Designing for Outer Space: Design and Evaluation Methods for NASA’s Next Generation Space Suit

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Role of the Space Suit

- Protects astronaut from hazards during various phases of mission
- **Launch/Entry Space Suit**
  - Normally unpressurized
  - Pressurizes if spacecraft loses cabin pressure
  - Some mobility is required when suit is pressurized in emergency scenario
  - Provides additional protection against:
    - No breathable atmosphere
    - Toxic substances
- **Extra-Vehicular Activity (EVA) Space Suit**
  - Used to perform spacewalks
  - Normally pressurized
  - Pressurized mobility is required when astronaut performs EVAs
  - Provides additional protection against:
    - No breathable atmosphere
    - Micrometeoroids
    - Thermal extremes
    - Radiation
History of Space Suits

1960s

Apollo Space Suit

1980s

Shuttle ACES Space Suit

1990s

Shuttle/ISS EMU Space Suit
Z-2 Space Suit

- Z-2 space suit is NASA’s newest prototype, micro-gravity and planetary walking suit
- Z-2 is a part of a development effort to build a suit for NASA missions in low-earth orbit (micro-gravity) and on Mars or other planetary surfaces
- Culmination of knowledge from 20 years of space suit research and development
- Flight-like version of Z-2 will be constructed after Z-2 has been extensively evaluated in various environments (lab environment, micro-gravity environment)
Z-2 Space Suit Development

• Goal of project was to validate pressure garment mobility architecture and sizing approach for smaller sized crew

• Design of upper torso was meant to address most common complaints about the current EMU space suit
  • Lack of overhead mobility
  • Reduced work envelope for those with short arms and/or narrow shoulders
  • Reduced visibility for those with shorter torsos
  • Contact with shoulder bearings during task completion

• Budget and schedule only permitted single build of upper torso
  • Anthropometric requirements reduced to target smaller range
  • Selected specific maximum and minimums based off anthropometries of identified crew and engineering test subjects
Suit sizing is critical to the performance of the suit.

A bad suit fit can lead to injuries or poor suit performance.

Z-2 is the first use of 3-D human laser scans and 3-D printed hardware for suit development and sizing.

Used 3-D computer models to perform digital fit checks with body scans of test subjects.

Created a 3-D printed prototype to validate models.
How does NASA evaluate space suits?

• Space suit evaluations consist of unmanned and manned tests
  • Unmanned Tests
    • Joint cycle testing
    • Joint torque testing
    • Environmental testing (radiation, dust, thermal, sharp edges, etc.)
  • Manned Tests
    • Joint cycle testing
    • Task evaluations

• A space suit is designed for operation with a human subject, so we ultimately need to understand how a person performs with the suit
Z-2 NBL Testing – Overview

• Unmanned testing occurred during development of Z-2
• Z-2 was designed to enable manned exploration missions in low-earth orbit and beyond, so we needed to do manned testing to evaluate Z-2
  • First envisioned use would be during demonstration of the Deep Space Gateway (DSG) orbiting Earth’s moon
• Neutral Buoyancy Laboratory (NBL) provides closest analog to DSG missions
  • Large pool where space suits are made neutrally buoyant to simulate micro-gravity
  • Existing ISS mock-ups submerged in pool for ISS training provide approximation of tasks anticipated for DSG and Mars transit
• Goal of Z-2 NBL Testing: Evaluate performance of Z-2 space suit, relative to the current state-of-the-art space suit (EMU) in a simulated micro-gravity environment
Z-2 NBL Testing – Overview

- Z-2 NBL test series consisted of 2 engineering subjects and 5 astronaut subjects (end users)
- 17 evaluations were performed in NBL
- Subjects performed critical tasks that would need to be performed on the International Space Station
- Subjects performed the same tasks in Z-2 and EMU space suit to gain relative comparisons between the space suits
A challenge in evaluating space suits with human test subjects is how to obtain objective data.

Subjective feedback from test subjects is the primary data that we collect during suit tests (e.g., comments).

- **Advantage:** Subjects can provide open-ended responses (responses are not constrained)
- **Disadvantages:**
  - Test subject comments can be difficult to interpret
  - Subject may not know how a space suit can be improved – they just want to perform work with minimal effort
  - Subjects may not be able to articulate their comments in a way that engineers can use to improve the design of the suit
  - Comments can be difficult to coalesce to identify trends

Other evaluation metrics:

- Rating scales
- Objective task performance
- Subject's reach envelope while in space suit
- Subject’s work rate
- Life cycle/fatigue of suit components
- Internal suit forces on human body
Z-2 NBL Testing – Evaluation Metrics

• Subjective Metrics
  • Subject comments
  • Rating scales

• Objective Metrics
  • Objective task performance
  • Subject’s subject work rate
  • Subject’s reach envelope
Subjective Data – Rating Scales

- For space suit testing, rating scales are often unique to each test because they are developed to provide specific data to suit engineers
  - Are you trying to determine pass/fail criteria?
  - Are you trying to refine the design of a joint?
  - Are you trying to compare performances of different space suits?
- Rating scales were used to assess: Acceptability, Discomfort, Muscle Fatigue, Exertion, Simulation Quality

  - Provides measure of absolute suit performance
  - Provides clear delineation between suits
  - Easy for test subjects to interpret

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Example of Acceptability Scale for Z-2 NBL Testing

Example of Discomfort/Fatigue Scales for Z-2 NBL Testing
Objective Data – Work Rate

- Subject’s work rate provides measure of how hard subject is working inside space suit
- Work rate is correlated to carbon dioxide that is generated by test subject inside space suit
  
  Subject Work Rate ≈ [suit gas flow rate] * [percent of carbon dioxide generated by test subject]

- Test subjects in EMU and Z-2 performed identical tasks

Example of Task-Based Work Rate Data
Objective Data – Work Rate

• Advantages
  • Data can be viewed in real time
  • Data is related to on-orbit consumables required for suit
  • Data can help interpret subjective data (acceptability, comfort, etc.)

• Disadvantages
  • Task timelines must be rigidly controlled, which may not be possible for research and development tests
  • Poor simulation quality can adversely affect data
Objective Data – Reach Envelope

• Motion capture is commonly used in laboratory environments to evaluate and compare mobility of different space suits

• Prior to NBL test series, underwater motion capture system for space suits was not available

• Underwater motion capture system was developed for NBL test series
  • Four GoPro cameras
  • Calibration targets

• Subjects performed prescribed motions in space suits to identify all “reachable” areas

• Post-test processing provided digital reach envelopes of Z-2 space suit and EMU space suit

• Metrics derived from motion capture data
  • Reach envelope (where you can reach)
  • Range of motion angles
  • Reach volume
Objective Data – Reach Envelope

- Underwater motion capture system provided quantifiable data for comparing reach of Z-2 and EMU space suits
- Z-2 subjects commented that Z-2 provided better overhead reach and rotational reach than EMU – this was confirmed by motion capture data

Advantages of System
- Provides comparative data between suits
- Enables suit engineers to better understand suit mobility
- Data can help interpret subjective data (acceptability, comfort, etc.)

Disadvantages of System
- Subjects must be fixed to location on pool floor
- Post-test data processing is time-consuming and labor intensive
- Data cannot be viewed in real time
- Motion capture system required periodic re-calibration

Z-2 Rotational Reach: 317 deg
EMU Rotational Reach: 214 deg

Z-2 and EMU Cross-Reach

Z-2 and EMU Waist Rotation
Forward Work

• Complete analysis of Z-2 NBL test data
  • Evaluate motion capture data to better understand mobility differences between Z-2 and EMU space suits
  • Analyze work rate data to quantify energy differences between the suits when performing micro-gravity tasks
  • Assess task performance data to quantify functional capabilities of Z-2 and differences between Z-2 and the EMU

• Use results from Z-2 NBL test series to make design changes to advanced space suit architecture in support of NASA’s Deep Space Gateway program
Discussion Topics

• Questions for automotive industry
  • What types of testing does industry perform to evaluate HMI technologies?
  • What metrics does automotive industry consider when evaluating HMI technologies?
  • Does industry primarily rely on objective data or subjective data when evaluating HMI technologies?
  • How does industry evaluate HMI designs with different sizes of people?
Questions?