NASA Marshall Space Flight Center Human Factors Engineering Analysis of Various Hatch Sizes

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Abstract. The NASA Docking System (NDS) is a 31.4961-inch (800 mm) diameter circular hatch for astronauts to pass through when docked to other pressurized elements in space or for entrance or egress on surface environments. The NDS is utilized on the Orion Spacecraft and has been implemented as the International Docking System Standard (IDSS). The EV74 Human Factors Engineering (HFE) Team at NASA's Marshall Space Flight Center (MSFC) conducted human factors analyses with various hatch shapes and sizes to accommodate for all astronaut anthropometries and daily task comfort. It is believed that the hatch, approximately 32 inches, is too small, and a bigger hatch size would better accommodate most astronauts. In order to conduct human factors analyses, four participants were gathered based on anthropometry percentiles: 1st female, 5th female, 95th male, and 99th male.

Keywords: Human Factors Engineering · Human Factors Analyses · NASA · Common Berthing Mechanism · Jacobs Space Exploration Group · Self-Contained Atmospheric Protective Ensemble · US Space and Rocket Center · Anthropometries · Underwater Astronaut Training · Microgravity

1 Introduction

Human Factors Engineering (HFE) has a key role in any system that contains human interaction with hardware. The purpose of this project was to conduct HFE analyses on various hatch shapes and sizes. Futuristic deep space missions need a standard size and shape of a hatch or common berthing mechanism (CBM) to connect modules or serve as an entryway or exit. CBMs are pressurized hatch connections between pressurized elements (PE). The five hatch sizes that were analyzed were 32", 42", 50x50", 50x50" 45°, and 62x50" (Figure 1). The 32" hatch is in place on the Orion Spacecraft and the 50x50" CBM is currently being used on the International Space Station (ISS). The Advanced Concepts Office tasked the EV74 HFE team with conducting analyses to collect data that contributes to changing the standard from the 32" hatch to a larger, more accommodating hatch for future missions.

Fig. 1. The 32” and 42” shapes are circular hatches and the 50x50”, 50x50” 45°, and 62x50” hatches are CBMs.

Each analysis was conducted in both a gravity and a microgravity environment. Surface analyses, performed in a gravity environment, were conducted at Marshall Space Flight Center’s (MSFC) Building 4649. The tank analyses, performed in a microgravity environment, were conducted at the Underwater Astronaut Training Facility (UAT) at the US Space and Rocket Center (USSRC). All hatches were analyzed in both docked and undocked configurations. The docked configuration contains two hatches parallel to each other to simulate when two PE’s are connected for astronauts to pass from one module to the other. An undocked configuration contains only one hatch. This simulates when there is only one PE used for astronaut entry or egress onto a surface. Because of this, participants wore Self-Contained Atmospheric Protective Ensemble (SCAPE suits) to represent suits that astronauts would wear in space. All analyses were observed for task difficulty, adequate volume, reach difficulty, visual access, and overall comfort.

1.1 Participants

Analyses were performed with four participants of different anthropometric dimensions. To accommodate all astronauts using these passageways, the 1st and 5th percentile female and 95th and 99th percentile male height was used. The Orion Spacecraft expanded the anthropometric dimensions to range from the 1st to 99th percentile, compared to the previous range of 5th to 95th percentile dimensions. The 1st and 99th percentile participant heights are very close to the accepted value. The 5th and 95th percentile participant heights are one or two inches different, but within the accepted value (Table 1).

Table 1. Participant Anthropometries.

Participant	Accepted Value	Participant Height
1st percentile female	4’10.5”	4’10.5”
5th percentile female	5’2”	5’3”
95th percentile male	6’2.8”	6’1”
99th percentile male	6’4.6”	6’4.5”

1.2 Safety

All participants were asked to thoroughly read and sign a consent form before the project began (Appendix A). For all surface analyses, participants were spotted while performing step-throughs with each hatch. The environment was prepared beforehand to ensure a clean and safe working space.
For all tank analyses, participants read and signed a waiver from the USSRC. The USSRC Dive Team then discussed diving basics, communication hand signs, safety hand signs, and questions that new divers had. After getting into the water and preparing dive equipment, participants went through training at the surface of the tank. They were shown diving basics and special skills to successfully dive in the UAT. While the test administrator, participants, and project assistants were in the tank, there were always enough USSRC divers to provide supervision inside and outside of the tank.

2 Surface Analyses

All surface analyses were conducted in MSFC's Building 4649. All hatches were analyzed in both docked and undocked configurations by all participants. Participants were asked to step through the hatch both frontwards and sideways, stepping through to the other side and back to the original position for each pass-through.
A JSEG Intern and JSEG full time employee were responsible for the procurement, designs, and construction for the high-fidelity wooden mockups used.

2.1 Designs

The 32" and 42" hatches were already assembled from previous analyses. The 50x50" hatch design was obtained from HP-25 as a drawing. The 62x50" hatch design was obtained from the Advanced Concepts Office as a CAD model.
All hatches were designed with a specific tunnel length and depth (See Figure 5). The depth lengths were found in the obtained designs. The tunnel lengths were either collected from designs or estimated by the test administrator and builder. The CBM tunnel lengths, all 15", were calculated using the 99th percentile shoe size, also considering clothing and boots worn. A wooden platform was used for the 50x50" docked configuration to help participants step through the hatch safely. The platform was 15" in depth and 8" in height.

Table 2. High-Fidelity Mockup Dimensions.

Hatch Size	Tunnel Length (in.)	Hatch Depth (in.)	Docked Distance
32"	10"	6 ¼"	16 ¼"
42"	10"	6 ¼"	16 ¼"
50x50"	15"	½"	15 ½"
50x50" 45°	15"	½"	15 ½"
62x50"	15"	4 ¼"	19 ¼"

2.2 Construction

The 32” and 42” hatches were constructed prior to this project; however, there were only one of each. For the docked configurations, two of each hatch were needed, so low fidelity PVC structures were used as a parallel to the high fidelity wooden mockups. The 50x50”, 50x50” 45°, and 62x50” hatches were constructed using a CNC machine. All pieces were built using ¼” plywood sheets, painted, and attached to a Cygnus mockup in Building 4649. Reconfigurations between hatches took approximately 15 minutes.

3 Tank Analyses

All tank analyses were conducted in the USSRC’s UAT which is 24 feet deep. All five hatches were analyzed by all four participants. Participants were asked to propel themselves through each hatch by pushing off the tank wall. Participants then turned around and pushed themselves off the center structure in the tank to go back through the hatch. The test administrator and supporting NASA high school interns were responsible for the procurement, designs, and construction for the PVC structures used.

3.1 Designs

A universal base design was created, allowing for simple reconfiguration for each hatch design. 1 ½” PVC was used for the universal base and for the 50x50” 45° hatch. The other hatches were built using ¾” CPVC. Fittings and adaptors were incorporated into designs for construction of each hatch.

3.2 Construction

PVC structures were constructed by hand. Both small and large pipe cutters were used to cut the PVC and CPVC pipe. The circular/ovular hatches were bent by hand, sometimes mounted while volunteers used force to form the correct shape and angle. Heavy duty primer and glue were used on the piping to secure into place and withstand strong chemicals in the UAT.

4 Results

4.1 Methodology

All analyses were observed and analyzed by the test administrator and surveys were given to participants after each analysis (Appendix B). As stated previously, the survey covered five topics: task difficulty, volume, reach difficulty, visual access, and overall comfort while performing the task of crossing through each hatch. The survey had five possible answers ranging from Strongly Disagree to Strongly Agree, with a scoring system ranging from one to five respectively. The questions were intentional-

ly written so that higher scores would represent higher satisfaction with the task of passing through the hatch participants analyzed.

4.2 Data

All question scores were totaled for each participant. Each question counted for five points, making the maximum score per participant a 25. Each participants score was then totaled for all five hatches, making the maximum overall score a 125. Scores were taken as a percentage out of 125. Percentages for each participant were analyzed for each hatch configuration – surface docked, surface undocked, and microgravity analyses (Appendix C). Microgravity analyses were done in only one configuration because participants were floating through the hatches. This data was used in two different ways to show the results. First, a bar graph was made for each hatch configuration showing the overall scores per participant for all hatches (Figure 2). Both the surface undocked and docked configurations mimicked a bell curve. The first percentile always scored the configurations the lowest and the 5th and 95th percentile scores were always greater than the 1st and 99th percentile scores. The 99th percentile score for the microgravity analyses was unexpected and therefore does not follow the same pattern as the surface analyses.

The data was also used to create a line graph for each percentile that contains all five hatch scores for all three hatch configurations (Figure 3). Scores increased as the hatch size grew larger from the 32” to the 50x50” hatch; however, results became constant as the hatch increased from 50x50” to the 50x50” 45° hatch.

Fig. 2. Configuration scores based on each anthropometry.

Fig. 3. Hatch scores based on individual anthropometries.

Data was also analyzed by compiling total participant scores per hatch for each configuration (Appendix D). Each question had a maximum score of 20 and each hatch had a maximum score of 100. The percentage was calculated for each hatch in each configuration. Results were used to compile three bar graphs to show the increasing scores as hatch size grew larger (Figure 4). As hatch size increased, total participant scores increased for surface analyses. Total participant scores increased from the 32" to the 42" hatch for the micro gravity analyses; however, the results grew constant from the 50x50" to the 50x50" 45° hatch.

Fig. 4. Configuration scores based on all anthropometries.

4.3 Conclusion

As hatch size increases, total participant scores increase as well (Figure 3). This shows a direct correlation between hatch size and comfort for all anthropometries (Figure 2). Participant satisfaction increases as hatch size increases from the 32" to the 50x50" hatch; however, the 50x50", 62x50", and 50x50" 45° have very similar scores, resulting in the graphs flat lining.

Although the scores increase as the hatch size increases for the surface analyses, the same pattern does not occur with the microgravity analyses (Figure 4). The only significant difference of scores for the microgravity analyses occurs between the 32" and 42" hatch. As the hatch grows larger from the 42" hatch, the score barely increases and remains approximately the same for the three larger hatches.

As hatch size increases, all anthropometries will be better accommodated; however, for future deep space missions, the largest hatch size (62x50") presented very similar data to the 50x50" hatch. For NASA's purposes, smaller hatches are more efficient overall. The results show that scores are constant once the size reaches the 50x50" hatch. A 50x50" or greater size hatch will better accommodate all anthropometries.

4.4 Future Work

This project was completed in approximately 10 weeks. If this project is extended and continued in the future, several factors should be considered and implemented.

Considering the hardware configurations for both surface and tank analyses, handles could be implemented to better simulate realistic hatch pass-throughs. For surface analyses, future participants could use the specifically placed handles for stability and handholds while stepping through the hatches. For tank analyses, future participants could use the handles to propel themselves through. This would better simulate microgravity environments, as opposed to pushing off the tank wall and center structure.

High fidelity mockups would also be necessary for all hatch configurations. Lack of time and machine resources for this project contributed to some hatches for surface analyses using PVC structures for the docked configuration. If studied further in the future, high fidelity mockups would be needed for each hatch in each configuration.

Surveys could be adjusted to target more specific factors for both surface and tank analyses. Also, instead of using a scoring system to analyze the survey data, statistical analysis could be done to find more specific trends, outliers, and deviations in the data.

5 References

1. Federal Aviation Administration: Human Factors Design Standard. WJHTC U.S. Department of Transportation, Atlantic City Airport (2003).
2. National Aeronautics and Space Administration: Human Integration Design Handbook. , Washington, D.C. (2014).

Appendix A

Participant Consent Form

Informed Consent for CBM Human Factors Assessments

Test Administrator: Becky Stewart (rebecca.a.stewart@nasa.gov)
Department/Organization: EV74 Human Factors Engineering
Location: Marshall Space Flight Center, Building 4649 & US Space and Rocket Center

Mentors: Eric Staton (eric.j.staton@nasa.gov)
Tanya Andrews (tanya.c.andrews@nasa.gov)

Part I: Information Sheet
Introduction: As a Human Factors Engineering Intern for the summer of 2018, I have been assigned with the task of performing human factors assessments on various common berthing mechanisms and hatches of various shapes and sizes. Each hatch will be tested in both docked and undocked configurations and in both gravity and microgravity environments. Both wooden and PVC structures have been built to represent the dimensions of all hatches. Assessments will be done in Building 4649 and in the Underwater Astronaut Training environment at the US Space and Rocket Center.

Purpose: These analyses are being conducted to determine which hatch shape and size will be the most objectively and subjectively accommodating to all people for future deep space modules. Participants of different anthropometries will be used in order to account for all heights.

Research: The participants will be informed and trained in a meeting prior to any analyses. The test administrator will inform the participants about the project in more depth and will instruct them what to do for each analyses. During each analyses, the test administrator will be observing how each participant steps (or floats) through each hatch. The volume, reach envelope, height, visual access, and comfort of each hatch will be observed for each participant. After each assessment, all participants will be asked to provide feedback. This will be done by a survey given by the administrator. The participants will be asked factual questions about the task as well as subjective questions like comfort, ease, and overall satisfaction.

Participant Selection: Participants of 4 anthropometries and one videographer were selected for the analyses. Participant height and experience was used to find volunteers, and specific heights and weights were used to select individuals. The four participants needed are listed below. Participants with the most similar heights to the standards were chosen.

1st percentile female	4’10.5”
5th percentile female	5’2.0”
95th percentile male	6’2.8”
99th percentile male	6’4.6”

Height will be recorded for each participant.

Voluntary Participation: Participation for this assessment is voluntary. Participants have complete authority to stop the assessment at any given time for any reason. Even after signing this form, participants can still choose not to participate in this assessment.

Risks:
Gravity Analyses: There are no major risks associated with the analyses held in 4649. Participants will simply step through various hatches. This may cause participants to bend over, crouch, or duck their heads. Closed toe shoes are required.

Microgravity Analyses: The analyses at the US Space and Rocket Center are somewhat dangerous. Those who have asthma should not participate. Proper equipment will be provided and each participant will be subject to a training course from the USSRC Aquatics Manager. The Aquatics Manager will be in the tank at all times, and two lifeguards and divers will be at the tank at all times. Diving has the potential to cause participants to be nervous and/or minor claustrophobia. All divers should pay close attention during training and remain calm and focused while performing analyses.

Benefits: The data and results gathered from these analyses will be used by NASA and the Advanced Concept Office in determining futuristic hatch designs and decisions. The participants will get to contribute to these important findings and perform analyses in the astronaut training facility at the USSRC.

Privacy/Confidentiality: Information collected from the participants will not be shared. All the information the EV74 Human Factors team collects will be kept confidential. If the data is published or presented, names will not be included. Participant information may be stored for future projects relating to the Common Berthing Mechanism, but will only be used as a resource for interns and the Human Factors team.

Multimedia Release: Photographs, video and/or audio recordings will be taken during the assessments. These photographs and videos will not be published unless given written approval in the statement below by the participants. Participants cannot participate in the assessment if multimedia release is refused. Participant names will not be stored with any photos, videos, or audio. Please initial next to your decision below:

_____ I agree to have video/audio recorded and photographs taken during my participation.
_____ I DO NOT agree to have video/audio recorded and photographs taken during my participation.

Right to Refuse or Withdraw: You do not have to take part in this research if you do not wish to do so. You may also stop participating in the research at any time you choose without any negative effects. It is your choice and all of your rights will be respected.
Who to contact: You may ask Becky Stewart any questions related to your participation before you sign this form. This procedure has been approved by Tanya Andrews. Please contact her with any additional concerns related to this research study.

Part II: Certificate of Consent
I have read and understood the information on this form. I've had the opportunity to ask questions, and any questions I have asked have been answered to my satisfaction. I consent voluntarily to be a participant in this assessment.
Print Name of Participant: _____
Signature of Participant: _____ Date: _____
Printed Name of Administrator: _____
Signature of Administrator: _____ Date: _____

Appendix B

Participant Survey Form

Please elaborate on any responses marked (Neutral), (Disagree), or (Strongly Disagree)
Please answer quickly; extensive thought should not be required, as these are first impressions.
Task: pass through specified hatch

1. I was able to perform the task without difficulty.

(Strongly Disagree) (Disagree) (Neutral) (Agree) (Strongly Agree)

2. I felt I could complete the task in the allocated volume.

(Strongly Disagree) (Disagree) (Neutral) (Agree) (Strongly Agree)

3. I did not encounter any reach difficulties when completing the task.

(Strongly Disagree) (Disagree) (Neutral) (Agree) (Strongly Agree)

4. I had adequate visual access necessary to perform the task.

(Strongly Disagree) (Disagree) (Neutral) (Agree) (Strongly Agree)

5. I felt comfortable inside the hatch.

(Strongly Disagree) (Disagree) (Neutral) (Agree) (Strongly Agree)

Appendix C

Data: Configuration scores based on each anthropometry

SURFACE ANALYSES UNDOCKED		**Participants**		
Hatch	**1st**	**5th**	**95th**	**99th**
32"	5	11	13	11
42"	11	21	21	18
50x50"	21	23	23	23
62x50"	21	24	24	24
50x50 R	25	23	25	23
Sum:	83	102	106	99
Percentage:	66.4%	81.6%	84.8%	79.2%

SURFACE ANALYSES DOCKED		**Participants**		
Hatch	**1st**	**5th**	**95th**	**99th**
32"	9	13	16	11
42"	13	23	20	21
50x50"	24	24	24	23
62x50"	25	25	24	24
50x50 R	25	25	25	24
Sum:	96	110	109	103
Percentage:	76.8%	88.0%	87.2%	82.4%

MICROGRAVITY ANALYSES		**Participants**		
Hatch	**1st**	**5th**	**95th**	**99th**
32"	13	17	18	**20**
42"	22	25	25	25
50x50"	25	25	25	25
62x50"	25	25	25	25
50x50 R	25	25	25	25
Sum:	110	117	118	120
Percentage:	88.0%	93.6%	94.4%	96.0%

Each score is the individual participant score given for each hatch. Each table is a different configuration or environment. The maximum score for each participant for each hatch was 25. Scores in bold are unexpected results.

Appendix D

Data: Configuration scores based on all anthropometries

UNDOCKED

Hatch	UD Q1	UD Q2	UD Q3	UD Q4	UD Q5	TOTAL	PERCENTAGE
32"	5.00	10.00	8.00	12.00	5.00	40.00	40%
42"	12.00	18.00	15.00	14.00	12.00	71.00	71%
50x50"	17.00	20.00	15.00	20.00	19.00	91.00	91%
62x50"	19.00	19.00	18.00	18.00	19.00	93.00	93%
50x50 R	18.00	20.00	19.00	20.00	19.00	96.00	96%

DOCKED

Hatch	D Q1	D Q2	D Q3	D Q4	D Q5	TOTAL	PERCENTAGE
32"	6.00	12.00	11.00	14.00	6.00	49.00	49%
42"	14.00	18.00	14.00	18.00	13.00	77.00	77%
50x50"	19.00	20.00	17.00	20.00	19.00	95.00	95%
62x50"	20.00	20.00	19.00	20.00	19.00	98.00	98%
50x50 R	20.00	20.00	20.00	20.00	19.00	99.00	99%

MICROGRAVITY

Hatch	D Q1	D Q2	D Q3	D Q4	D Q5	TOTAL	PERCENTAGE
32"	10.00	14.00	16.00	15.00	13.00	68.00	68%
42"	19.00	19.00	20.00	20.00	19.00	97.00	97%
50x50"	20.00	20.00	20.00	20.00	20.00	100.00	100%
62x50"	20.00	20.00	20.00	20.00	20.00	100.00	100%
50x50 R	20.00	20.00	20.00	20.00	20.00	100.00	100%

The sum of participant scores is shown for each question for each hatch. The maximum total score possible is 20.