Designing Tomorrow's Lunar Habitat with Today's Technology

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Abstract

Traditionally, space exploration has been reserved for a select few, highly qualified individuals that undergo specialized training required to complete specific missions. In reality, the average individual is not skilled in every aspect of a mission and every mission does not go according to plan. In the near future, serious thought about what requirements and restrictions are placed on near earth orbit and lunar space exploration will have to become more relaxed in order to expand the realm of space exploration. In order to feasibly create a viable moon habitat that is able to sustain an ever-growing population of eighty-plus occupants, consisting of men, women, and children, we must create a habitat that is accommodating for the occupants. Although each inhabitant cannot be proficient in every aspect of a lunar base of this size, each inhabitant will have or will be actively learning a set of specific skills that will help progress the growth of the community as a whole.

As a community, each individual will need to interact with the rest of the population on certain activities, but also each individual and their families will need solitude from the daily work grind. For these reasons, there are several different recreational elements of the habitat that include:

- Multi-Purpose Recreational Facility
- Exercise Facility
- Cafeteria
- Green Houses
- Crew’s Quarters

This paper will examine the last facility. The Crew’s Quarters is where the habitat’s occupants will go for solitude from the rest of the occupants on several levels. Occupants may retreat to a communal space within the Crew’s Quarters, where they can gather and mingle. For even more privacy, occupants will need personal family accommodations where they will be able to spend time with their family, away from the rest of the community. Furthermore, the individual will need a private space where they can spend time in solitude or a place to sleep. The Crew’s Quarters has space for each level of solitude and provides the average family with their own home. Within that home, each member of the family has their own room. These quarters provide personal down time away from the rigors of daily work that is required of each inhabitant to keep the lunar habitat functioning.

I. PREMISE

In conjunction with the Houston Museum of Natural Sciences, the Sasakawa International Center for Space Architecture (SICSA) is designing a lunar base for use in an interactive virtual environment. The lunar base design will consist of various aspects necessary for a successful lunar outpost including:

- Landing site
- Expanding Habitat
- Energy Generation
- Lunar Research Capabilities
- Closed Loop Life Support System

The moon base should be a feasible, near future design realization and will only consist of proven technology. The product of the collaboration will be used to teach space enthusiasts about essential functions and design aspects of life on the moon.

II. BACKGROUND

The lunar base is a combination of several elements that allow the outpost to operate and grow as a sole entity with minimum to no supporting logistic required. The settlement is nested on the rim of the Shackleton crater at 29.9 degrees south and 00.0 degrees east. The Shackleton crater is 20 km in diameter, approximately 4 km from rim to base, and the sides of the crater may exceed up to 35 degrees. The base of the crater is so close to the South Pole that there is a line of perpetual darkness where light never penetrates inside the crater.

The Shackleton crater provides an abundance of necessary qualifications for a self-sustainable lunar outpost. Using this site, the crew will be able to take advantage of the crater’s terrain and spread its various elements in their appropriate locations along the crater’s rim. The base is comprised of three main elements; the landing site, two solar farms, and the habitat.

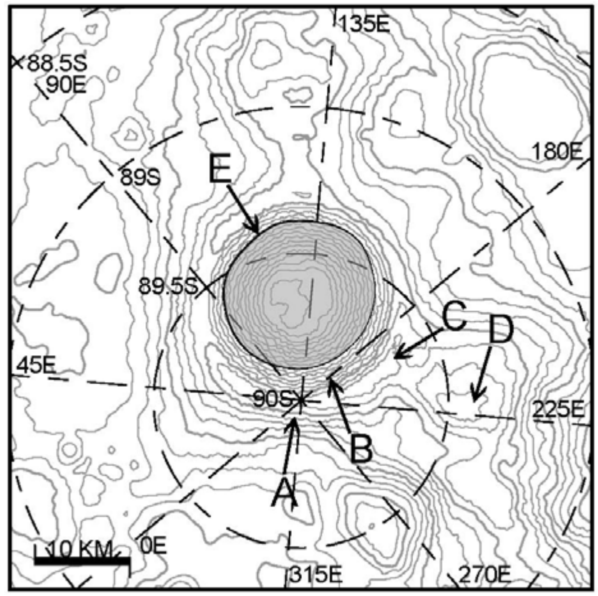

Fig. 1: Diagram of lunar base at the Shackleton crater. (A) Landing site, (B) habitat site, (C) solar array farm one, (D) solar array farm two, (E) line of perpetual darkness inside the Shackleton crater.

The landing site is located on a downward slope, outside of the crater’s rim, so that any debris that is blasted of the surface will not affect the other two sites.

The habitat is located on a downward slope, inside the crater’s rim, approximately 5 km away from the landing site. The habitat will take advantage of this location in a couple of different ways. The habitat design uses a plateau step-down design so the regolith on the surface of the crater will shield the habitat from solar radiation on one side. The proximity of the habitat to the line of perpetual darkness inside the Shackleton crater will give the inhabitants close access to frozen H2O that is presumed to exist at the bottom of the crater, a place the sun has never touched. The same proximity to the interior of the crater will provide useful placement for propellant and other energy sources that require storage at below freezing temperatures.

Planned for the southernmost tip of the Lunar South Pole, the base’s two solar farms, at locations (89.63 degrees south, 166.00 degrees west) and (89.44 degrees south, 141.00 degrees west), will generate power for 94% of a solar year (343 days). The longest time of perpetual darkness the base will endure is two days. During these two days and the other 6%, or 22 days, the solar farms will store excess solar energy, in onsite batteries during peak intensity periods. The solar farms will provide 100% of the energy requirements for the lunar outpost, year round without any external energy or nuclear power source required.

Placing this settlement along the rim of the Shackleton crater will provide for a lunar outpost that is fully self-sustainable. A closed loop system of aeroponics, oxygen regeneration systems, and water regeneration systems will provide the inhabitants with an abundance of food, H2O, and oxygen to sustain a growing outpost of 80 people on the moon.

III. HABITAT

The lunar outpost consists of three main elements to provide a self-sustainable design—the landing site, two solar farms, and the habitat. All elements of the design consist only of existing technology that is either currently in use or has been researched and is applicable to the lunar surface. The habitat is designed using current ISS (International Space Station) type elements as design precedents. There are five typical ISS type modules, two typical inflatable modules and a typical cupola that make up the pressurized volume of the habitat.

An ISS type module is defined as:

"An atmospheric pressurized module of four and half meters in diameter, a length of various dimensions, and a hard shell consistent with M.O.D. Shielding (Meteoroid Orbital Debris Shielding)."

These typical modules are prefabricated as generic elements and can be outfitted for several different functions on Earth and then delivered to the lunar construction site ready to install. The generic modules include:

- Atmospheric-Pressurization Modules
- Lateral Circulation Module
- Vertical Circulation Module
- Core Transfer Module
- Branch Transfer Module
- Habitable Torus Inflatable
- Habitable Mushroom Inflatable
- Cupola

These modules combine to make up a lunar habitat that has occupancy of 80 people and a volume of roughly 16,000 cubic meters.

The master plan of the habitat is designed to branch out along the crater's side wall as the population grows. For occupancy of 80 people the habitat is designed as a core and a series of branches. The core goes from the top entrance to the lower exit in four levels, each level consistent of a series of three Lateral Circulation Modules, four Vertical Circulation Modules with Habitable Torus Inflatables attached to the mid vertical circulation modules, and a Core Transfer Module.

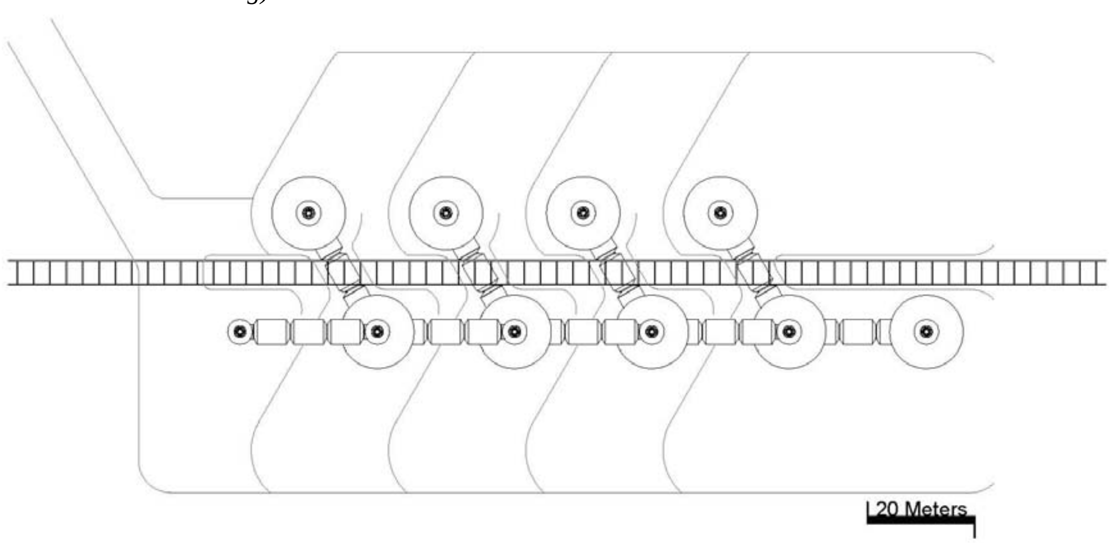

Fig. 2: Aerial plan of the proposed habitat

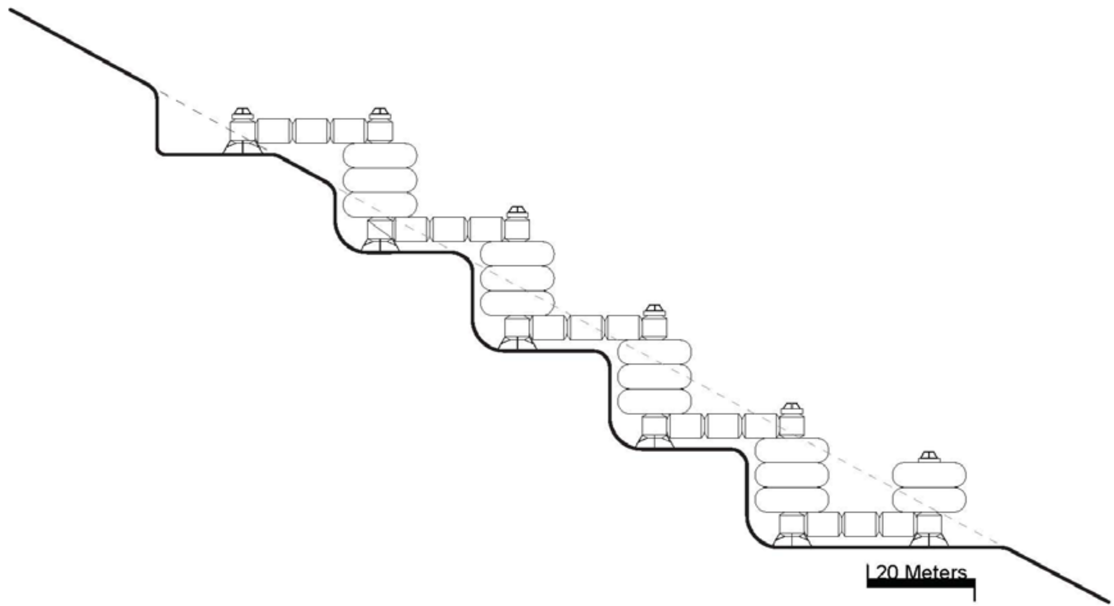

Fig. 3: Cut away view of the habitat elevation showing the core modules.

At each Core Transfer Module the habitat branches out with three Lateral Circulation Modules, a Branch Transfer Module, and one to four Vertical Circulation Modules with Habitable Torus Inflatables attached to the mid vertical circulation modules.

The attachment of the Vertical Circulation Modules and the Habitable Torus Inflatables combine to house various different functions throughout the habitat:

- Medical Facilities
- Fitness Facilities
- Green Houses
- Command Control Facilities
- Research Facilities
- Multi-Purpose Recreational Facility
- Class Rooms
- Cafeteria
- Crew's Quarters

Each of the Facilities presents its own design challenges and shows interesting capabilities in their own right. However, for the purposes of this paper the design of the Crew's Quarters in particular is a complex entity and will be the main focus.

IV. CREW'S QUARTERS

The Crew's Quarters presents a unique set of challenges to the project. The inhabitants will need a place to retreat from the daily grind and will look to their Crew's Quarters as a place they can call home. The lunar occupants will need a place of comfort and solitude that will assimilate the lifestyle of Earth and home.

The overall concept, layout, and programming of the lunar habitat and the Crew's Quarters are comparable to that of Earth. The habitat, as a whole, is equivalent to a city. Within the city, are various duties and tasks that must be performed daily to keep the city functioning properly. After a long work day, most people return to their homes, situated in a neighborhood. Each stack of Crew's Quarters is considered a neighborhood. In each neighborhood, there are many streets with multiple homes on each street, as there are multiple family spaces in each crew quarter module. On each street, there are individual houses and in these houses, there are separate private rooms for each family member. In each crew's quarter module, each family has their own private family accommodations, or "home," and each family member has their own private room in their home.

Design

There are seven crew quarter modules and each accommodates three private family accommodations and one public communal space. Each family accommodation allows public, private, and sleeping spaces for an average size family of four inhabitants.

Each crew quarter module has two main elements--a core module and an inflatable module. The core module is an ISS type module with a height of 4.5 meters and has a floor area of 17.2 m². These core modules provide the main vertical circulation throughout the habitat. In each of these core modules, there is room for six racks that house the various liquid necessities and life support systems for each crew's quarters.

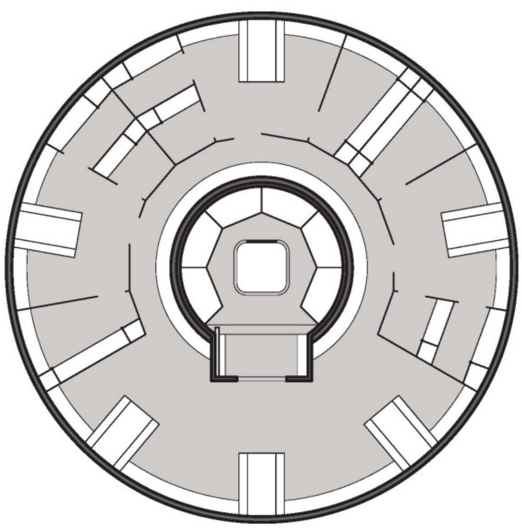

Fig. 4: Floor plan of the Crew Quarters.

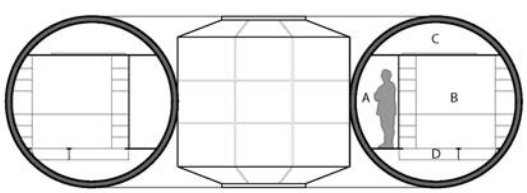

Fig. 5: Section of the Crew Quarters. (A) Central Corridor, (B) Family Space, (C) Sleeping Accommodations, (D) Stowage.

The inflatable module is toroidal in shape and when pressurized, has an inner diameter of 9 meters and a band width of 4.5 meters. Surrounding the hard module like a donut, the inflatable module has a pressurized volume of 471.6 cubic meters and a floor area of 98.7 square meters plus the additional sleeping quarters. Each inflatable crew's quarter module will house the main living, private, and sleeping volumes for each of the moon's eighty inhabitants.

Core Module

The core modules will serve three essential roles in the life of the habitat. First, as the habitat grows to accommodate the population and these modules are stacked on top of each other, these core modules will take on the responsibility of transferring weight from all the attaching modules to the lunar surface. Second, in the basic form of design the core module will serve as the sole form of vertical circulation throughout the habitat and connect the upper levels to the lower levels. The core module's third role will be to provide a galley space to house necessary elements for the well-being of the crew in each adjoining inflatable.

The adjoining inflatable module, where the crew will live, is designed as a simple reconfigurable system with maximum flexibility. This reconfigurable design works well with elements of that module that are easily detachable. However, certain elements necessary to sustain life are not easily reconfigurable and when introduced to this type of application may cause subsequent malfunctions. Rather than allowing these elements to become the defining factor in these inflatable modules, these elements will be placed in the core module to service the occupants of each inflatable.

The core module is designed to have a standard ISS type hatch opening in the center of the module at the bottom and top with a ladder connecting the two. These openings will allow inhabitants to move easily through the vertical segments of the habitat. These standard ISS hatches will also allow easy egress and closed isolation in the event that a module becomes depressurized. Surrounding the centralized hatches is a built up floor to maximize the amount of square meter of walkable area around the lower hatch. The perimeter of the core module will house six standardized rack receptors. These receptors will be populated with the various resources needed by the occupants of the crew's quarter. The resource allocation for these racks will include:

- Hygiene (2)
- Refrigeration and Sink
- Oven/Microwave
- Environmental Control
- Health Monitoring

Each of the two hygiene racks will house a communal restroom and sanitation resources. The refrigerator and sink rack will allow the occupants to hold individual food and drink rations for when they might want a snack without traveling to the cafeteria. The sink will be used for hygiene purposes. To heat up the food rations there will be an oven/microwave rack housing multiple microwaves and one oven. Although the overall habitat's atmospheric control is controlled through the command control module, each crew's quarter will have an environmental control rack to allow slight changes to individual inflatable modules. This rack will also relay pertinent information on each crew's quarter module's atmosphere properties and statistics such as thermal temperature, atmospheric pressurization fluctuation, carbon dioxide and oxygen level, etc. back to the command control center. The health monitoring rack will read all individual's vital statistics currently in the adjacent inflatable and motor the health of each occupant. The rack will then relay any concerning information on a particular individual to the command control center for follow up.

<u>Inflatable Module</u>

Inflatable Bladder

The second half of the crew's quarter module is the inflatable where the occupants will spend their time at the beginning and end of each day, to relax and spend time with friends and family. The inflatable module is prefabricated and attached to the core module on Earth populated with design elements. Then the module is deflated and delivered to the moon site ready for atmospheric pressurization and population.

Utilizing the properties of an inflatable structure allows the habitat to increase livable pressurized volume without jeopardizing the restraints of the current payload lift capabilities. To achieve the same pressurized volume with a non-inflatable the launch system would require a payload diameter of 14 meters. On the other hand, the inflatable shell can be depressurized and deflated during transport and then re-pressurized after installation. The inflatable would fit inside a payload shroud of five meters and would allow for all non-rigid elements to be prefabricated and put in place in a controlled environment on Earth. A rigid structure would require more structure and mass to allow stability of prefabricated elements during transport. An inflatable would require less support and mass elements to achieve more satisfactory results after pressurization.

The inflatable shell is 30 centimeters thick and weighs roughly the same as the exterior of a traditional core module's shell and structure. The shell is composed of 24 sub layers, originally designed for NASA's TransHab inflatable module and designed to breakup debris and meteorites that hit the shell. The outer layers are designed to protect the inner layers that hold in the atmospheric pressure of the module and keep the module's shape. The shell is also designed to provide insulation for the module against the sever fluctuations of the moon's temperatures.

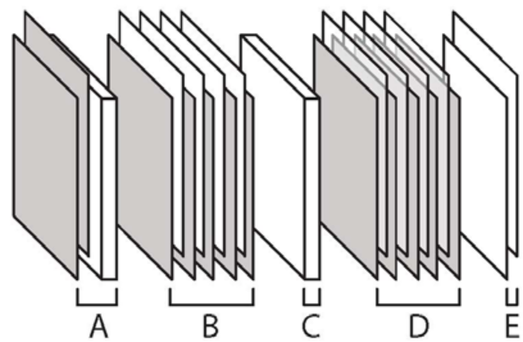

Fig. 6: Inflatable bladder sub layer makeup.

A) Outer Insulation: Blankets and Mylar that make up the outside shell of all ISS modules.
B) Debris Protection: Layers of Nextel cloth separated by foam rubber and Kevlar fabric.
C) Woven Kevlar: Holds the torus's shape after pressurization.
D) Pressure Bladders: Layers of air tight bladder materials separated by layers of Kevlar.
E) Inside Wall: Nomex interior scuff protection cloth.

Floor System

The concept for the inflatable module is a simple deign to allow for maximum flexibility. The main structure for the majority of elements in the inflatable module utilizes a soft, flexible membrane material that allows elements to collapse during transportation and remain ridged when the module is pressurized. The structural support during pressurization for this membrane is a grid of braided steel cables.

When the module is pressurized the inflatable shell will expand until it receives a designated amount of kilogram per square meter across its surface. The steel cables attach to the inflatable bladder and when pressurized the cables will remain in tension, supported by the pressurized force on the shell. The tension force placed on the steel cables will then support the horizontal and vertical soft membrane material. The floor grid is replicated approximately 2.5 meters vertically to create a ceiling grid that is held in tension in the same fashion.

With these two elements we have created an open space that has a structural floor and open volume ceiling. In each of these systems, there is an intersection through the cable grid as the radial and circular cables meet. These intersections allow for placement of a multi-directional attachment point. At each of these points the system has the option of adding vertical steel cables. When steel cables are attached at designed intersections and then a membrane is attached to these cables, a privacy wall is formed. Using this tension cable system, the inflatable module is designed to allow for multiple private spaces for three families and one common public space. This system also allows the inhabitants to have maximum flexibility and personalization of their module. If the inhabitants become tired of their surroundings, they are able to detach the vertical elements from their supports and redesign the space to accommodate their needs.

Communal Space

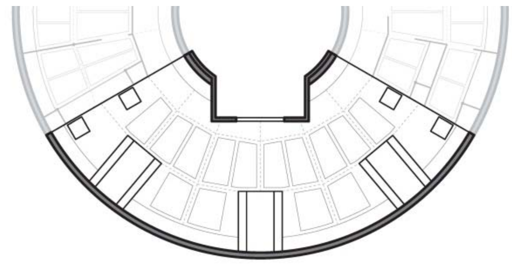

Fig. 7: Floor plan of Communal Space.

The first area that an occupant will enter in the inflatable module is the communal space. This space is open to the public but is only capable of holding a limited amount of people. If the occupants wish to congregate in a large group, they have different options of either the multi-purpose recreational facility located at different branches in the habitat or the cafeteria. The commons space provides the occupants a smaller, more private setting inside the habitat.

Space Properties:

Accessible from:
Core Module

Allows access to:
Family Accommodations

Area:	32.3 m²
Ceiling Height:	3.4 m
Occupancy Load:	18 people
Stowage Area:	11 m²

The communal space is an open design; there is no ceiling and no walls separating the space. There are three picnic table style sitting areas that allow for groups to sit and talk, play games, or other leisurely activities.

At these tables there are two bench seats and a flat table surface between them, which reassembles that of a picnic table. Each picnic table is six feet long and extends inward from the outside inflatable wall. The structure of the picnic table works in the same idea as the floor and wall systems. The two benches and table are made up of the same soft membrane material that is used for the walls and floor. These elements use the same tension structural system and are held in tension through the same steel cable system that is tied into the floor and ceiling tension systems. This tension system allows each table to be preinstalled on Earth, deflated, delivered to the habitat, and becomes structural after the module is re-pressurized. This type of element also works with the flexibility of the modules and allows for each table to be removed if more space is required.

Family Accommodations

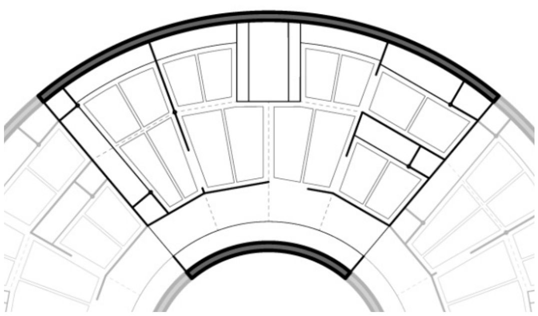

Fig. 8: Floor plan of Family Accommodations.

On either side of the communal space, along the inner radius of the inflated module, there is a central circulation corridor that allows access to each private family accommodation. Each private family space is thought of by the inhabitants, as a home away from their daily work duties. These family spaces are comparable in design to the homes on Earth. There is a living and dining room, a master bedroom, and two individual rooms. This type of home on the moon is equivalent to a three bedroom two bath house arrangement on Earth. Using the flexibility design of the structural system in this module the occupants are able redesign and rearrange certain elements to fit different living circumstances.

Space Properties:

Accessible from:
Communal Space

Area:	19 m^2
Living Room:	9.5 m^2
Master Bedroom:	4.75 m^2
Individual Rooms:	4.75 m^2
Ceiling Height:	
Living Room:	3.4 m
Master Bedroom:	2.6 m
Individual Rooms:	2.6 m
Occupancy Load:	8 people
Stowage Area:	14.8 m^2
Living Room:	8 m^2
Master Bedroom:	3.4 m^2
Individual Rooms:	3.4 m^2

Through the central corridor, each of the three family accommodations has a private family living room that allows the occupants of that family to congregate with each other in private. In each living room there is a bench style table of the same design as the three in the communal space, and a hard rack module for storage of common family items. The living room is designed for a family to hang out and spend time together before and after each work day much like a family room in a house is used. The occupants will wake up in the morning and share a common meal before heading off to their work duties. After the long work day the family is able to come back to their home and sit around the dinner table and share their experiences of the day. Following the same design philosophy as the communal space the ceiling is left open. Leaving the structural cables bear will allow the occupants a private, spacious area to come and relax, watch a movie, and spend time with family.

When an occupant needs time to themself, there are two private areas on either side of the living room. There are two types of rooms that fit into this design, a single room and a double room. The single room is for a single person, either child or adult. The double room allows two individuals to occupy the same room. The main allocation for this room is designed for two married individuals to share the same room. Although this is the designed use, the flexible design of this system may accommodate for different combinations such as two children or a child and a parent.

Using the flexible design of the module the family accommodation is able to accommodate multiple arrangements of living situations. Although the average family accommodation is designed for two parents and two children, this flexible design may accommodate for:

- One family of two parents and two children
- Two adult couples
- Two families of one parent and one child
- Four individual adults

For each of the arrangements, the occupants can choose from individual room arrangements to accommodate their needs.

The single room is designed to fit the needs of a child or an adult. The room is outfitted with multiple cable attachments on each of its membrane walls, to allow for a collapsible desk and shelving element. The desk will provide a place for the occupant to sit and use a computer, read a book, use a sketch pad, or various other tasks that require a stiff flat surface. The shelves are used for traditional storage of items that may need to be quickly accessible to the occupant. If the individual has no need of this element, it is quickly detachable and folded for easy stowage.

The double room accommodation will house the same type desk element. However, the double room desk element will be twice as long and have two shelves on either side of the desk to accommodate for the requirements of two people.

Each of the rooms does require a flexible membrane ceiling element to allow for individual sleeping quarters above the room areas. To get to this area the ceilings will have pre-cut passage ways tailored into the membrane.

Sleeping Quarters

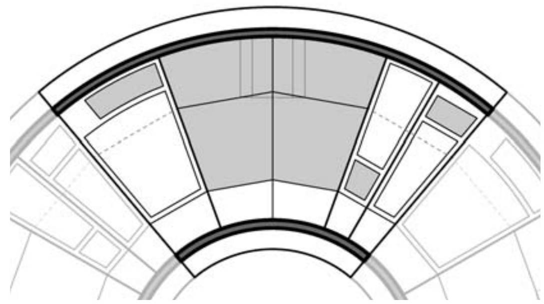

Fig. 9: Floor plan of sleeping quarters.

The sleeping quarters are located directly above each room with the entrance through the ceiling of the individual rooms. Each sleeping area has inflatable mattresses that accommodate one individual in the single room and two people in the double room or master bedroom. Each sleeping area is separated from the other sleeping quarters with the same membrane wall system as the rest of the module. This system provides a private space for each individual from the rest of the occupied spaces. This space is not a full head height space but enough head height to sit up and sleep in. Over the central corridor, there is room for a storage area for miscellaneous materials that might be of use before and after sleep, much like a night stand.

V. CONCLUSION

Whether living on Earth or on the Moon, this paper presents a unique set of design principles that allows the average family to live parallel lives. From morning till night, the Crew's Quarter serves as a home for its occupants. This proven technology and design will allow for a sustainable, realistic, near-future lunar outpost for the average family.

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