

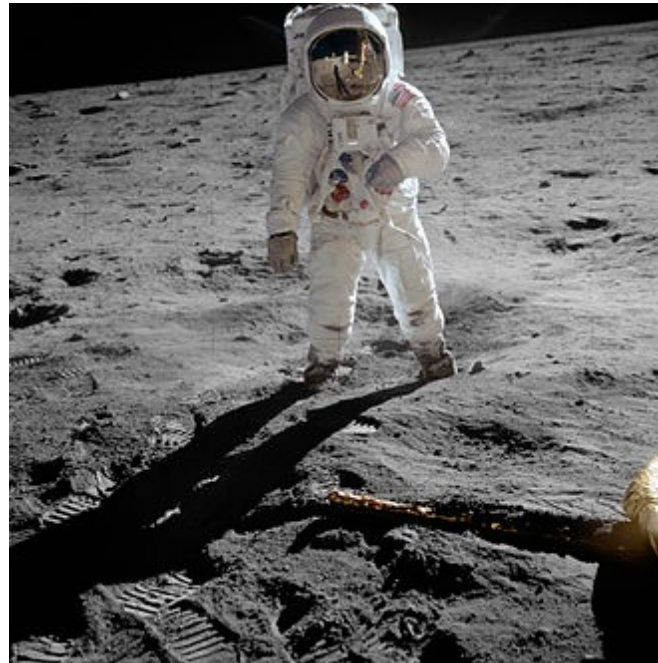
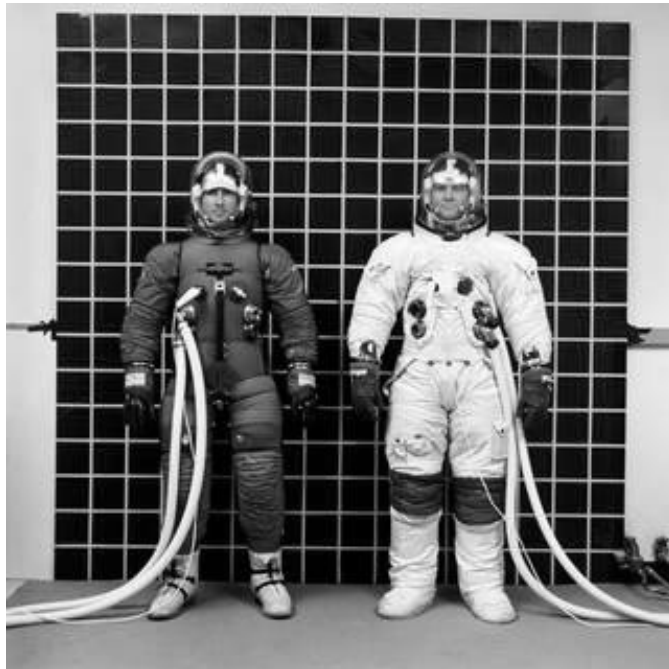


Virtual Fit Assessment: Validation using Historical Spacesuit Fit Data

K. Han Kim, Karen Young (Leidos)
Elizabeth Benson, Donald Campbell (KBR)
Richard Rhodes, Sudhakar Rajulu (NASA Johnson Space Center)

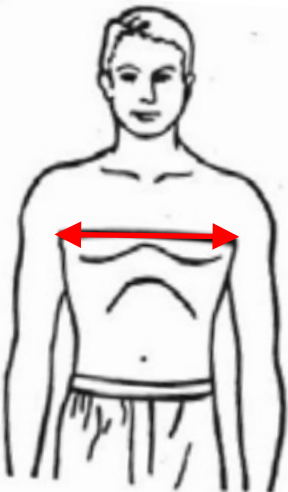
Background: Spacesuit Sizing & Fit

- Spacesuits were previously custom fitted during early space programs (Apollo, Gemini, & Mercury)
- Spacesuits were designed as a single mission garment and custom built to each astronaut's body
- With growing number of astronauts in various anthropometry, cost and logistics became an issue (Number of crewmembers flown: 24 in Apollo vs. 848 in Shuttle)



Spacesuit Fit (Cont'd)

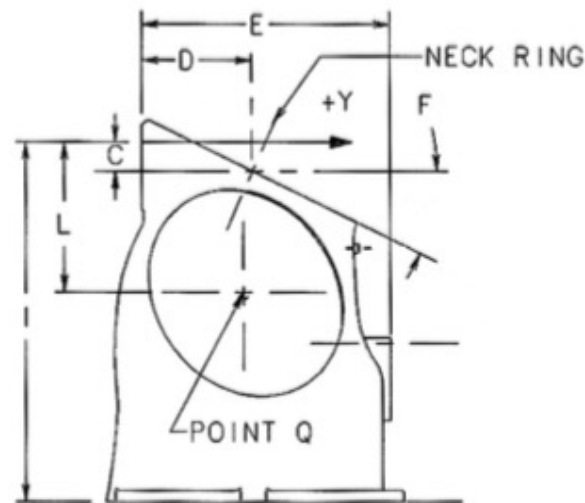
- During the subsequent programs, modular components and sizes were adopted: Shuttle Extravehicular Mobility Unit (EMU)
- EMU is currently in use through Shuttle and International Space Station Programs
- Design and sizing were intended to fit 5th percentile female to 95th percentile male
- Hard Upper Torso (HUT) available in Medium, Large & Extra-Large size
- Other components, such as arms, legs and gloves, were also available in multiple different sizes
- Design and fit based on linear dimensions of body segments



Chest Breadth

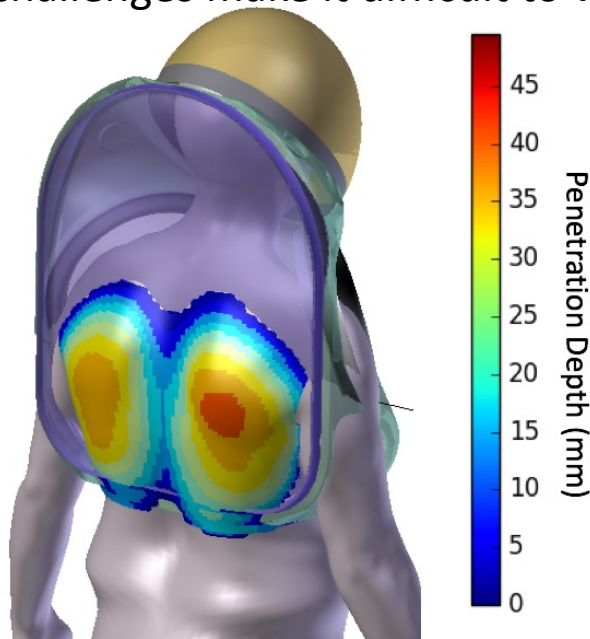


Chest Depth



Virtual Fit Assessments

- The next generation spacesuit xEMU has been developed on a virtual fit test method, in which 3D body scans were overlaid with the CAD drawing of a spacesuit hard upper torso (HUT) assembly
- This study focuses on HUT with its central role in wearer safety, the shape and size are critical for overall fit
- The suit-to-body contact and overlap volume were estimated from subjects' body scans, and used to predict the probability of fit using a machine learning classifier
- Virtual fit tests using 3D body scans have provided a cost-effective means to predictively assess spacesuit fit
- However, fit is a complex issue influenced by physical interferences, subjective preference, and other factors. These challenges make it difficult to validate virtual fit methods



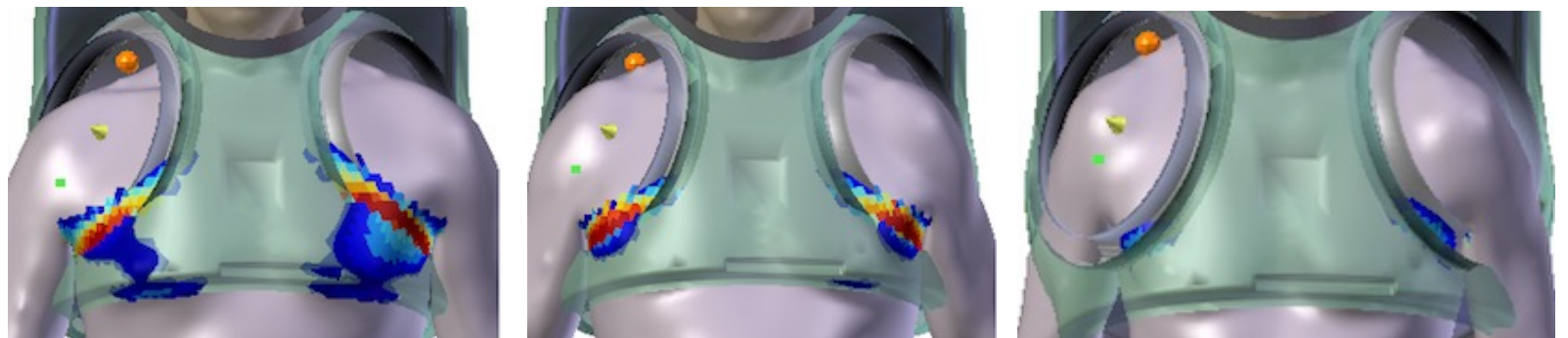
Suit-to-Body Contact & Overlap

Fit probability estimation by machine learning classifier

$Pr(\text{Fit})$: 0.001

0.255

0.754



Goals and Methods

- The goal of this study is to validate a virtual fit method using historically archived suit fit data for the legacy Extravehicular Mobility Unit (EMU)
- Suit fit was physically assessed and recorded from astronauts and test volunteers ($N=105$)
- Each participant was measured for spacesuit-critical dimensions, and 3D scanned for body shape. All scans were anonymized and deidentified
- The participants' selection for HUT size (Medium, Large, or Extra-Large) was retrieved from their pressurized suit fit check records for the 1-g EVA or neutral buoyancy training

Medium



Large



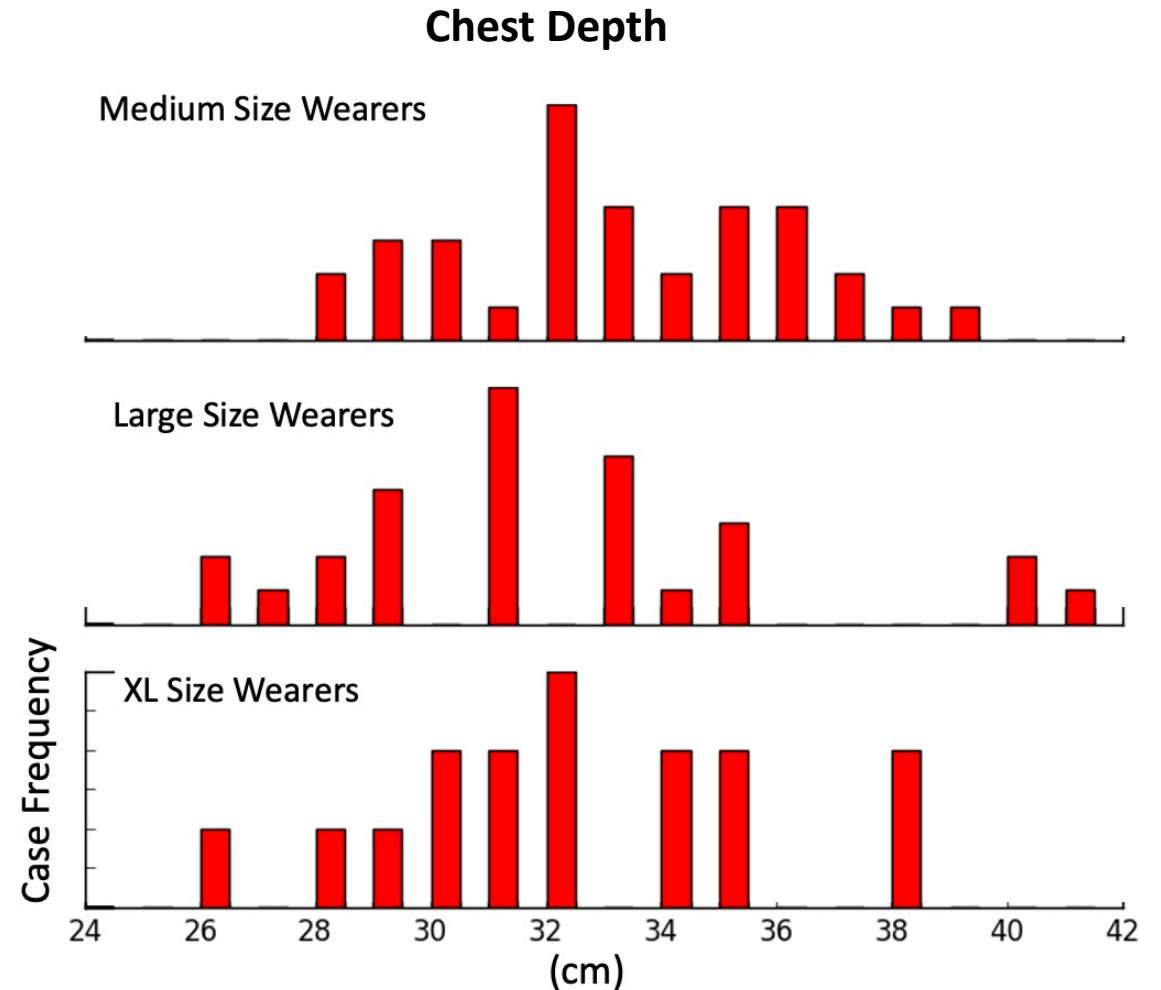
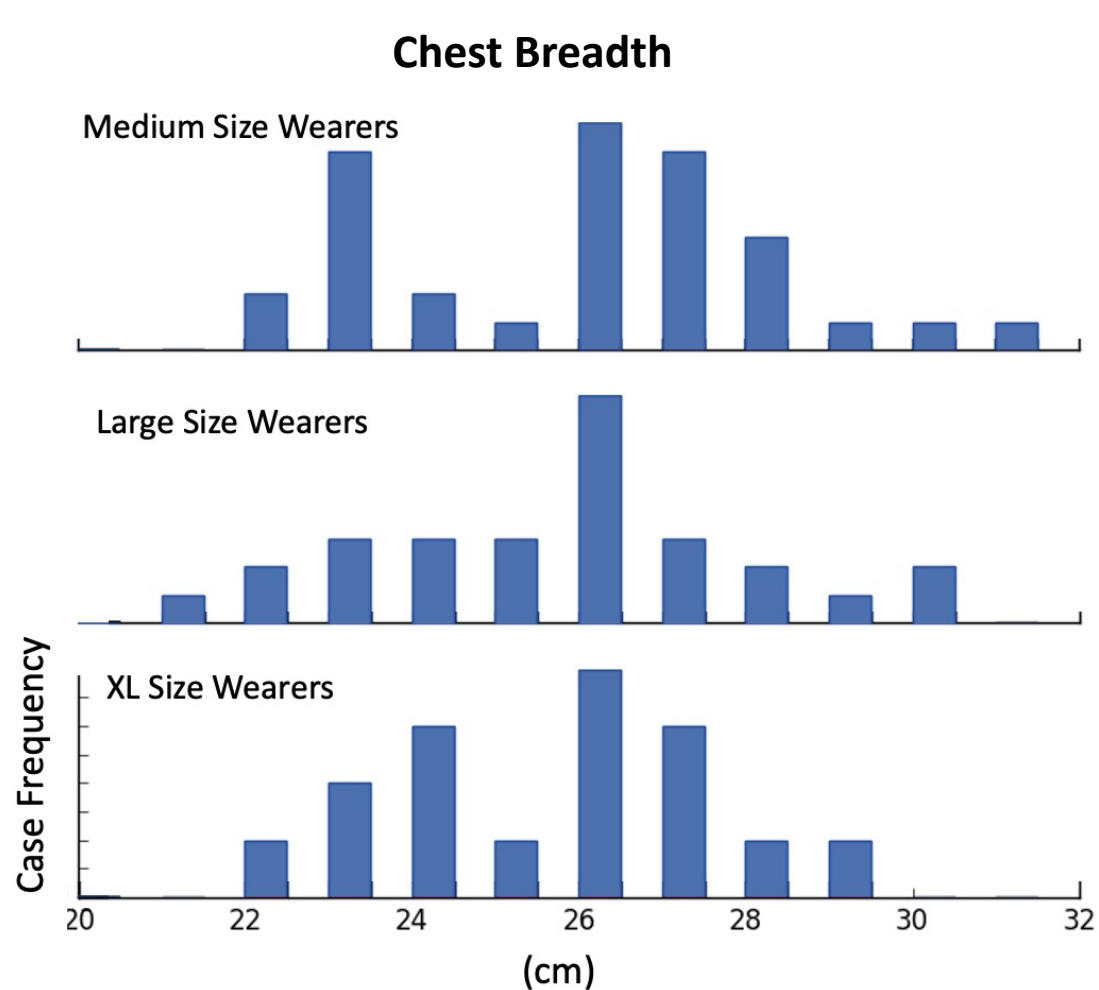
Extra Large



HUT inner surface scans, reverse engineered from 3D scans

Fit Estimation by Linear Anthropometry

- Overall, 46 subjects selected to wear Medium (44%), 37 subjects Large (35%) and 22 subjects XL (21%)
- The size selections were compared to individual anthropometry measurements (chest breadth and depth)
- Chest breadth or depth did not seem to be closely correlated with HUT size selections

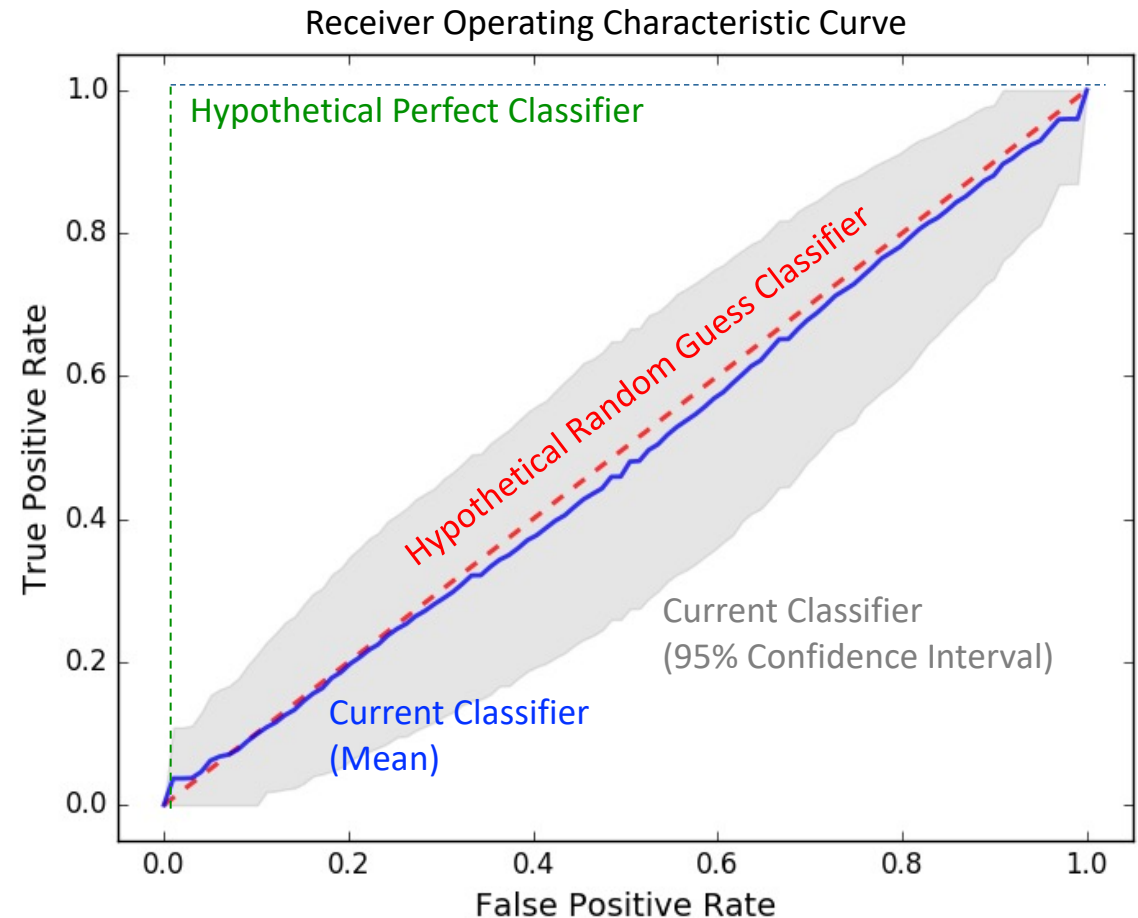


Fit Estimation by Linear Anthropometry (Cont'd)

- Individual size selection was predicted by chest breadth (CB) and depth (CD) using a multinomial logistic regression
- The HUT size with the highest probability constituted the most likely size selection for the person
- The prediction did not show a good discrimination performance (area under curve 0.48), nearly a random guess level

$$Prob(\text{Selection}=c) = \frac{e^{(\beta_{c,0} + \beta_{c,1}CB + \beta_{c,2}CD)}}{\sum_{k=1}^K e^{(\beta_{k,0} + \beta_{k,1}CB + \beta_{k,2}CD)}}$$

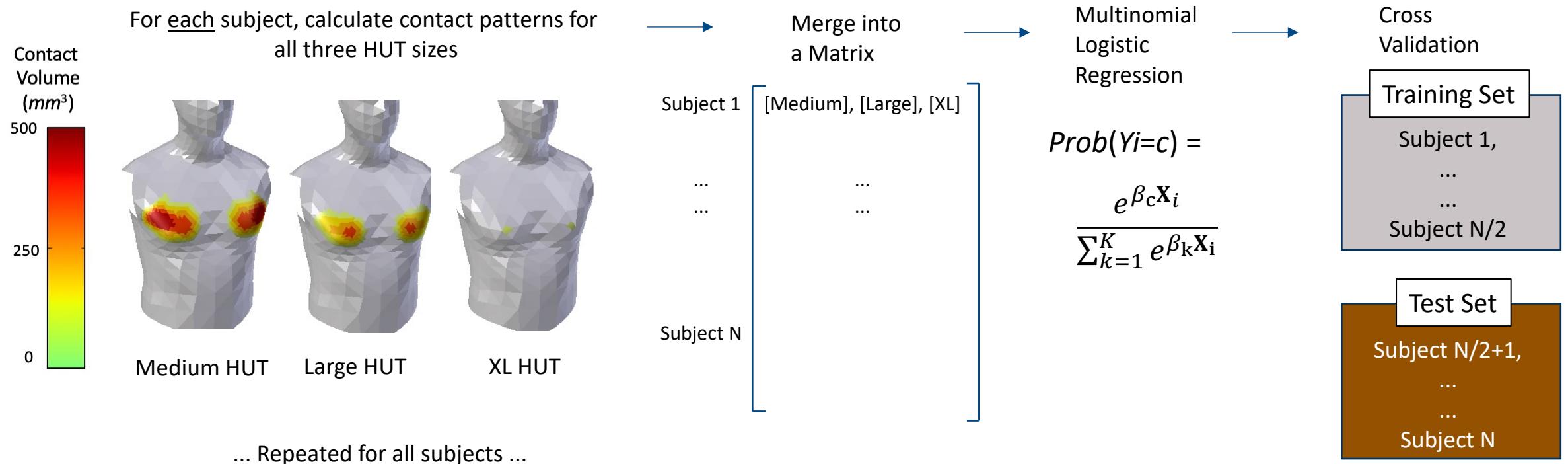
		Actual Size Selection			
Predicted Size		Medium	Large	XL	Total
	Medium	51.0%	27.5%	21.6%	100%
	Large	29.6%	51.9%	18.5%	100%
	XL	0.0%	0.0%	0.0%	0.0%



Area Under Curve: Mean 0.4839, 95% CI [0.3554,0.5887] "No discrimination capability"
Pseudo R^2 : mean -0.8583, 95% CI [-1.9018,-0.1143]

Fit Estimation by Suit-to-Body Contact (Methods)

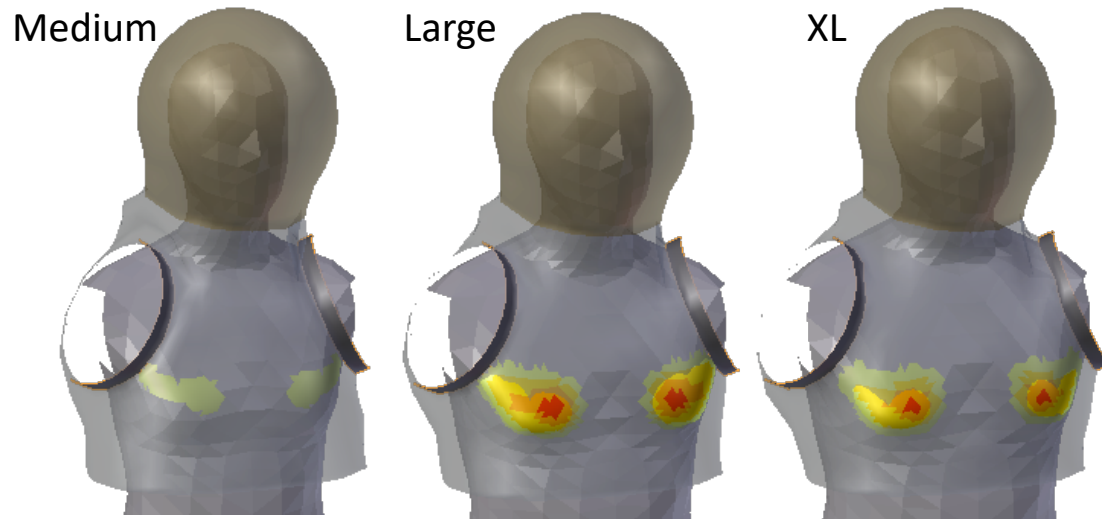
- With each subject's body scan, the CAD model of the different sizes of HUT were overlaid
- The suit-to-body contact pattern was calculated for each HUT size, and merged into a matrix
- The matrix was dimensionally reduced by principal component analysis, and used to build a logistic regression model to predict HUT size selection
- The available data set ($N=105$) was randomly divided into two groups: A training set was used to build a prediction model, and a test data set was used for cross-validation
- Cross-validation was repeated (5,000 times) and estimated the bootstrap distribution of model performance



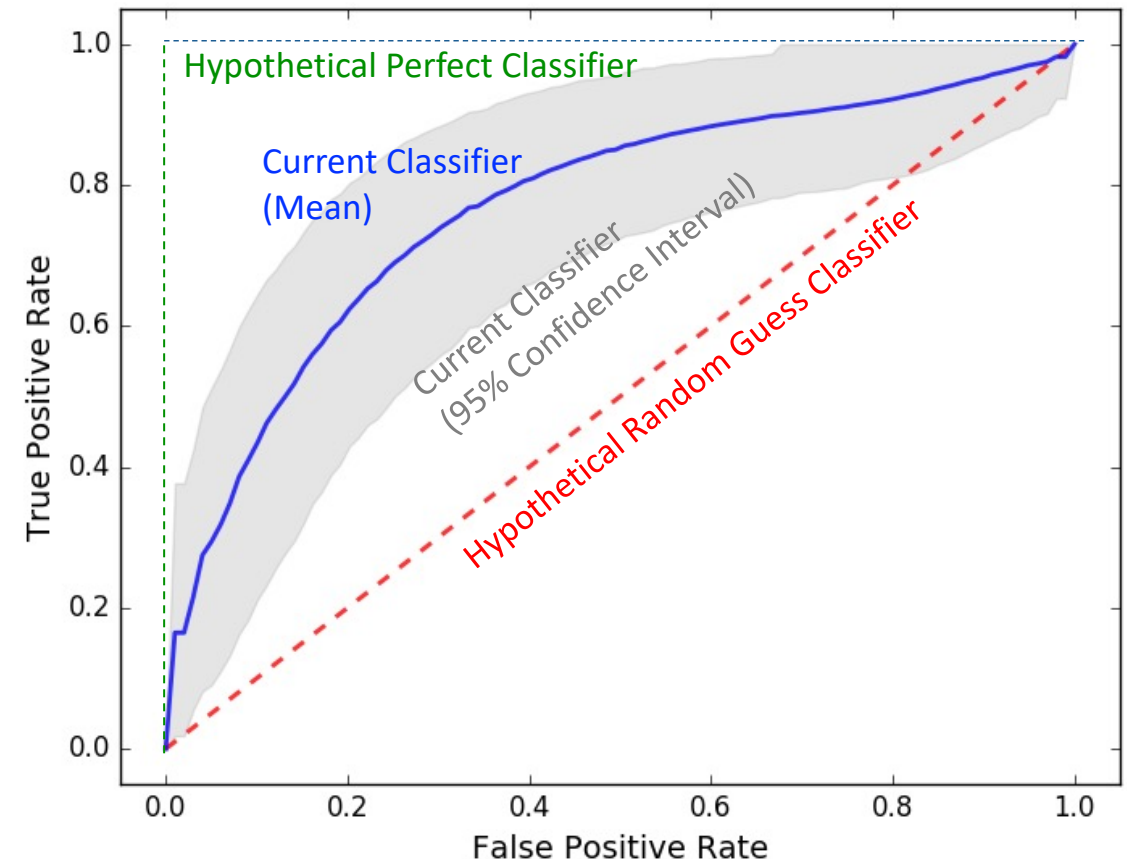
Fit Estimation by Suit-to-Body Contact (Results)

- Overall, the suit-to-body contact-based prediction showed a good accuracy performance, with the area under curve metric 0.7689 (“good” discrimination capability)
- The average contact pattern also varied with the HUT size selection, in general showing an increasing volume

Average suit-to-body contacts for different HUT sizes



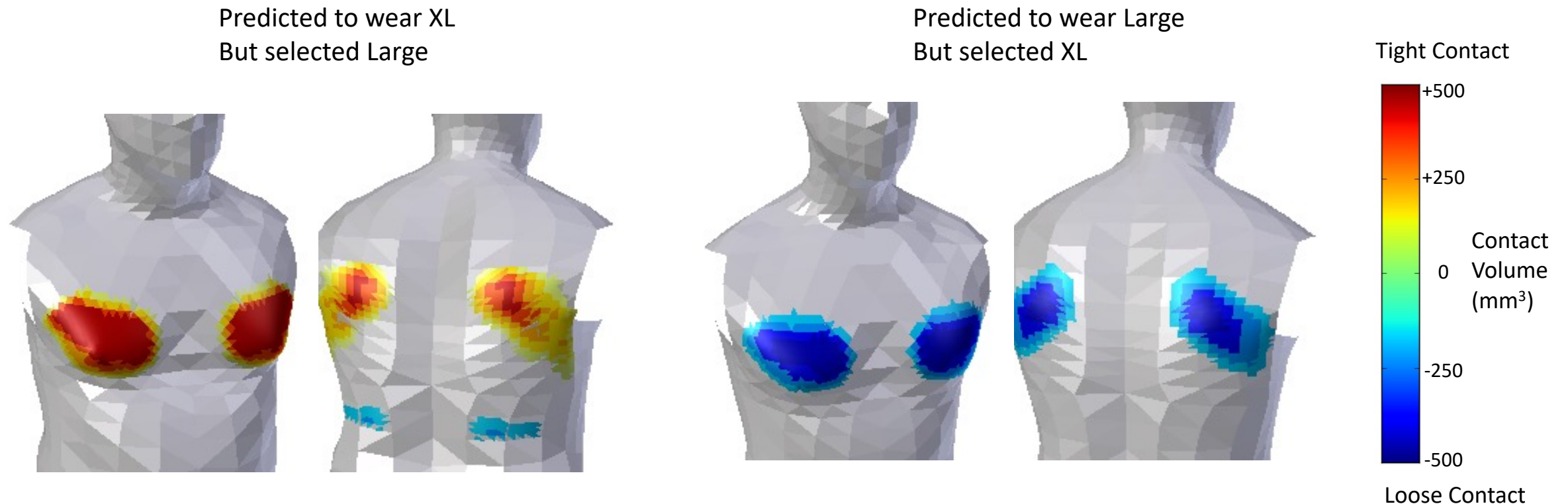
		Actual Size Selection			
Predicted Size		Medium	Large	XL	Total
	Medium	86.6%	11.8%	11.9%	100%
	Large	38.8%	43.4%	29.2%	100%
	XL	16.7%	41.2%	50.6%	100%



Area Under Curve: Mean 0.7689, 95% CI [0.6537,0.8642]
Pseudo R^2 : mean 0.1598, 95% CI [- 0.2383, 0.5580]

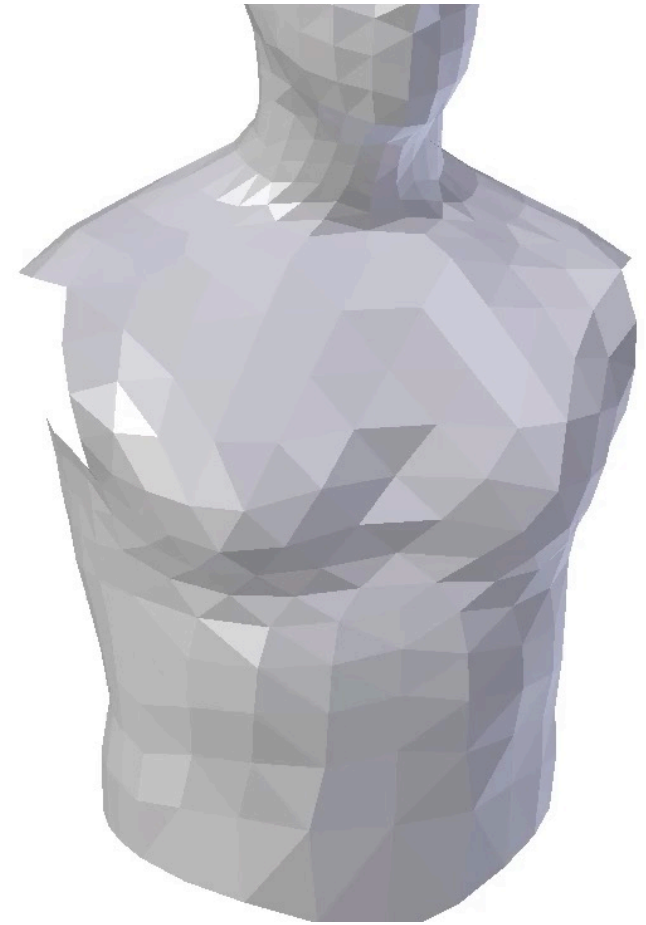
Fit Estimation by Suit-to-Body Contact (Limitation)

- The incorrectly predicted cases were investigated, e.g., subjects predicted to wear XL but selected Large
- Subjects' contact against the predicted and actual HUT size was compared. The difference represents the subjects' preference for either a tight versus loose fit compared to the group average
- Overall, some subjects prefer tight contacts, but other subjects preferred loose contacts
- The location and absolute magnitudes of the tight versus loose contacts are approximately similar
- This result indicates the suit fit can differ, potentially by subjective preference



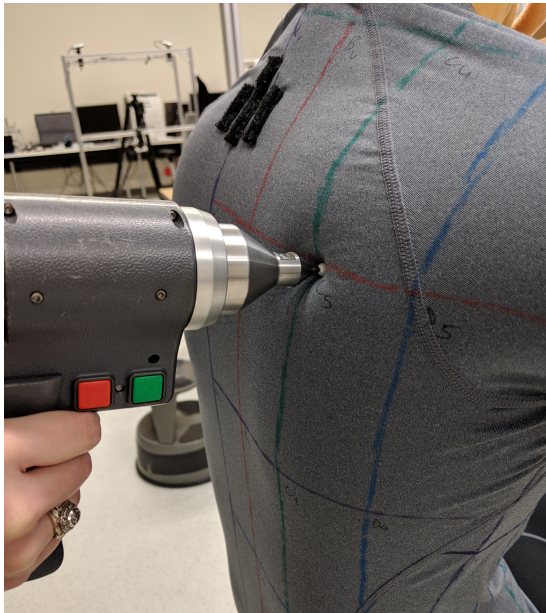
Fit Estimation by Suit-to-Body Contact (Limitation- Cont'd)

- The difference of body shape* is shown between:
 - Subjects predicted to wear a Large but selected a Medium HUT (“tight fit wearer”) vs.
 - Subjects predicted to wear a Medium but selected a Large HUT (“loose fit wearer”)
- * Body shape shown is multiple persons’ average
- The difference demonstrates characteristic body shapes, which may not be easily captured by linear anthropometry or 3D body scanning
- Thus, the tight vs. loose fit preference can be related to the body composition and tolerance to suit-to-body contacts

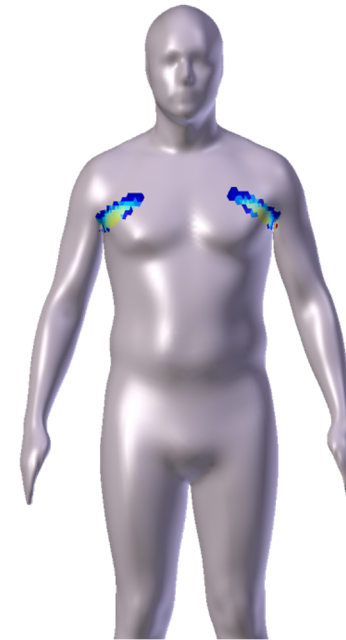
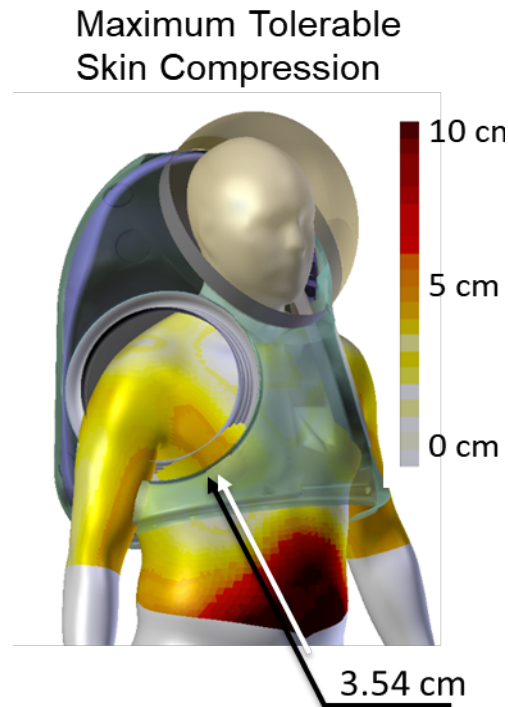


Discussion

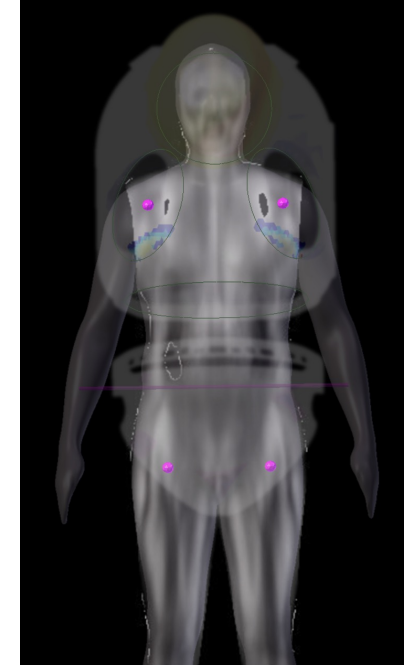
- This study provided a structured validation of a virtual suit fit method, which has not been possible in the past
- Overall, this study demonstrated that suit fit may not be accurately predicted by linear anthropometry. However, suit-to-body contact pattern showed a better prediction performance
- Subjective preference seems to play a substantial role in suit fit
- The outcome provided useful insights and limitations for interpreting virtual fit tests
- However, more detailed aspects of suit fit, for example, padding or ancillary material use has not been considered
- Also, a direct measurements of body composition and compression tolerance can be useful for suit fit prediction

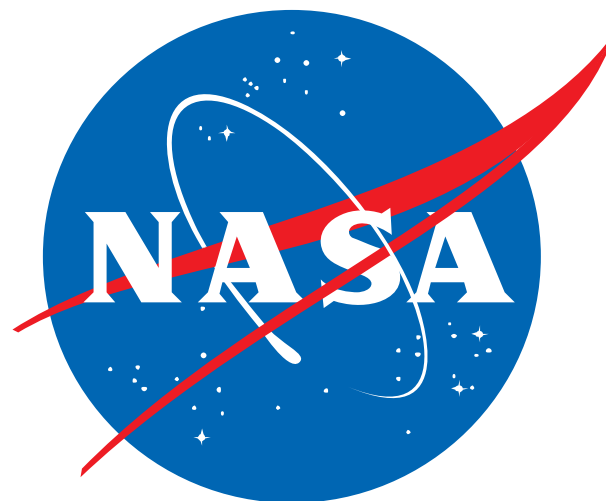


Hernandez et al., 2019



Leong, 2020





K. Han Kim

han.kim@nasa.gov