Habitation Concepts For Human Missions Beyond Low-Earth-Orbit

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The Advanced Concepts Office at the NASA Marshall Space Flight Center has been engaged for several years in a variety of study activities to help define various options for deep space habitation. This work includes study activities supporting asteroid, lunar and Mars mission activities for the Human spaceflight Architecture Team (HAT), the Deep Space Habitat (DSH) project, and the Exploration Augmentation Module (EAM) project through the NASA Advanced Exploration Systems (AES) Program. The missions under consideration required human habitation beyond low-Earth-orbit (LEO) including deep space habitation in the lunar vicinity to support asteroid retrieval missions, human and robotic lunar surface missions, deep space research facilities, Mars vehicle servicing, and Mars transit missions. Additional considerations included international interest and near term capabilities through the International Space Station (ISS) and Space Launch System (SLS) programs. A variety of habitat layouts have been considered, including those derived from the existing ISS systems, those that could be fabricated from SLS components, and other approaches. This paper presents an overview of several leading designs explored in late fiscal year (FY) 2015 for asteroid, lunar, and Mars mission habitats and identifies some of the known advantages and disadvantages inherent in each. Key findings indicate that module diameters larger than those used for ISS can offer lighter structures per unit volume, and sufficient volume to accommodate consumables for long-duration missions in deep space. The information provided with the findings includes mass and volume data that should be helpful to future exploration mission planning and deep space habitat design efforts.

I. Introduction

THE human missions beyond LEO considered include establishment of a deep space habitation capability in the cislunar vicinity. Cislunar typically refers to a location between the Earth and the Moon, such as the Earth-Moon Lagrange point 1 (EML1), but for the purposes of recent studies, also includes the lunar vicinity shown in Figure 1—EML1, EML2, lunar distant retrograde orbits (DRO), and other orbits around or near the Moon. The lunar DRO is the baseline destination for the concepts presented here because it is a stable orbit that requires little orbital maintenance, and was identified as the final destination for recent asteroid retrieval mission scenarios.[1] In addition, a facility in a lunar DRO can act as a transportation hub for other asteroid missions, lander access to the lunar surface, and vehicle assembly and servicing for large Mars transit missions.

SLS will provide a capability in the 2020s to launch habitable volumes as co-manifested payloads with the crew using the Orion and its service module for propulsion, and dedicated payloads without the crew using built-in or attached propulsion elements. The payload mass difference between the two approaches is on the order of 10 mt for co-manifested payloads, and 40 mt for dedicated payloads delivered on trajectories to cislunar space. The co-manifested payload option was explored last year and is summarized in the paper "Space Launch System Co-Manifested Payload Options For Habitation"[2] indicating that habitable volume can be built up with small, ISS-sized modules, but that larger dedicated payloads seem more efficient by providing more volume per unit mass, and significantly reducing the number of launches required to build up a habitation capability. The emphasis for this paper is on a variety of options for the larger habitat in an SLS 1b payload configuration.

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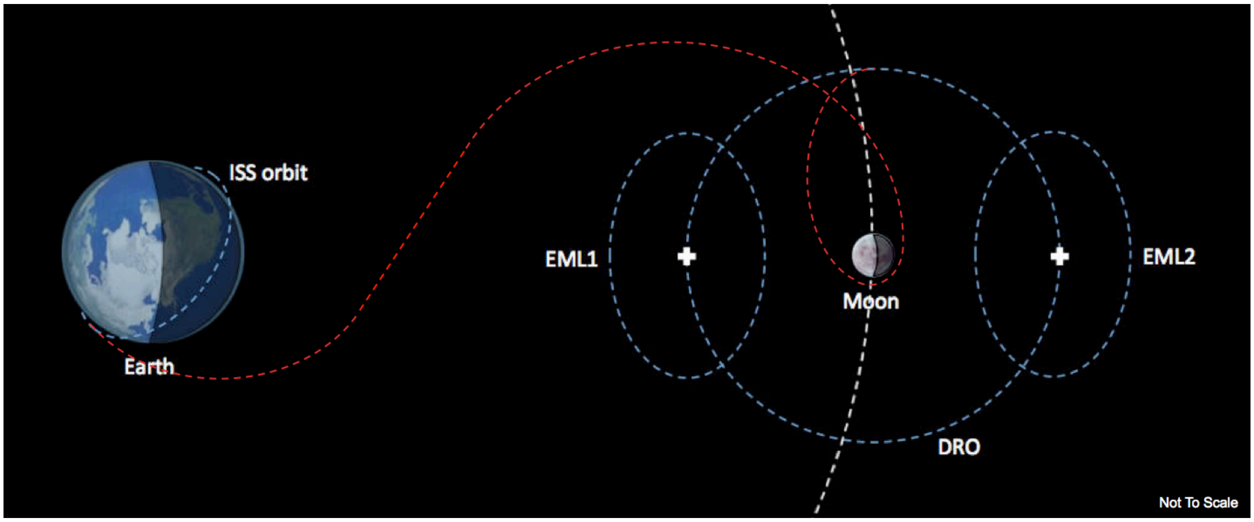


Figure 1. Cislunar Vicinity. *The Lunar DRO is the final destination for each configuration depicted. The SLS 1b and EUS deliver their payloads through TLI in route to the Moon. The Orion service module or an attached propulsion stage is utilized to complete the propulsive maneuvers required around the Moon and into the Lunar DRO.*

II. SLS Payload Configurations

The SLS co-manifested payloads are delivered with the Orion through the trans-lunar injection (TLI) burn by the Exploration Upper Stage (EUS). With the payload still attached to the EUS, the Universal Stage Adapter (USA) 2 fairing is jettisoned and the Orion rotates to dock with the payload. After docking, the EUS releases the payload and the Orion service module delivers the payload to the lunar DRO destination. The SLS payload delivery flights are simpler, but each requires an attached propulsion bus with the payload to complete the delivery from the end of the EUS TLI burn to the final destination in the lunar DRO.

Figures 2 and 3 show the SLS vehicle configurations and corresponding payload configurations. An SLS 1b with the Orion crew module uses a USA2 payload fairing between the Orion and the EUS to deliver the first two elements of the cislunar habitat configuration under consideration for the lunar DRO. Both the Augmentation Service Module (ASM) and the Docking Module (DM) were sized to fit within an assumed 10-mt co-manifested payload mass goal. The payload mass budget was found to be tight for both elements. For the ASM, the amount of logistics and pressurized module size could vary depending on the amount of propellant loaded into the service module's propulsion bus. For the DM, delivery of the robotic arm was an open issue that could be manifested on a separate logistics flight. Issues like logistics and outfitting for the co-manifested payloads are covered in the co-manifested payload paper referenced.[2]

The four SLS 1b payload configurations used different fairing configurations to fit each of the habitat designs. A long 5.5 m diameter habitat module uses the SLS Long Fairing; a 7.2 m diameter habitat module uses the SLS Short Fairing; and an 8.4 m diameter habitat module uses two configurations: a nose cone only, and a 10 m diameter fairing. The standard SLS fairings are the same diameter as the core stage (8.4 m in diameter), 90 feet long for the Long Fairing, and 67 feet long for the Short Fairing. The Long Fairing and the large 10 m diameter fairing shown bring the SLS vehicle height close to the maximum height available to fit inside the vertical assembly building (VAB) at the Kennedy Space Center (KSC). The two 8.4 m diameter habitat launch configurations were explored because it was found that the un-shrouded configuration placed the habitat module in the primary launch-loads path and subjected it to local pressure loads which increased the structural mass when compared to the same module packaged inside the 10 m diameter payload fairing.

As noted, propulsion capability beyond the TLI burn is required to maneuver around the Moon and into the lunar DRO orbit. This is accomplished using the Orion service module for the two co-manifested payloads shown. The propulsion bus on the ASM is required only to do station keeping of the built-up stack in the lunar DRO. The 5.5m diameter habitat uses a similar propulsion element for delivery, and the 7.2 and 8.4 m diameter habitats use a propulsion system built into an 8.4 m diameter skirt, the same diameter as the EUS stage below.

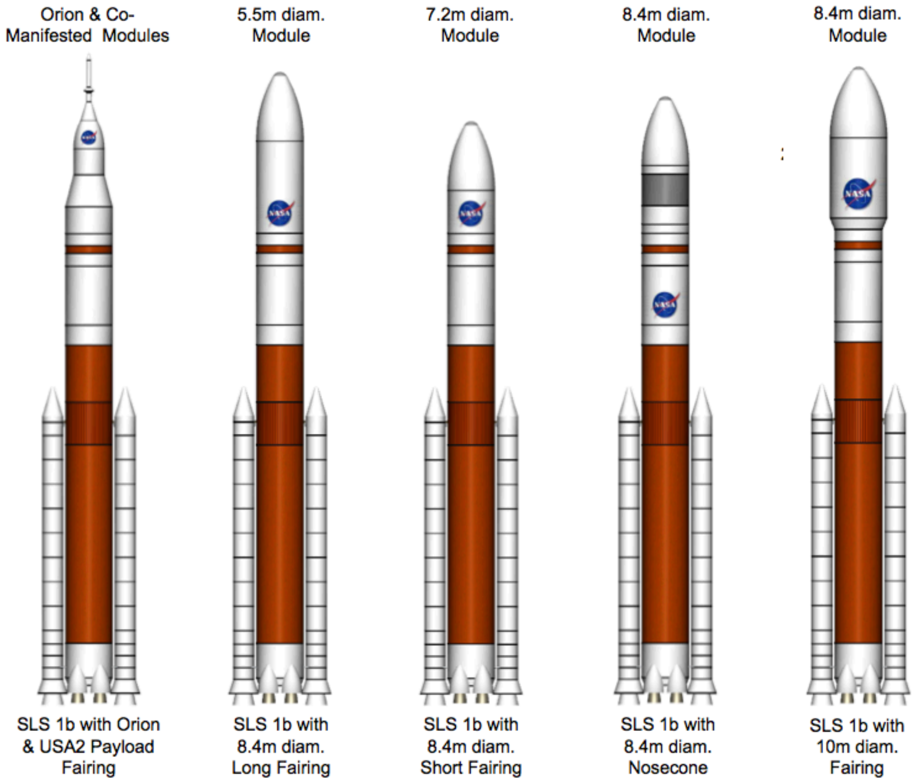


Figure 2. SLS Co-Manifested And Dedicated Payload Vehicle Configurations. *Five payload configurations were explored to accommodate a variety of habitat options for this study.*

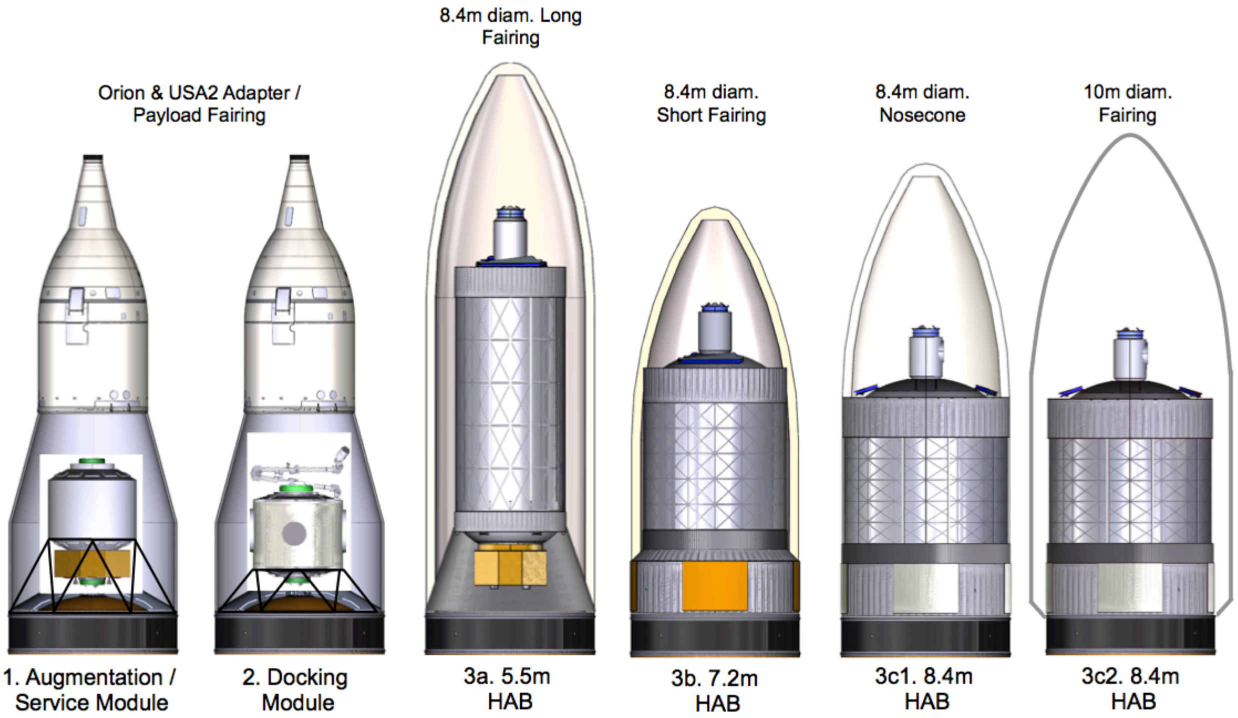


Figure 3. SLS Co-Manifested And Dedicated Payload Configurations. *Two co-manifested elements and one of three large habitats complete the configuration planned for the lunar DRO.*

III. Build Sequence

The build sequence for the cislunar habitat in the lunar DRO is the same for each of the three large habitats examined here. Figure 4 provides a depiction of the build sequence using the 7.2 m diameter habitat; however, the same sequence is applicable to both the 5.5 m diameter and 8.4m diameter habitats.

The first element is the ASM, which is delivered by the Orion with the crew to the lunar DRO. It provides a small habitable volume for logistics and open-loop environmental control and life support system (ECLSS) to supplement the capabilities of the Orion. Each flight has the open-loop ECLSS provision to protect the reserves on the Orion and provide an approach to longer duration missions during the build sequence. The propulsion bus was sized for basic station keeping of the entire stack in the lunar DRO and includes a pressurized tunnel and docking port to permit docking at either end of the ASM. Propellant loads could vary, but a capability for refueling was considered along with relocation of the entire stack across the lunar DRO orbit in the event that the asteroid retrieval vehicle arrived much later and in a different orbit.

The second element is the DM and is also delivered by the Orion with the crew to the lunar DRO. The docking module provides both NASA Docking System (NDS) and Common Berthing Mechanism (CBM) ports with pressurized mating adapters similar to the ISS standard. This permits both docking by the Orion for crew transfers and berthing using a robotic arm for logistics transfers and interior circulation with utility feed-through for the habitable volumes. Adoption of the larger CBM standard with the 50 x 50 inch hatch is an important Mars-forward feature that will aid in the refurbishment of the large Mars-transit habitats between missions and adaption to future surface docking systems using a 50 x 60 inch step-through hatch. In addition, the DM includes an EVA hatch for contingency purposes only so it can serve as an airlock if needed.

The third element is a large habitat or HAB, which is delivered on a payload flight by the SLS. Included with the payload, an attached propulsion stage provides propulsion beyond the EUS TLI burn for transfer around the Moon and into the lunar DRO. Three diameters were analyzed for the large HAB element, 5.5 m, 7.2 m, and 8.4 m. The large HAB supports a crew of 4 for 1000 days when fully outfitted with provisions.

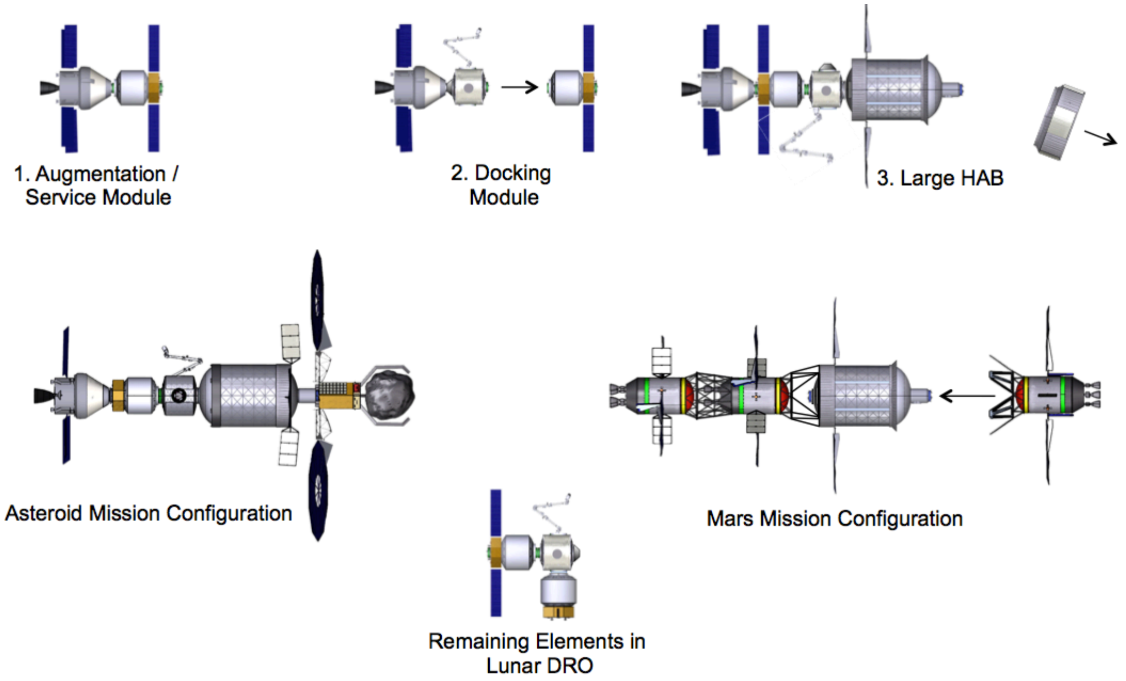


Figure 4. Build Sequence. *The build sequence for a cislunar facility in deep space begins with a Service Module, Docking Module, and a Large Habitat. The configuration can support a 300-Day Demonstration mission, Asteroid Mission, and be assembled into a Mars Mission configuration for Mars transit. Remaining elements include the Service Module, Docking Module, and any attached logistics modules, which provide a station to support ongoing activities in the lunar vicinity.*

A. Asteroid Vehicle Configuration

The asteroid mission assumes that an Asteroid Retrieval Vehicle (ARV) will return a small asteroid or boulder from an asteroid to the lunar DRO in the mid to late 2020s for exploration by a crew. Figure 5 depicts the cislunar facility attached to the ARV for exploration. The large HAB includes an airlock at the end with an NDS and an adapter for ARV attachment. The airlock provides easy access for astronauts to conduct extravehicular activities (EVA) on the asteroid, collecting samples and setting up experiments for potential in situ resource utilization (ISRU) activities.

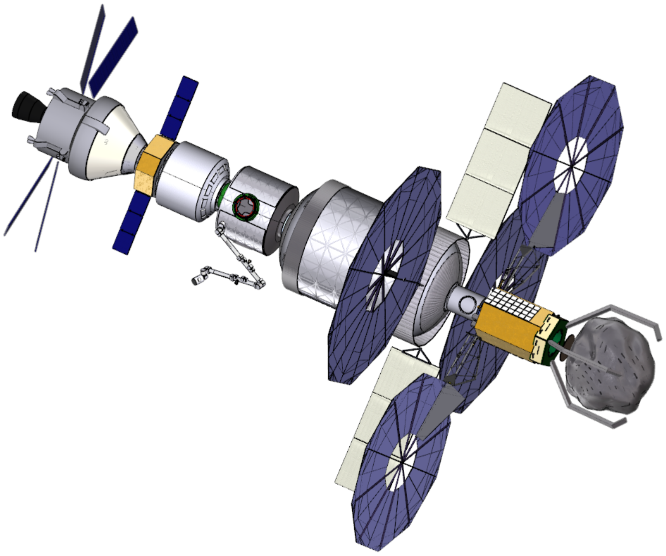


Figure 5. Asteroid Vehicle Configuration. *The Orion is shown docked to the Service Module, and the entire cislunar habitat is shown docked to the Asteroid Retrieval Vehicle at the airlock end of the large HAB.*

B. 300-Day Mission Configuration

Figure 6 shows the 300-day mission configuration using the completed cislunar facility. The intent is to demonstrate long-duration missions completely independent from Earth in preparation for Mars-transit missions. A variety of configurations have been studied, including large habitats without the Orion attached and utilizing solar electric propulsion (SEP) systems derived from the ARV in place of the Service Module.

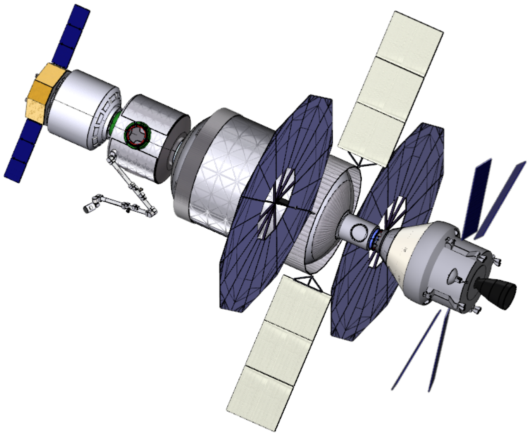


Figure 6. 300-Day Mission Configuration. *An objective for the cislunar facility is to conduct long-duration missions to demonstrate Mars transit mission capabilities independent of Earth. A variety of configurations have been considered using the large HABs described in this paper.*

C. Mars Vehicle Configuration

The Mars transit vehicle configuration shown in Figure 7 includes a large HAB and two propulsion stages for the trans-Mars injection (TMI) and Mars orbital insertion (MOI) maneuvers. In the transportation concept proposed, a return trans-Earth injection (TEI) stage is prepositioned in Mars orbit along with landers and other assets depending on the overall mission objectives. The large habitat designs depicted here demonstrate Mars mission capabilities with a mass goal in the lower 40 mt range (40 mt to 43 mt), so the use of the same habitat as shown for the demonstration mission is still an open question as additional requirements are developed and mission scenarios refined.

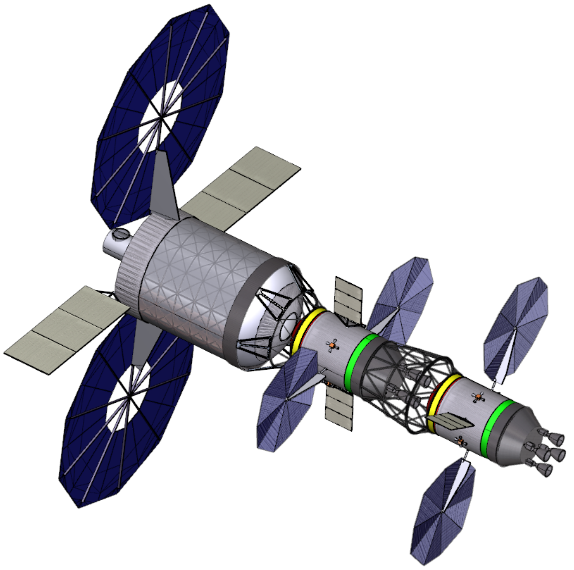


Figure 7. Mars Vehicle Configuration. *The large HAB shown here is in a Mars transit vehicle configuration with the TMI and MOI propulsion stages attached. In this scenario, a prepositioned TEI stage is located in Mars orbit for the return trip.*

IV. Habitat Layouts

A variety of internal layouts were explored for several different module diameters to begin understanding the internal packaging and launch configuration issues for each. The following sections provide an overview of some of the layouts explored for a 5.5 m, 7.2 m, and 8.4 m diameter habitat module as depicted in Figure 3 above for the packaging of payloads on the SLS.

A. 5.5 m Diameter Habitat Modules

Figures 8 and 9 provide plan and section layouts for what is described as a horizontal layout for a 5.5m diameter module. This means the cylinder section is horizontal in relation to the floor layout. A two-level layout is shown that places the utility systems and exercise area on the lower deck; the crew work areas, galley, and sleeping quarters on the upper deck. Additional floor to ceiling height will likely be necessary in the exercise area. Solutions include moving that function to the upper deck, or reversing the orientation of the lower deck to extend the ceiling volume to the outer cylinder wall. The end domes are open and used for translation between decks and provide access to an airlock at one end and docking ports at each end. Several important findings from this configuration are as follows:

Positive findings include:

1) The overall layout is workable from a habitability perspective for supporting a crew of four over the 1000-day Mars transit mission.
2) The overall mass summary provided in Figure 14, configuration 3a, indicates that the module is within the range needed for Mars transit missions.
3) Manufacturing capability is available for 5.5 m diameter modules based on Ares I upper stage and other propellant tank developments.

Negative findings include:

1) Stowage volumes are shown behind the systems racks indicating potential access issues and the possible need for a separately attached logistics module.
2) The structural mass of the 5.5 m diameter module is not efficient when compared to the 7.2 m diameter module. Results show that the structural mass of both modules is about the same, but because the 7.2m diameter module is closer to a spherical shape, it has an additional 92 m^3 available (see Appendix A, Figures 15 and 16).
3) Analysis of the launch configuration shown in Figure 3 indicated possible vibration issues within the fairing. A stiffer module would increase the mass of the payload and the addition of snubber attachments between the shroud and the upper end of the module will add complexity.

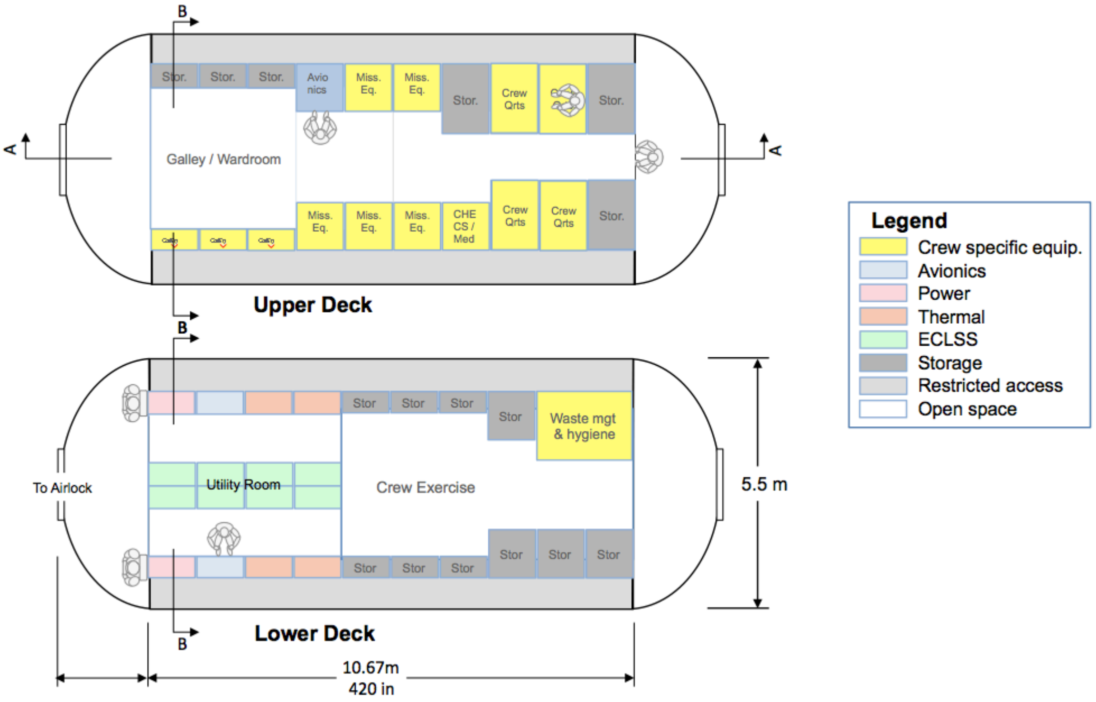


Figure 8. 5.5 m Diameter Habitat Module Plans. *This module provides an upper deck for most of the crew functions and a lower deck for utility systems and crew exercise. The layout works toward grouping open work areas at one end, private areas at another, and separating potentially noisy utility systems and workout areas.*

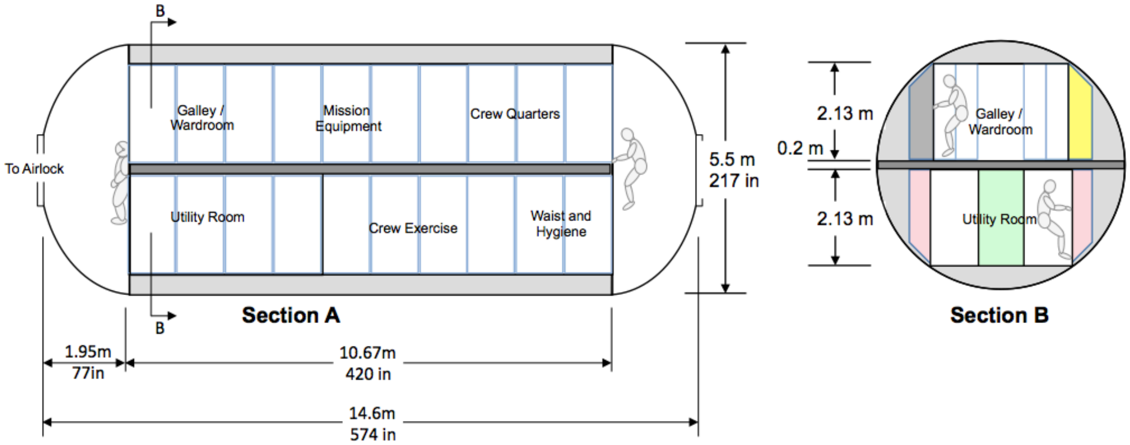


Figure 9. 5.5 m Diameter Habitat Module Sections. *Circulation between decks is through open end-domes with an airlock at one end and docking ports at each end.*

Another approach to the 5.5 m diameter module is included in Figure 14, configuration 2a, from the co-manifested payload study.[2] The configuration uses a similar two-level horizontal layout, but divides the functions into two habitat modules and an attached logistics module. Although no detailed layout is provided here, there are several important findings worth further consideration:

Positive findings include:

1) The use of two habitation modules provides an opportunity for duplicate life support systems so each module can act as a safe haven for the other in the event of a fire or pressure-loss emergency.
2) The attached logistics module provides a convenient trash disposal method that can be ejected prior to the return trip
3) The smaller size elements will fit in the co-manifest volume of a USA2 adapter with the Orion above if the mass capability is available with the SLS block 2 as planned

Negative findings include:

1) The overall mass is about 12,000 kg higher than configuration 3a due to the number of elements and larger volume

B. 7.2 m Diameter Habitat Modules

Figures 10 and 11 provide plan and section layouts for a 7.2 m diameter horizontal layout on three deck levels. The lower deck has a utility room and two workstations; the main deck has two workstations, four crew quarters, and the waste management compartment in the middle with stowage along the outside walls; the upper deck has the galley and crew exercise areas. The overall layout is nearly identical to an 8.4 m diameter habitat module that has been presented in previous papers.[3,4,5] The end domes are open and used for translation between decks and provide access to an airlock at one end and docking ports at each end. Several important findings from this configuration are as follows.

Positive findings include:

1) The overall layout is workable from a habitability perspective for supporting a crew of 4 over the 1000-day Mars transit mission.
2) The overall mass summary provided in Figure 14, configuration 3b, indicates that the module is within the range needed for Mars transit missions.
3) The crew quarters located in the center of the module provides maximum radiation protection using surround systems and stowage volumes
4) The launch configurations shown in Figure 3 fits within a standard 8.4 m Short fairing on an SLS 1b

Negative findings include:

1) The launch configuration shown in Figure 3, when compared to the 8.4 m diameter module, requires a payload adapter to transition from the 8.4 m diameter EUS stage to the 7.2m payload diameter.
2) A production capability for the 7.2 m diameter is believed to be available in research laboratories, but probably not available in the commercial sector.

In addition to the horizontal layout shown in Figure 10, a vertical layout was designed as shown in Figure 12. In general, the vertical layouts with the circular plans are more difficult and less efficient for packaging for the same reason circular floor plans are rarely used for terrestrial construction. Regardless, vertical layouts with circular plans are considered for two primary reasons: 1) they tend to work with artificial gravity vehicle configurations where a long vehicle is rotated end over end to generate low level gravity during transit; and 2) the layout is compatible with surface lander designs where the transit habitat and the surface habitat might have similar layouts. In addition to the findings above for the horizontal layout, this configuration has the following positive and negative attributes.

Positive findings include:

1) Vertical layout is applicable to artificial gravity and surface system configurations.

Negative findings include:

1) The lower packaging efficiency may make total stowage volume available an issue when compared to a horizontal layout.

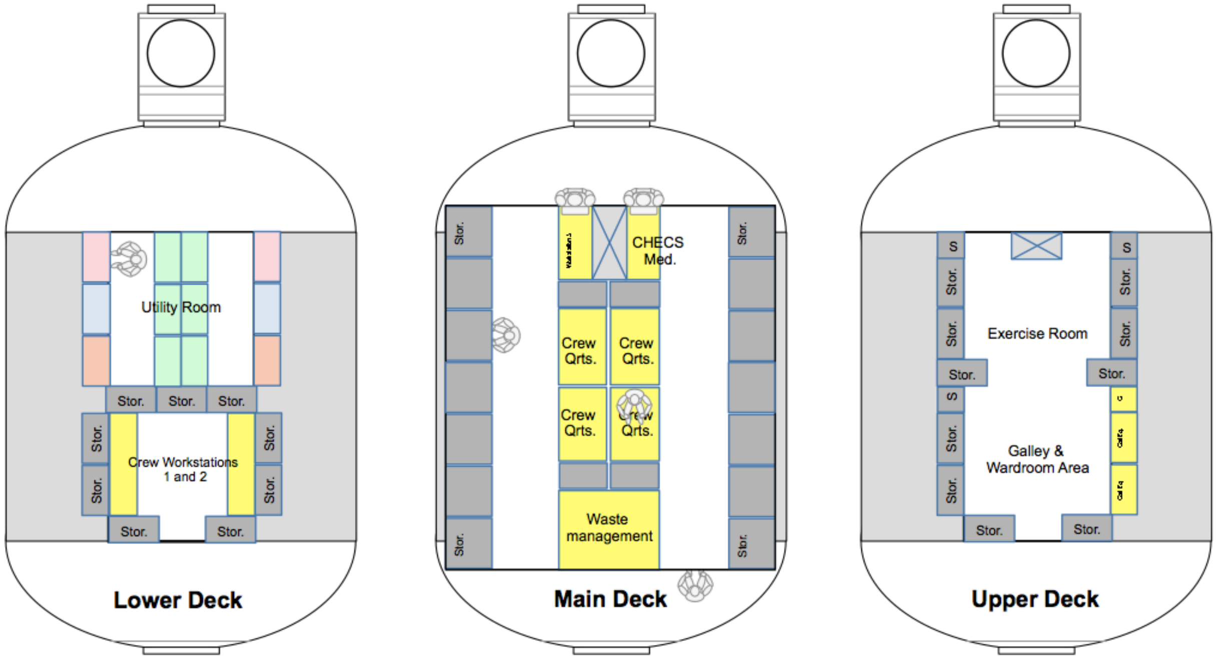


Figure 10. 7.2 m Diameter Habitat Module Plans. *The main deck includes the crew quarters in the middle to achieve maximum radiation protection from the surrounding systems and stowage volumes.*

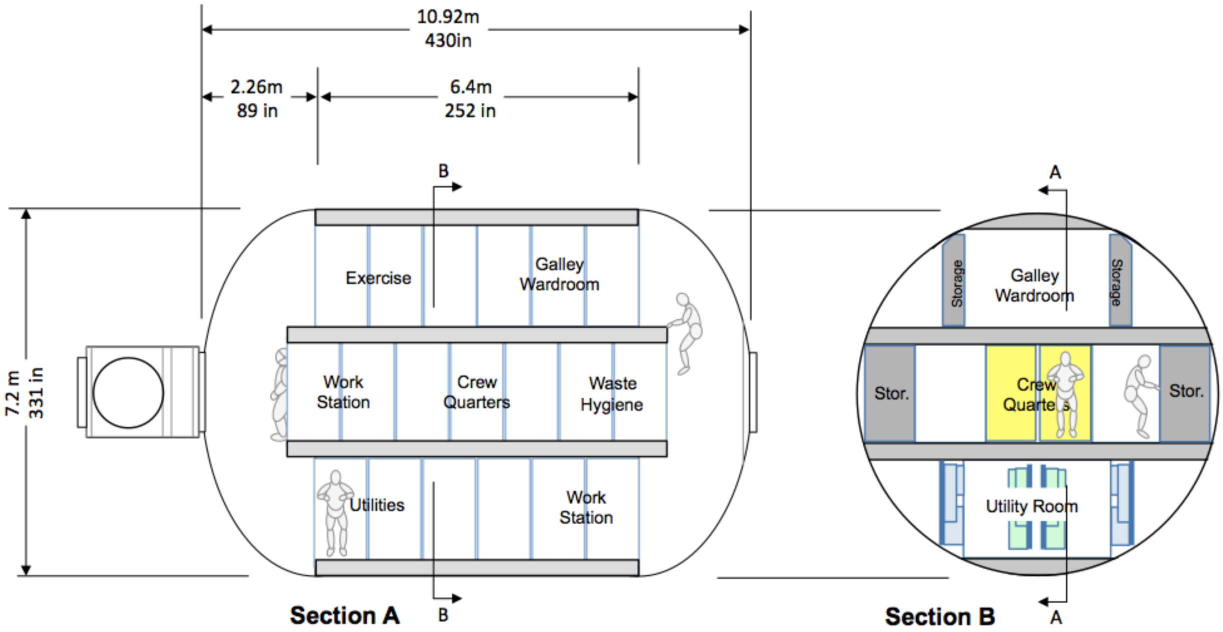
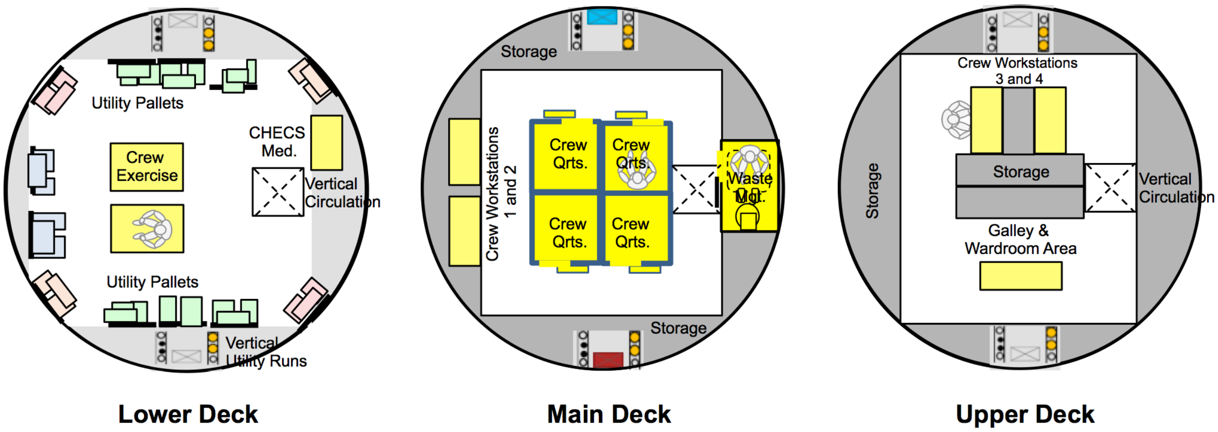


Figure 11. 7.2 m Diameter Habitat Module Sections. *Circulation between decks is through open end-domes with an airlock at one end and docking ports at each end.*



Lower Deck **Main Deck** **Upper Deck**

Figure 12. 7.2 m Diameter Vertical Plan Layout. *The main deck includes the crew quarters in the middle to achieve maximum radiation protection from the surrounding systems and stowage volumes.*

C. 8.4 m Diameter Habitat Modules

The 8.4m diameter habitat module uses the same three-deck layout as shown in Figures 10 and 11 for the 7.2 m diameter module and has been shown is several previous papers.[3,4,5] Additional volume is available in all areas proportionately due to the larger diameter. Several important findings from this configuration are as follows:

Positive findings include:

1) The overall layout is workable from a habitability perspective for supporting a crew of four over the 1000-day Mars transit mission
2) The crew quarters located in the center of the module provides maximum radiation protection using surround systems and stowage volumes
3) The larger diameter provides more volume for stowage and crew systems with minimal additional mass.
4) The launch configuration shown in Figure 3 is the most efficient since it flies in line with the EUS and does not require a payload adapter.
5) A manufacturing capability is available based on SLS core stage propellant tank manufacturing

Negative findings include:

1) The overall mass summary provided in Figure 14, configuration 3c2, indicates that the module is about 2,000 kg more massive than the 7.2 m diameter module in configuration 3b. This places it within, but at the upper end of current Mars mission goals.
2) The launch configurations shown in Figure 3 require development of a nosecone fairing for configuration 3c1 or a 10 m diameter fairing for configuration 3c2
3) The nosecone with configuration 3c1 exposes the outer shell to aero loads requiring special consideration for surface radiator system designs.

The difference between configurations 3c1 and configuration 3c2 is that 3c1 is launched with a nosecone, which exposes the payload to aero loads resulting in about 2,000 kg additional mass on the primary structure. Configuration 3c2 packaged inside a 10 m fairing is the preferred approach for the following reasons:

Positive findings include:

1) The habitat module is completely enclosed in a payload fairing reducing the risk of damage during launch
2) The surface radiators are not exposed to the air stream reducing complexity and potential damage
3) The final structural mass for the payload is reduced by about 2000 kg due to reduced loading

Negative findings include:

1) Configuration 3c2 requires a 10 m diameter payload fairing development.

D. 8.4 m Diameter Laboratory Modules

An alternative configuration for the 8.4 m diameter habitat was also considered for a large cislunar laboratory[6] (LAB). Figure 13 provides a notional layout for the LAB by substituting the stowage along the cylinder walls on the main deck with laboratory racks. The volume is such that standard international space station payload racks (ISPR) could be utilized as they currently are on the ISS. The layout includes ideas on ISPR utilization for internal payloads, along with external payloads similar to the external pallets on the ISS.

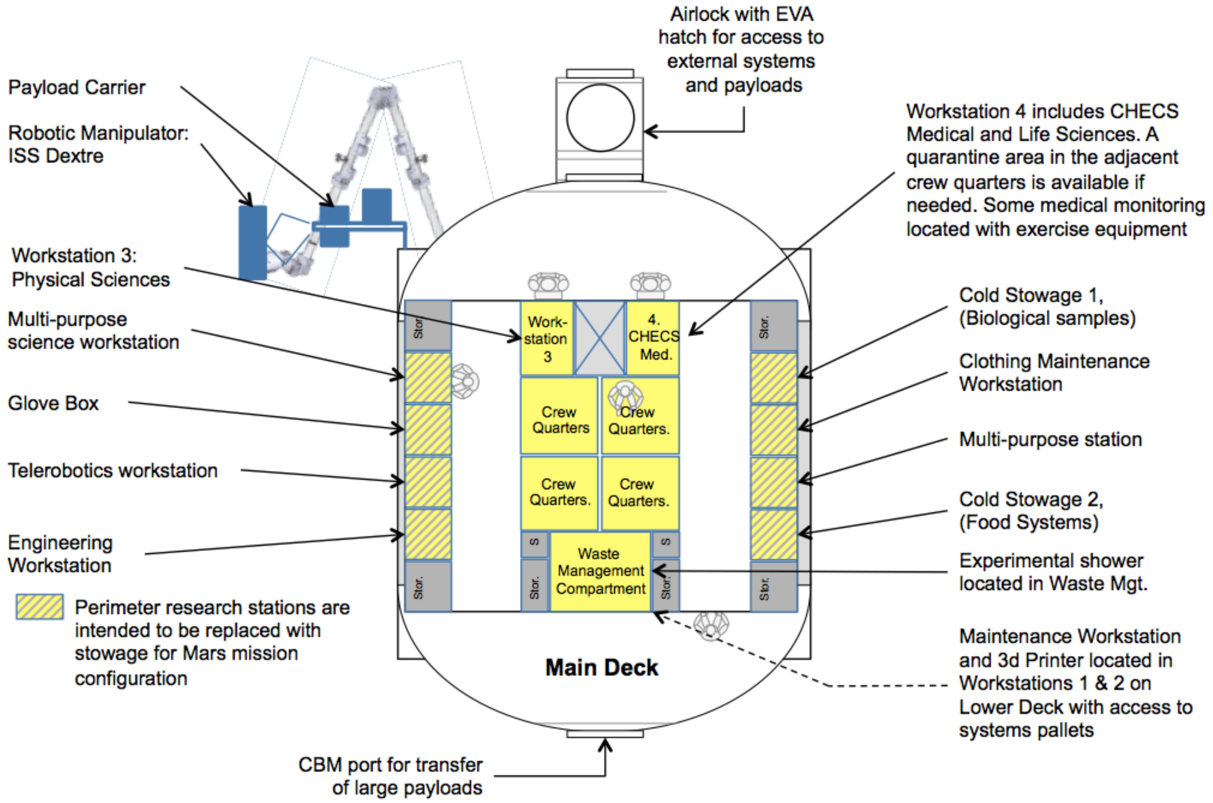


Figure 13. 8.4 m Diameter Laboratory Module Plan. *A laboratory version of the habitat module is shown by replacing the stowage compartments along the exterior walls on the main deck with research equipment. Sizing is such that the ISPR system could be utilized.*

V. Mars Vehicle Summaries

Figure 14 provides a summary of some of the Mars vehicle configurations studied over the past few years. Configuration 2a is from a previous study on co-manifested payload options for build up of that capability.[2] Configurations 3a, 3b, and 3c2 are discussed in more detail in this paper and are notable for comparison with the earlier work. Several important findings from these configurations are as follows:

Configuration 2c
1) The multiple modules provide opportunities for development of safe haven capabilities in the event of fire or pressure loss
2) The separate logistics module provides a means for trash disposal prior to return from Mars orbit
3) The three-module set is the most massive option

Configuration 3a
1) The long cylinder length is not efficient structurally and may present complications for the launch configuration
2) The volume available may not be sufficient for the logistics volume required.
3) There are no safe-haven capabilities

Configuration 3b
1) The overall mass and volume appear adequate for the mission.
2) Crew quarters located in the center provide maximum radiation protection.
3) There are no safe-haven capabilities
4) There are no known commercial manufacturing capabilities for this size module.

Configuration 3c2
1) The overall mass and volume appear adequate for the mission.
2) Crew quarters located in the center provide maximum radiation protection.
3) There are no safe haven capabilities

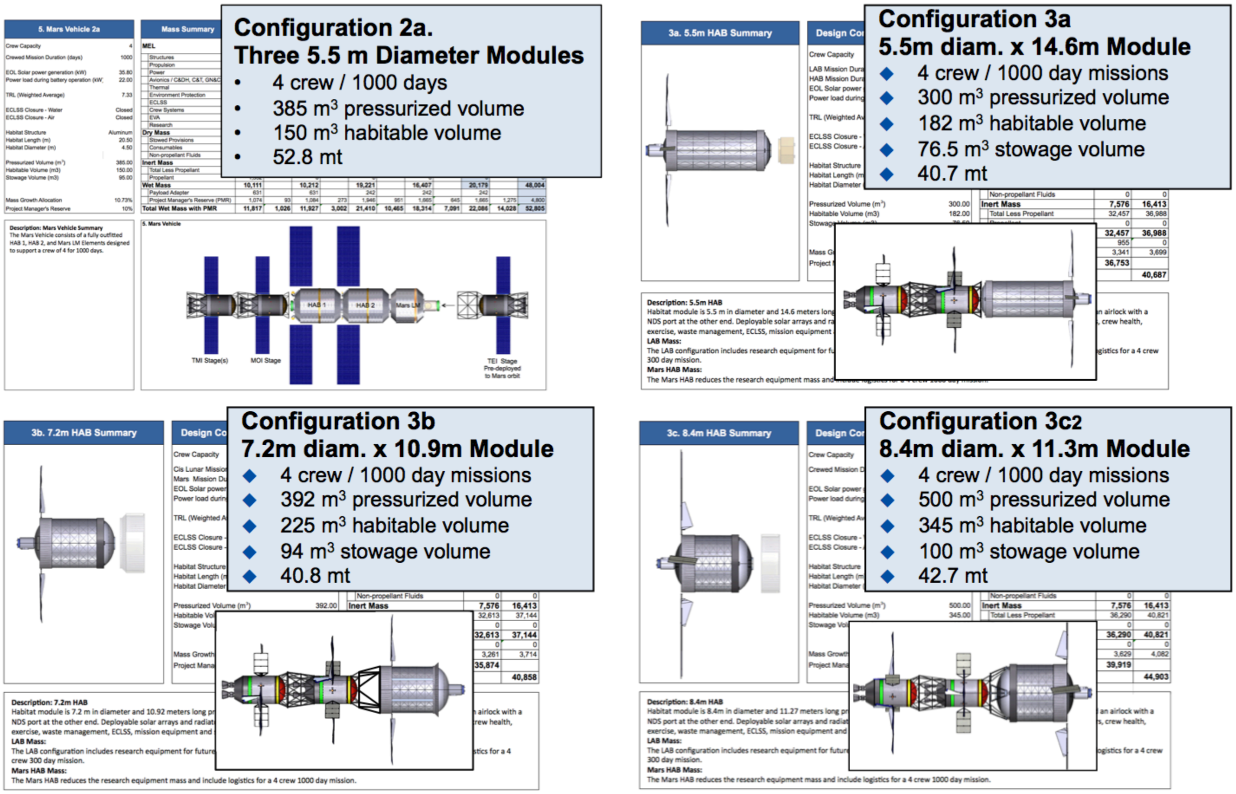


Figure 14. Mars Transit Habitat Summaries. *Configuration 2a from a previous study*[2] *along with three configurations presented in this paper are summarized in comparison with each other.*

In summary, there are advantages and disadvantages for each of the configurations studied to date. New configurations that incorporate the best of each should result in a solution that is safe, efficient, and comfortable for the crew. There are additional issues that have not been fully incorporated into these designs that need future consideration too. Some of the ideas mentioned during these studies that need further consideration include the following:

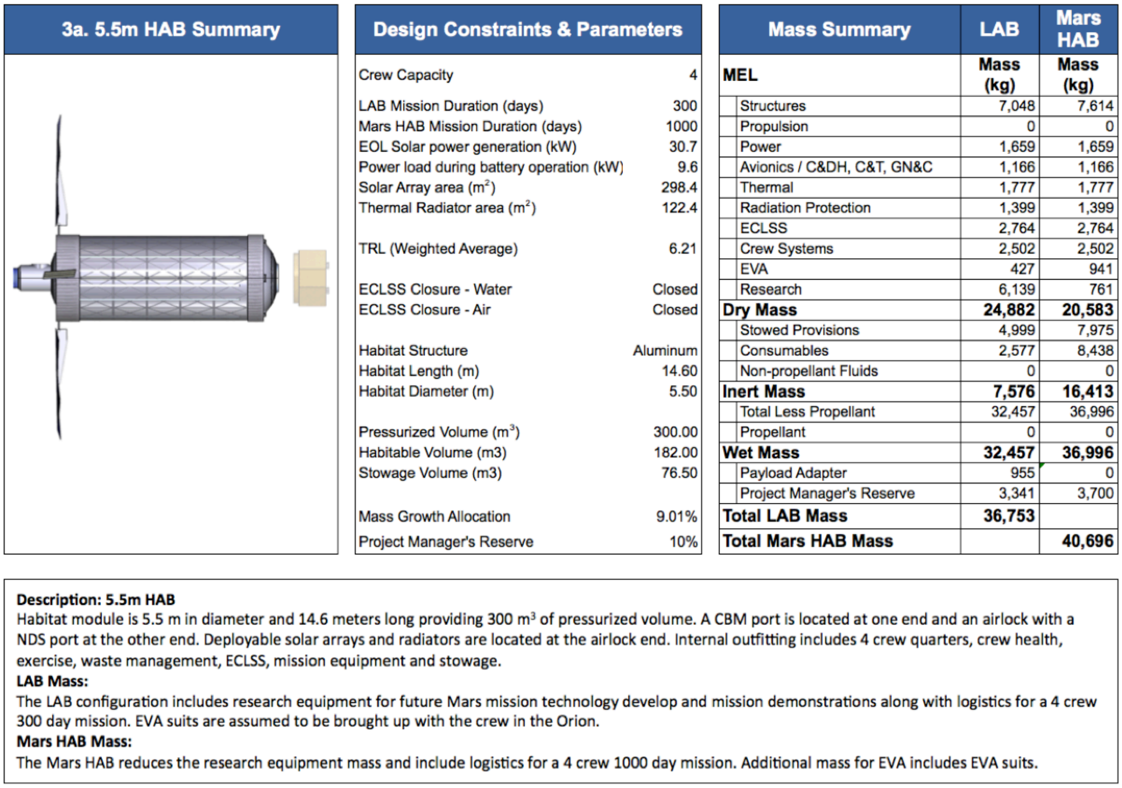
1) Add windows and possibly a cupola as provided on the ISS. Current designs assume electronic windows using high-resolution cameras and monitors.
2) Design a safe-haven system such that the crew can move into a second habitat while working to recover from smoke, fire, or pressure loss.
3) Design the surface habitat and the transit habitat using a similar layout so transition from orbit to surface will be simplified with all functions and stowage items in a similar configuration.
4) Consider implications for the transit habitat if it is used for a Mars orbital mission only, and in combination with a Phobos mission, and/or a Mars surface mission
5) Develop configurations that generate an artificial gravity so the crew will be fully functional when they arrive on the surface of Mars.
6) Explore completely the functions of a cislunar facility that can support missions to the moon, asteroid collection and research, Mars vehicle assembly and refurbishment, and the incorporation of international and commercial activities.
7) Incorporation of expandable systems needs further consideration.
8) Definition and incorporation of a full medical suite, research, and mission equipment

VI. Conclusion

Significant progress has been made to define the next steps towards human missions to Mars. The community at large appears to be in agreement that a cislunar capability needs to be developed that can support multiple mission initiatives by multiple groups. The initial establishment of a service module and node with some habitable capability could support a wide variety of options. In this paper and in recent studies, further definition of the Mars transit habitat has been a major goal. Clear advantages can be seen from a mass and volume standpoint by going to larger diameter module. But, utilization of multiple modules has advantages too that need further consideration. Pursuit of commonality between orbital and surface habitats needs further exploration along with artificial gravity considerations. Over time these issues will be resolved and the best solutions will become apparent.

Appendix A
Habitat Summaries

Appendix A provides a more detailed summary of the configurations discussed in this paper. Each is presented in a cislunar LAB configuration as described in Figure 14 for the 8.4 m diameter module, and in a Mars HAB configuration fully outfitted for a 4-crew, 1000-day Mars transit mission.



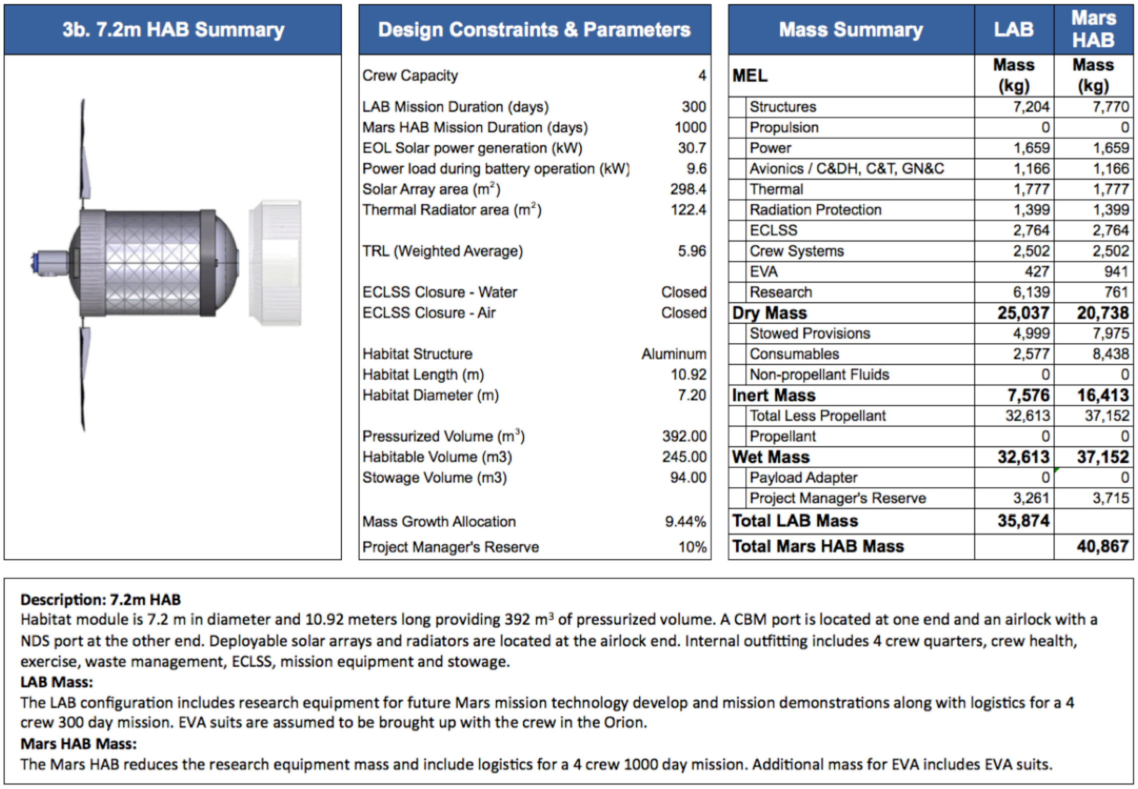
3a. 5.5m HAB Summary

Design Constraints & Parameters	
Crew Capacity	4
LAB Mission Duration (days)	300
Mars HAB Mission Duration (days)	1000
EOL Solar power generation (kW)	30.7
Power load during battery operation (kW)	9.6
Solar Array area (m^2)	298.4
Thermal Radiator area (m^2)	122.4
TRL (Weighted Average)	6.21
ECLSS Closure - Water	Closed
ECLSS Closure - Air	Closed
Habitat Structure	Aluminum
Habitat Length (m)	14.60
Habitat Diameter (m)	5.50
Pressurized Volume (m^3)	300.00
Habitable Volume (m3)	182.00
Stowage Volume (m3)	76.50
Mass Growth Allocation	9.01%
Project Manager's Reserve	10%

Mass Summary	LAB	Mars HAB
MEL	**Mass (kg)**	**Mass (kg)**
Structures	7,048	7,614
Propulsion	0	0
Power	1,659	1,659
Avionics / C&DH, C&T, GN&C	1,166	1,166
Thermal	1,777	1,777
Radiation Protection	1,399	1,399
ECLSS	2,764	2,764
Crew Systems	2,502	2,502
EVA	427	941
Research	6,139	761
Dry Mass	**24,882**	**20,583**
Stowed Provisions	4,999	7,975
Consumables	2,577	8,438
Non-propellant Fluids	0	0
Inert Mass	**7,576**	**16,413**
Total Less Propellant	32,457	36,996
Propellant	0	0
Wet Mass	**32,457**	**36,996**
Payload Adapter	955	0
Project Manager's Reserve	3,341	3,700
Total LAB Mass	**36,753**	
Total Mars HAB Mass		**40,696**

Description: 5.5m HAB
Habitat module is 5.5 m in diameter and 14.6 meters long providing 300 m^3 of pressurized volume. A CBM port is located at one end and an airlock with a NDS port at the other end. Deployable solar arrays and radiators are located at the airlock end. Internal outfitting includes 4 crew quarters, crew health, exercise, waste management, ECLSS, mission equipment and stowage.
LAB Mass:
The LAB configuration includes research equipment for future Mars mission technology develop and mission demonstrations along with logistics for a 4 crew 300 day mission. EVA suits are assumed to be brought up with the crew in the Orion.
Mars HAB Mass:
The Mars HAB reduces the research equipment mass and include logistics for a 4 crew 1000 day mission. Additional mass for EVA includes EVA suits.

Figure 15. 5.5 m Diameter Habitat Module.



3b. 7.2m HAB Summary

Design Constraints & Parameters	
Crew Capacity	4
LAB Mission Duration (days)	300
Mars HAB Mission Duration (days)	1000
EOL Solar power generation (kW)	30.7
Power load during battery operation (kW)	9.6
Solar Array area (m^2)	298.4
Thermal Radiator area (m^2)	122.4
TRL (Weighted Average)	5.96
ECLSS Closure - Water	Closed
ECLSS Closure - Air	Closed
Habitat Structure	Aluminum
Habitat Length (m)	10.92
Habitat Diameter (m)	7.20
Pressurized Volume (m^3)	392.00
Habitable Volume (m3)	245.00
Stowage Volume (m3)	94.00
Mass Growth Allocation	9.44%
Project Manager's Reserve	10%

Mass Summary	LAB	Mars HAB
MEL	**Mass (kg)**	**Mass (kg)**
Structures	7,204	7,770
Propulsion	0	0
Power	1,659	1,659
Avionics / C&DH, C&T, GN&C	1,166	1,166
Thermal	1,777	1,777
Radiation Protection	1,399	1,399
ECLSS	2,764	2,764
Crew Systems	2,502	2,502
EVA	427	941
Research	6,139	761
Dry Mass	**25,037**	**20,738**
Stowed Provisions	4,999	7,975
Consumables	2,577	8,438
Non-propellant Fluids	0	0
Inert Mass	**7,576**	**16,413**
Total Less Propellant	32,613	37,152
Propellant	0	0
Wet Mass	**32,613**	**37,152**
Payload Adapter	0	0
Project Manager's Reserve	3,261	3,715
Total LAB Mass	**35,874**	
Total Mars HAB Mass		**40,867**

Description: 7.2m HAB

Habitat module is 7.2 m in diameter and 10.92 meters long providing 392 m^3 of pressurized volume. A CBM port is located at one end and an airlock with a NDS port at the other end. Deployable solar arrays and radiators are located at the airlock end. Internal outfitting includes 4 crew quarters, crew health, exercise, waste management, ECLSS, mission equipment and stowage.

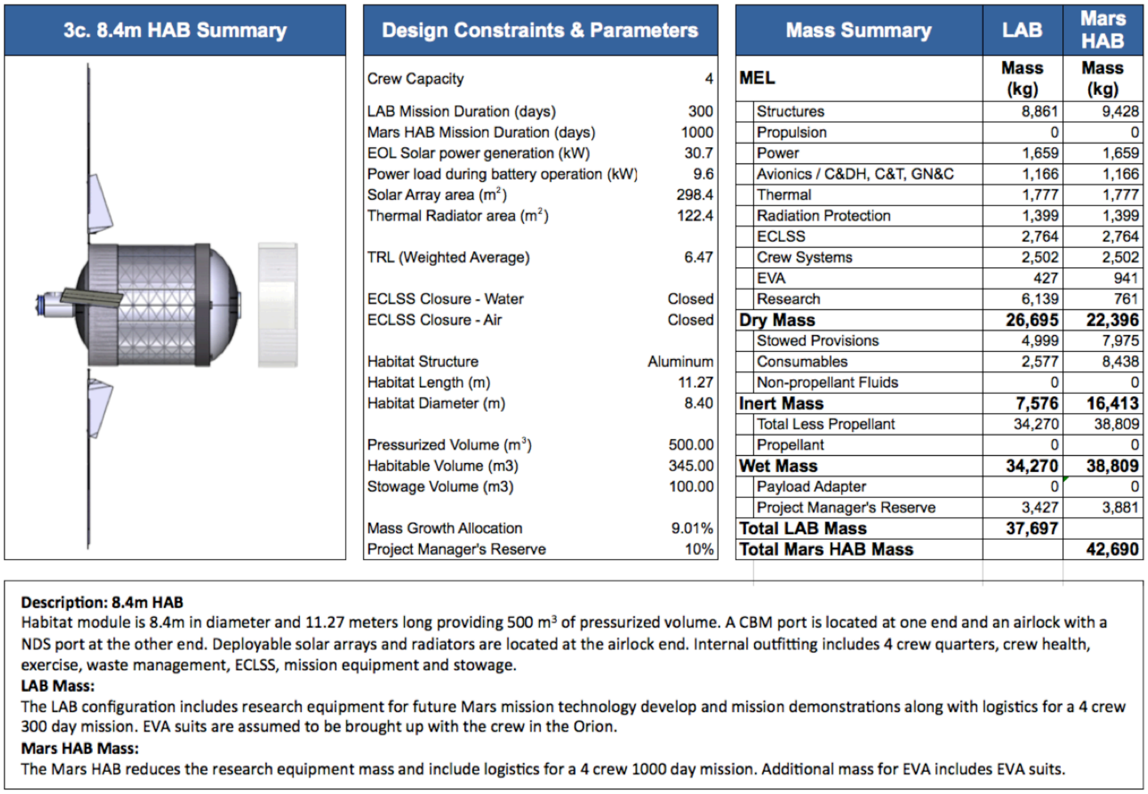
LAB Mass:

The LAB configuration includes research equipment for future Mars mission technology develop and mission demonstrations along with logistics for a 4 crew 300 day mission. EVA suits are assumed to be brought up with the crew in the Orion.

Mars HAB Mass:

The Mars HAB reduces the research equipment mass and include logistics for a 4 crew 1000 day mission. Additional mass for EVA includes EVA suits.

Figure 16. 7.2 m Diameter Habitat Module.



3c. 8.4m HAB Summary

Design Constraints & Parameters	
Crew Capacity	4
LAB Mission Duration (days)	300
Mars HAB Mission Duration (days)	1000
EOL Solar power generation (kW)	30.7
Power load during battery operation (kW)	9.6
Solar Array area (m^2)	298.4
Thermal Radiator area (m^2)	122.4
TRL (Weighted Average)	6.47
ECLSS Closure - Water	Closed
ECLSS Closure - Air	Closed
Habitat Structure	Aluminum
Habitat Length (m)	11.27
Habitat Diameter (m)	8.40
Pressurized Volume (m^3)	500.00
Habitable Volume (m3)	345.00
Stowage Volume (m3)	100.00
Mass Growth Allocation	9.01%
Project Manager's Reserve	10%

Mass Summary	LAB	Mars HAB
MEL	**Mass (kg)**	**Mass (kg)**
Structures	8,861	9,428
Propulsion	0	0
Power	1,659	1,659
Avionics / C&DH, C&T, GN&C	1,166	1,166
Thermal	1,777	1,777
Radiation Protection	1,399	1,399
ECLSS	2,764	2,764
Crew Systems	2,502	2,502
EVA	427	941
Research	6,139	761
Dry Mass	**26,695**	**22,396**
Stowed Provisions	4,999	7,975
Consumables	2,577	8,438
Non-propellant Fluids	0	0
Inert Mass	**7,576**	**16,413**
Total Less Propellant	34,270	38,809
Propellant	0	0
Wet Mass	**34,270**	**38,809**
Payload Adapter	0	0
Project Manager's Reserve	3,427	3,881
Total LAB Mass	**37,697**	
Total Mars HAB Mass		**42,690**

Description: 8.4m HAB

Habitat module is 8.4m in diameter and 11.27 meters long providing 500 m^3 of pressurized volume. A CBM port is located at one end and an airlock with a NDS port at the other end. Deployable solar arrays and radiators are located at the airlock end. Internal outfitting includes 4 crew quarters, crew health, exercise, waste management, ECLSS, mission equipment and stowage.

LAB Mass:

The LAB configuration includes research equipment for future Mars mission technology develop and mission demonstrations along with logistics for a 4 crew 300 day mission. EVA suits are assumed to be brought up with the crew in the Orion.

Mars HAB Mass:

The Mars HAB reduces the research equipment mass and include logistics for a 4 crew 1000 day mission. Additional mass for EVA includes EVA suits.

Figure 17. 8.4 m Diameter Habitat Module.

Appendix B
Abbreviations & Acronyms

AES	Advanced Exploration Systems
ARV	Asteroid Retrieval Vehicle
ASM	Augmentation/Service Module
CBM	Common Berthing Mechanism
CHCS	Crew Health Care System
diam.	diameter
DM	Docking Module
DRO	Distant Retrograde Orbit
DSH	Deep Space Habitat
EAM	Exploration Augmentation Module
ECLSS	Environmental Control & Life Support System
EML1	Earth-Moon Lagrange Point 1
EML2	Earth-Moon Lagrange Point 2
Eq.	Equipment
EUS	Exploration Upper Stage
EVA	Extra-Vehicular Activity
FY	Fiscal Year
HAB	Habitat
HAT	Human spaceflight Architecture Team
in	inches
ISPR	International Space Station Payload Rack
ISRU	In situ Resource Utilization
ISS	International Space Station
kg	kilograms
KSC	Kennedy Space Center
LAB	Laboratory Module
LEO	Low-Earth-Orbit
m	meter
Med.	Medical
mgt.	management
MOI	Mars Orbital Insertion
mt	metric tons (1000 kg)
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDS	NASA Docking System
Qrts.	Quarters
SEP	Solar Electric Propulsion
SLS	Space Launch System
Stor.	Storage
TEI	Trans-Earth Injection
TLI	Trans-Lunar Injection
TMI	Trans-Mars Injection
TRL	Technology Readiness Level
USA	Universal Stage Adapter
VAB	Vertical Assembly Building

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