Development of Human-Spacesuit Interaction Models

ICES Paper 2019-371

Sarah Jarvis – MEI Technologies, Houston, TX

Linh Vu – MEI Technologies, Houston, TX

Elizabeth Benson – MEI Technologies, Houston, TX

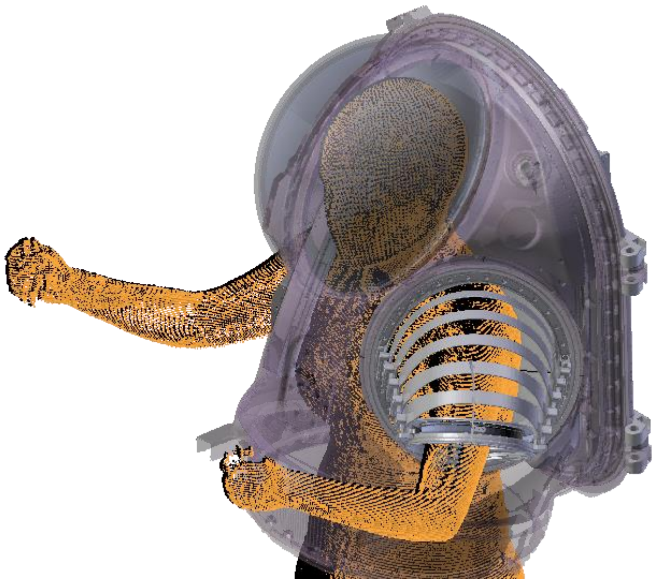
Sudhakar Rajulu – NASA JSC, Houston, TX

International Conference on Environmental Systems,
Boston, MA 2019

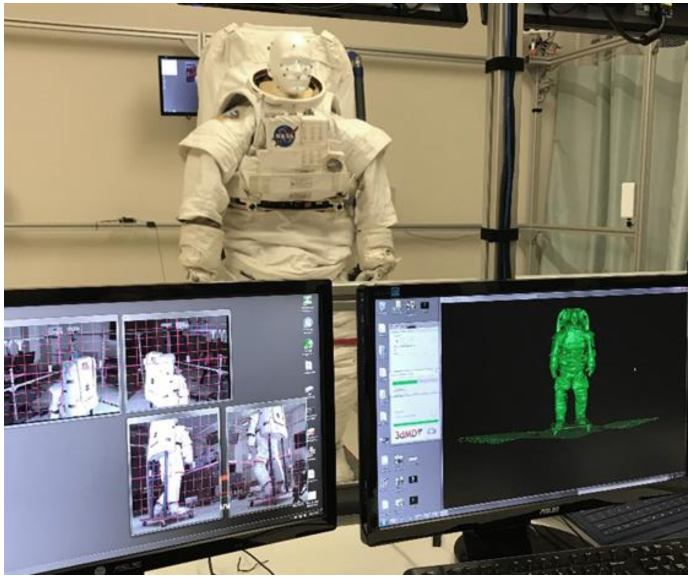
Background

The Anthropometry and Biomechanics Facility (ABF) specializes in assessments of human-suit interaction

- Suit fit and accommodation modeling, including suit and human 3D scans
- Suited performance assessments using motion capture and kinematic analyses
- Ergonomic analyses of humans working in a spacesuit



Full body reach assessment



Suited scanning

Introduction

Spacesuit fit and mobility are essential considerations of spacesuit design, however…

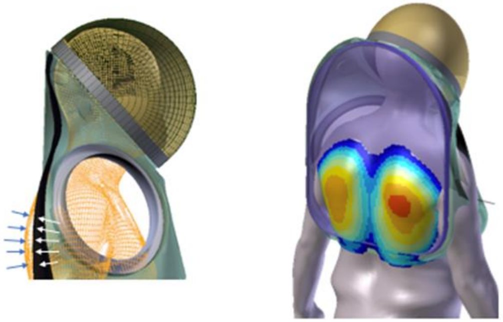
- Human vs spacesuit mobility is difficult to assess
  - Suited data is logistically challenging and expensive to collect
  - Motion capture only measures the outside of the suit
  - Internal measurement sensors need to be durable to withstand the suited environment
- Every human is different
  - A person's body size cannot be represented by a single variable term (i.e., percentile)
  - 90^{th} percentile in stature doesn't mean a person will be 90^{th} percentile in other dimensions, such as body weight or chest circumference

Human-Suit Modeling

Models can help with understanding how a user is moving inside a suit

- Overlap and suit contact areas
  - Suit component-to-component interferences
  - Human-suit interferences
  - Suit Fit assessments
- Mobility performance
  - Reach envelope assessments
  - Mobility patterns
  - General motion characterization
- Suited task visualizations
  - Test planning
  - Data analysis

EMU lower torso modeling



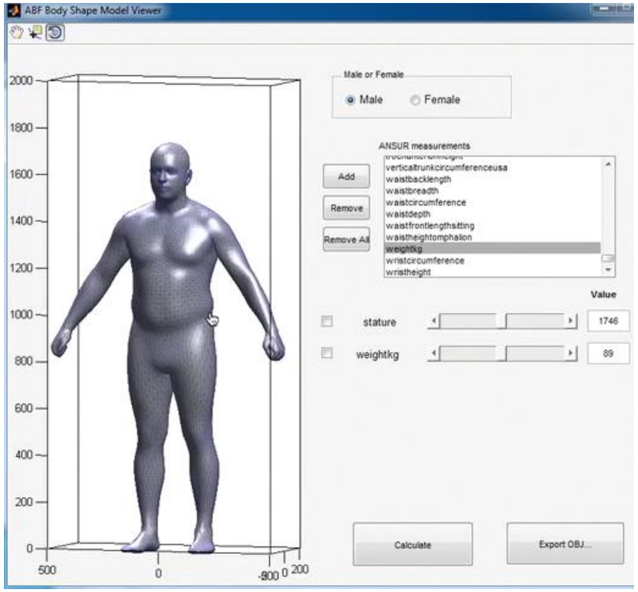
Suit fit modeling

Human Modeling at ABF

Early iterations
- Primitive rigid shapes
- Based on linear anthropometry measures
- Lacked deformation capability

Current version
- Parametric 3D models derived from a database of volumetric scans
- Scan geometry can be statistically generated to fit critical dimensions
- Enables analysis on a wide variety of anthropometry

Linear measurement-based primitive shape models of the pelvis and thighs

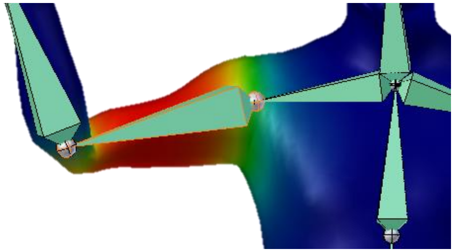


Statistically generated human models

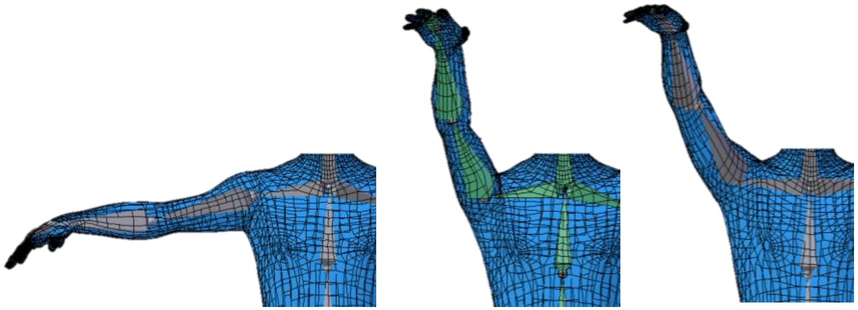
Reposing Human Models

Techniques of Body Reposing:

1. Skeletal-based rigging:
   - Each skeletal link influences the geometry of the nearby skin surfaces as a function of joint angle
   - Skin point clouds are displaced based on the linear weighting and distance from the joint
   - Defined ROM constraints limit joint motion
2. Statistical parametric modeling:
   - A resizable and reposable model (upper body) was developed using subjects scanned in multiple postures
   - Approximates realistic tissue deformation in different postures



Vertices in red are entirely affected by the movement of the upper arm. As the color fades to blue, the vertices are decreasingly affected.



Shoulder deformation comparisons: neutral (left), vertex-weighting (middle), statistical parametric modeling (right)

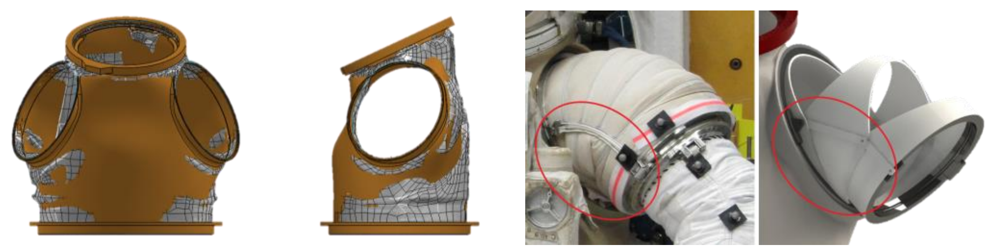
Suit Models at ABF

EMU & MKIII

- Hard goods
  - Reconstructed in CAD based on 3D scans and manual measurements
  - EMU shoulders are represented as two pivoting convolute linkages
- Soft goods
  - Arms & legs were built from 3D scans for the (EMU) and generic mesh objects for the MKIII

Z2/xEMU Series

- Hard goods
  - Directly imported CAD models
- Soft goods
  - Work in progress (using 3D scans)



EMU scan (grey mesh) overlaid on CAD (orange), and the actual EMU shoulder convolute (middle right) vs the CAD shoulder convolutes (far right)

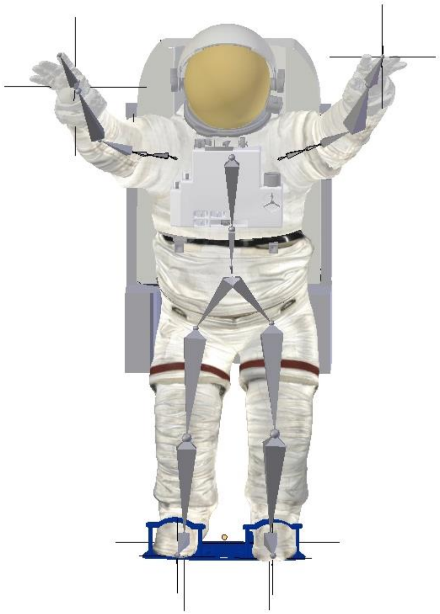
Suit Model Articulation

Skeletal Armature Embedding (similar to human)

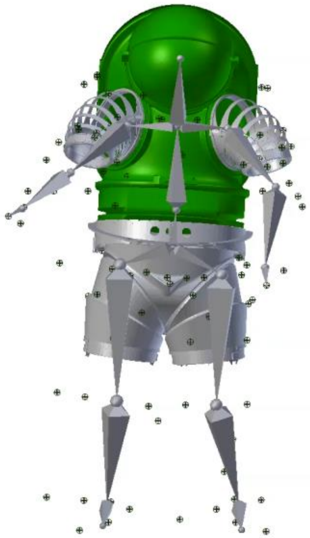
- Joint centers were aligned with bearing centers of rotation
- ROM constraints limit motion
- Hard/soft good integration
  - Hard goods use rigid body transformations
  - Soft goods are allowed to deform (currently by surface geometry weighting)

Reposing

- Forward Kinematics
  - The suit posture is adjusted by manipulating each bone of the skeletal armature
- Inverse Kinematics (IK)
  - The end effector (hand or foot) is constrained to track a specified target, and ROM constraints are applied to limit impossible motions
- Imported Motion Capture
  - Bones are constrained to follow the marker positions imported from motion capture
  - Can be combined with IK tracking if marker data is limited



Object tracking

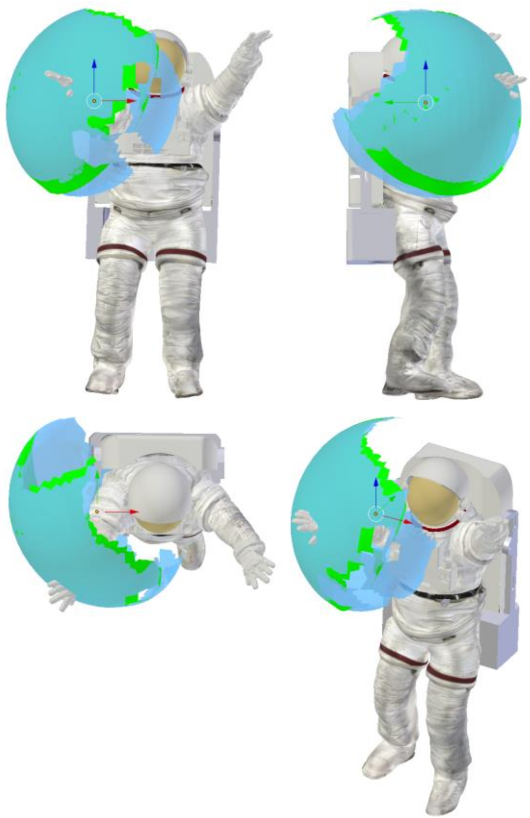


Motion capture tracking

Modeling Applications

Models can help with understanding the movement patterns of the body inside a suit

- Overlap and suit contact areas
  - Suit component-to-component interferences
  - Human-to-suit interferences
  - Suit Fit assessments
- Mobility performance
  - Reach envelope assessments
  - Mobility patterns
  - General motion characterization
- Suited task visualizations
  - Test planning
  - Data analysis



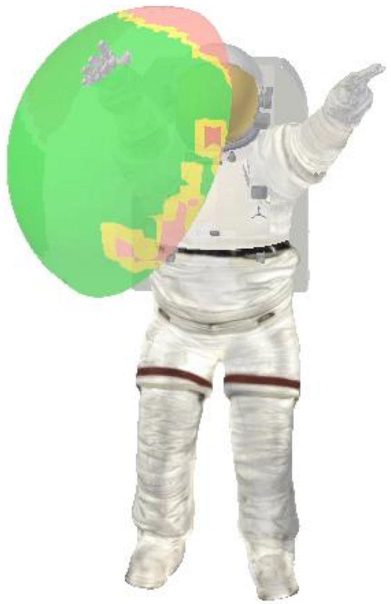
Using Models to Assess Motion

Single degree of freedom motion

- Unsuited: simple (i.e. flexion/extension)
- Suited: challenging or ambiguous
- Covers only a limited plane of motion

Human-in-the-Suit Reach envelope (RE)

- More comprehensively describes reach capability
- Represents the reachable area around the body through the selected joint manipulation
- Human-suit interferences



EMU mechanical reach envelope with intra-suit interferences highlighted

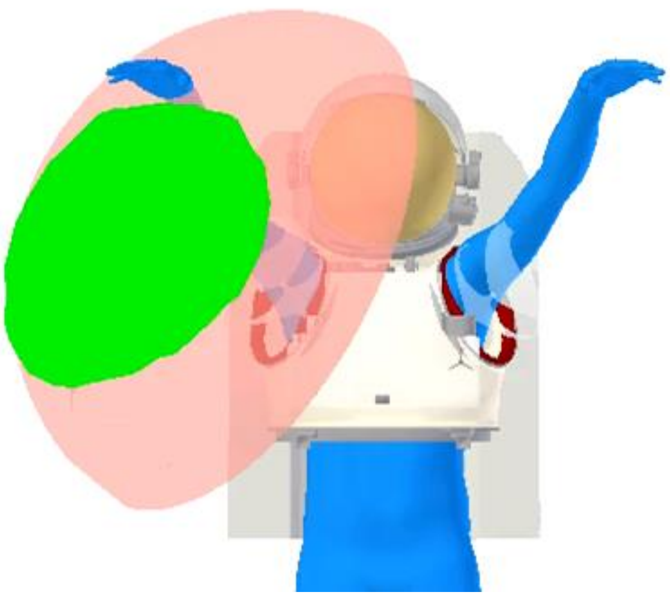
Applications: Reach Analysis

Mechanical reach envelope

- Represents suit mobility (without wearer)
- Specific to that suit size/configuration

Combining RE with interference detection

- Intra-suit interferences (helmet, DCM, PLSS)
- Predictions of human-suit interference points
- Impacts of anthropometry on ROM
- Suit fit assessments
- Case example:
  - Two parametric human models were created with similar stature, but different measures in other critical dimensions
  - Interference detection was run between the human and the suit shoulder components
  - The reachable area without human-suit interference decreased in the larger subject
  - The model illustrates that anthropometry changes that impact fit may affect ROM



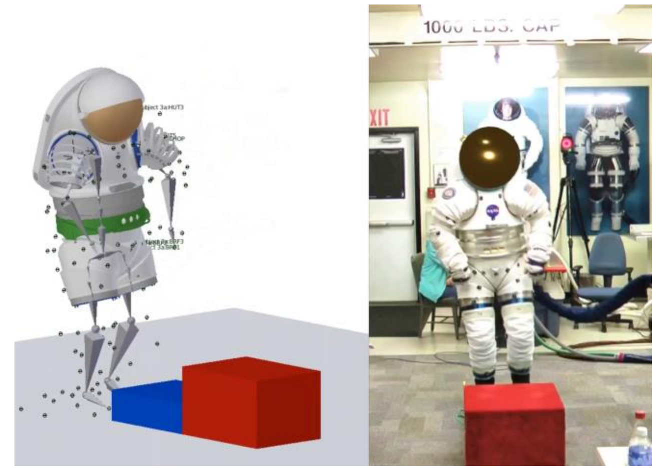
Anthropometry impacts on body-suit interference

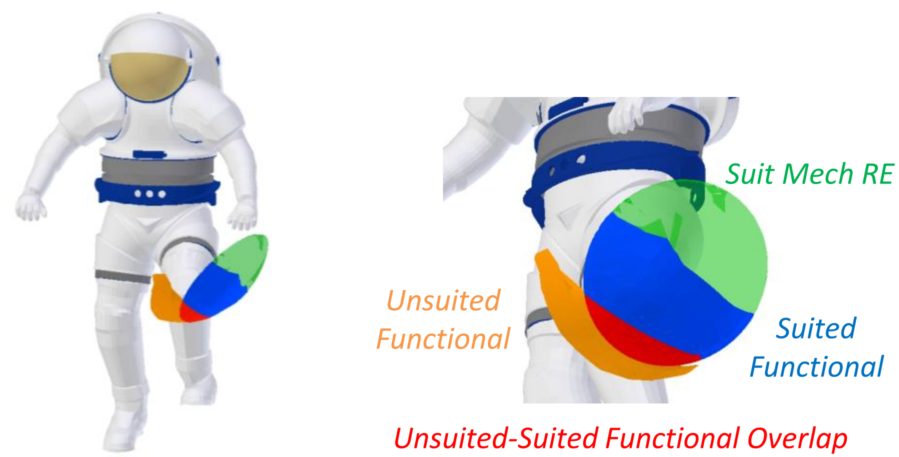
Applications: Mobility Analysis

Integrating motion capture

- Compare suit design capabilities vs actual usage patterns
- Compare unsuited functional motion with suited functional motion
- Identify overall mobility patterns
- Compare across different suit architectures
- Case example:
    - Motion capture data from suited and unsuited functional tasks were overlaid or the MKIII mechanical RE
    - The resulting overlap (red) shows how different the mobility patterns are for the same tasks between the MKIII and unsuited conditions

MKIII Suited Motion Capture





MKIII Suited ROM usage

Limitations

Suit Models

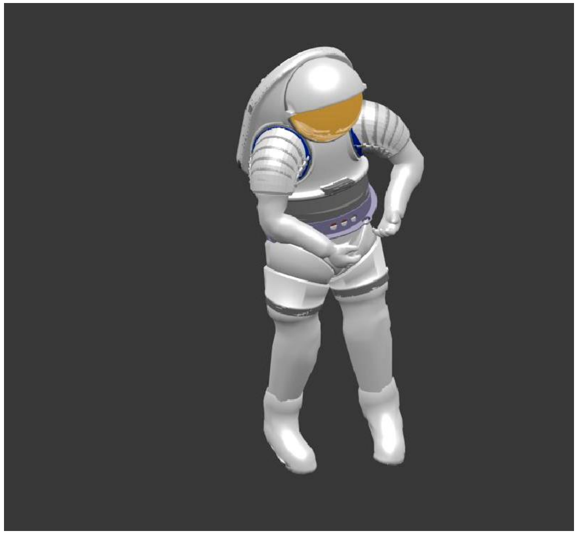
- Bearing ranges of motion over-estimate human capabilities because stiffness of surrounding softgoods are not accounted for
- Ranges of motion are affected by the arm/leg length

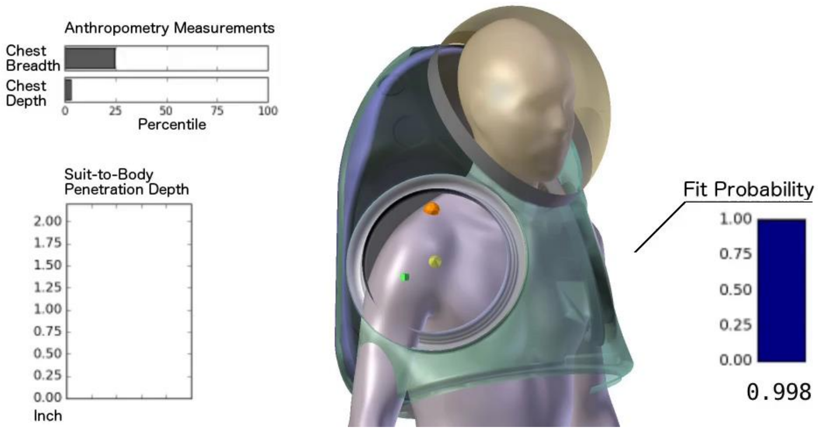
Human Models

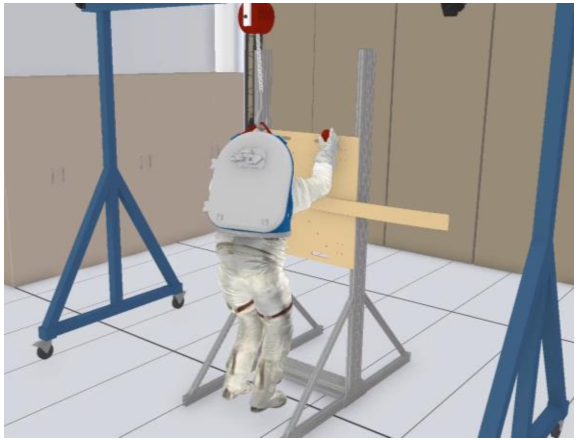
- Positioning in the suit is only an estimate
- Tissue tolerance to suit contact and geometric deformation have not been represented
- ROM should not be regarded as the only performance metric for suited mobility; suit-body clearance, discomfort, force exertions can substantially vary

Future Work

- Expanding case study simulations to include a wider range of anthropometry
- Improving motion capture integration tools
- Improving fidelity of softgoods deformation through parametric modeling
- Whole-body human-suit interaction models
- Work is in progress to support xEMU efforts:
  - Full body articulating xEMU suit model
  - Suit fit analysis for z2.5 HUT
  - Compression tolerance mapping across the torso
  - Incorporate outcomes from current suit sizing & fit studies







Acknowledgements

The authors would like to thank for their contributions to this paper:

NASA EVA Project Office

NASA Advanced Suit Lab

Scott Cupples (JSC-EVA Office)

Han Kim (JSC-ABF)

Gabriel Roper (JSC-ABF)

Seth Abramczyk (JSC-ABF)

Matthew Cowley (JSC-ABF)

Yaritza Hernandez (JSC-ABF)

Lauren Elizondo (JSC-ABF)

Questions?

Sudhakar Rajulu, Ph.D.
Anthropometry and Biomechanics Facility
NASA Johnson Space Center
Office: 281-483-3725
Email: Sudhakar.Rajulu-1@nasa.gov

Sarah Jarvis
MEI Technologies Inc.
Anthropometry and Biomechanics Facility
Email: sarah.jarvis@nasa.gov