

## Abstract

A rule based approach to ISS interior volume control and layout

Brian Peacock, Jim Maida, David Fitts, Jonathan Dory

Traditional human factors design involves the development of human factors requirements based on a desire to accommodate a certain percentage of the intended user population. As the product is developed human factors evaluation involves comparison between the resulting design and the specifications. Sometimes performance metrics are involved that allow leniency in the design requirements given that the human performance result is satisfactory. Clearly such approaches may work but they give rise to uncertainty and negotiation. An alternative approach is to adopt human factors design rules that articulate a range of each design continuum over which there are varying outcome expectations and interactions with other variables, including time. These rules are based on a consensus of human factors specialists, designers, managers and customers. The International Space Station faces exactly this challenge in interior volume control, which is based on anthropometric, performance and subjective preference criteria. This paper describes the traditional approach and then proposes a rule-based alternative. The proposed rules involve spatial, temporal and importance dimensions. If successful this rule-based concept could be applied to many traditional human factors design variables and could lead to a more effective and efficient contribution of human factors input to the design process.

# A Rule Based Approach to ISS Interior Volume Control and Layout

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NASA Space Human Factors

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# Question From the Customer?

- What should be the spatial dimensions of space station work areas and translation pathways?
- What is behind the question?
  - There are over-riding limits in the modules (84 x 84) and hatches (50 x 50)
  - The payload and other equipment must be moved in and out and used
  - Emergency egress must not be compromised
  - There must be clearance for movement of people
  - There must be room to work
  - There must be access (including visual) to emergency equipment
  - Stowage (construction, maintenance and consumables) competes for space
  - The conditions of work and movement may be complex
  - There may be a case for time share
  - The duration and frequency of crew activities need to be considered

# Human Factors Approaches to the Question of Spatial Design

- Reference to existing information and guidelines.
- Task analysis – assessment of the conditions of use (emergency, frequency, duration, importance etc.).
- Anthropometry – clearance envelopes (for people and objects).
- Performance – speed and accuracy as affected by clearance.
- Preference – judgment of customers in fitting trials.
- **Consensus SHFE Rules based on all available evidence.**

# Existing Information

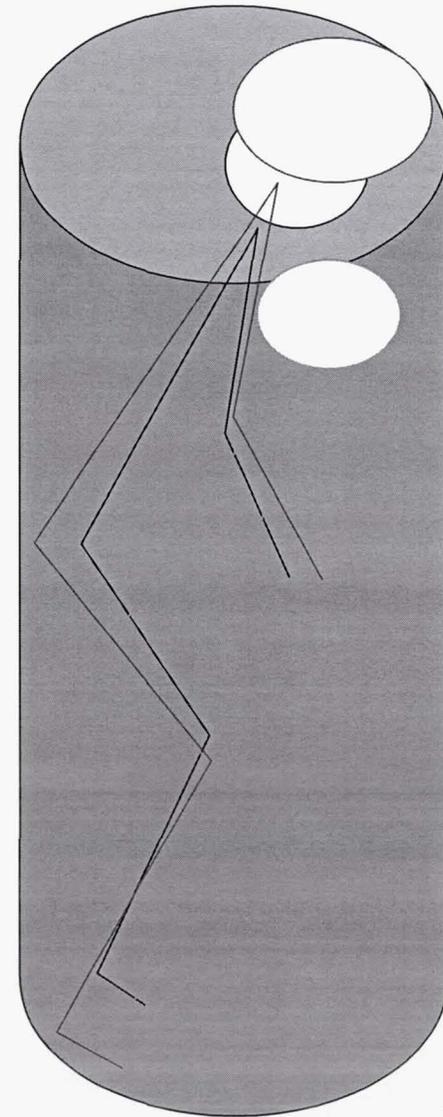
- NASA standard 3000 man-systems integration standard.
- Military standards / HFE literature (Woodson, Tilman and Tilman, 1992).
- Anthropometry and biomechanics facility report on “translation and operational clearance requirements.”
- Geometric data regarding needed and proposed space utilization.
- Customer feedback.
- Management mandate that safety must not be compromised.

# Anthropometry approach

- Body segment dimensions of astronaut population
- Assumptions regarding neutral posture joint angles
  - Individual / behavioral variability
  - +10% to joint angles
- Policy on accommodation
  - 95%, 99%, 100%
- Allowances
  - Clothing, loads, “clearance”

*Insufficient evidence without context*

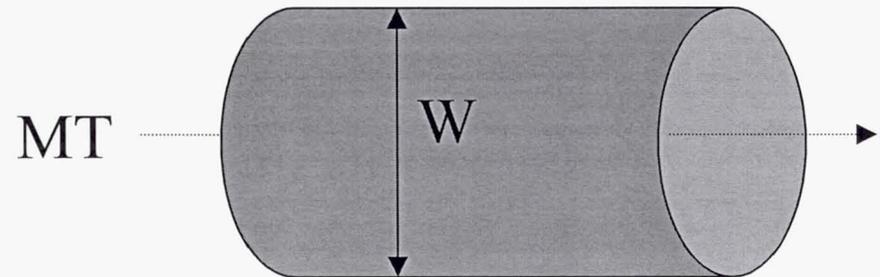
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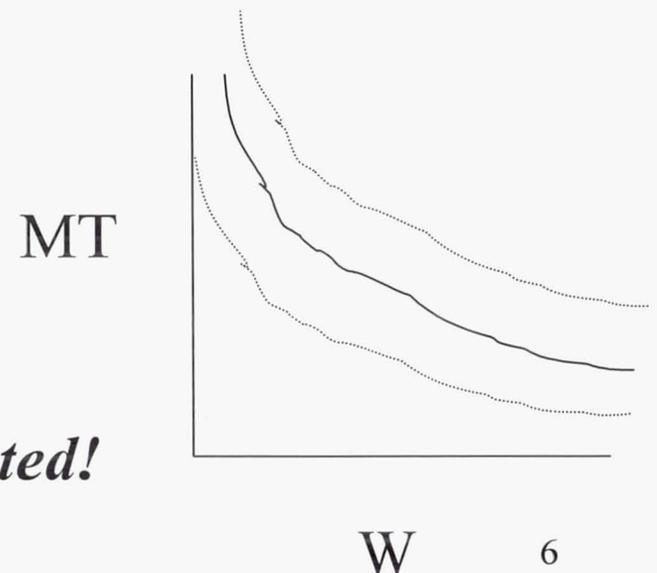
# Human Performance Approach

*(Fitts law)*

- $MT = k \cdot \log_2 2A/W$ 
  - MT is Movement Time, A is amplitude, W is target width
  - For fixed W and steady state velocity (V),  $MT = A/V_{av}$
  - Drury has shown that vehicle velocity is related to lane width
- Experimental approach:
  - Have different subjects move through different pathways with different encumbrances
  - Perform experiment under earth / reduced / zero gravity conditions (pool, KC135)



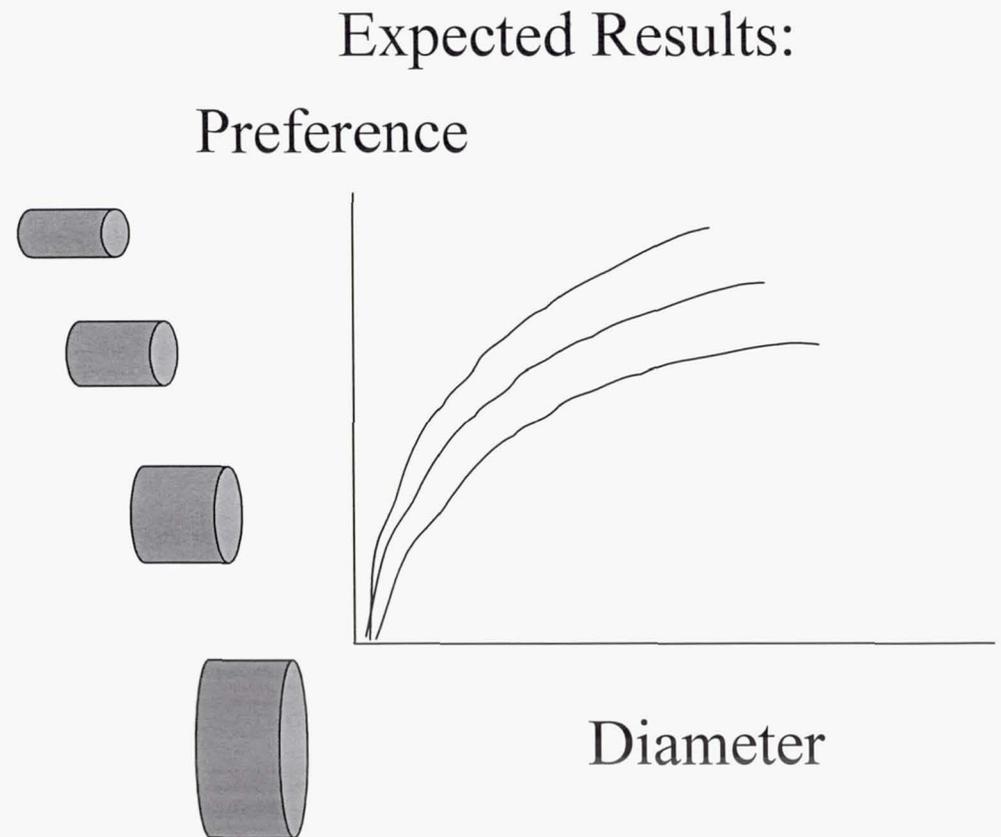
Expected Results:



*Would really show how performance is affected!*

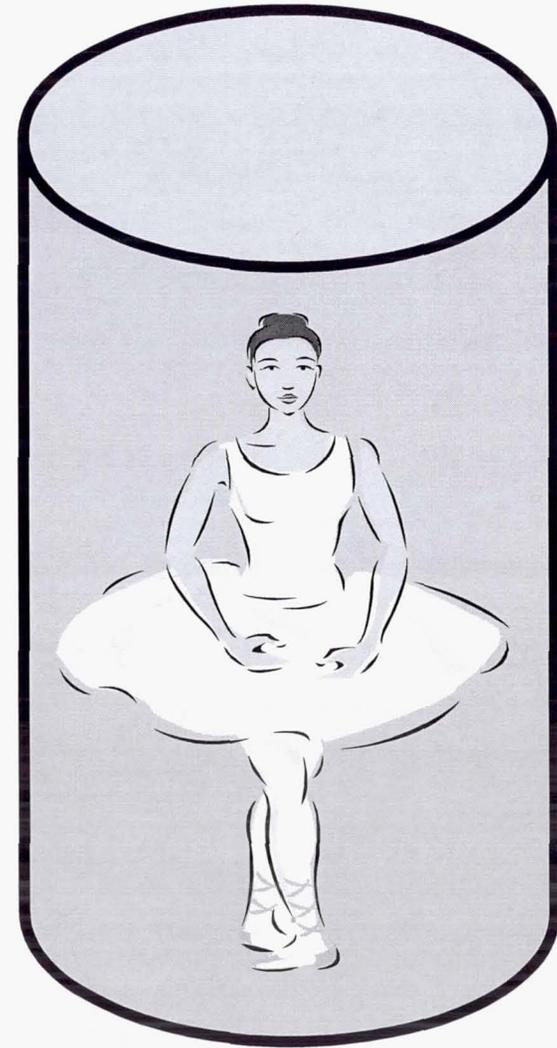
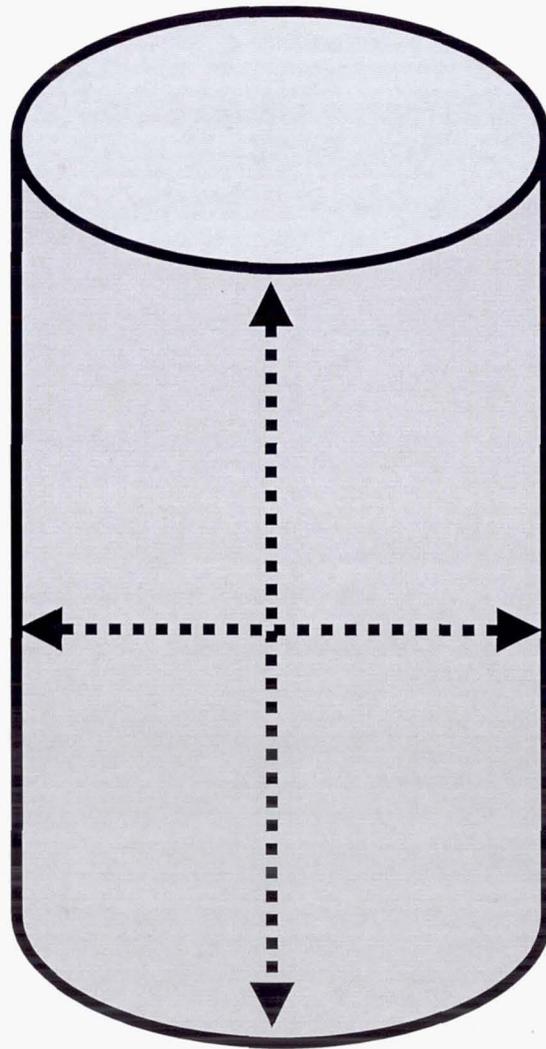
# Preference Approach (Psychophysics)

- Present subjects with examples of different clearances under different conditions (lighting, loads, stress etc.) And have them judge which clearance diameter (or shape) is ideal /acceptable / tolerable
- This investigation could be carried out under 1g conditions, in the pool or in the KC-135



*Would confirm the Voice of the Customer under controlled conditions*

# Standards Approach



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MSIS - 32 X 72

# SHFE Rules

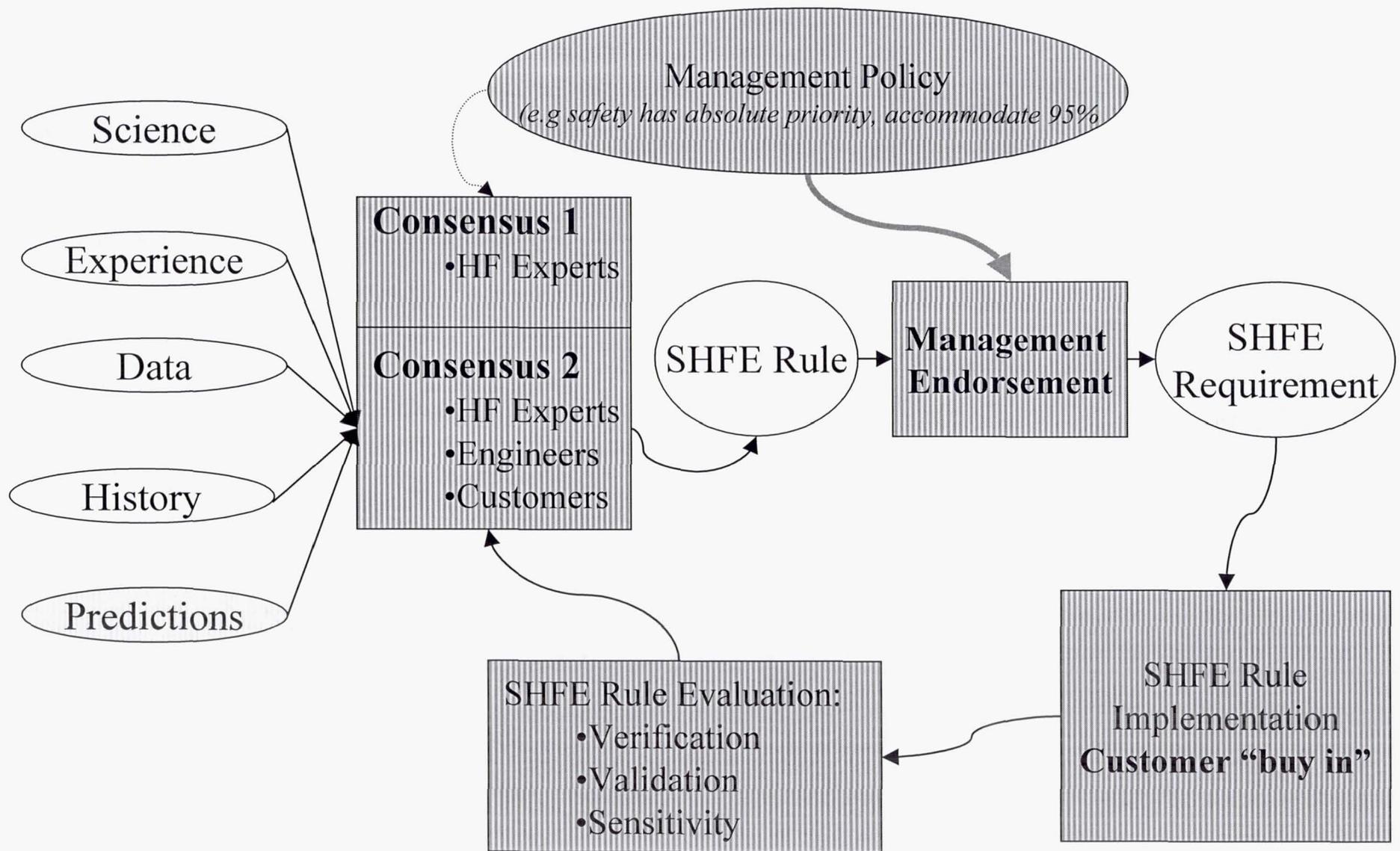


- SHFE Rules are a consensus based approach to amalgamating multiple sources of data, experience and policy.
- The rules describe a mapping from an engineering continuum into an ordinal scale of acceptability with due regard to **protection, performance and preference.**
- The inclusion of the policy dimension creates a requirement that should be acceptable to all.

# Why Are HFE Rules Useful?

- The **traditional experimental approach** to problem solving and design is un-timely and may be invalid due to sampling and subject selection issues.
- The “**expert opinion,**” with reference to experience, training and the literature, may be subject to bias.
- The “**voice of the customer (crew member)**” approach is too volatile (but may be useful for fine tuning).
- **There exists ample HF information to formulate a collection of rules that will satisfy the majority of situations.**
  - *HFE Rules are a way of delegating the analysis, decision and design processes to the point of application – the engineers and contractors.*
- HFE Rules are a first (and sometimes sufficient) screening process– they may lead to more in depth investigations.

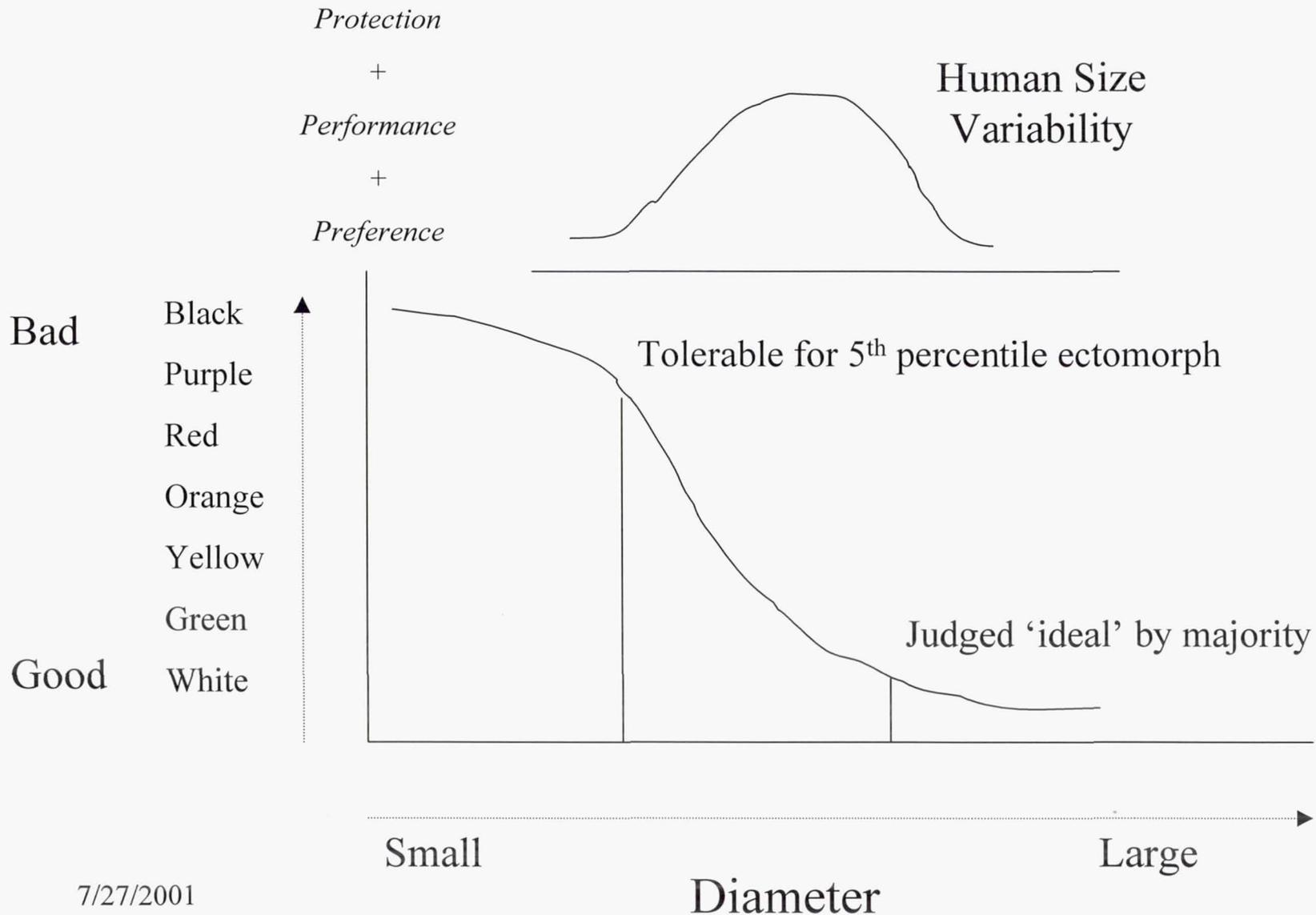
# Consensus HFE Rule Approach



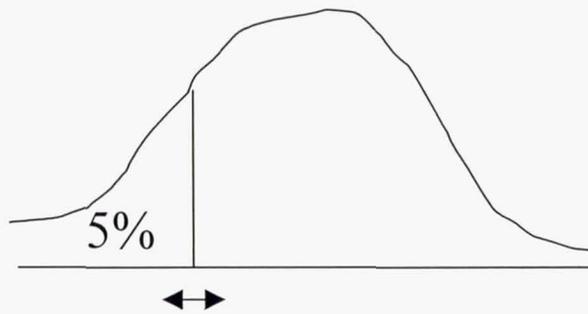
# Rule Code Format

<b><u>Numerical</u></b>	<b><u>Color</u></b>	<b><u>Verbal</u></b>	<b><u>Decision</u></b>
0	White	Ideal	Acceptable
1	Green	Adequate	Acceptable
2	Yellow	Tolerable	Investigate
3	Orange	Marginal	Investigate
4	Red	Undesirable	Unacceptable
5	Purple	Intolerable	Unacceptable
6 - 10	Black	Unthinkable	Unacceptable

# Mapping of the Diameter Question



# Accommodation, Margin of Safety and The Law of Round Numbers



Most design requirements consist of some point on a continuum. The choice of % population accommodation or “margin of safety” is a policy decision.

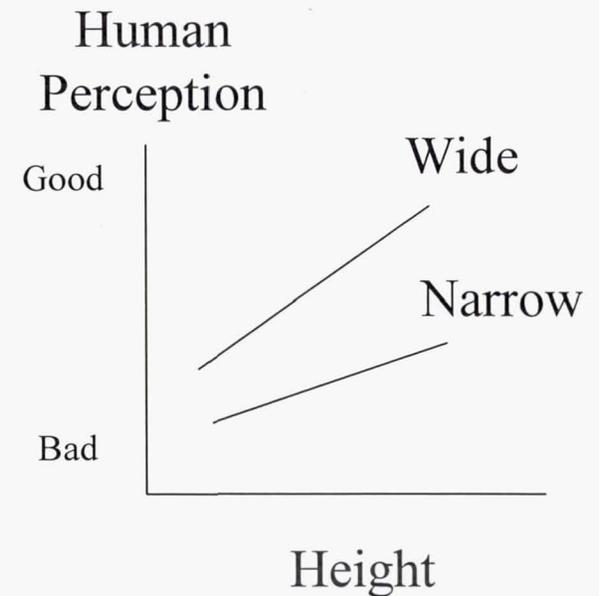
*For most general purposes ROUND NUMBERS are sufficiently accurate.*

*Greater precision may not produce greater utility*

10      20      30

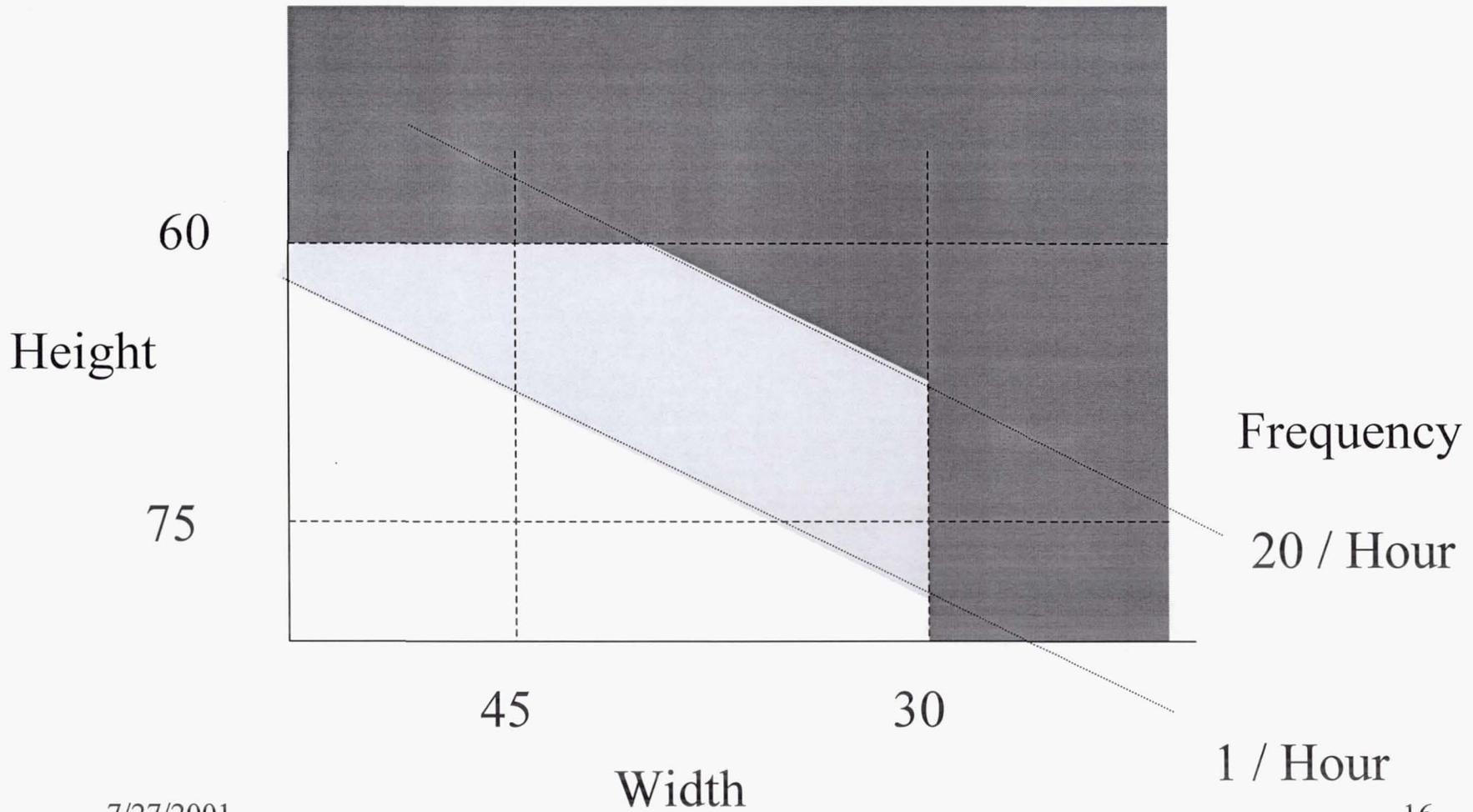
# Interactions

- Most variables interact with others to create an “environment”
- Interacting variables may be considered as limiting conditions for the application of a main variable
- These interactions may be addressed formally in the form of a complex index eg height x width x length = volume (which is a relevant index for air quality measures)
- But complex indices have to be decomposed for the purposes of intervention

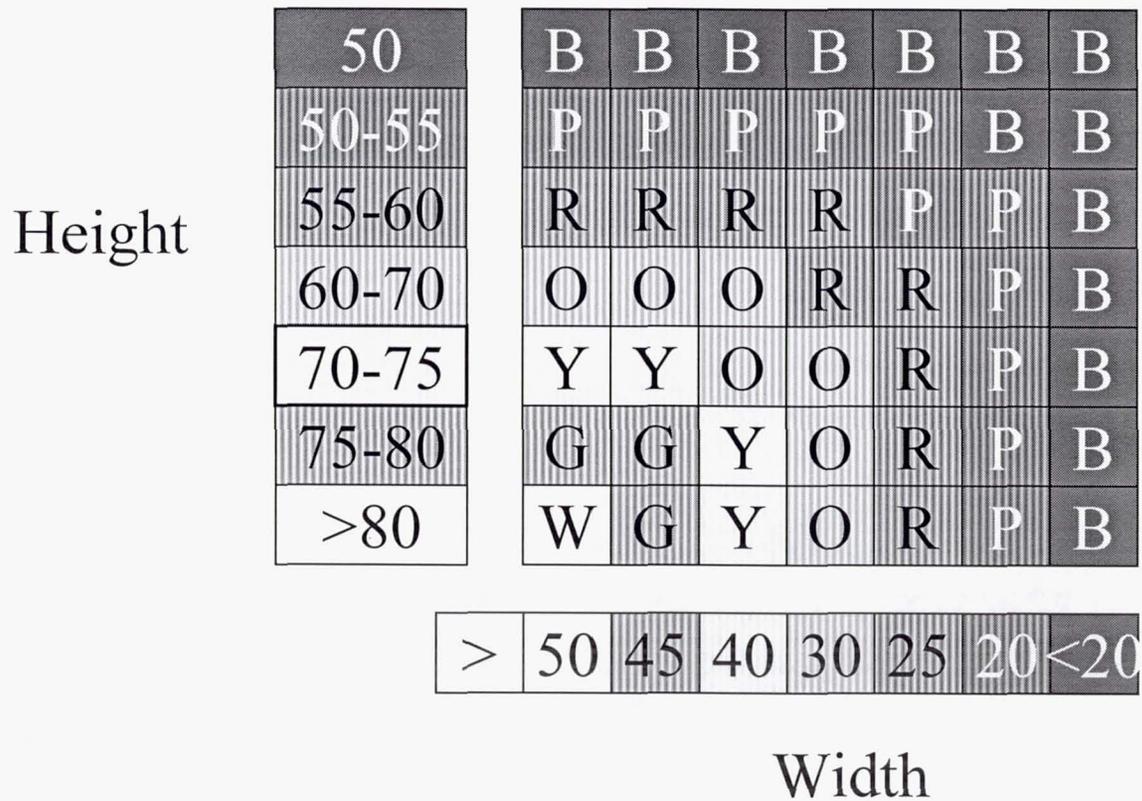


# Graphical Analysis

## For Interacting Variables



# 2D Matrices For Interactions

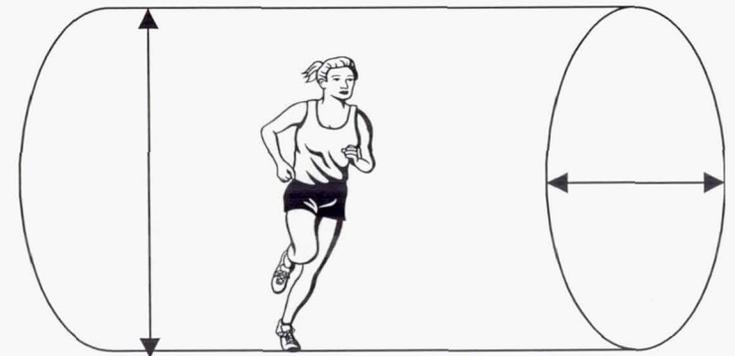


# 1. Passageways for Translation and Work Activities

Minimum Width or Length (W<L)

Height(ins)

	>70	60-70	50-60	40-50	<40
>80	1	2	3	4	5
70-80	2	3	4	5	
60-70	3	4	5		
50-60	4	5			
<50	5				



## 2. Equipment translations / EVA suited crew member / Exercise facility

Minimum Width or Length (W<L)

Height(ins)

	>80	70-80	60-70	50-60	<50
>80	1	2	3	4	5
70-80	2	3	4	5	
60-70	3	4	5		
50-60	4	5			
<50	5				



Notes: TVIS 24x42x84, IRED 74x55x86, CEVIS 63x40x43, Russian Ergometer 90x42x72

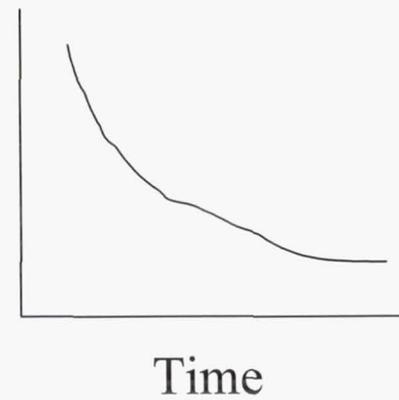
# The Exposure Problem - Time

- Mission Duration (log) days
- Shift Duration (eg. EVA) (log) hours
- Task Duration (log) minutes
- Transaction Duration (log) seconds
- Frequency Operations per hour
  
- *Sometimes there may be too little “exposure” time:*
- Viewing Time 1 / Seconds

### 3. Interactions with Time

Duration (min)	<1	1-2	2-5	5-10	>10
Frequency / hour	<1	1-5	6-10	11-20	>20
Height x Weight					
1 Green	1	2	3	4	5
2 Yellow	2	3	4	5	
3 Orange	3	4	5		
4 Red	4	5			
5 Purple	5				

Tolerance



# Example of Interactions with Time (Exposure)

Frequency  
(Movements /  
Hour)

>40	B	B	B	B	B	B	B
30-40	P	P	P	P	P	B	B
20-30	R	R	R	R	P	P	B
10-20	O	O	O	R	R	P	B
5-10	Y	Y	O	O	R	P	B
1-5	G	G	Y	O	R	P	B
<1	W	G	Y	O	R	P	B

<50	45-50	40-45	30-40	25-30	20-25	<20
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Width

## 4. Emergency egress (passthroughs)

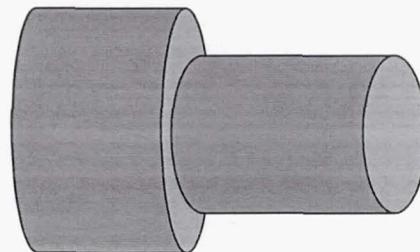
Minimum Width or Length (W<L)

Height(ins)

	>70	>60	>50	>40	<40	
>70	2	1	2	3	4	5
>60	1	2	3	4	5	
>50	2	3	4	5		
>40	3	4	5			
<40	4	5				
	5					

*Notes:*

- “5” / Intolerable / “Black” is out of the question for emergency situations
- Over large dimensions may lead to greater disorientation in visually limited conditions



## 5. Protrusions / Encroachments in Passageways and Passthroughs

(Duration (min)                      <1            1-2            2-5            5-10            >10)

**Frequency / hour                      <1            1-5            6-10            11-20            >20**

Height x Weight

1 Green	1	2	3	4	5
2 Yellow	2	3	4	5	
3 Orange	3	4	5		
4 Red	4	5			
5 Purple	5				

Apply equipment  
translation rule (#2)

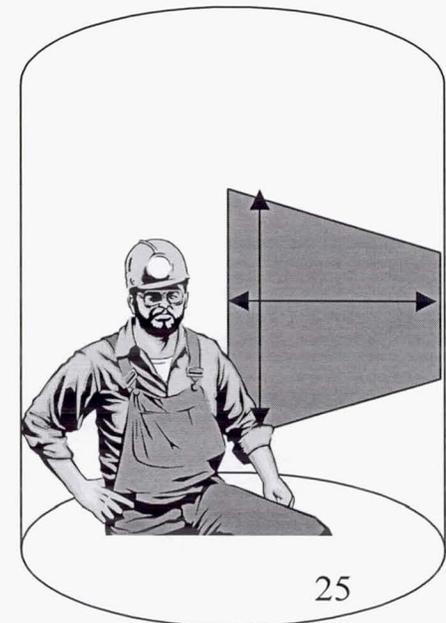


## 6. Physical and visual access to work area and lighting pathways

### Truncated Cone Base Diameter

Cone Height(ins)

	>40	30-40	20-30	10-20	<10
>50	1	2	3	4	5
40-50	2	3	4	5	
30-40	3	4	5		
20-30	4	5			
<20	5				

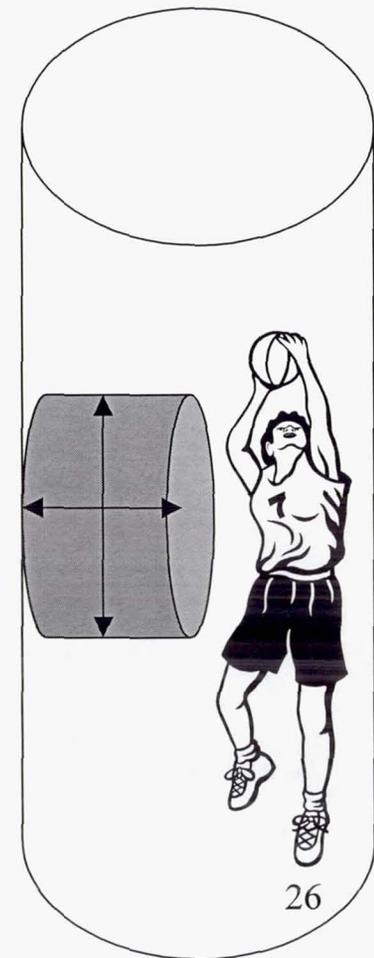


# 7. Obstructions to Physical or Visual Access (cylindrical or elliptical solids)

Major Axis Diameter

Length

	<10	10-20	20-30	30-40	>40
<10	1	2	3	4	5
10-20	2	3	4	5	
20-30	3	4	5		
30-40	4	5			
>40	5				



# Fine Tuning – Soft / Fuzzy Colors

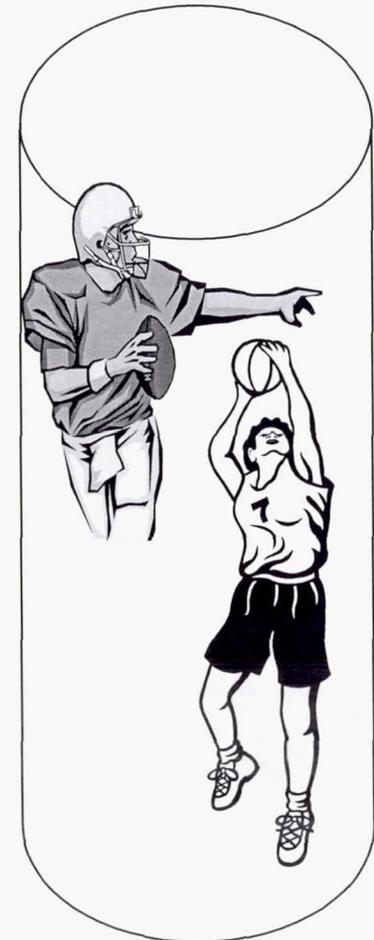
- The resolution of a rule may be broad to cover the spectrum of possibility, whereas the problem at hand may be focused around a much narrower region
  - For example the range of entry / egress widths was from 20” to 50”
  - The range of discussion may be in the marginal region 30” to 35”
- It should be noted that throughout human factors practice there are no clear boundaries, but rules are useful for design, compliance and enforcement purposes
  - Speed limits, blood alcohol level
- Where compromise is necessary it may be necessary to revert to “soft” or “fuzzy” boundaries, with the following provisos:
  - Rule creep / precedent must be avoided
  - Conflicting requirements must be justified
  - Context of situation and severity of outcome must be considered
- ***The borders may be moved +/- half an interval if the above conditions are resolved***

# Management Endorsement – Policy Enforcement

- **It is management’s responsibility to overlay policy on HFE Rules**
  - The SHFE Rule consensus group articulates the risks and benefits
  - Management decides upon level of accommodation, acceptable risk etc. in light of all the available evidence
- Management should say “*No reds will be accepted without a signed waiver.*”
  - **But, depending on the conditions and interacting variables more or less risk may be acceptable.**
- The SHFE Rule process is a useful prerequisite for a formal benefit / cost ratio analysis process

# Conclusions

- Spatial design can involve a lot of very specific detail
- This detail may be investigated by a variety of approaches – anthropometry, performance, preference, modeling
- The aim of this approach is to reduce the complexity to a set of basic rules that will satisfy most (but not all) of the design challenges
- Detailed investigations may be required to address complex interactions
- A key element is the adoption of a common currency of acceptability – 1 – 5 or WGYORPB – that can be applied to any human or design variable



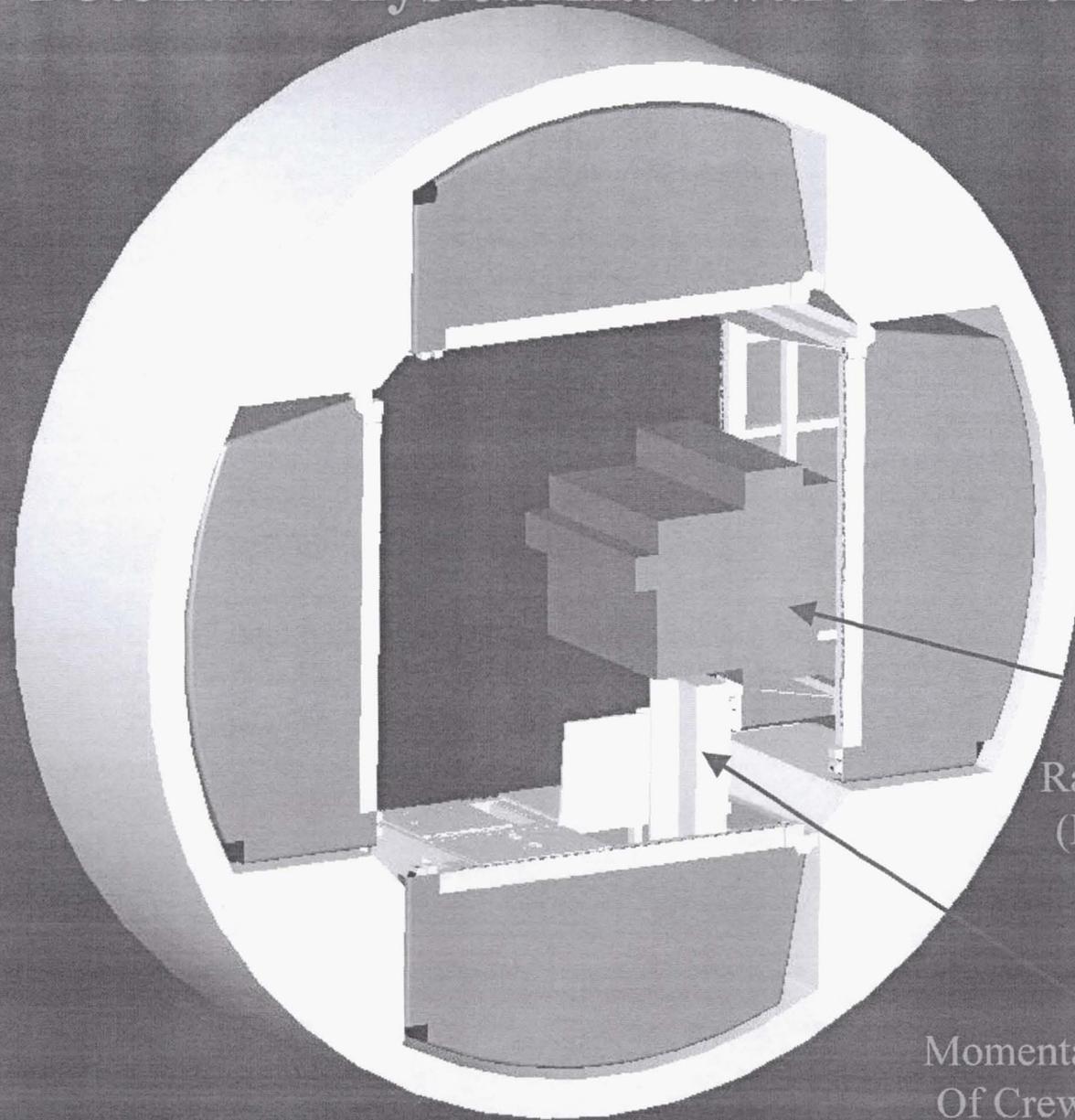
# ISS Internal Volume Configuration Control and Analysis

- 1) Physical Hardware and Open Volume Geometry Modeled using 3D Computer Graphics
  - a) Hardware Data Acquired From Hardware Providers, Interface Control Documents, and Validated Drawings
  - b) Open Volume Data Acquired from Hardware Operation Managers, MSIS, and Other Sources, or Determined through Graphical Anthropometric Analysis
- 2) Hardware Categorized by Temporal Influence to ISS Environment
  - a) Permanent Nominal Hardware and Protrusions
  - b) Maximum Semi-permanent Protrusion Extents
  - c) Maximum Temporary Protrusion Extents
  - d) Maximum Momentary Protrusion Extents
- 3) Open Volumes Categorized by Importance
  - a) Minimum Safety and Life Support Constraints
  - b) Minimum Worksite Volume and Habitability Constraints
  - c) Minimum Translation Path Constraints
- 4) Interfering Volumes Identified through Automated CAD Process
  - a) Individual interferences assessed based on degree and duration of impact to ISS operations
  - b) Recommend Operational Fix, Topology Change, Hardware Fix, or Assign Waiver

# Spatial “Rules” as Implemented for Interior Volume Control on the ISS

- Crew / Equipment Translation Path: 50" x 72" Rectangular
- Crew Worksite Volume: 36" x 41" x 76"
- Fire Port Visibility Cone: 60 degree cone with 28" height from Fire Port
- Fire Port Extinguisher Access Volume: 12" x 24" x 28"
- Light / Vent Visibility Cone: 60 degree cone with 28" height from Light / Vent and length equal to Light / Vent

# Potential Physical Hardware Protrusion

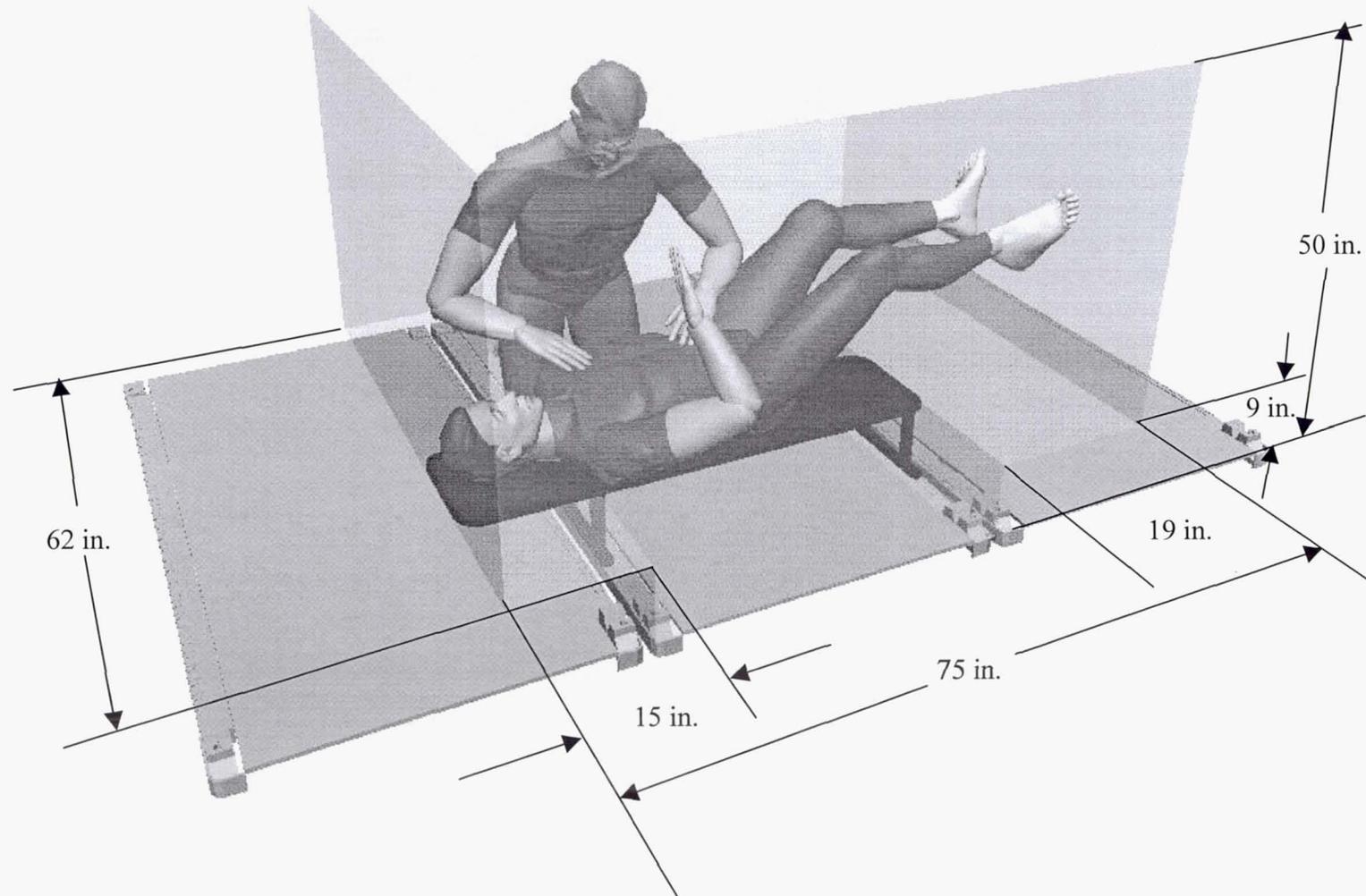


Temporary  
Experiment  
Rack Protrusion  
(Low Priority)

Momentary Protrusion  
Of Crew Health Care  
System Rack  
(High Priority)

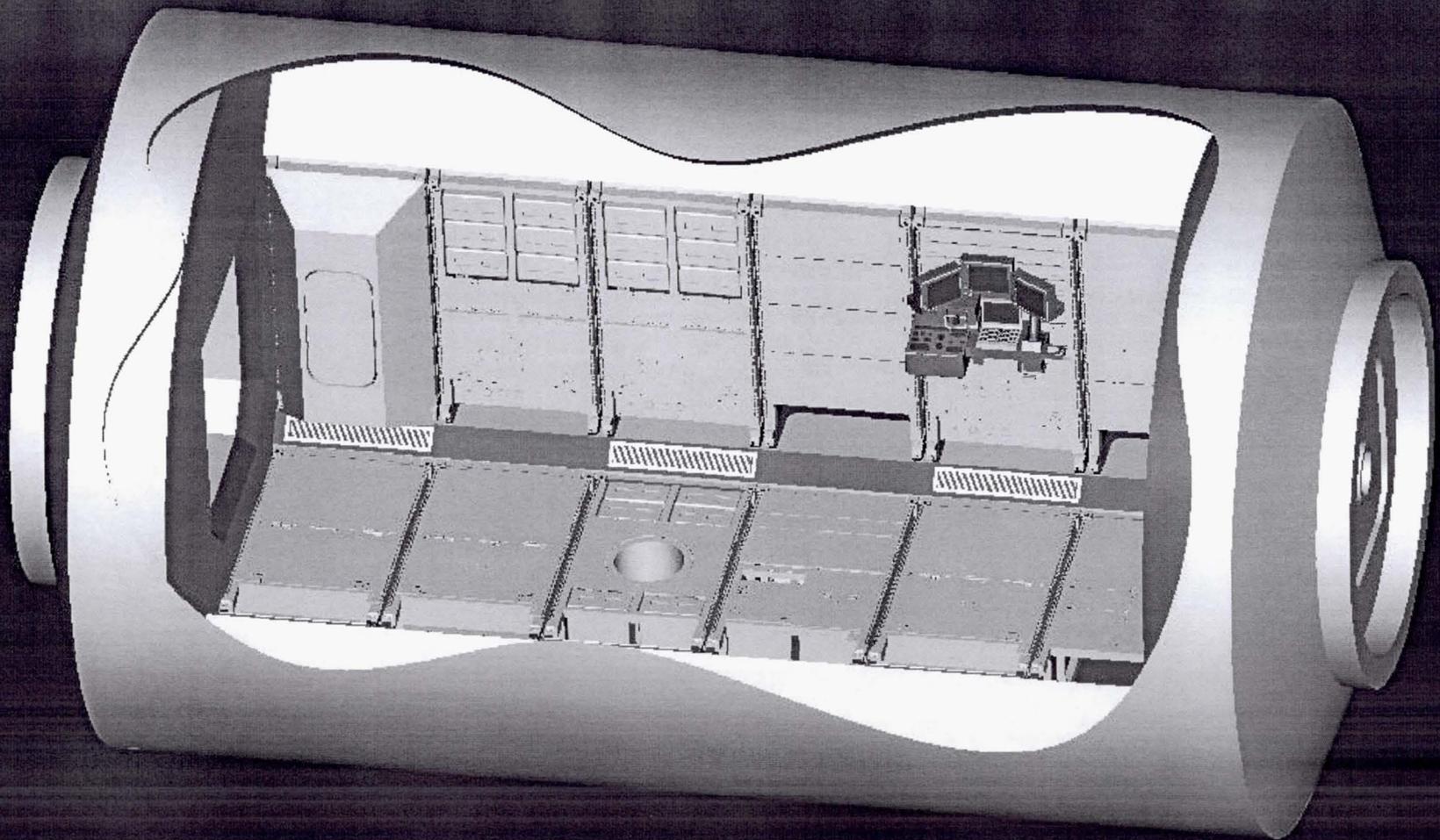
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# Graphical Anthropometric Analysis Determination of Free Volume Constraint



Minimum Required Volume for Crew Medical Restraint System Operation

# US Lab - Analysis of Integrated Environment



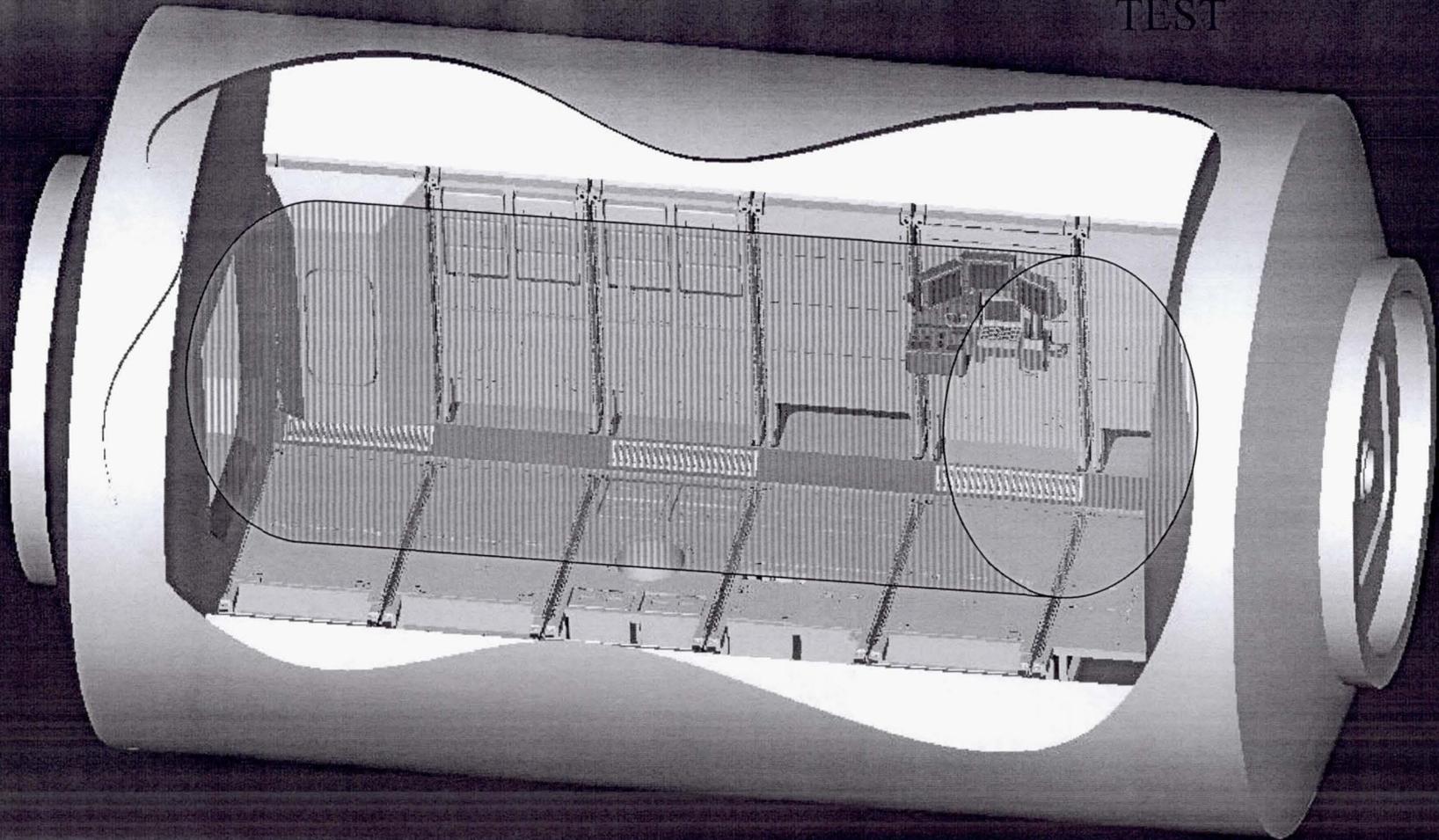
## Starboard – Deck Section

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Nominal Permanent Hardware

# US Lab - Analysis of Integrated Environment

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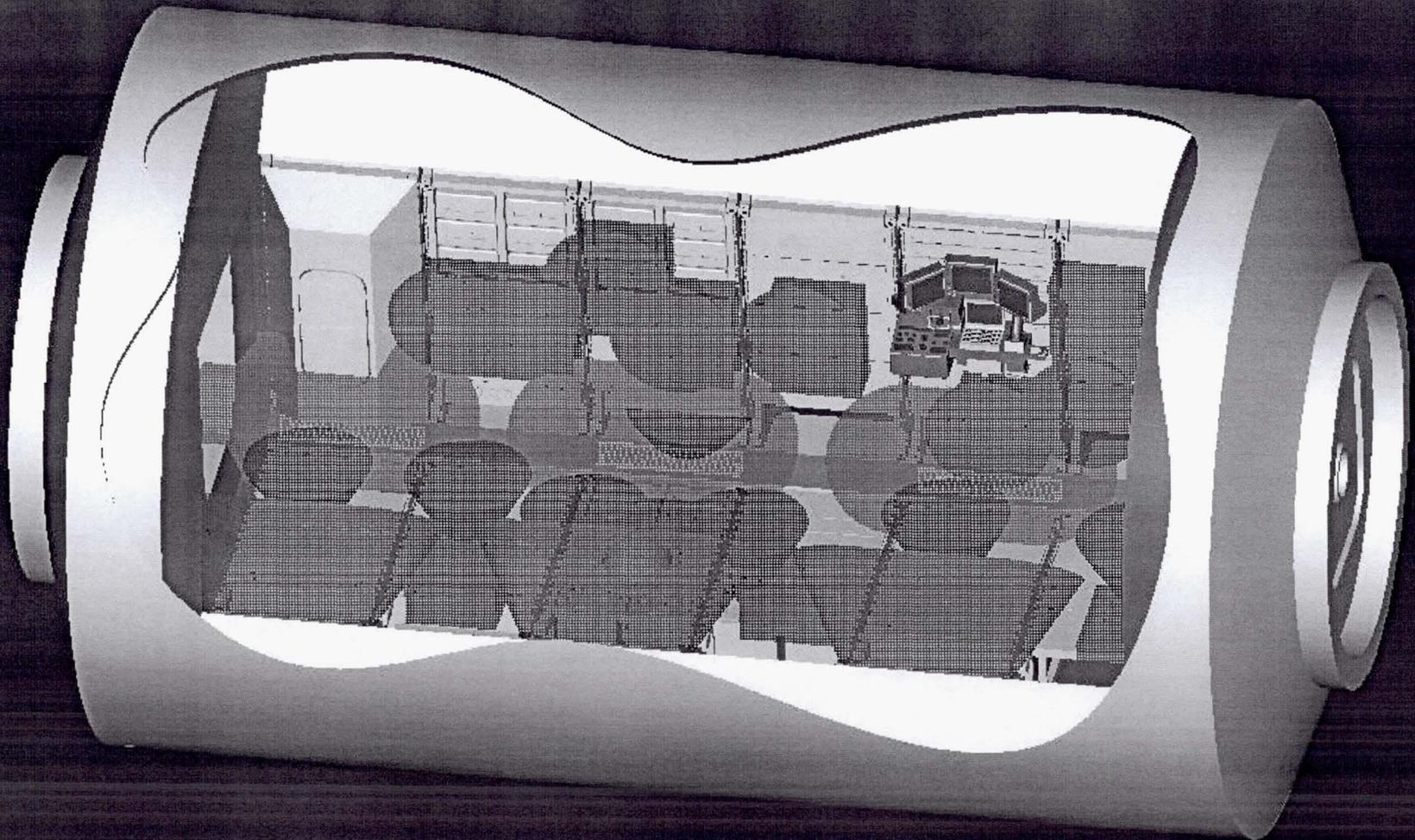


**Starboard – Deck Section**

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Nominal Permanent Hardware

# US Lab - Analysis of Integrated Environment

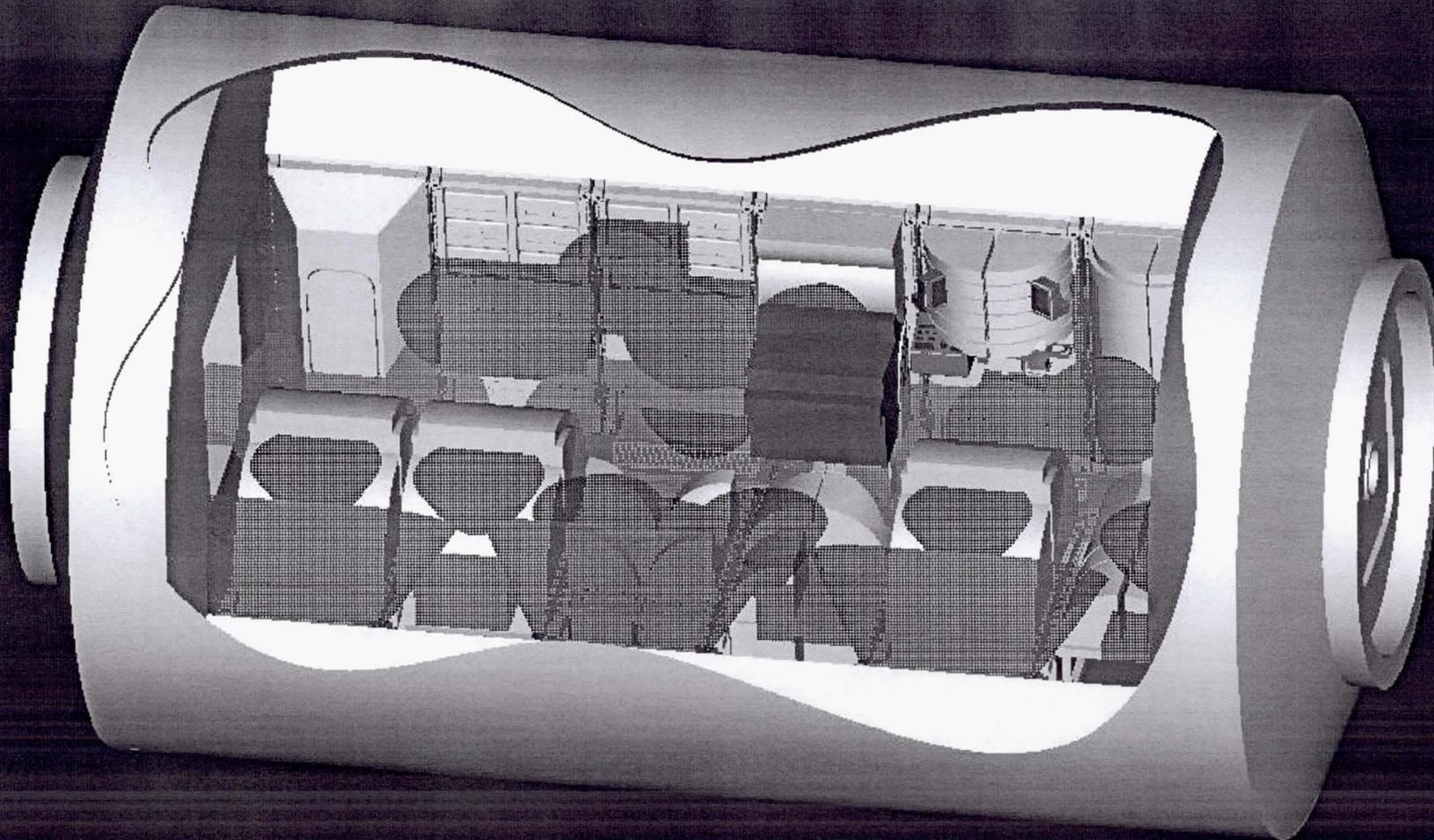


## Starboard – Deck Section

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Safety Constraints  
Nominal Permanent Hardware

# US Lab - Analysis of Integrated Environment



## Starboard – Deck Section

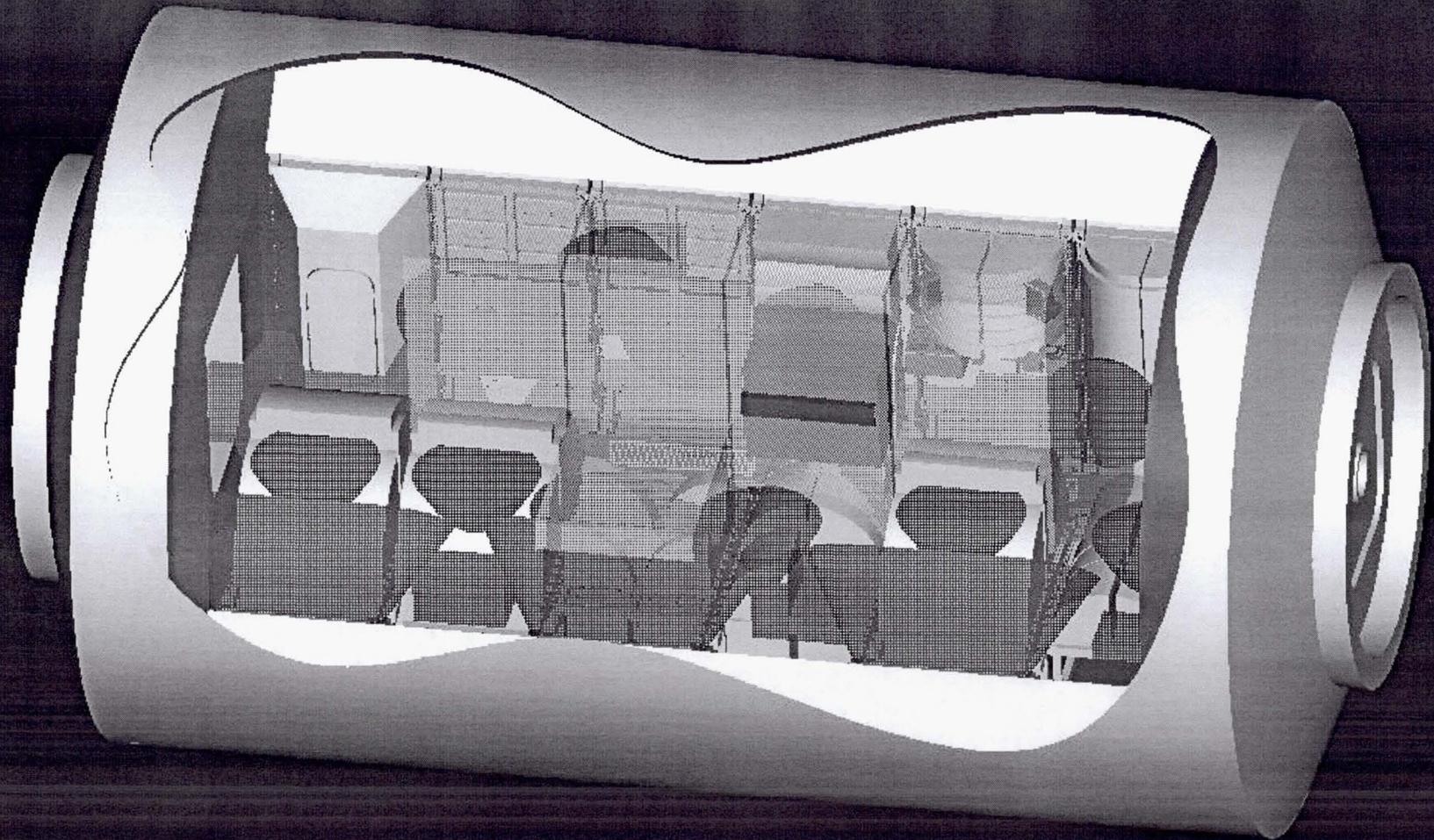
Hardware Protrusions

Safety Constraints

Nominal Permanent Hardware

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## Starboard – Deck Section

Operational Work Volumes

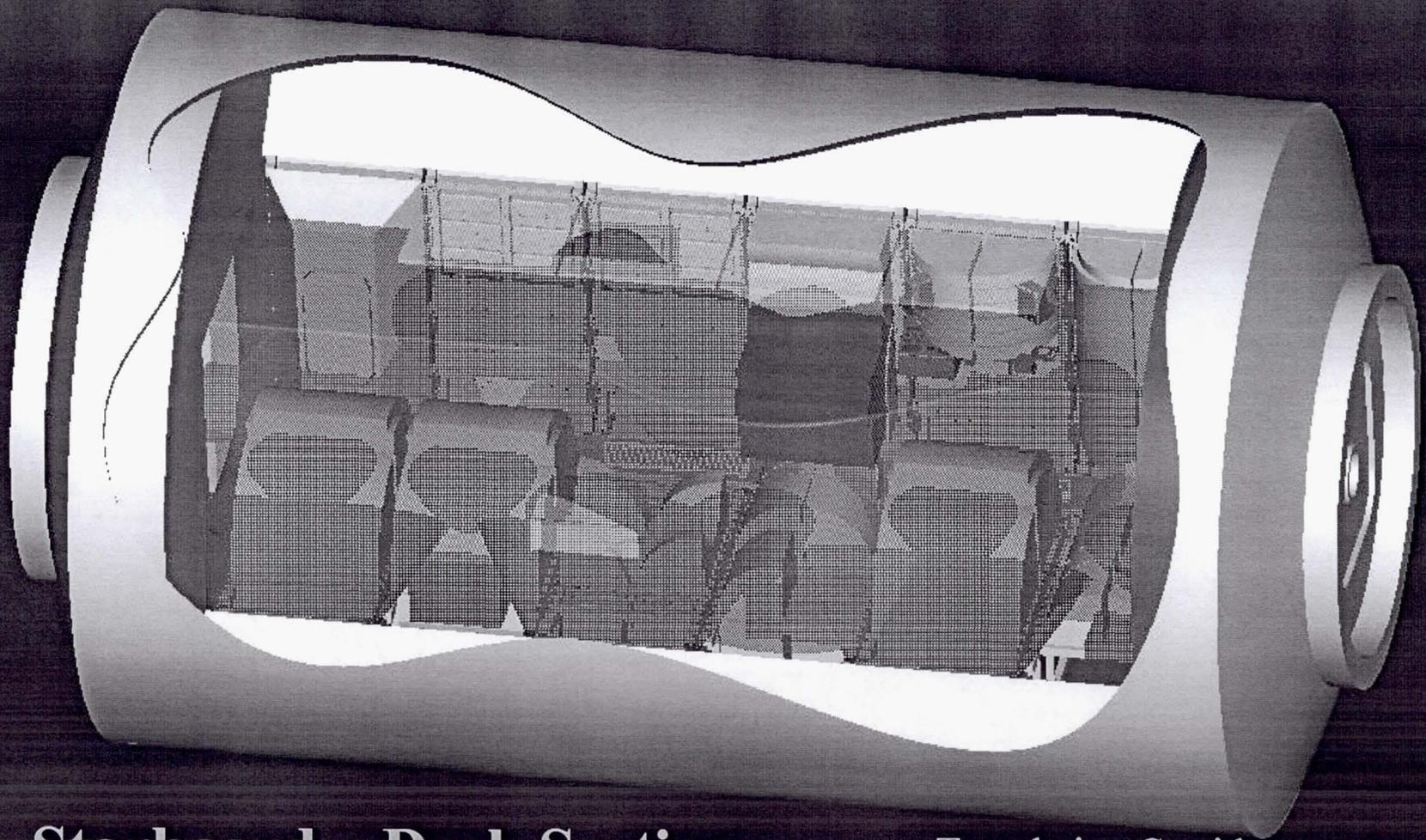
Hardware Protrusions

Safety Constraints

Nominal Permanent Hardware

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# US Lab - Analysis of Integrated Environment

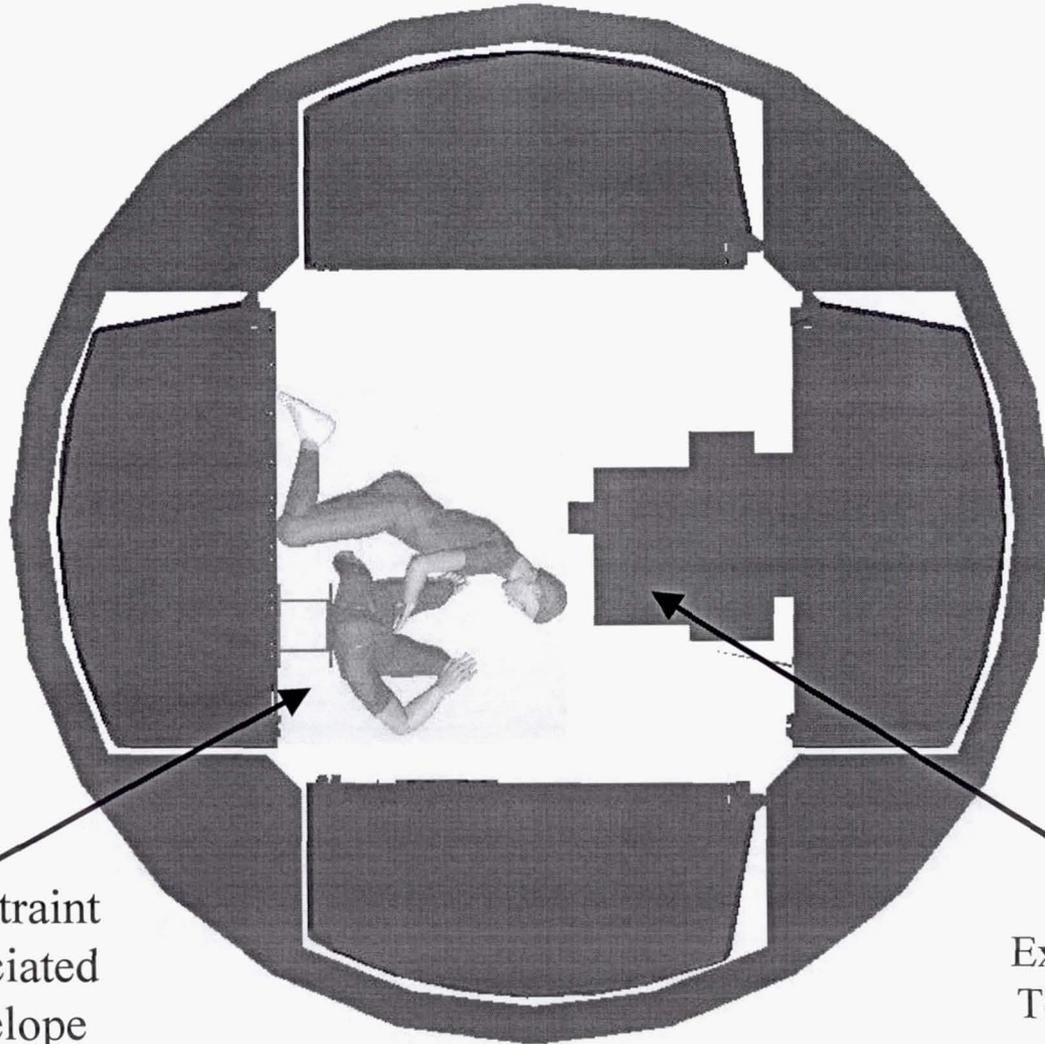


## Starboard – Deck Section

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Translation Corridors  
Operational Work Volumes  
Hardware Protrusions  
Safety Constraints  
Nominal Permanent Hardware

# Weighing Specific Constraint Against Physical Environment



Crew Medical Restraint System and Associated Operational Envelope (High Priority)

Experimental Payload Temporary Protrusion (Low Priority)