A Safe Space Suit : A Human Factors (Anthropometry and Biomechanics) Approach

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Introduction

- Constellation Program
  - Goal is to return to the Moon and Mars and beyond
  - Build habitats on the Moon and Mars
  - Permanent presence of humans
- Efforts are underway to develop
  - Crew Exploration Vehicle (CEV-Orion)
  - Exploration Suits (Launch and Entry, Planetary)
  - Lunar Rovers
  - Habitation Module and many more

Human Factors Impact

- Existing suits and space hardware have issues
  - Poor accommodation
  - Fit issues
  - Mobility constraints
  - Strength issues
  - Suit size availability

Source Issues

- Lack of clear human factors requirements
  - Space suit related human factors requirements are complex
  - Expectation of mobility and reach as comparable to minimal clothing mobility is nearly impossible to achieve
  - Uncertainty over who is accommodated and who is not
  - Suit size Fit issues – not all crewmembers have a suit size that fits their body shape
  - Lack of data translates to no transparency in human factors requirements from the perspective of engineering

Goal and Objectives

- Habitability and Human Factors Branch efforts
  - Overcome the accommodation, fit, mobility, and sizing issues
    - Determine the current limitations and capabilities of all current suits and space hardware
    - Develop new methodologies to capture functional mobility requirements, functional strength requirements, new analytical tools to monitor the range of accommodation, and new analytical tools to verify and validate the suit size and fit
    - Establish feasible and engineering-specific human factors requirements

Determination of Critical Anthropometric Dimensional Requirements

- Crew Accommodation
    - Apollo and pre–Apollo Programs - intended to be accommodate 70% of the user population
    - Shuttle and Station Programs – intended to accommodate 90% percent of the population
- Yet, not all Shuttle and Station crewmembers can be accommodated in the suits
- The effects of Clothing, Posture, and Pressurization were not clearly identified numerically other than qualitatively for designers designing seats, seat layouts, cockpit, etc

Determination of Critical Anthropometric Dimensional Requirements

Accomplishments:

•Updated the Constellation requirement to reflect the range of critical dimensions

  •Result 1st percentile to 99th percentile

•Identified critical anthropometric dimensions based on functionality for cockpit, seat layout and suit design

•Selected a comprehensive anthropometric database that represented all critical dimensions

•Conducted tests to quantify the effects of clothing (different suits), pressurization, and postures

  • Suit increases the fingertip height by about 6 to 17% - control location would have to change accordingly.

  • Forearm-Forearm Breadth increased by 28% due to suit and 10% more due to pressurization in a standing posture

  • Forearm-forearm Breadth increased more (46%) when the posture changed from standing to seated, launch position.

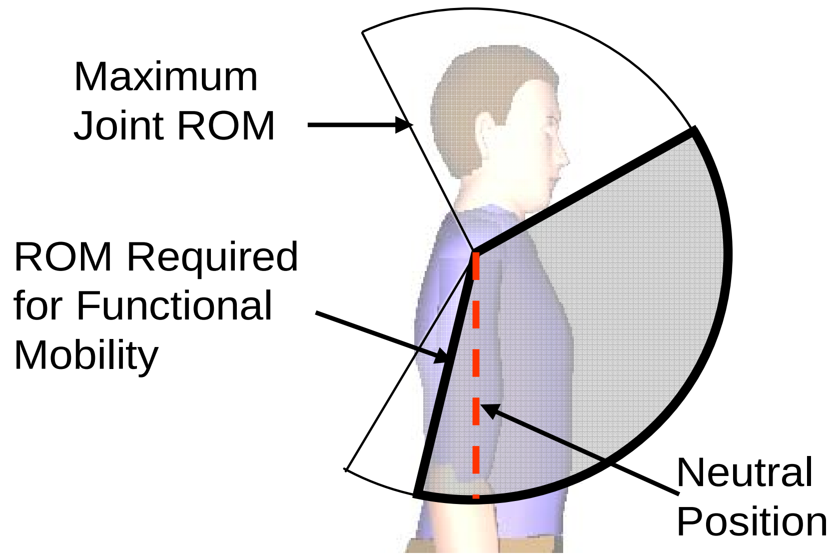
Functional Mobility Testing:

A Novel Method to Create Suit Design Requirements

- Historical suit requirements demanded full mobility of a minimally clothed human
- The Anthropometry & Biomechanics Facility (ABF) was tasked with updating mobility numbers
  - Requirements to dictate the minimum joint range of motion necessary for Constellation launch/re-entry and planetary space suits
  - Requirements based on objective data that represent the actual joint ranges of motion necessary to perform all potential launch/entry/abort, 0-G and outpost tasks

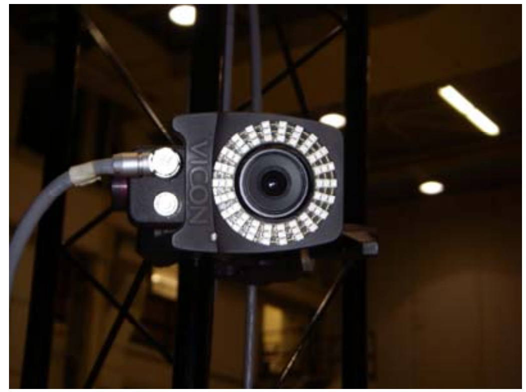
Functional Methodology

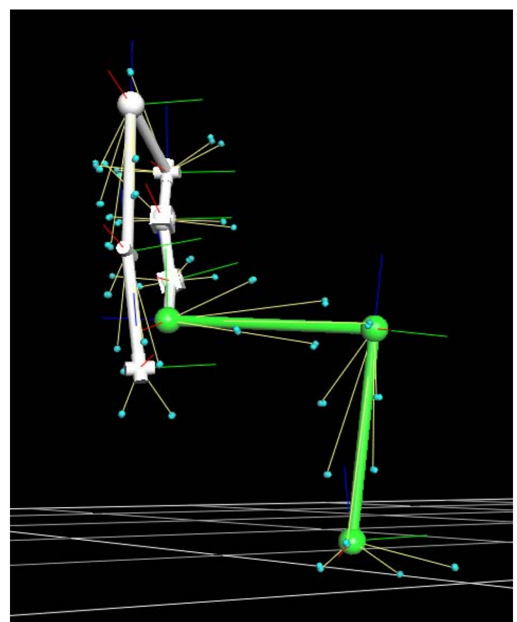
- New concept for establishing mobility requirements
- Not technically feasible to quantify until recently
- Focus on functional necessities
  - Maintain subject safety and mobility
  - Reduce extraneous mobility components

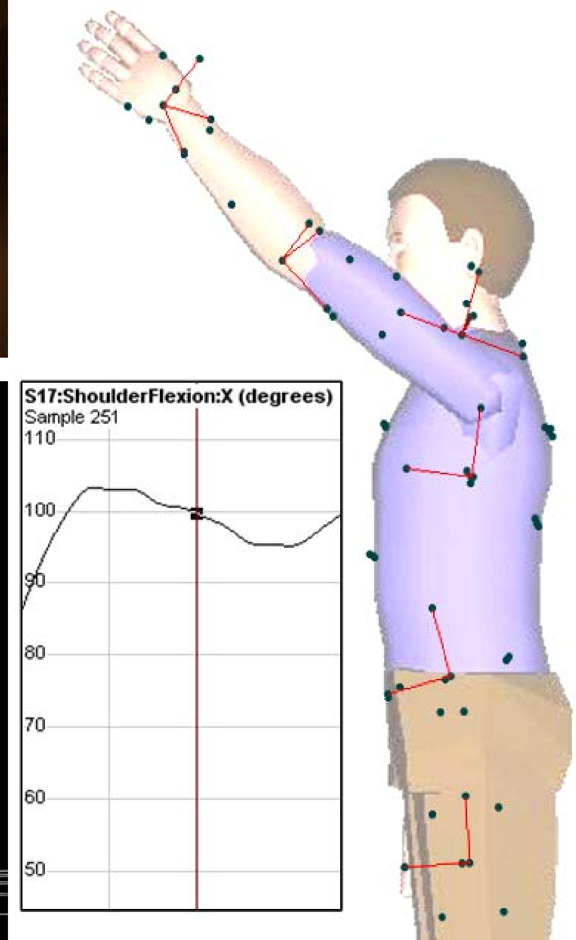


Data collection

- Vicon 612/SV
- 41 retro reflective markers
- 20 unsuited subjects
- 4 suited subjects in each of 3 suits both pressurized and unpressurized





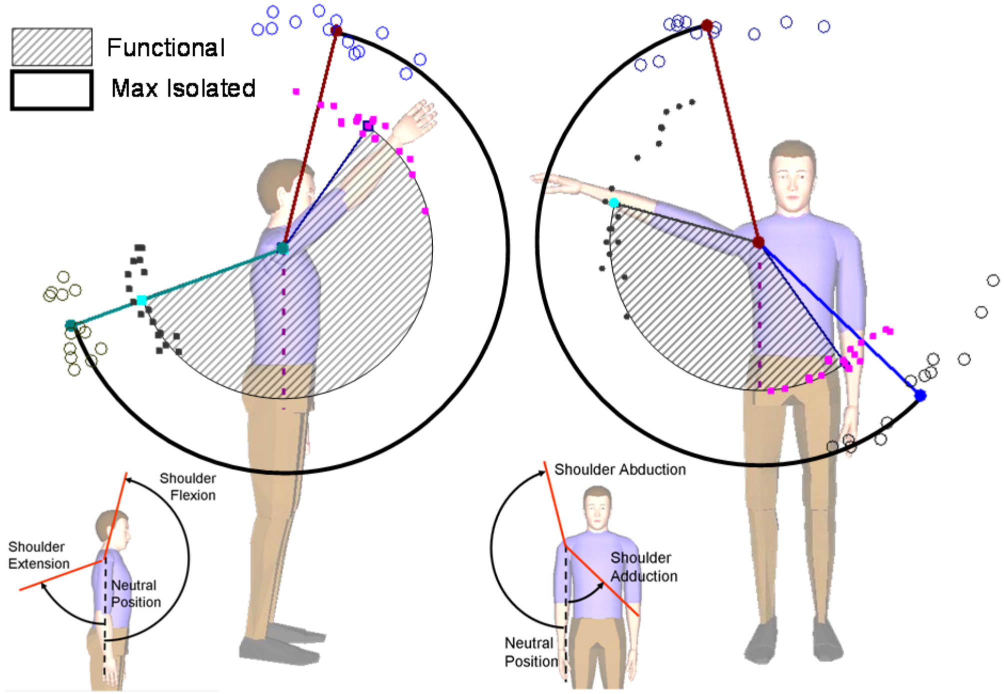


Functional Task List

- Considered every anticipated task following suit donning to return/egress
- Over 200 tasks considered
- Parsed to ~50 likely to maximize some joint angle
- Variations made to task list completed in each suit in the interests of safety

Functional vs Isolated ROM

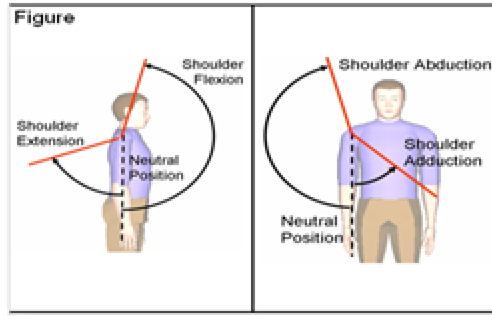
- Functional data represents what should be required of a suit to enable completion of a task
- Isolated data illustrates maximum physiological limits relevant for other system design
- Each has important implications for suit and vehicle design



Results

- Tables presenting mobility were generated and provided to suit designers, vehicle interface group, and various other stakeholders
- Unsuited, suited unpressurized, and suited pressurized ranges of motion were provided to be applied where appropriate
- Videos and subjective comments were delivered to provide a more accurate representation of mobility

Figure

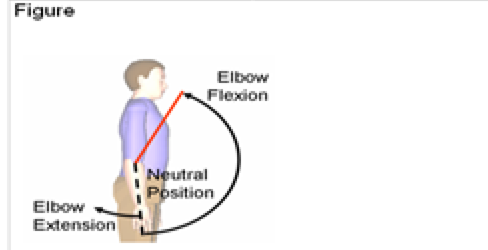


Shoulder – Range of Motion

	Flexion	Extension
Unsuited Maximum	166	-70
Unsuited Functional	145	-70
Suited Press. Iso	150	-47
Suited Unpress Func	154	-74

	Abduction	Adduction
Unsuited Maximum	-154	43
Unsuited Functional	-105	35
Suited Press. Iso	-142	9
Suited Unpress Func	-163	24

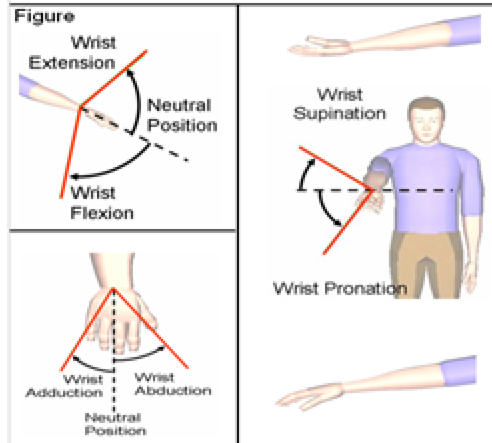
Figure



Elbow – Range of Motion

	Flexion	Extension
Unsuited Maximum	148	0
Unsuited Functional	130	0
Suited Press. Iso	98	0
Suited Unpress Func	96	-5

Figure



Wrist – Range of Motion

	Flexion	Extension
Unsuited Maximum	-85	60
Unsuited Functional	-85	60
Suited Press. Iso	-41	78
Suited Unpress Func	-59	64

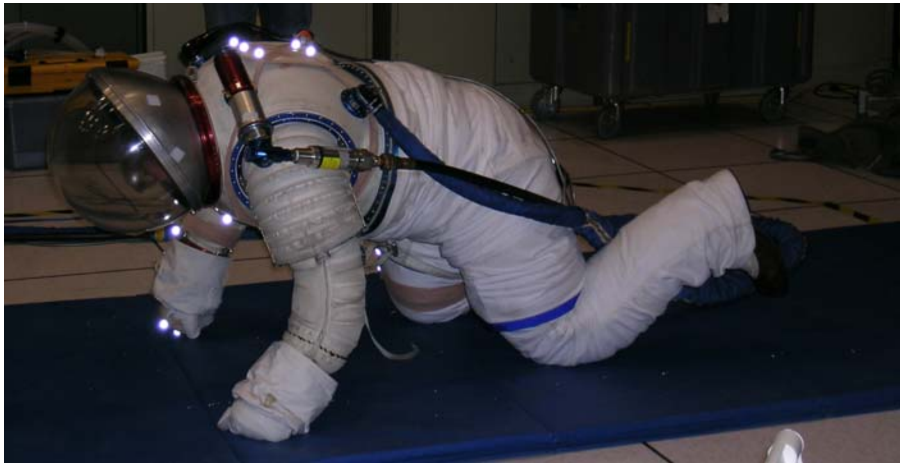
	Abduction	Adduction
Unsuited Maximum	-30	32
Unsuited Functional	-30	25
Suited Press. Iso	-16	29
Suited Unpress Func	-27	35

	Pronation	Supination
Unsuited Maximum	-61	35
Unsuited Functional	-60	30
Suited Press. Iso	-121	100
Suited Unpress Func	-116	133

*example data, do not reference

Conclusions

- Meaningful & enforceable requirements are vital in human-systems integration
- Savings to be had
  - Reduced cost of system
    - Materials
    - Development
  - Reduced cost of use
    - Weight
    - Reliability
- Functional methods are useful for a breadth of potential applications including improving digital models and providing more conservative requirements



Suited Strength De-Rating

- Purpose of testing
  - Determine the effect of space suit on strength as compared to shirt-sleeve strength
- Approach
  - Measure force production during functional tasks
    - Pushing, pulling, gripping, pinching
  - Compare force production between suited and unsuited conditions
  - Use findings as means of estimating suited strength capabilities based on known unsuited strength

Data Collection

- Tested subjects performing functional tasks
  - Unsuited
  - Unpressurized I-suit
  - Pressurized I-suit
- Measured strength capabilities with force dynamometer

Table 2. Functional tasks for strength testing during Phase I

1	One-handed	push	horizontal	standing
2	Two-handed	push	horizontal	standing
3	Two-handed	push	horizontal	sitting
4	One-handed	pull	horizontal	sitting
5	Two-handed	pull	horizontal	sitting
6	One-handed	push	horizontal	sitting
7	One-handed	pull	horizontal	standing
8	Two-handed	pull	horizontal	standing
9	One-handed	pull	up	sitting
10	Two-handed	pull	up	sitting
11	One-handed	pull	up	standing
12	Two-handed	pull	up	standing
13	One-handed	push	down	standing
14	Two-handed	push	down	standing
15	One-handed	push	down	sitting
16	Two-handed	push	down	sitting
17	One-handed	push	up	sitting
18	Two-handed	push	up	sitting
19	One-handed	push	up	standing
20	Two-handed	push	up	standing
21	One-handed	pull	down	standing
22	Two-handed	pull	down	standing
23	One-handed	pull	down	sitting
24	Two-handed	pull	down	sitting

Table 3. Functional tasks for strength testing during Phase II

Two-handed	push	up	sitting
Two-handed	pull	up	sitting
Two-handed	pull	up	standing
Two-handed	push	down	standing
One-handed	push	up	sitting
One-handed	push	down	sitting
One-handed	pull	down	sitting
One-handed	pull	down	standing
Hatch			
Grip			
Pronation			
Supination			
Pinch			

Results

- Found ratios of suited to unsuited force production
  - Unpressurized suit tended to reduce strength
  - Pressurized suit tended to reduce strength further
- Produced guidelines based on ratios across subjects by functional task
  - Ratios applied by multiplying with shirt-sleeve force production to predict suited strength

	Unpressurized	**Pressurized**
General functional tasks	0.7	0.5
Hatch	1.0	1.0
Grip	0.5	0.5
Pinch	1.5	0.8

Volume/Shape effects on Size Fit

- Develop a tool that will allow the ABF to make critical decisions regarding the components needed to accommodate the minimum to maximum measurement ranges of the HSIR population.

- Quantification of the differences between the various measurements of the human body
  - Crucial to parse the population into optimized groups.

Volume/Shape effects on Size Fit

- Body Shape and Size
  - Ideally, the human body could be easily parsed into ‘small’, ‘medium’, and ‘large’ across every dimension.
  - In reality, the human body isn’t that simple.
  - Populations can be grouped into body somatotypes, representing the structure or build of a person.

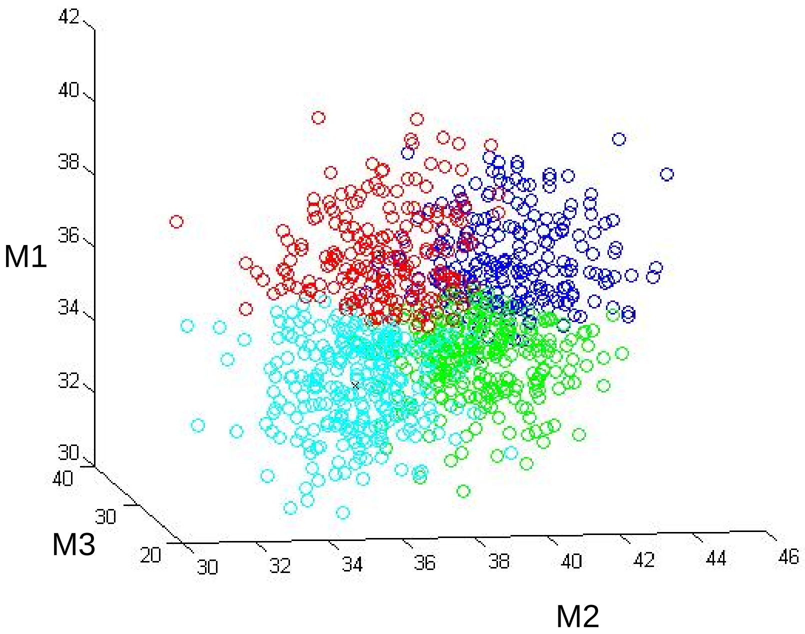
- The classification of the population into similar groups, or ‘clusters’, is a method that can aid in the identification of body somatotypes
  - Uses the multivariable aspects of the population to group individuals into the most distinct groups
  - Resulting subgroups can be used as a basis to classify sets of sizes needed within suit design.

Volume/Shape effects on Size Fit

- K-means cluster analysis using the squared Euclidean distance between clusters.
  - Data is partitioned into mutually exclusive clusters by calculating the distance measure and maximizing the distance between clusters while minimizing the distance within clusters.
  - Each cluster is defined by the individual data points and its corresponding centroid, the mean value of all the individual data points.

•Example Cluster Analysis

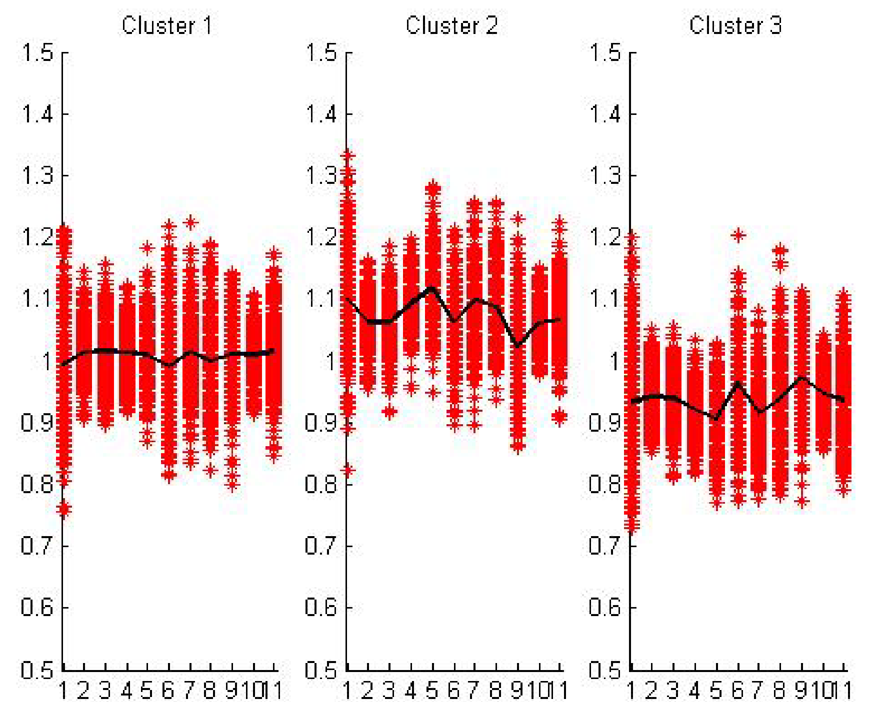
- Four clusters, identified by color
  - •red, blue, cyan, and green)
- Three Input measurements
  - •x, y, and z axes,
- Distinct cluster formation with minimal overlap



Volume/Shape effects on Size Fit

- Torso Example
  - Eleven normalized, descriptive torso measurements
  - A two, three, four, five, and six cluster analysis
  - Three cluster analysis is shown below as an example
    - Black line represents the means of the measurements
    - Red dots are the individual data points.

Measurements
Abdominal Extension Depth, Sitting
Acromial Height, Sitting
Biacromial Breadth
Bideltoid Breadth
Chest Breadth
Chest Depth
Interscye 1
Waist Breadth
Waist Height, Sitting (Omphalion)
Torso Height
Chest Height Sitting



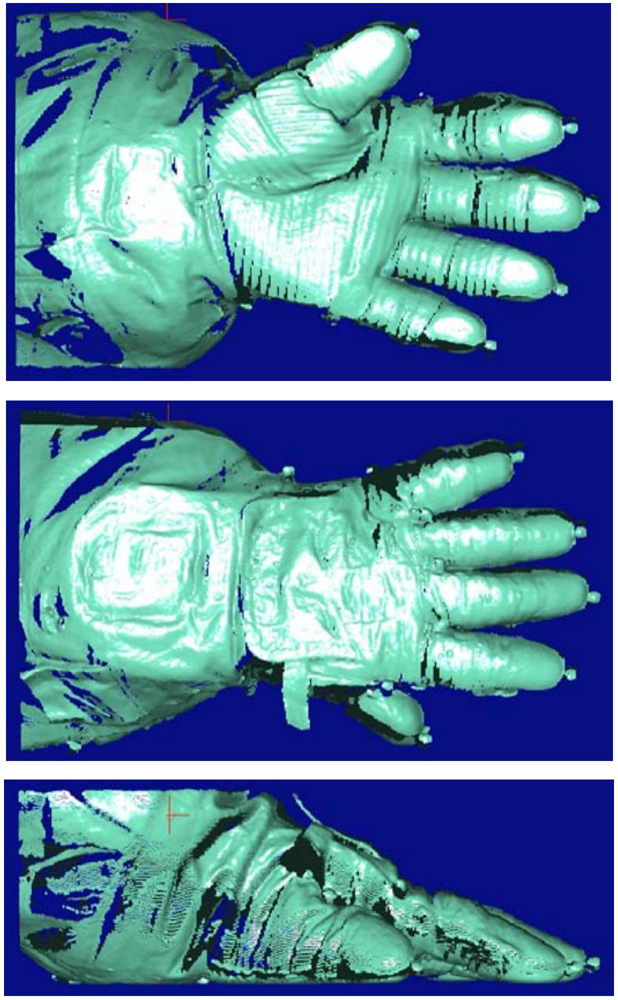
Volume/Shape effects on Size Fit

- Benefits
  - Simple yet powerful technique for defining groups of individuals based on a set of measurements
  - Results can be used as a basis for sizing and accommodation

- The cluster analysis parses individuals into logical, relevant groups and provides a quantifiable result that accommodated the maximal amount of people.
  - Produces optimal sizing configurations for that particular suit component.
  - Avoids scenarios where the groupings are done inappropriately
    - Reduces the risk that the population will be improperly accommodated across all critical dimensions.

Tactility and Dexterity

- Objective:
  - Quantify the strength, tactile feedback for a gloved hand, and the dexterity of a gloved finger and thumb using the current gloves
  - Benchmark the current gloves to aid in development of requirements for the future glove and hand controller design.



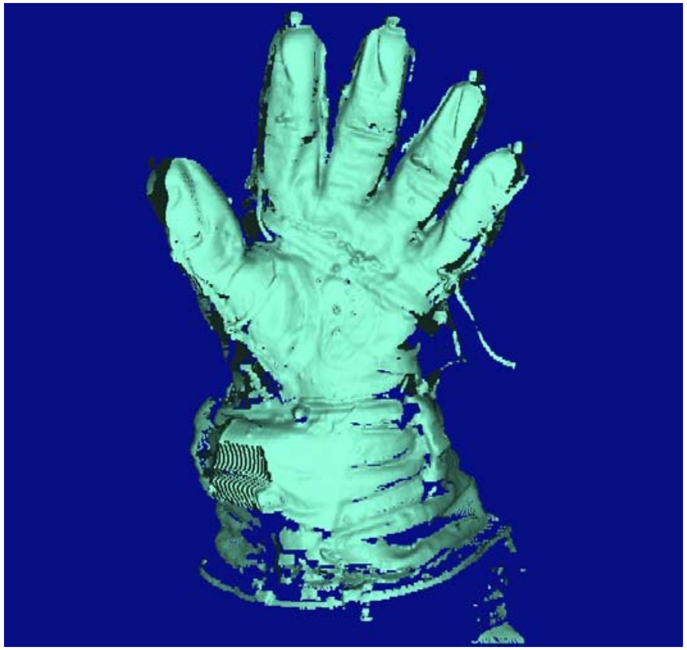
Tactility and Dexterity

- Independent variables
  - Glove types: unsuited/barehand, suited unpressurized (0 psid), and suited pressurized (4.3 psid)
  - Hands: right and left
  - Glove conditions: no TMG and TMG.
  - Barehanded values used as the baseline for comparison

- Dependent variables
  - Pinch strength, grip strength, dexterity average test time, dexterity number of errors, tactility average test time, tactility number of errors, tactility two point discrimination distance, and subject feedback.

Tactility and Dexterity

- Tactility and dexterity of the Phase VI gloves will provide a valuable benchmark to quantify the effects of the suit on performance
- Use as a basis to develop meaningful, realistic design requirements that will ensure all crewmembers wearing gloves can be assured of optimal hand performance capabilities while wearing the future gloves



Conclusions

- The Anthropometry and Biomechanics Facility Engineers have successfully presented project ideas to the Constellation EVA Project office to:
  - Benchmark the current capabilities and limitations of the space suit hardware
  - Developed new methodologies and tools to quantify space human factors requirements
  - Established new criteria and requirements to enable engineers to apply human factors requirements into their design
  - Working on providing tools to monitor the fit and accommodation in to the suit and the seat and the vehicle.

Thank You!!!

Any Questions???