Common Habitat Design for Microgravity, Artificial Gravity and Partial Gravity in a Safe Haven Configuration

Paola M. Gonzalez Marquez[1]
David Smitherman[2]

NASA Marshall Space Flight Center, Huntsville, Al, 35812, USA

As space exploration efforts advance towards the returning to Lunar surface and later to Mars, new challenges emerge, and habitation becomes one of them. Having a custom manufacturing line for deep space transit and surface habitats (the Moon or Mars) implies a longer design and production line. Instead of spending great amounts of money and time on custom designs a common development has been explored where the interior architectural functions can be multifunctional, capable of being adapted into distinct gravity conditions. The concept developed for a common design is capable of being adapted to two (2) different layout configurations for a common habitat in a safe haven design: (#1) a habitat that could be used both as a deep space transport in micro gravity and on Mars surface partial gravity; and (#2) a habitat that could be used both as a deep space transport in artificial gravity and on Mars surface partial gravity. These designs have the potential to diminish manufacturing time and cost, but also reducing crew training time increasing crew adaptability to their habitation and gravity condition.

Nomenclature

ACO	=	Advanced Concepts Office
AG	=	Artificial gravity
CAD	=	Computer-Aided Design
CBM	=	Common Birth Mechanism
CTB	=	Cargo Transfer Bag
DST	=	Deep Space Transport
ECL	=	EVA Crew Lock
EVA	=	Extra Vehicular Activity
LED	=	Light-emitting diode
MG	=	Microgravity
MSFC	=	Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
PG	=	Partial gravity
SLS	=	Space Launch System
UE	=	Unreal Engine
WCS	=	Waste Collection System

I. Introduction

As it is known, manned space exploration efforts advance towards the return to Lunar surface and later to Mars [1] causing new challenges, habitation being a crucial one. However, a custom manufacturing line for deep space transports and surface habitats imply a long design production line, causing a greater expenditure versus investing the time and money in a common development [2]. Consequently, endeavors towards commonality have been emerging

[1] Space Architect, Advanced Concepts Office Intern, AIAA.
[2] Space Architect, Technical Management, ED04 Advanced Concepts Office, Senior Member AIAA.

with greater efforts recently, as a means to reduce custom manufacturing. For this reason, the Advanced Concepts Office (ACO) at NASA Marshall Space Flight Center has developed the following habitat study.

It is to be noted that common does not equal identical, commonality means the state of sharing features or attributes [3]. Therefore, having a common habitat development does not mean that the products will be completely identical, but that they are capable of adapting.

The following habitat study has been grounded on the practice of commonality applications. It can service as a deep space transport (DST) in a safe haven configuration, meaning that if one of the two habitat nodes fails the crew should be able to survive on the remaining one. Furthermore, the habitat has been designed so one of the nodes could be settled on the surface of Mars. As it can be deduced, the habitat is meant to be common for both microgravity (MG) in deep space and partial gravity (PG) on the surface of Mars. Additionally, it contains another layer of complexity as the habitat ports and interior functions have been laid out so that both nodes can be connected in an artificial gravity (AG) DST configuration.

In resume, the habitat study is based on (#1) a habitat that could be used both as a DST in MG and as a surface PG habitat; and (#2) a habitat that could be used both as a DST in AG and as a surface PG habitat. Further on, the results of the study demonstrate minor differences between the layouts due to the distinct gravity conditions, those being in microgravity, partial gravity and artificial gravity.

II. Design Constraints and Requirements

The common habitat study has been constrained by the gravity conditions of PG on Mars surface, and MG and AG on transit in deep space [Figure 1]. Another constraint is the safe haven application.

Mission requirements include a crew size of 4, a mission duration of 1,200 days, 24 extra vehicular activities (EVA), and 2 crew per EVA [Figure 2]. Other mission requirements include that the DST node configuration must include a propulsion tank, two habitat modules, an EVA crew airlock, a logistics module and a lander. On the other hand, the surface node configuration includes one habitat module, an EVA crew airlock, a logistic module, a lander and a rover. Additionally, the common berth mechanisms (CBM) size is to use a 50in x 50in hatch. As another mission requirement, 4 crew members will be distributed into 2 nodes in deep space (when no emergency occurs) and on the surface 4 will be living on the same node.

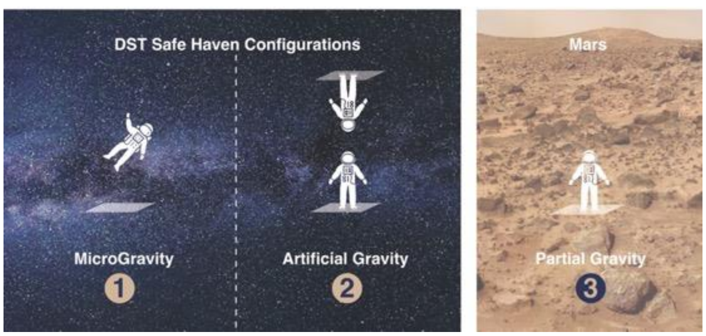

Fig 1: Gravity constraints include MG (left), AG (center) & PG (right)

Crew Size	4 crew icons
Mission Duration	**1200**
Extravehicular Activity Number of EVA's Crew per EVA	 **24** **2**

Fig 2: Mission requirements

On the other hand, the habitat nodes of the DST and surface are made of an aluminum pressure vessel construction derived from Space Launch System (SLS) 8.4m diameter manufacturing tooling but cut to the smaller

7.2m diameter size. This approach provides a flatter dome with a longer 7.2m diameter cylinder section than normally found in standard propellant tank profile.

III. Assumptions

It was assumed that, for the safe-haven configuration serving as a DST in MG and AG, the central crew airlock will function at all times during the duration of the mission and only one of the habitat nodes will stop working as the worst-case scenario. The worst-case scenario was assumed to be the loss of a habitat node from causes such as, but not limited to, smoke, fire, life support equipment failure, depressurization from stresses, seal failures, micrometeoroid strikes and collisions during docking operations with other vehicles.

There are other assumptions regarding the interior of the habitat. Firstly, it was assumed that the habitat is pressurized; including radiation protection. In the case of a solar particle event the crew quarters serve as shelter. On the other hand, it is assumed that stowage will be tracked by a software system informing the crew members the zone and locker in which the object is found. Moreover, there is the assumption that plants in the interior of the habitat are contained and maintained properly. Regarding the windows it is assumed that they contain smart glass that dims the exterior light through electrochromic technology using electricity to change the color and light transmission [4]. In the same manner, there is an assumption that windows have the technology to project virtual views. As per assumption, the light fixtures in the habitat will follow the circadian rhythm. Finally, it is assumed that the stairs will be moved through a mechanical system, but in case power goes off it should also be functioning manually.

IV. Top Level Concept of Operations

A top-level concept of operations has been established both for the DST and the Martian surface habitats. It is of high importance to explain beforehand that in this particular study five habitat modules will be manufactured in series. Series 01A (MG), 02A (MG), 01B (AG) and 02B (AG) to service as the DST, basically as a taxi from Earth to the Moon and later to Mars, and series 01C to be landed and settled on the surface of Mars.

The study's concept of operations begins by launching multiple times from Earth using NASA's Space Launch System (SLS), containing all the payload components to be assembled at Gateway. Once the Mars surface habitat is assembled, it will be sent un-crewed to descend on the surface of Mars and wait there for the crew to arrive by the DST. The DST will be assembled and crewed at Gateway. Then, it will continue towards Mars orbit so that crew transfers to the lander and can successfully descend and inhabit the already settled Mars habitat. For future travels, the DST will be travelling from Mars back to the Moon's orbit to be serviced by Gateway. Figure 3 demonstrates a diagram of the top-level concept of operations.

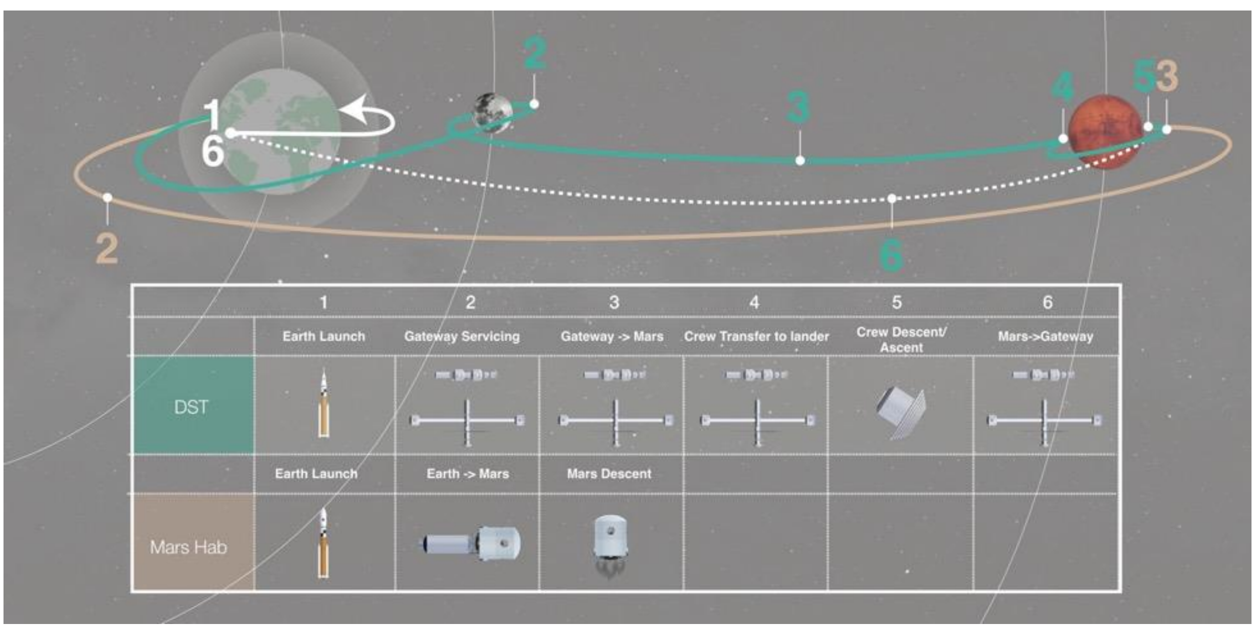

Fig 3: Top level concept of operations

V. Challenges

During the design process two main challenges were encountered; their solutions being key to commonality and safe haven applications. The importance of solving these challenges had a direct influence on the interior design layout of the habitat.

A. Challenge 1: Achieve Common Ports Configuration

The first challenge was to establish a common port configuration that could fit all of the gravity conditions. This challenge was of high importance as it influences the interior design layout for the surface and the deep space habitats. For example, the location of the CBM will influence the proximity of the medical operations area to an ingress path in case a crew member gets injured on the surface of Mars and needs to be placed immediately on the cot. Other aspects include the quantity, diversity and volumes of the connections. Another example is that a big window takes more space than a small window, but it is preferred in areas where you sit or restraint your body to relax and enjoy the actual or virtual view, versus a small window where it can be used for observation in laboratory operations. These points previously mentioned were just a few reasons why this challenge was important to resolve.

Before digging into the explanation of the two iterations for the port configuration it is important to clarify that common connections and common ports are not referred to the same thing. Common connections mean that the same type of “object” is connected to those openings, and common ports mean that even though the “objects” connected to those openings are different, the connection is the same.

The iterations mentioned previously are shown in the port analysis in Figure 4. The first iteration, shown on the first three columns on the left side of the graph, show only one common connection marked by one hexagon in each of the gravity conditions. Therefore, for the second iteration a modification to the surface habitat ports location was made, where the EVA crew lock was placed in the lower hatch of the habitat module, as shown on the 6th column row 3. This change also made it possible to transfer the rover and logistics module to the surface leaving the habitat module elevated. Making this shift in the second iteration made it viable to have 3 common connections instead of one, different from the first iteration, marked by 3 hexagons in each of the gravity conditions.

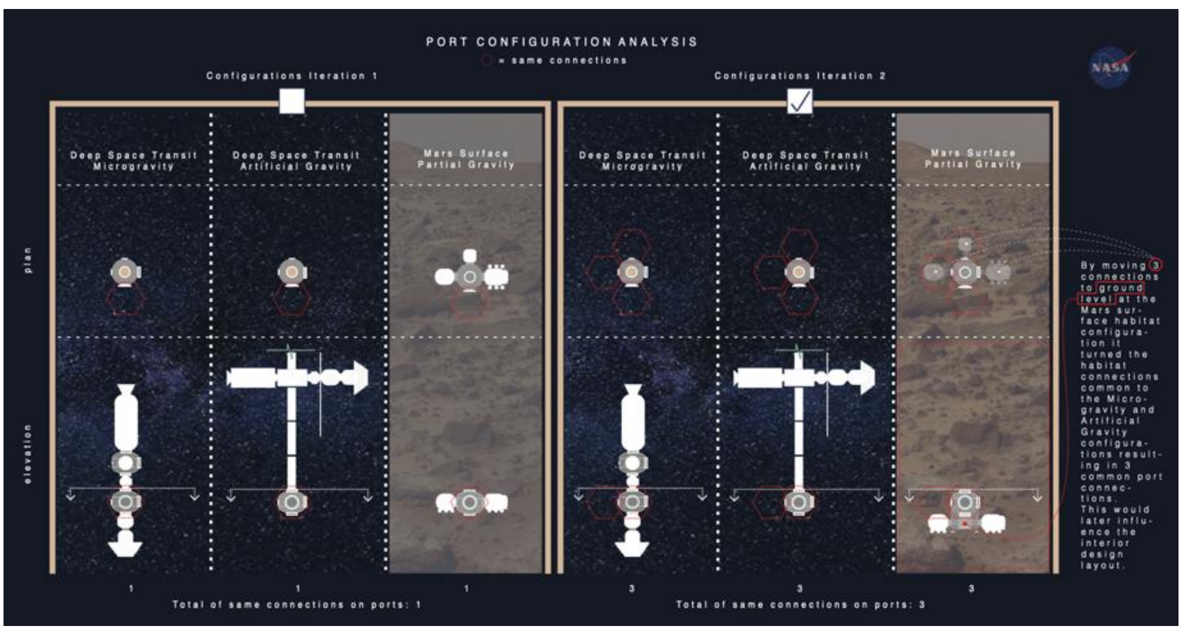

Fig 4: Port configuration analysis

As shown in the pink curbed bar in Figure 5, the 3 common connections for all gravity conditions are horizontally placed. These three common connections are 3 windows; one big and two smalls. The other 3 ports are commonly located for the 3 gravity conditions, although their connections differ as these are CBM’s, permitting distinct modules to be attached in either of those locations. Therefore, there are 6 fixed ports for the three gravity conditions, 3 common connections all being windows (two small and one big); and 3 common ports being CBMs.

Fig 5: 3 Common ports (CBM) & 3 common connections (windows)

Due to the port configuration analysis, the viable node configurations for the DST and Mars surface habitats were completed [Figure 6]. Figures 7, 8 and 9 show the types of components that the configurations contain. These configurations have been the result of the first resolved challenge.

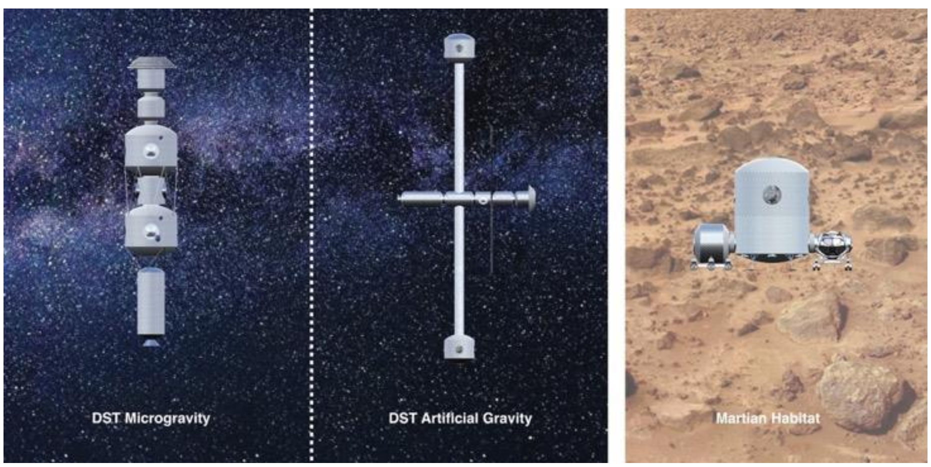

Fig 6: Nodes configurations for DST in MG (left), DST in AG (center) & the surface habitat in PG (right).

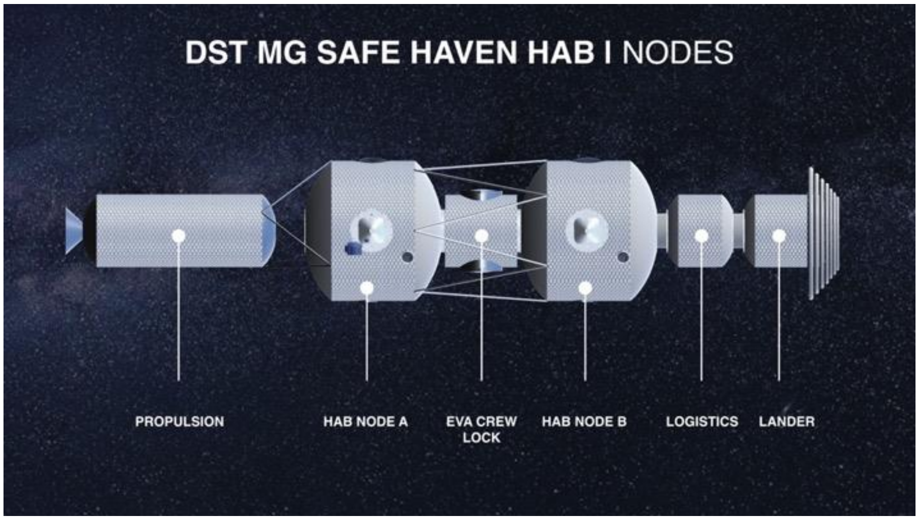

Fig 7: Components of the safe haven DST configuration

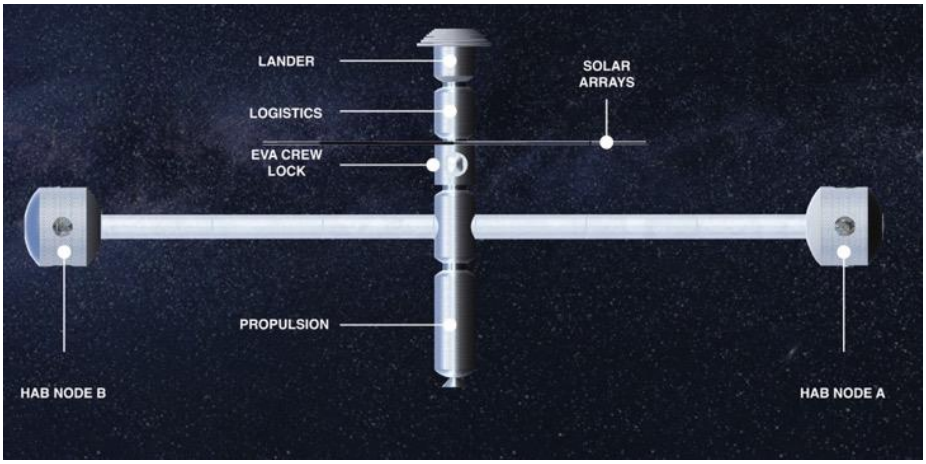

Fig 8: Components of the safe haven AG configuration

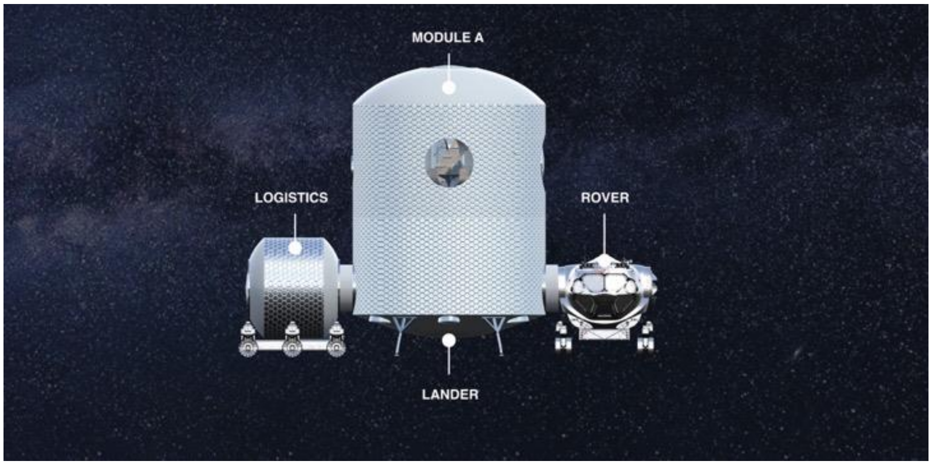

Fig 9: Components of the Mars surface configuration

B. Challenge 2: Achieve Safe Haven Functions Distribution for DST

The second challenge encountered was to achieve a safe haven function distribution in the two habitat modules of the deep space transit configurations; as shown in Figures 7 and 8. The first step towards being successful in the second challenge was to firstly identify the living and working functions. Once those were identified, then they were categorized between the ones critical for survival versus the ones that were not. The purpose of this categorization was to know which habitat functions critical for survival needed to be placed on both habitat nodes and which habitat functions not critical for survival needed to be distributed into the two nodes. This identification, categorization and distribution are shown in Figure 10.

	LIVING AREAS	WORKING AREAS	EXTRA
CRITICAL FOR SURVIVAL	Private Habitation	Maintenance	ECLSS
	Waste Collection		
	Meal Preparation		
	Medical Operations		
NOT CRITICAL FOR SURVIVAL	Exercise	Scientific Research	
	Hygiene	Robotics/teleoperations	
	Meal Consumption	EVA operations	
	Group Socialization and Recreation	Spacecraft monitoring and commanding	
		Mission Planning Logistics Operations	

Fig 10: DST safe haven functions analysis

Once the habitat functions were identified, categorized, and distributed, the two habitat nodes were named 'Node A' and 'Node B'. Node A has been deemed as the 'suite node', acquiring the one with the most living functional areas. Node B has been classified as the 'non-suite node', being the one with the least living functional areas, but more working functional areas. Figure 11 shows the location of both Node A and Node B in the DST and surface configurations. Additionally, as shown in Figure 11, the Martian surface habitat has been displayed as acquiring only the suite node, Node A. Figure 12 shows the specifics of the placement of the functions for survival and the distribution of the functions for none survival in both Node A and Node B. Notice the column for Node B, showing plus and negative signs, indicating which functions have been increased and decreased in area.

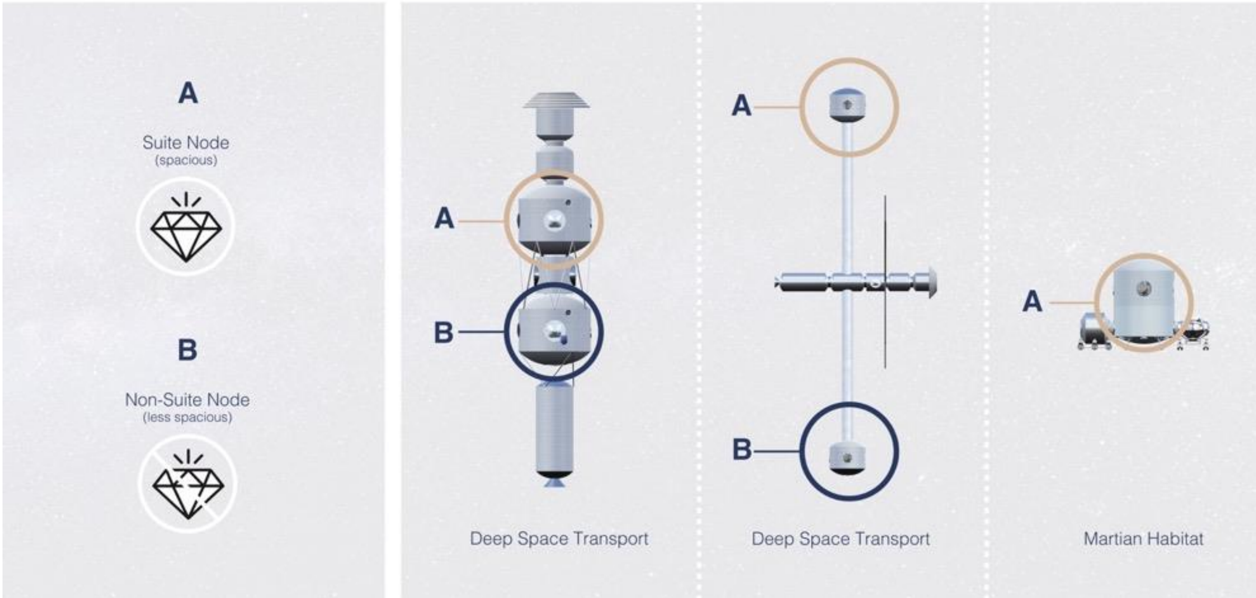

Fig 11: Habitat functions distribution in Node A and Node B

Fig 12: Safe haven habitat functions distribution in Node A and Node B

VI. Design Criteria

The design criteria include: adjacency of functions, human anthropometrics and biophilic design.

A. Adjacency of Functions

The relative locations of the space module functions were based on the results of a functional relationships analysis (Figure 13) derived from the space station functional relationships analysis [5]. The four categories considered were group versus individual, and private versus public.

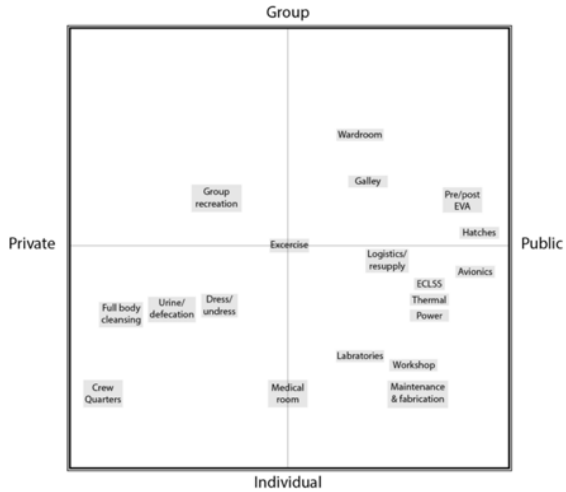

Fig 13: Relative locations of space module functions based on the results of functional relationship analysis

B. Human Anthropometrics

The interior design of the habitat was intended to be purely based on human centered design. For this reason, the human body became the main criteria for the dimensioning of the interior functions. However, due to time restraints commonality application in the interior habitat design was not completed in this study, but in a succeeding refinement study. Therefore, commonality in the smaller scale has not been investigated into detail in this paper. “Smaller scale” is referred to the components inside the habitat, such as the furniture, body restraints, vertical circulation, etc.

C. Biophilic Design

According to Merriam Webster, biophilia is the human tendency to interact or be closely associated with other forms of life in nature; a desire or tendency to commune with nature [6]. As our innate tendency is to seek connections with nature [7], wanting to live in a tin can is far from that. For this reason, the design was aimed to integrate materials, textures, organic forms applied on surfaces and locations for plants. Nature is proved to reduce stress and anxiety [8], critical factors that must be addressed for a long duration mission distant from our home, planet Earth.

VII. Habitat Interior Design Layout

A. Functions General Distribution

Both Nodes A and B of the common habitat have been divided into 3 levels: level 1 containing mainly the support systems, being public between crew members; level 2 containing living and working functions being communal spaces; and level 3 containing the crew quarters that are private. Figure 14 shows a section of the general distribution for each level.

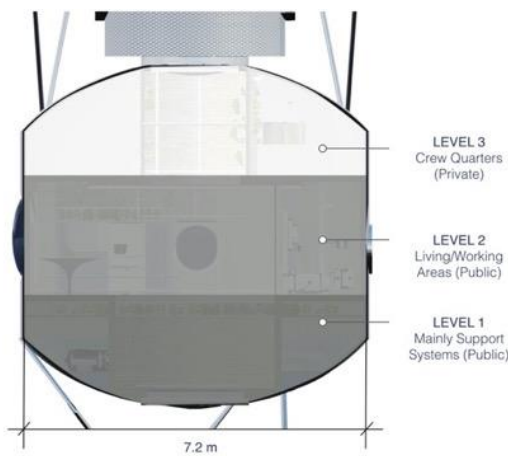

Fig 14: Common habitat general functions distribution between 3 levels

B. Plans

The following plans and sections will show the interior layout of Node A and Node B of the common habitat in MG. Nevertheless, it is important to point out that the habitat has some differences depending on its location, MG or PG/AG. These differences include: the central vertical circulation, which stairs have been placed in PG/AG and removed in MG; the seating is located only for PG and AG and removed in MG; and handlebars and body restraints are located for MG and removed in PG and AG. As a reminder, only Node A will be part of the Martian habitat, but both Node A and Node B will be used as the DST in MG and AG.

Level 1 [Figure 15] includes mainly the support systems as shown earlier [Figure 14], such as the nitrogen and oxygen tanks, a trash compactor, the environmental control and life support systems (ECLSS), stowage compartments above ECLSS and water storage underneath. These support areas are accessed from the central open space through a sliding door system. By having sliding doors, the doors do not occupy the central space when opened, leaving the central area clear for circulation. In MG there are foot restraints in front of the sliding doors so that the crew's body may be steady meanwhile managing the systems. In the same level [Figure 15] there is a CBM on the "floor" as an optional entrance for DST, but it is the main entrance for the Martian habitat. There are handlebars around the CBM (and all CBMs in the habitat) for a comfortable egress and ingress in MG. Level 1 in Node B is exactly the same as Node A, this is why transparency has been given on the right side of Figure 15 to create the effect of being unlit.

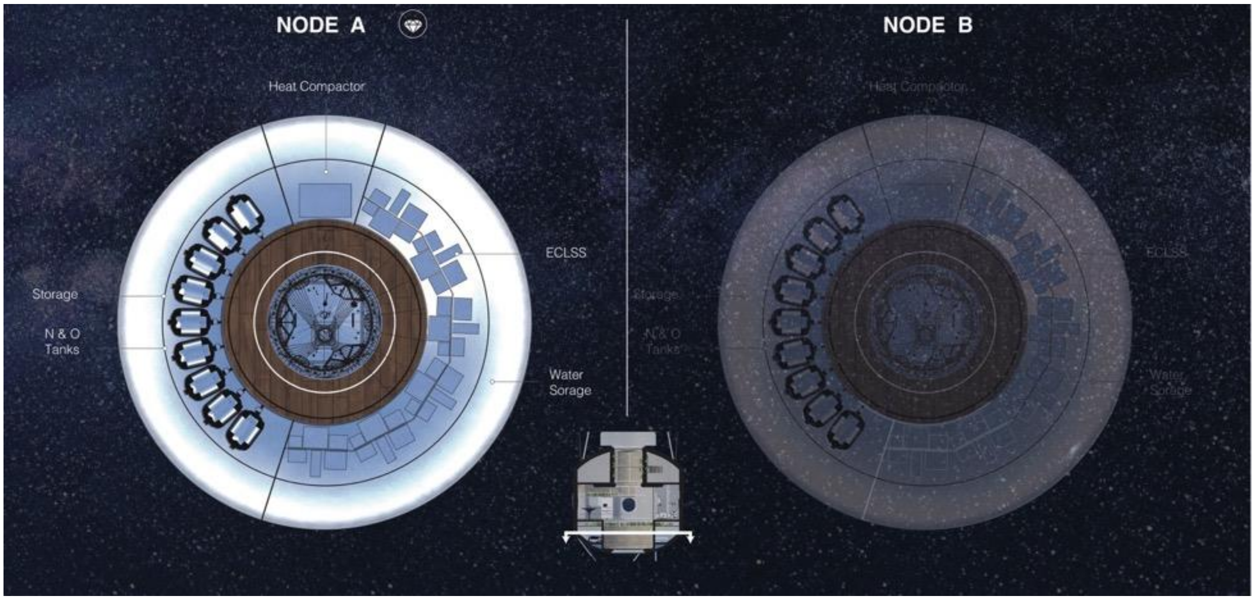

Fig 15: Level 1 plan layouts of Nodes A and B in MG showing mainly support systems.

As shown in Figure 16, there is also a plant chamber above all of the systems mentioned beforehand. These plants would be accessed easily through a series of tray system, where you can pull out the tray and maintain the plants.

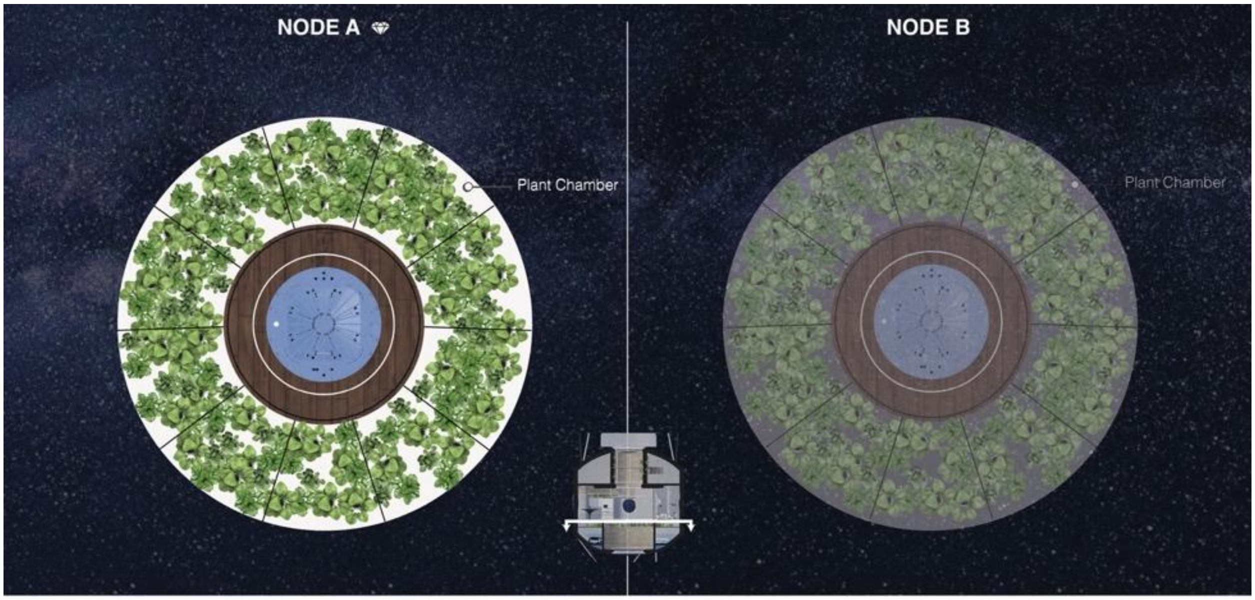

Fig 16: Level 1.75 plan layouts of Nodes A and B in MG showing plant chambers.

Once floating through the central vertical pathway or walking up the stairs along the wall in the case of PG or AG, you would reach level 2. (The stairs system for PG/AG will be further explained in more detail.) Figure 17 shows the plan layouts of Node A and B for level 2. As shown, both plans have been lighted, signifying that both nodes A and B in level 2 are different from each other. Starting with Node A [Figure 17] from the bottom of the plan, at "6 o' clock" and moving clockwise, there is the wardroom. At the wardroom a table is placed in front of a big window, where crew members may enjoy the actual or virtual view for relaxation as they are eating, socializing or meeting around the table. The table includes leg restraints for MG. The big window in front is capable of being completely transparent showing the actual view at the exterior (deep space or Martian landscapes), or it may also project an earthly view desired by the crew such as the woods, the beach, the sky, etc. as shown in Figure 38. The purpose of placing virtual windows has been to diminish stress levels by influencing the crew through biophilia effects, which is the human innate attraction to nature [9]. Additionally, it should be mentioned that this window and the other small windows mentioned further on are capable of being covered from the exterior galactical light through electrochromic technology [4], converting the interior of the spacecraft in an Earthly night environment following the circadian rhythm.

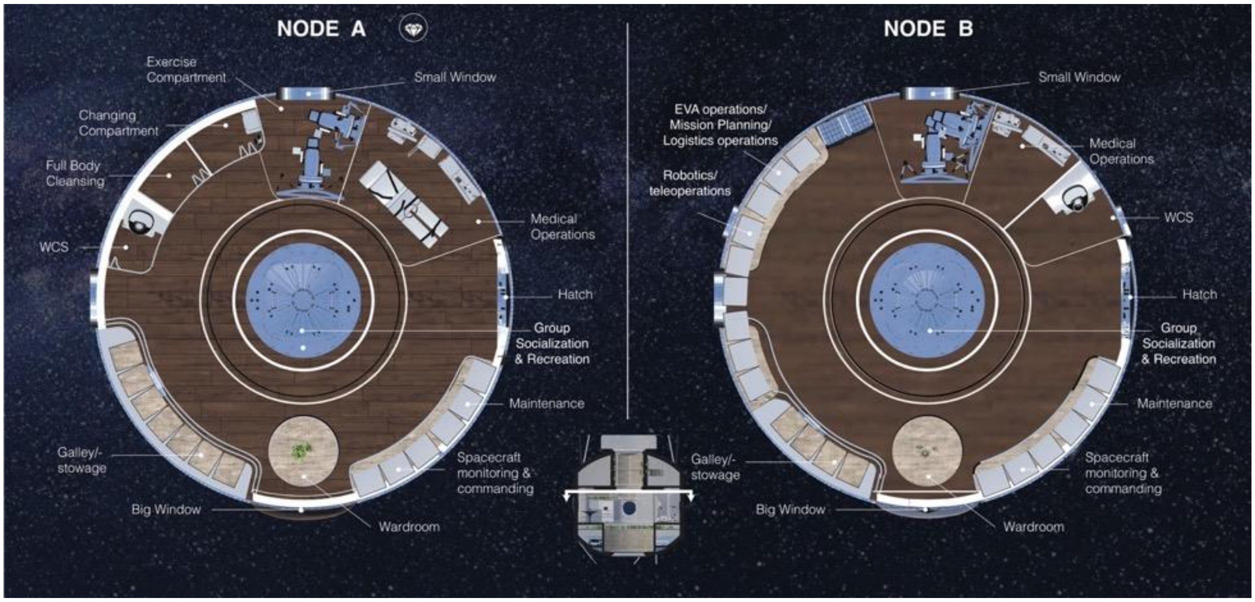

Fig 17: Level 2 plan layout of Nodes A and B in MG

Adjacent to the wardroom, at "7 and 8 o' clock" there is the galley area for meal preparation and food serving logistics. The galley includes systems that have already been developed for ISS [10], such as a re-hydration system using a water dispenser with heated or unheated water, food warmers and a refrigerator cooled by water flow. Mid-deck lockers have been placed on top and at the sides of the galley. Lockers have been chosen as opposed to the crew transfer bags, since it allows more stowage control and organization. As a side note, stowage around the habitat has been assumed to be tracked by a software system informing the crew members the zone and locker in which the object is found. Regarding leg restraints, they have been placed in the galley area for meal preparation purposes in MG; and handlebars have been located near the top part, where the lockers are for easy body control as they access the stowage.

A small window proceeds the galley area ("9 o' clock") dividing the galley from the hygiene compartment. This window serves the same purpose as the big window, where it helps to reduce stress diminishing the crew's feeling of enclosure providing the option to view outside or to project natural views. Additionally, it psychologically shortens the distance between the habitat's location and planet Earth. It should also be mentioned that handlebars have been located around the windows so that crew may hold on when looking outside in MG.

As previously mentioned, next to the small window the hygiene compartments are found, including the waste collection system (WCS), the full body cleansing compartment and the changing compartment. The full body cleansing is adjacent to the changing compartment since you can clean your body and then open the division wall and don/doff clothes. The reason why these last two compartments, the full body cleansing and the changing compartment are closer to "12 o' clock" than "9 o' clock" is due to the proximity of the exercise area which is at "12 o' clock". When the crew finishes exercising, they can access quickly those hygiene services, reducing the risk of contaminants around the habitat. Additionally, the hygiene compartments are placed on top of the support systems so that the connecting ducts and pipes run a short distance. The same reason goes for the galley area, which lays on top of the support systems.

As shown, there has been a small window integrated in the exercise compartment in front of the exercise machine in the enclosed space. The reasoning behind this is that as they exercise, they can be entertained by the real view outside in case the crew would not want to use the immersive virtual reality glasses which provide trekking trails for the treadmill, and other features adjusted to exercise activities.

As shown in Node A [Figure 17], the exercise compartment is located completely opposite from the galley, as that is preferable by previous astronauts in ISS and Skylab since the hygiene factor is better suited this way.

Adjacent to the exercise compartment is the medical operations area at "1 and 2 o' clock", which has direct access to the hatch located at "3 o' clock". The proximity to this hatch is in case an ill/injured person needs to be evacuated from the DST to an Earth descent vehicle. On the other hand, note that both the exercise compartment and the medical operations are enclosed by a thin partition wall, whereas the medical's partition wall is non-translucent for privacy and the exercise's is translucent to give the illusion of a larger space than it is. Lastly, the maintenance and spacecraft monitoring/commanding areas are located adjacent to the hatch at "4 and 5 o' clock". Above these areas lockers are placed for stowage.

As level 2 for Node A has been explained, continuously, the differences in Node B will be mentioned. As a reminder, Node B consists of more laboratory functions. Different from Node A, Node B has half of the area of the galley meanwhile the other half serves to be part of the teleoperations ("8 o' clock"). In replacement of the full hygiene compartment, the following areas have been placed, adjacent to the exercise equipment: robotics, EVA operations, mission planning/logistics operations and a glove box compartment. Due to the fact that the hygiene compartment has been replaced by the previously mentioned areas, only the WCS has been maintained, but relocated. Now the WCS is adjacent to the medical operations, shown at "2 o' clock" in Node B [Figure 17]. Also, different from Node A, Node B has half the medical operations area because the medical cot has been removed. It should be stated that just as in Node A, Node B also contains the appropriate leg restraint and handlebars appropriate for MG.

It is important to point out that the DST module configuration allows crew members to transfer easily from Node A to B. The transfer between nodes will occur during a safe-haven scenario, in daily activities such as full-body cleansing or in case the medical cot is needed. As an example, crew members owning crew quarters in Node B, will have to visit Node A for full-body cleansing or use the medical cot if needed.

Now, let's transfer to level 3 through the central vertical pathway, walking up the stairs in PG/AG or using handlebars for translation in MG. Due to the limited public floor area on level 3 in PG/AG, the stairs have an integrated system that rotates around and stops before the door of your requested room. The stairs have appropriate integrated railings securing the crew members from falling from their room in case they would slide open their doors and the stairs are not in front of their door. Figure 18 shows a diagram illustrating the rotation of the stairs. The number one in the diagram indicates the initial position of the stairs and the number two indicates the first moved position.

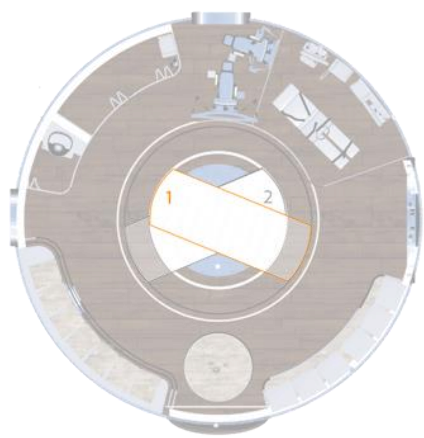

Fig 18: Diagram of stairs for artificial gravity and partial gravity

As shown in Figure 19, level 3 is composed of two crew quarters and 2 stowage rooms. When the conditions are normal and no emergency has occurred, the two rooms at "6 o' clock" in the plan are meant for stowage, and the two rooms at "12 o' clock" in the plan are crew quarters. The stowage rooms have a clear walkable/floatable space in the central part from where the "wall" area containing stowage can be fully accessed. On the other hand, the two crew quarters have their own private small window located near the sleeping area, so crew members can be distracted and entertained by the view of a living city, a seasonal forest or the real view of deep space or the Martian red-ish landscape.

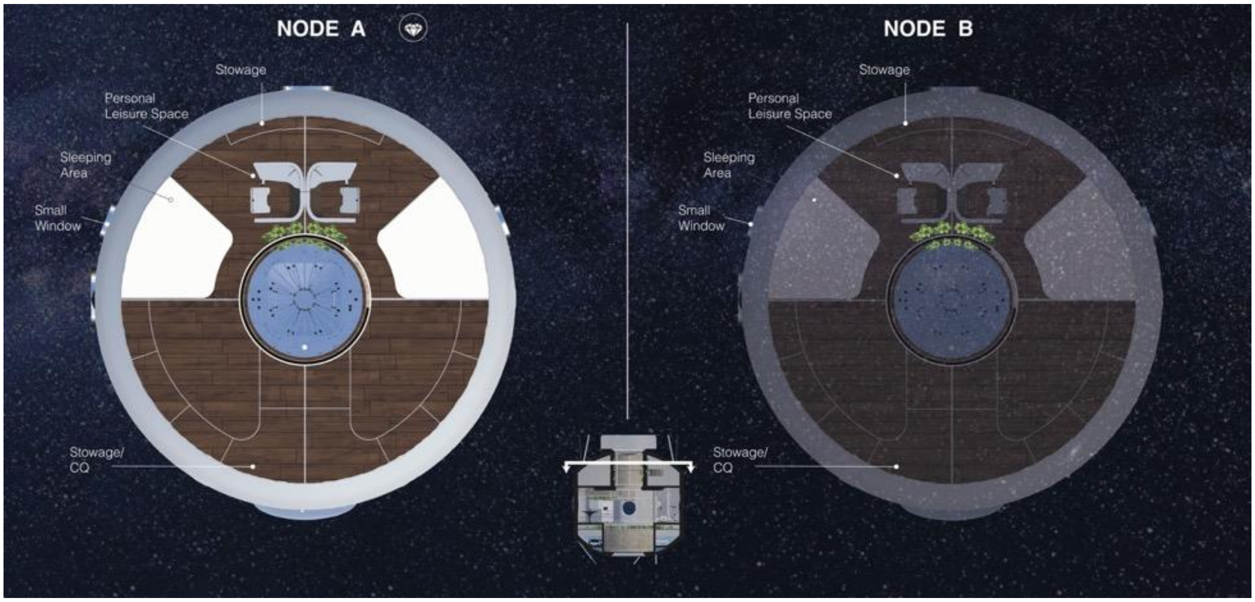

Fig 19: Level 3 plan layout of Nodes A and B in MG

Additionally, the crew quarters contain a private office-like area with furniture for leisure activities where when in PG/AG the crew can sit, or in MG they can restrain their body. The furniture has a table space allowing activities such as, but not limited to, placing a laptop, reading a book, writing, small scale projects, etc. Also, the crew quarters contain an area for personal stowage, and "wall" area so that they can personalize it with Earth memories, such as family pictures, tokens, among others. Furthermore, the room "walls" have the capability of containing a vertical personal "garden" where they can grow vegetables or flowers approved to be "flown" and contained in the volume of the room [11].

Although level 3 on both Nodes A and B are exactly the same, each node has the capability of transforming from 2 crew quarters into 4 in case of the depressurization of one of the nodes. In that case, the two stowage areas would be transformed into 2 extra crew quarters providing private places to sleep for each crew member. The stowage that would have been in those two rooms, would be moved inside the logistics module. Not only will the two stowage rooms serve for crew quarters in deep space, but they will be already outfitted as such for the surface Martian habitat, as the 4 crew members will be living there.

C. Sections

Figures 20 and 21 show the sections of Node A and B. Node A in Figure 20 shows the section looking towards "9 o' clock" in the plan, demonstrating the wardroom to the left, the full size galley behind, the small window at the center followed by the hygiene compartments and the exercise area on the right. Compared to Node A, Node B shows how the galley has been reduced in size, permitting more table space to the laboratory working functions all the way towards the boundary of the exercise area.

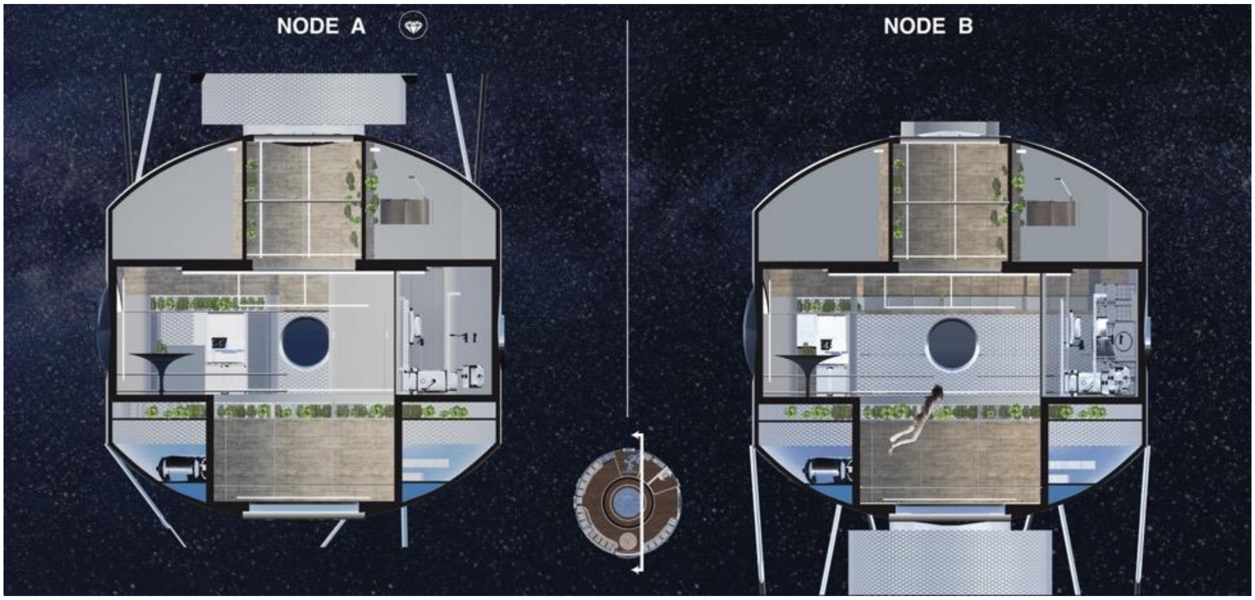

Fig 20: Sections of both Node A and Node B in MG

Figure 21 shows both Nodes A and B sections, but this time looking towards “6 o’ clock” of the plan where the big window is located in front of the wardroom table. The left of the section shows how the command and control area kept the same area size. Nevertheless, the only difference shown between the 2 nodes is the longitude of the galley and lab area. The galley in Node B is smaller than Node A, but the lab area in Node B is bigger than node A.

Regarding all of the sections shown in both Figures 20 and 21, openness can be perceived through the central triple height. This design decision was made so that the opened spacial sensation helps mitigate the adverse psychological stressor of being confined in a constrained environment. Additionally, vegetation is shown in both sections at different locations of the habitat, with the intention for the crew to feel live nature close to them, triggering the biophilia effect. In the same manner, the vegetation allows the advantage of growing crops for garnishing meals and consume.

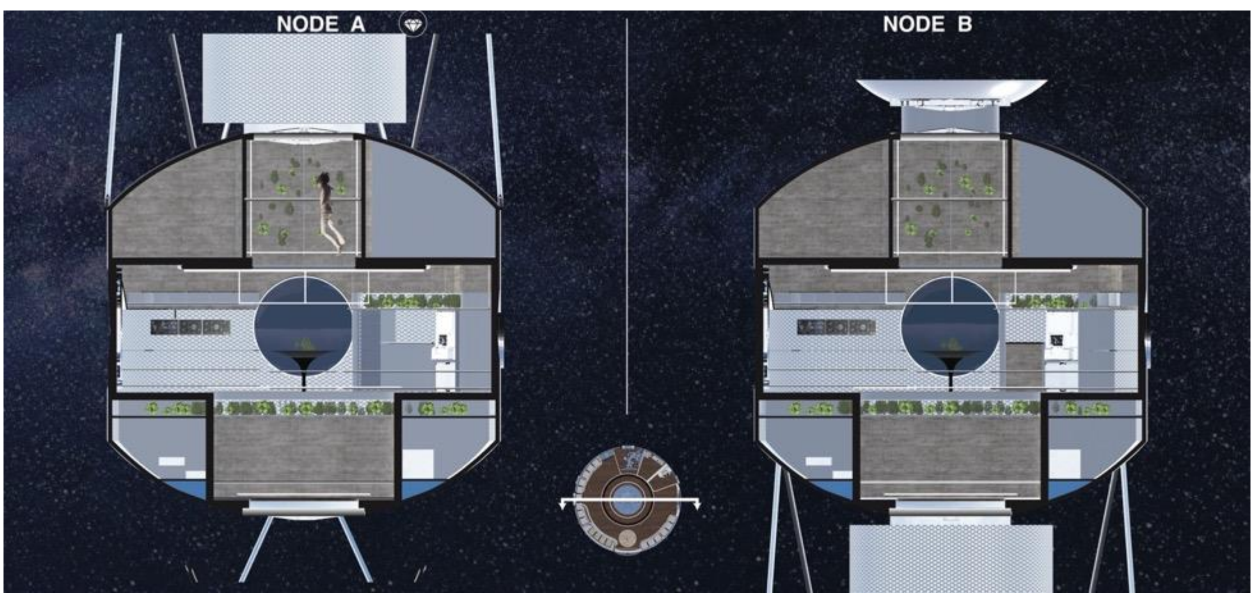

Fig 21: Sections of both Node A and Node B in MG

D. Materials and Lighting

The interior materials, textures and lightings for the common habitat have been carefully selected. It is important to state that the materials and textures shown inside the common habitat design would be a loyal graphical representation of the material but will not be the real material itself containing its natural component properties due to possible hazards such as, but not limited to, flammability. The graphical representation could be achieved through laminations of the materials or a printed image pasted on to a texturized material to create the appearance of the natural material depths.

Regarding the lightings inside the habitat, these have been chosen to be LEDs, which can be modified in distinct hue colors to follow the circadian light patterns. Additionally, the lighting can be changed as preferred by the crew members in their own private quarters or in the exercise compartment.

Furthermore, the LEDs have been integrated into the railings for MG, so that crew members may lead their way in the case that the windows have been covered from the exterior galactical light. Also, lighting has been integrated in other areas of the habitat such as the walls and beneath table spaces for functional reasons.

E. Visualizations

1. Renders in partial gravity and artificial gravity conditions:

Fig 22: View from Mars surface through the big window of the Martian habitat looking at the galley. [Node A-Level 2 - PG]

Fig 23: View from the small window located between the galley and the hygiene compartment. [Node A - Level 2 – PG]

Fig 24: View from the galley. [Node A - Level 2 - PG]

Fig 25: View from the spacecraft monitoring/commanding and maintenance areas. [Node A -Level 2 - PG]

Fig 26: View from the galley towards the vertical circulation. [Node A - Level 2 – AG]

Fig 27: View down the stairs from the entrance of a crew quarter towards level 2. [Node A/B - Level 3 - AG/PG]

2. Renders in microgravity conditions:

Fig 28: Section view towards the crew quarters, from the sleeping surface towards the stowage and leisure furniture. [Node A/B - Level 3 – MG]

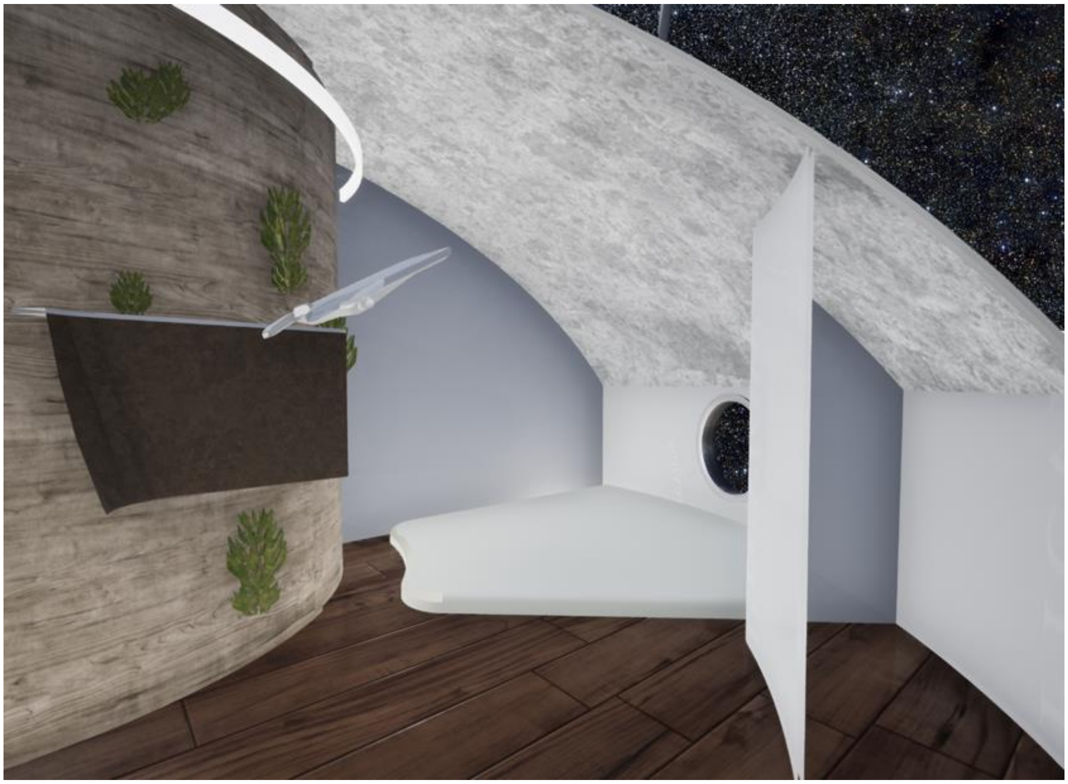

Fig 29: Section view towards the crew quarters from the stowage corner towards the sleeping area. [Node A/B - Level 3 – MG]

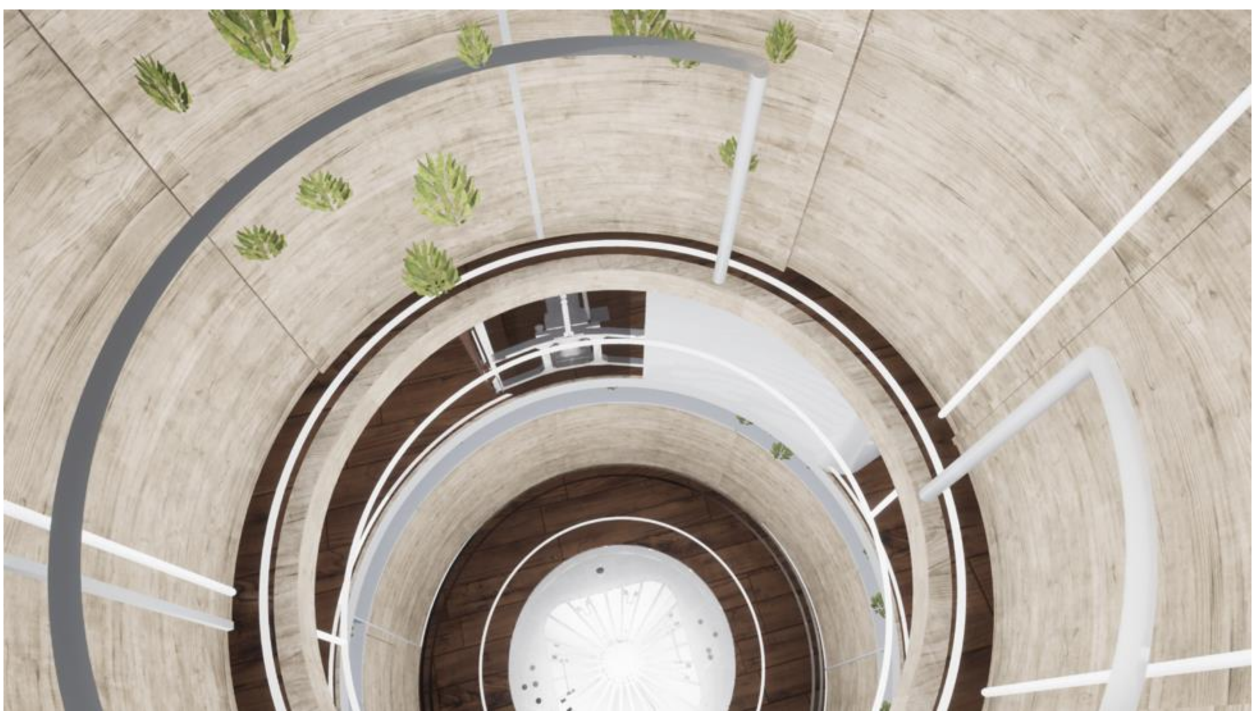

Fig 30: View from the "top" CBM, looking towards the lower most hatch in level 1. At the top, the entrances to the crew quarters and stowage rooms are shown. Additionally, a "vertical" garden is shown attached to the fixed walls where the pocket doors slide in. [Node A - Level 3 - MG]

Fig 31: View towards the plant chambers and support system sliding doors. [Node A - Level 1 - MG]

Fig 32: View from the "bottom" CBM towards levels 2 and 3. [Node A - Level 1 - MG]

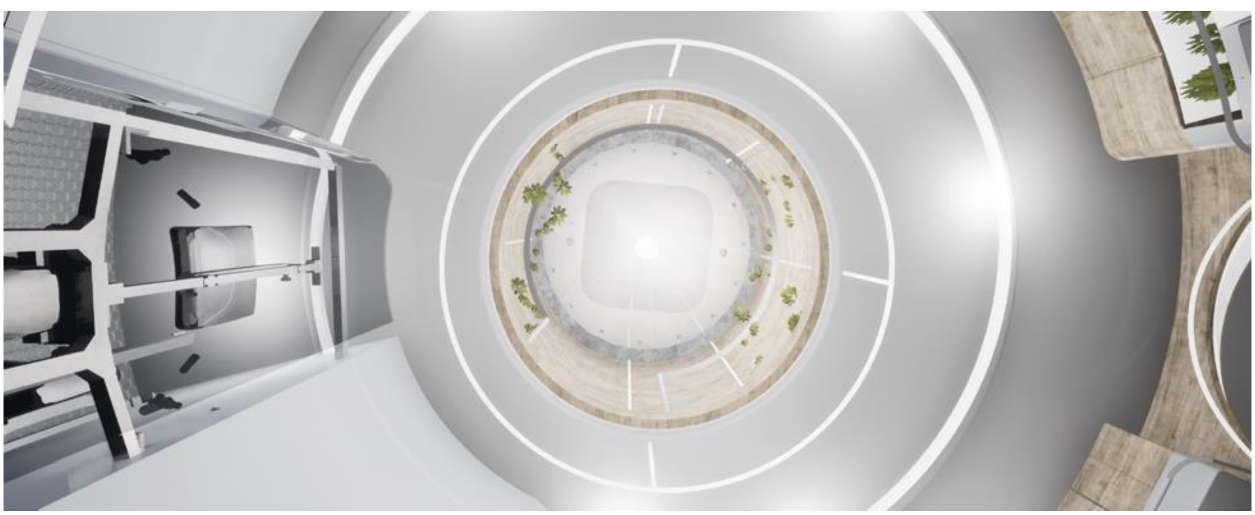

Fig 33: View from the central pathway in level 2, towards level 3. [Node A - Level 2 - MG]

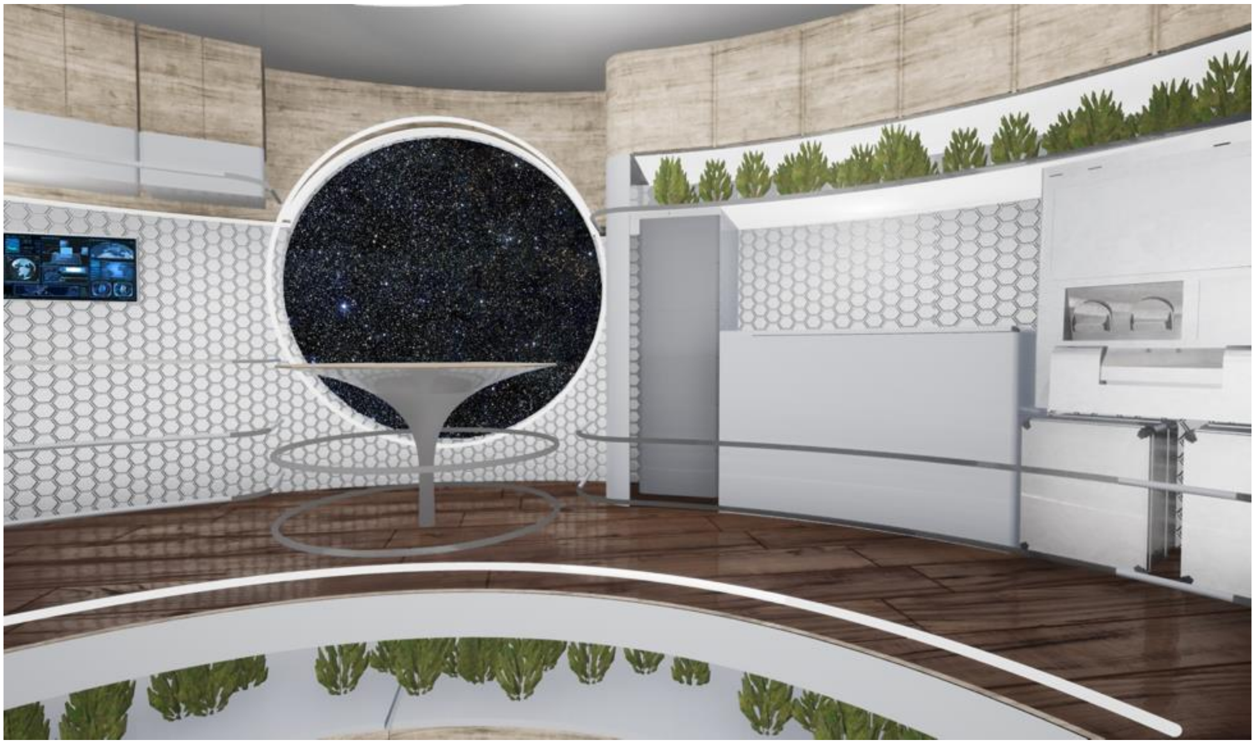

Fig 34: View from the central pathway towards part of the command/control area, galley and wardroom. [Node A - Level 2 -MG]

Fig 35: View from the hygiene compartments. [Node A - Level 2 - MG]

Fig 36: View from the wardroom towards the vertical circulation pathways. [Node A - Level 2 - MG]

Fig 37: View from the CBM located in level 2. The windows are showing the real view. [Node A - Level 2 - MG]

Fig 38: View from the CBM located in level 2. The windows are projecting an Earthly view. [Node A - Level 2 - MG]

Fig 39: View towards the laboratory area, where it has replaced half of the galley area and the hygiene compartments. [Node B - Level 2 - MG]

Fig 40: View towards the relocated WCS and the reduced area of the medical compartment in Node B. [Node B - Level 2 - MG]

VIII. Methods and Software Utilized as a Tool for Designing

The software utilized to generate the initial CAD, 2D plans and 3D models, was Rhinoceros 3D. Afterwards 3D Max was used to place the UVW mapping on the 3D model. Later, the 3D models were imported inside the gaming software called Unreal Engine (UE) to apply material, textures, lighting, etc. Once the environment was created inside the UE world then the illustrated plans, sections and renders were exported. As a final touch the images were imported into Adobe Photoshop for some final touches. Lastly, the final presentation and diagrams were completed in Adobe Illustrator, and the technical paper was written in Microsoft Word.

IX. Way forward

As part of the way forward, this conceptual common habitat design for microgravity, artificial gravity and partial gravity has been studied and evaluated by the multidisciplinary team at the Advanced Concepts Office at MSFC. The purpose of the evaluation has been to verify and test the viability of commonality for the common habitat areas to function in the three gravity conditions. The viability is being verified through human factors assessments based on the chosen design criteria: human body orientation, human anthropometrics, and the geometry and volume required within the living space. Additionally, the design refinement is being developed based on the design tool created grounded on the design criteria: a catalogue of design requirements for partial gravity and microgravity.

As part of the assessments, a multidisciplinary collaboration between the Advanced Concepts Office and the Human Factors Team has been held at the Virtual Reality Laboratory at MSFC, where the 3D models of the three habitat configurations (MG, AG and PG) have been imported into the immersive virtual world as a tool for evaluations and human factors assessments for further design refinement and multi-purpose applications.

A 1:1 mockup construction of the habitat and its components must be built and tested by astronauts in the three gravity environments, to finally conclude that it can serve for future missions. Also, through testing it physically it can be confirmed that astronaut training is simplified and the time to adapt to the habitats is reduced.

Furthermore, an analysis quantifying the cost benefits of the habitat after the refinement must be completed in order to conclude commonality is applicable and cost effective for future manned missions. The cost analysis method developed by the Mars Evolvable Campaign is considered to be used for the common habitat cost quantification.

X. Conclusion

In conclusion, the previous habitat study has been grounded on the practice of commonality applications. The common ports configuration for the habitat in AG, MG and PG was completed. Also, the distribution of the interior habitat areas/functions for DST was completed to achieve a safe haven configuration. This means that a layout of the habitat functions for PG, MG and AG was also established.

However, as common does not equal identical, but only the share of features or attributes, the final product of this study showed minor differences in the habitat interior components when in different gravity conditions. Therefore, the habitat demonstrated that it is not completely identical in all scenarios, as there are differences in aspects such as vertical circulation, seats, body restraints, handlebars, etc. Nevertheless, the habitat showed the potential for the interior components to be designed with multi-uses serving all gravity conditions.

Acknowledgments

Paola Gonzalez thanks the co-author, David Smitherman, for his initial proposal of investigating commonality applied in deep space and surface habitats. Paola also thanks Justin Rowe for collaborating and contributing with expertise within artificial gravity applications; and Tanya Andrews for opening collaboration with the Human Factors Team to further test and evaluate the habitat. A special thanks to the Advanced Concepts Office at NASA Marshall Space Flight Center for supporting research endeavors within common habitats.

References

[1] NASA [2019]. Apollo's legacy is NASA's future. [Accessed: 07.04.2020]. https://www.nasa.gov/specials/apollo50th/ back.html

[2] B.N. Griffin, R.Lepsh, J. Martin, R.Howard, M. Rucker,E.Zapata, C. McCleskey, S.Howe, N. Mary, P. Nerren [2015]. Small habitat commonality reduces cost for human mars missions. https://ntrs.nasa.gov/search.jsp?R=20150021413 (NASA, 2019)

[3] Lexico [2020]. Commonality. [Accessed: 26.02.2020]. https://www.lexico.com/en/definition/commonality

[4] D. Driscoll [2017]. Electronically dimmable aircraft windows. [Accessed: 08.04.2020]. https://www.aerodefensetech.com/component/content/article/adt/features/articles/27502

[5] T.S., T. and Bied [n.d.]. Mdc h2068, space station functional relationships analysis - final technical report mcdonnell douglas astrona 2-86. [Accessed: 22.04.2020].

[6] Merriam-Webster [n.d.]. Biophilia. [Accessed: 22.04.2020]. https://www.merriam-webster.com/dictionary/biophilia

[7] Britannica [n.d.]. Biophilia hypothesis. [Accessed: 22.04.2020]. https://www.britannica.com/science/biophilia-hypothesis

[8] Spend Time in Nature to Reduce Stress and Anxiety [n.d.]. [Accessed: 22.04.2020]. https://www.heart.org/en/healthy-living/healthy-lifestyle/stress-management/spend- time-in-nature-to-reduce-stress-and-anxiety

[9] Oliver Heath Design [2020]. Biophilic design – connecting with nature to improve health & wellbeing. [Accessed: 08.04.2020]. https:// www.oliverheath.com/ biophilic-design-connecting-nature-improve-health-well/

[10] C. L. Mansfield [2008]. International space station. [Accessed: 08.04.2020]. https://www.nasa.gov/mission\ pages/station/behindscenes/126\ payload.html

[11] Wikipedia [2020d]. Plants in space. [Accessed: 08.04.2020]. https:// en.wikipedia.org/ wiki/ Plants\ in\ space

[12] Howard, R., "Opportunities and Challenges of a Common Habitat for Transit and Surface Operations," IEEE, 2019.

[13] Polsgrove, T.P., Waggoner, J.D., Smitherman, D.V., and Percy, T.K., "Transit Habitat Design for Mars Exploration," AIAA, 2018.

[14] Polsgrove, T.P., Waggoner, J.D., Smitherman, D.V., and Percy, T.K., "Transit Habitat Design for Mars Exploration," AIAA, 2018.
[15] Rowe, J., "Artificial Gravity in Mars Orbit for Crew Acclimation," NASA.
[16] Kelly, B.K. "Living and Working in Space," NASA, 2019.
[17] Smitherman, D.V., Polsgrove, T.P., Rowe, J., "Safe Haven Configurations for Deep Space Transit Habitats," AIAA, 2017.
[18] NASA, "NASA Space Flight Human-System Standard, Volume 2: Human Factors, Habitability, and Environmental Health," NASA, 2015.
[19] NASA, "Human Integration Design Handbook," NASA, 2010.
[20] NASA, "Human Integration Design Handbook," NASA, 2014.
[21] Cohen, M., "Habitat Distinctions: Planetary versus Interplanetary Architecture" AIAA, 1996.
[22] B.N. Griffin, R.Lepsh, J. Martin, R.Howard, M. Rucker,E.Zapata, C. McCleskey, S.Howe, N. Mary, P. Nerren [2015]. Small habitat commonality reduces cost for human mars missions. AIAA, 2015.