Space Simulation and Human Testing

• Focus is on human-in-the-loop operational simulations, not component sims (e.g., thermal vacuum chambers)
• Microgravity
• Planetary surfaces
• Specialty simulations
• Human factors testing
• Methods of rigorous subjective evaluation
Microgravity Simulation Approaches

- Parabolic flight
- Neutral buoyancy
- Suspension harnesses
- Flat floors
Parabolic Flight Profile

Altitude: Feet

Maneuver Time: Seconds

45° Nose High
20° Nose Low
Parabolic Flight Summary

• Advantages
  – Actual microgravity

• Disadvantages
  – Motion sickness
  – Limits of cabin volume
  – Limited time
  – Limited crew size
  – Substantial certification requirements
  – High cost (~$5-10K/flight hour)
Neutral Buoyancy
Neutral Buoyancy Summary

• Advantages
  – No restrictions on number or relative position of items
  – No significant time limitations
  – Few size limitations to workspace

• Disadvantages
  – Hydrodynamic effects (especially damping)
  – Need to waterproof hardware (particularly sensors)
  – All items must have net specific gravity = 1
  – Significant subject qualification requirements
  – Limited access to test environment (except us!)
Air-Bearing Floor/Suspension Harness
Air-Bearing Floor Summary

• Advantages
  – Somewhat realistic 2D dynamics

• Disadvantages
  – Dedicated facility requirements
  – Acoustic issues
  – Boundary control
  – Limited configurations (no over/under transits)
Suspension Harness Summary

• Advantages
  – Cheap

• Disadvantages
  – Limited dynamic fidelity
  – Pendulum modes (need high ceilings)
  – Comfort/safety
Simulation of Partial Gravity Ops

• Only major activity dates back to Apollo
• Science and operational issues to be examined
  – Biomechanics
  – Mobility
  – Sampling
  – Instrument placement
  – Equipment development
  – Pressure suit design
  – Field exploration
Approaches to Partial Gravity Sims

- Parabolic flight
- Counterbalance suspension
- Inclined suspension
- 1g simulations
- Ballasted underwater testing
Parabolic Flight

- True “partial gravity” during parabolic pushover
- Same disadvantages as in microgravity section
- Primarily used for interface testing
Counterweighted Suspension
Counterweighted Suspension

• Numerous approaches to offsetting portion of Earth weight
  – Mass counterbalance
  – Linear springs
  – Nonlinear (e.g., constant-force) springs
  – Active force control
  – Buoyant offset (e.g., balloons)

• Generally limited to counterbalance of gross body weight
  – Gimballed harness required for body rotational freedom
  – Difficult to counterbalance individual limbs

• Additional complexity required to maintain suspension point above test subject, provide counterbalance for test hardware

• Best suited to interior simulations with limited traverses
Active Suspension Body Gimbals
Vertical Jump Profile (Earth)
Comparative Vertical Jump Profiles

![Graph showing comparative vertical jump profiles for Earth, Mars, and Moon.](image)

- **Y-axis**: Jump Height (m)
- **X-axis**: Time (sec)

- **Legend**:
  - Blue line: Earth
  - Red line: Mars
  - Yellow line: Moon
Active Suspension Approaches

[Diagram of active suspension system with labeled parts such as pivot, vertical servo assembly, load cell, and gimbal support.]
Inclined Suspension

- Provides appropriate normal force to inclined wall
  - Lunar simulation angle 80.8°
  - Mars simulation angle 67.7°
- Requires complex suspension system
  - Complex rigid harness required to suspend lower leg without interference to upper leg
  - Pendulum dynamics based on length of wires
  - Overhead suspension point must follow subject motion
- Best suited to mobility studies
1 g Testing

- Approach: ignore entire issue of partial gravity; test in Earth-normal conditions
- Enabled by non-flight configuration for selected systems
  - External life support
  - Lightweight backpacks, instrument mockups
  - Use of additional personnel for relieving crew from some tasks
  - Omission of pressure suit for some field testing
- Primarily used for crew training
Ballasted Partial Gravity Simulation
Sample Motion Analysis

![Sample Motion Analysis](image)

**Chart Details:**
- **X-axis:** Time (sec)
- **Y-axis:** Shoulder State (radians)
- **Legend:**
  - Black line: Shoulder Angle
  - Red line: Angular Rate
  - Blue line: Angular Acceleration
Sample Motion Analysis

![Sample Motion Analysis](image)

- **Shoulder State (radians)**
- **Time (sec)**

- **Shoulder Angle**
- **Angular Rate**
- **Angular Acceleration**
Effects of Lunar & Sim Environments

![Graph showing the effects of different environments on shoulder torque. The graph compares Earth, Moon, and an UW Moon Sim scenario. The x-axis represents time in seconds, ranging from 0 to 2, and the y-axis represents shoulder torque in N-m, ranging from -6 to 8. The Earth line is black, the Moon line is red, and the UW Moon Sim line is blue. The graph illustrates a decrease in torque over time, with a significant drop at 1.5 seconds.]
Effects of Mars & Sim Environments

![Graph showing shoulder torque (N-m) vs. time (sec) for Earth, Mars, and UW Mars Sim environments.](image)
## Ballasting for UW Planetary Simulation

IVA Simulation assuming 150 lb test subject

<table>
<thead>
<tr>
<th>Body Segment</th>
<th>Lunar Ballast</th>
<th>Mars Ballast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torso/Head</td>
<td>12.1</td>
<td>28.5</td>
</tr>
<tr>
<td>Upper Arm (each)</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Lower Arm (each)</td>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Thigh (each)</td>
<td>3.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Lower Leg (each)</td>
<td>1.4</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>24</strong></td>
<td><strong>57</strong></td>
</tr>
</tbody>
</table>

All ballast weights in pounds
Ballasting the Test Subject
Treadmill: Lunar Gravity - Slow Speed
Comparison of 1-G Leg Motions

Underwater

Laboratory
Ballasted UW Simulation - Advantages

- Simple arm torque analysis shows 52% reduction in RMS torque error compared to 1 g Lunar case; Mars error reduced by 9%
- Produces accurate levels of preload on legs
  - Sensorimotor control loops closer to actual partial gravity
  - Accurate simulation of postural responses
- Ability to work with test hardware of realistic mass and complexity
- Freedom from wires or other simulation-specific interferences
- Realistic static and quasistatic test applications
  - Balance and postural studies
  - Reach and force envelopes
  - Surface sampling
Ballasted UW Simulation - Disadvantages

- Dynamics effects of underwater environment
  - Water drag
  - Virtual mass
- Requires added inertial mass to achieve desired counterweight
- Safety implications of underwater testing
  - Life support of test subject
  - Emergency extraction
- Access to pressure suits for EVA simulations
MX-2 – EVA Simulation Testbed

- Maryland Advanced Research/Simulation (MARS) Suit developed under internal support by UMd Space Systems Laboratory
- Integral ballasting system
- Modular interchangeable suit components
- Pressurized to 3 psid for suit performance fidelity
Potential Applications of UW Simulation

• **EVA Interfaces**
  – Installation of science packages
  – Rover ingress/egress/seating
  – Habitat access (e.g., ladders, stairs, ramps)
  – Pressure suit design evaluation (e.g., foot visibility, recovery from fall)

• **Ergonomics and human factors**
  – Partial gravity neutral body posture and postural maintenance
  – Effects of backpack weight and CG on balance
  – Reach envelopes with strength correlation

• **Walking and other gaits**
  – Use of treadmill to reduce effects of water drag (primarily leg motion)
  – Useful for evaluating pressure suit design for mobility, understanding effect of backpack size and mass on gaits and stability
484 2014 Simulation Planning

• 1G habitat studies
  – Alternative layout designs
  – Virtual reality “walk-throughs” and evaluations
  – Interior mockup and assessment
  – Short (≤1 day) simulated mission activities

• Underwater habitat studies (possibly for 0G, Moon, Mars conditions)
  – Workstation design and assessment
  – Interior mobility and accessibility
  – Assessment of vertical vs. horizontal layouts
  – Exterior accessibility

• Other innovative possibilities?
The Scope of Human Factors

from Chapanis, Human Factors in Systems Engineering - Wiley Interscience, 1996
Taxonomy of Human Factors Methods

- Data collection techniques
- Task analysis techniques
- Cognitive task analysis techniques
- Charting techniques
- Human error identification (HEI) techniques
- Mental workload assessment techniques
- Situational awareness measurement techniques
- Interface analysis techniques
- Systems design techniques
- Performance time prediction/assessment tech.
- Team performance analysis techniques
Data Collection Techniques

• Interviews
• Questionnaires
• Observation
Interviews

- Structured, semi-structured, unstructured
- Closed, open, and probing questions
- Focus groups instead of multiple interviews
- Interviews take the longest to train of all data collection techniques
- Should last a minimum of 20 and maximum of 40 minutes
- Data collection: notes, audio/video recorder
Questionnaires

- Types of questions used
  - Multiple choice
  - Rating scales (“strongly agree”, “agree”...)
  - Paired associates (“Which is more difficult, A or B?”)
  - Ranking (“On a scale of 1-10...”)
  - Open-ended (“What did you think of...”)
  - Closed questions (“yes/no”)

- Easy to collate and reduce data
- Usually have poor voluntary response
- Needs to be designed well for best results
Analytical Hierarchy Process

- Considering a range of options, e.g., ice cream
  - Vanilla (V)
  - Peach (P)
  - Strawberry (S)
  - Chocolate (C)

- Could ask for a rank ordering, e.g. (1) vanilla, (2) strawberry, (3) peach, (4) chocolate - but that doesn’t give any information on how firm the rankings are

- Use pairwise comparisons to get numerical evaluation of the degree of preference
Pairwise Comparisons

• Ideally, do exhaustive combinations
  – Vanilla >> chocolate (strongly agree)
  – Vanilla >> peach (agree)
  – Vanilla >> strawberry (agree)
  – Peach >> chocolate (strongly agree)
  – Peach >> strawberry (disagree)
  – Strawberry >> chocolate (strongly agree)

• Number of required pairings out of N options is \( \frac{(N)(N-1)}{2} \) - e.g., N=20 requires 190 pairings!

• Can use hierarchies of subgroupings to keep it manageable
Evaluation Metric

• Create a numerical scaling function, e.g.
  – “strongly agree” = 9
  – “agree” = 3
  – “neither agree nor disagree” = 1
  – “disagree” = 1/3
  – “strongly disagree” = 1/9

• Numerical rankings are arbitrary, but often follow geometric progressions
  – 9, 3, 1, 1/3, 1/9
  – 8, 4, 2, 1, 1/2, 1/4, 1/8
### Evaluation Matrix

- Fill out matrix preferring rows over columns

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>S</th>
<th>P</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>9</td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
## Evaluation Matrix

- Fill out matrix preferring rows over columns
- Fill opposite diagonal with reciprocals

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>S</th>
<th>P</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
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<td></td>
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</tr>
<tr>
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<td>9</td>
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<td>1/3</td>
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</tr>
<tr>
<td>V</td>
<td>9</td>
<td>3</td>
<td>3</td>
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</table>

<table>
<thead>
<tr>
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<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>9</td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
## Normalization of Matrix Elements

- Normalize columns by column sums

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>S</th>
<th>P</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1/9</td>
<td>1/9</td>
<td>1/9</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td>3</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>9</td>
<td>1/3</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>S</th>
<th>P</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.032</td>
<td>0.018</td>
<td>0.143</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.333</td>
<td>0.491</td>
<td>0.429</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.333</td>
<td>0.097</td>
<td>0.429</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.333</td>
<td>0.871</td>
<td>0.491</td>
<td></td>
</tr>
</tbody>
</table>

27 3.44 6.11 0.78
Evaluation of Hierarchy Among Options

- Average across the populated row elements

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>S</th>
<th>P</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.032</td>
<td>0.018</td>
<td>0.143</td>
<td>0.048</td>
</tr>
<tr>
<td>S</td>
<td>0.333</td>
<td>0.491</td>
<td>0.429</td>
<td>0.313</td>
</tr>
<tr>
<td>P</td>
<td>0.333</td>
<td>0.097</td>
<td>0.429</td>
<td>0.215</td>
</tr>
<tr>
<td>V</td>
<td>0.333</td>
<td>0.871</td>
<td>0.491</td>
<td>0.424 ← Top ranking</td>
</tr>
</tbody>
</table>
## Space Allocation and Crew Flow

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>% of habitable volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>Operational or Mission-related tasks</td>
<td>40%</td>
</tr>
<tr>
<td>Public</td>
<td>Dining, food, management, recreation, and exercise</td>
<td>25%</td>
</tr>
<tr>
<td>Personal</td>
<td>Sleeping, privacy, personal stowage</td>
<td>20%</td>
</tr>
<tr>
<td>Service</td>
<td>Hygiene, waste management, public stowage</td>
<td>15%</td>
</tr>
</tbody>
</table>

Data from Parker & Every (1972) and Schowalter & Malone (1972)
Analytical Hierarchy Process

- Used an Analytical Hierarchy Process survey to determine the relative importance of possible habitat functions for an MFH
  - Life support assumed present
  - Two-level AHP ranks 34 functions based on 90 pair-wise rankings

- Targeted population with experience in remote/confined environments:
  - Astronauts
  - Submariners/ship crews
  - “Submarines were found to be most similar overall to the space ship situation…”
    
      Source: Habitability Issues in Long-Duration Undersea and Space Missions Jul 1972
    
  - Arctic/Antarctic research scientists
    - “The south pole is the closest place to space on earth where a permanent, manned US presence exists, and represents a good scientific/logistics/operations analogue for future moon/mars missions”
      
        Source: Antarctic Exploration: Proxy for Safe, Sustainable Exploration of the Moon and Mars
Survey Hierarchy

- Top-level matrix
  - Health and Hygiene
    - Habitat cleanliness
    - Personal hygiene
    - Comfort of bathroom
    - Quality of medical
    - Clothing cleanliness
  - Communications
    - Comms functions
    - Comms time/day
    - Comms privacy
    - Connec-tion quality
  - General environ.
    - Lighting control
    - Noise control
    - Windows
    - Odor control
    - Temp. control
    - Standing clearance
    - Food quality
  - Recreation area
    - Rec. time/day
    - Rec. space
    - Rec. variety
    - Rec. alone ratio
    - EVA time/day
  - Exercise area
    - Exe. time/day
    - Exe. space
    - Exe. variety
    - Exe. alone ratio
    - Work alone ratio
  - Work area
    - Work time/day
    - Work space
    - Prep time/EVA
    - Sleep alone ratio
  - Sleep area
    - Sleep time/day
    - Sleep space
    - Sleep privacy
    - Sleep comfort
    - No hot-racking
Data Analysis Method

- Subjective survey responses converted to numerical relative importance values and fed into AHP matrices:
  
  - “Much less important” = $0.125 = 2^{-3}$
  - “Moderately less important” = $0.354 = 2^{-1.5}$
  - “A little less important” = $0.707 = 2^{-0.5}$
  - “About as important” = $1.000 = 2^{0}$
  - “A little more important” = $1.414 = 2^{0.5}$
  - “Moderately more important” = $2.828 = 2^{1.5}$
  - “Much more important” = $8.000 = 2^{3}$

- Remaining matrix elements filled in with reciprocals of conjugate elements

- For each AHP matrix:
  - Importance values of each function or sub-category are the elements of the normalized principal eigenvector
  - “Consistency” is matrix size divided by the principal eigenvalue, with a value of 1 indicating complete consistency
  - Function importance values multiplied by importance value of the sub-category

- Overall importance values are the averaged values generated from all respondents, weighted by matrix consistency
AHP Results: Function Importance Values

Importance value

Habitat functions

1. No hot racking
2. Quality of medical
3. Quality of comms
4. Personal hygiene
5. Work time/day
6. Work space
7. Sleep comfort
8. Prep time/EVA
9. Comms functions
10. Comms privacy
11. Cleanliness of habitat
12. Comfort of bathroom
13. Comms time/day
14. Sleep privacy
15. Food quality
16. Exercise variety
17. Cleanliness of clothing
18. Work alone ratio
19. Sleep time/day
20. Exercise space
21. Temperature control
22. Exercise time/day
23. Sleep space
24. Standing clearance
25. EVA time/day
26. Odor control
27. Exercise alone ratio
28. Noise control
29. Recreation space
30. Recreation variety
31. Recreation alone ratio
32. Recreation time/day
33. Lights control
34. Windows

Space Simulation and Human Factors Testing
ENAE 483/788D - Principles of Space Systems Design

UNIVERSITY OF MARYLAND
AHP Results: Important Functions

- Hot racking considered unacceptable, the most important function at 2.3 times the average importance value.
- Medical facilities, communications connection quality, and personal hygiene round out vital functions.
- Work time and space were highly ranked.
- Non-physical recreation features considered especially unimportant.
- Lighting quality and windows were the least important functions considered, with windows 0.35 times as important as the average function.
- The most important function was 6.5 times as important as the least important function.
AHP Results: Consistency and Variation

- Overall matrix consistency: 92.5%
  - Most consistent matrix: “Work space”, at 96.6%
  - Least consistent matrix: “General environmental quality”, at 90.3%
  - Importance value averages are weighted by matrix consistency to improve reliability of results

- Standard deviation and coefficient of variation were computed for each habitat function
  - Average standard deviation was 0.0215, average coefficient of variation was 73.4%
    - Greatest std. dev.: “No hot racking” ($\sigma = .0645$, $c_v = 97.4\%$)
    - Greatest coeff. of variation: “Quality of comms” ($\sigma = .0637$, $c_v = 112.5\%$)
    - Lowest std. dev.: “Recreation time per day” ($\sigma = .0066$, $c_v = 45.5\%$)
AHP Results: Consistency

• Matrix size divided by principal eigenvalue is a measure of internal consistency, ranging from zero to one
  – Overall matrix consistency: 92.5%
  – Most consistent matrix: “Work space”, at 96.6%
  – Least consistent matrix: “General environmental quality”, at 90.3%

• Importance value averages are weighted by matrix consistency to improve reliability of results
  – Mean difference from un-weighted average: 1.7%
  – Greatest difference: recreation alone-time ratio (3.9% more important in weighted average)
AHP: Demographics and Analysis of Variance

- Respondents:
  - By nationality:
    - American (15)
    - Italian (11)
    - French (2)
    - Romanian (1)
  - By experience:
    - Submarine (19)
    - Ship (11)
    - Arctic/Antarctic base (3)
    - Other (2)
  - By age group:
    - ≤40 years (16)
    - >40 years (13)
- Performing ANOVA between astronaut and analogue populations can justify the statistical relevance of analogue populations

## Statistically significant variances, at 95% confidence

<table>
<thead>
<tr>
<th>Demographic set</th>
<th>Feature</th>
<th>Difference from complimentary set</th>
</tr>
</thead>
<tbody>
<tr>
<td>French</td>
<td>EVA time/day</td>
<td>+26.3%</td>
</tr>
<tr>
<td></td>
<td>Exercise alone ratio</td>
<td>-11.9%</td>
</tr>
<tr>
<td>American</td>
<td>Quality of comms</td>
<td>-5.3%</td>
</tr>
<tr>
<td>Ship crew members</td>
<td>Personal hygiene</td>
<td>+0.9%</td>
</tr>
<tr>
<td></td>
<td>Quality of medical</td>
<td>+1.3%</td>
</tr>
<tr>
<td></td>
<td>Recreation alone-time ratio</td>
<td>-0.8%</td>
</tr>
<tr>
<td></td>
<td>Sleep privacy</td>
<td>+0.3%</td>
</tr>
<tr>
<td>Submariners</td>
<td>Bathroom comfort</td>
<td>-0.6%</td>
</tr>
<tr>
<td>Age 40+</td>
<td>Comms privacy</td>
<td>-1.4%</td>
</tr>
<tr>
<td></td>
<td>Temperature control</td>
<td>-0.8%</td>
</tr>
</tbody>
</table>
Fidelity of Analogue Environments

• The analogue environments considered in the survey may be of low fidelity, due to several factors:
  – Windows may be less important in environments with a static view/no external view
  – Affects of reduced gravity on the importance of habitat functions not accounted for
  – Ability to leave environment may impact importance of habitat functions

• Larger samples and samples of the astronaut population would be needed to identify statistical significance of variations between analogue and space environments
Observation

• Provides “real-life” insight into actual operations
• Intrusive (Heisenberg’s principle)
  – “fly on wall”
  – “hanging over the shoulder”
• Time consuming (1 hr of audio = 8 hrs of transcription)
• Difficult to set up, expensive, time consuming
• Generally requires teams to cover all critical areas
Mental Workload Assessment

- Primary Task Performance Measures
- Secondary Task Performance Measures
- Bedford Scale
- Defense Research Agency Workload Scale
- Instantaneous Self Assessment Workload
- Malvern Capacity Estimate
- Modified Cooper-Harper Rating
- NASA Task Load Index
- Subjective Workload Assessment Technique
- Workload Profile Technique
- Cognitive Task Load Analysis
Cooper-Harper Rating Scale

Handling Qualities Rating Scale

Adequacy for Selected Task or Required Operation

- Is it satisfactory without improvement?
  - Yes
  - No
    - Deficiencies warrant improvement
      - Is adequate performance attainable with a tolerable pilot workload?
        - Yes
        - No
          - Deficiencies warrant improvement
            - Is it controllable?
              - Yes
              - No
                - Improvement mandatory

Aircraft Characteristics

- Excellent
- Highly desirable
- Good
- Negligible deficiencies
- Fair - Some mildly unpleasant deficiencies
- Minor but annoying deficiencies
- Moderately objectionable deficiencies
- Very objectionable but tolerable deficiencies
- Major deficiencies

Demands on the Pilot in Selected Task or Required Operation

- Pilot compensation not a factor for desired performance
- Desired performance requires moderate pilot compensation
- Adequate performance requires considerable pilot compensation
- Adequate performance requires extensive pilot compensation
- Adequate performance not attainable with maximum tolerable pilot compensation
- Considerable pilot compensation is required for control
- Intense pilot compensation is required to retain control
- Control will be lost during some portion of required operation

Pilot Rating

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

* Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.
NASA Task Load Index (TLX)

- Subjective assessment on 6 scales
  - Mental demand
  - Physical demand
  - Temporal demand
  - Effort
  - Performance
  - Frustration level
  - Rating from 1 (low) to 5 (high)

- 15 pairwise comparisons for assessment of relative importance of scales

- Final score is weighted average of scale values
NASA Task Load Index

Hart and Staveland’s NASA Task Load Index (TLX) method assesses workload on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name   Task   Date

Mental Demand  How mentally demanding was the task?

Very Low   Very High

Physical Demand  How physically demanding was the task?

Very Low   Very High
NASA Task Load Index (continued)

Temporal Demand
How hurried or rushed was the pace of the task?

Very Low

Performance
How successful were you in accomplishing what you were asked to do?

Perfect

Failure

Effort
How hard did you have to work to accomplish your level of performance?

Very Low

Frustration
How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low

Very High
Four Designated Exploration Sites

Space Simulation and Human Factors Testing
ENAE 483/788D - Principles of Space Systems Design
EVA Walking Traverse
Night Geology Exploration with Suit Lights
## Cooper-Harper Assessment Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>Shirtsleeve</th>
<th>EVA/Walking</th>
<th>EVA/Rover</th>
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<tr>
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<td>5</td>
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<td>Std. Dev.</td>
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<td>0.82</td>
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NASA Task Load Index (TLX) Results
References

• Neville A. Stanton, P. M. Salmon, G. H. Walker, C. Baber, and D. P. Jenkins, Human Factors Methods: A Practical Guide for Engineering and Design - Ashgate, 2005

• Alphonse Chapanis, Human Factors in Systems Engineering - Wiley Interscience, 1996