Estimation of Preferred Work Envelope from Simulated Functional Tasks in a Spacesuit

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Background: Working in a Spacesuit

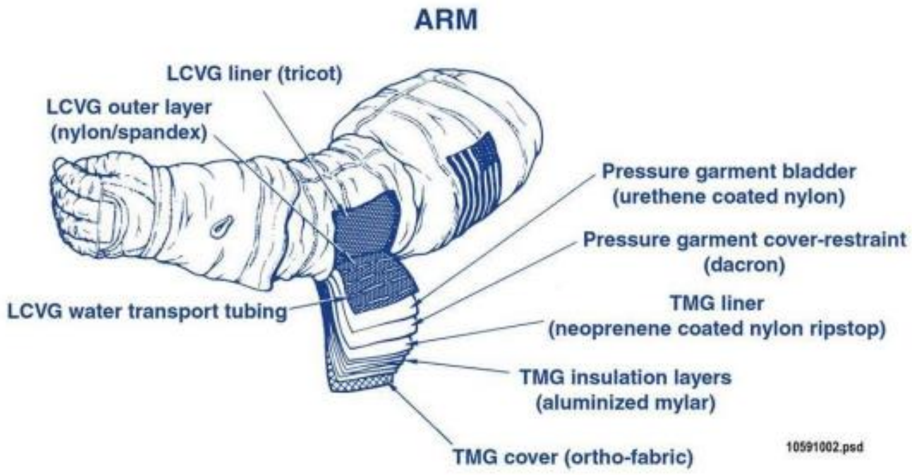
- Spacesuits allow humans to function in an incredibly harsh environment. However, they introduce some restrictions to human capabilities.
- In general, crewmembers in a spacesuit have a restricted maximal reach envelope, reduced field of view, and reduced tactility.
- When tasks and interfaces are being designed, they need to take into account the restrictions associated with working in an Extravehicular Activity (EVA) suit.

Video of a crewmember translating along the ISS in a spacesuit

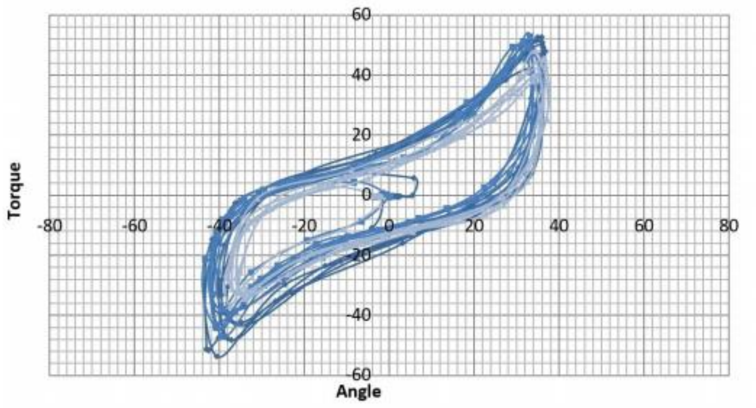
Why is Reach in a Spacesuit Constrained?

- Contact between body and suit components
- Contact between adjacent suit segments at extremes of motion
- Friction between layers in the protective cover
- Stiffness of pressurized fabric joints
- Field of view restrictions – capable of reaching, but cannot see

Scan of an EMU hard upper torso



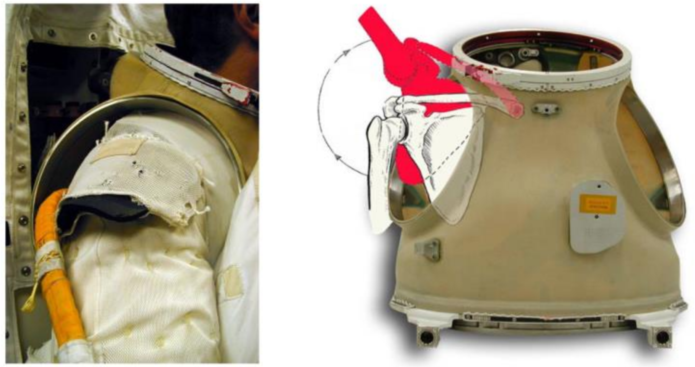
Layers of an EVA suit



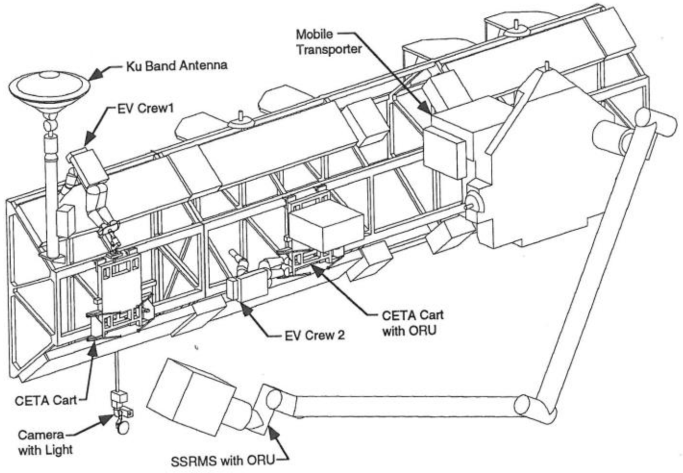
Wrist joint stiffness, showing hysteresis and non-linearity

Preferred Work Envelope

- The suited subject can only move and see within a set of constraints
- It is important to avoid designing tasks or interfaces that are at the extremes of the suit’s reachable and visible space
- Uses of preferred work envelope
  - Lighting system design
  - Design of EVA interfaces
  - EVA task planning
  - Avoidance of ‘risky’ shoulder postures
- Question: where is the preferred work envelope for the suit?



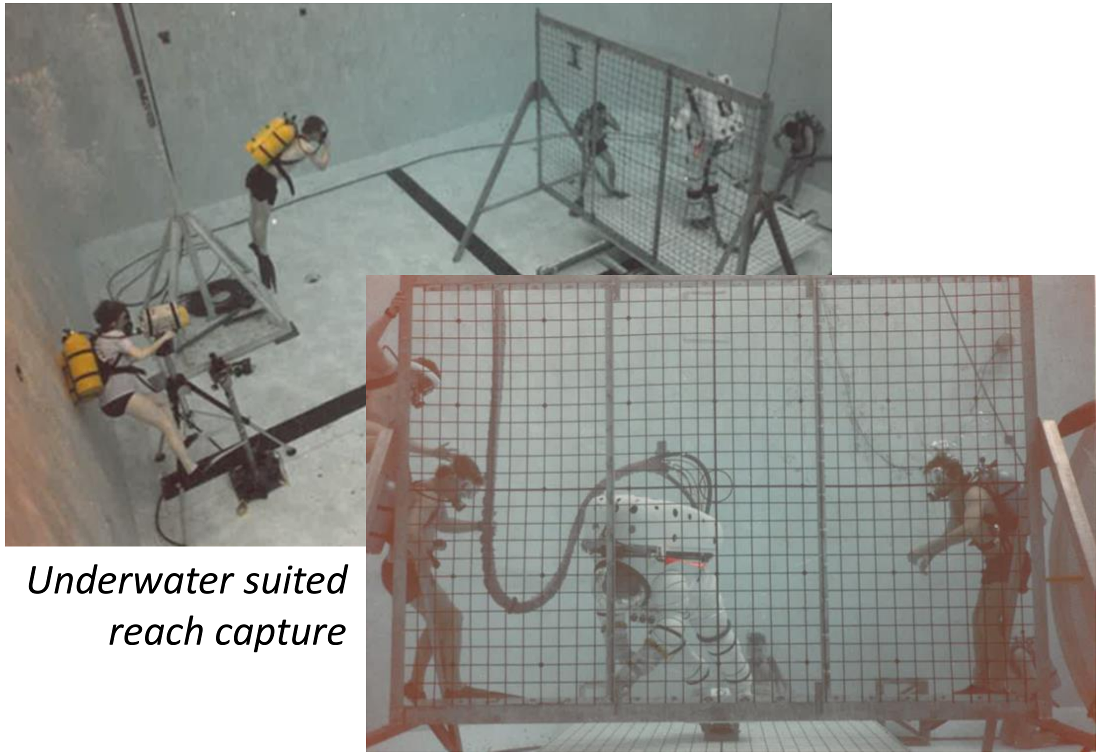
Shoulder interference with spacesuit hard upper torso



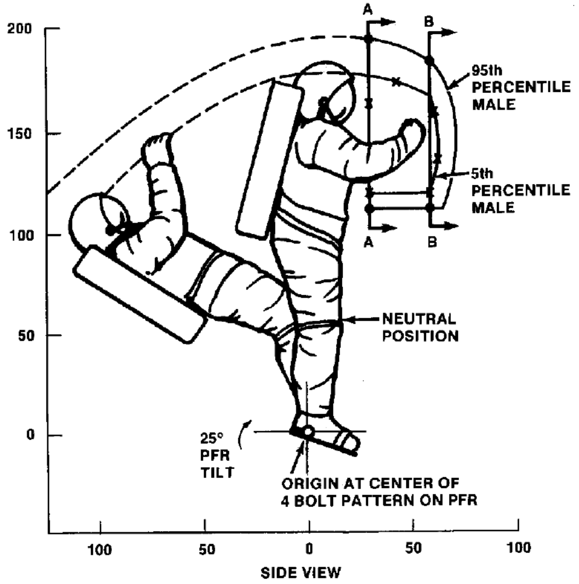
EVA Task Planning Design Model (Klaus, 1994)

Historical Suited Work Envelope Measurement

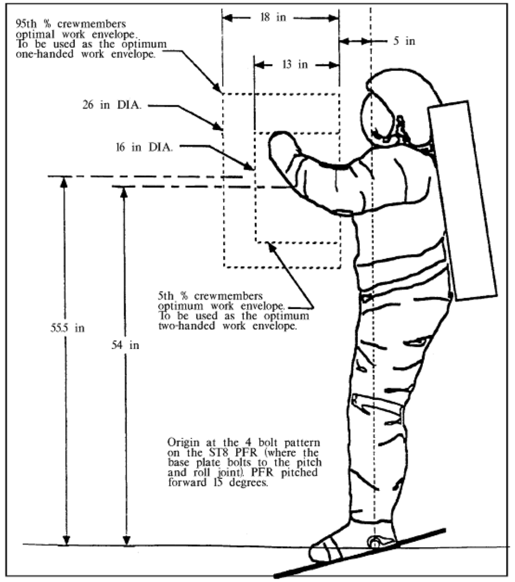
- Since the 1960’s, attempts have been made to quantify the reach of spacesuits
- In the late 80’s and early 90’s, NASA collected work envelope data in an underwater microgravity analog
  - Data was used to create simplified ‘5^{th} and 95^{th} percentile’ work envelope recommendations
  - Only male data was used, and motion analysis was constrained to 2D planes
  - Suit design was changed after the development of the preferred reach envelope model



Underwater suited reach capture



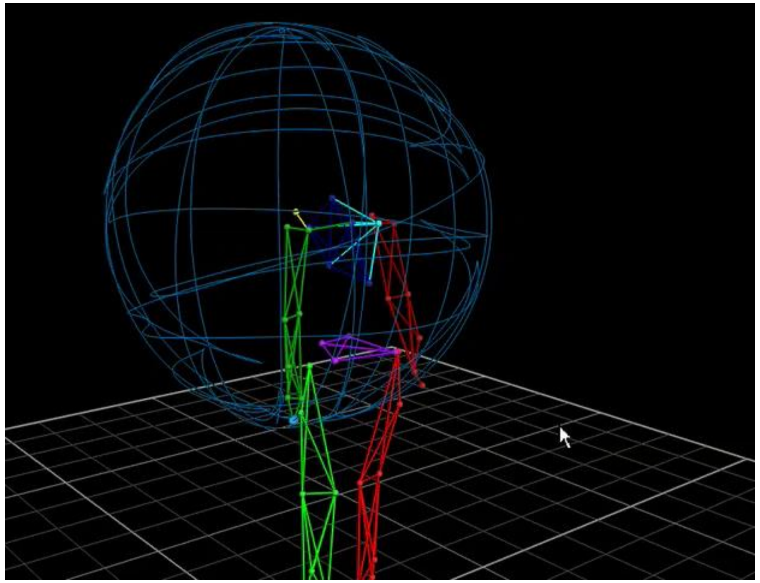
Underwater reach data



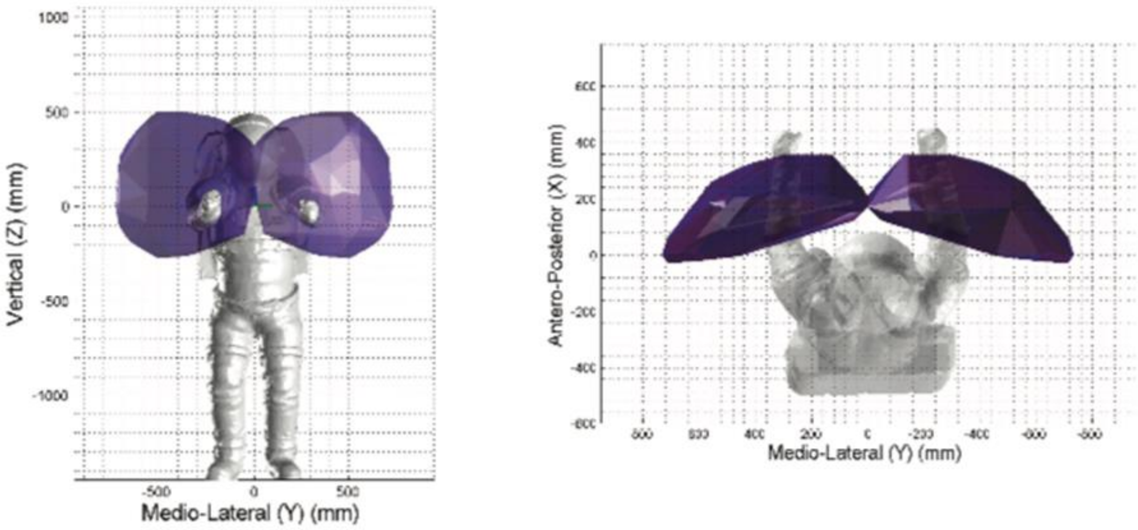
Simplified representation of suited reach

3D Motion Capture of Suited Reach

- In 2008, NASA measured preferred reach envelope data on the updated EMU suit design, with a wider range of subject anthropometry than in previous testing
    - A Vicon optical motion capture system was used to collect 3D reach and work envelopes, without requiring subjects to restrict their motion to a plane
    - This data, however, was purely based on subject preference, and did not determine what is actually needed to complete an example EVA task



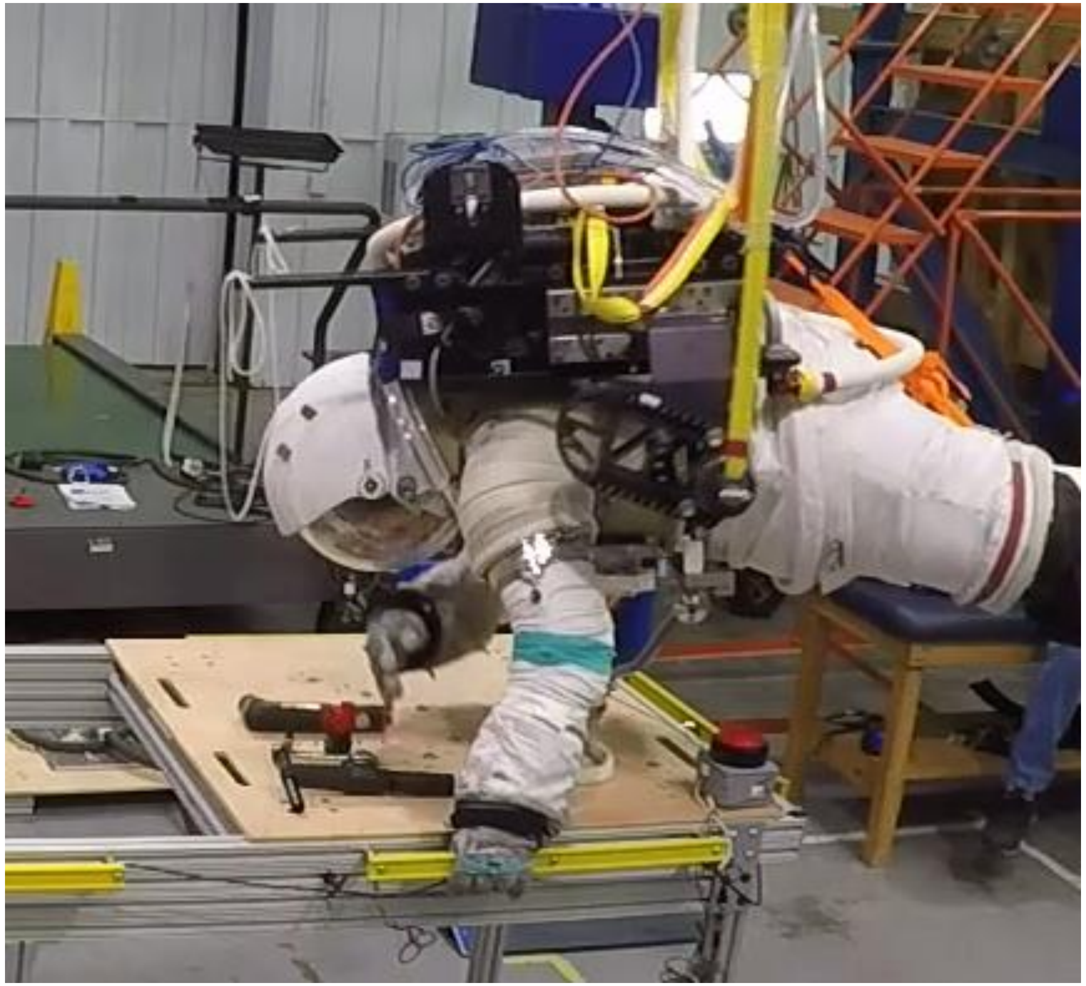
Vicon Motion Analysis



Reach envelopes from suited data collection

EVA Task Simulation – Benchmarking Study

- The EVA Benchmarking Study was simulated suited task performance in a microgravity analog - the ARGOS (Active Response Gravity Offload system)
- Subjects in an Extravehicular Mobility Unit (EMU) were suspended from a robotic crane on a gantry to offload the suit weight and allow translation through the volume
- While offloaded, subjects completed a series of functional tasks meant to represent an example EVA

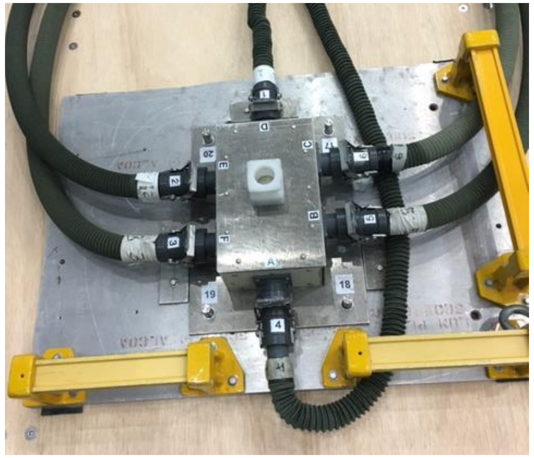


Functional task data collection for the EVA benchmarking study

Data Analysis

- As a proof of concept, reach envelope and hand position distributions were evaluated for simulated EVA tasks in the ARGOS microgravity analog
  - Both suited (EMU) and unsuited data was analyzed for one subject
  - Maximal reach and functional work envelopes were reconstructed
  - Kernel density estimation was used to evaluate hand position distribution during tasks
  - Data from left and right hand was mirrored and combined
- Tasks analyzed:
  - Bolt busy board, free floating
  - Bolt busy board, secured in PFR (Portable Foot Restraint)
  - Quick Disconnect (QD) task

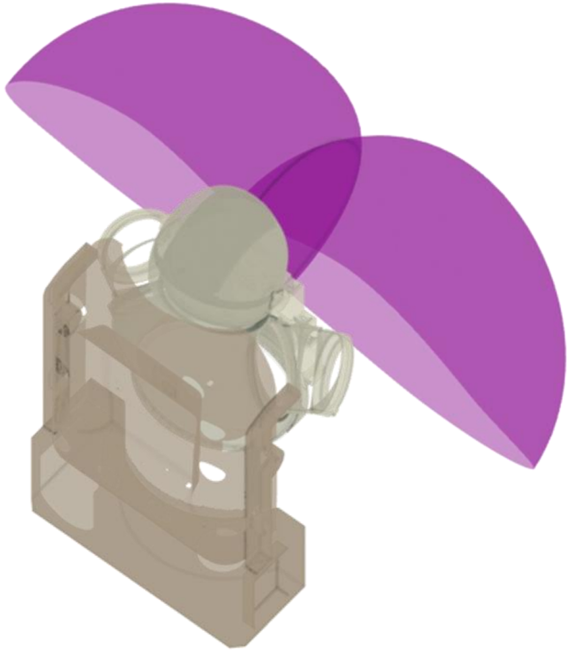
Bolt Busy Board



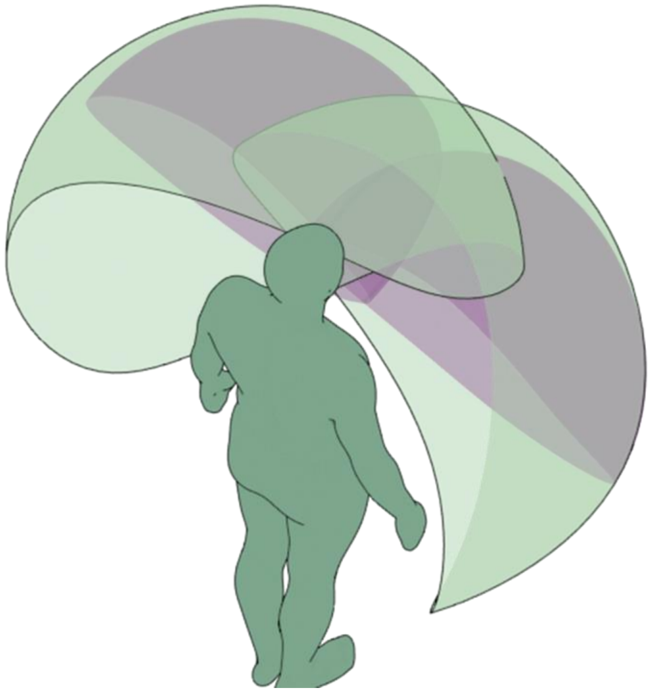
Quick Disconnect Busy Board

Results: Maximal Reach Envelope

- Maximal reach envelope in the suit was substantially reduced from the subject's unsuited baseline
- Largest delta was in cross reach – 8X higher in unsuited compared to suited
- A narrow cross reach capability is characteristic of the EMU



Suited isolated maximal reach envelope (purple)

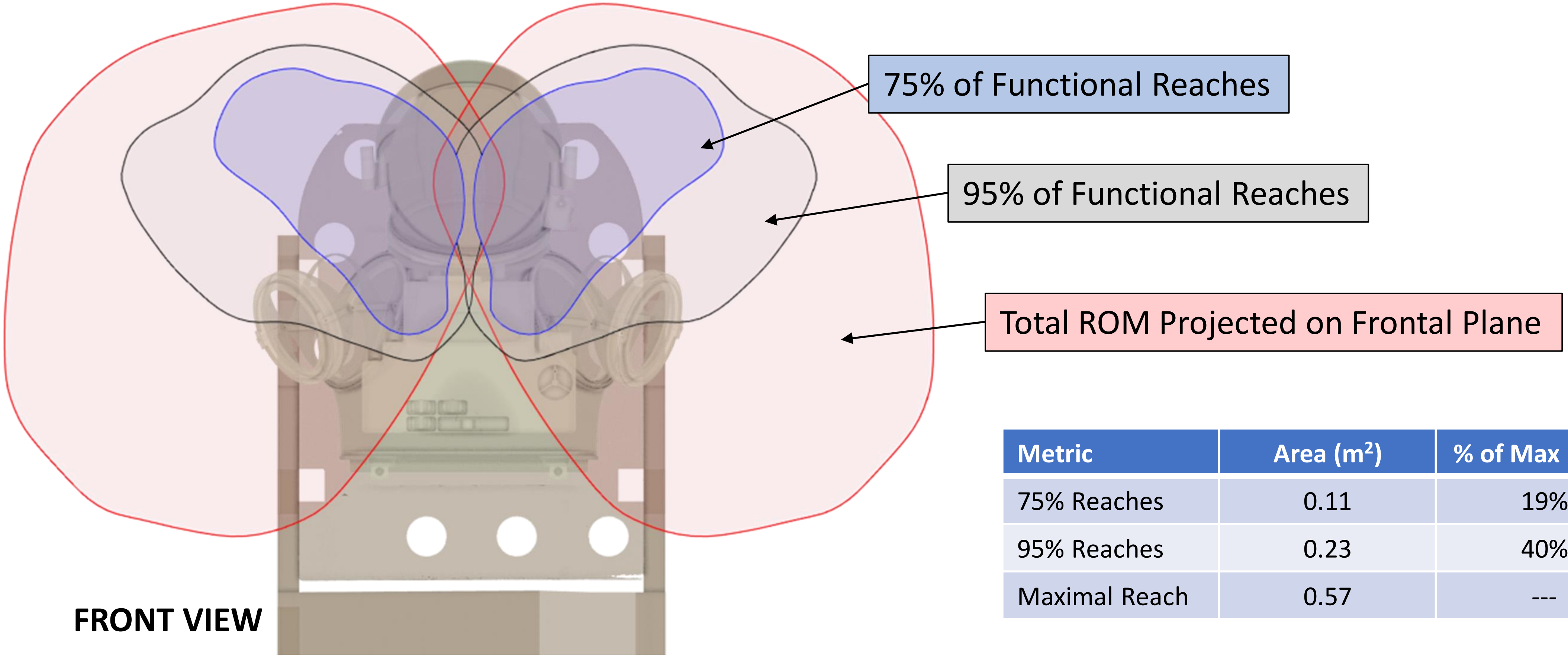


Unsuited maximal reach envelope (green) overlaid on suited maximal reach envelope (purple)

Metric	Units	Unsuited	Suited
One-Handed Reach Envelope Surface Area	(m^2)	2.34	1.31
One-Handed Reach Envelope Breadth	(m)	1.14	0.86
One-Handed Reach Envelope Height	(m)	1.21	0.95
Cross Reach Span	(m)	1.14	0.14

Hand Position during Functional Tasks

- Kernel density estimation indicates that only a small proportion of available reach is utilized for functional work.
- Specifically 40% and 19% of the projected reach envelope area are used for 95% and 75% of functional work
- Cross reach was not used for most functional reaches in the suit, and neither was the lower lateral region

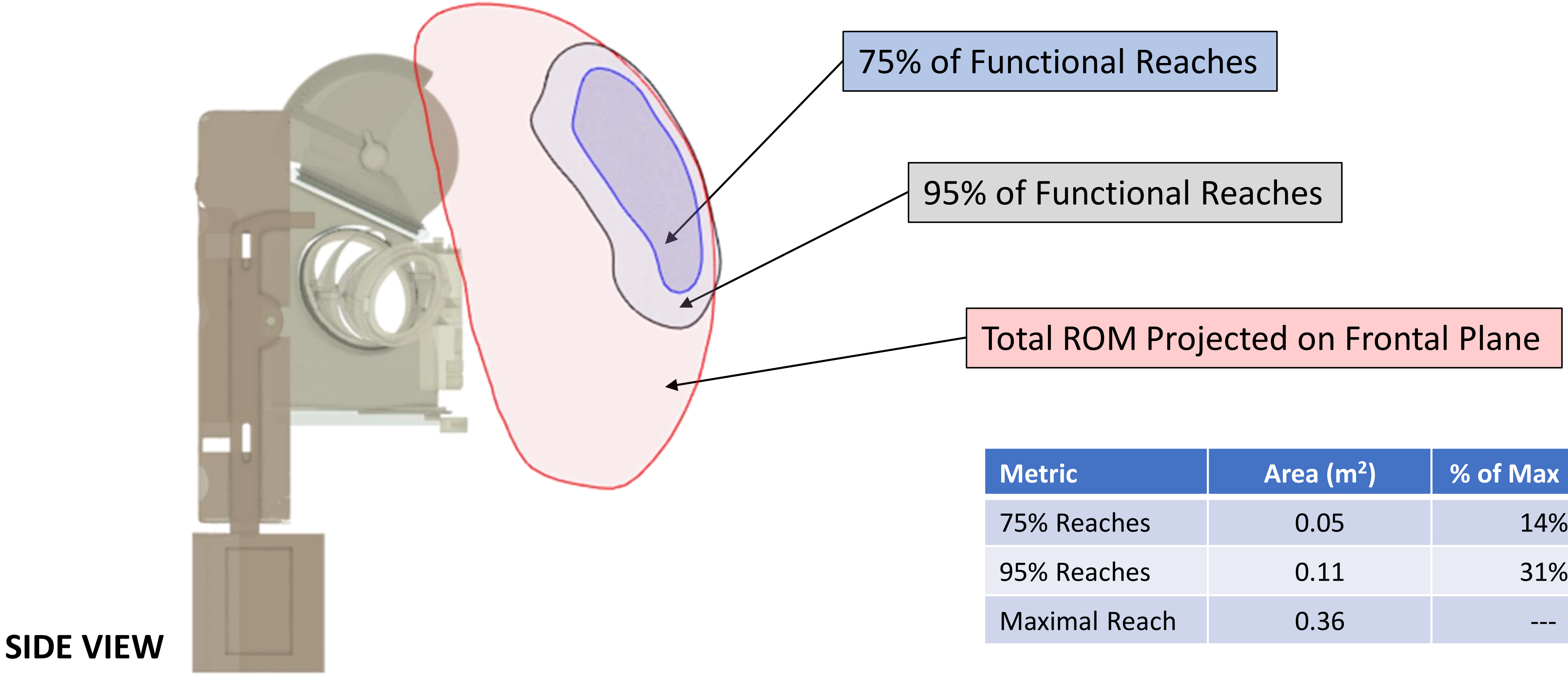


FRONT VIEW

Metric	Area (m^2)	% of Max Reach
75% Reaches	0.11	19%
95% Reaches	0.23	40%
Maximal Reach	0.57	---

Hand Position during Functional Tasks

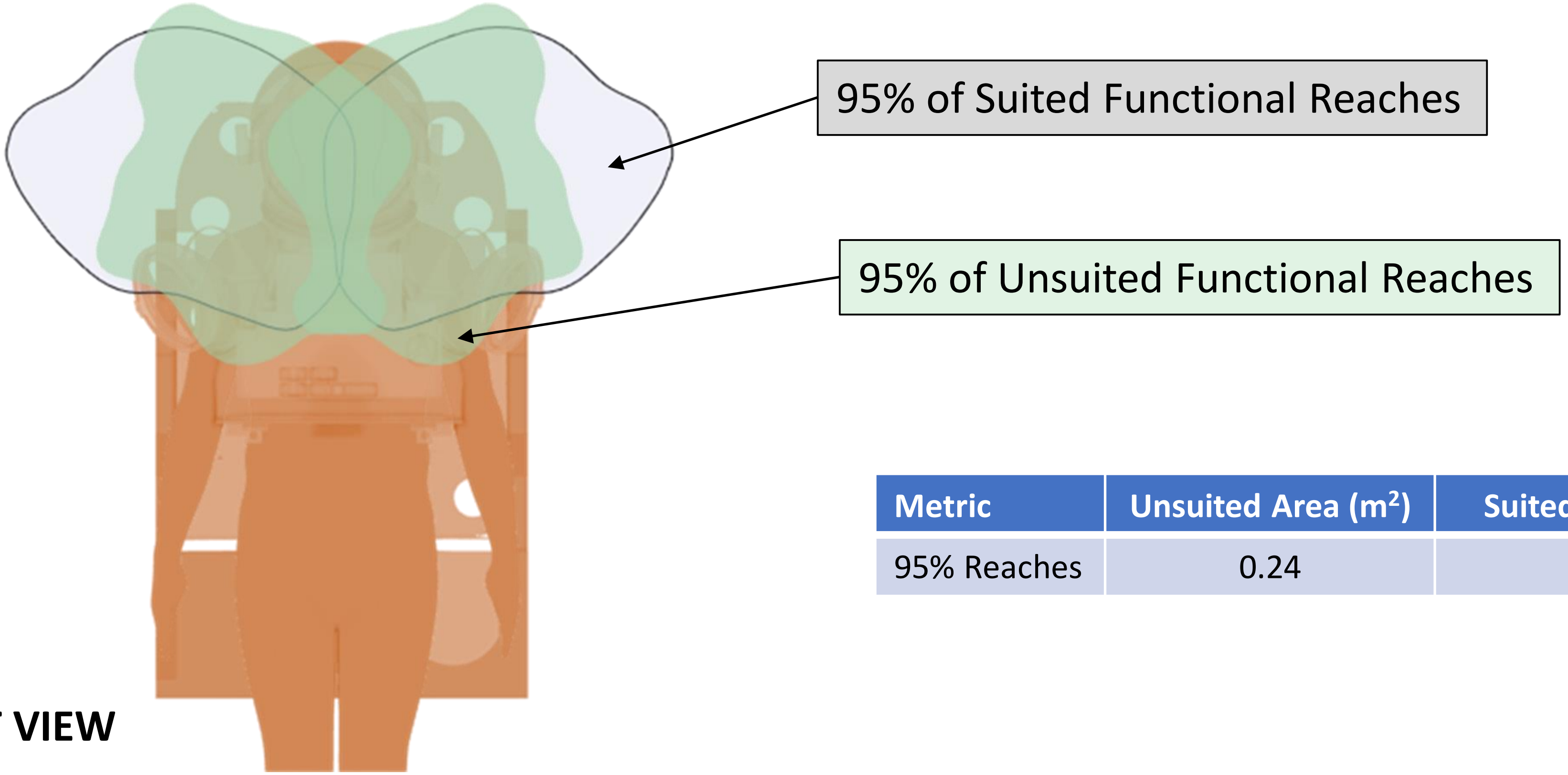
- Similar observations were made from the sagittal view. Only small areas are utilized for functional work.
- Specifically 31% and 14% of the projected reach envelope area are used for 95% and 75% of functional work.
- Reaches were most frequently at the front and high extreme of the reachable envelope – from shoulder to top of helmet.



Metric	Area (m^2)	% of Max Reach
75% Reaches	0.05	14%
95% Reaches	0.11	31%
Maximal Reach	0.36	---

Hand Position – Suited vs. Unsuited

- The functional reach areas in the frontal plan were similar between unsuited and suited – however, in unsuited they used more cross reach
- The suited reach during functional tasks was also slightly wider than unsuited
- Suited to unsuited difference may have been a function of a slightly reduced task set analyzed for unsuited

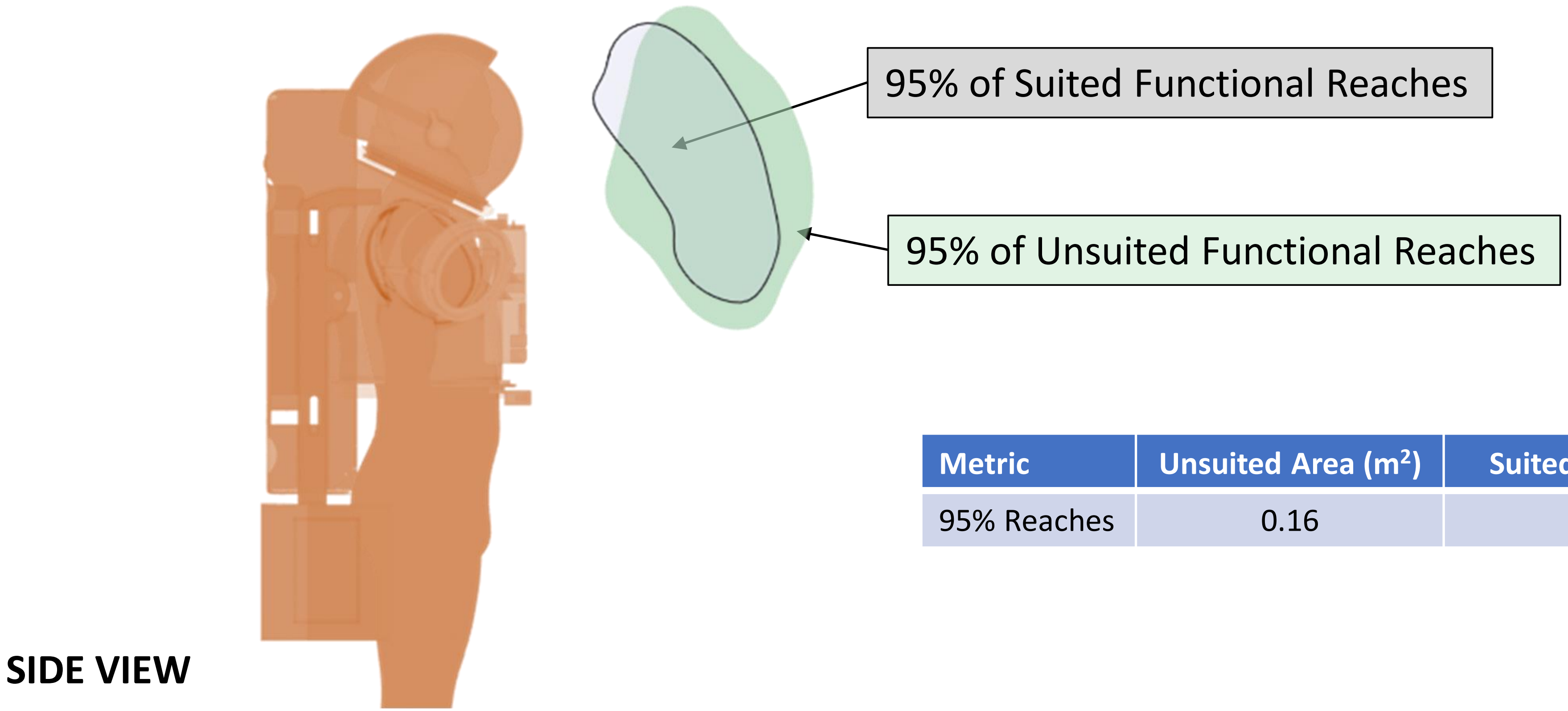


FRONT VIEW

Metric	Unsuited Area (m^2)	Suited Area (m^2)
95% Reaches	0.24	0.23

Hand Position – Suited vs. Unsuited

- The functional reach areas in the sagittal plane, like reaches in the frontal plane, were very similar in size and shape from suited to unsuited



Metric	Unsuited Area (m^2)	Suited Area (m^2)
95% Reaches	0.16	0.11

Discussion

- Results from a microgravity simulation suggested that the reach area used to complete functional EVA tasks in a space suit may only be a small proportion of the total available reach area.
- The reach area used to complete these specific functional tasks was very similar from suited to unsuited, with the exception of reduced cross reach in the suit.
- This study suggests that it may be more beneficial to optimize metrics such as cross reach, mobility, visibility and comfort in this most utilized region, rather than in areas of reachable area that may be infrequently utilized
- The outcome of this preliminary analysis can be enhanced by including a larger number of subjects of different anthropometry and strength levels, and with a larger variety of EVA tasks.

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