Viability of Small Dimension Crew Quarters for Surface Habitation

Harry L. Litaker, Jr.
NASA/Leidos Incorporated
2101 East NASA Parkway
Houston, TX 77058
harry.l.litaker@nass.gov

Dr. Robert L. Howard, Jr.
NASA Johnson Space Center
2101 East NASA Parkway
Houston, TX 77058
robert.l.howard@nasa.gov

Abstract— **It is possible that in the next twenty years NASA may fly crew quarters on twice as many spacecraft as it has in the past fifty years. In short, US experience with spacecraft crew quarters is limited and with few available standards to guide their design there is significant uncertainty facing spacecraft currently in development, several of which are also subject to substantial mass and volume challenges. Those spacecraft developments will face considerable pressure to minimize crew quarters size, including those intended for use on the lunar surface. Given that a crew quarters is the only space a crew member can call his or her own during missions that can last weeks to years in duration, providing an appropriate volume is especially important. This is even more critical when one considers the reality that all crew quarters flown to date have been smaller than minimum standards for US jail cells. This research will categorize functional capabilities of crew quarters and explore physical and virtual prototypes of small crew quarters that have attempted to include these capabilities. The Exploration Atmospheres Test at NASA Johnson Space Center represents the first opportunity to collect multi-day test data on crew quarters of this size in a gravitational environment. Intended to validate exploration prebreathe protocols, this test will house eight people inside a vacuum chamber that has been outfitted as a habitat prototype for twelve days. In addition to their other test activity, the crew will evaluate the acceptability of their crew quarters. This data will aid in establishing design guidelines for crew quarters in both short and long duration missions beyond low Earth orbit.**

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1. INTRODUCTION

To date, the United States has only manufactured and flown three spacecraft that have contained any permanent or temporary accommodations that could be described as crew quarters – Skylab, the Space Shuttle, and the International Space Station (ISS). All three implementations were different. NASA, commercial partners, and international partners are presently working to define spacecraft for Artemis and Mars human exploration, four to six of which may have private crew quarters. Effectively, the Agency may be overseeing the parallel development of twice as many crew quarters in the next ten years as the Agency has produced in the past fifty years.

Artemis and Mars spacecraft that may include crew quarters include:

Gateway—The habitation and logistics outpost (HALO) module will serve as the pressurized living quarters for the Gateway outpost. [1]

Human Landing System—According to an article posted by spacepolicyonline.com, "the Starship [selected by NASA for the first lunar landing] second stage combines a propulsion system with crew quarters or a cargo hold depending on what is being launched." [2]

Pressurized Rover—The Pressurized Rover will support two person crews for missions up to roughly 30 days on the surfaces of the Moon and Mars.

Surface Habitat—The Surface Habitat will accommodate two crew on the surface of the Moon for 33-day surface missions.

Transit Habitat—The Transit Habitat will accommodate a four-person crew in microgravity between Earth and Mars for 700-1200-day missions.

Mars Surface Habitat—Initial Mars missions will not remain on the surface long enough to require a habitat, but future Mars exploration during conjunction class missions may require habitation for several hundred days.

Studies from Dietz and Dorrene (1990) [3] and Adams (1998) [4] have documented the history of previous crew quarters (CQ). These researchers noted crew quarters provide a relatively quiet and private retreat from the rest of the spacecraft for the crewmember to have conversations with family, conduct private medical consultations and get restful sleep [5], [6]. All US human spaceflight experience with crew quarters is in microgravity, but some of the spacecraft currently in development will operate in lunar or Martian gravity. Additionally, some of these spacecraft are expected to be volume constrained.

This may drive solutions in some cases that are volumetrically similar to ISS crew quarters, but with potentially unanticipated differences due to the presence of gravity. Thus, there is a need to collect and disseminate objective test data.

2. LACK OF CREW QUARTERS STANDARDS

Limited Experience Base for US Spacecraft Crew Quarters

As previously mentioned, the United States has only flown crew quarters on three spacecraft to date.

Skylab

The Skylab crew quarters, shown in Figure 1 were slightly uneven in size, varying from 0.7m by 0.96m by 1.98m (2.29 x 3.15 x 6.5ft) with a volume of 1.33m^3 (47ft^3) to 0.73m by 1.22m by 1.98m (2.4 x 4.0 x 6.5ft) with a volume of 1.76m^3 (62.2ft^3). [7] It is worth noting that these were referred to as Sleeping Quarters at the time and the architectural evaluation of them focused specifically on their use for sleep, nearly discounting the SL-4 science pilot's comment "that the sleeping area should be larger to provide the crewman with a place to 'sit down'." [7]

The Skylab quarters provided visual privacy but did not offer acoustic isolation or light isolation. Ventilation control was also limited, and taller crew members complained of insufficient headroom. [8]

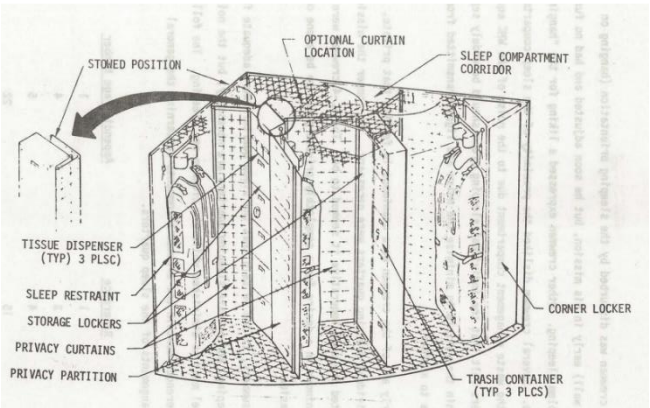


Figure 1. Skylab Sleeping Quarters

Space Shuttle

Most shuttle missions were flown with no crew quarters. The crew slept in sleeping bags attached to surfaces in the mid-deck. But for dual-shift missions, a sleeping bunk was included in the Orbiter mid-deck for crew use. [9] Unlike Skylab's sleeping quarters, these bunks were eventually modified to include acoustic liners. Very little other data has been archived on these bunks, visible in Figure 2. However, in anecdotal conversation with shuttle-era astronauts their reception was limited. One expressed that they reminded him of a coffin and he was not interested in using them. The dimensions are not published but they appear to have a 0.66m (2.17ft) front to back depth (height), potentially making them slightly smaller than the Skylab sleeping quarters.



Figure 2. Space Shuttle Sleep Bunks

International Space Station (ISS)

While by no means the largest crew quarters ever designed for human spacecraft, the ISS crew quarters are the largest US crew quarters flown to date, with a volume of 2.1m^3 (74.2ft^3). The US operational segment includes four identical crew quarters, one of which is shown in Figure 3. Unlike the Skylab or Shuttle crew quarters, these include capabilities for private use outside of sleep. Crew members are able to set up multiple computers and add personal items within their quarters as shown in Figure 4.



Figure 3. ISS Crew Quarters



Figure 4. Crew Quarters Computer Set Up and Personalization

Relevant NASA-STD-3001 Standards

NASA human systems standards identify where there is a known response that is able to counter one or more of the adverse effects of spaceflight on human beings. Correspondingly, where there is not a sufficient evidence base to have a prescribed solution, no standards can be written. As a result, NASA standards may not address all of the design considerations relevant to a particular spacecraft function.

NASA-STD-3001 is considered the "go-to" reference source for human factors information to apply to the design of habitable space environments. It is a two-volume set of NASA Agency-level standards established by the Office of the Chief Health and Medical Officer, directed at minimizing health and performance risks for flight crews in human space flight programs.

As previously noted, there is very little experience with spacecraft crew quarters. This limited experience presents itself in regard to NASA standards for crew quarters.

NASA-STD-3001 Volume 1 has a very high-level general health and well-being requirement that requires countermeasures to address human factors issues such as privacy and leisure activities. [10]

Volume 2 includes three requirements that limit noise levels and vibration exposure inside crew quarters and one concerning auditory alarms. It also requires lighting on-off controls and window light blocking. It requires horizontal sleep surfaces and individual privacy. [11] Other than these, there are no requirements that govern crew quarters.

Comparison of ISS Crew Quarters to US Prison Standards

Interestingly, all flown US crew quarters are smaller than minimum standards for jail cells. The American Correctional Association's Core Jail Standards specifies that single cells provide at least 3.25m² (35ft²) of unencumbered space. [12] This does not include space allocated to beds, desks, or other furnishings. The Core Jail Standards do not require any furnishings, though it is obvious that at minimum a jail cell must have a bed. The smallest mattress size available from corrections and detention facilities supplier Bob Barker Company is 63.5cm x 190.5cm (25 x 75inches). [13] The Core Jail Standards has no standards governing ceiling height, but the International Building Code Section 1208.2 specifies a minimum ceiling height of 2.286m (7ft 6in). [14] Collectively, these dimensions result in a minimum cell volume of 10.19m^3 (359.9ft³). This is significantly larger than Skylab, Shuttle, or ISS crew quarters.

3. Anticipation of Small Crew Quarters

Crew Quarters Functional Goals

The range of capabilities for private habitation can be expressed in both environmental and operational domains. Environmentally, private quarters can encompass visual, auditory, olfactory, and tactile separation, air temperature and flow control, radiation protection, and lighting control. Operationally, private quarters can include direct window viewing, single person personal computing (including data entry/manipulation, video watching, etc.), physical work surface access, sleep accommodations, non-sleep rest/relaxation, meditation, stretching, two person meetings, snacking, changing clothes, viewing appearance, video communication, audio communication, and housekeeping. [15]

As previously mentioned, very few standards exist to specify these capabilities in requirements for human spaceflight. This research defines each of these capabilities and identifies rationale for their existence:

Visual Separation—

Description: Opaque barrier fully encloses crew quarters making it impossible to see in or out, or for light from exterior cabin to penetrate into quarters.

Rationale: Isolation from the view of others is a key component of privacy; prevention of light leaks enables crew sleep.

Auditory Separation—

Description: Sound insulation reduces transmission of sound, containing normal conversation and personal device audio within quarters while preventing external audio from entering quarters; STC rating 50 or better.

Rationale: Isolation from external sounds and containment of internal sounds is a key component of privacy.

Olfactory Separation—

Description: Odor control to prevent transmission of smells into or out of the crew quarters.

Rationale: Smells entering would be an invasion of privacy; smells escaping would destroy the owner's privacy.

Tactile Separation—

Description: Hard-walled barrier that prevents deflection and reduces vibration as a result of human or equipment contact.

Rationale: Prevents external contact to crew quarters walls from being perceived as invasive from inside; prevents internal contact to walls from being perceived as disruptive from outside.

Air Temperature and Flow Control—

Description: Control to independently vary ambient temperature and air flow rate in crew quarters relative to spacecraft cabin.

Rationale: Independent control necessary to ensure crew comfort in the face of varying physiological and psychological stresses.

Radiation Protection—

Description: Material to reduce penetration of ionizing radiation into crew quarters interior.

Rationale: Crew spend in excess of 8 hours a day inside crew quarters making it an ideal location for increased radiation protection.

Lighting Control—

Description: Control to vary lighting level for physiological, psychological, and operational needs.

Rationale: Enables circadian support, situational awareness, crew comfort, and health and reduces vision-related task errors.

Direct Window Viewing—

Description: Ability to open and close a direct window view to the environment outside the spacecraft with a JSC 63307 Category B window (40cm diameter) or larger.

Rationale: Personal viewing of the local destination environment offers psychological support.

Single Person Personal Computing—

Description: Data entry/manipulation, video watching, etc. Accommodation for at least four computing devices to use network or LAN connectivity.

Rationale: Area needed for "office", "journaling", and "television/gaming" activity.

Physical Work Surface Access—

Description: Deployable or fixed general-purpose surface for mounting items with repositionable chair or other body restraint.

Rationale: Multi-purpose surface enables support of many private activities (organizing personal stowage, hobbies, games, office work, etc.).

Sleep Accommodations—

Description: Volume and environment conducive to quality, uninterrupted sleep.

Rationale: Health requirement.

Non-Sleep Rest/Relaxation—

Description: Rapid access to private volume and ability to conduct single-person activity within volume.

Rationale: Crew needs off-duty space to get out the way to maintain psychological health.

Meditation—

Description: Sufficient crew quarters volume to support meditation postures consistent with most philosophies and religious faiths.

Rationale: Reduces anxiety, improves sleep, important to some philosophical and religious beliefs.

Stretching—

Description: Sufficient crew quarters volume to stretch standing, sitting, or prone.

Rationale: Loosens and realigns muscles, improves circulation, massages body fluids to proper position, reduces stress, improves flexibility.

Two-Person Meetings—

Description: Sufficient volume for two crew to sit, facing each other, with unobstructed line of sight, with physical work surface between them, with at least six inches separation between the nearest body parts of the two.

Rationale: Enables "sensitive" conversations away from other crew members (e.g. fitness for duty, bad news from Earth, work performance, etc.).

Snacking—

Description: Volume to assume posture compatible with eating; accommodation to temp stow food packets within reach for consumption; local trash stowage.

Rationale: Freedom to eat in privacy when desired.

Changing Clothes—

Description: Volume to don and doff clothing.

Rationale: Daily and pre/post exercise attire without requiring use of hygiene area.

Viewing Appearance—

Description: Direct (mirror) viewing of face (minimum).

Rationale: Verify suitability of appearance before entering view of cameras (global broadcast).

Video Communication—

Description: Pan-Tilt-Zoom camera with camera cover; projector with display surface viewable from desk and bunk.

Rationale: Individual communication with family, doctor, psychologist, flight ops/science team(s), media, etc.

Audio Communication—

Description: Interface with audio input and output.

Rationale: Individual communication with family, doctor, psychologist, flight ops/science team(s), media, etc.

Housekeeping—

Description: Volume and physical access to clean all surfaces and crevices; ability to remove portions of crew quarters (e.g. liners) for more aggressive cleaning.

Rationale: Prevent buildup of dirt, mold, smells, etc. and ensure proper hygiene in key crew habitation areas.

Small Crew Quarters Prototyping

As a precursor activity, several prototype crew quarters were mocked up prior to incorporation in the 20-Foot Chamber. A wooden proof of concept was quickly constructed to set the basic dimensions. This was followed by an intern project to construct a more substantive crew quarters. Two units were assembled, as shown in Figure 5. Each is roughly $2m^3$ in volume, measuring roughly 2m long x 1m wide x 1m tall.



Figure 5. Prototype Small Crew Quarters

The interior configuration applied sound insulation on the floor and walls, represented by the gray material in Figure 6. A desk surface is at the opposite end of the crew quarters and includes 0.75 mid deck locker equivalent (MDLE) stowage in trays beneath the desk surface. A collapsible laptop stand is visible in Figure 6, beneath the desk and is visible in a fully collapsed state on top of the desk in Figure 7 and Figure 8. This stand can straddle a crew member's legs while in a seated or reclined position, enabling private work or private viewing of entertainment videos. There is also a small cell phone or table holder on a flexible arm and a trash can (under the desk in Figure 6 and on the desk in Figure 7).



Figure 6. Crew Quarters Interior Configuration

On the wall above the desk is a ventilation fan, electrical power outlets, and a mirror, all visible in Figure 7. There is room on the floor of the bunk to lay flat, with feet towards the end of the crew quarters with the desk. The mirror is intended to provide sufficient viewing area for personal grooming, as depicted in Figure 8.

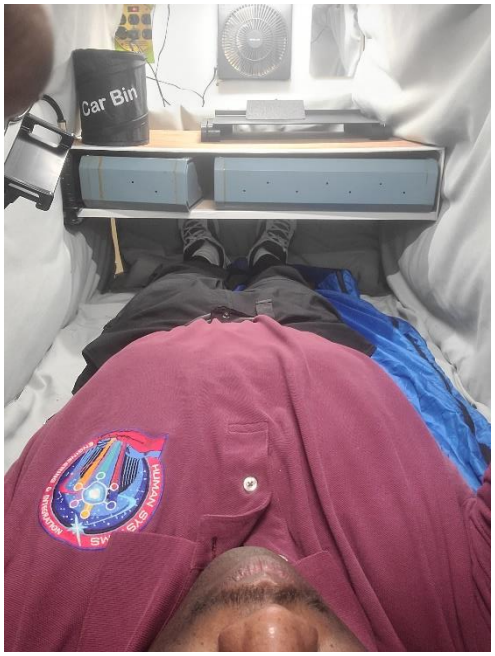


Figure 7. Sufficient Room to Lie Down in Crew Quarters

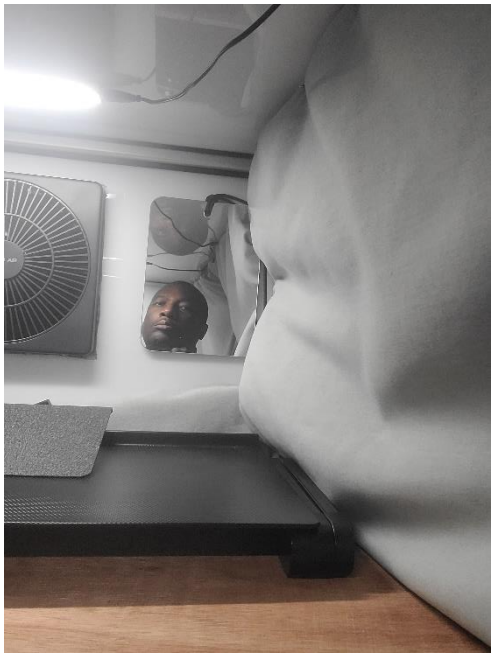


Figure 8. Mirror Provides View for Personal Grooming

Lunar Architecture Team Surface Habitat Study

The small crew quarters were briefly considered as a possible option for a small Surface Habitat. One of the early NASA reference configurations used an ISS Multi-Purpose Logistics Module (MPLM) pressure vessel as the Surface Habitat primary structure. Intended to house four crew for 30 days, there was very little room to package all of the associated functionality. The team quickly moved away from this concept and there was never an official layout, but a notional configuration was created for human factors analysis. Figure 9 shows notional habitat components tightly packaged into an MPLM-sized volume. Four small crew quarters were included, identified in green. As shown in Figure 10, the crew quarters provided some room to sit up, but employed a deployable back rest as a 99th percentile stature male crew member would not have enough room to sit fully upright without hitting his head on the crew quarters ceiling. As shown in Figure 11, there was room for a 99th percentile stature male crew member to lie down for sleep. The crew quarters included a notional sliding desk, derived from the desk used in the prototype. But unlike the prototype, this desk could slide forward for use or back for crew sleep. This can be seen in the ghosted CAD images in Figure 12. In theory, with the desk in the middle of the crew quarters, the small volume could support a two-person meeting with the desk used as a small conference table. A notional wall mounted intercom and trash can are also visible in figure 9.

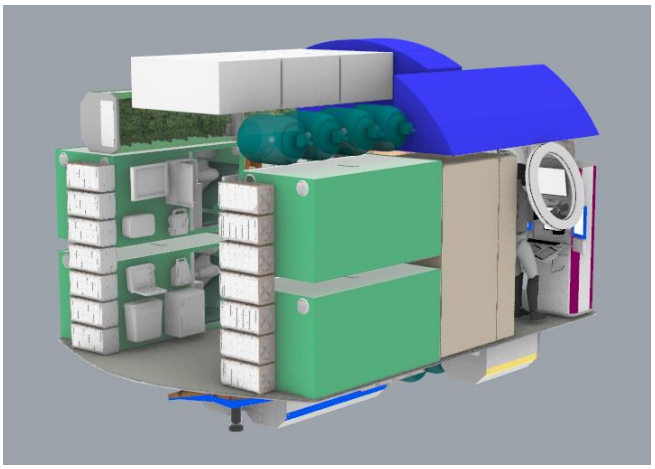


Figure 9. Packaging of Notional Components into an MPLM-Sized Surface Habitat



Figure 10. 99th Percentile Male Crew Member Seated at Desk in Small Crew Quarters

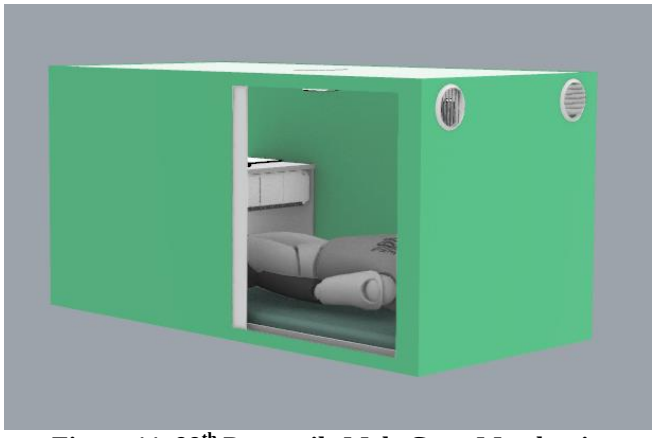


Figure 11. 99th Percentile Male Crew Member in Sleeping Posture in Small Crew Quarters

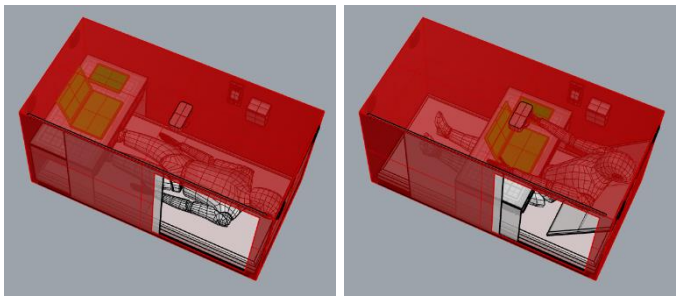


Figure 12. Desk Translation for Night and Working Configurations

Future Surface Habitat Concepts

NASA is working with US industry through the NextSTEP partnership to develop options for the Surface Habitat. It is not clear how much volume will be available for crew quarters. Thus, the possibility continues to exist that small crew quarters may be needed in order to meet mass and volume constraints. There is no data presently available regarding the acceptability of small crew quarters for surface missions to inform such a decision. Fortunately, the NASA Exploration Atmospheres Test provides a convenient opportunity to collect human-in-the-loop test data on small crew quarters.

4. EXPLORATION ATMOSPHERES TEST

Test Purpose

The primary objective of the test is to validate the exploration prebreathe protocol. Prebreathe is performed by astronauts prior to an EVA to purge nitrogen from the bloodstream, thereby reducing the risk of Decompression Sickness (DCS).

Secondary objectives are to characterize any physiological and/or cognitive adaptations to the exploration protocol 8.2psia / 34% O_2, 66% N_2 atmosphere [16]; and to utilize and potentially expand on the Materials and Processes Technical Information System (MAPTIS) database to inform materials selection for spaceflight (i.e. clothing, flight crew equipment, etc.).

This test is important for the Artemis lunar exploration initiative because significantly more frequent EVA is expected on the Moon than on ISS (up to 24 hours of EVA per crew member per week). Additionally, the Pressurized Rover and Surface Habitat will operate at a cabin pressure of 8.2psia. Currently, there are no validated protocols for planetary EVA. Space Shuttle and ISS protocols are only applicable to microgravity.

Six test subjects and two doppler technicians will live inside the chamber for twelve days while the test subjects perform planetary EVA simulations. The chamber will be pressurized at 8.2psia for most of the test, with excursions down to 4.3psia during simulated 6-hour EVAs every other day. The protocol for the eleven days of actual testing is indicated in Table 1. Note that the table only indicates days 1-11. There is a day 0 for crew move-in that is spent at sea-level ambient conditions. While day 0 does not contribute to the exploration atmospheres test data it does contribute to the habitability data. There are twelve days of crew living inside the chamber, but eleven days of exploration atmosphere test operations. From a habitability perspective, this means twelve days of crew living with the small crew quarters.

Table 1. Test Overview

Day 1	3hr PB @ 100% O_2, 14.7 psia; Depress to 8.2 psia, equilibrate
Day 2	Equilibrate + Hypoxia Characterization
Day 3	Prebreathe; 6hr EVA @ 4.3 psia, 85% O_2
Day 4	Hypoxia Characterization
Day 5	Prebreathe; 6hr EVA @ 4.3 psia, 85% O_2
Day 6	Hypoxia Characterization
Day 7	Prebreathe; 6hr EVA @ 4.3 psia, 85% O_2
Day 8	Hypoxia Characterization
Day 9	Prebreathe; 6hr EVA @ 4.3 psia, 85% O_2
Day 10	Hypoxia Characterization
Day 11	Prebreathe; 6hr EVA @ 4.3 psia, 85% O_2

The NASA Johnson Space Center Human Factors Engineering Lab and Center for Design and Space Architecture are collaborating to leverage this test to conduct habitability assessments of the crew living spaces within the 20-Foot Chamber. With respect to the crew quarters, the assessments will determine the overall acceptability of these small dimension crew quarters and the extent to which they can support the previously mentioned capabilities.

Test Facility

The 20-Foot Chamber, shown in Figure 13, is a three-level vacuum chamber at NASA Johnson Space Center that was originally constructed to support Gemini and Apollo

missions. It was later used to support Skylab and the International Space Station (ISS). The chamber is 6.1m in diameter by 8.4m in height (20.0 x 27.5ft) with a total volume of 229m³ (8,090 ft³). The chamber has two airlocks, a rapid decompression chamber, and a removable bulkhead on the outer lock compartment.

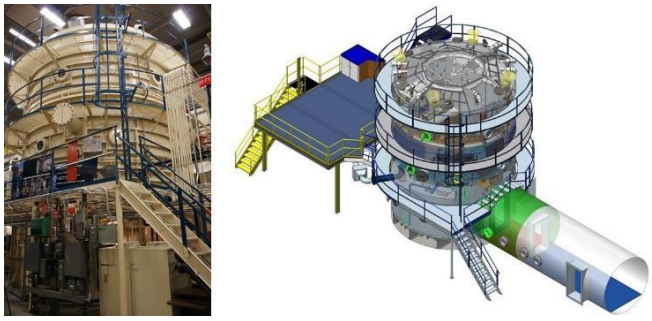


Figure 13. 20-Foot Chamber

It was used in the 1990s to conduct 30-, 60-, and 90-day human environmental control and life support subsystem (ECLSS) closed-loop testing as part of the Lunar-Mars Life Support Test Project. [17] With only four-person crews the chamber was able to support larger crew quarters, shown in Figure 14, than will be possible for the Exploration Atmospheres Test.

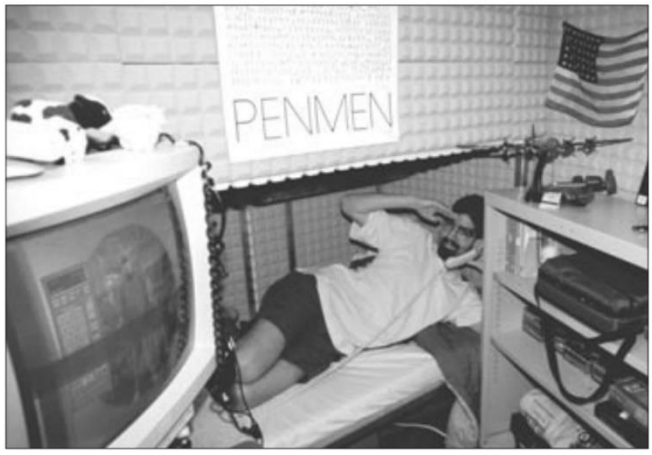


Figure 14. 20-Foot Chamber Crew Quarters During the Lunar-Mars Life Support Test Project

For the Exploration Atmospheres Test, the chamber was reconfigured to support an eight-person crew for a twelve-day mission. However, the lower deck was reserved for test equipment and could not be used for any human habitation, leaving only the mid deck and upper deck for crew systems, as shown in the cutaway view in Figure 15. The mid deck contains eight crew quarters, two waste management compartments, and two hygiene compartments, linked by a central hallway. The upper deck is a social volume with a crew dining and meeting table, stowage cabinets, television, food systems, and small games.

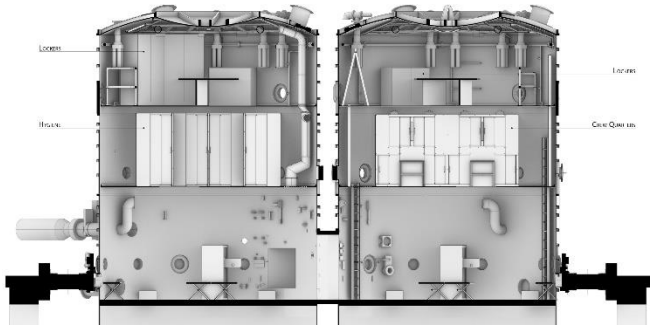


Figure 15. 20-Foot Chamber Layout for Exploration Atmospheres Test

Test Crew Quarters

The crew quarters installed in the 20-Foot Chamber were inspired by the prototype and lunar CAD small crew quarters. Eight private crew quarters were constructed in a box configuration as shown by the framing in Figure 16. Each crew quarters is 89cm wide, 195.7cm long, and 84.5cm tall.

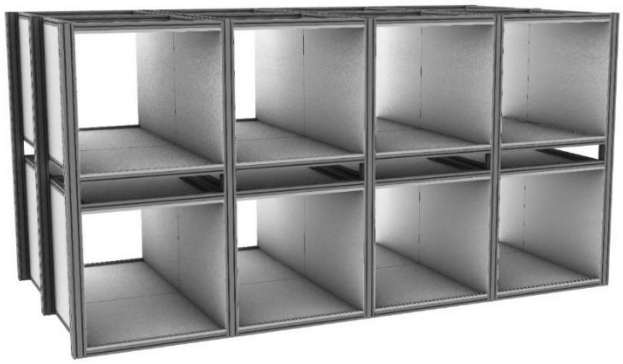


Figure 16. Crew Quarters Configuration for Exploration Atmospheres Test

These crew quarters were limited in some respects by the Exploration Atmospheres Test. Because the test will lower the chamber pressure to 4.3 psi with up to 85% oxygen limitations were imposed on acceptable materials within the chamber. Thus, many of the items used to outfit the crew quarters in either the prototype or CAD model could not be obtained within the material constraints.

The crew quarters were constructed of a powder coated aluminum, as shown in Figure 17. They will still have lighting, bedding, and a stowage compartment. The stowage compartment is built into the far end of the crew quarters and is visible in Figure 18. The fan will be replaced with a fixed ventilation register connected to the chamber's air handling system. But there will be no sound insulation, mirror (though the walls are semi-reflective), power outlets, desk surface, laptop stand, cell phone or tablet holder, or trash can.



Figure 17. Crew Quarters as Assembled in the 20-Foot Chamber



Figure 18. Crew Quarters with Stowage Compartment at Far End

5. TEST METHODOLOGY

Habitability is often thought of merely in terms of comfort and convenience, but experience has shown that good habitability features can improve crew productivity [18]. With an increase in space flight durations from the early days of Gemini/Apollo to a few weeks in Skylab and extended months in the Russian MIR and the ISS, private crew quarters (CQ) have become essential [5].

NASA's human factors team has the opportunity to test a small crew quarters design in the actual exploration atmospheric environment that may provide lessons learned to help guide lunar surface habitat and small pressurized rover development. The purpose of the human-in-the-loop (HITL) study within the 20-foot chamber is to assess the effectiveness of the CQ architectural design, environmental factors, and its functional volume for a simulated 12-day exploration mission. This knowledge will be applied to future Artemis habitation systems as well as to potential chamber enhancements and other analog facilities for future investigations.

The study design includes a series of preplanned habitation tasks that will be performed to exercise the internal layout of the habitat over the 11 days of test operations. The first days will have the crew living in the habitat and prepping for their first Extravehicular Activity (EVA) on Mission Day 3 (other EVA days include Mission Days 5, 7, 9, and 11). Habitation days, where the crew is not prepping and conducting EVAs, are Mission Days 1, 2, 4, 6, 8, and 10 (Table 2). On these days, crew will be working, sleeping, and living in the habitat conducting daily tasks such as hygiene, science, food prep, sleeping, and housekeeping. On Mission Day 8, having already spent some time in the CQs, the crew will be tasked to study their individual CQ and rate the acceptability of the design, shown in Figure 19.

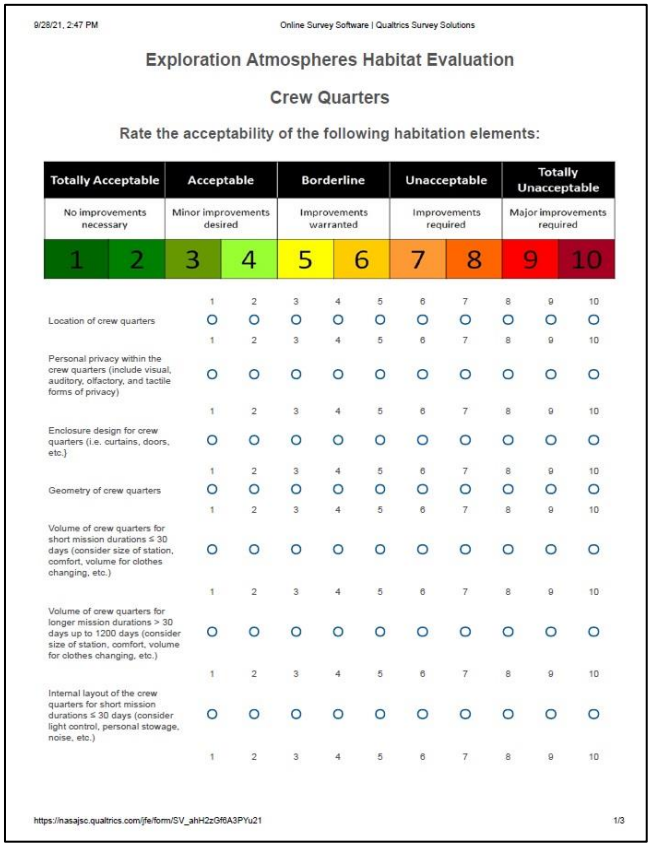


Figure 19. Example of the Crew Quarters Acceptability Questionnaire.

Table 2. Subjective Questionnaire Test Matrix

Session Duration	Frequency	Mission Day(s)	Schedule Constraints and/or Special Requirements
PRE-MISSION			
30 mins	All crew	MD-2	Habitat Systems Training
15 mins	All crew	MD-2	Human Factors Questionnaire Training
IN-MISSION			
25 mins/subject	1/subject	MD2	General Layout 1 Questionnaire
10 mins/subject	1/subject	MD3	Emergency Egress Questionnaire
10 mins/subject	1/subject	MD4	
20 mins/subject	1/subject	MD5	
20 mins/subject	1/subject	MD6	Full Body Hygiene Questionnaire Stowage Questionnaire
20 mins/subject	1/subject	MD7	WMC Questionnaire Crew Equipment and Supplies Questionnaire
20 mins/subject	1/subject	MD8	Crew Quarters Questionnaire Wardroom/Entertainment Area Questionnaire
20 mins/subject	1/subject	MD9	Meal Consumption Questionnaire Unplanned First Aid and Maintenance Questionnaire
25 mins/subject	1/subject	MD10	General Layout 2 Questionnaire
POST-MISSION			
30 mins	Can do 1 time if all crew available	MD +1	Crew Debrief

The methodology for the study includes conducting ten subjective daily in-test questionnaires using the a 10-point Acceptability Scale which was developed by NASA's Exploration Analogs and Mission Development (EAMD) project in 2008 for a series of habitation tests with a small pressurized rover. The scale has been used in multiple analogs and studies for the last 15 years. The scale consists of 5 categories with two numerical ratings within each category to discriminated preferences, shown in Figure 20. The criteria for the scale is as follows: 1) Criteria for the design being acceptable is a rating of ≤ 4; 2) Between a rating range of 5 and 6, the design is considered borderline; and 3) Criteria for a design being unacceptable is a rating ≥ 7 to 10. All criteria are based on using median values. Outlying data points > 4 will be recorded to help inform the design of future habitat internal configurations. Additionally, practical significance while using the Acceptability Scale is defined as a categorical difference between each of the five categories on the scale shown in Figure 20. For example, the difference between a 3 and 4 rating is not considered practically significant, whereas, the difference between a 4 and 5 is considered practically significant.

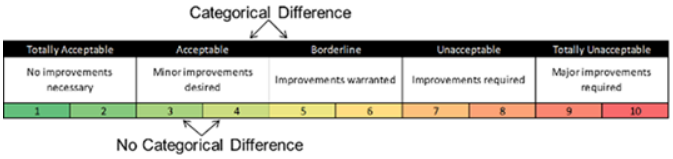


Figure 20. The Acceptability Scale.

6. RESULTS AND DISCUSSION

The current test status from the vacuum chamber test team has a target date of November 2021 to begin the official crew testing with some smaller systems engineering runs beginning in late October 2021. Test results and analysis will be discussed in an upcoming paper in FY22.

7. CONCLUSIONS

Enhancing the human performance data already collected during several habitat evaluations conducted at Johnson Space Center (JSC) [19], [20], in the deserts of Arizona [21], [22], [23], and with the latest Broad Agency Announcement (BAA) NextSTEP Ground Test Program for cislunar habitats [24], [25] will be a value to the Artemis architecture team when considering the interior design on a surface habitat and the crew quarters in which the crew will live.

The outfitting of the 20-Foot Chamber as a testbed for a proposed lunar habitat interior offers the ability to examine alternative mission architectures, gain knowledge in requirements definition and validation, and define operational concepts, thereby advancing NASA's understanding in the efficiency of quality habitation layout and crew quarters optimization for long duration surface missions.

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BIOGRAPHY



Harry L. Litaker, Jr., *is a Senior Human Factors Design Engineer for Leidos working with the Human Systems Engineering and Integration Division of the Human Health and Performance Directorate at Johnson Space Center. He received his Bachelor of Science degree in Communications from Western Carolina University and a Masters in Aeronautical Science degree from Embry-Riddle Aeronautical University in Human Factors Engineering and Safety Engineering. He has extensive human factors experience in spacecraft design, aviation and airport safety, human-machine interfaces, virtual reality simulation testing and communications. He has worked for the US military conducting human factors evaluation of prototype vehicles and human performance. Currently, Mr. Litaker is the contractor human factor lead for the Lunar Surface Mobility project, the Orion Aft Stowage IVA System (OASIS) and the Orion Speech Intelligibility Testing. His lead responsibilities have also supported the Mars Ascent Vehicle (MAV) design testing, performance research with the Low-Latency Teleoperations (LLT) study, for the Evolvable Mars Campaign (EMC), the Small Pressurized Rover (SPR) and Unpressurized Rover (UPR) project, the Multiple Mission Space Exploration Vehicle (MMSEV) Near Earth Asteroid (NEA) project, the Habitable Airlock (HAL) project, the Broad Agency Announcement (BAA) Cislunar Habitat testing, and the Altair Lunar Lander program. Mr. Litaker has conducted human performance and design research studies in such exploration analog environments as the Desert Research and Technologies Studies (DRATS), the NASA Extreme Environment Mission Operations (NEEMO), and in practical gravity simulators.*



Dr. Robert L. Howard. Jr. *is the Habitability Domain Lead in the Habitability and Human Factors Branch and co-lead of the Center for Design and Space Architecture at Johnson Space Center in Houston, TX. He leads teams of architects, industrial designers, engineers and usability experts to develop and evaluate concepts for spacecraft cabin and cockpit configurations. He has served on design teams for several NASA spacecraft study teams including the Orion Multi-Purpose Crew Vehicle, Orion Capsule Parachute Assembly System, Altair Lunar Lander, Lunar Electric Rover / Multi-Mission Space Exploration Vehicle, Deep Space Habitat, Waypoint Spacecraft, Exploration Augmentation Module, Asteroid Retrieval Utilization Mission, Mars Ascent Vehicle, Deep Space Gateway, as well as Mars surface and Phobos mission studies. He received a B.S. in General Science from Morehouse College, a Bachelor of Aerospace Engineering from Georgia Tech, a Master of Science in Industrial Engineering with a focus in Human Factors from North Carolina A&T State University, and a Ph.D. in Aerospace Engineering with a focus in Spacecraft Engineering from the University of Tennessee Space Institute. He also holds a certificate in Human Systems Integration from the Naval Postgraduate School and is a graduate of the NASA Space Systems Engineering Development Program.*