CREW POPULATION CHARACTERISTICS – PERSPECTIVES FOR SPACESUIT FIT

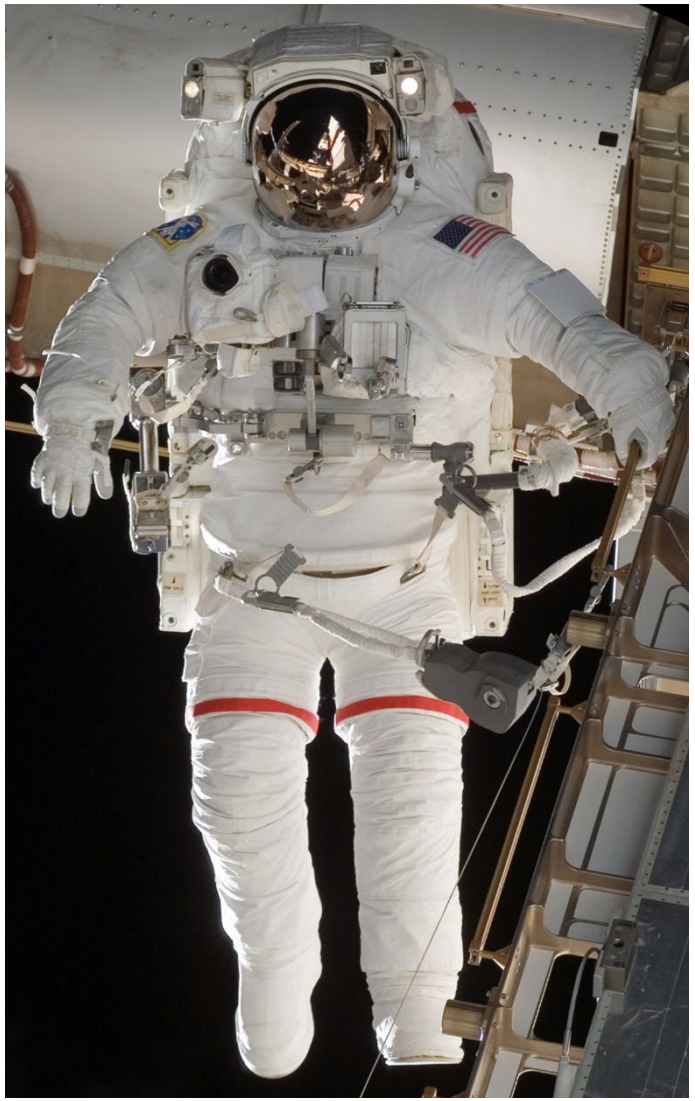




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Introduction Background & Aim

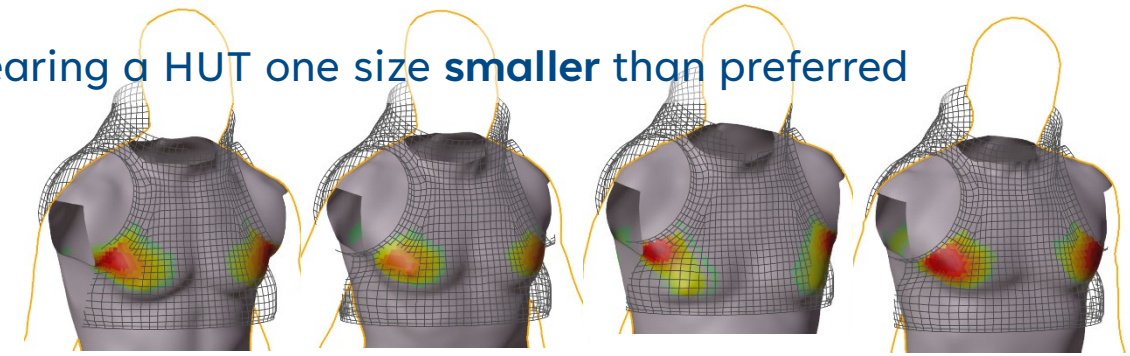
- NASA has operated Shuttle Extravehicular Mobility Unit (EMU) for over 40 years
  - The Hard Upper Torso (HUT) is a critical component for crew protection and suit functionalities
  - The EMU HUT accommodates 40th percentile female to 95th percentile male
  - Inadequate HUT fit has impacts to EVA objectives and crew health
- There is a demonstrated need for more robust sizing schema
- This study aims to develop a framework for designing custom-fit HUTs for future spacesuit development
  - A custom fit model was developed using historical NASA spacesuit-operations data
  - The framework was projected onto the crew population to identify key anthropometric characteristics from the perspective of spacesuit fit



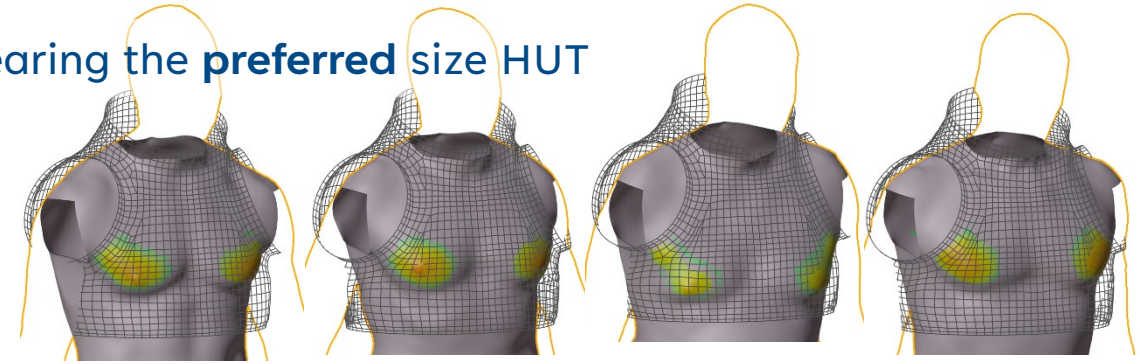
Introduction Premise & Aim

- When a person wears their preferred HUT size, the HUT-to-body contact shows a distinct pattern compared to wearing one size larger or smaller
- Hypothesis: Selecting an optimal HUT size is driven by achieving optimal HUT-to-body contact

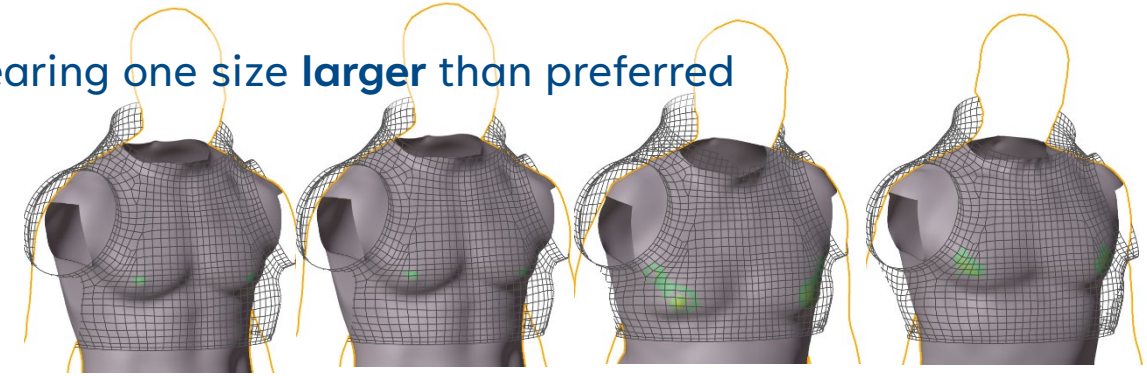
Wearing a HUT one size **smaller** than preferred



Wearing the **preferred** size HUT



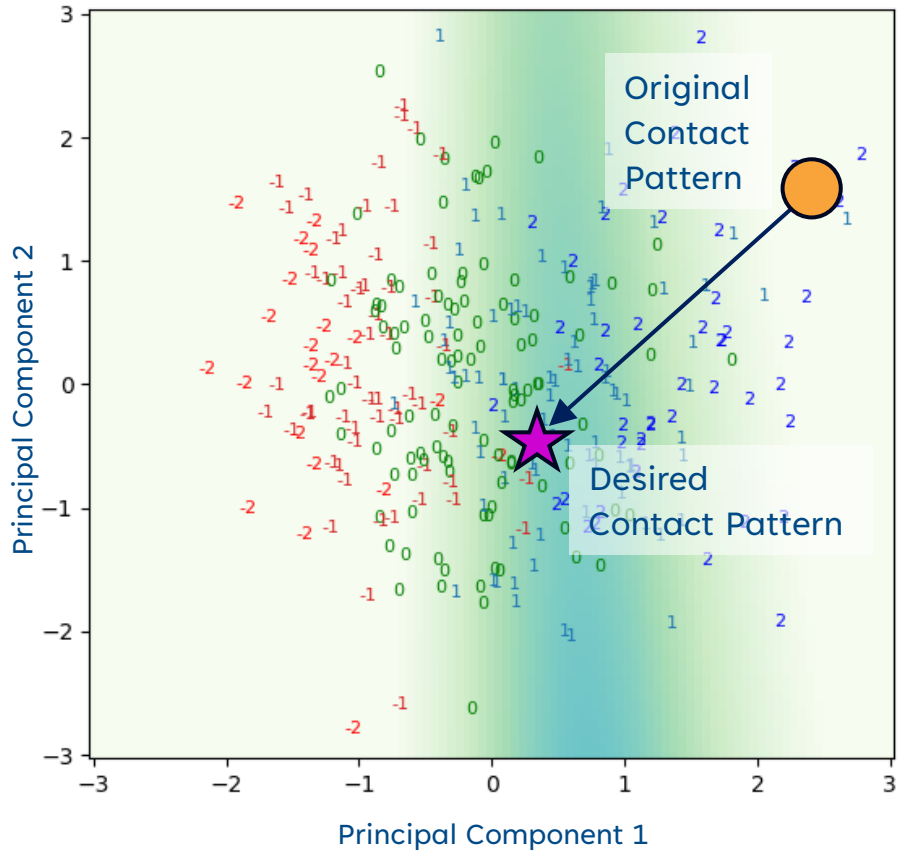
Wearing one size **larger** than preferred



Methods

Underlying Data

- HUT size preferences were obtained from historical Shuttle EMU fit-check data (N = 105, Medium 44%, Large 35%, XL 21%)
- Body scan was overlaid with shuttle EMU internal surface geometry; Suit-to-body contact patterns were computed and reduced using partial least squares regression based on the HUT size delta
  - EMU internal surface geometry was obtained via scanning; for HUTs that were not developed (such as Small size), geometry was extrapolated from existing HUTs
- This demonstrates that HUT size deltas can be categorized using contact pattern
  - This capability enables adjusting the HUT shape to achieve the desired level of fit

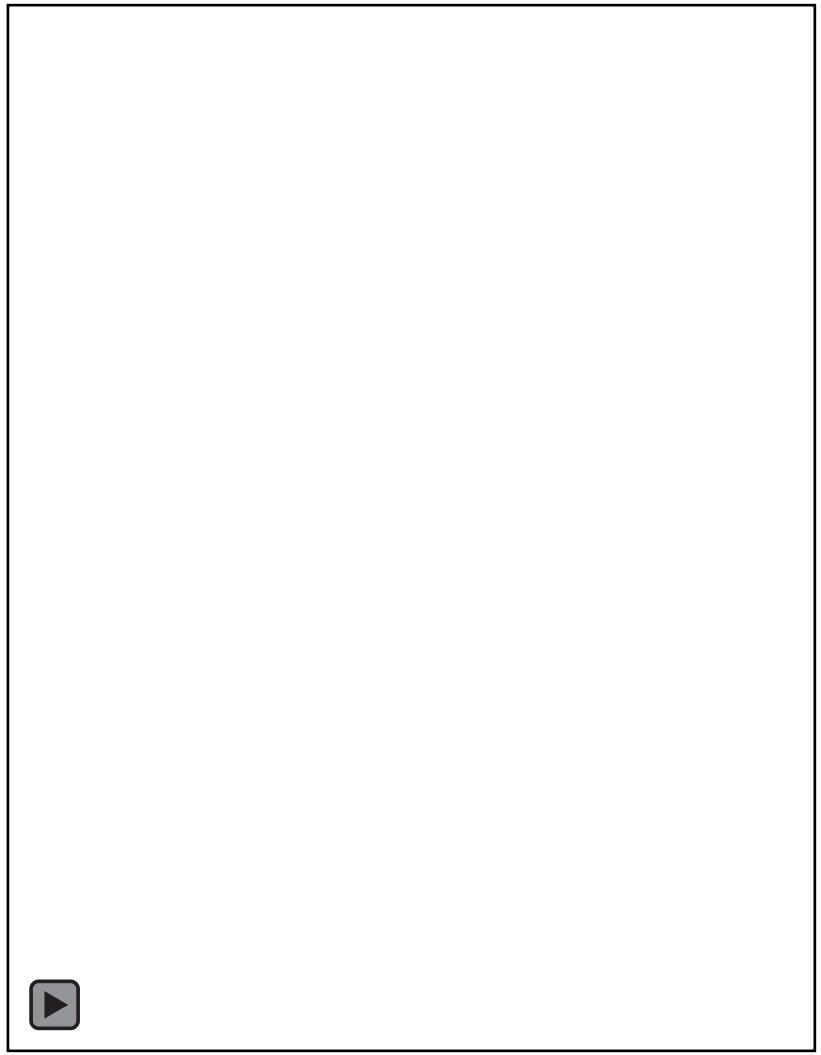


Reduced contact pattern data. Points are labeled with how many sizes the HUT is from nominal. For instance, “0” represents an optimal size HUT, and “-2” represents a HUT two sizes smaller than optimal. Distinct clusters appear corresponding to each HUT size offset.

Methods

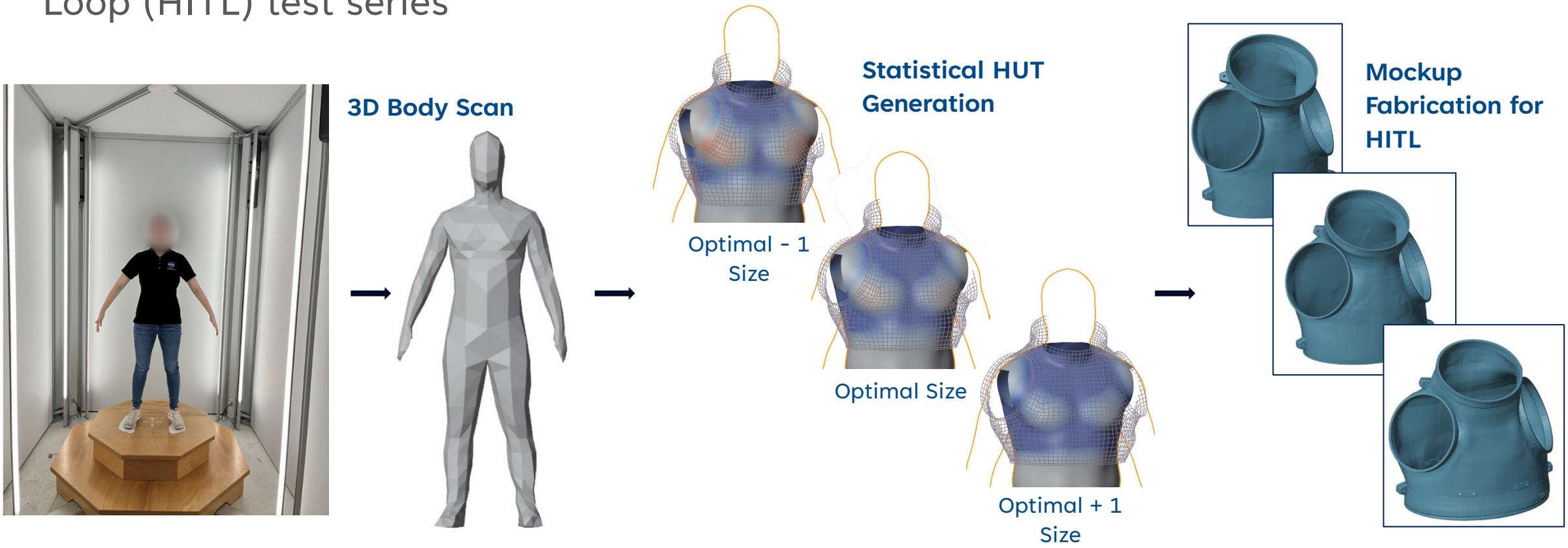
Statistical Models

- Contact patterns are a function of a person's body shape and suit geometry
- Therefore, a person's "optimal" HUT geometry can be generated by adjusting the suit shape to create the "optimal" HUT-to-body contact pattern
- An optimization model was built to parametrically adjust suit shape to achieve a contact pattern associated with a targeted fit and size condition for a given person



Model Validation Human in the Loop Testing

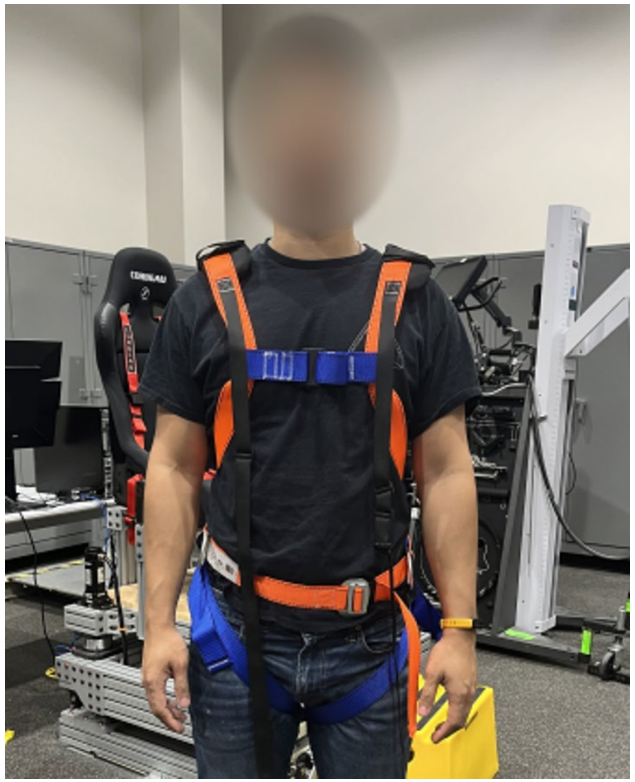
- Subject body scan data are used to generate the contact pattern associated with wearing the predicted “Optimal”, “Optimal + 1”, and “Optimal – 1” sized HUTs
- Each subject evaluates all three of their customized HUTs during a Human-In-The-Loop (HITL) test series



Model Validation HITL Hardware

- HUT is 3D printed based on generated internal geometry
  - Harness and internal hardware are used to hold HUT in a realistic position
  - Sizing inserts eliminate need to fully print each HUT







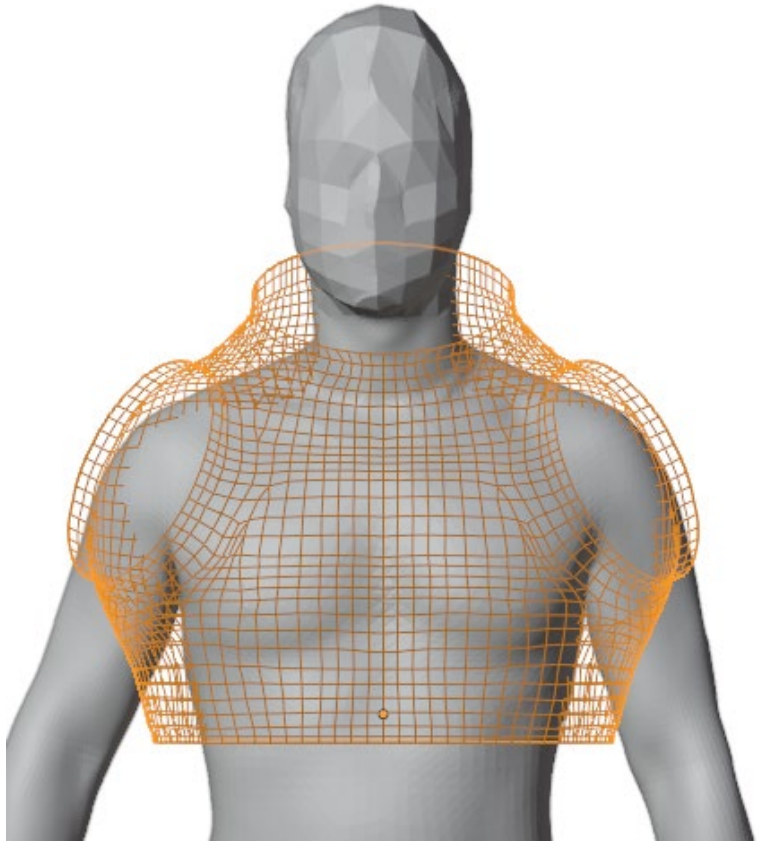
Model Validation Evaluation Metrics

Indexing	Reach	Functional Mobility	Subjective Experience
How the HUT sits on the body	Maximal and comfortable reach capacity	Ability to complete EVA-analogous tasks	Perceived body-to-HUT contact pattern Discomfort or pain

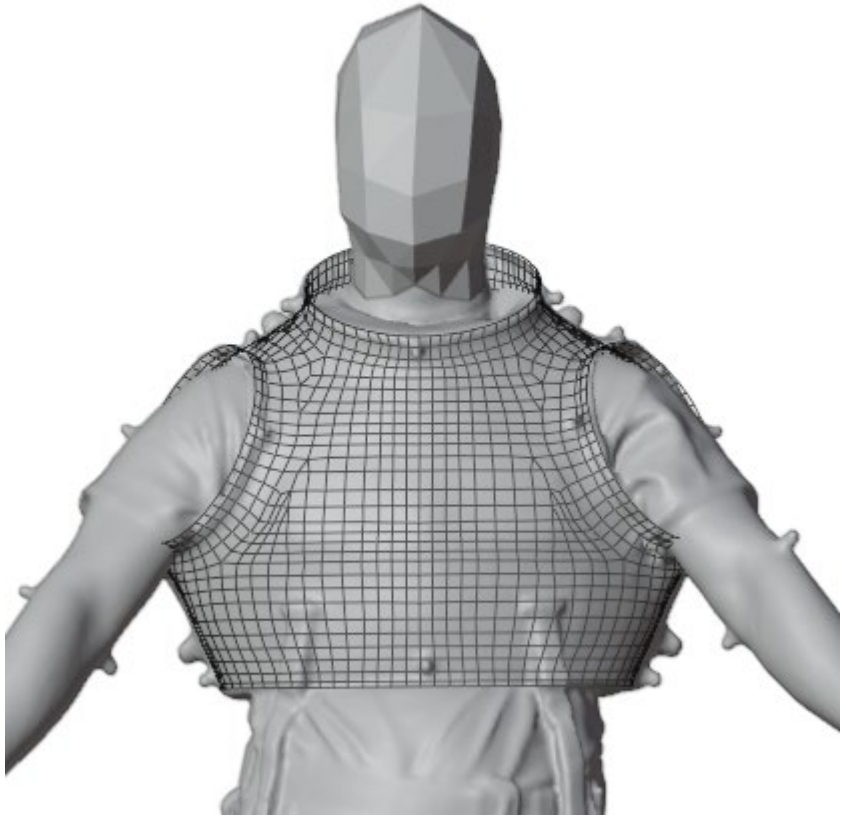
Model Validation Data Collection

Indexing	Reach	Functional Mobility	Subjective Experience
Laser scanning	Motion capture- Reach envelope and tasks	Motion capture- Mobility tasks	Subject feedback Questionnaires Subjective contact pattern mapping
			

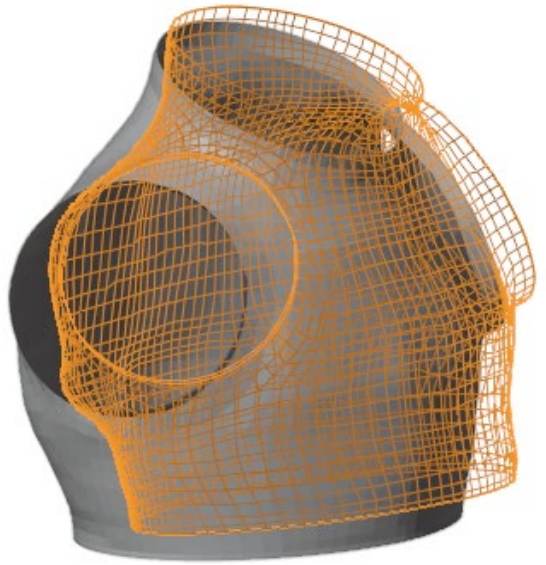
Data and Analysis Indexing



Model predicted indexing

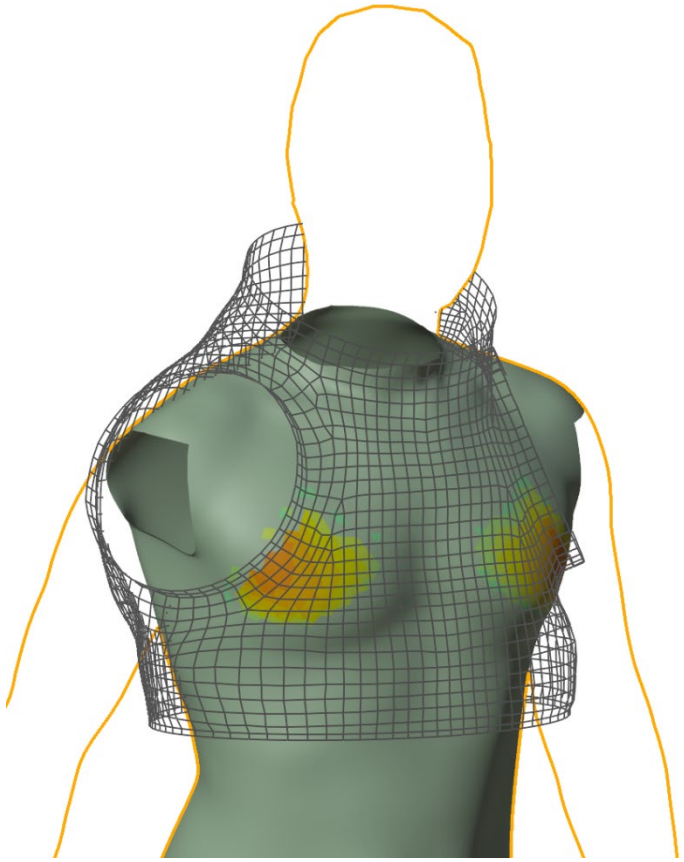


HUT geometry overlaid with scan of subject wearing HUT

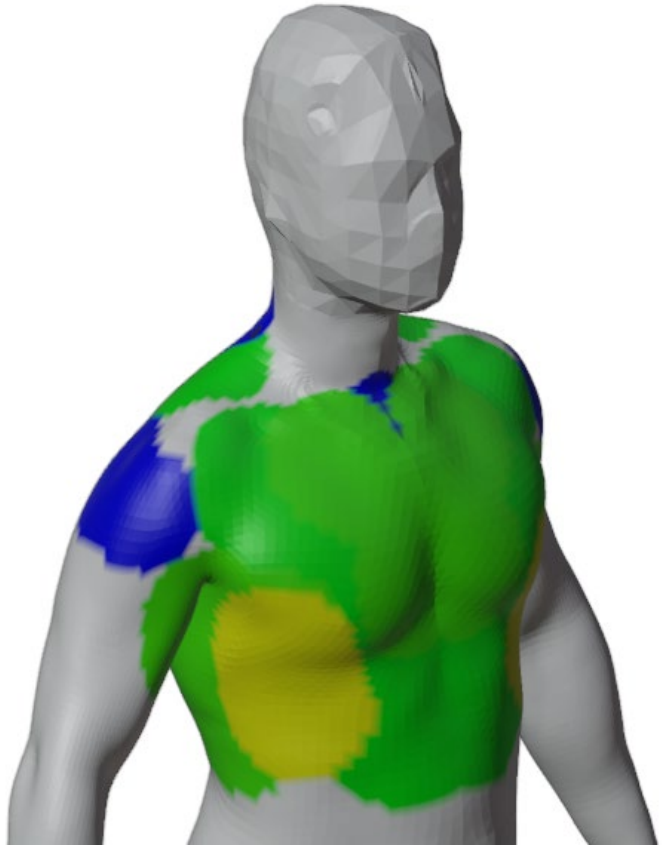


Comparison of model prediction vs. actual HUT placement

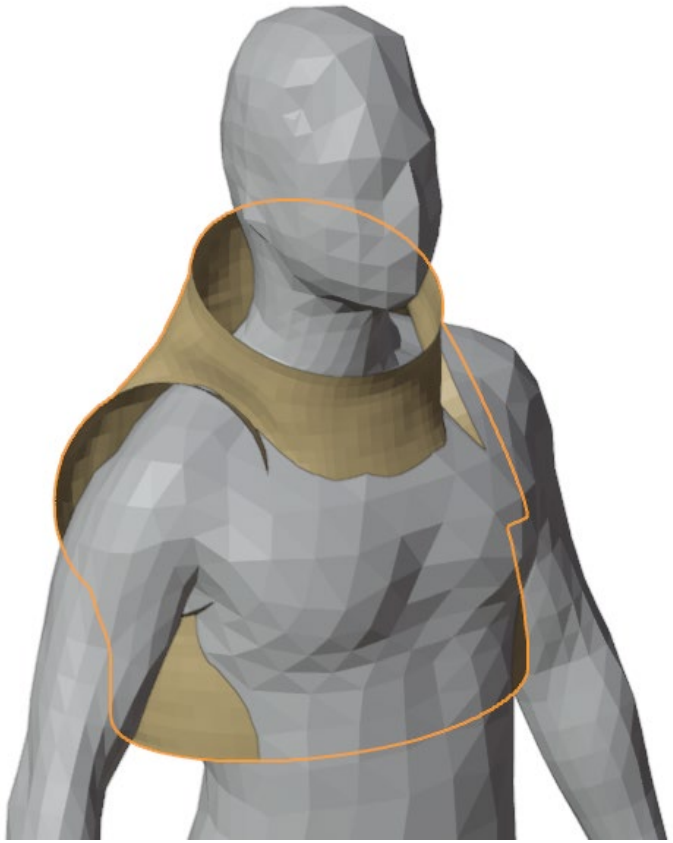
Data and Analysis Contact Patterns



Model predicted contact pattern



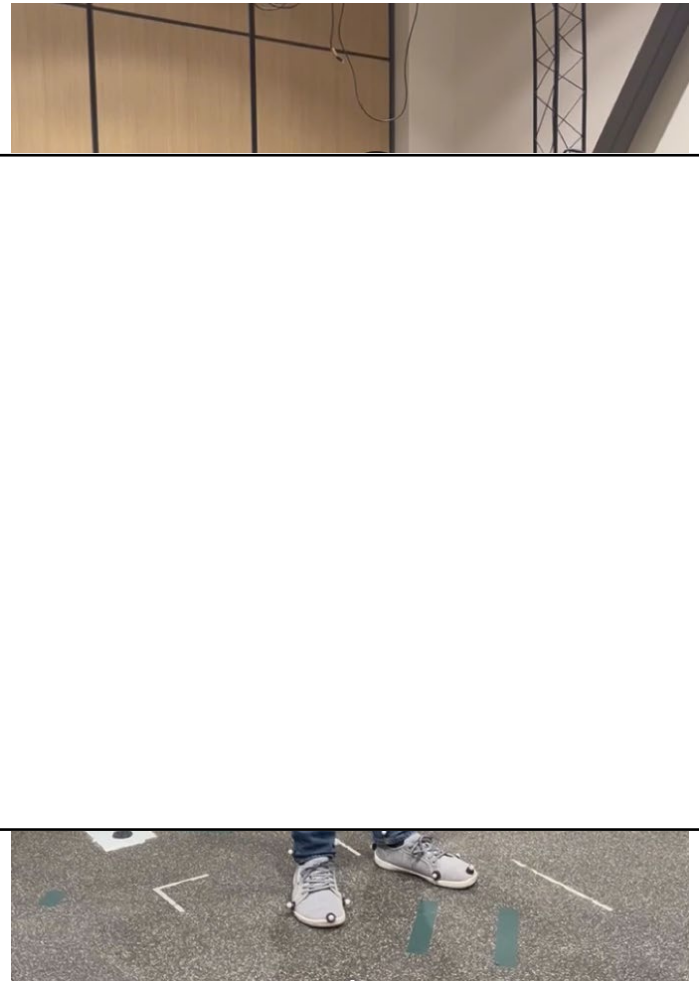
Subject perceived contact pattern



HUT geometry overlaid with body scan geometry

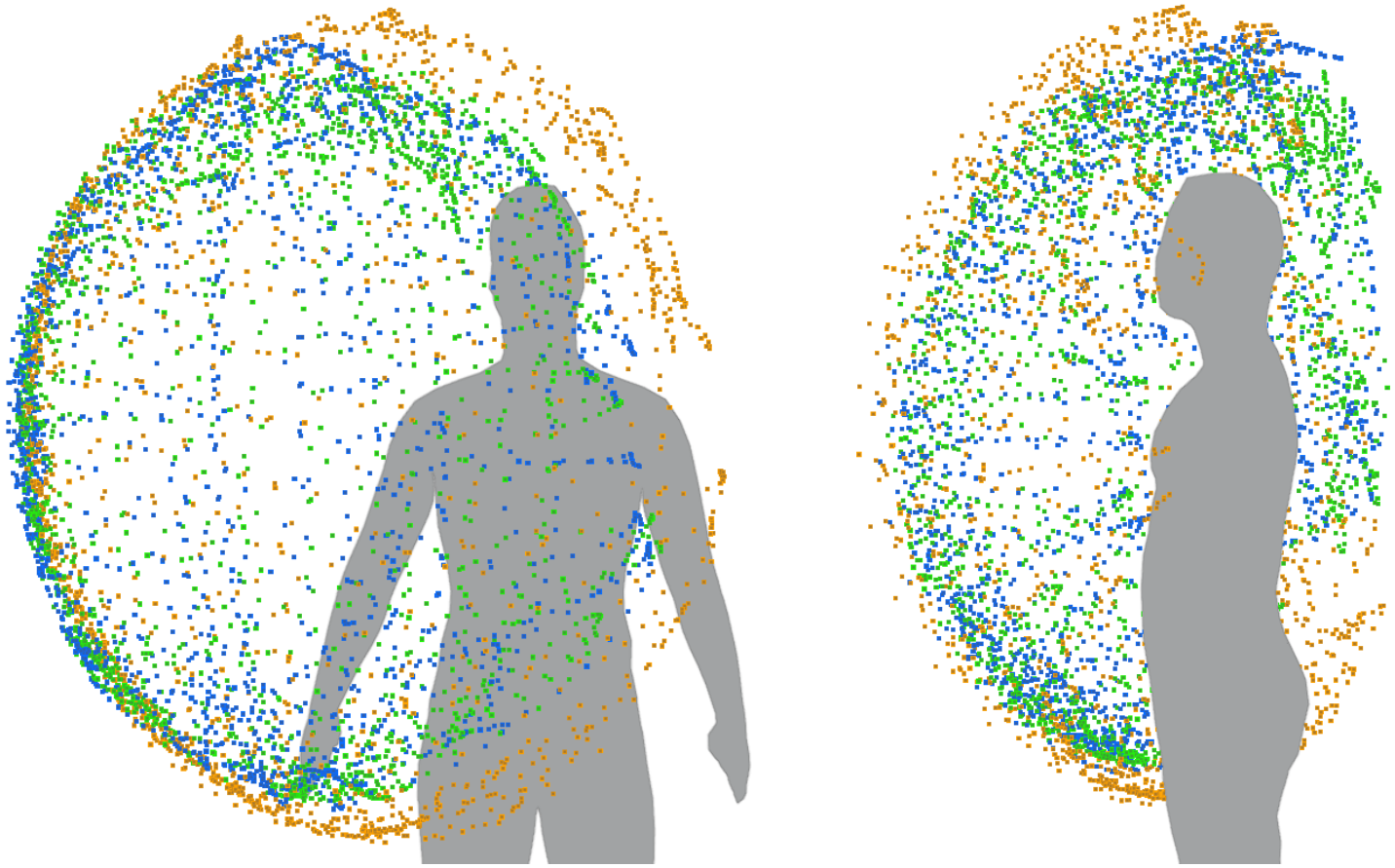
Data and Analysis Functional Mobility + Reach

- Subject completed various tasks to evaluate full-body mobility and reach
- Measured maximum arm reach envelopes (sweeping extreme-to-extreme locations) and “comfortable” range of motion



Data and Analysis Reach Envelopes

- "Optimal + 1" HUT size reduced reach envelope dimensions, potentially due to arm-to-scye bearing interference
- In the "Optimal - 1" size, the subject showed larger maximal range of motion and larger comfortable range of motion than with the other sizes.



Comparison of **"Optimal"**, **"Optimal + 1"**, and **"Optimal - 1"** size conditions

Data and Analysis Subjective Evaluation

- All three HUTs were considered comfortable as tested
  - “Optimal + 1” was comfortable, but the subject noted that it would not feel secure in a simulated reduced gravity condition (e.g., Neutral Buoyancy Laboratory)
  - “Optimal – 1” was tight but very comfortable; subject noted that there was no clearance to add other suit components such as the LCVG
- Scye ring was a consistent source of discomfort, particularly for larger HUT sizes
- Subjective contact pattern mapping was evaluated for static and dynamic postures. The difference between static and dynamic contact patterns was smaller for larger HUT sizes (e.g., there was no difference in mapped contact pattern for “Optimal + 1” static and dynamic conditions)

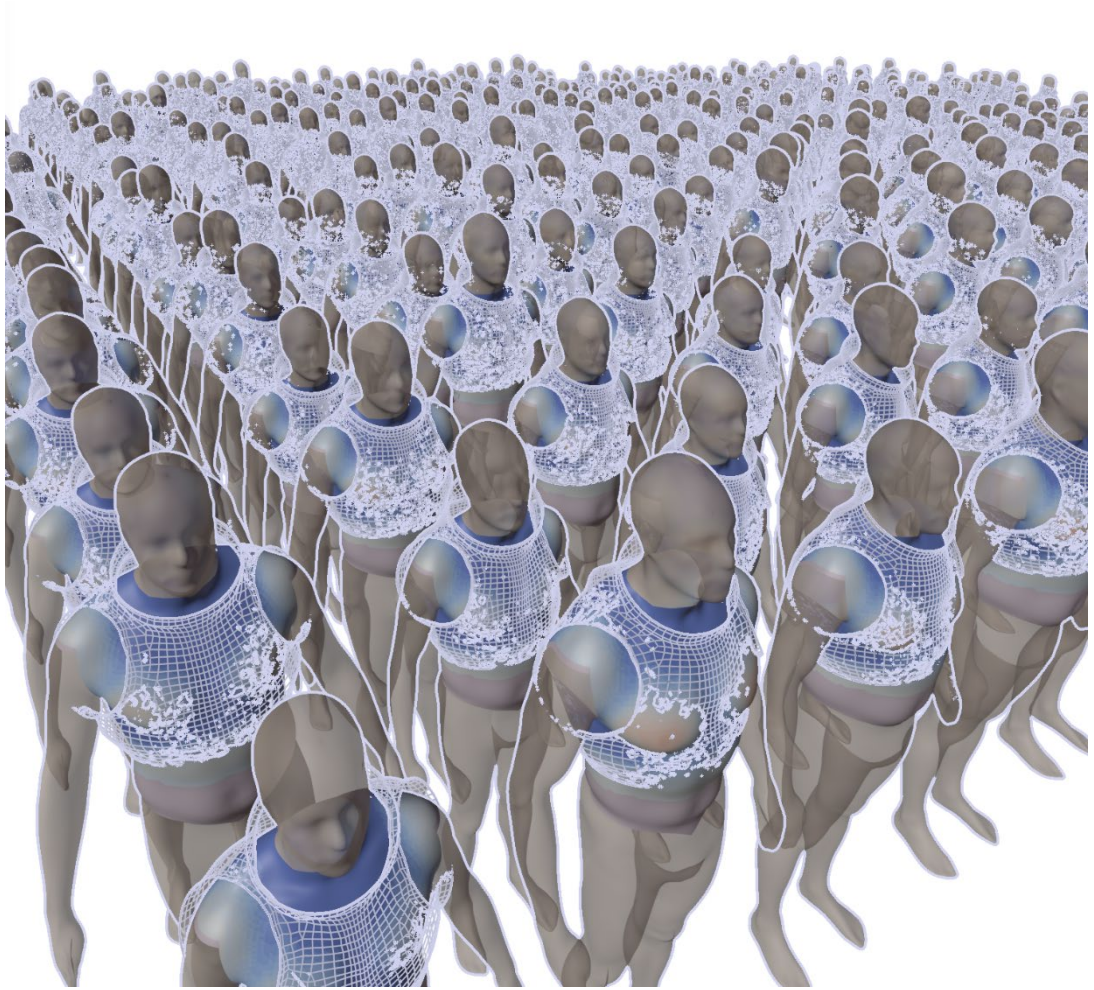
Conclusion Discussion

- This is the first study to apply quantifiable metrics from historical fit check data to future HUT architecture development
- Provides potential framework updates for Mars suits
  - Historically, it was not feasible to implement multiple sizes that could match critical interfaces (e.g., body seal closure diameter) due to cost and logistical challenges
  - Producing a discrete set of critical interface sizes could now be practical
- This work characterized the crew population not by standalone anthropometry, but by how the crew interacted with the spacesuit, yielding more meaningful insights for suit design and crew performance
- Limitations
  - Architecture specific (EMU)
  - No HUT fixtures (e.g., LCVG, drink bag, etc.) nor supplemental hardware included in the model and HITL tests

Conclusion

Future Work

- Collect and assess data for remaining HITL subjects
- Estimate optimal suit shape for individual cases across entire crew population
- Group the optimal suit shapes by clustering analysis; Identify the population segments that are associated with non-common suit shapes or dimensions



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This study is funded by NASA HRP Human Factors and Behavioral Performance Element Directed Study.