

# Human Factors Evaluations of Two-Dimensional Spacecraft Conceptual Layouts

**Robert L. Howard, Jr., Ph.D.**  
Habitability and Human Factors Branch,  
Lunar Surface Systems Habitation Team  
NASA Johnson Space Center  
Houston, TX, USA  
robert.l.howard@nasa.gov

**Abstract** – *Much of the human factors work done in support of the NASA Constellation lunar program has been with low fidelity mockups. These volumetric replicas of the future lunar spacecraft allow researchers to insert test subjects from the engineering and astronaut population and evaluate the vehicle design as the test subjects perform simulations of various operational tasks. However, lunar outpost designs must be evaluated without the use of mockups, creating a need for evaluation tools that can be performed on two-dimension conceptual spacecraft layouts, such as floor plans. A tool based on the Cooper-Harper scale was developed and applied to one lunar scenario, enabling engineers to select between two competing floor plan layouts.*

**Keywords:** Constellation, human factors, tools, processes, habitat, outpost, Net Habitable Volume, Cooper-Harper.

## 1 Introduction

One of the first questions asked by program managers and senior engineers during the Exploration Systems Architecture Study (the research effort that kicked off the Constellation program) is “how big does the Crew Exploration Vehicle need to be?” The conceptual design engineers wanted that information to plug into their parametric models and convert a volume into a structural mass estimate. Unfortunately, it doesn’t work that way. There are no reliable tools for answering the volume question. (There are many unreliable tools.)

Human Factors engineers at the Johnson Space Center developed several tools in an attempt to answer the volume question before turning to the tried and true method that was used in the Apollo Program – mockup testing.

Human Factors engineers built a detailed low fidelity mockup of the Orion Crew Exploration Vehicle (after an earlier, extremely low fidelity mockup) in order to bring in test subjects to evaluate the volume and provide a minimum volume to drive vehicle requirements. Similar mockups have been since constructed for use by the Altair Lunar Lander Project, Lunar Electric Rover, and a small number of Lunar Outpost Habitats.

However, the Lunar Surface Systems Project (responsible for the outpost) has adopted a strategy of developing multiple lunar scenarios, each of which is organized around different assumptions for lunar mission objectives, budget, timeline, etc. The scenarios incorporate numerous different types of habitats, often of different size and internal configuration. These scenarios (up to twelve in number as of the time of this writing) are processed too quickly to allow the development time to construct and evaluate mockups. Additionally, the Lunar Surface Systems budget is insufficient to fund construction of all possible outpost configurations. Thus, how can the question of volume be answered for Lunar Surface Systems?

In many cases, Lunar Surface Systems Scenarios are developed primarily as analytical (Excel-based) models, with PowerPoint and Word reports. A limited amount of CAD work is also conducted, but most layout and interior outfitting is via hand sketch or Adobe Illustrator graphics (not to scale). Thus, only two-dimensional floor plans and other non-graphical data are available to make decisions about the habitability of various scenarios.

Conducting habitability trades without the use of mockups introduces significant challenges. It is often difficult for three-dimensional volume to be perceived in a two-dimensional representation. Thus, instances of excess or insufficient volume often go unnoticed. Additionally, horizontal cylindrical habitats (e.g. circular cross section, such as the ISS Lab Module) are often misinterpreted as if their cross sections were rectangular, creating a tendency to improperly assess floor and wall space. Further, because no tool existed to make informed evaluations of such floor plans, design team discussions were often reduced to semi-emotional aesthetic preferences of one concept over another, illustrating the need for a tool to make comparisons of different floor plans on the basis of their ability to support human habitation.

## 2 Habitability Cooper-Harper

The Cooper-Harper scale was chosen as the basis for a habitability evaluation tool due to the wide usage of the

scale and its acceptance in the engineering community. Cooper-Harper is a ten-point rating scale that assesses the degree of compensation required to perform a task. It was initially used to evaluate handling qualities of flying an airplane, but has been adapted for many other purposes and applications. The Habitability Cooper-Harper assesses how well various criteria are met within a habitable volume, in this case a lunar habitat. It essentially assesses whether a particular task or workstation is acceptable or requires improvement to support human space missions. This scale can be used on concepts at any level of fidelity, from paper sketches or paragraph descriptions, through scale mockups, all the way to flight vehicles.

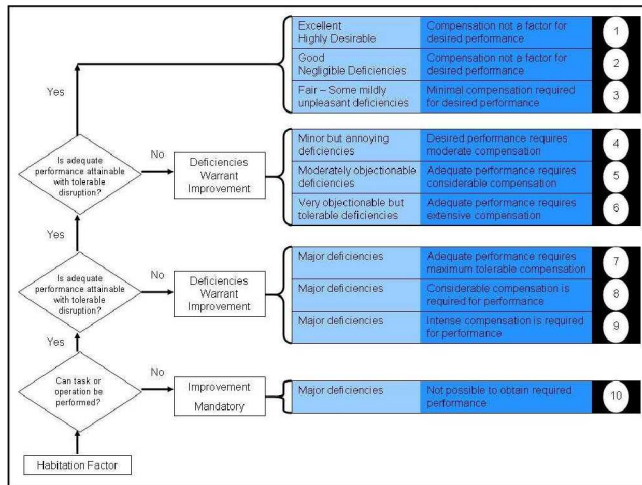


Figure 1. Habitability Cooper-Harper Scale

## 2.1 Workstation Criterion

Based on the NASA Human Systems Integration Requirements (HSIR) document [1], a set of six workstation-specific criteria and nineteen Outpost criterion were developed for use with the Habitability Cooper-Harper scale to assess the habitability of a given lunar habitat concept. The workstation-specific criteria are used in conjunction with sixteen typical habitat workstations. Each workstation is given a Habitability Cooper-Harper rating for each workstation-specific criterion.

### 2.1.1 Workstation Efficiency

The degree to which tasks within a given workstation can be accomplished at that workstation without having to traverse to other sections of the habitat. For instance, a galley with no food stowage, with all food stowage located in a separate module would be an example of poor workstation efficiency.

### 2.1.2 Workstation Visual Demarcations

The degree to which visual demarcations are readily identified for all adjacent workstations

### 2.1.3 Workstation Volume

The degree to which each workstation provides adequate volume for the crew to conduct tasks associated with the workstation.

### 2.1.4 Field of View and Reach

The degree to which displays, controls, and other equipment used within a given workstation lie within the field of view and functional reach envelope of the intended operator(s).

### 2.1.5 Multiple-Crew Operations

The degree to which the layout allows multiple operators to view and confirm each other's inputs for mission critical functions.

### 2.1.6 Maintenance Access

The degree to which replaceable or reconfigurable equipment is accessible to crew members, including anthropometric accommodation within the maintenance work envelope and the efficiency / ease at which such equipment can be installed or removed.

## 2.2 Outpost Criterion

The Outpost is given a Habitability Cooper-Harper rating for each Outpost criterion. A weighting ranks the significance of each rating with respect to the others in order to combine all ratings into a single Habitability Cooper-Harper result for the floor plan under investigation.

### 2.2.1 Circulation

The degree to which crew members can move from one part of the habitat to another, particularly without disrupting a crewmember performing a task at a workstation.

### 2.2.2 Suited Translation Paths

The degree to which suited ingress, egress, and escape operations can be performed without being hampered by protrusions and snag points

### 2.2.3 Medical Transport

The degree to which a suited or unsuited incapacitated crewmember can be moved by another crew member between the following locations: (1) from a point of injury to a medical treatment facility, (2) from the airlock to a medical treatment facility, and (3) between a medical treatment facility and a docked LER.

#### **2.2.4 Hatch Operability**

The degree to which a suited or unsuited crew member can operate hatches – pressure equalization, visual observation through hatch window of the other side, opening, closing, latch, and unlatching – from both sides of the hatch.

#### **2.2.5 Window Functionality**

The degree to which the number and placement of windows supports operations tasks, including vehicle piloting/teleoperation, docking, external viewing, motion imagery and photography, etc.

#### **2.2.6 Lighting**

The quality of lighting within the mockup, as indicated by type and placement of lights and obscuration by internal systems, equipment, or stowage.

#### **2.2.7 Food Systems**

The degree to which the layout of the food systems prevents cross-contamination, enables timely meal preparation, provides sufficient food and food equipment stowage, and efficient access to eating and food clean-up areas.

#### **2.2.8 Personal Hygiene**

The degree to which hygiene systems provide visual, auditory, and olfactory privacy, stowage, waste disposal, as well as sufficient volume and comfort for body self-inspection and cleaning, and bodily discharge.

#### **2.2.9 Exercise**

The degree to which the habitat provides stowage and operational volume, environmental control, and equipment for each crew member to exercise for 30 continuous minutes per day.

#### **2.2.10 Medical Care**

The degree to which the habitat provides for medical services, including private communication, private treatment, medical treatment volume, deployed and fixed medical equipment, and level of medical care capability.

#### **2.2.11 Sleep Accommodations**

The degree to which crew sleep is accommodated by separate sleep stations, including visual and auditory privacy for sleep and changing clothes.

#### **2.2.12 Stowage Accommodations**

The degree to which volume is provided for stowage of spares, consumables, and other equipment, including both sufficient quantity and ease of access.

#### **2.2.13 Trash Management**

The degree to which volume is provided for generated trash, as well as controls for odor control, trash removal, contamination control, and hazard containment.

#### **2.2.14 Emergency Equipment**

The degree to which the layout facilitates rapid access to emergency equipment, from within any location in the habitat.

#### **2.2.15 Radiation Protection**

The degree to which the layout provides crew member protection against radiation events.

#### **2.2.16 Work-Life Separation**

The degree to which crew work tasks, equipment, and workstations are physically separated from off-duty habitation tasks, equipment, and workstations.

#### **2.2.17 Clean-Dirty Separation**

The degree to which “dirty” environments (e.g. lunar dust, hygiene activities, maintenance activities, etc.) are separated from “clean” environments and the degree to which the architecture mitigates cross-contamination risks of activities that generate airborne particulates.

#### **2.2.18 Noise-Quiet Separation**

The degree to which noise-generating tasks and equipment are separated from workstations which require quiet conditions (e.g. high concentration tasks, sleeping tasks, voice communications, etc.)

#### **2.2.19 Personal Space**

The degree to which the architecture provides off-duty personal space that is not shared by other crew members, can provide both visual and auditory privacy for crew members, and is amenable to personalization and reconfiguration.

### **3 LSS Scenario 1.1.0**

This technique was applied at NASA Johnson Space Center to evaluate candidate layouts for the Lunar Surface Systems Scenario 1.1.0, depicted in Figure 2. The scenario involves the use of two inflatable habitats, each roughly nine meters in diameter, along with disposable logistics modules, ATHLETE robots, an inflatable airlock, power units, and two Lunar Electric Rovers.

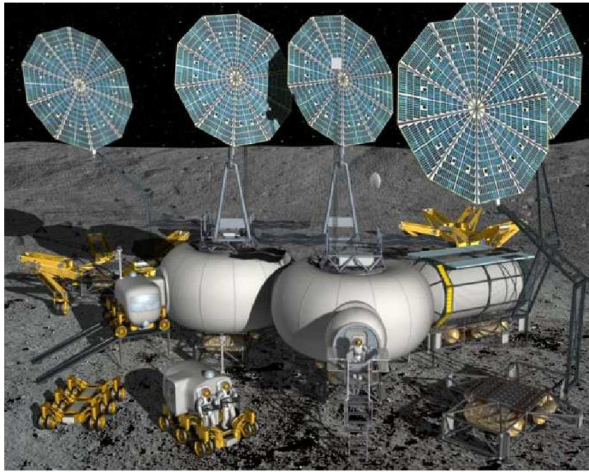


Figure 2. Scenario 1.1.0 Lunar Outpost

This lunar outpost is intended for use by a crew of four under mission durations ranging up to 180 days. A “buildup” phase is intended to deploy the outpost over a period of several years. During a portion of this time, there will be short duration missions, potentially up to 28 days, which involve the crew living and working in a single module. Unlike some other lunar scenarios, the crew has crew quarters in the outpost and does not live in the Lunar Electric Rover, except during rover excursions away from the Outpost.

Two layouts were developed for this scenario, reflecting different strategies for the positioning of systems equipment inside each module, shown in Figures 3 and 4 as Options A and B.

Option A is based on a design approach that uses the central core of the inflatable torus as an architectural element. The idea is to build a deployment scheme that centers all things around the central core, with the hope of simplifying deployment. The core itself remained a fixed structure, primarily housing vehicle subsystems and crew bunks. (An inflatable has a mandatory post-landing deployment phase. Everything inside the module must be packed in the center of the vehicle for launch. Even if automated mechanisms are used to deploy structures, there is still some remaining crew installation activity.)

Option B is based on a design approach to maximize usability of the core volume, with subsystems relocated to above the ceilings and beneath floors. Crew bunks were relocated from the core to the torus section, enabling individual crew quarters. The core remained an “open” volume to increase utilization options.

In order to capture a diversity of viewpoints, several stakeholders were invited to participate in the evaluation. Interior Design, Usability, Exercise, Medical, Geo Sciences, Life Sciences, and Engineering communities were

invited to evaluate the two layouts. These stakeholders were consulted in weekly meetings over several months as the two layouts were developed and were then asked to use the Habitability Cooper Harper to evaluate the resulting configurations. Their data was used to compare the strengths and weaknesses of each layout, both absolutely and relative to each other. This enabled an analytical down select to a single concept, rather than simply voting on a basis of which layout “looks prettier.”

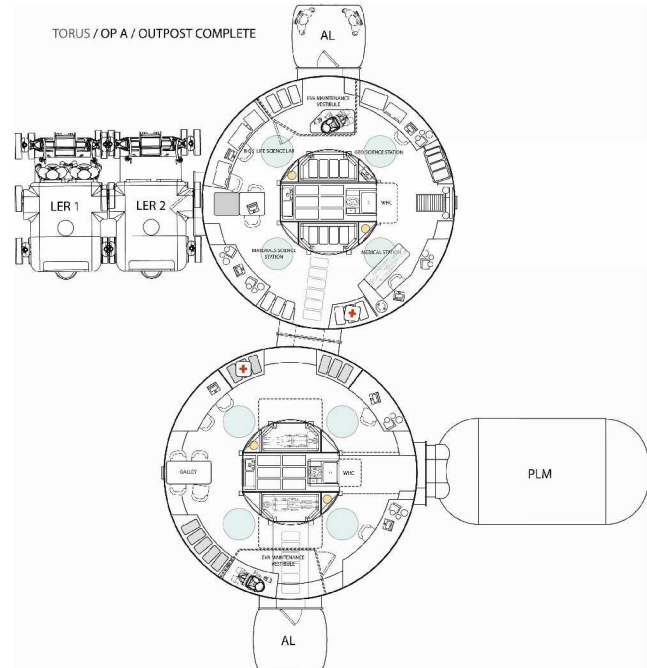


Figure 3. Lunar Outpost Option A Layout

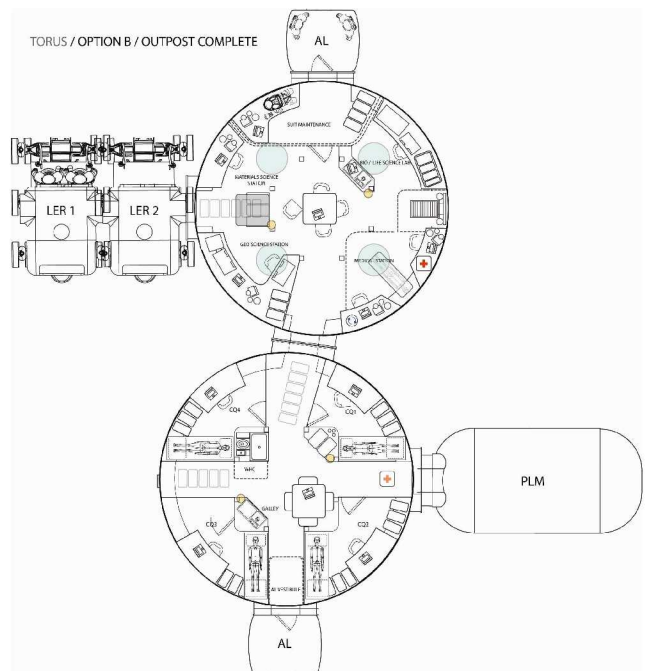


Figure 4. Lunar Outpost Option B Layout

## 4 Results and Lessons Learned

Habitability Cooper Harper ratings can be viewed at the level of each workstation and outpost criterion, or combined to give an overall vehicle rating. For the LSS Scenario 1.1.0 evaluation, only the overall vehicle rating was used to compare the two layouts. Compared ratings from LSS domain experts are shown in Table 1.

Table 1. Habitability Cooper-Harper Ratings.

Discipline	Concept A	Concept B
Interior Design	3.45 ~ 3	2.01 ~ 2
Usability	3.58 ~ 4	2.12 ~ 3
Exercise	3.92 ~ 4	3.00 ~ 2
Medical	5.00 ~ 5	4.33 ~ 4
Geo Sciences	2.75 ~ 3	2.99 ~ 3
Engineering	2.18 ~ 2	1.70 ~ 2
Life Sciences	Not submitted	Not submitted
Average Rating	4	3

While the evaluation did enable an informed comparison between the two Scenario 1.1.0 concepts, it also revealed key limits in two-dimensional evaluations and drove out instances where higher fidelity mockups (beyond Foamcore or other non-load bearing materials) will be needed.

In particular, the life sciences community reported a need from the behavioral sciences group for multi-day evaluations, suggesting medium to high fidelity mockups to be used in analogue mission studies. Groups such as exercise, medical, and geologic sciences similarly wanted to actually put test subjects inside an analogue spacecraft environment to physically conduct simulated mission activities.

Of course, such facilities and evaluation runs are expensive, meaning we cannot possibly conduct them for every Lunar Surface Systems Scenario. At best, one such study might be accomplished per year, such as the annual NASA Desert RATS studies. The 2009 Desert RATS was the first analogue study of a lunar spacecraft (Lunar Electric Rover) for a 14-day mission. This duration is expected to

be repeated in 2010 and include one of the three habitat modules associated with LSS Scenario 12.1, but it is unlikely that longer durations representing actual lunar mission durations will be conducted. Consequently, it will be critical to use tools such as the Habitability Cooper-Harper to identify the most promising lunar habitat layouts to promote for more extensive (and expensive) evaluation.

Based on this first use of the tool, the JSC human factors team anticipates continued use of the Habitability Cooper-Harper to evaluate 2-D layouts across lunar vehicles, in both the Altair Lunar Lander and Lunar Surface Systems Projects. For LSS in particular, this tool will provide the team with habitation-based metrics to compare LSS Scenarios against each other and against HSIR. The lineage to HSIR is important as it catches major omissions early that might otherwise not be noticed until significant design decisions are already made, resulting in expensive costs to refit the design to meet requirements.

Some tweaking of the tool needed (clarity, conformity to terminology in usability community, consistent rounding, etc.) and it may be necessary to incorporate a method to track the fidelity of a given layout. Even with this tool, the level of fidelity of the layout being evaluated can affect the quality of the resulting assessment. It is much easier to evaluate the effectiveness of an exercise layout in a detailed scale drawing, for instance, than in a not to scale drawing on the back of a napkin. Evaluations of the two should not be used without taking the level of fidelity into account. The greater level of engineering analysis in one may reveal or resolve human factors issues that cannot be assessed in the other.

## 5 Acknowledgment

The author would like to thank members of the Habitability Design Center and Usability Testing and Analysis Facility at NASA Johnson Space Center for their efforts designing, building, and testing Constellation spacecraft mockups. The author thanks the Orion, Altair, Lunar Electric Rover, and Lunar Surface Systems projects for their funding of human factors research and design activity.

## 6 References

- [1] NASA, *Constellation Program Human-Systems Integration Requirements*, National Aeronautics and Space Administration, Houston, TX, 2006.