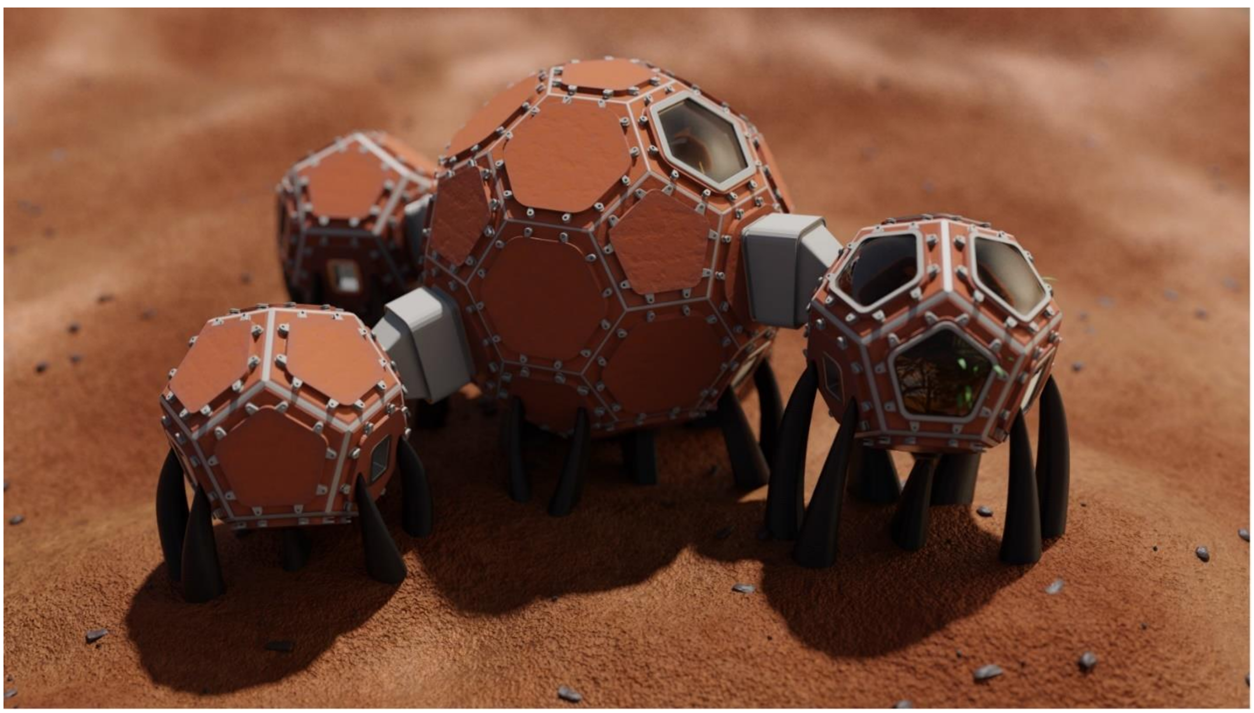
3D-PRINTED HABITAT CHALLENGE
A NASA CENTENNIAL CHALLENGE

Mars Incubator

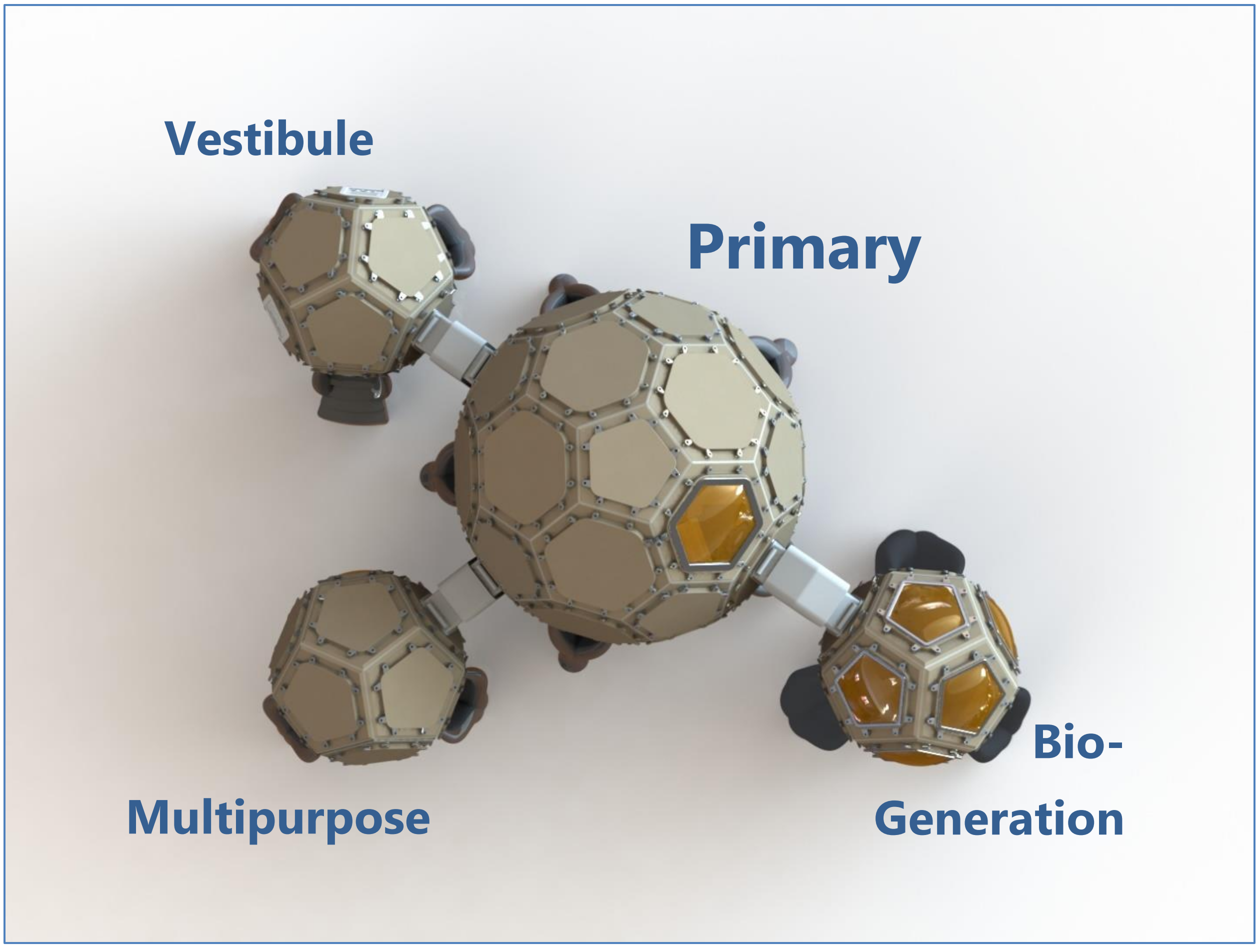


01.16.2019
Nicholas McGhee, et al.

Overview:

This document is meant to supplement the electronic model submission for the Mars Incubator Team. It provides detailed information about the model and the individual components within the habitat, including construction techniques and the ECLS system. It is meant to clarify details about the model which are not easily apparent or answer some questions which may arise.

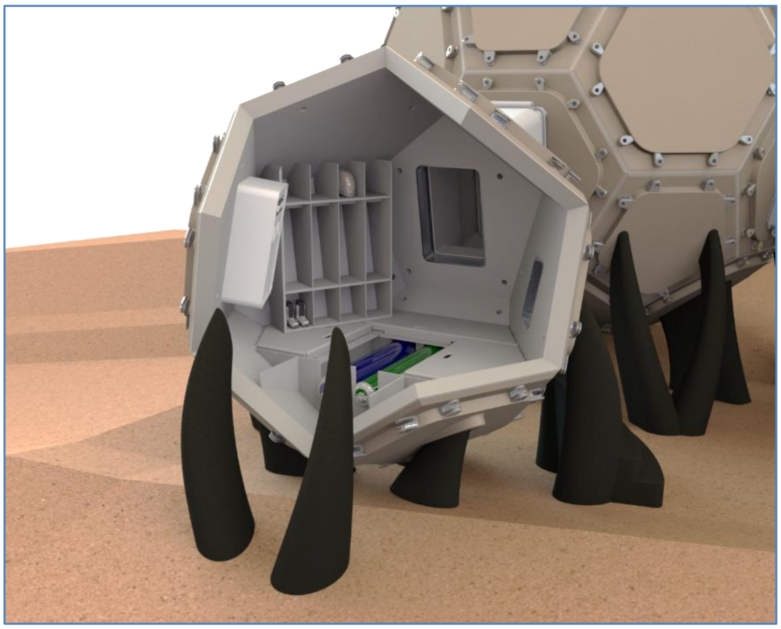
Habitat:



The Habitat consists of 4 volumes as shown above. They each provide unique functional environment for a year-long mission to Mars. All the individual cells have an independent electrical supply for redundancy. In addition, there are emergency air tanks in each of the small cells to supply fresh air for a period in case of a breach in the seals or a catastrophic failure of a volume.

Vestibule

The Vestibule is the entry and exit for the habitat. The focus of this cell is the exploration of the Martian surface. The exterior tiles chosen support entry and exit via rover, suit, or direct depressurization of the module. This cell has two MEPS units, one for temperature control of this cell, the second to support rapid pressurization of the small volume. Additionally, as with all the small volumes, there is a store of pressurization gas to be used in an emergency. The space opens directly to the hallway between the two lab spaces for efficiency of processing samples upon return from the surface.



Primary Volume

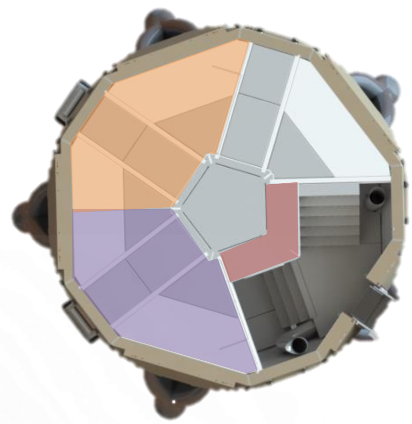
As can be seen in the diagram on the next page, the primary cell houses much of the operational environment. It is where the inhabitants will spend most of their time. The cell contains the sleeping quarters, recreation area, kitchen, sanitation facility and lab area. There are two MEPS panels that utilized in this cell have a heat exchanger/electrical input, and a fluid input/discharge, with additional MEPs volume below the decks. Although the storage tanks/processing system are designed to house waste and water storage for a year, the service life of the hab should provide the need to pump out for the next years crew.

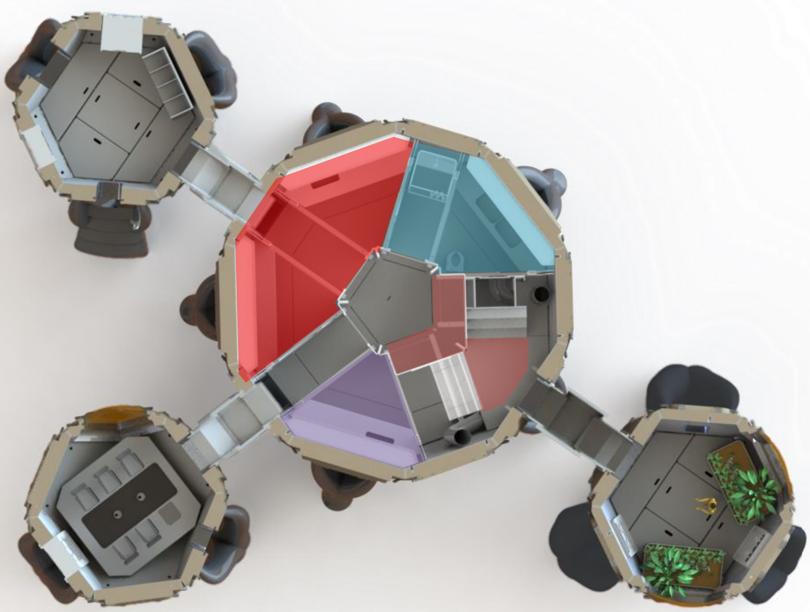
Upper Deck

Bunk 1

Bunk 2

Storage





Lower Deck

Lab Space

Sanitation

Food Prep

Storage

Below Deck

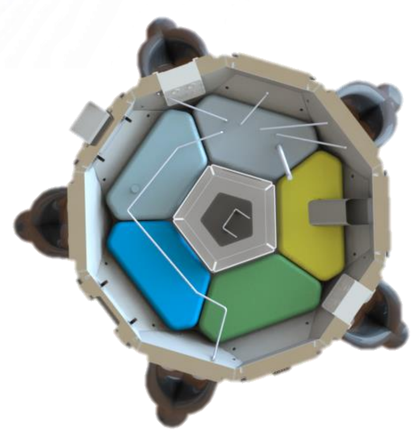
HVAC

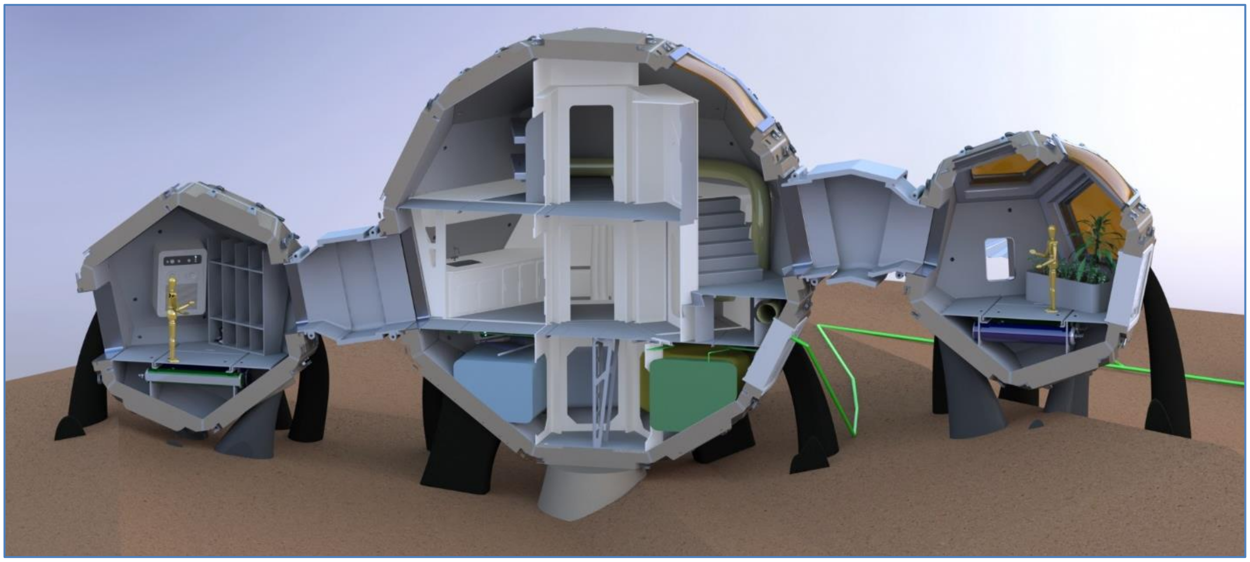
Fresh Water

H20 Processing

Waste Water

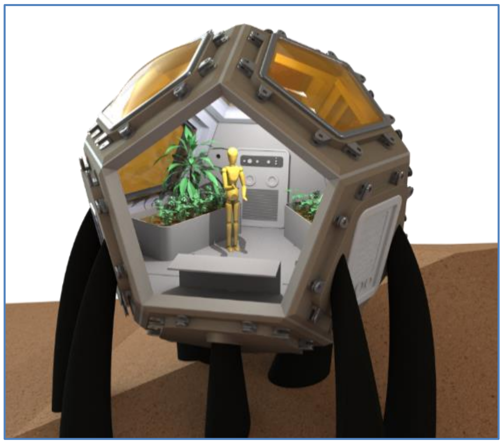
Oxygen Generation

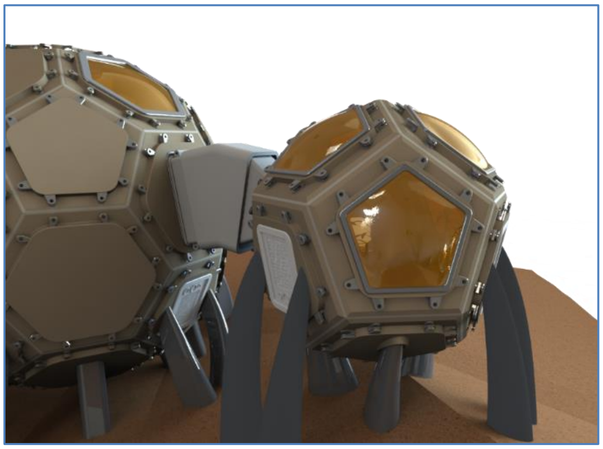




Bio-Generation Volume

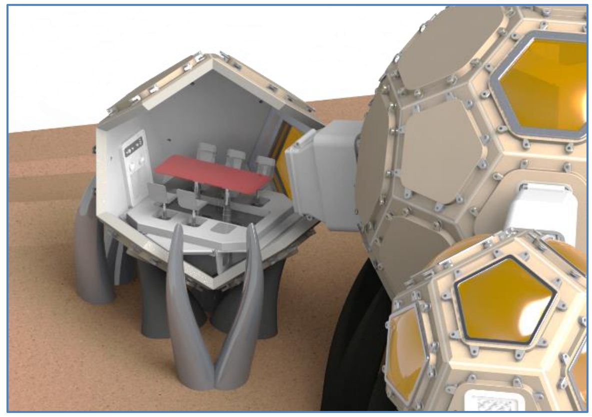
This volume will be used to conduct experiments with plant life in the Martian environment. This cell includes 5 viewports to allow sunlight into the habitat. This cell will have MEPS for heating and cooling as well as independent mechanical system for freshwater for plant growth. As with all the secondary volumes, there is reserve air below the deck.





Having plant life to tend to will be a pleasant diversion for the crew that will result in real scientific development. Additionally, it will help scrub the air, and reduce the isolating affects of the Martian desert environment. The view ports will provide stunning views of the Martian landscape. This space offsets the allocation of living space/vs lab space because we will be able to achieve scientific results in a crew friendly atmosphere.

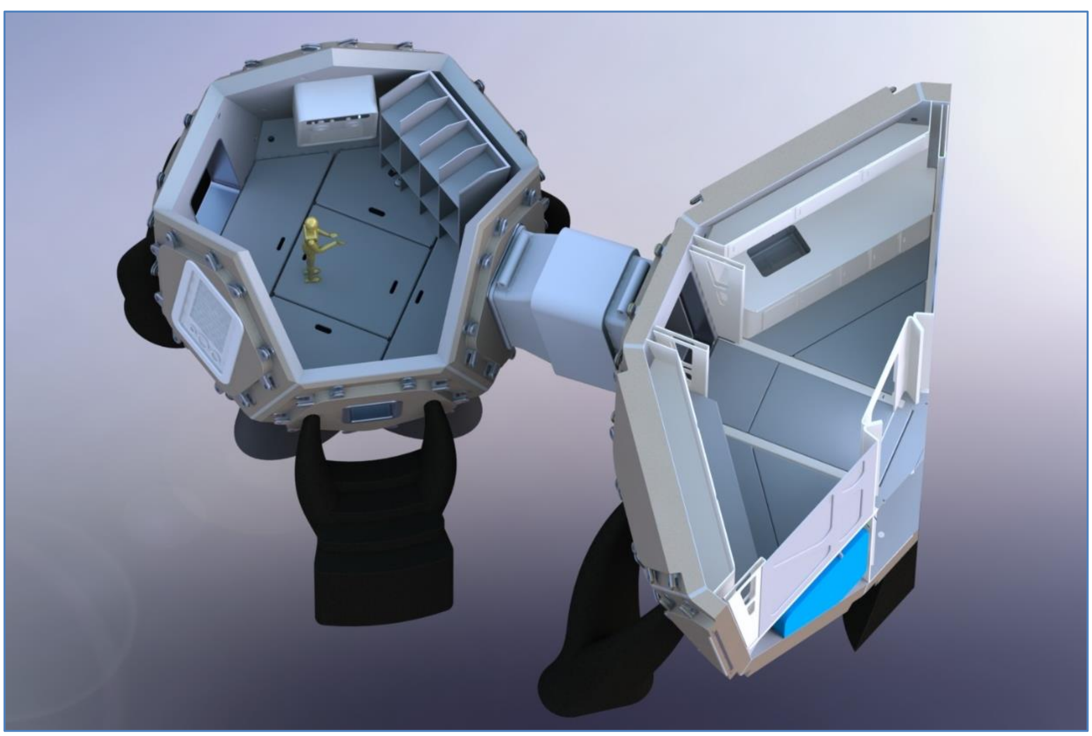
Multipurpose Volume



The multipurpose room will be used for communication with earth as well as serve the social and recreational needs of the crew. While this cell has been designed to accommodate a suit hatch it is only intended to be used for emergencies. The Table and chairs are stowable, and if outfitted with spherical projection and treadmill, one could get their exercise jogging through the forests back on Earth.

Lab space

The primary lab space is located inside the large volume. It consists of two sections of the Base pentagon. Because it is important to keep the lab space separated from the living quarters, the HVAC system was designed to push air through HEPA filtration in the floor tiles both above and below the lab space in order to provide a sterile environment. Additionally, the lab was positioned such that samples could be preprocessed in the "dirty" vestibule area prior to being brought to the lab. The idea is to try to minimize the cross contamination of the Martian environment to the living space, and vice versa.

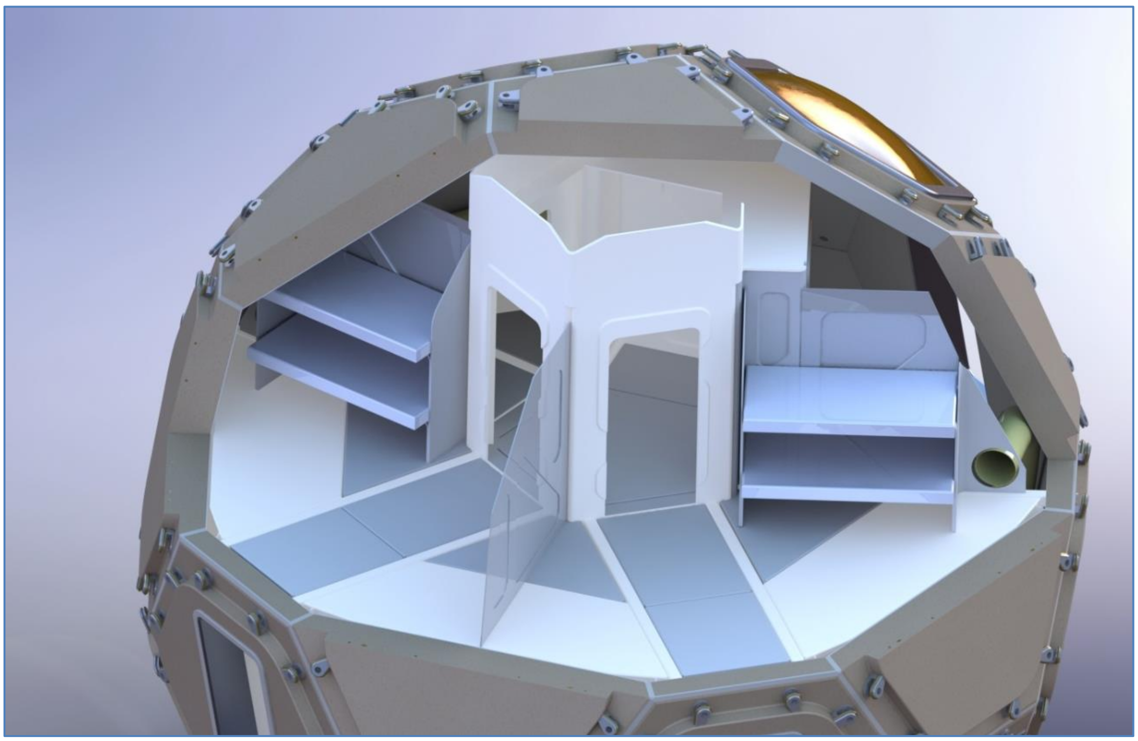


Storage

The primary storage areas are located in the asymmetrical portions of the central column. This area totals over 4 cubic meters per deck. 10+ total cubic meters. Additionally, there is about 3 cubic meters for storage under the stair landing. It is unclear how much of this space will eb required for food storage, and how much equipment will be located here. Additionally, there is ample storage of over 10 cubic meters in the bunk areas.

Bunks

The bunks are located on the upper deck of the primary volume. This dedicated area is split into two sections, with two crew bunks per section. Though private single bunks seemed more appealing, this would negate the potential for desk or closet space in the bunks, which we determined to outweigh the need for individual privacy. (Privacy is almost an illusion in such close quarters.) There is ample space in each bunk for a closet or clothes store, and the final configuration can be tailored to the specific needs for the crew or mission.



Physical components:

Each of the components that make up the habitat were carefully developed with Martian Materials in mind. Additionally, we believe that quality control over the production of the Habitat is of the utmost importance. Therefore, by creating modular reproducible components. we can ensure a robust environment for our astronauts.

Material Choices:

The first material used is the basalt fibers. Basalt fibers can be generated from basalt bedrock which is naturally occurring and widely available. The benefits of basalt rock over glass fiber is that it is already "pre-batched" by the natural lava flows that deposited it. It will be important to the landing site that the bedrock contain the correct chemical makeup allowing it to be drawn into fibers. Once the fibers are created, they will be used for multiple applications in our structure, each of which will be explained in more detail in the below sections.

The second material used is the regolith. For our application the regolith does not need to be chemically modified. It simply needs to be sieved to better control the particle size.

The third material is polyethylene. On earth, it is believed that using carbon dioxide to create polyethylene is becoming a viable method of producing plastics while reducing greenhouse gas emissions from pollution sources. On Mars, the CO_2 is already abundant in the atmosphere, making it a resource we can readily extract. In our habitat the polyethylene will be used both as a binder material for two different types of materials, as well as an extremely strong fiber similar to the commercial product Dyneema.

External Tiles

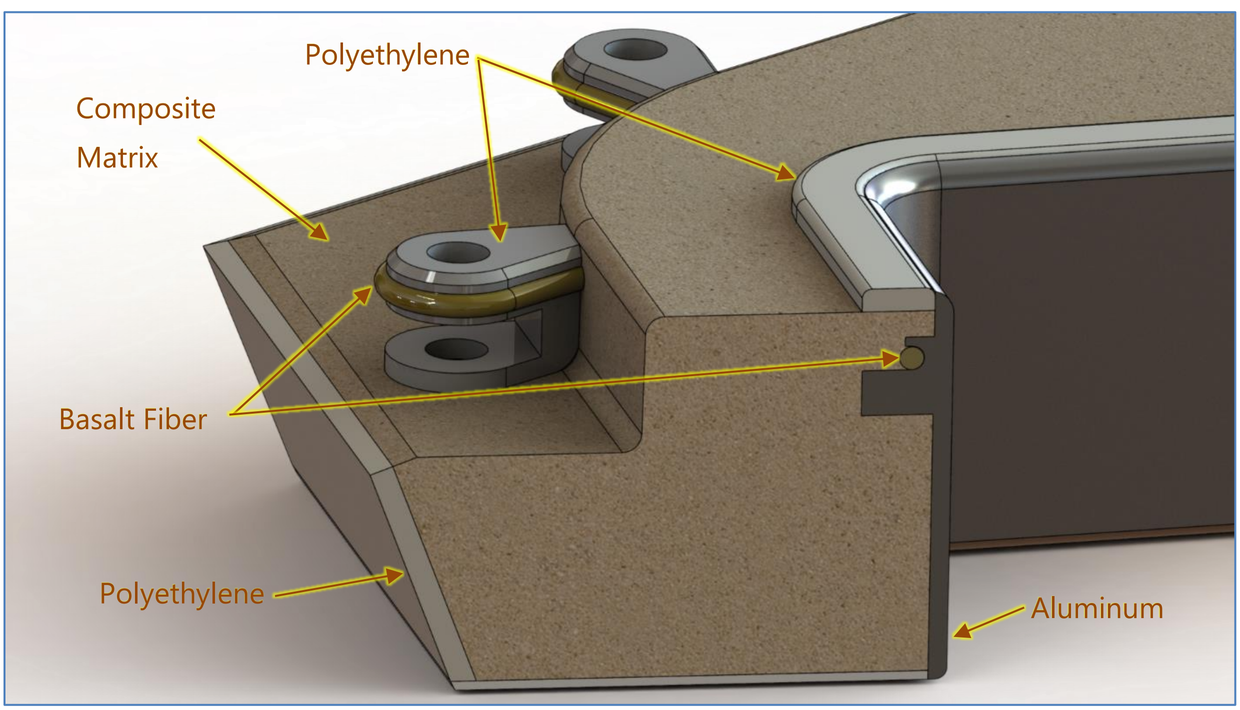
Hexagonal and pentagonal tiles are the standard building block for the habitat. There are three standard geometries used to complete the habitat, one hexagonal and two pentagonal. The pentagonal tiles in the smaller pentagonal polyhedrons have a different mating angle than the larger tiles, however they are of the same basic size.

All the tiles are made from the same materials, use the same reinforcement technique and are 16 inches thick. Most of the volume of the tile will be made from a mixture of polyethylene powder and Martian regolith. This material will be pressed into a mold and heated to approximately 130° C. This process melts the polyethylene and regolith mixture to form a composite. The addition of the regolith reduces the amount of the polyethylene required by consuming some of the volume of the molded part. Using the regolith and polyethylene adds strength while maintaining pliability. Other advantages of using polyethylene are that it is effective at shielding against GCR (galactic cosmic rays) and has good wear resistance. Its typical use on Earth as shot peen masking demonstrates its effectiveness as protection against high velocity small particles such as rocket motor ejecta.

Because of the force exerted on the tiles when the habitat is pressurized the tiles need anchoring points to mechanically secure them to each other. To achieve this, the press tool has provisions for basalt fibers to be wound through the internal volume of the tile before the polyethylene and regolith are pressed. These windings act as anchoring points to distribute the load throughout the tile, and they help to harden the tiles against impacts. Where the anchor points are located outside of the tile the basalt fiber passes through an insert molded from polyethylene to help reduce the bend radius of the basalt fiber. Finally, the border of the tile has polyethylene molded into the tile to act as a weld preparation area for sealing the habitat. These features can be seen in the images below. More research on the appropriate mix ration of plastic to sand and fiber is need, additionally, more work is needed on winding patterns.

Hatchway Tile

The hatchway tile is very similar to the MEPS tile in construction. A once again an aluminum supporting structure is used to bear the tensile Load from tensioning the panel. The basalt fiber anchors are wound around the aluminum insert. Additionally, a molded poly Insert is used to make the seal to the hatchway. The tile is then sintered in the same method as a standard tile.



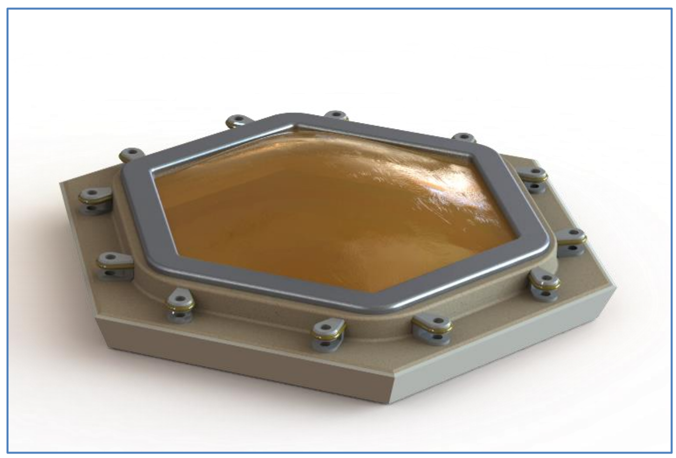
While each of the three smaller cells have a hatchway tile, it is only used for emergencies in the Environmental Development Cell and the Multipurpose Cell.

MEPS Tiles

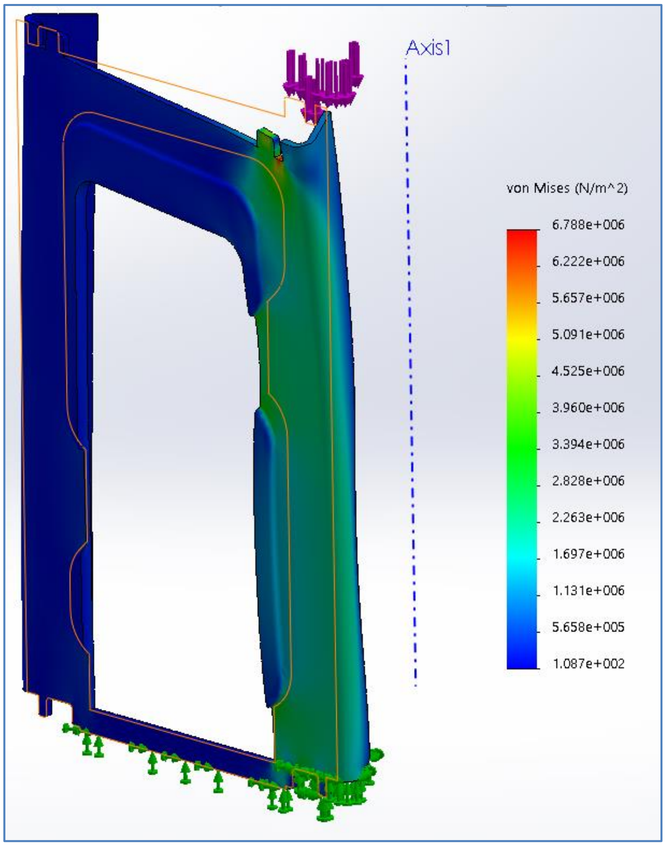
The Mechanical Electrical Plumbing (MEP) tile is like the standard tile in its construction except for special inserts in the center of the tile. It has all the same features of the standard tile, using the basalt fiber windings and the polyethylene inserts for welding. The same mold tooling can be used to create this tile by utilizing a mold insert to create space in the center of the tile for the MEP inserts. The fiber windings go around the MEP insert and are still used as mechanical reinforcement for the pressure retaining aspect of the structure. The MEP inserts are used in this structure to provide methods of heating and cooling the habitat, additionally they provide pass throughs for the electrical inputs, water inputs and methane outputs. A representation of a MEP tile can be seen below.

Viewport Tile

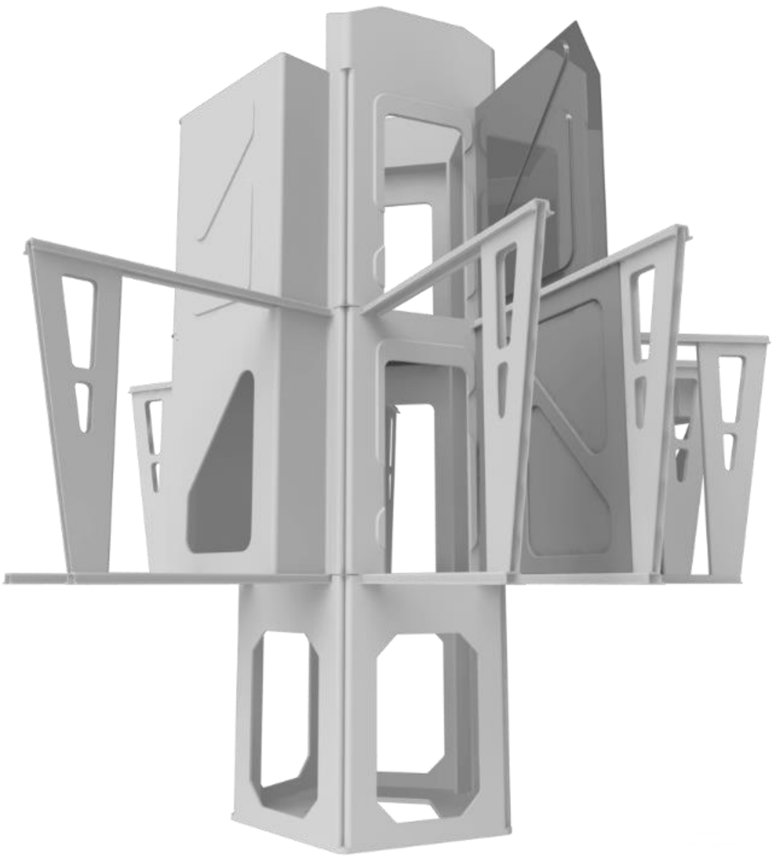
The viewport tile is once again constructed in a similar method as the standard tile. It utilizes the same design features as the standard tile but using a mold insert, a viewport is added to the center of the tile. The basalt fiber winding wraps around the parameter of the viewport insert. The fiber windings support the insert and help to retain it in place. The viewport tiles are used in the Environmental Development Cell to allow sunlight into the habitat, more on this can be seen later while discussing the Environmental Development Cell. A viewport tile can be seen below.



Internal Supports

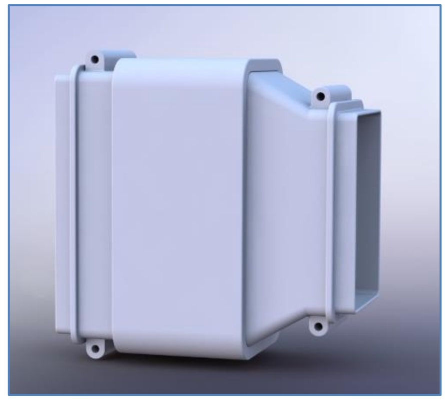


The internal support structure is molded from polyethylene with basalt fibers used as reinforcement and are thermoformed into their final configuration. The structure provides support for the upper, external tiles and allows for multiple floors within the large cell. structure. During the construction process, the upper, inward sloping external tiles are supported by this structure. Once complete it serves as the support structure for the floor panels, stairs and internal systems routing. The mass of the upper tiles will be transmitted through interior polyethylene skeleton into the lower tiles and into the foundation.



Hatchways

The hatchways are constructed of the same basalt-fiber reinforced polyethylene. At each of the mating faces, there is a purely polyethylene flange to be welded in order to provide a seam to the hatch as discussed n the hatch tile section above. In the image you will notice four holes that will accept the shaft from the panel clamping mechanism detailed below.

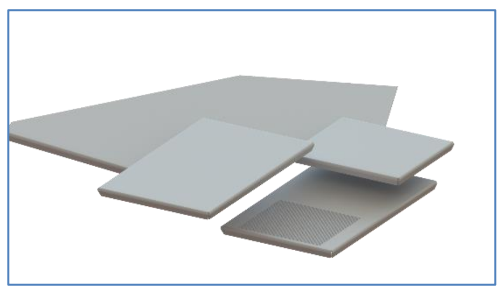


Work Stations and Equipment

To the right is an image of a station in the primary volume. It is intended that these be produced of polyethylene and welded together. Living hinges could be produced for the cabinetry, or alternatively, shelving without closure could reduce the part complexity. As the design is refined, the potential options can be more accurately specified.

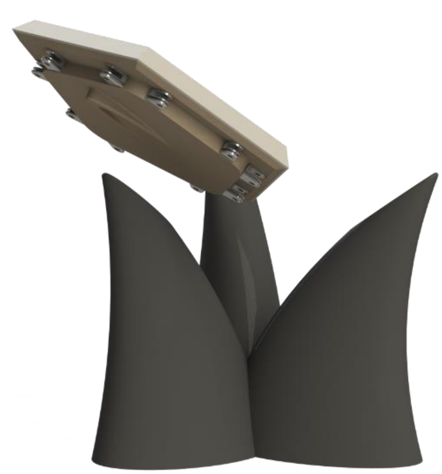
Floor Panels

The floor panels are made from the same basalt fiber polyethylene composite as the structural elements and fabricated in the same manner. They are configurable to match the layout of the facility and have the potential to be vented and mate with HEPA filtration for the lab spaces.



Basalt Supports

The initial supporting structure will be created by an additive manufacturing process using basalt fibers generated on Mars. The material will be deposited in columns which will act as the foundation for the lower panels supporting them from the surface of the planet. Once the interior supporting structure has been placed the upper sintered tiles can be applied. In our testing we have found that melted basalt we have generated is extremely



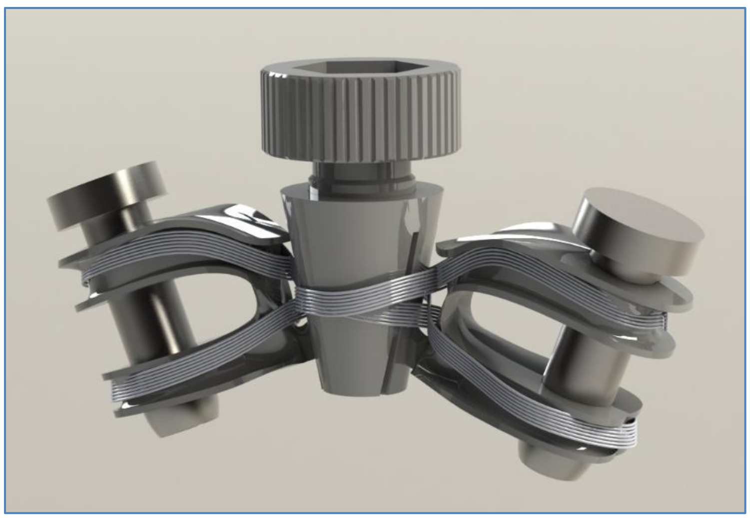
brittle and weak in tension. To overcome this, the supports created with this material will be and minimal build angles and only loaded in compression. Below the basalt supporting structure can be seen, as well as a Tile with a positioning feature molded in place. This is only required on the lower tiles of the small volumes.

Anchor Supports

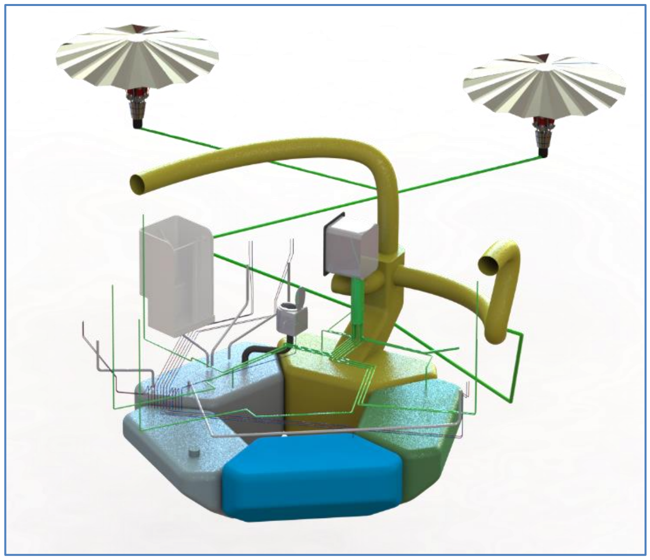
The anchor supports mentioned in the description of the tiles are fabricated by molding polyethylene and facilitate the transfer of mechanical load from the basalt fibers to the Dyneema rope in the cinching assembly. During the fabrication of the external tiles, they are placed inside the molding tool and to support the winding of the basalt fibers. When assembling the panels, these supports align with the cinching assembly and increase the bend radius of the basalt fibers in the tiles. Increasing the bend radius is critical to the strength of the basalt fibers.

Cinching Assembly

The cinching assembly is critical to the function of the habitat as well. Because the force exerted on the external walls is so great from the internal pressure, and the cinch will require a dynamic load scheme, UHMW rope is utilized to achieve the mechanical strength required. The devise will be pretensioned to hold the panels in compression after assembly to prevent damaging the polyethylene seal when the habitat is pressurized.

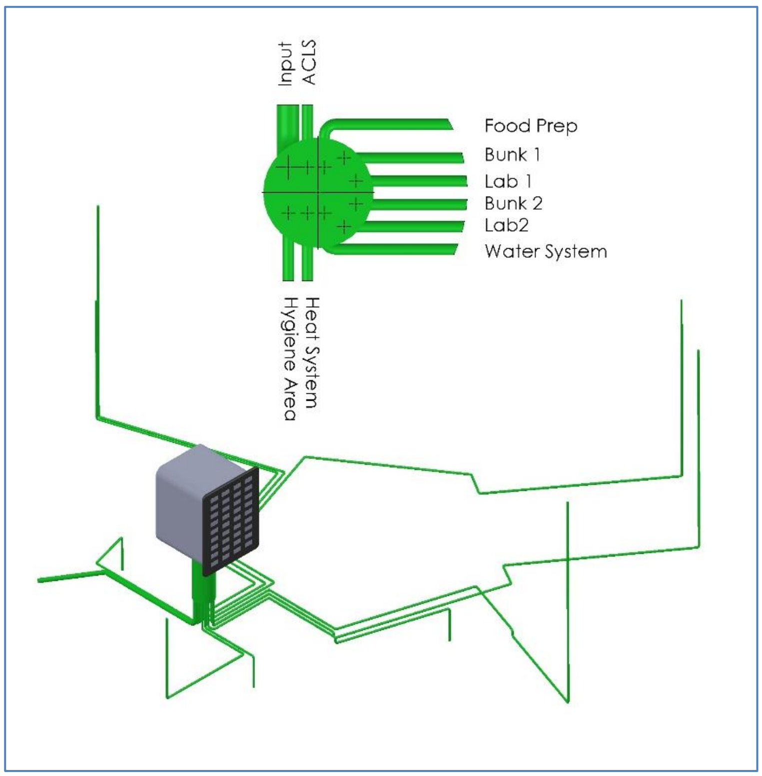


ECLS Systems



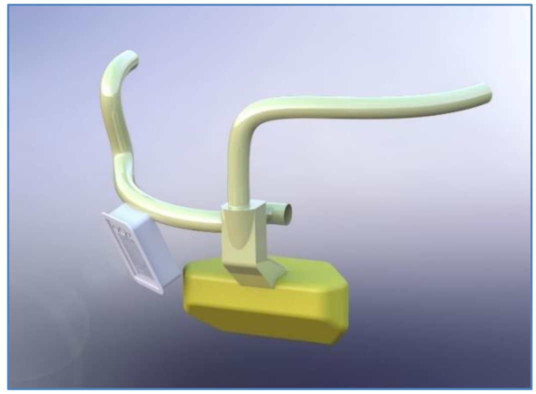
The ECLS System consist of four subsystems, Electrical, HVAC, Oxygen Generation, and waste and water treatment. Each are detailed in the following sections. Together they will to serve a crew of 4 over a year, however it is expected the habitat will be able to serve multiple generations of crew. It is estimated that a total of 4 or 5 Kilo power units will be required to sustain operation of the base.

Electrical

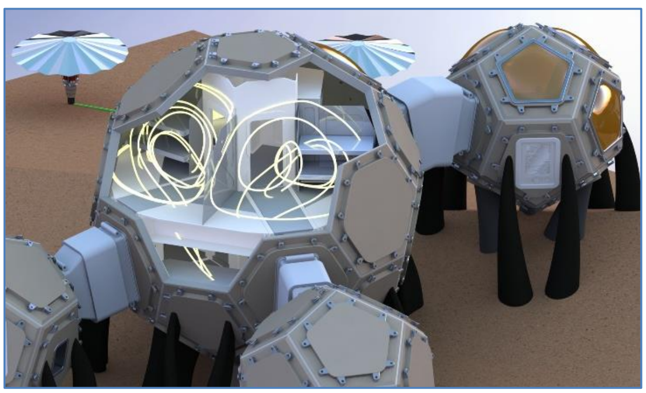


The primary volume is equipped with two externally facing tile mounted MEPS Units (detailed below) through one of which the main power supply will be routed. Additionally, power is to be routed externally to each of the secondary volumes directly from the Kilo Power installation. This allows the cells to function independently in case of an emergency. Each of the functional zones of the primary cell receive power from the main distribution box located under the second flight of stairs accessible through the sanitation area.

HVAC

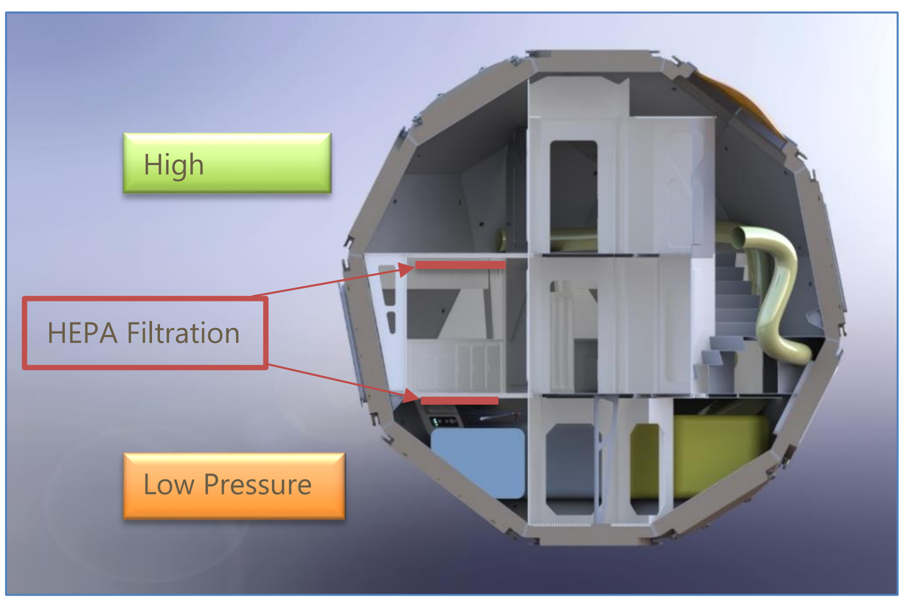


The heating and cooling system has been allocated about 6 cubic meters, plus the ducting space. The airflow of the habitat is intended to distribute oxygenated air directly to the living quarters, provide HEPA filtered air to the Labs, and allow oxygen dispersal to the secondary volumes by diffusion. The tile mounted MEPS unit shown in the image at the right is fitted with a heat exchanger in order to help regulate the temperature if operational equipment overheats the space. The flow paths were validated by simulation, though more specific detail on components, equipment, heating and cooling loads are required to further develop this model.

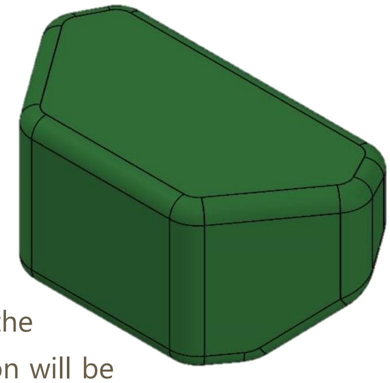


Additionally, detailed below, are the individual heater/CO2 Scrubbing units for the smaller volumes. Though the primary heating and oxygen generation is to take place in the lower level of the primary volume, it is important to be able to heat the volumes and scrub CO2 independently in the event of a separation of the volumes due to unscheduled depressurization of the habitat.

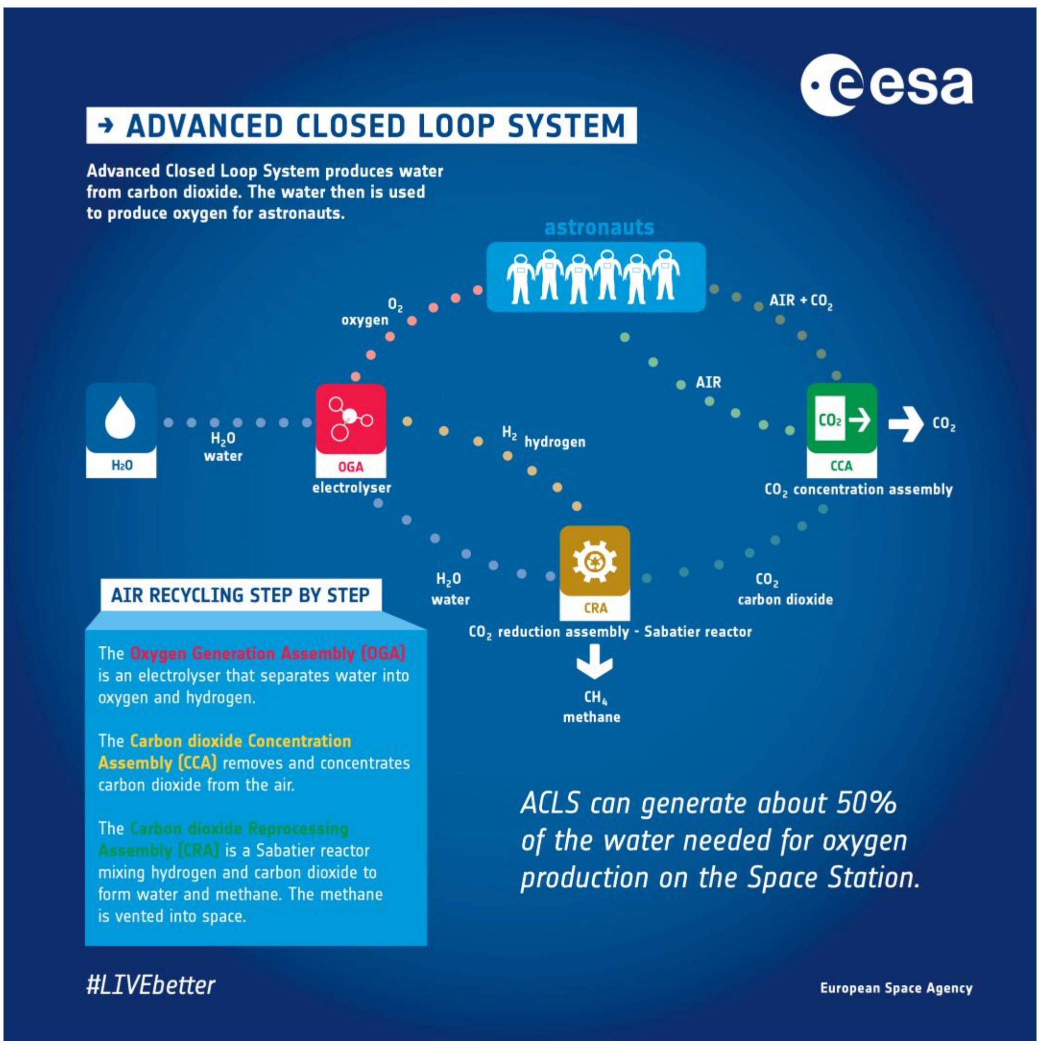
The heating, cooling and distribution of oxygen throughout the habitat is achieve by the forced air HVAC system. This system was design to ensure proper ventilation throughout the sealed volume. The flow paths were validated by simulation.

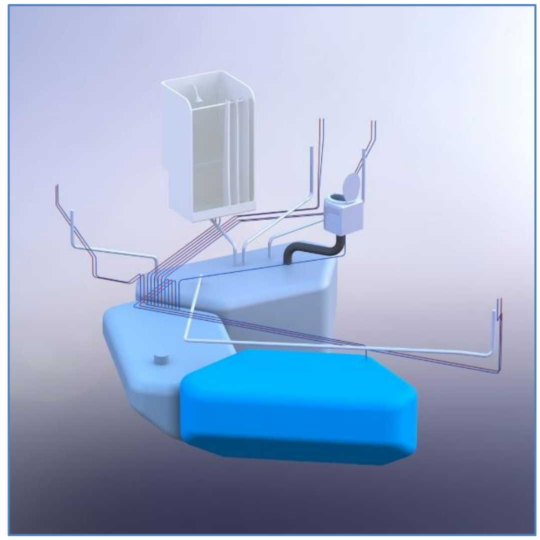


Oxygen Production:



The Oxygeneration system is designed to replicate the ACLS system used on the Inernational Space Station. At approximaetly 4 Cubic Meters, the ACLS in the destiny module produces enough oxygen for 3 crew members. It Scrubs approximatley 3 kg/day of Co2, produces about 2.5 Kg/day of O2, and has a power consumption of about 3.5 kW average. Our system will need to be scaled up by about 40%, and will rely on the same underlying technology. The water produced by the system will be returned to the freshwater reservoir, while the methane produced form the Sabatier reaction will be collected and stored for use as fuel for any methane-powered equipment, potentially rovers or rockets. We've allocated about 5.5 cubic meters of space for this equipment. This does not include the water reservoir.





H2O System

Handling the H2O in the habitat is one of the most challenging and critical aspects of the system. Humans on Earth use can average 80 gallons per day, and the space shuttle crew uses as little as 3 gallons per day. With these numbers in mind, we've allocated a large amount of space for our water reservoir, treatment system, and waste volume. At over 15 cubic meters, we have ample storage for over 1,200 Gallons of fresh water, 600 gallons of waste, 600 gallons of process water, and 5.5 cubic meters of equipment.

Both our freshwater reservoir and waste containment volume can be resupplied/pumped out externally through one of the MEPS ports. More work needs to be done on the specifics of the waste containment and reclamation processes before we can ascertain more detail about the affects on the larger habitation system.

MEP Inserts

The MEP inserts are a common component of the assembly to be transported from earth. There are five different configurations of these units used in the current assembly, each with a common mating interface for interchangeability. Each will be powered externally and can serve as an electrical interface to the volume. Additionally, MEP interfaces in tiles can provide modularity for future growth or development of the habitat.

Bio-generation

This unit would house the pumps and filtration needed for the maintenance of the plants in the bio-generation area.

Fluid Fill/ Discharge

This unit would serve to interface between to the H2O system. It would enable to fill and discharge of the fluid reservoirs in the lower section of the Hab.

Heating Unit

The small eating unit small heating unit and CO2 scrubber will provide the crew with enough time for a rescue mission from another crew or from another module.

Heat Exchanger

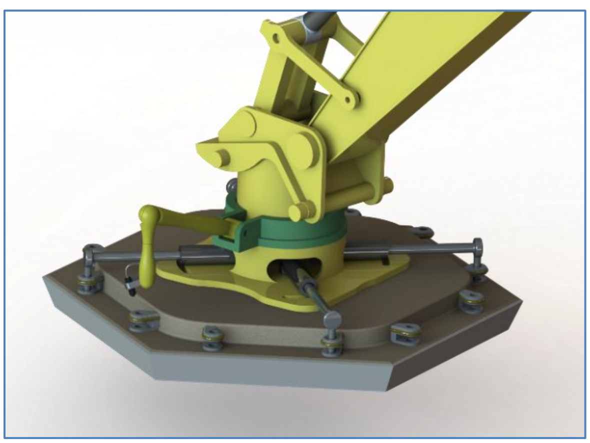
The HVAC system will at time need to cool the unit and will require a heat exchange with the external environment. This will be accomplished through an external MEP unit with a heat exchanger.

Pressurization unit

The vestibule of the habitat will require the ability to rapidly generate pressure and vacuum. A MEP unit paired with reserve pressure cylinders will handle this functionality.

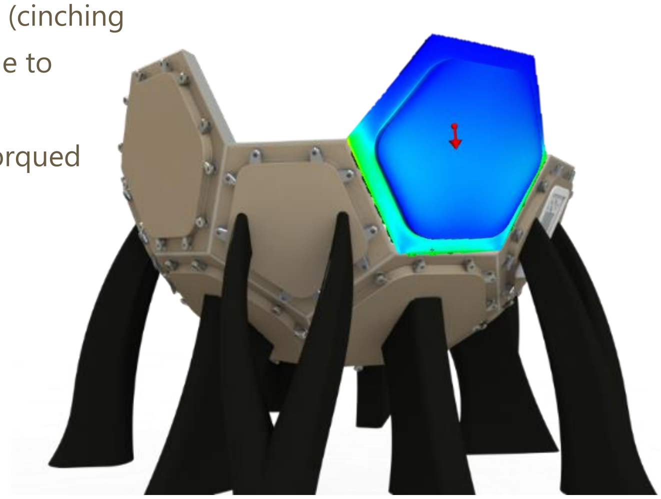
Construction Process:

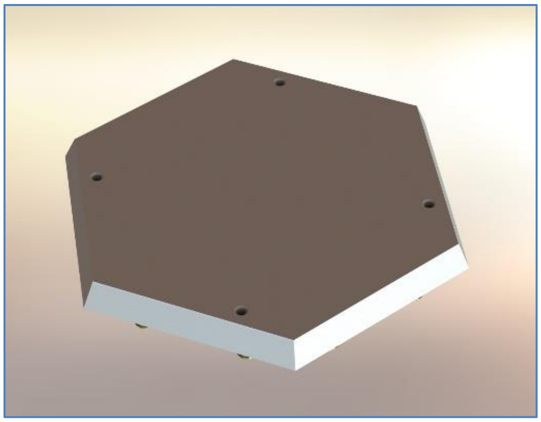
Some site preparation will be necessary for the construction of the habitat. A firm base for the printing of the external supports is required. This could be achieved through compacting soil, or printing directly onto exposed bedrock. Once all the external support structures are printed in place, the assembly of the pressure retaining portion of the habitat can begin.



The assembly of the structure will be accomplished by a robotic excavator with a specialized end affecter consisting of set of hydraulic grippers and a robotic welding arm. It will lift the panels by inserting the gripper ends into the anchor supports and extending the hydraulic arms, creating tension within the panel. Once the tile is lifted and aligned in place, the laser welding arm can travers the perimeter, welding the adjacent panels. Initially we were conservative on the strength of these welds, but as we uncovered more research on the topic, we found that many of the overhanging tiles can be temporarily held in place by the welds while other tiles or a cinching assembly is attached.

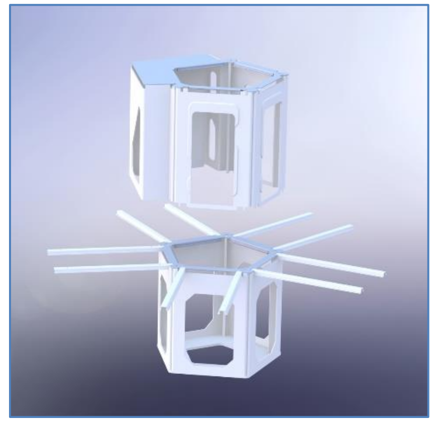
As the tiles are placed and welded, the panel connection (cinching assembly) will be placed and torqued to a minimum value to provide reinforcement during construction. After all the external tiles are placed, the panel connections can be torqued to apply tension prior to pressurization.





The incorporation of lifting pockets on the internal faces of the panels allows the placement of supported tiles from the top side.

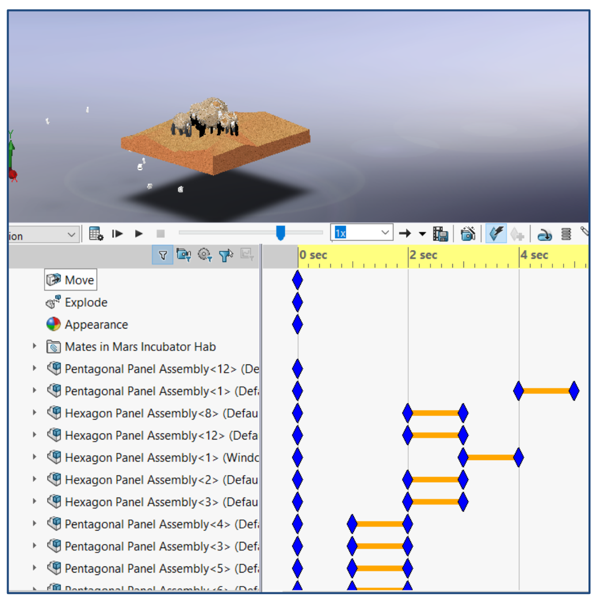
The internal structure will be installed concurrently with the external panels. The lower panels support the internal structure, forming an endoskeleton for the internal decks and support the upper external tiles during placement prior to welding and tensioning. Each component or sub assembly is carefully designed to have interlocking features that ensure proper alignment and provide clean interfaces that obviate the need for trim.



The last piece of the assembly process will be to insert the MEP units. Though the MEP ports can be used to install mechanical systems imported form earth, there is additional access granted through the central column if necessary. Items can be loaded in to an unpressurized habitat though the uppermost external tile, lowered through the central column to their respective areas in the lowest portion of the hab.

4D Simulation

The video we produced show the 4D assembly of the model. Additionally, there is an exploded view that represents the 4d sequencing of the assembly, however it is extremely taxing on the CPU given the complexity of the assembly. Please be patient and it should load and animate. Not all steps are broken out. Often, there are three panels removed at once. In practice this would be performed in sequence. Also, the internal assembly does not collapse. In retrospect, these sequences should have been performed individually on each sub assembly then reused in the large assembly.



Previous Feedback:

In the first round of the virtual competitions the below was the scores we received for each of the categories.

Rules Section 4.0			Virtual Construction (BIM) Level 1 – 60% Design		
	4.7	Scoring – Virtual Construction Level 1 Judging Rubric		Total Points Available	Total Points Received
	4.7.1		**Completeness of 3D Model**		
			Level of Development of Element Information Items	125	125
			System Information (MEP, ECLSS, etc.)	125	70
			Max score	**250**	**195**
	4.7.1		**BIM Use Functionality**		
			Layout, Programming and Efficiency	250	100
			3D-Printing Constructability and Robustness of the Model (Design)	250	230
			Max score	**500**	**330**
	4.7.2		**Aesthetic Representation**		
			Aesthetics	250	205
			Max score	**250**	**205**
	4.7.3		Overall Score for Virtual Construction Level 1		
			Completeness of 3D Model	250	195
			BIM Use Functionality	500	330
			Aesthetic Representation	250	205
			Total Level 1 Score	**1000**	**730**

While we scored well for the level of development for the mechanical aspects of the structure, we did not provide enough information about the MEP and ECLSS components. This was addressed by providing more detail about the placement as well as function for each of the MEP and ECLSS components placed in the tiles. The electrical and plumbing systems were defined in the model to show the routing throughout the cells.

Another area for improvement was the layout of the cells and the efficiency of the use of the space. In the first submission a large amount of the interior volume was taken up by the basalt supports used during assembly. They had unique shapes to facilitate the manufacturing, but this meant a lot of internal space unnecessarily occupied. In the new design a more efficient polyethylene skeleton structure was developed to serve the same purpose while taking up less of the valuable internal volume. Along with the polyethylene skeleton, the layout of the cells has been rearranged to better utilize the space available. The interior layout and location of various equipment is much more defined.

Finally, the aesthetics of the first submission were improved in this most recent submission. The most powerful change has been the reduction of the monolithic internal supports, replaced by the basalt reinforced plastic. Additionally, we were able to reduce the number of external supports on the large volume.

Moving Forward

This exciting competition has opened up an avenue for continued research on composite materials, and any financial support awarded through the challenge would have a huge impact of the technology our organization will be able to develop. Initially inspired by African recycled plastic brick making, our concept has real-world application. In order to push this design forward, we need to focus on obtaining material properties from the tiles and panels. This will require a heated platen press. Having this equipment would allow us to continue development on the mix of material and identify a proper winding pattern for each tile type. The equipment would be housed at MakeHaven, a local makerspace, where both the team and the public would have access to the equipment. Ideally, this will lead to some research we can publish at next year's IAC conference.

Not only has this effort been extremely exciting to work on, it has also had a positive effect on those who have been associated with it. In the first round, the team received local news coverage about our efforts, which ultimately lead to the team being contacted by a local FIRST Robotics Team. Although the relationship thus far has been limited to speaking and mentorship, if we were to be awarded funding, we use some of that money to purchase needed equipment and help teach, and learn, the necessary techniques to remotely build on another planetary body.

Additionally, in order to progress our design further we need a much more powerful microprocessor. Graphic rendering was a huge challenge in the development of this model. Even with decent model management practices, the computers we used to develop the model were highly inadequate. We would like to purchase a new work station and additional graphic processors in order to further develop the Modelling, simulation and visualization of our design.

Lastly, I'd like to thank the Challenge Administration for organizing such an inspirational program. It has been a pleasure and quite the learning experience. It has provided a nucleation site for my passions and inspired me to invest my efforts in developing new technology for this planet and beyond. Thank you.

-Nick McGhee