Quantifying Suit Fit & Performance

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ADVANCED SPAC ESUIT DEVELOPMENT TEAM
Panel: Quantifying Suit Fit & Performance

- Panel Topic Description
- Panelist Presentations
- Q & A / Discussion
- Wrap-up

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Suit Development Goal: Enable crew to perform EVA required tasks with the least amount of energy expenditure

- If no specific tasks are identified, maximize mobility with a goal of achieving unsuited performance
- Quantifying performance and fit allows for consistent evaluation and verification of hardware design

Mobility is a combination of:
- Range of motion
- Work or joint torque throughout that range of motion
- Natural movement (programming)

Mobility is also heavily impacted by fit
- Fit is usually evaluated by how well the suit’s mobility joints line up with the crew’s joints throughout the required tasks
- Comfort is also a key aspect of good suit fit
Suit and Suited Performance Characterization

EVA Technology Workshop 2017

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Amy Ross
NASA/JSC/Crew and Thermal Systems Division
Suit and Suited Performance Characterization

• The Goal of Suit and Suited Performance Characterization
• Difference between suit and suited performance
• Methods we have tried
• Test environment effects
The Goal of Suit and Suited Performance Characterization

• The need is to provide realistic, component-level requirements that:
  – Can be assessed at the component-level during the development process
  – When components are combined at the system-level ensure that functional suited performance is met

• It is difficult to break down the system-level performance into component level specifications
  – The kinematic chain is multi-path and affects component level contribution to overall performance that is different for each task, by subject, and by technique

• An additional need is to compare component and system performance to inform and justify design decisions
Difference between suit and suited performance

• What the suit can do is NOT the same as suited performance
  – As a hardware system, focus is normally on hardware performance
  – However, suit hardware performance often doesn’t match suited performance
    • A suit waist bearing can rotate 360°; a human should not

• Requirements verification/acceptance tests typically includes both suit and suited performance testing because:

• Suit performance testing alone does not address:
  – The mobility triangle
  – Customer acceptance
  – Ability to perform mission tasks
The Mobility Triangle

Mobility
Fit
Comfort
Methods We Have Tried

• Joint range of motion and torque
  – Photogrammetry; 3D motion capture
  – Fish scales
  – BTE and other equipment

• Work envelope

• Task performance
  – Various tasks: Walking, kneeling, hammering, shoveling, stairs
  – In various environments: 1-g lab, 1-g analog site, reduced gravity aircraft, weight relieved systems, neutral buoyancy

• Robotic and manned cycle testing

• Effect of fit on performance
  – Arm sizing
  – Indexing

• Energy-based Mobility

• Vehicle systems interfaces
  – Hatches, tunnels, seats, don/doff volumes, umbilicals, tools, rovers
Test Environment Effects

• No single test environment exists that perfectly simulates micro-g space or planetary surfaces

• Experience with and knowledge of what is and is not representative and how that affects data analysis is of paramount importance
  – While water viscosity is of limited and well-understood impact on ISS micro-gravity simulation, it is a major confounding factor for simulated surface translations and could lead to incorrect conclusions
• Introduction
• Spacesuit Modeling, Sizing and Performance Overview
• Phase VI EVA Gloves
• Z-2 Spacesuit Modeling and Performance Testing
Introduction

• David Graziosi – Chief Engineer - ILC Dover
• 26 years of spacesuit development experience
  • EMU, Mk III, I-Suits, Pathfinder, Z-1, StratEx, Z-2
  • Glove Laserscan Process and Phase V and VI Glove Development
• Led fit and performance testing of suits and gloves noted above
  • Difficult to have enough data points for statistically significant results
  • Human factors make objective data difficult to support
    • This if for both fit and performance
• Fit can be advanced through the use of compliant human dynamic models evaluated within 3D suit models
  • Still cannot capture individual human preferences
• Use of full scale rapid prototyping models can be used in conjunction with computer based analysis to validate sizing predictions
Spacesuit Modeling, Sizing and Performance Overview

Developed techniques critical to accurate sizing, comfort, and operational performance

- Custom algorithms
- Develop integrated models of bladder, restraint, and TMG layers
- Unique knowledge of unfolding complex pressurized shapes
- Experienced in the use of lasers can data for component development and anthropometric analysis

Utilize SLA for rapid prototyping of prototype parts

U.S. Export Classification: EAR 9E515.a
Spacesuit Modeling, Sizing and Performance Overview

Performance Evaluation

Suit - Vehicle Interface
- CSSS Demo Suit 1 G seat belt and rapid egress testing

Vehicle/Habitat Interface
- Hatch sizing
- Min volume airlock

Quantify Comfort and Protection

Mobility Testing

Robotic Interface

Surface EVA Analog Testing

U.S. Export Classification: EAR 9E515.a
Phase VI Glove Modeling and Sizing

- ILC Laserscan Glove Process utilized for all layers of the glove (Bladder, Restraint, TMG)
- Sizing algorithm developed and refined over many years of operational glove use
- Use of Additive Manufacturing reduces sizing errors in manufacturing tooling
Phase VI Glove Performance Testing

- Phase VI Glove Certification Stand utilizes flight hardware
  - Rigorous testing insures a safe product given limited number of test units
- Glove torque and range tested with specialized equipment

U.S. Export Classification: EAR 9E515
Z-2 Spacesuit Modeling, Sizing and Performance

Full Scale Mockup Grown In Glass Filled Nylon

- Fit-Checked Eight Subjects Including Max and Min Anthros
- Verified HUT dimensions were chosen correctly
- Determined VTD was ½” too long
- Reviewed internal volume
- Prototyped shoulder harness to assess location of mount points and don/doff ability
- Assessed the need for a back pad while fitting various subjects
- Evaluated field of vision

U.S. Export Classification: EAR 9E515.a
Z-2 Spacesuit Modeling, Sizing and Performance

- Use of 3D Modeling, full body laser scans, and AM to improve suit fit and performance
  - Evaluated 3D body scans in the Z-2 suit model to verify fit prior to completing design and starting manufacturing
  - Evaluated HUT fit with test subjects and AM model to aide in validating HUT model
  - Evaluated Shoulder and Waist Harness designs using AM model instead of waiting for finished composite HUT

U.S. Export Classification: EAR 9E515.a
Z-2 Spacesuit Modeling, Sizing and Performance

- Z-2 pre-delivery testing included 24 manned requirements to verify sizing and performance
  - 6 tasks performed by each test subject to aide in verifying fit/sizing and comfort
  - 8 functional mobility tasks performed to verify overall Z-2 suit performance
- NASA performed numerous post delivery performance test including chamber and NBL

- Mobility Exercises Verifying Suit Fit
  - Touch Helmet
  - Cross Arms
  - Reach Straight in Front of HUT
  - Waist Full Flex
  - Kneel
  - Walk

- Four of Eight Required Function Mobility Tasks
  - NASA post delivery CO2 Washout Testing
Anthropometry & Biomechanics Facility - Assessing Suit Fit & Performance

Elizabeth Benson  MEI Technologies
Sudhakar Rajulu  NASA Johnson Space Center
Assessing Suit Fit and Performance

• What are some challenges in assessing suit fit and performance?
• How are suit fit and performance generally assessed?
• What are some examples of ABF-related studies that have quantified suit fit and performance?
Challenges – Assessing Suit Fit

• Major challenges in assessing suit fit:
  – Hardware constraints
    • Because there are limitations in how many suit components are available, and how the suit can be resized, some subjects will have sub-optimal suit fit.
  – Variability in human body shape
    • Humans are highly variable, and also change shape once you enter microgravity – spinal elongation and fluid shifts
    • Must do a multivariate analysis to determine true worst case, and must include volumetric shape information
  – Variability in suit fit across tasks and postures
    • Suit fit is a highly dynamic quantity, changing as a wearer moves and completes tasks, and by gravity environment
      – As an example: you might want a suit fit with a lot of extra space to ingress the suit, while you may want a tighter suit fit for EVA tasks
Suit Fit Assessment

- Suit Fit Questionnaire
  - It is important to take into account an individual’s perception of their fit
  - Inputs from an experienced suit engineer are also incorporated into an overall suit fit score
Challenges – Assessing Suit Performance

• Functional vs. controlled tasks – test design
  – Having a subject perform a complicated task can be highly functional, but not very controlled

• Complexity in measuring, describing suited motion (dissimilar to human motion)

• Challenging environments
  – NBL, ARGOS, reduced gravity flights, glovebox

• The challenges in assessing suit performance are exacerbated when evaluating gloves
Suit Performance Assessment

• Z-2 NBL Mobility Testing
Glove Performance Assessment

• FY09 Glove Study: Phase VI Benchmarking
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Performance Metrics for Quantifying Fit in Spacesuit Systems

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EVA Technology Workshop, October 17-19, 2017
Cognitive Task Analysis of Mark III Fit Checks

Overview

Motivation

Background

Aim 1

Aim 2

Aim 3

Conclusion

Methods

Results

Future Work

Background

Motivation

Methods

Results

Future Work

Legend

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Types of Suit Fit

**Overview**

**Motivation**

**Background**

- Static Fit
  - Human Joint Center
  - Indexing of Suit and Human Joint Center
  - Suit Joint Center
  - Length of Soft Goods

- Dynamic Fit
  - Differences in Human and Suit Joint Angles during motion
  - Relative Motion between suit and Human
  - Contact between suit and Human
Quantifying Dynamic Fit

Motivation

- Strap down inertial measurement units (IMUs) were placed on upper leg/suit and lower leg/suit
  - We defined a coordination metric to measure the relative motion between participant and suit using IMU gyroscopes

Methods

- Hypothesis: Increased indexing between the Mark III hip brief (Static Fit) will reduce the relative motion between the suit and participant (Dynamic Fit)

Participants performed a series of walking tasks using three configurations of padding between the participant and the Mark III hip brief
  - Hypothesis: Increased indexing between the Mark III hip brief (Static Fit) will reduce the relative motion between the suit and participant (Dynamic Fit)

Results

Future Work
Peak in relative motion prior to toe off indicative of foot lifting out of the boot
• How can we expand this analysis to other spacesuit systems? (e.g. xEMU and Z2)
• Would integrating sensors into current suit fits inform future design changes and requirements?
• How does fit change in more operationally relevant environments?
• Development of metrics for other components of dynamic and static fit:
  • Postural stability with the HUT
  • Shoulder Strap Tension?
Acknowledgements

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Back-up
Discussion Topics

- **Topic Title: Quantifying Suit Fit & Performance**
  - What are the challenges with quantifying suit fit and performance?
  - What are the benefits of quantifying suit fit and performance over subjective evaluations?
  - What methods of quantifying suit fit have been used in the past?
  - What methods of quantifying suit performance have been used in the past?
  - What is the future of suit evaluations?
Challenges

- Development budgets usually do not allow multiple sizes of suits
  - Consistent subject fit and performance can be a challenge when evaluating various suit architectures and performance
  - Enacting any desired design tweaks can be expensive and cost prohibitive

- Number of test samples is often limited due to either schedule or financial restrictions
  - A sample size of 6 is pretty good for suit tests

- Modeling tools have been limited in the past and difficult to validate
  - NASA is still pursuing modeling as more recent sensing technology and models are showing progress
Test Method Considerations

• Repetitious, mobility driving tasks vs. simulated EVA timelines
• Subjective vs./and quantitative data collection
• Subject selection and participation
• Pressurized vs. unpressurized
• Glove box vs. suited
• Number of tests
• Test order