Concepts for a Shroud or Propellant Tank Derived Deep Space Habitat

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Abstract – *Long duration human spaceflight missions beyond Low Earth Orbit will require much larger spacecraft than capsules such as the Russian Soyuz or American Orion Multi-Purpose Crew Vehicle. A concept spacecraft under development is the Deep Space Habitat, with volumes approaching that of space stations such as Skylab, Mir, and the International Space Station. This paper explores several concepts for Deep Space Habitats constructed from a launch vehicle shroud or propellant tank. It also recommends future research using mockups and prototypes to validate the size and crew station capabilities of such a habitat.*

Keywords: Exploration, space station, lunar outpost, NEA, habitat, long duration, deep space habitat, shroud, propellant tank.

1 Introduction

NASA has flown two space stations over the course of its history. The most recent, the International Space Station, was assembled over a thirteen-year period, consuming the majority of Space Shuttle missions during that time. The other, Skylab, was assembled in essentially a day, requiring a single Saturn V launch. The monolithic, propellant tank-derived construction of Skylab offers certain attributes worthy of consideration in future spacecraft design. This paper will explore the concept of a Deep Space Habitat derived from the launch shroud or propellant tank of a super heavy lift booster such as the Ares V or Space Launch System (SLS), primarily from the domain perspective of human factors and habitability. Architectural layout and habitable volume will be explored for both microgravity and planetary surface missions.

2 NASA Space Stations

NASA's Skylab space station was constructed from excess Project Apollo hardware. Skylab was built from a converted Saturn S-IVB upper stage. It was launched on the final Saturn V rocket flight, thus deploying in a single mission. The station sustained significant damage during launch, requiring critical extra-vehicular activity (EVA) to repair. It was utilized by three crews before re-entering the Earth's atmosphere in 1979.

The International Space Station (ISS) was born from cancelled plans for the NASA Space Station Freedom, Russian Mir 2, and the European Columbus space station. All US, European, and Japanese designed components were designed to fit inside the payload bay of the Space Shuttle and the Russian components were designed to launch as payloads of the Proton rocket. The first component was launched in 1998, with the final US launch in 2011. (Additional expansion remains possible with at least one planned Russian expansion and potential commercial expansions.) It has been continuously occupied since November 2000 and is expected to remain in service at least through 2020, potentially as long as 2028.

3 Potential Deep Space Habitat Missions

The Deep Space Habitat could potentially be used across any of several primary missions, including: Earth-Moon Lagrange Point One (L1) Command Post, Lunar Surface, Near Earth Asteroid (NEA), Martian Moon, Mars Transit, and Mars Surface. It should be noted that all of these missions involve exposure to high radiation environments, though the surface missions potentially have the option to gain some shielding from surface materials.

3.1 L1 Command Post

The L1 Command Post is used to assemble, service, or fuel spacecraft for deep space missions. The habitat is placed at a lagrange point, presumably the Earth-Moon L1 or L2 point. The habitat may be unmanned between missions, but is reused and resupplied as a permanent outpost. It may or may not require extensive extravehicular activity (EVA) capability, but unlike the planetary missions there are no dust concerns. It does involve a microgravity environment (versus planetary).

3.2 Lunar Surface Mission

The lunar surface mission involves permanent emplacement of the habitat on the lunar surface. Under the former Constellation program, these missions could last up to 180 days in length. This is a 1/6 gravity environment with extensive EVA activity and significant dust isolation requirements. The habitat is used for subsequent missions, but may or may not have unmanned quiescent periods between missions.

3.3 Near Earth Asteroid

The NEA mission is an exploration mission to a near Earth asteroid. Many, but not all, studies focus on the asteroid 2008 EV5, which is a 380-day mission. The habitat is used for outbound cruise and stationkeeps about 1-2 kilometers from the asteroid during the exploration phase, with one or two Space Exploration Vehicles used to shuttle between the habitat and the asteroid. The habitat is also used for inbound cruise to return to Earth and is currently expected to be discarded at end of mission, though there is some discussion of alternately capturing the habitat at Earth-Moon L1 for reuse.

3.4 Martian Moons

Missions to Mars Moons are essentially similar to the NEA mission, but are transits to Mars orbit instead of to a NEA. The Mars transit phase would be followed by exploration of Phobos and/or Deimos. The Deep Space Habitat would remain in a microgravity environment, orbiting the selected moon(s) and use one or two SEVs to explore the moons. The exploration phase is followed by an inbound transit phase returning to Earth. The habitat is presumably discarded at the end of its mission, but in theory could be captured at Earth-Moon L1.

3.5 Mars Transit

The Mars transit mission is a cruise mission to and from Mars orbit, as a component of a Mars surface exploration mission. The transit habitat is a microgravity habitat with minimal EVA activity and no dust isolation concerns. Each transit phase is approximately 180 days in duration. Like other microgravity DSH missions, the habitat is presumably discarded at end of mission but could be captured at Earth-Moon L1.

3.6 Mars Surface

The Mars surface mission involves a 500-day stay on the surface of Mars. This variation of the Deep Space Habitat would operate in 3/8 gravity and support EVA activity requiring significant dust isolation. The habitat is left on the surface of Mars at the end of the surface mission and may or may not be reused for subsequent expeditions.

4 NASA Habitat Concept Exploration

Numerous NASA studies have considered shroud or propellant tank derived habitats since the 1960s. The Skylab space station is the most obvious of these, having been constructed from a Saturn V upper stage, using the liquid hydrogen tank as the space station habitat and the liquid oxygen tank as a waste containment volume. Skylab was referred to as a dry hab, meaning the upper stage was manufactured as a space station on the ground and was not used as a propellant tank. By comparison, a wet hab would refer to a propellant tank actually filled with propellant and used as such to help power the rocket launch, but then converted into a habitat in orbit. Wet habs are orders of magnitude more complex and have been considered in a much smaller number of studies, which will not be explored in this paper.

4.1 External Tank Derived Lunar Outpost

Prior to retirement of the Space Shuttle, various studies had considered the idea of a lunar habitat constructed from various elements of the Space Shuttle External Tank. In the case of the Space Shuttle External Tank, its oxygen tank is a propellant tank that is also an aeroshell. (As such it could be launched as the payload of an Ares V class vehicle, arguably serving as its own shroud, gaining certain launch performance benefits.) Because the tank was designed to hold liquid oxygen at a pressure range of 20-22 psig[1] and to withstand launch loads, the structure was more than adequate for containing atmosphere at the 8-10 psi ranges being considered for human exploration missions. This welded metal tank was briefly studied by the NASA Habitability Design Center as a candidate lunar outpost[1]. Measuring 8.4 meters in diameter and 15.04 meters tall, the tank has a volume of 553.96 m^3, significantly larger than most of the habitat concepts considered within NASA Constellation or Deep Space Habitat studies.

This “LOXHAB” used the physical construction of the liquid oxygen tank to drive its deck layout, with each deck attaching to one of the primary tank segments. As shown in Figure 1, the tank is composed of a dome cap, barrel, aft ogive, and forward ogive. The tank also includes a slosh baffle that would not be installed in the LOXHAB configuration. Like Skylab, this would be a dry habitat, manufactured on the ground as a lunar outpost. Figures 2 and 3 show conceptual deck layouts for the barrel and aft ogive sections.

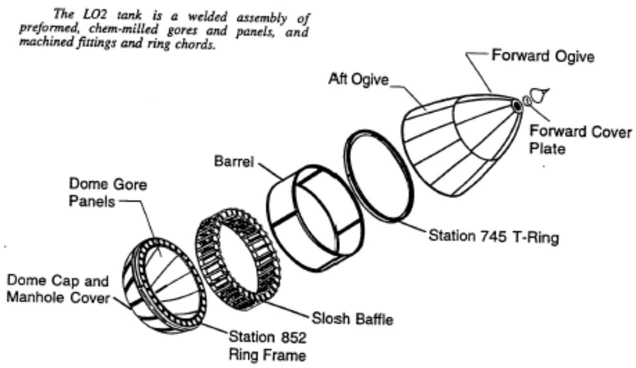

Figure 1. Liquid Oxygen Tank Physical Construction [1]

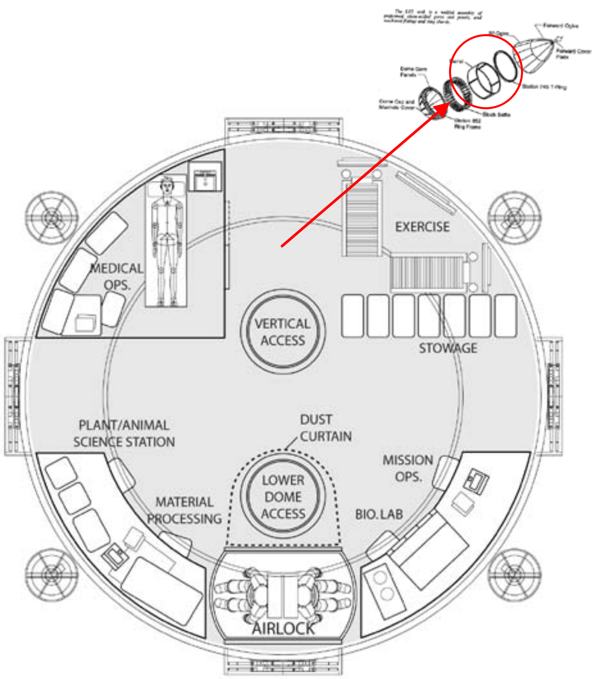

Figure 2. Deck 2 of External Tank Derived Habitat [1]

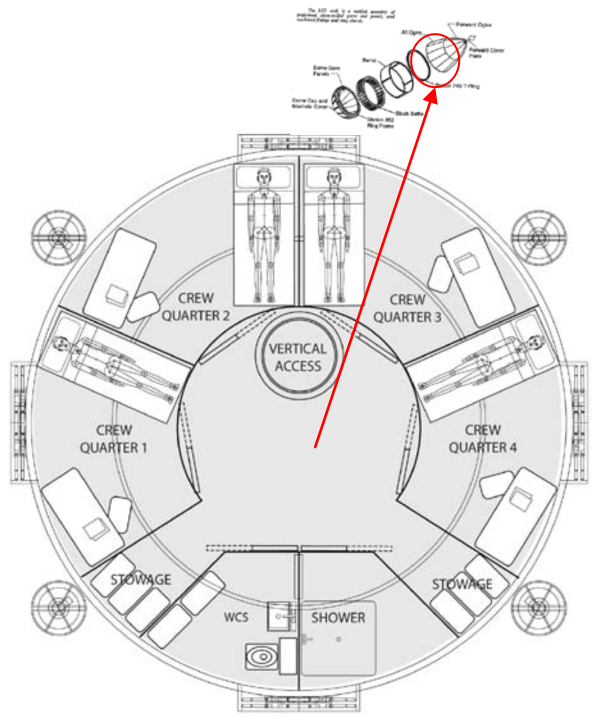

Figure 3. Deck 3 of External Tank Derived Habitat [1]

4.2 SLS Shroud Derived Microgravity Habitat

With both the Saturn V and the Space Shuttle now retired, the next heavy lift, large diameter rocket on the drawing boards for NASA is the Space Launch System (SLS). Essentially similar to what was dubbed the Ares IV under Constellation, the SLS is composed of a first stage derived from the shuttle External Tank with a cluster of Space Shuttle main engines mounted beneath and two five-segment solid rocket boosters strapped to the sides. At the time of this writing there are still multiple design options for the upper stage, including the use of a J-2X engine as well as commercial upper stages. The payload is encapsulated in a shroud above the upper stage.

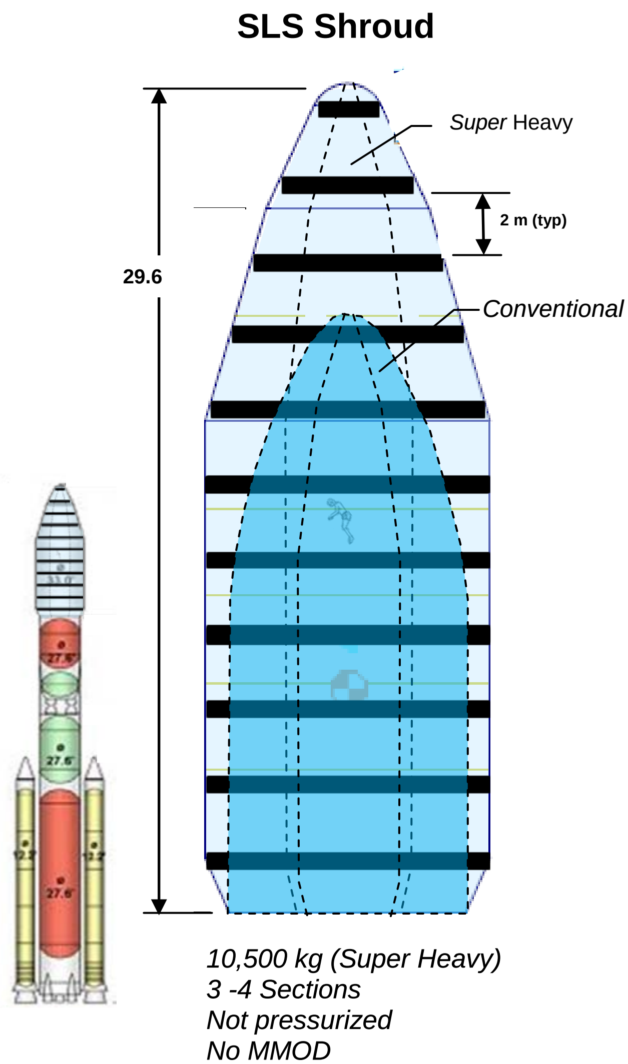

Figure 4. SLS Shroud-Derived Habitat[3]

In theory, the SLS shroud would represent the largest possible habitat if it were sealed as a pressure vessel and used as the Deep Space Habitat. This may, however, prove more complicated than adaptation of the shuttle External Tank oxygen tank.

The SLS shroud is likely to be a composite structure. Under the Constellation Program, the Ares V payload shroud was intended to be a 10 meter diameter by 22 meter long composite payload fairing[2]. Many other rockets such as the Atlas, Delta, and Falcon also use composite payload fairings. Figure 4 shows the relative size of the SLS shroud. The black horizontal lines denote potential decks, assuming two-meter deck heights. Note the shape of an astronaut floating inside the shroud./habitat.

Members of the Deep Space Habitat design team at NASA Marshall Space Flight Center briefly evaluated the use of the SLS Shroud as a Deep Space Habitat candidate but quickly determined it to be undesirable[3]. Consequently, no internal layouts were developed for SLS shroud-derived habitats.

These composite structures are optimized for launch loading only. Thus, they may or may not be adequate for containing pressure. Further, they are not designed to seal. There is no lower dome to contain the interior, which would require a new design effort[3].

Additionally, composites require coatings to survive the space environment[3]. This is not necessarily a show-stopper, as several manned spacecraft are currently evaluating composite pressure vessels, but it may add complexity and weight.

Composite shrouds do not have inherent micrometeorite and orbital debris shielding[3] and the difficulty of adding shielding may outweigh the benefit of using the shroud. Similarly, they do not have any inherent means of attaching internal structure[3].

Finally, it is possible that the SLS shroud may be oversized. This is not conclusive as there is significant discussion and debate about the appropriate volume for Deep Space Habitats. However, excess volumes will increase size and complexity of subsystems such as environmental control, thermal control, and radiation shielding[3].

4.3 SLS Upper Stage Derived Microgravity Habitat

4.3.1 Skylab II Deep Space Habitat

The Advanced Concepts Office at NASA Marshall Space Flight Center recently partnered with the American Society of Civil Engineers to promote a student design competition to design a space habitat from the SLS Upper Stage liquid hydrogen tank[4]. Figure 5 illustrates the size of the tank compared to a large house.

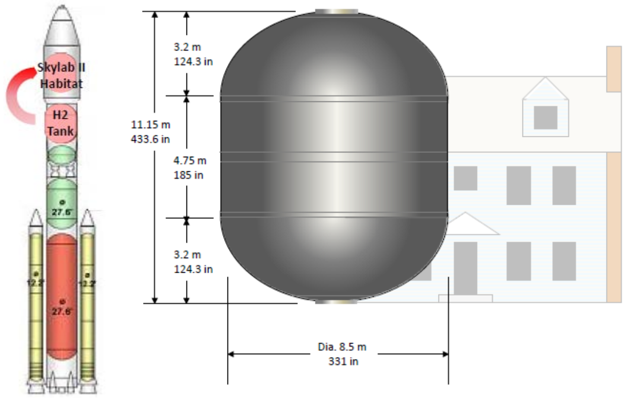

Figure 5. Skylab II Deep Space Habitat[4]

The Skylab II DSH is responsible for the following volume driving crew functions and subsystems:[4]

4.3.1.1 Crew Member Functions

a. Full Body Cleansing

b. Hand/Face Cleansing

c. Exercise

d. Personal Hygiene

e. Urination/Defecation

f. Sleep Provisions

g. Recreation

h. Wash/Dry Clothing

i. Dressing/Undressing

j. Medical Care

k. Private Communications

l. Food Preparations

m. Eating

n. Cleanup

4.3.1.2 Subsystems

a. Structures/Mechanisms

b. Environmental Control Life Support

c. Thermal Control

d. Avionics

e. External Operations (space suits or personal spacecraft)

With a pressurized volume of 495 m^3[3], this DSH variant provides 123.75 m^3 per crew member, which is only slightly smaller than the per person volume provided by the International Space Station, which has a volume of 139.5 m^3 per crew member[5]. As of the date of this writing, no internal layouts have been developed for this DSH concept.

It appears from the general construction that it is likely to be a four deck habitat, with two full height decks in the barrel section and a partial deck in each of the upper and lower domes. The decks in the domes are of course constrained in that they do not have even deck heights across the entire diameter. It is arguably possible, however, that five decks could be contained within this volume if they are constrained to approximately 2 meters in height, with the third deck centered at the middle of the pressure vessel (it being the only full height deck). There would likely be structural issues with such a design, however, as the floor locations would not coincide with structural interfaces inherent to its manufacture as a pressure vessel.

It should be noted that a potential drawback to the use of the SLS tank is that NASA Marshall Space Flight Center engineers are currently attempting to make the tank as light as possible with the view that the tank is disposable immediately upon completion of the upper stage burn[6]. This may result in a shell material that is unsuitable as a pressure vessel for human habitation. However, more study of the mass savings approach employed by the Marshall SLS team is required to determine if the tank is or is not usable as a habitat.

4.3.2 Spacecraft Conceptual Design Office Deep Space Habitat

The Spacecraft Conceptual Design Office (SCDO) at NASA Johnson Space Center conducted a bottom's up design study of the Deep Space Habitat and concluded with a four deck design somewhat comparable to the Skylab II configuration.

The SCDO study focused specifically on the 380-day NEA mission to asteroid 2008 EV5 and did not consider implications of any other destination. It also assumed as a key driving constraint air transportation of the habitat from its point of manufacture to launch site[5]. While this study did not specifically assume that the pressure shell is a propellant tank, its dimensions are similar enough to the SLS Upper Stage Derived habitat that it deserves mention as the two studies are highly complimentary. The SCDO DSH developed an extensive list of volume drivers, including crew member functions, subsystems, logistics & resupply, and contingencies:[7]

4.3.2.1 Crew Member Functions

a. Full Body Cleansing

b. Hand/Face Cleansing

c. Exercise

d. Personal Hygiene

e. Urination/Defecation

f. Sleep

g. Private Recreation/Leisure

h. Clothing Maintenance

i. Dressing/Undressing

j. Medical Care

k. Meal Prep

l. Eating

m. Meal Cleanup

n. Group Recreation/Leisure

o. General Housekeeping

p. Maintenance/repair

q. Subsystem Monitoring and Control

r. Integrated Stack Command & Control

s. Cryogenic Propulsion Stage Dock/Command & Data interface

t. Solar Electric Propulsion Stage Dock/Command & Data interface

u. Space Exploration Vehicle (SEV) Dock/Command & Data interface

v. Multi-Purpose Crew Vehicle (MPCV) Dock/Command & Data interface

w. Meetings

x. Planning/Scheduling

y. SEV Crew Transfer

z. MPCV Crew Transfer

aa. EVA

bb. Pre/Post EVA Ops

cc. EVA Support

dd. Proximity Ops

ee. Training

ff. Payload Support

gg. Life Sciences Experiments

hh. Materials Processing Experiments

4.3.2.2 Subsystem Equipment

a. Life Support

b. Thermal Control

c. Power

d. EVA

e. Command and Data Handling (C&DH)

f. Guidance, Navigation and Control (GNC)

g. Structures

h. Mechanisms

i. Propulsion

j. Communications and Telemetry (C&T)

4.3.2.3 Logistics & Resupply

a. Food and Water

b. Clothing

c. Medicine

d. Subsystem Spares

e. Other consumables, such as filters or wipes

4.3.2.4 Contingencies

a. Fire

b. Toxic Atmosphere

c. Cabin Depressurization

d. Radiation Event

e. Crew Fatality

As can be seen, this is a much more extensive list of functions than that assumed by the Skylab II study. All of these volume drivers were assessed to determine their respective volume requirements and which functions could share overlapping volumes[7]. The study team then considered efficiency of horizontal or vertical cylinder orientations, diameter, and length to set a habitat size of 7 meters in diameter and 8 meters in length[5],[7]. Figure 6 shows the resulting layout of this Deep Space Habitat Configuration. However, the study team noted that the volume of this habitat, 274.9 m^3[5], is significantly smaller than the International Space Station, both in terms of total pressurized volume and volume per crew member and cautions that it could be argued that the DSH may be undersized[7]. (The SCDO approach for estimating volume was based strictly on a task analysis and may overlook psychological drivers that cannot be analytically modeled. By comparison, the Skylab II approach simply used an existing pressure vessel.)

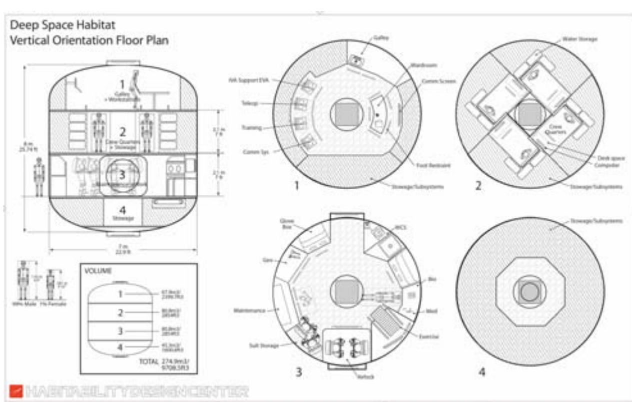

Figure 6. SCDO Deep Space Habitat[5]

While an in-depth assessment of this layout has yet to be conducted via mockup testing, a cursory glance at the layout does suggest some potential habitability issues, including stowage and subsystems access on deck 4, crowding among the lab facilities on deck 3, small crew quarters (relative to overall deck size) on deck 2, and low ceilings on deck 1. It is interesting to note that the SCDO DSH is very similar in basic shape to the Skylab II DSH, though 3.15 meters shorter in length and 1.5 meters narrower in diameter.

5 Conclusions

The work conducted to date does indicate a likely superiority of propellant tanks over shrouds as candidate habitat material, but this work is not conclusive and further study of shrouds would be needed to entirely rule out their potential applicability. Study should also be conducted to assess the viability of shroud material for micro-meteorite and orbital debris shielding of an encapsulated propellant tank based habitat. A propellant tank adapted for use as a habitat does not have inherent shielding so it is worth considering the question as to whether or not the shroud can serve this purpose.

With respect to propellant tank derived habitats, sizing remains an unresolved issue. It is clear that the External Tank based habitat is no longer viable due to the retirement of the Space Shuttle and dismantling of its assembly facilities. While there may be one or more External Tanks somewhere in the nation that were not destined for flight, this would be an inappropriate strategy for a Deep Space Habitat given the number of potential destinations – it would not be credible to assume there are available tanks for both ground testing and all potential missions. Thus, regardless of the outcome of a volume discussion the LOXHAB is not a useful approach.

It would be useful to explore an adaptation of the SCDO DSH layout into the Skylab II DSH pressure vessel. It is possible that relaxing the dimensions of the SCDO DSH into those of the Skylab II DSH will alleviate the potential human factors and habitability issues currently suspected of the design. This may also reveal potential differences in workstation performance. As an example, the type of medical workstation that can fit into a 1 m^3 volume is likely to be less capable than a medical workstation designed for a 3 m^3 volume. Medical, maintenance, scientific and other workstation performance capabilities may trade differently across different size DSH concepts, which should also be explored.

This study primarily focused on shrouds and propellant tanks associated with the SLS booster. However, other booster options do exist. Future studies should also consider shrouds and propellant tanks of expendable launch vehicle (ELV) boosters such as the Atlas V, Falcon 9 / Falcon 9 Heavy, and Delta IV Heavy. Some of these, for instance the 5m diameter Delta IV Heavy boosters, are similar in dimension to other NASA long duration habitat concepts.

In an ideal situation, it would be best from a human factors and habitability perspective to construct medium fidelity prototypes of the Skylab II/SCDO DSH, Delta IV tank derived DSH, and other DSH concepts (e.g. ISS derived, inflatables, etc.) and outfit each for long duration analogue missions similar to the Mars 500 expedition recently conducted by Russia, thereby providing human performance and psychological data to help rank the viability of various DSH design options.

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