



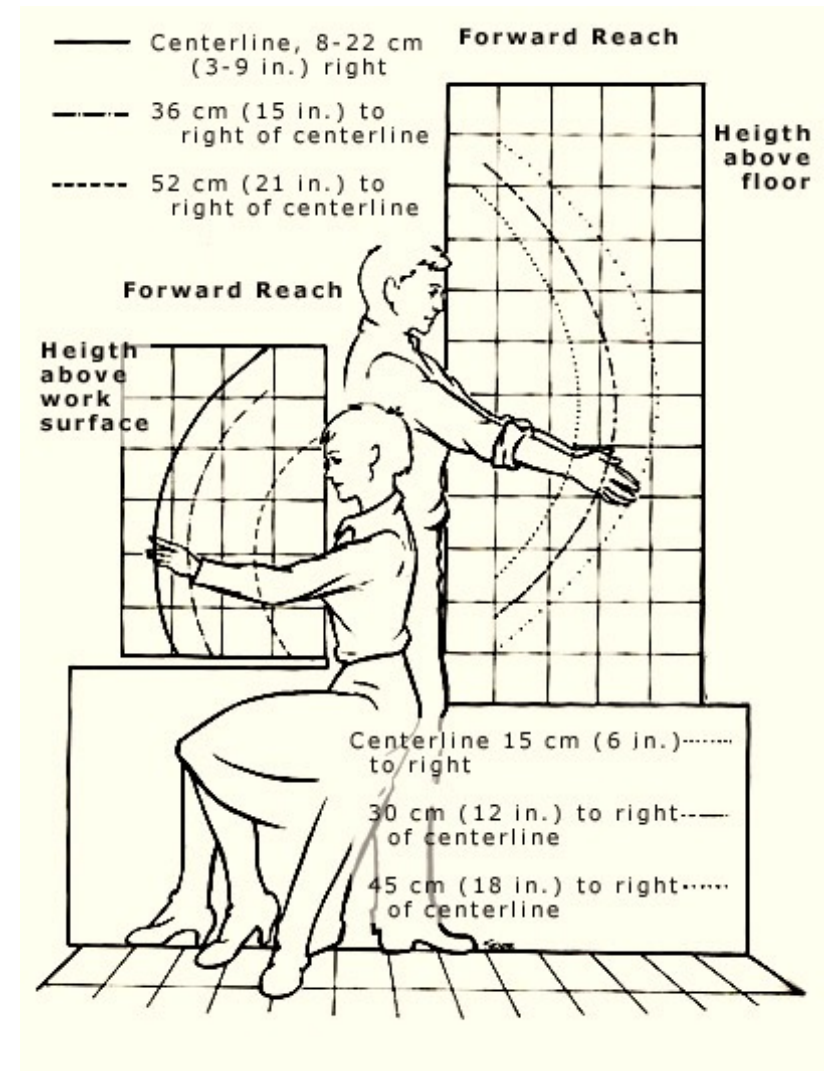
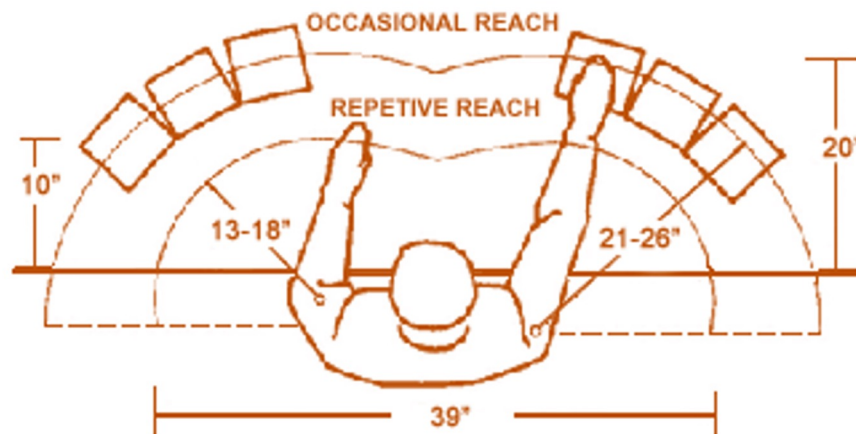
Spacesuit and Mobility Performance Changes: Metric Definition and Evaluation

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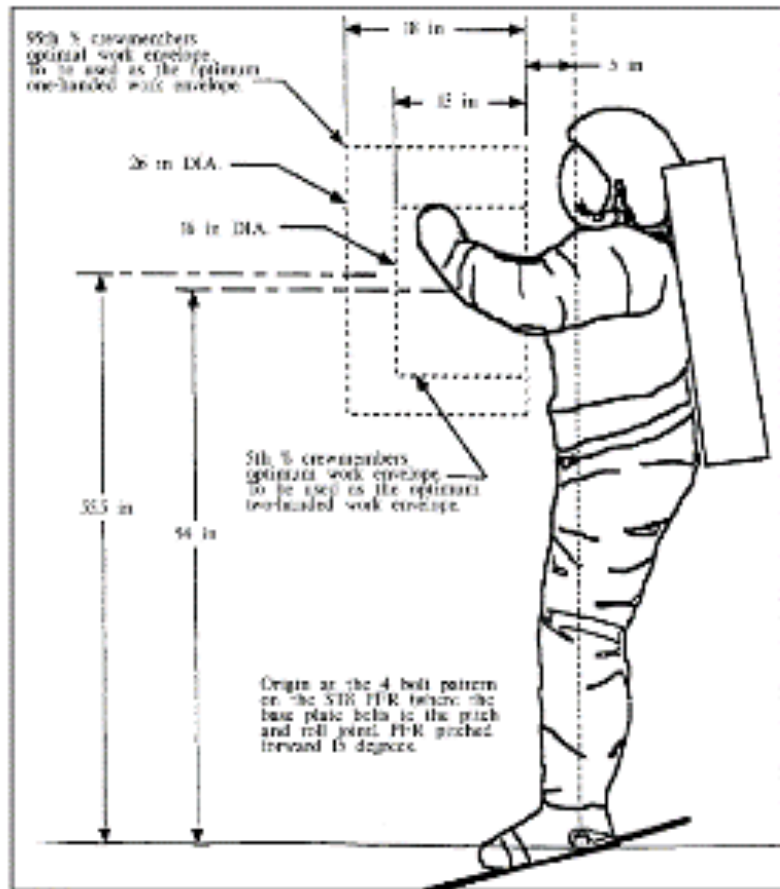
Reach Envelopes for Occupational Ergonomics

- Reach envelope defines the area and volume that can be reached by a person in the workspace
- Reach envelope has been used commonly to define ergonomically acceptable work zone
- Reach envelope can help to improve workspace design and organize work objects and hardware in optimal places



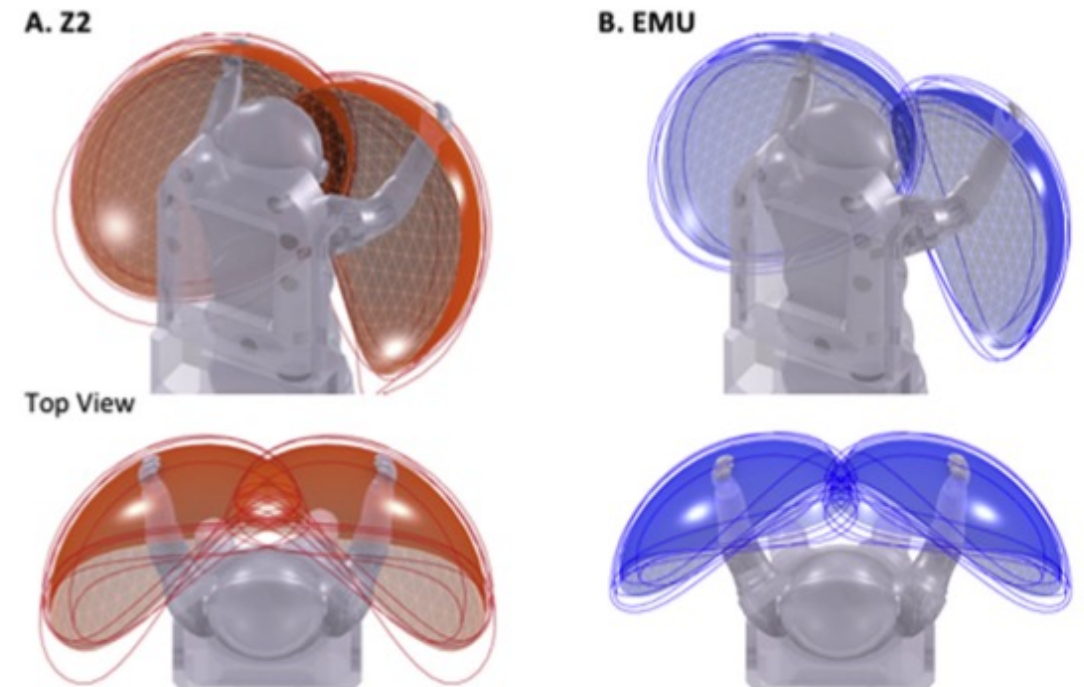
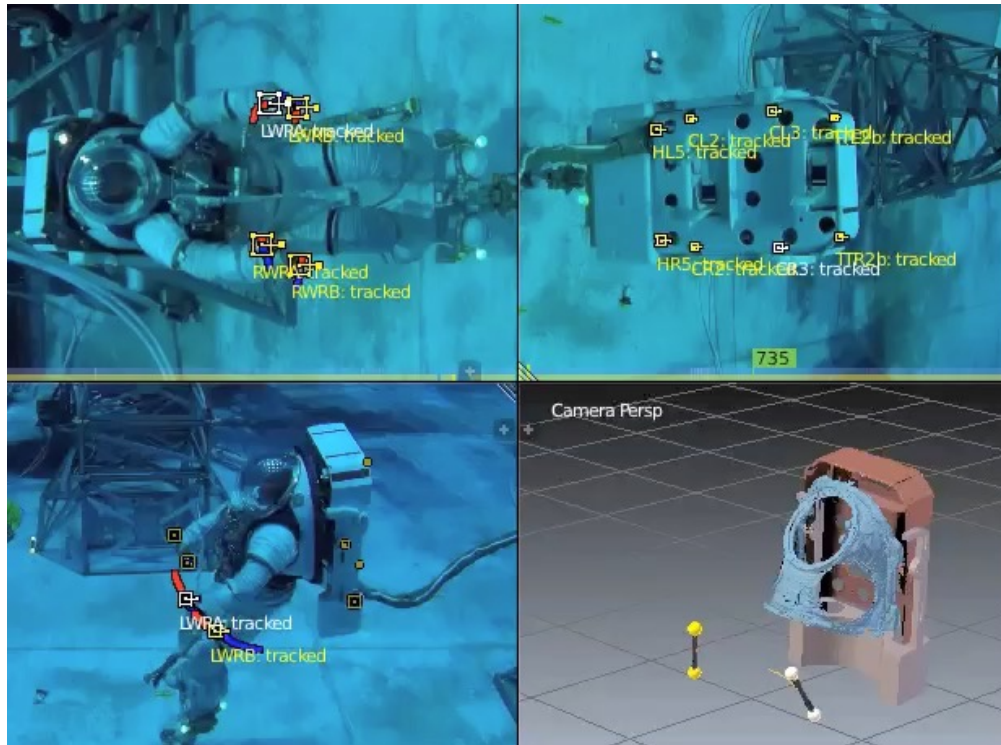
Reach Envelopes for Spacesuit Design & Operations

- Defining the correct dimensions for work zone is critical for extravehicular activities (EVAs), as EVA work is in general hand-intensive.
- Spacesuit imposes unique restrictions due to mechanical configurations and pressurization, thus reach envelope can represent the mobility characteristics of the spacesuit
- Thus, spacesuit and EVA design and optimization require accurate measurements of reach envelopes



Past Study: Spacesuit Reach Envelope Assessment

- Maximum reach envelopes were measured from two different types of EVA spacesuit
- Measurements were performed in the underwater microgravity analogue at the Neutral Buoyancy Laboratory
- Results showed increased arm/hand reach envelopes with the newly developed spacesuit, especially for the cross-reach capabilities (i.e., intersection between the left- and right-hand reach envelopes)
- The cross-reach is of particular importance as it represents the work area where both hands can be used



Test Goals, Conditions & Methods

- The goal of this study is to identify the component-wise contribution for spacesuit mobility
- Arm/hand reach capability was measured in 3 different conditions: unsuited, 3D printed mockup and pressurized suit
- Each condition represent the incrementally added components and associated mobility restrictions (table below)
- Tested 3 male subjects



	“Unsuited”	“3D Printed Mockup”	“Pressurized Suit”
Inner Layer Garment	X	X	X
Hard Upper Torso		X	X
Shoulder Convolute			X
Arm/Glove Soft Goods			X
Pressurization			X

One-Handed Reach Envelope

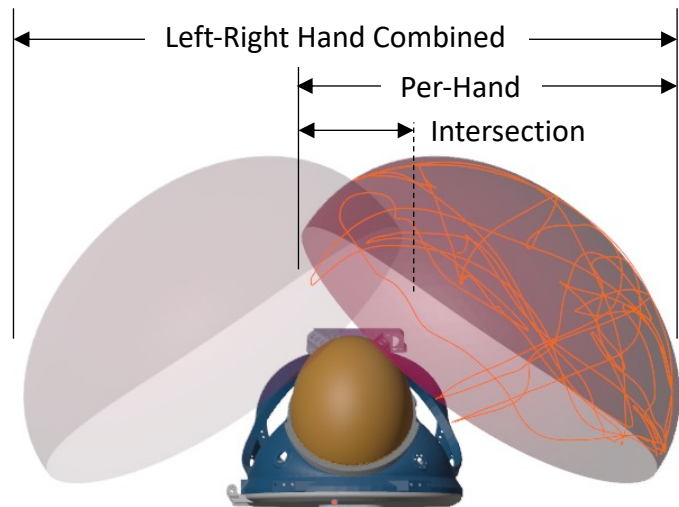
- Maximum sweeping motions were measured with extended right arm/hand
 - Horizontal (left-right) sweeps at different elevations
 - Vertical (up-down) at different azimuths
- Vicon motion capture system recorded the motions of the hands, body/suit landmarks
- Right hand position (back of the hand) was traced, and represented by the torso or hard upper torso attached coordinate system
- Left hand reach envelopes were virtually generated by mirroring the right arm traces across the mid-sagittal plane



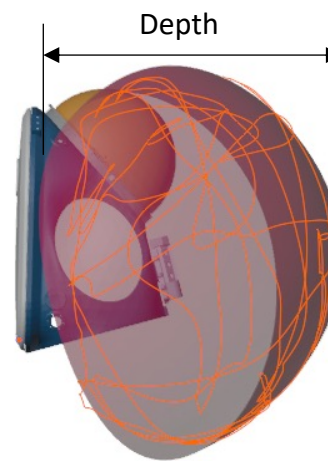
One-Handed Reach Envelope (Cont'd)

- Measurements were represented by % of unsuited condition. Table below shows cross-subjects averages
- Compared to the unsuited condition, 3D printed mockup did not substantially change reach zone width, while depth and height were reduced to 80% and 97%
- Pressurized suit condition substantially decreased the reach zone, especially the right-left hand reach intersection (69%) and reach depth (65%)

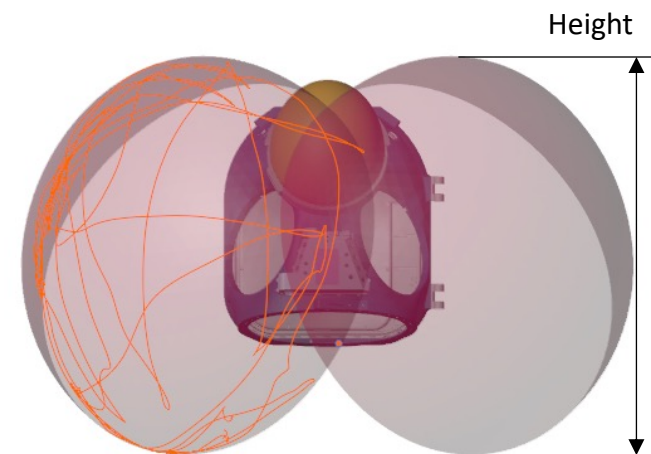
	Width			Depth	Height
	Per-Hand	Lt-Rt Combined	Intersection		
Unsuited	100%	100%	100%	100%	100%
3D Printed Mockup	102%	101%	100%	80%	97%
Pressurized Suit	92%	93%	69%	65%	82%



Width Measurements



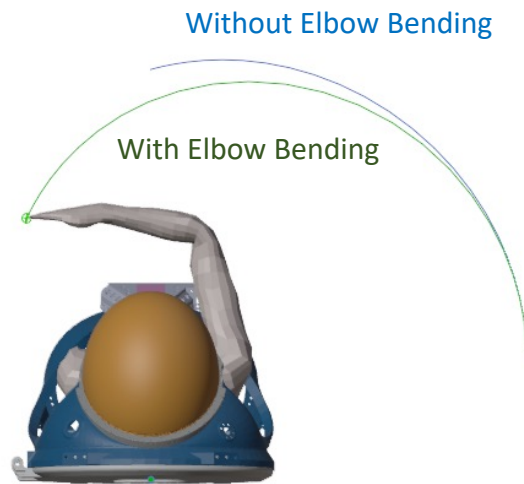
Depth Measurement



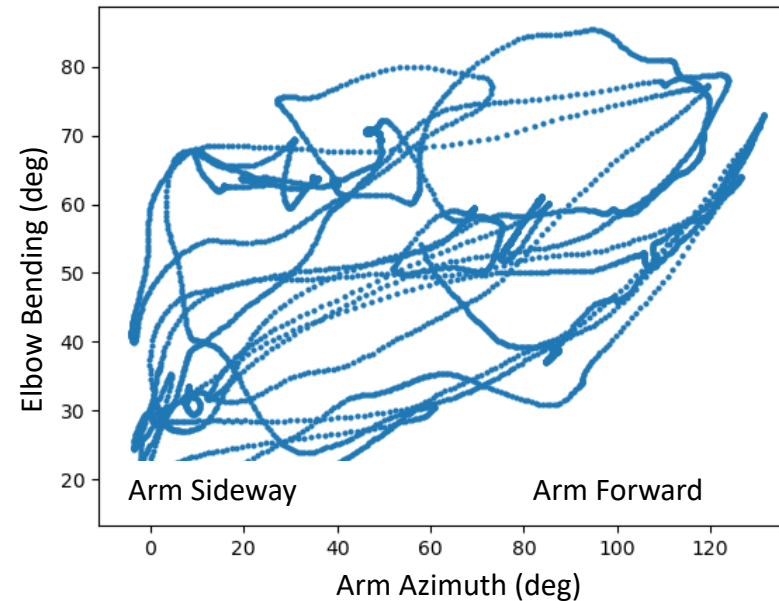
Height Measurement

Elbow Bending Artifacts

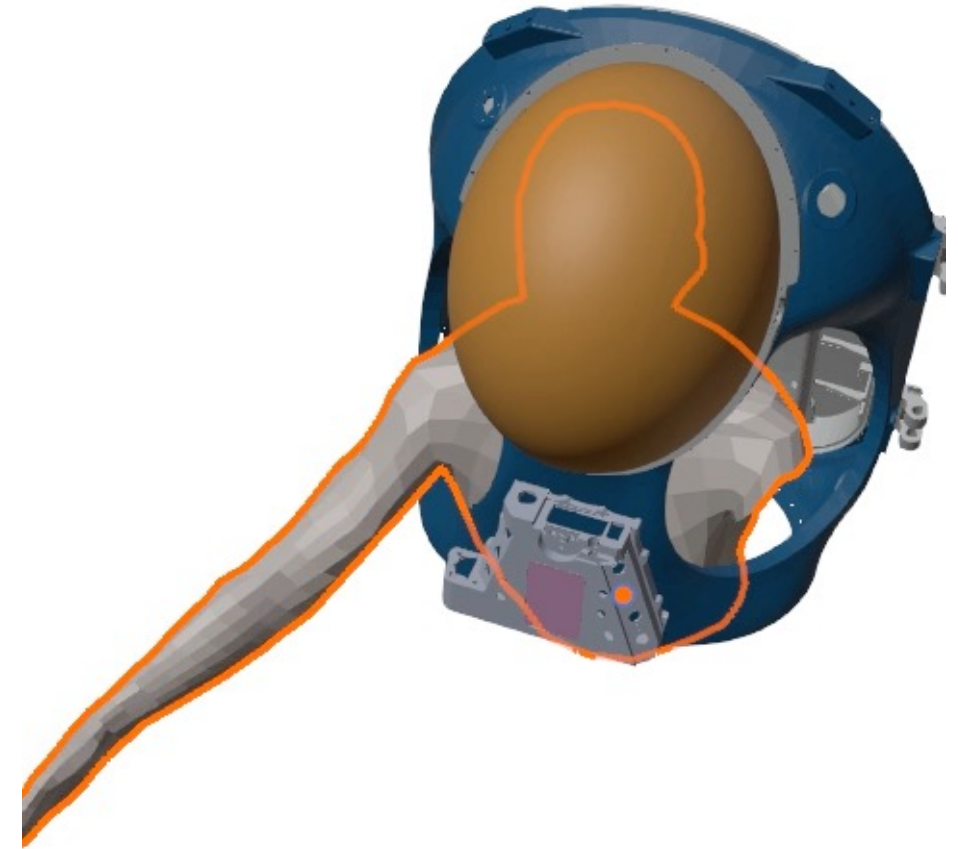
- While one-handed reach envelopes can provide a simple metric for mobility characteristics, the envelopes may not accurately represent the maximum reachable zone
- The issue is potentially related to the elbow which tend to bend unknowingly, especially near the extreme reach areas
- The outcome can result in different reach envelope shape and size, potentially exaggerating cross-reach and overhead reach capabilities



Simulated Hand Traces



Test Data from One Subject

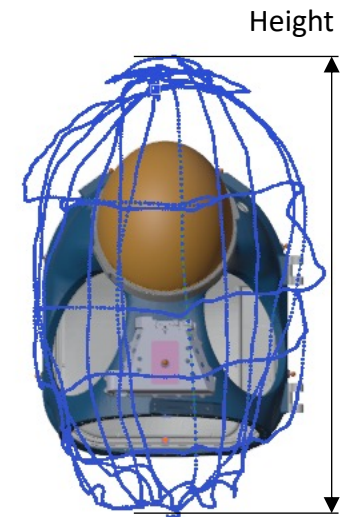
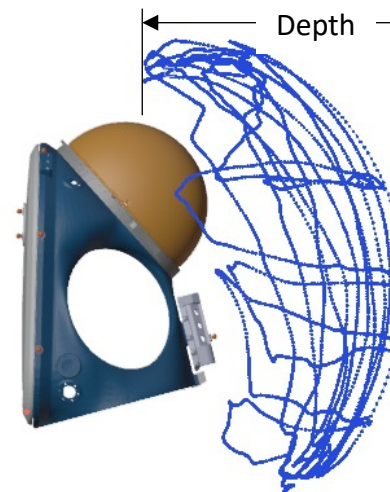
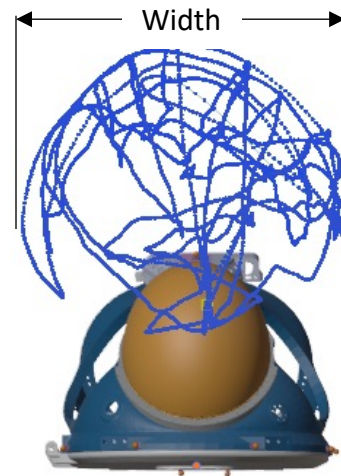


Two-Handed Reach Envelope

- Measuring the work zone that can be reached by the mid-point between the hands
- This method can partially reduce elbow bending artifacts
- Compared to unsuited condition, 3D printed mockup and pressurized suit conditions tend to reduce the work envelop dimensions

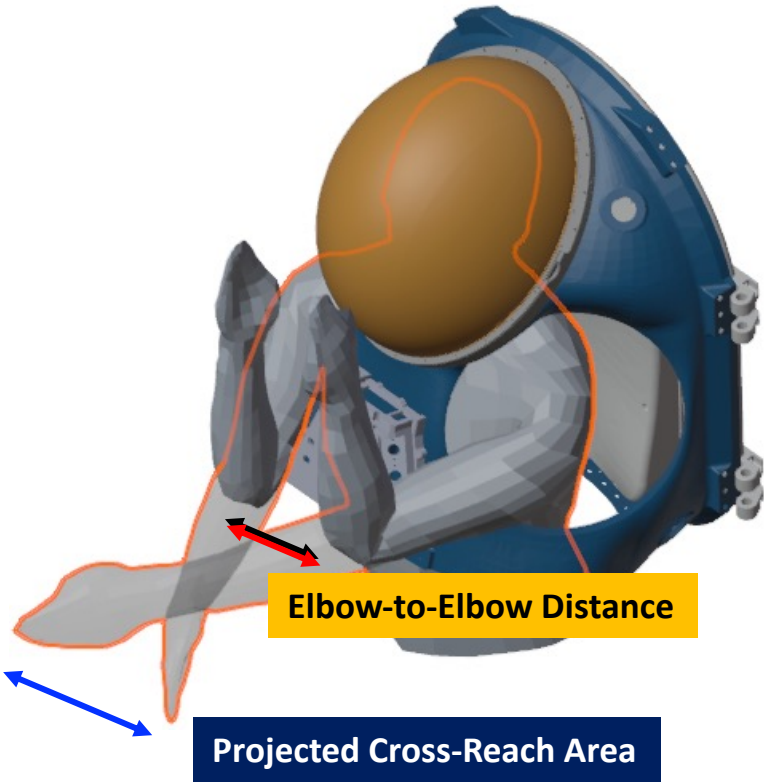
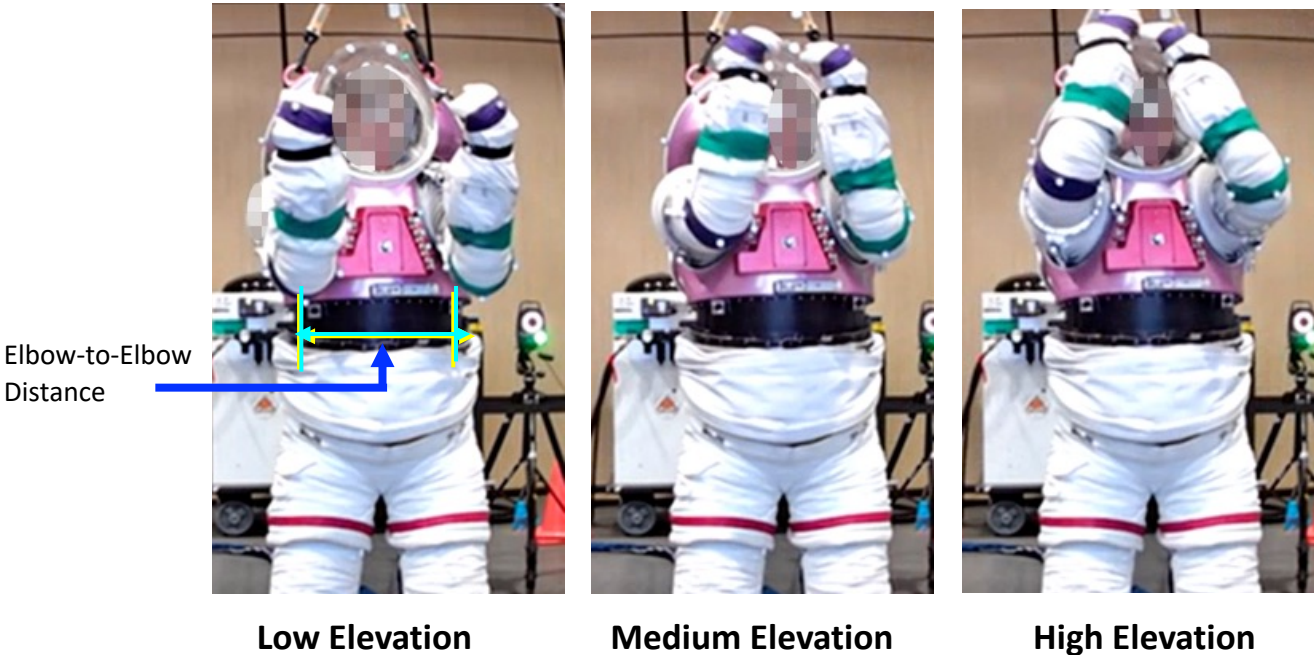


	Width	Depth	Height
Unsuited	100%	100%	100%
3D Printed Mockup	95%	91%	91%
Pressurized Suit	79%	69%	75%



Elbow-to-Elbow Distance Measurements

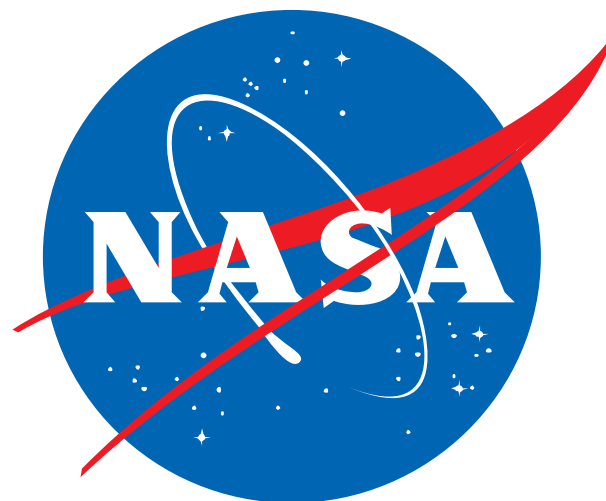
- Measuring the distance between the elbow tips, effectively eliminating elbow bending artifacts
- Elbow-to-elbow distances largely increased with the 3D printed mockup, then increased further with pressurized suit
- The large increase with the 3D printed mockup can be attributed to the geometric constraints from the scyes
- The results indicate the reduction in the projected cross-reach areas, especially at the low elevation



	Low Elevation	Medium Elevation	High Elevation
Unsuited	100%	100%	100%
3D Printed Mockup	251% ^{+151%}	240% ^{+140%}	207% ^{+107%}
Pressurized Suit	350% ^{+101%}	263% ^{+23%}	215% ^{+8%}

Discussion

- Spacesuit and vehicle design can be optimized with reach capability data
 - Reach envelopes show unique mobility patterns associated with specific component conditions
 - Compared to the unsuited condition, the 3D printed mockup and pressurized suit conditions decreased overall size of the reach envelopes
- The amount contribution for mobility pattern change is different between the 3D printed mockup and pressurized suit conditions
 - Although pressurized suit is associated with more mobility-restricting components (e.g., shoulders, soft goods, pressurization), the 3D printed mockup also induces significant mobility changes
 - Thus, the shape and size of the hard upper torso and other “rigid” parts are crucial for spacesuit mobility
- The one-handed reach envelop has been widely used to represent spacesuit mobility performance
 - However, the actual size and shape should be interpreted with caution, due to the concurrent motions of the elbow and other joints
 - Other metrics, such as two-handed reach envelopes and elbow-to-elbow distances can be used to complement the limitation of the one-handed reach envelope
- The interactions between the anthropometry and reach characteristics have not been investigated in this study
 - Future study needs to address the different mobility patterns between small vs. large size persons



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