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Understanding Human Movement Patterns within Cislunar Habitats

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ABSTRACT

In preparation for testing five Broad Agency Announcement (BAA) commercial cislunar habitat designs, the National Aeronautics and Space Administration (NASA) embarked on a yearlong in-house training program. This consisted of in-house testing for subject matter experts (SMEs) and crew to informed and ensure evaluation data collection techniques for each of the contractor options. Many evaluation techniques were tested with some continuing forward. Two-test conditions were employed - 1) habitat centric functions with one space element and 2) distributed functions across two or more space elements. This paper will look at one of these techniques—human circulation patterns—to assess a spacecraft habitat's internal configuration while the crew is working a three day simulated cislunar mission. Results indicated distributing functions across elements decreased crew interference and task wait times. Additionally, areas of underutilization were located, which lead to interior layout design changes.

INTRODUCTION

Human movement patterns have been a technique used by architects for several years to understand the efficiencies and pitfalls of traffic flow for a certain configurational layout. Architectural flow or movement refers to the way people move through and interact with a space. Layout and traffic flow are extremely important to any habitational configuration regardless if it is an Earth dwelling or a spacecraft. The objective of the three-day in-house testing was to study the distribution and layouts of the functions within the cislunar spacecraft and see if it could be a predictor of crew performance. The effects of these different distributions on crew performance used objective and subjective metrics to define the most acceptable distributions. Investigators for this study employed the AllTraq© real-time tracking and monitoring system to track test subjects within the mocked up space habitation configuration.

METHODS

Subjects

Sixteen participants took part in four separate evaluations. Eight were engineers and eight were astronauts with flight experience. Each evaluation used a crew of four participants.

Test Environment and Equipment

Conducted at NASA Johnson Space Center (JSC) in the Integrated Power, Avionics, and Software (iPAS) facility in Building 29 with ground support using the Analog Mission Control Center (AMCC) located in Building 30 (Figure 1). The mockup consisted of two elements and AllTraq©:

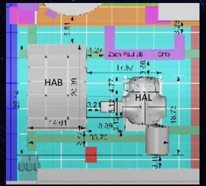

Figure 1. iPAS test area in Building 29 at JSC.

Main Habitat Module (Figure 2)
Dimensions: Length 20.4 feet, Diameter 14.04 feet
Habitable Volume: 1,059.4 cubic feet
Hatch (4): Diameter 31.5 inch
Docking Tunnel (1): Length 12 foot
Payloads were Space Shuttle Mid-Deck Lockers (MDL)
Cargo Transfer Bags (CTBs) were used for logistics
Lighting and work surfaces were also provided

Figure 2. The Main Habitat Module.

Habitable Airlock (HAL) Module (Figure 3)
Dimensions: Height 6.97 feet, Length 11.5 feet, Width 10.73 feet
Habitable Volume: 403 cubic feet
Side Hatch (2): Length 40 inch, Width 40 inch
Forward Hatch (1): Diameter 31.5 inch
Aft Hatch (2): Length 34.06 inch, Width 26 inch
Environmental Control Life Support System (ECLSS)
Avionics, habitation systems, workstations
EVA compatible equipment

Figure 3. The HAL Module.

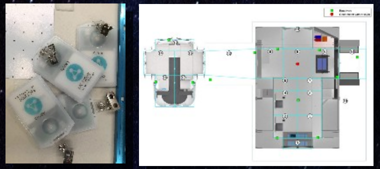

Figure 4. The AllTraq© RFID tags and test setup.

AllTraq© Test Equipment (Figure 4)
Collects human movement data
Receivers (13): Ultra-wideband (UWB) frequency
Radio Frequency Identification (RFID) tag (4):
- Accuracy: 6-8 inch between zones
- Small, non-intrusive
- Body worn

Stationary RFID Tag (1):
- Position accuracy
- 27,000 data points per day

Procedures

Subjects worked inside the mockup spacecraft for three-days executing a cislunar timeline. Their objective was to test the functional arrangement of each element configuration. Day 1 tested the Habitat-Centric Functional Allocation where all habitat functions were in a single habitat element. Day 2 tested the Distributed Functional Allocation, which spread the required habitat functions across multiple elements (Figure 5).

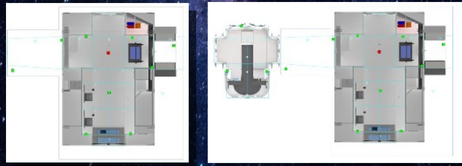

Figure 5. Habitat-Centric setup on left. Distributed Function Allocation setup on right.

RESULTS

During four three-day testing sessions, both subjective and objective data was collected on the test subjects as for their movement patterns and behavior in two test conditions. For subjective data, the Exploration Analogs and Mission Development (EAMD) project's 10-point scale of acceptability was used which measures the acceptability of different prototype systems and operations concepts. Alltraq© collected the objective subject movement data.

Location Frequency Distribution Analysis

Each zone, in the location frequency distribution, corresponds to a specific functional element. Zone numbers were assigned in a linear direction when viewed from above; where practical, the same zone number was assigned to a given function for both configurations (Figure 6 and Table 1).

Figure 6. The plan view of the test configuration with zones.

Table 1. *Functional Zones of the Tested Habitat Configuration*

Zones	Zone Description
1	Glove Box
2	Starboard Multi-purpose Workstation 1
3	Port Science Bay Multi-Purpose Area 1
4	Starboard Multi-purpose Workstation 2
5	Port Science Bay Multi-Purpose Area 2
6	Galley
7	Port Science Bay Multi-Purpose Area 3
8	Medical Area/Translation Path 2
9	Translation Path 1
10	Exercise
11	Hygiene/Maintenance
12	Tunnel
13	HAL Aft Area
14	HAL Starboard Side Hatch Area
15	HAL Port Side Hatch Area
16	HAL Starboard Area
17	HAL Port Forward Area
18	Logistics Module

Heat Map Analysis

Each zone is subdivided into a grid of 10 by 10-inch squares. The amount of time spent in each square can be inferred from the density of the geolocations within that area. In order to visualize the time spent in a particular area, a color gradation scale ranging from white (representing 0 minutes) to dark red (representing 60 minutes) (Figures 7 and 8). The heat maps show a clear reduction of cumulative zone utilization time in the distributed functional design over the single habitat design.

Figure 7. Single Habitat-Centric configuration

Figure 8. Distributed Function configuration

Histogram Analysis

Histograms were generated to show the relative distribution of high- and low-use zones; an equal distribution reference line was added that represents the total amount of time that would be spent in each zone if the crew spent an equal amount of time in each zone (Figures 9 and 10). This data provides insight into cabin layout, volume utilization, and efficiency of task/function distributions throughout the configuration.

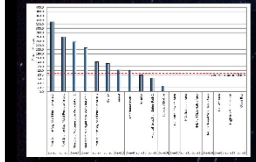

Figure 9. Single Habitat-Centric histogram

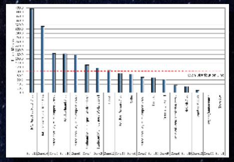

Figure 10. Distributed Function histogram

Discussion of Results

Results indicated subjects preferred distribution functionality of multiple habitat modules especially in regards to habitation and science functions. Separating functions aided in minimizing cross contamination of food, sweat (from exercise), noise, etc., with science payload activities. Additionally, duplicating devices, such as workstations, helped minimize interference and task wait times as tasks could be simultaneously. Habitat layout modifications included (Figures 11 and 12):

- Move the sleep stations from Zones 2-5 to Zones 8 and 9
- Move exercise station from Zone 10 to Zone 8
- Move galley from Zone 6 to Zone 1

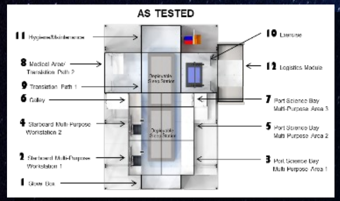

Figure 11. The As Tested habitat layout.

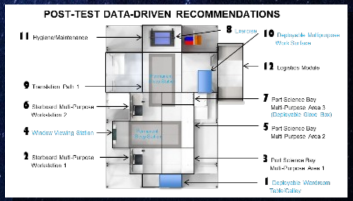

Figure 12. The Post-Test Data-Driven habitat layout.

CONCLUSIONS

Habitability is about quality of life [1]. Movement data, from AllTraq©, showed lower spikes in frequently used zones when tasks were distributed across elements compared to a single habitat. Both underutilized zones and highest density zones were identified by also using this method. Furthermore, the movement and frequency data enabled human factors engineers to make data-driven design recommendations to improve the layout configuration for optimal crew performance.

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Abstract

- In preparation for 5 commercial habitats, NASA embarked on a yearlong evaluation program
- Many evaluation techniques were tested and some continued forward
- Two test conditions were examined:
  - Habitat-Centric functions with one space element
  - Distributed Function Allocations functions across multiple elements
- This paper looked at one technique, human circulation patterns, within a habitat layout
- Results indicated distributing functions across elements decreased crew interference and identified underutilization areas within the design

Introduction

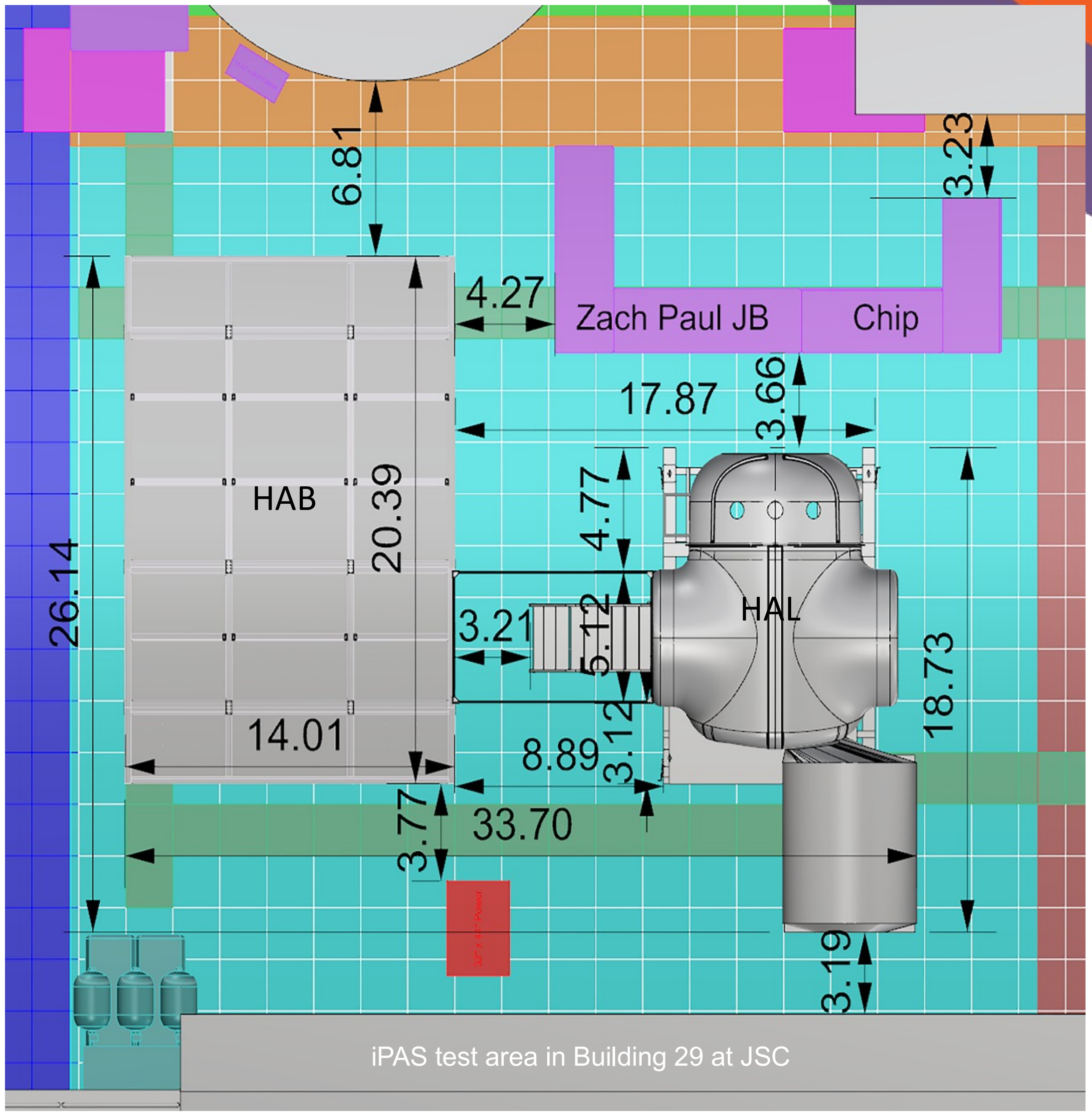
- Human movement patterns a technique used by architects for years to understand the efficiencies and pitfalls of a configurational layout
- Architectural flow refers to the way people move and interact with a space
- Layout and flow is extremely important to any habitational configuration
- The objective of the test:
  - To study the distribution and layouts of functions within the cislunar spacecraft and see if it could be a predictor of crew performance
- The effects of these different distributions on crew performance used objective and subjective metrics
- For collecting human movement, the Alltraq© system was used to track the test subjects

Methods (Subjects)

- Sixteen participants took part in four separated evaluations
  - Eight were engineers
  - Eight were flight-experience astronauts
- Each evaluation used a crew of four working through a 3-day cislunar mission timeline

Methods (Test Environment)

- Testing was conducted at JSC Integrated Power, Avionics and Software (iPAS) facility in Building 29
- Ground support used the Analog Mission Control Center (AMCC) located in Building 30



iPAS test area in Building 29 at JSC

Methods (Test Equipment)

- Main Habitat Module
  - Dimensions: Length 20.4 feet, Diameter 14.05 feet
  - Habitable Volume: 1,059.5 ft³
  - Hatch (4): Diameter 31.5 inch
  - Docking Tunnel (1): Length 12 foot
  - Payloads were Space Shuttle Mid-Deck Lockers (MDL)
  - Cargo Transfer Bags (CTBs) were used fo logistics
  - Lighting and work surfaces were also provided


The Main Habitat Module

Methods (Test Equipment)

- Habitable Airlock (HAL) Module
  - Dimensions: Height 6.97 feet, Length 11.5 feet, Width 10.73 feet
  - Habitable Volume: 403 ft^3
  - Side Hatch (2): Length 40 inch, Width 40 inch
  - Forward Hatch (1): Diameter 31.5 inch
  - Aft Hatch (2): Length 34.06 inch, Width 26 inch
  - Environmental Control Life Support System (ECLSS)
  - Avionics, habitation systems, workstations
  - EVA compatible equipment

The HAL Module

Methods (Test Equipment)

- Alltraq© Test Equipment
  - Collects human movement data
  - Receivers (13): Ultra-Wideband (UWB) Frequency
  - Radio Frequency Identification (RFID) tag (4):
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  - Stationary RFID Tag (1):
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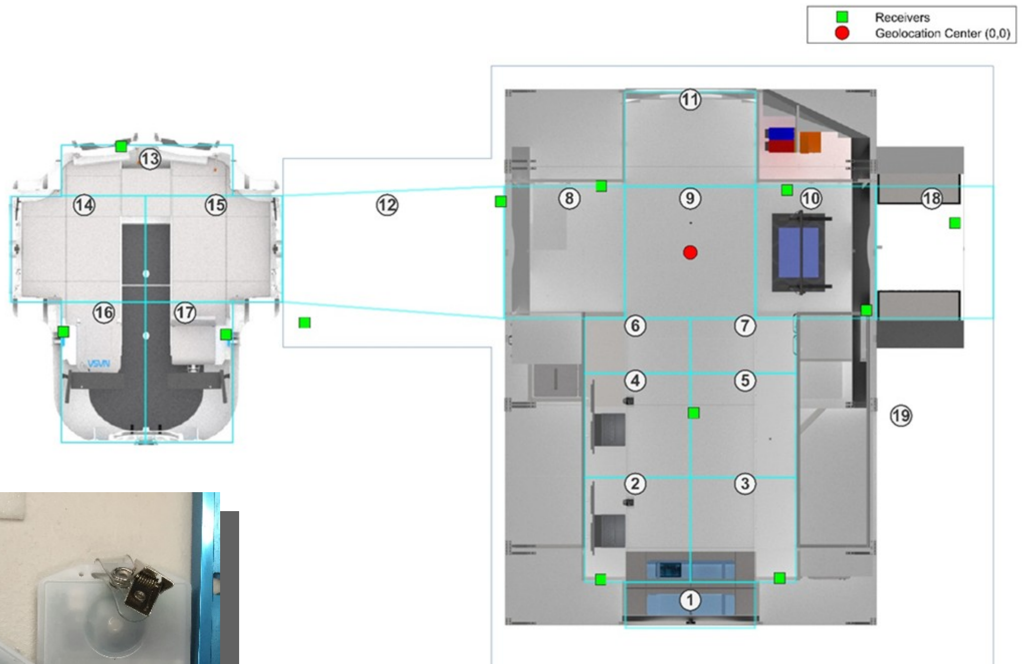

The Alltraq© RFID tags and test setup

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- Their objective was to test the functional arrangement of each element configuration
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  - All habitat functions in a single habitat element
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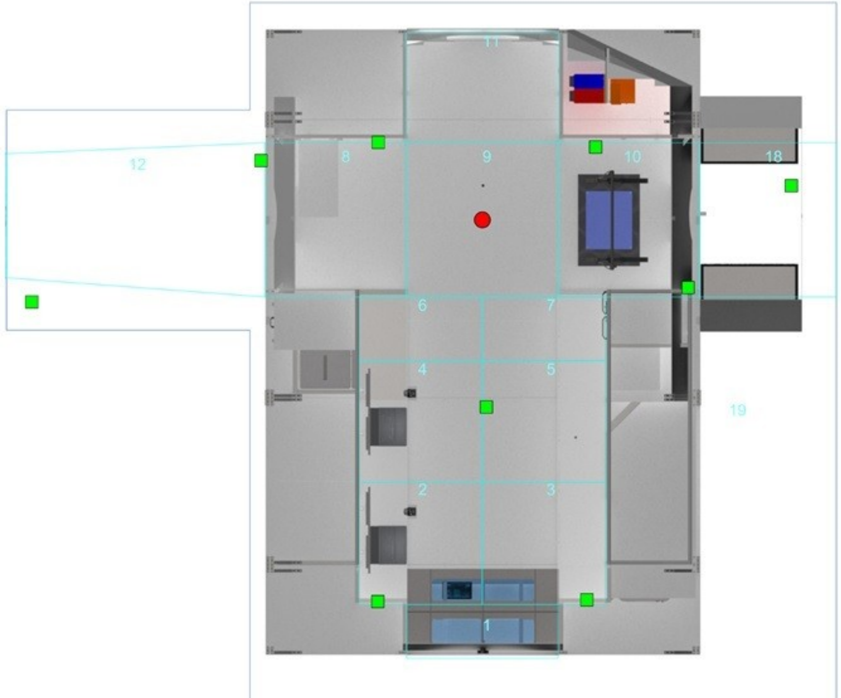
  - All habitat functions spread across multiple elements



Habitat-Centric setup

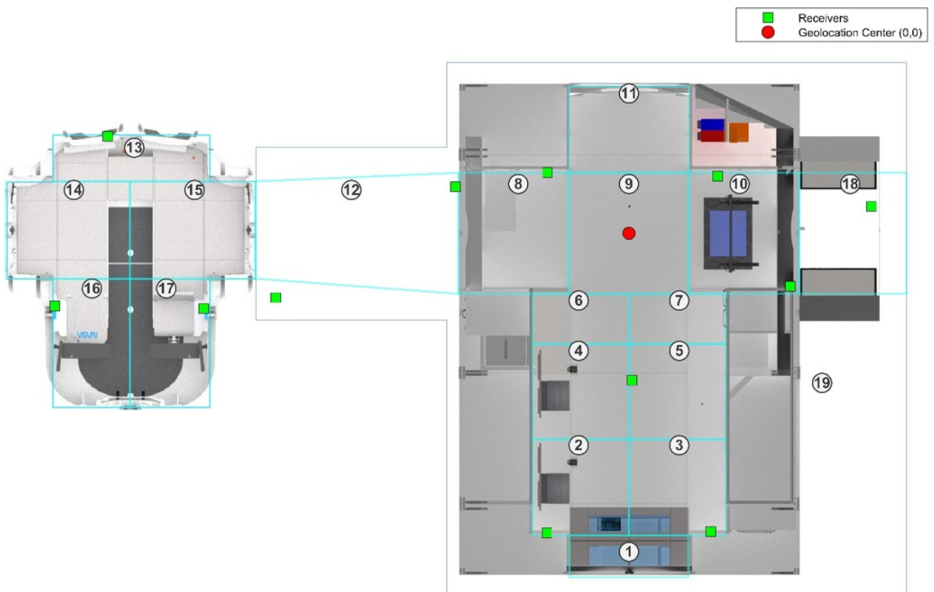
Distributed Functional Allocation setup

Results

- During four 3-day testing sessions, both subjective and objective data was collected on test subjects as for their movement patterns and behavior in two design conditions
- Subjective data use the Exploration Analog and Mission Development (EAMD) 10-point acceptable scale
    - Measures the acceptability of different prototype systems and operation concepts
- Objective movement data was collected using Alltraq©

Results

- Location Frequency Distribution Analysis
  - Each zone corresponds to a specific functional element
  - Zone numbers were assigned in a linear direction when viewed from above
  - Where practical, the same zone number was assigned to a given function for both configurations



The plan view of the test configuration with zones

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Results

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  - To visualize the time spent, a color gradation scale was used:
    - White represents 0 minutes
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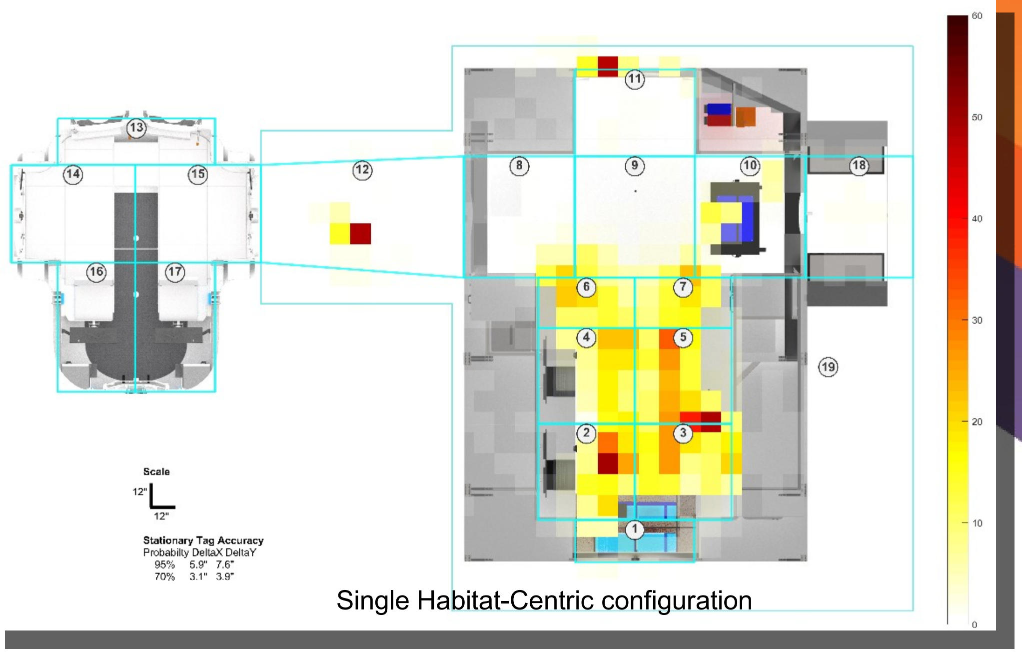
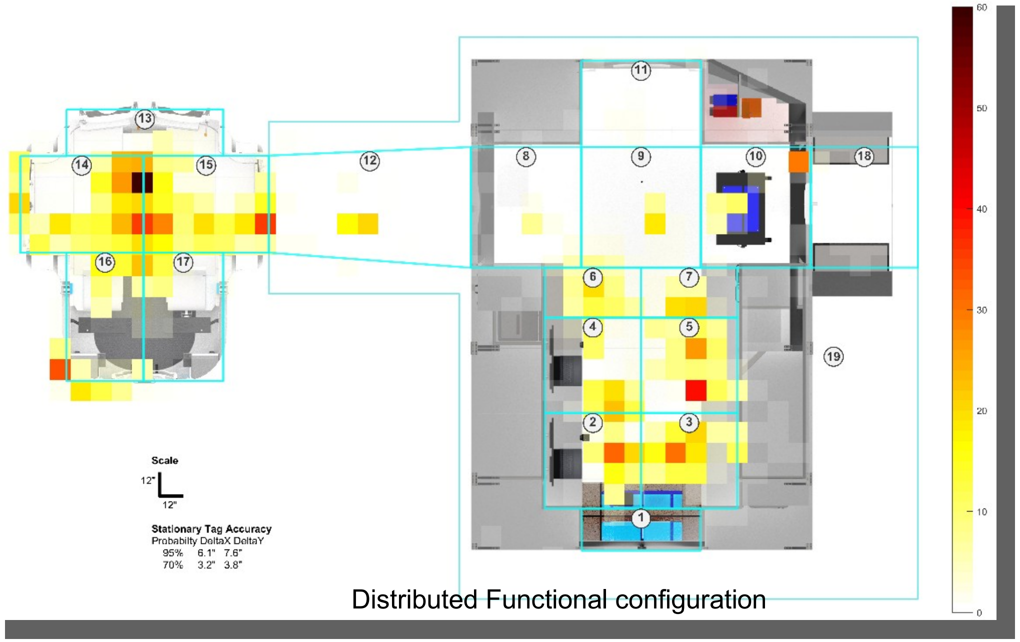


Single Habitat-Centric configuration



Distributed Functional configuration

Results

- Histogram Analysis
  - Histograms were generated to show the relative distribution of high- and low-use zones
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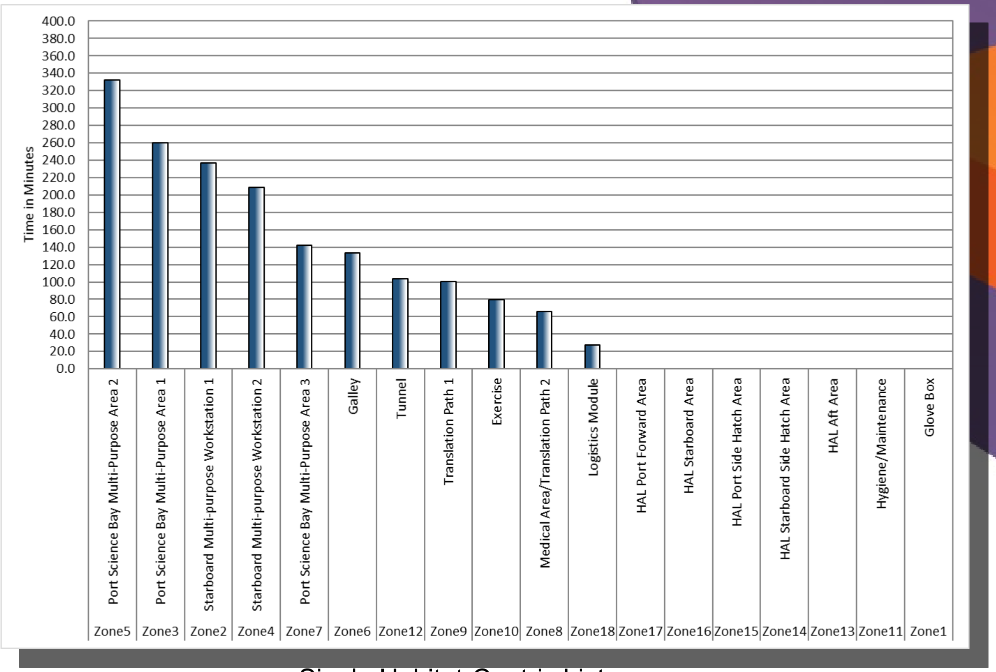
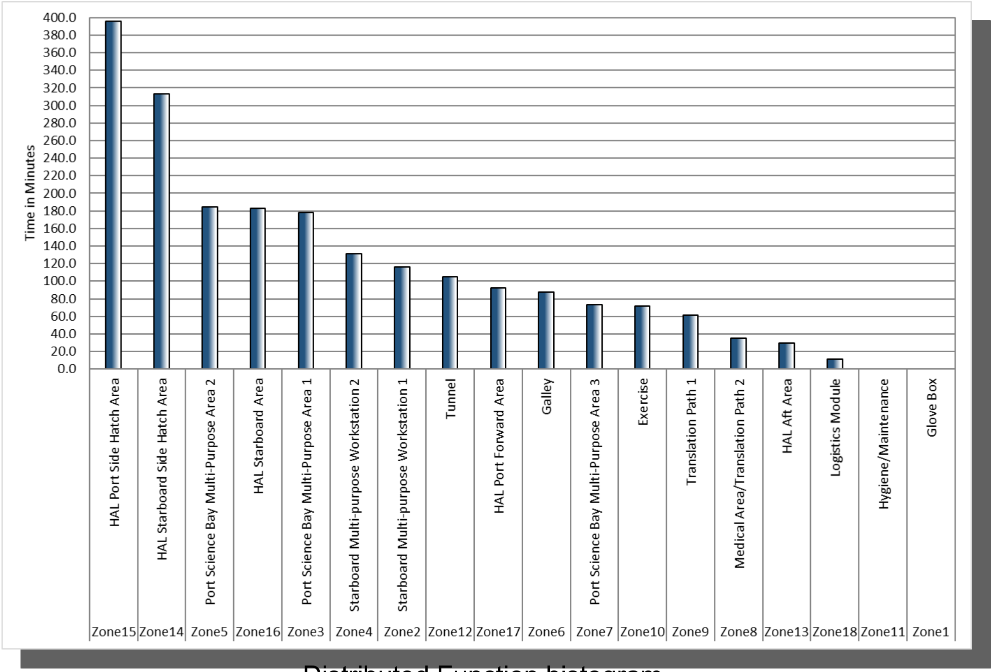
  - This data provides insight into cabin layout, volume utilization and efficiency of task/function distributions throughout the configuration



Single Habitat-Centric histogram



Distributed Function histogram

Results

- Discussion of Results
  - Results indicated subject preferred distribution functionality of multiple habitat modules especially in regards to habitation and science functions
  - Separating functions aided in minimizing the following:
    - Cross contamination of food
    - Sweat (from exercise)
    - Noise
  - Additionally, duplicating devices such as workstations, helped minimized interference and task wait times as tasks could be done simultaneously

Results

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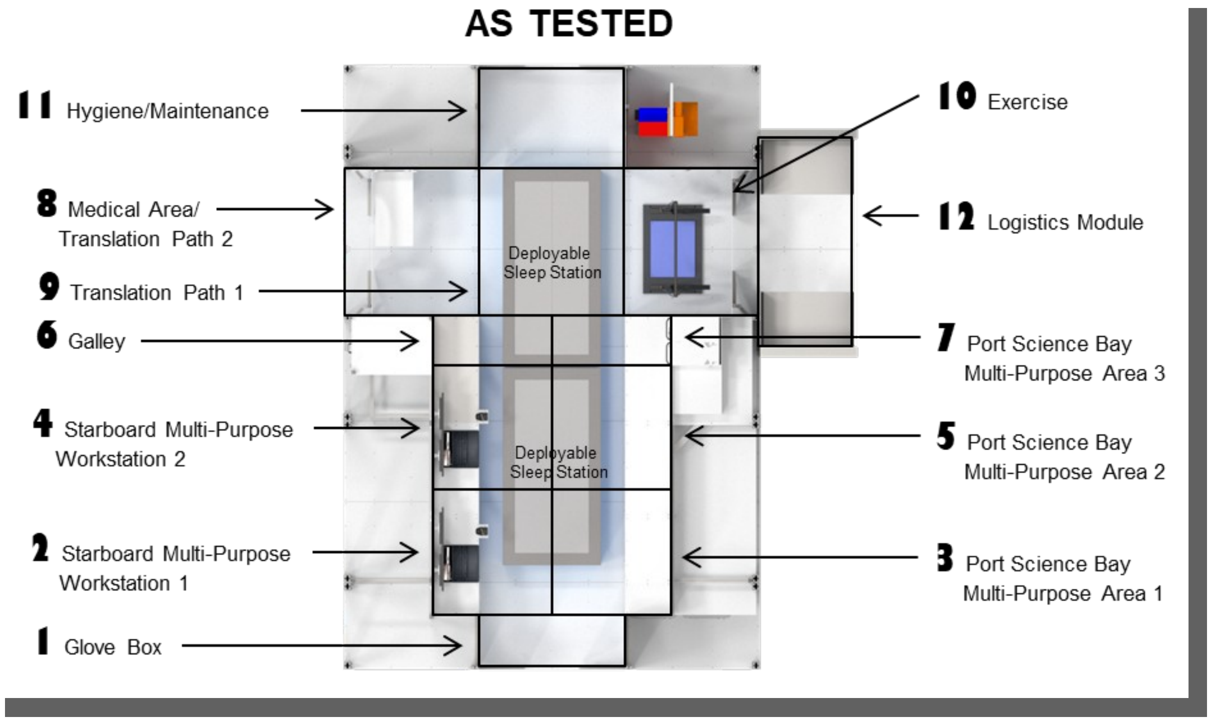

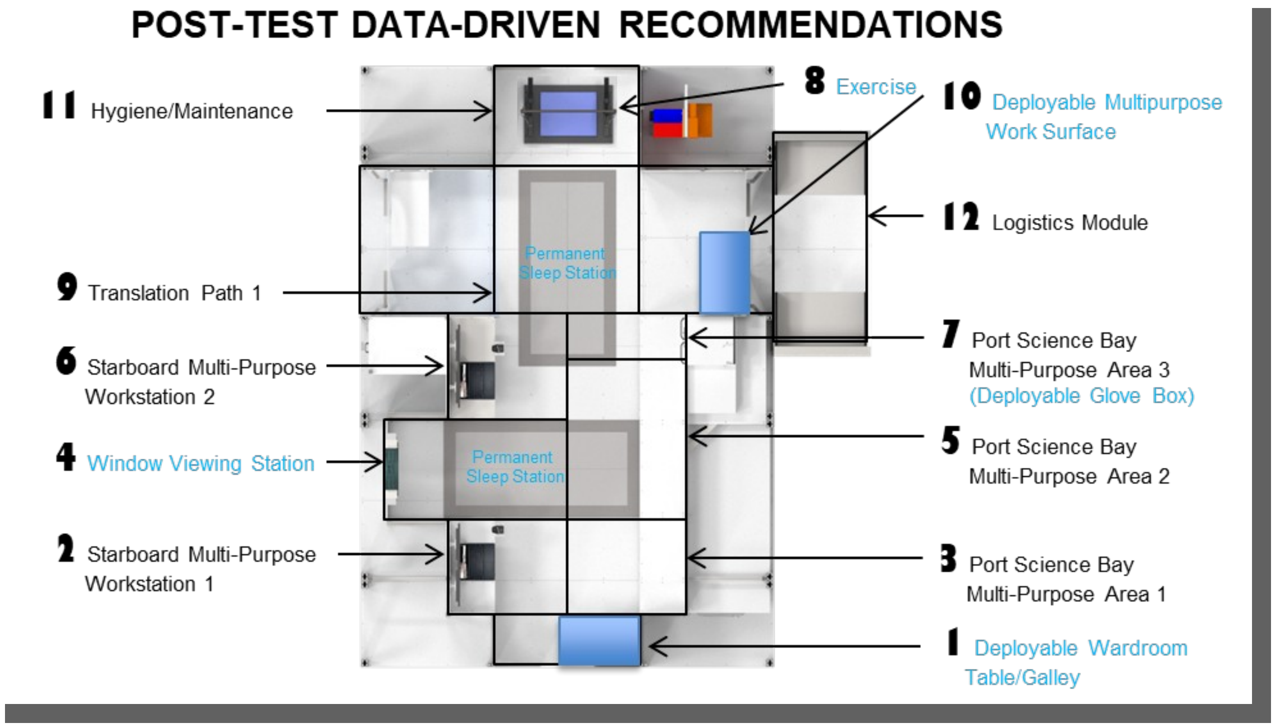

Conclusions

- Habitability is about quality of life [1]
- Movement data showed lower spikes in frequently used zones when tasks were distributed across elements compared to a single habitat
- Both underutilized zones and highest density zones were identified by using this method
- The movement and frequency data enabled human factors engineers to make data-driven design recommendations to improve the layout configuration for optimal crew performance

References

[1] Wise, J.A. (1985). "*The quantitative modelling of human spatial habitability,*" NASA Technical Reports Server, Document No. NASA-CR-179716, NAS 1.26:179716, 01 February 1985, pp. 1-154.

Other Sources

Litaker, Jr., H.L., Thompson, S.G., Szabo, R., Twyford, E.S., Conlee, C.s. and Howard, Jr., R.L. (2013). "*Dual rover human habitation filed study,*" Acta Astronautic, Vol. 90, No.2 (2013), pp. 378-390.

Litaker, Jr., H.L., Archer, R.D., Newton, C.E., Howard, Jr., R.L., Kennedy, K.J., Martin, C.S., & Montoya, B.D. (2018). *"A comparison of early conceptual design testing using virtual reality and physical environments,"* NASA/Johnson Space Center, NASA/TM-220301.

Benedikt, M.L. (1979). "*To take hold of space: Isovists and isovist fields*," Environment and Planning, B 47-65.

Tullis, T.S. and Bied, B.R. (1988). "*Space station functional relationships analysis final technical report*," NASA Contractor Report 177497, August 1988, NASA/Ames Research Center, pp 1-112.

Michalek, J.J., Choudhary, R., and Paplambros, P.Y. (2002). *"Architectural layout design optimization,"* Eng. Opt, Vol. 34(5), pp. 461-484.