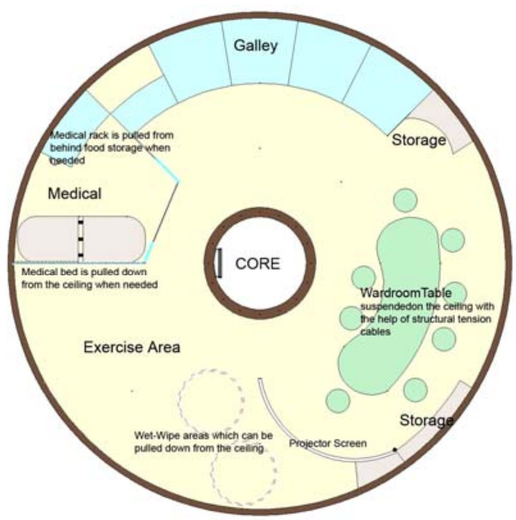

Fig. 8. Inflatable lower level floor plan.

Fig. 9. Inflatable lower level interior view.

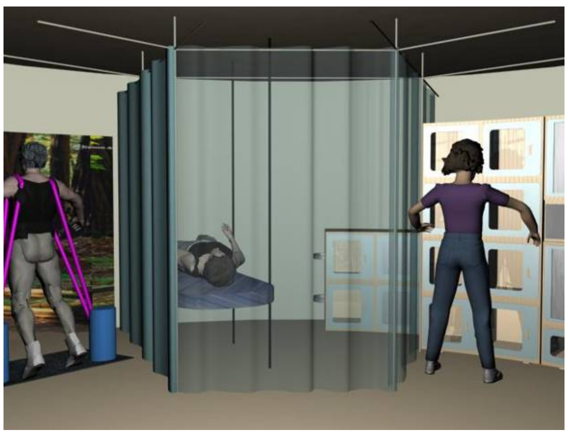

Fig. 10. Exercise and medical area.

Fig. 11. Sleeping area.

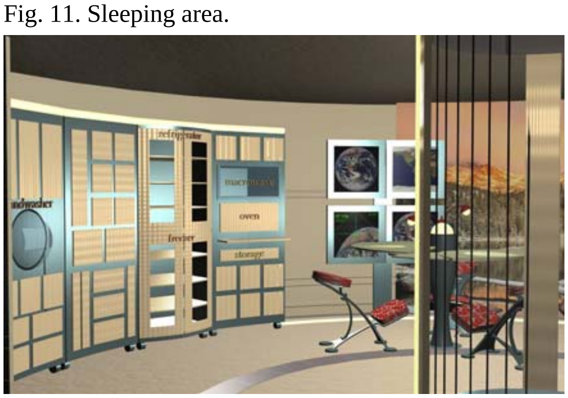

Fig. 12. Galley area.

CONCLUSIONS

A combination of inflatable and conventional modules is preferable over other options because it brings together advantages of large interior volumes of inflatables with means to integrate utilities and equipment systems afforded by conventional modules. The inflatable approach affords a logical means to provide adequate living and work spaces in an efficient manner, and horizontal conventional modules are most suitable for economical accommodation of fixed and stowable equipment systems.

Two variations of this combination can be considered: a vertical inflatable module combined with one long or two short conventional modules; and a horizontal inflatable module in combination with a short conventional module. The first approach is more preferred based on following:

- The vertical inflatable module appears to be the simplest to design and deploy because the soft section can be attached/stowed outside of the hard section. This will make compact folding for stowage less complex than fitting it into the hard section, and will also make evacuation much easier through the top of a module during inflation.
- A short and lightweight vertical inflatable module can be launched along with a lander in a single payload adding payload utilization efficiency.
- This scheme can provide very high site development economies. All space and volume requirements may be achieved, including EVA capabilities and water storage for radiation protection and habitants' consumption.
- It also permits using conventional modules to ship cargo and equipment that can not be carried in inflatables.
- It enables conventional modules to be standardized for use as laboratories and for use as logistics carriers that can be used for lab/hab functions when emptied (excellent commonality functions).
- It can evolve into a racetrack pattern, offering dual egress capabilities.
- It can accommodate separate attachable airlocks, but potentially will not require them.
- It also presents a small footprint minimizing site selection and preparation problems.

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