A Parametric Model of Shoulder Articulation for Virtual Assessment of Space Suit Fit

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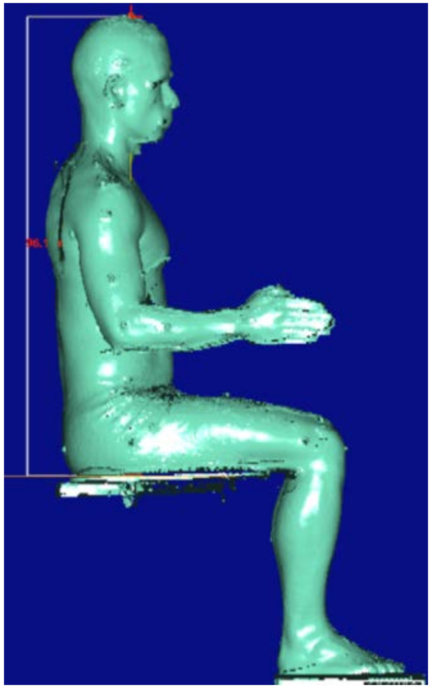
Introduction

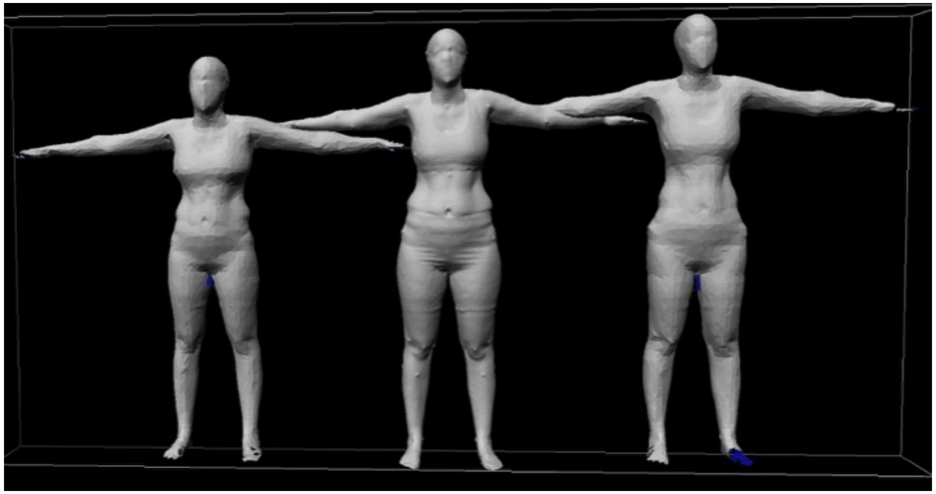
- **Goal of space human factors analyses:**

  Place the highly variable human body within these restrictive physical environments to ensure that the entire anticipated population can live, work, and interact

Introduction

- Space suits are a very restrictive space and if not properly sized can result in pain or injury
- The highly dynamic motions performed while wearing a space suit often make it difficult to model
- Limited human body models do not have much allowance for customization of anthropometry and representation of the population that may wear a space suit.

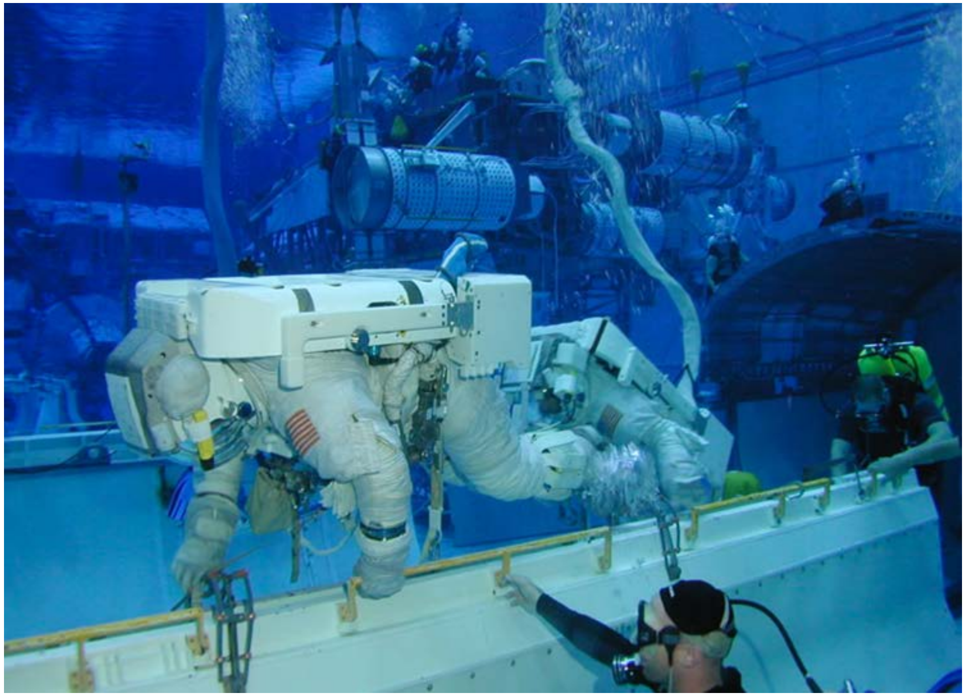


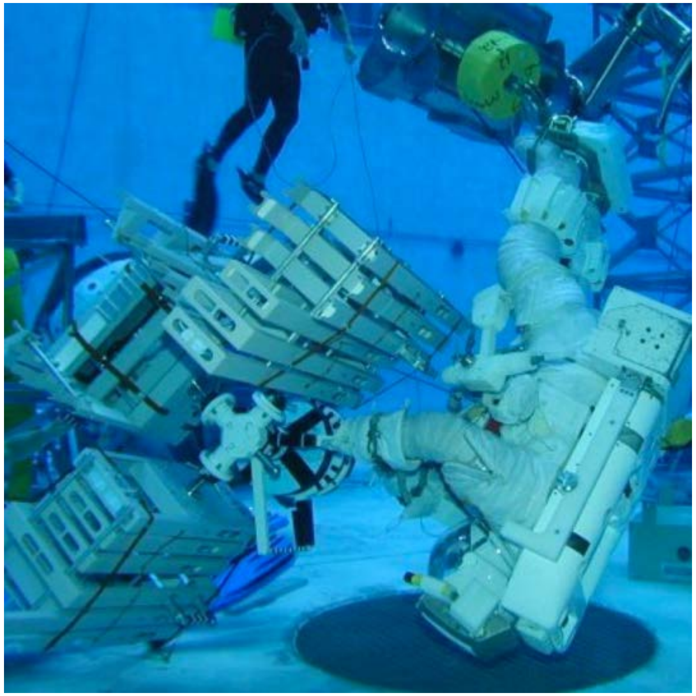


Background

Extravehicular Activity (EVA) Training

- Crewmembers go through pre-flight ground based training in a neutral buoyancy environment.
- Cumulative suited pre-flight training time can exceed 300 hours.
- Suited training has been associated with the risks of injuries due to physical demands from the work and suit.



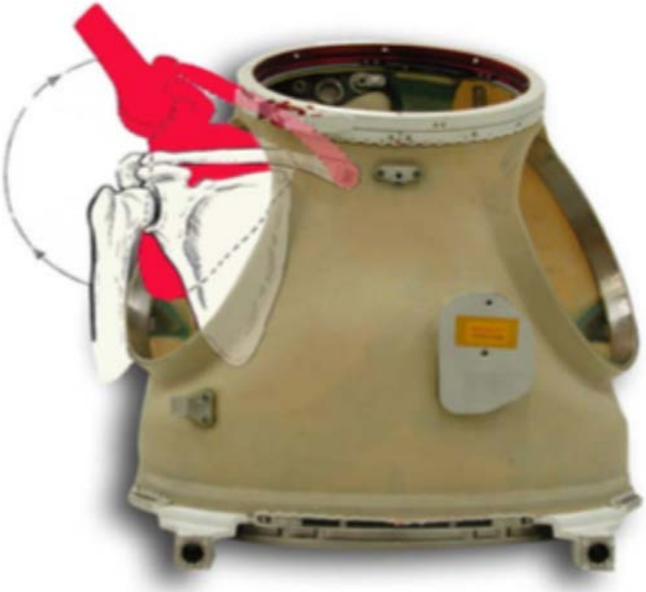


Source: www.nasa.gov
www.esa.int

Background

- Suboptimal suit fit, in particular at the shoulders, has been identified as one of the predominant risk factors for shoulder injury while wearing a space suit.
  - Approximately, 64% of crewmembers experience shoulder pain after extravehicular (EVA) training in a suit
  - Approximately, 14% of symptomatic crewmembers require surgical repair.

Shoulder clearance between scye bearing and liquid cooling and ventilation garment.



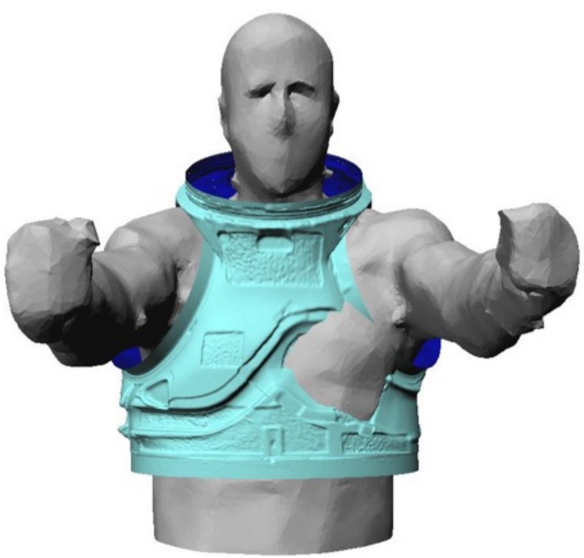
Restricted shoulder motion by hard upper torso (HUT) assembly

Shoulder irritation immediately after extravehicular activity training

Source: Williams & Johnson, 2003

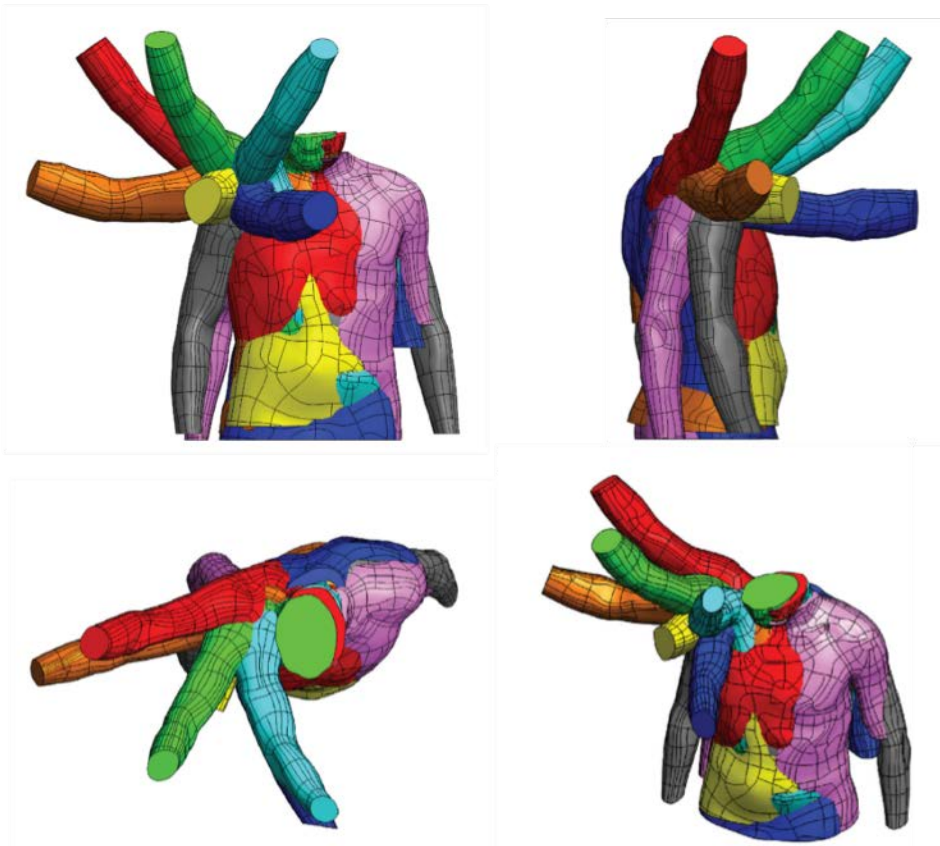
Past Work: Evaluation of Suit Components

- New suit development efforts
  - Allows for computer-aided design (CAD) modeling of suit components
  - Evaluate fit and some performance issues prior to prototype/ hardware build
  - Provides multivariate examination between the suit components and the human body
- Challenges to suit fit
  - Modularity of suits
  - Restrictions in spacesuit size availability
  - Placement of components
  - Performance and mobility impacts
  - Static vs dynamic of human model
  - Multiple human models to accommodate entire population (body size and shape)



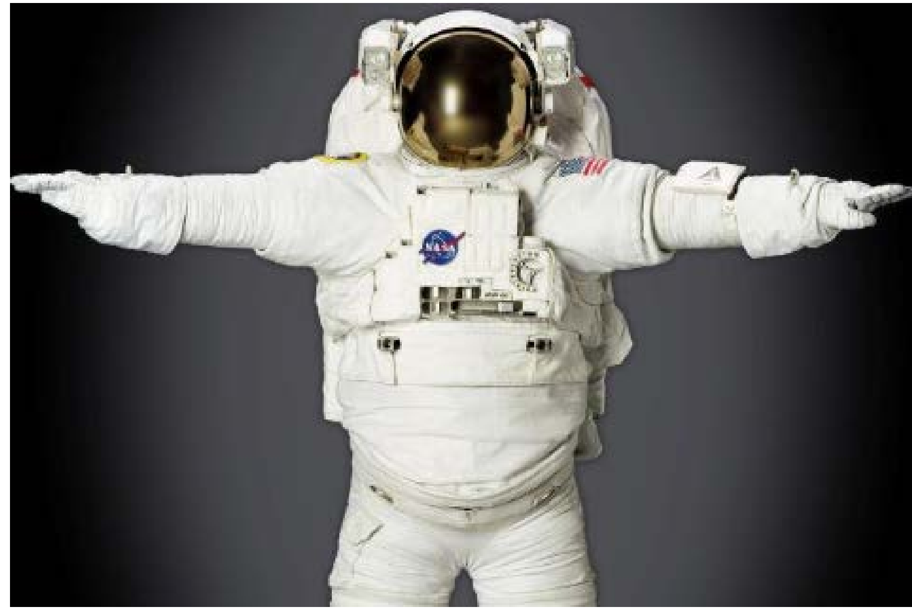
Past Work: Shoulder Deformation Modeling

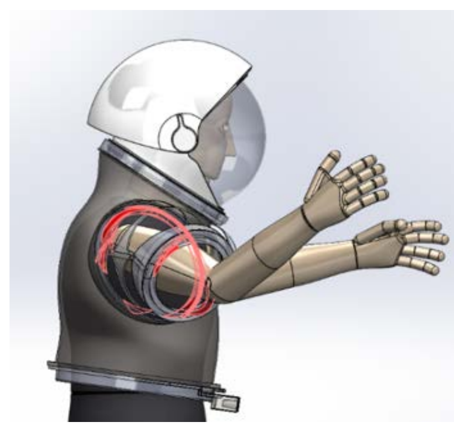
- Quasi-static models of the shoulder joint
  - Used static poses from subjects
  - Multiple subjects (n=3), multiple arm positions
- Models were incorporated in a CAD environment to determine interactions with a new prototype space suit.
- Method was limited due to the lack of ability to alter body poses or sizes.

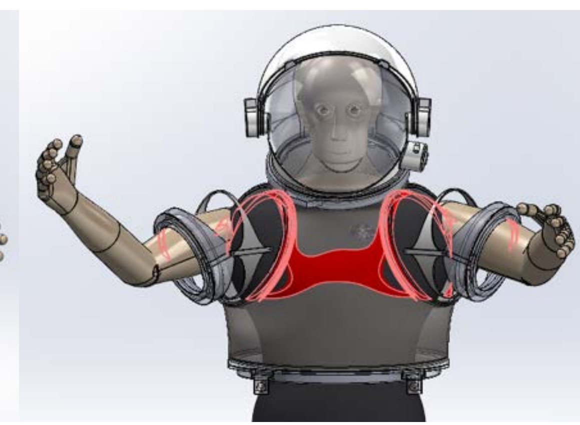


Current Work: Geometric Model of Space Suits

- Extravehicular Mobility Unit (EMU)
  - Pressurized personal protective suit.
  - Protects astronauts from the harsh environment of space during Extravehicular Activities (EVA).
- Suit geometry models were developed on CAD tools
- A human body manikin ("*Anthronaut*") was developed consisting in multi-link rigid segments
- Models enabled the quantification of suit-body interference and overlap volume
- **The next model needs to consider soft tissue deformation varying with segment articulation**

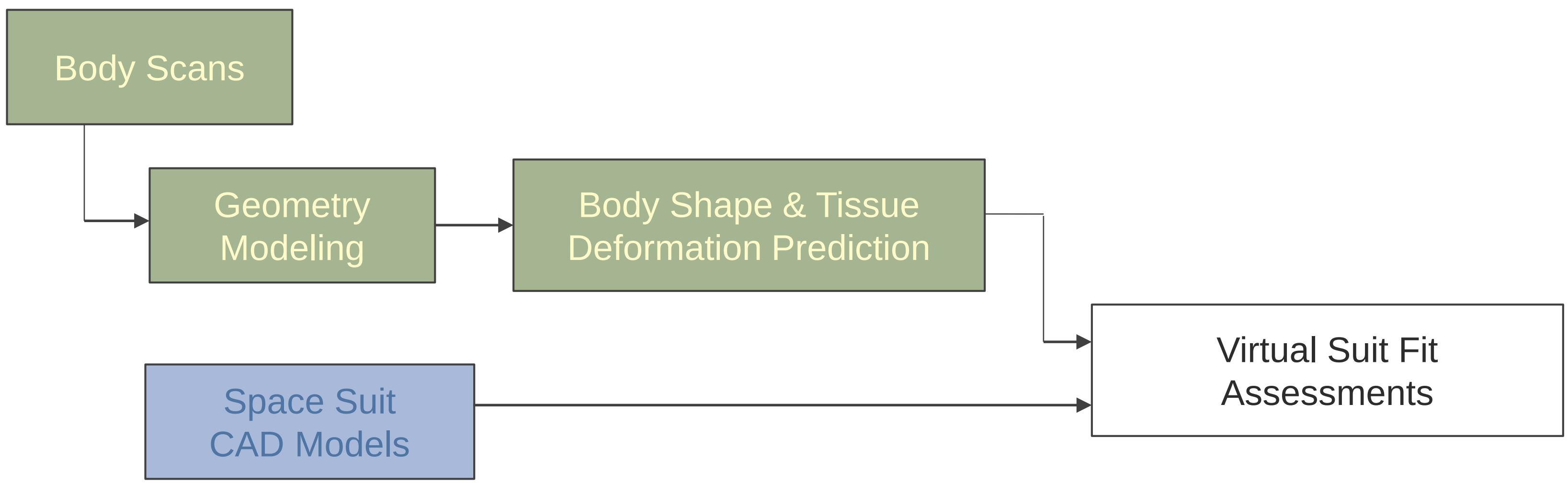






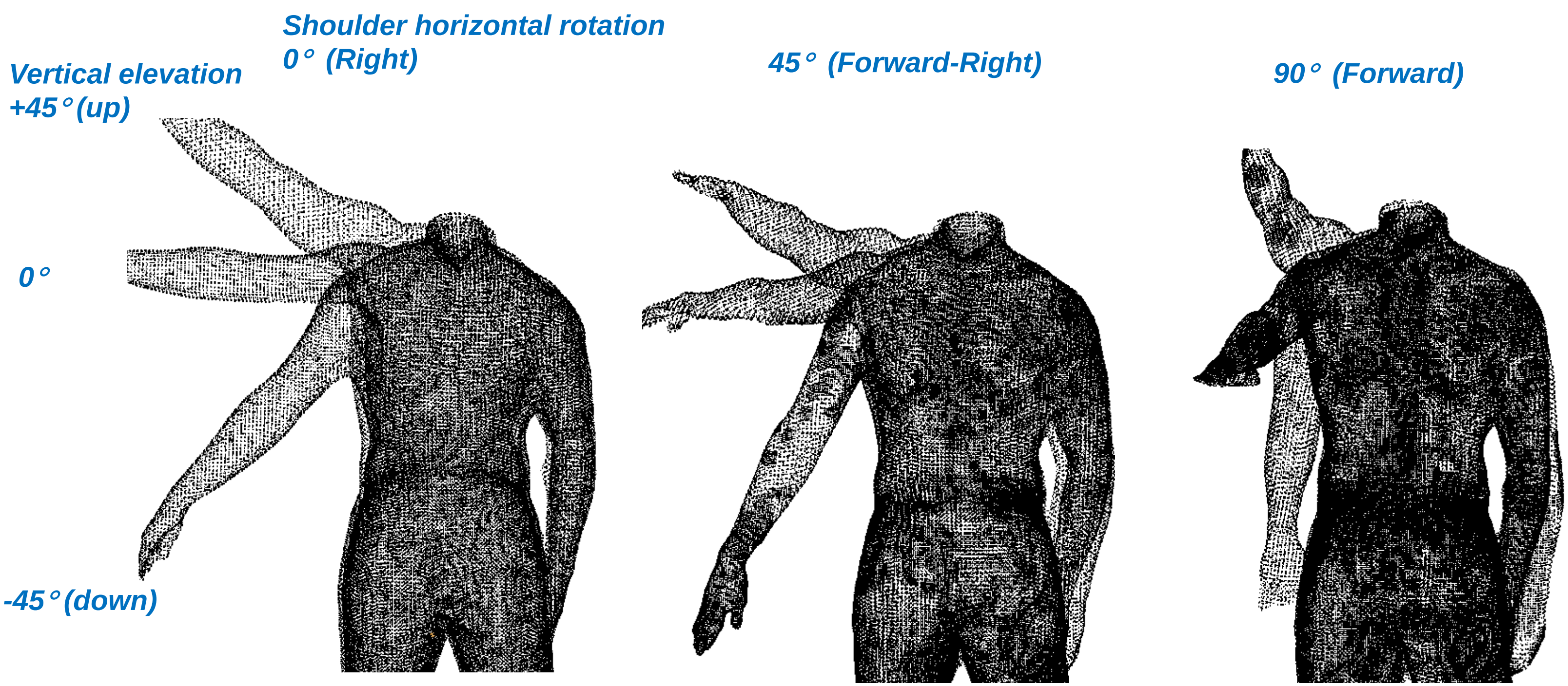
Goals of the Study

- Develop a software tool to predict the skin deformation and shape variations for any body size and shoulder pose for a crewmember population
- Transform the predicted body shape into standard CAD format data
- Evaluate geometry against suit models in CAD software for virtual fit assessments
- Provide quantitative guidelines for accommodating diverse crewmember populations in a wide variety of body sizes



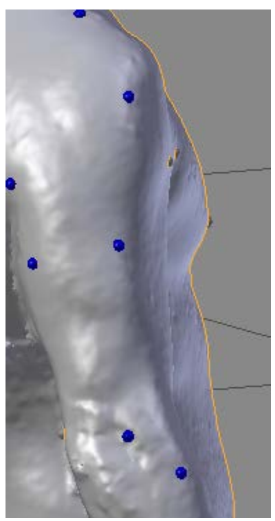
Methods: Body Scanning

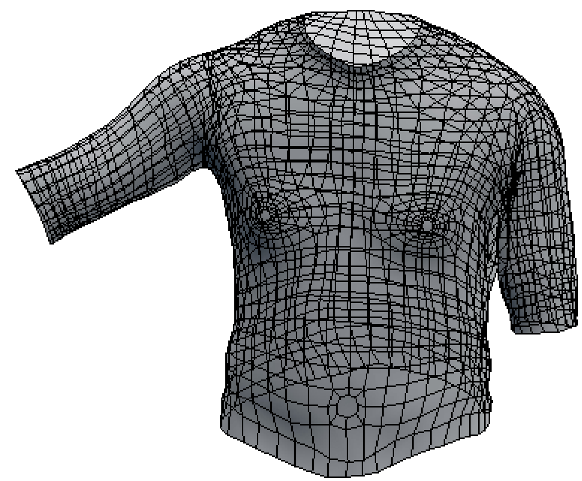
- 12 subjects (9 males and 3 females) participated in body scanning.
- A 3dMD optical whole-body scanner with 12 sets of camera modules captured the 3-D geometry and color texture of the subjects' upper body.
- The subject stood upright in the center of the scanner volume and assumed 9 different poses with the right arm and shoulder.



Scan Data Processing

- Paper stickers were attached on anatomical landmarks. A blob detection algorithm identified the corresponding pixel clusters from the color texture map, then transformed into 3-D coordinates.
- A reference mesh ("*template*") of ~2,000 vertices was used to homologically represent the scans across different subjects and poses.
- A two-step fitting process was used to align the template geometry with the scan surface:
    1. **Morphing**: a radial basis function interpolation aligned the landmark locations of the template and scanned mesh.
    2. **Implicit Surface Fit**: each template vertex was moved to match with the corresponding mathematical surface approximated from the scan.



Parametric Body Shape Estimation

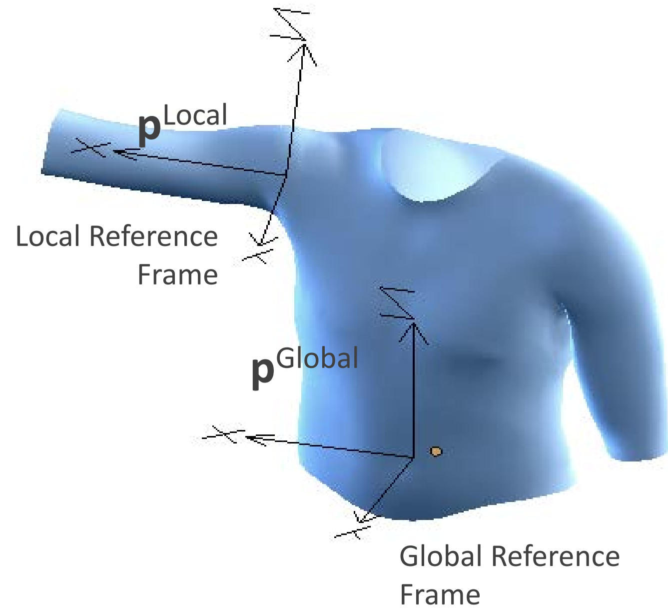
User Input:
Anthropometry
Shoulder Pose

PC Score Estimation
PC = *f* (anthropometry, shoulder pose)

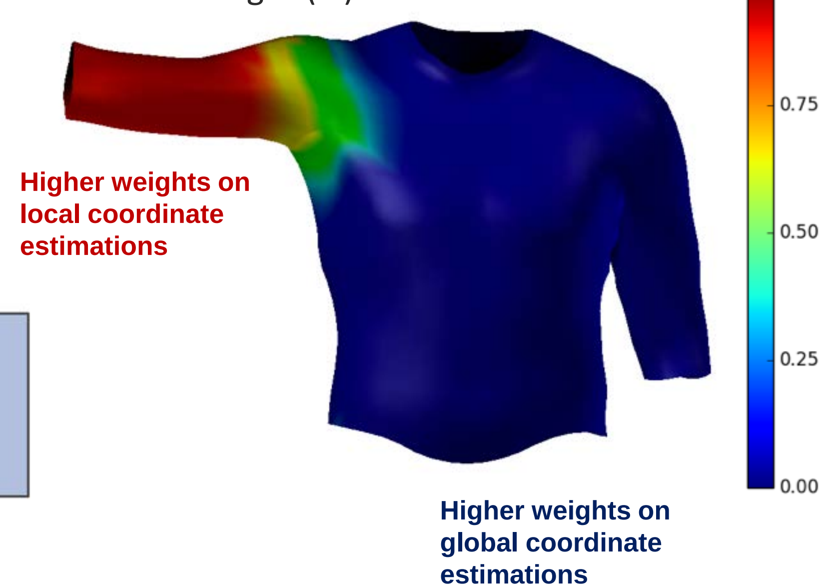
Inverse PC Transformation
$[\mathbf{p}^{Global}, \mathbf{p}^{Local}] = g^{-1}(PC)$

Weighted Averaging
Vertex Coordinates = $(1-w)\,\mathbf{p}^{Global} + w\,\mathbf{p}^{Local}$

Body Shape



Vertex Weight (*w*) Allocation

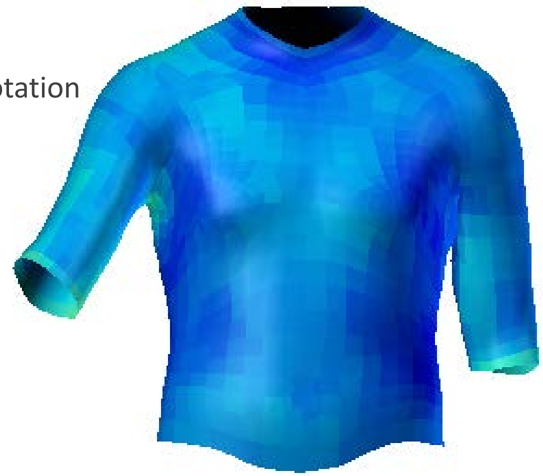


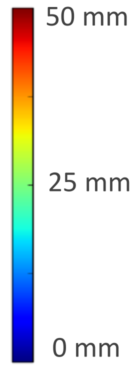
Results: Model-Estimated Body Shapes

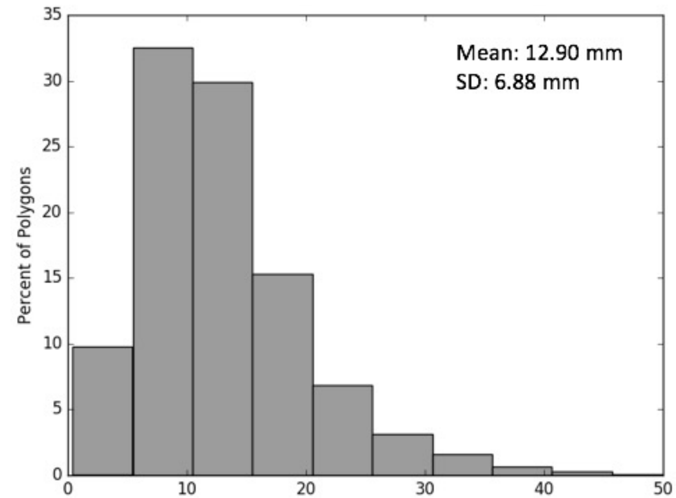
Estimation Accuracy

- Errors were estimated by L2-norms between the scan and model-estimated vertex coordinates
- Errors tend to be larger in the arms at the biceps and triceps areas and upper abdominal areas.

+45 horizontal rotation
-45 elevation







+45 horizontal rotation
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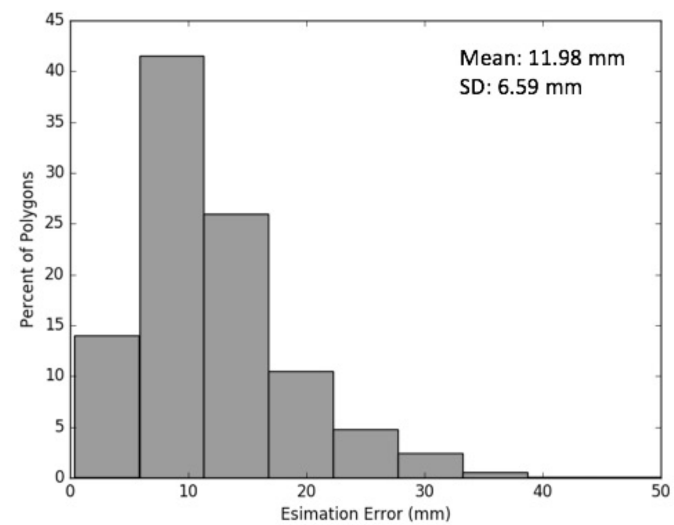
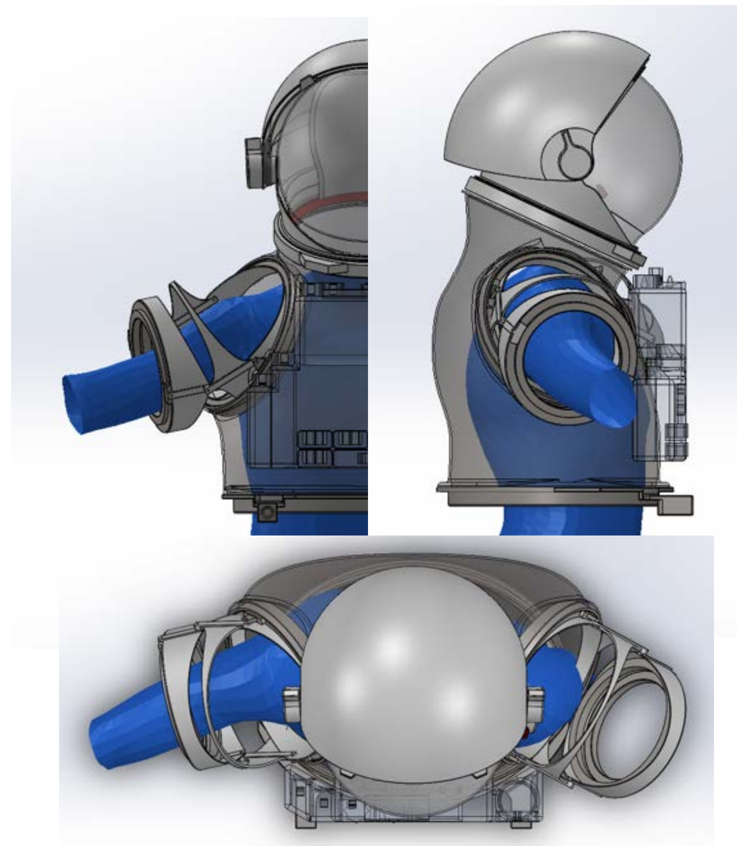


Suit Fit Assessments

- Model-estimated body shapes were incorporated with the CAD drawings of a medium-size Extravehicular Mobility Unit (EMU).
- CAD incorporation enables the quantification of the contact volume and clearance between the suit and body surfaces.



Summary

- Developed tool to change body shape and size as well as arm position
- Ability to export (static) posture of arm position varying body size and shape
- The estimation errors are approximately 11-12 mm on average, which are suitable for space suit fit assessments.
- The fit assessment was demonstrated as a proof of concept.
- Future effort will be made to quantify and analyze the interactions between the suit and body surface.

- Limitations:
  - The model represents the poses articulated without wearing a suit (*active pose*).
  - However, the hard upper torso (HUT) and scye bearings generally changes the upper-body poses.
    - For example, the scye bearings often results in subjects protracting their shoulders forward to a much greater extent even in a neutral pose.
- Thus a future study should represent the "*passive*" poses that suit geometry forces the body into.

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