Spacesuit Anthropometry for Crew Population Accommodation

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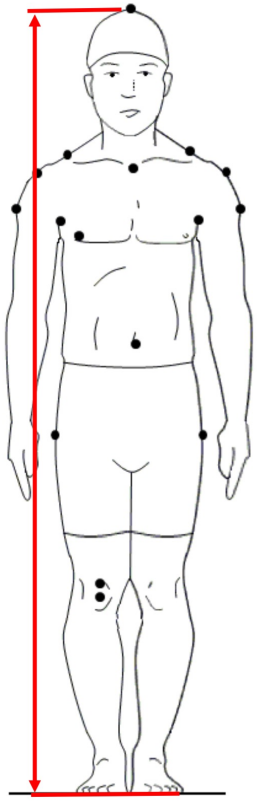
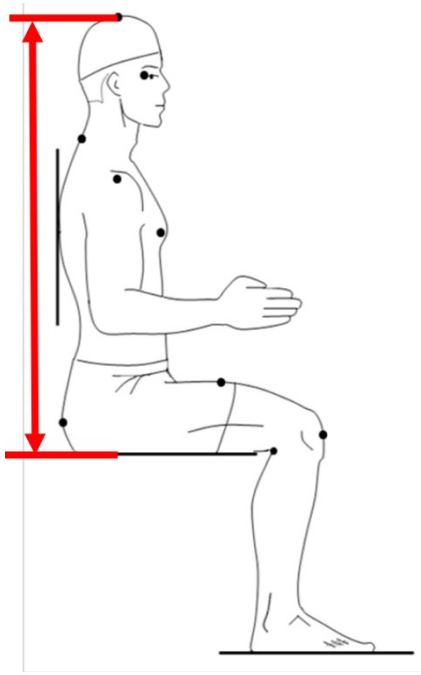
What is Anthropometry?

- Anthropometry is the science that defines physical measures of a person's size, form, and functional capacities.
- Anthropometry includes the measurements of body heights, lengths, and circumferences

Height Measurements

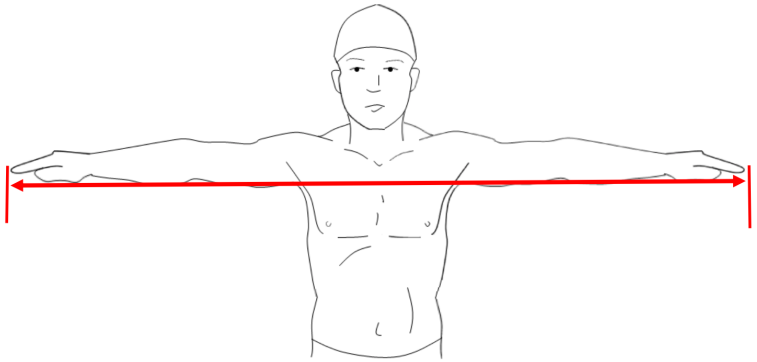


Stature

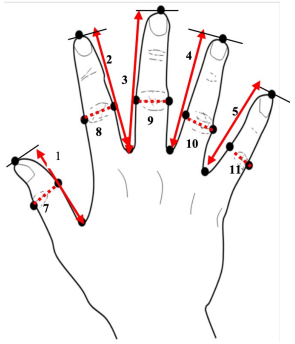


Sitting Height

Length Measurements

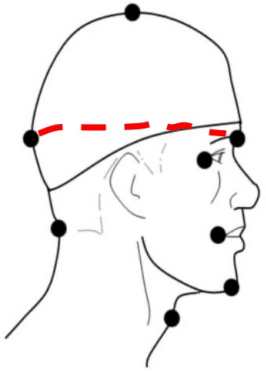


Inter-Fingertip Distance

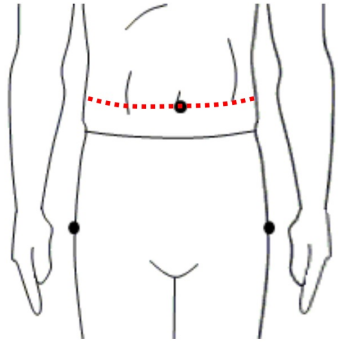


Finger Lengths

Circumference Measurements



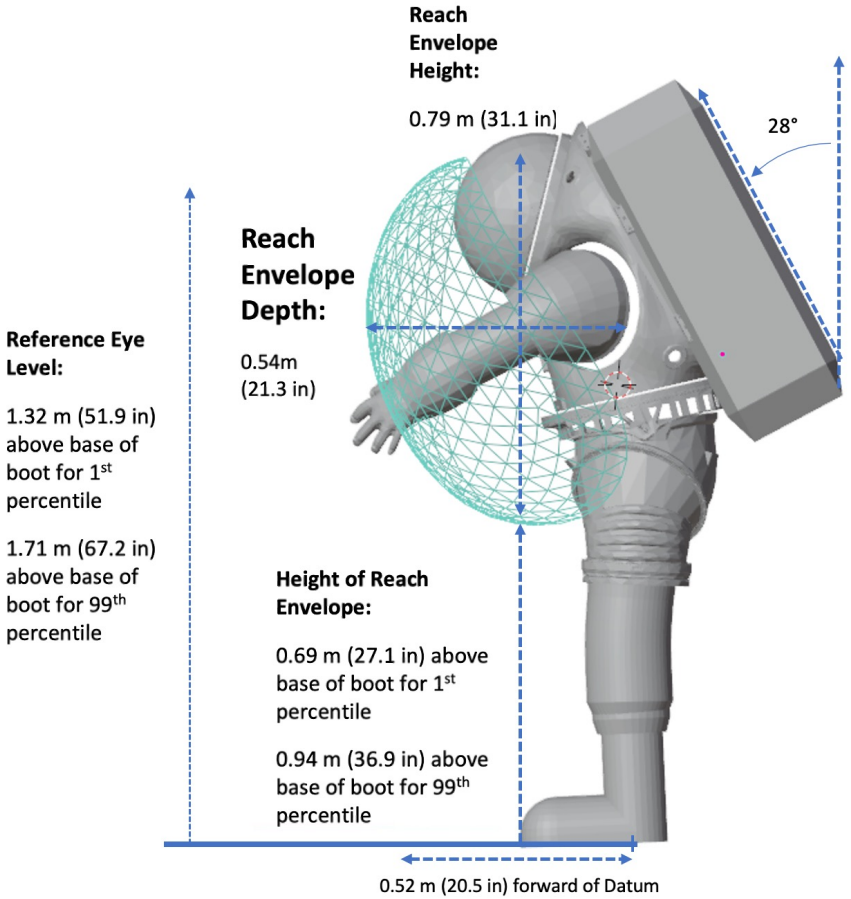
Head Circumference

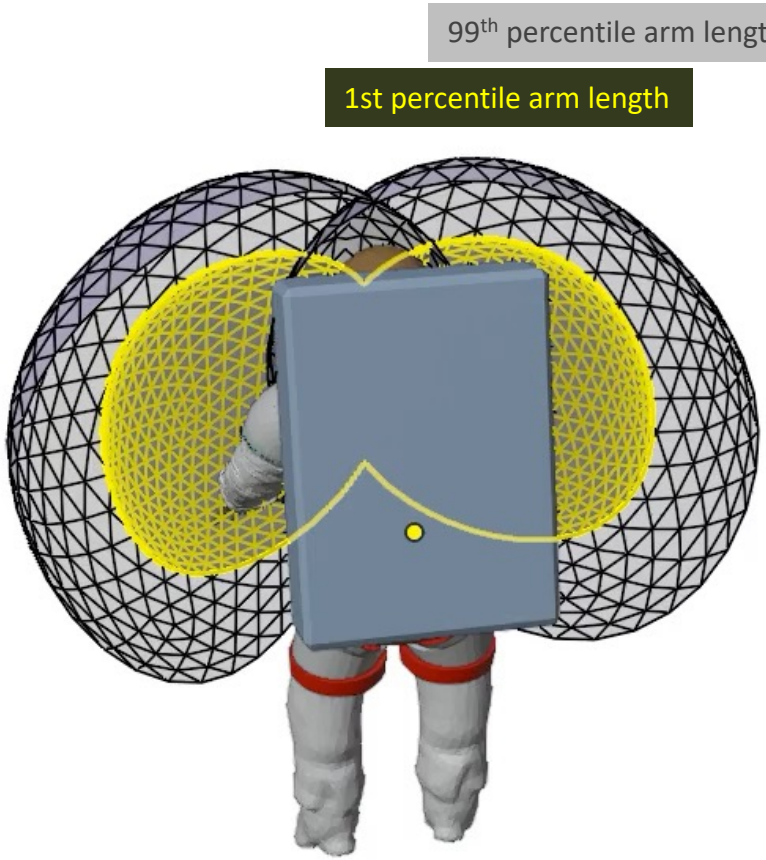


Waist Circumference

Anthropometry for Spacesuit and EVA

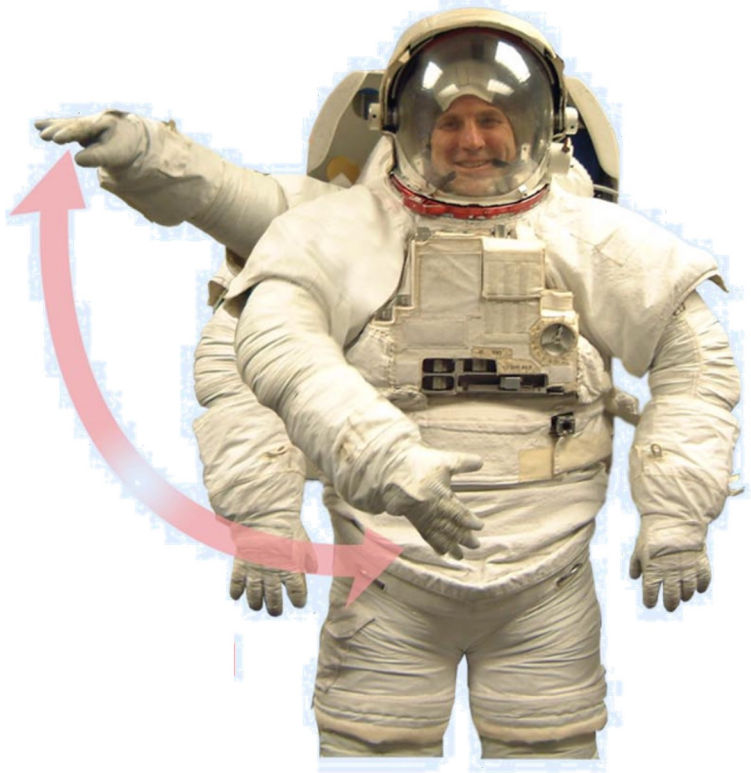
- Anthropometry is closely related to what a suited crewmember can safely perform or can't perform
- Reach capabilities, commonly used for EVA requirements, substantially vary with the individual body measurements

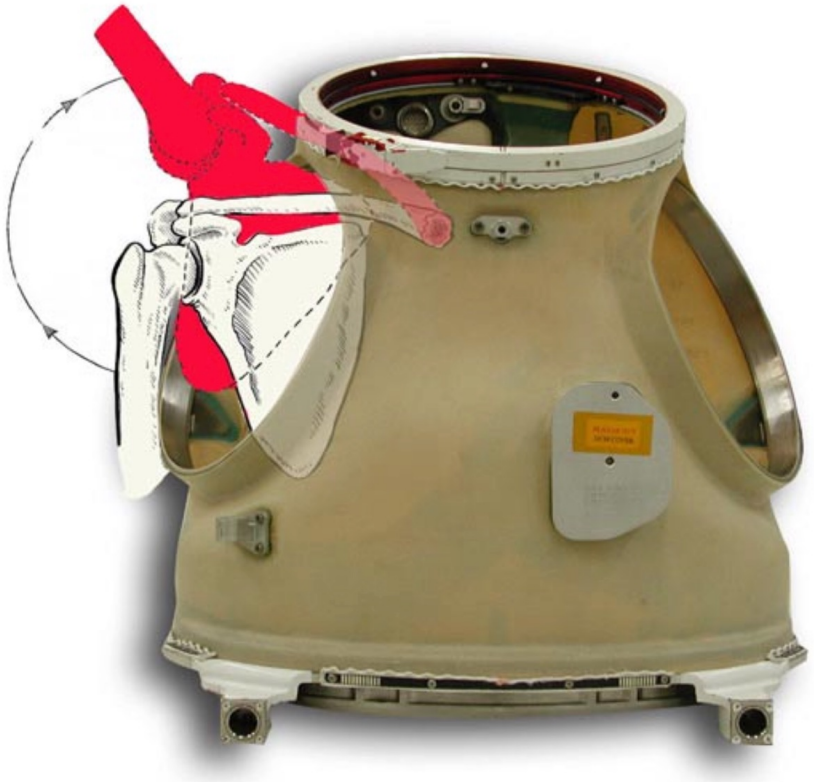




Anthropometry as Contributor to Injury

- Shoulder injuries were reported from persons wearing the heritage EMU suit
- NASA Tiger Team identified suboptimal suit fit as risk factors for injury
- NASA implemented standardized anthropometry definitions and protocols





Changes in Crew Population Characteristics

- Body sizes used to be “homogeneous” in early space ages
- Today, crews are in a wide variety of body sizes
- Optimal design and sizing are crucial for crew safety and performance

Crewmembers in 1960’s

Crewmembers in 2000’s

Artemis Era Crewmembers

Crew Population and Critical Measurement Definition

- Spacesuits are required to accommodate the current and future crew population
- NASA standards and requirements define the crew population anthropometry
  - Parent database based on US Army ANSUR
  - Down selected cases by astronaut age range (35-50 years old)
  - Growth trend was estimated from NHANES, and projected for population characteristics in 2015
  - 1st and 99th percentiles were identified for critical measurements with an aim to accommodate 90% of crew population
- In the past, NASA required to accommodate 5th to 95th measurements
- However, past crew data indicated many body dimensions exceed 5-95th percentile range
- Thus, some hardware did not accommodate 90% crew population

NASA STD 3001

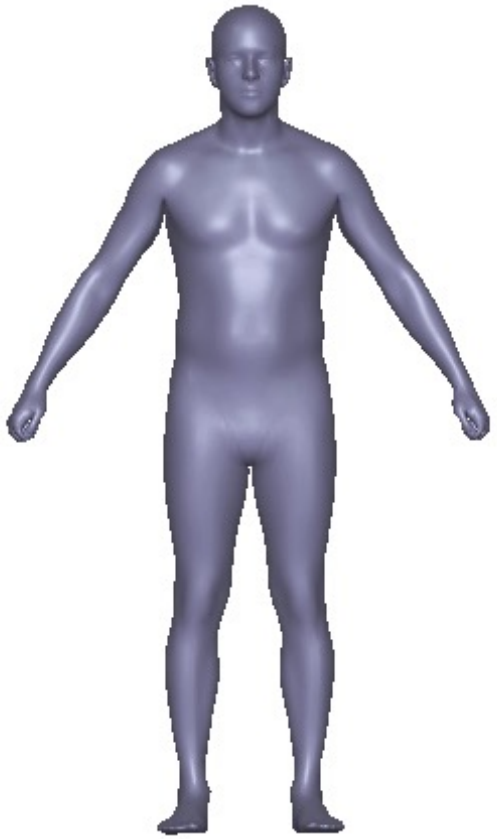
Critical Dimension	Application Example	Minimal Clothing	
		Min (cm, (in))	Max (cm, (in))
Stature, Standing[3]	Maximum vertical clearance	148.6 (58.5)	194.6 (76.6)
Sitting Height[2]	Vertical seating clearance	77.7 (30.6)	101.3 (39.9)
Eye Height, Sitting[2]	Placement of panels to be within line-of-sight	66.5 (26.2)	88.9 (35.0)
Acromial Height, Sitting[2]	Top of seatback	49.5 (19.5)	68.1 (26.8)
Thigh Clearance, Sitting	Placement of objects that may be overlap (panels, control wheel, etc.)	13.0 (5.1)	20.1 (7.9)
Knee Height, Sitting	Height of panels in front of subject	45.5 (17.9)	63.5 (25.0)
Popliteal Height, Sitting	Height of seat pan	33.0 (13.0)	50.0 (19.7)
Wrist Height, Sitting (with arm to the side)	Downward reach of subject	39.6 (15.6)	54.6 (21.5)
Biacromial Breadth	Placement of restraint straps	32.3 (12.7)	44.5 (17.5)
Bideltoid Breadth	Width of seatback	37.8 (14.9)	56.1 (22.1)
Forearm-Forearm breadth	Side clearance envelope, possible seatback width	38.9 (15.3)	66.0 (26.0)
Hip Breadth, Sitting[1]	Width of seat pan	31.5 (12.4)	46.5 (18.3)
Buttock-Popliteal Length, Sitting	Length of seat pan	42.2 (16.6)	57.2 (22.5)
Buttock-Knee Length, Sitting	Placement of panels in front of subject	52.1 (20.5)	69.9 (27.5)

1st percentile

99th percentile

Multi-Dimensional Characteristics of Body Measurements

- Body measurements are multi-dimensional, i.e., body shape may not be defined by one or two measurements
- Even for persons of average stature and body weight, the specific shape variations can be substantial
- The table below shows 10 sample subjects whose stature and body weight are near the 50th percentiles
- Their other body measurements vary substantially within, ranging from 1st to 97th percentiles



Males: 5 ft. 9 in. tall, 165 lb.

Females: 5 ft. 4 in. tall, 155 lb.

Measurement Percentiles

	Head Circumference	Chest Circumference	Waist Circumference	Thigh Circumference
Subject 1	5	70	65	68
Subject 2	84	94	64	59
Subject 3	57	76	43	23
Subject 4	77	97	24	20
Subject 5	77	57	13	33
Subject 6	91	28	54	25
Subject 7	38	60	96	9
Subject 8	14	15	26	72
Subject 9	40	33	54	25
Subject 10	17	36	1	80

Defining Accommodation Thresholds

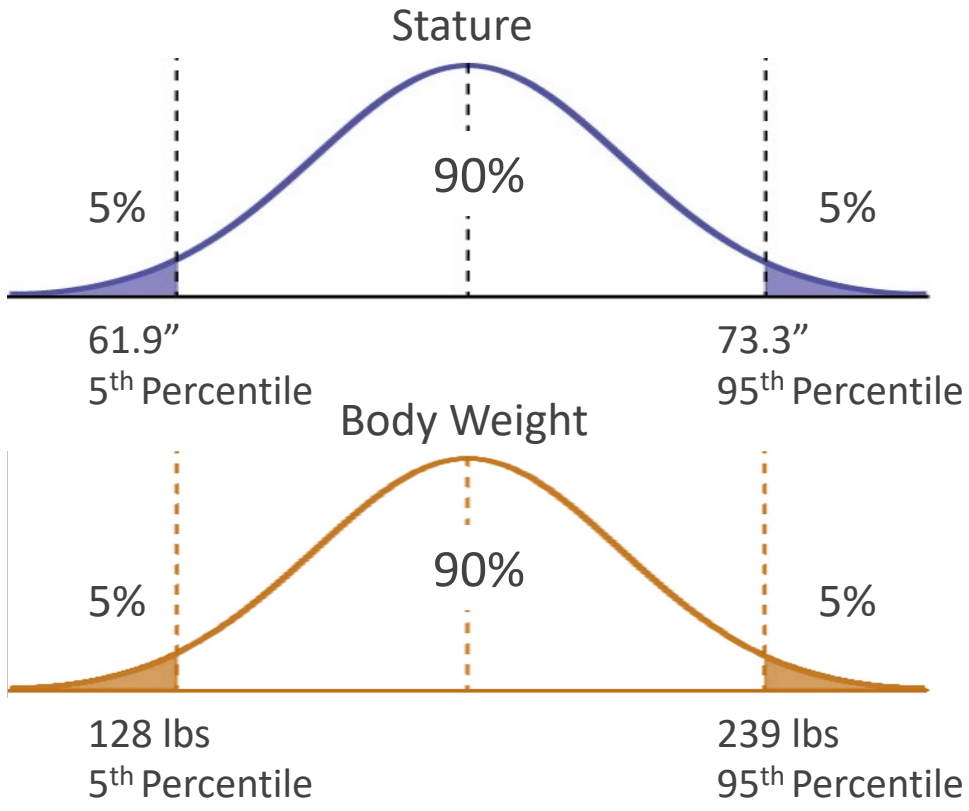
- Multi-variate nature of anthropometric data imposes a unique challenge in design and accommodation
- In most design problems, multiple measurements (e.g., stature and body weight) are simultaneously considered
- For example, some NASA programs intend to accommodate 90% of people in astronaut-like population
- To accommodate 90% of people, at which percentile extreme do we want to truncate each measurement?

Goal: Accommodate 90% of population
So how about 5th & 95th percentiles?

Step 1: Exclude cases with *stature* < 5th percentile and > 95th percentile

Step 2: Exclude cases with *body weight* < 5th and > 95th percentile

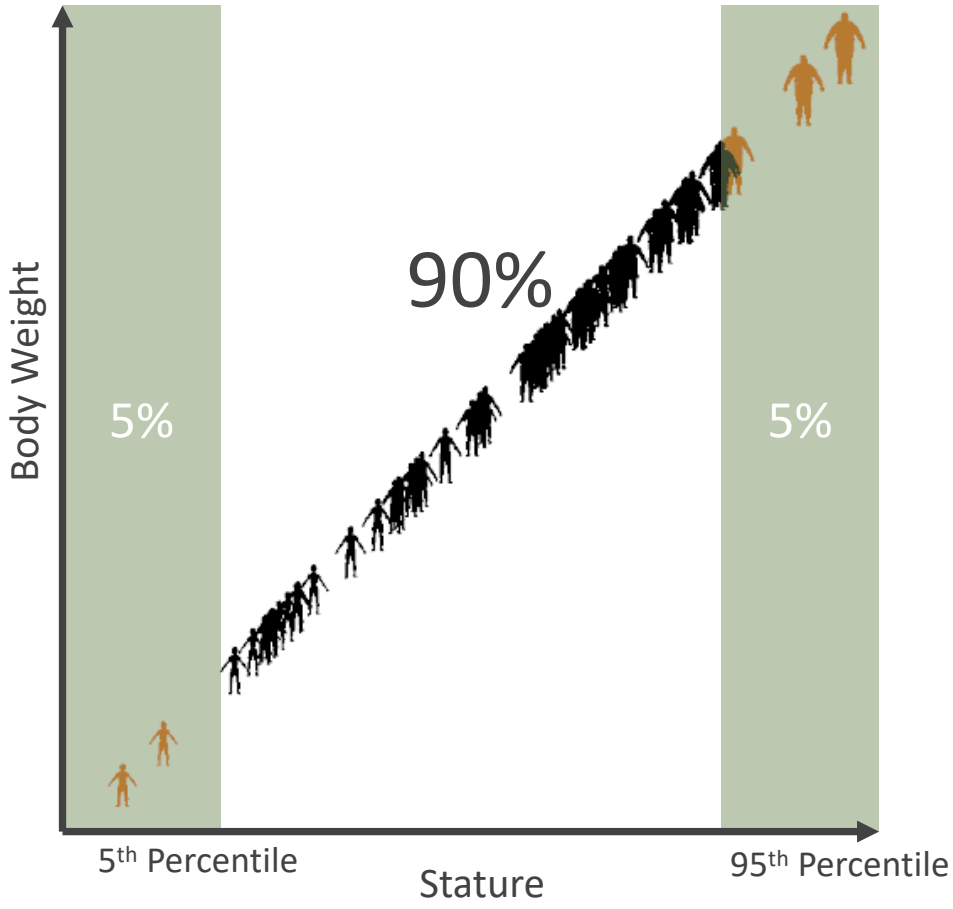
Question: How many people will be remaining after truncations? 90% or 80%?



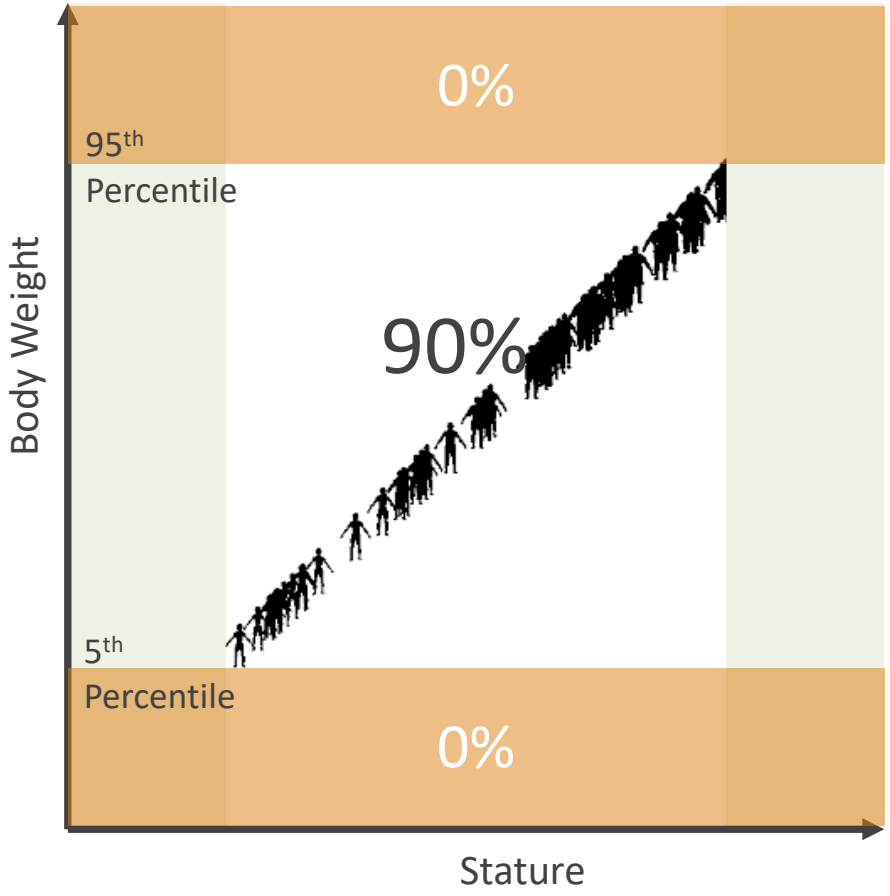
Difficulty of Multiple Measurement Truncation (Univariate Condition)

Hypothetical Univariate-Like Scenario: Stature and body weight perfectly covary with each other

Step 1: Truncate by stature at 5th and 95th percentiles. 90% of cases are remaining after truncation



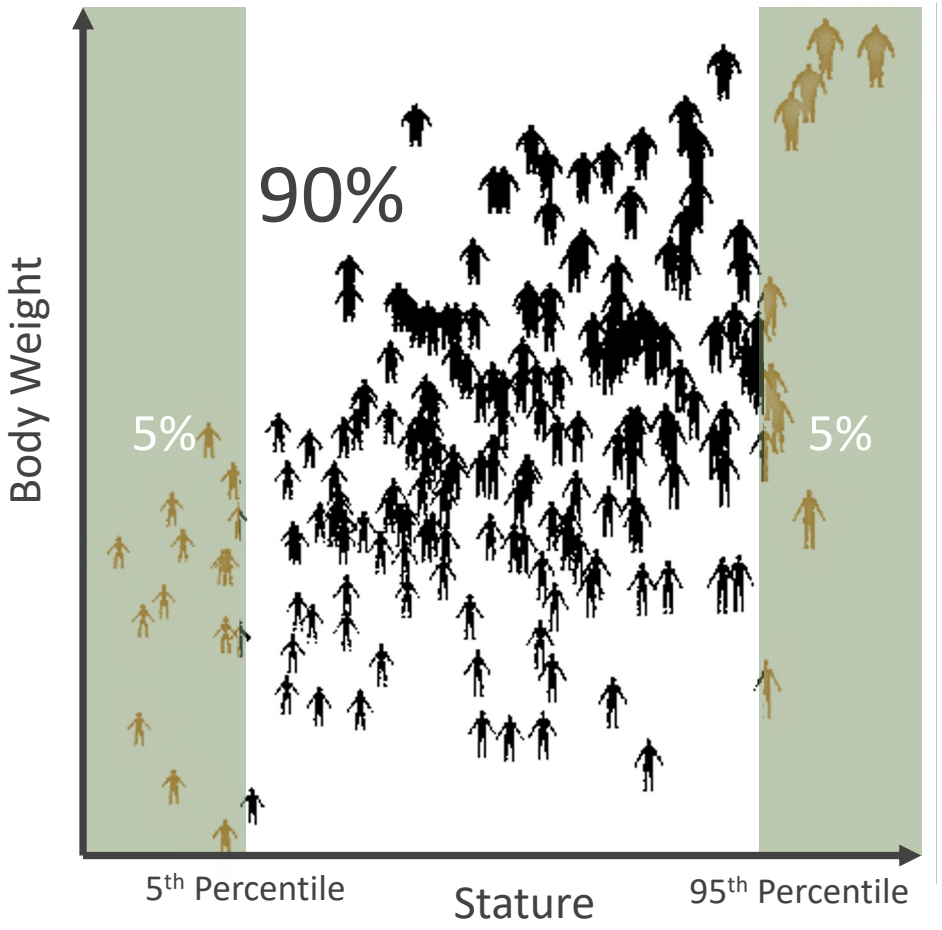
Step 2: Truncate by body weight. But no data left to be truncated. 90% of cases are still remaining.



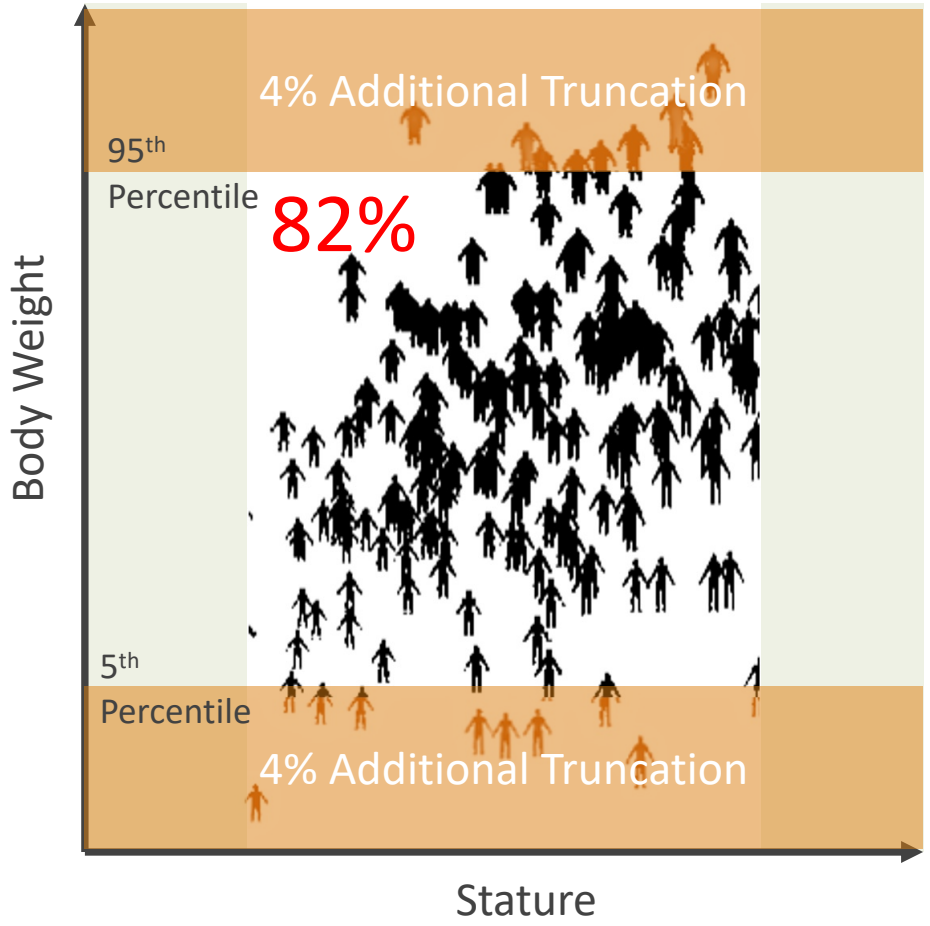
Difficulty of Multiple Measurement Truncation (Multivariate Condition)

Hypothetical Multivariate-Like Scenario: Stature and body weight vary with each other only in part

Step 1: Truncate by stature at 5th and 95th percentiles. 90% of people remain after truncation

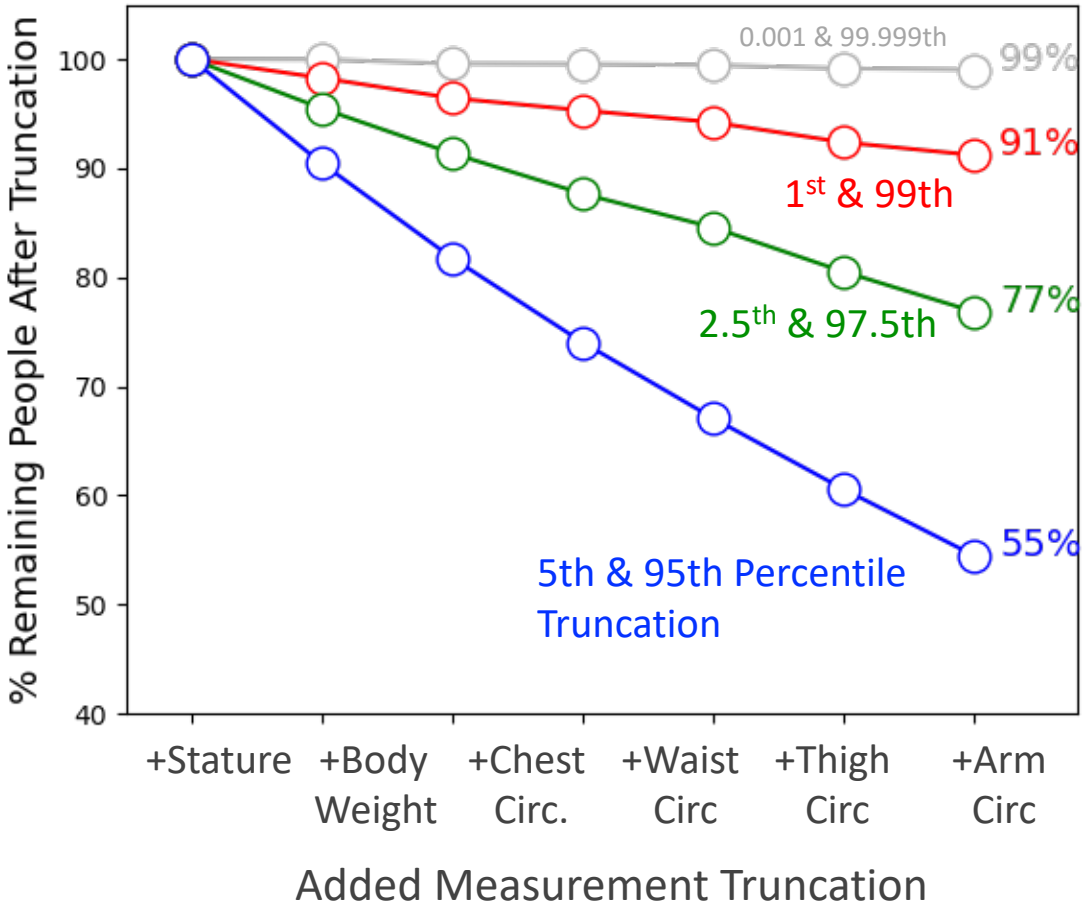


Step 2: Truncate by body weight, additional 8% cases are excluded. 82% of people remain.



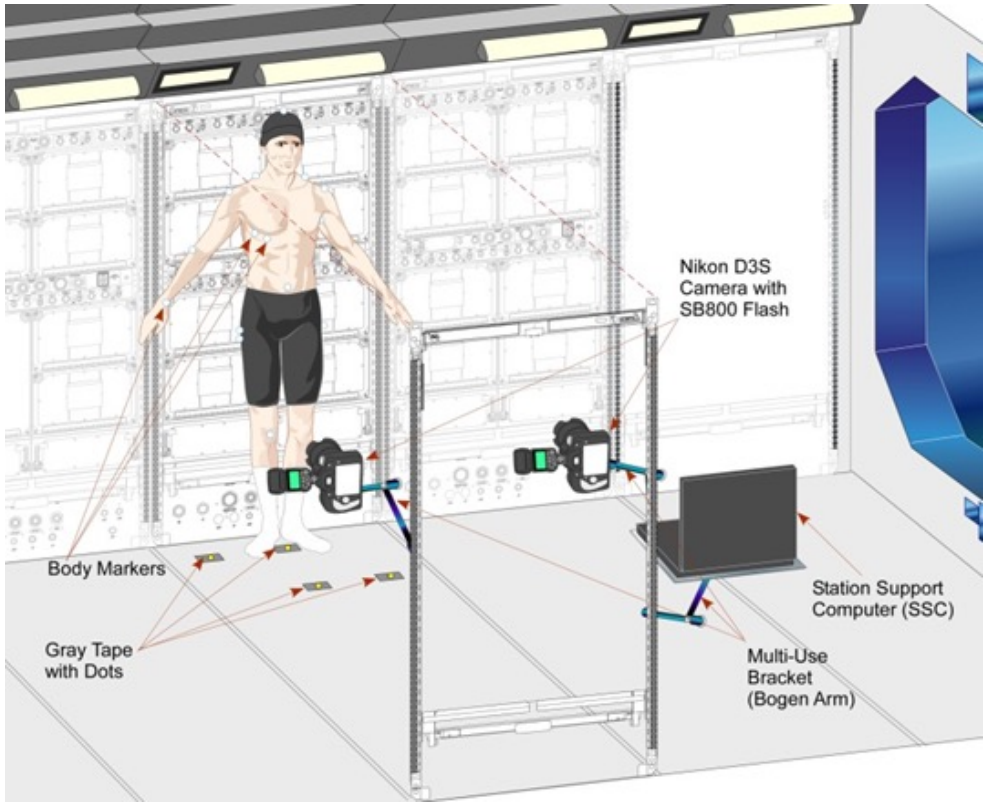
Simulation Results for Multiple Measurement Truncation

- As we include more measurements, more people are excluded with truncation
- For example, if 6 measurements were considered for hardware design:
  - Truncation at 5th and 95th percentiles: 45% of people excluded, 55% retained
  - Truncation at 2.5th and 97.5th percentiles: 23% excluded, 77% retained
  - Truncation at 1st and 99th percentiles: 9% excluded and 91% retained
- In other words, if we want to accommodate 90% of population the data should be truncated at 1st and 99th percentiles, not 5th and 95th percentiles
- If we hypothetically aimed at 99% accommodation, we should have truncated at 0.001 and 99.999th percentiles, which are sensitive to outlier measurements, thus extremely difficult to achieve



Anthropometry Variation with Gravity

- Anthropometry changes in microgravity due to spinal elongation, fluid shift and muscle atrophy
- Effort has been made to measure anthropometry change in ISS and Shuttles
- Measurement consistency was difficult to maintain but acquired usable results

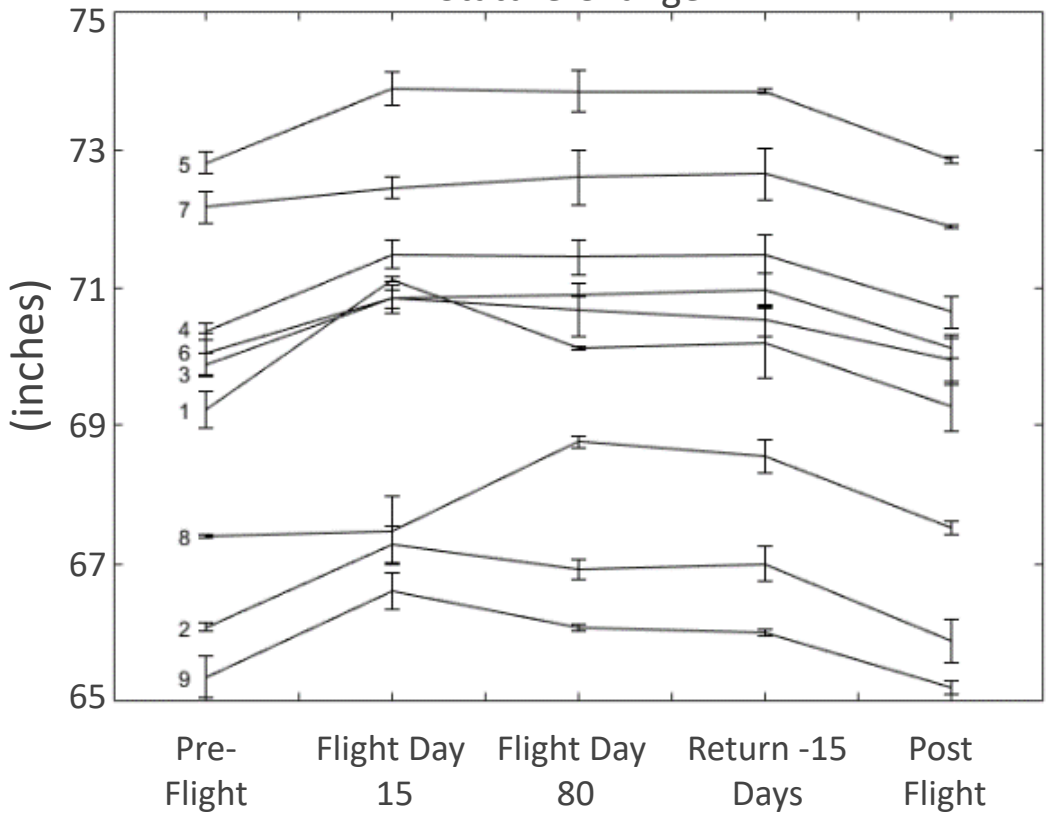


Young et al., 2021

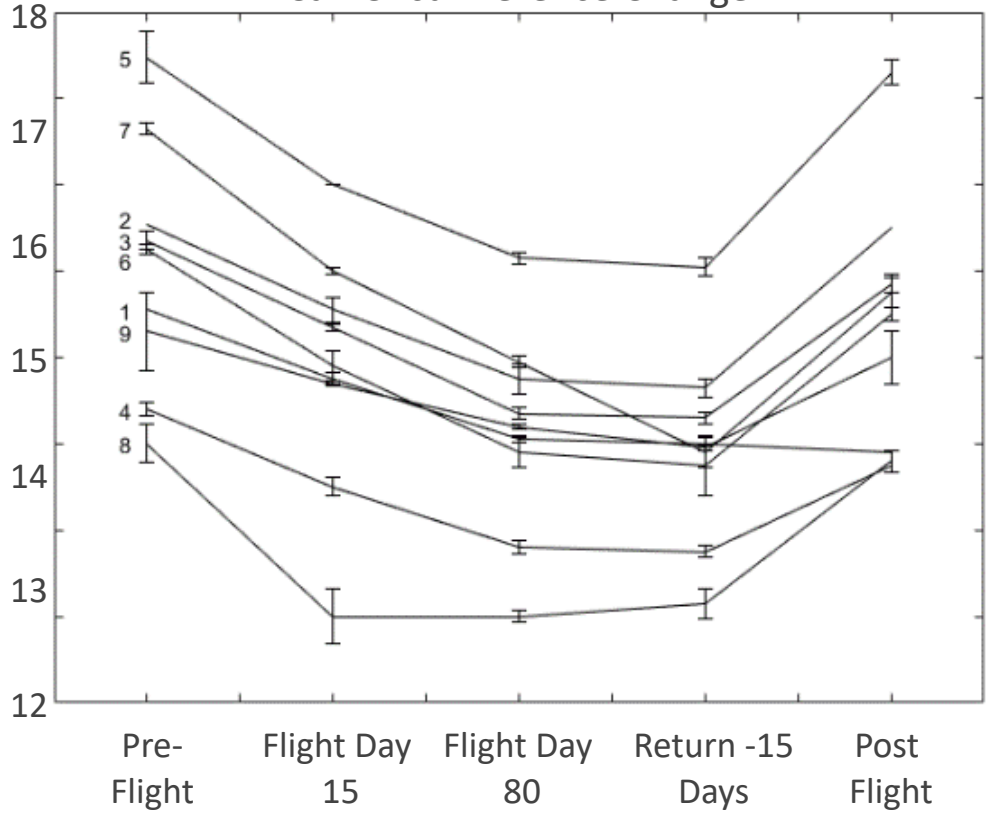
Anthropometry Variation with Gravity

- Upon exposure to microgravity, stature increases by 3% on average (about 2 inches)
- Calf circumference decreased by 11% (1.5”) up to flight day 80.
- Fluid shift and spinal elongation have been hypothesized to be the primary causes
- Anthropometric changes take place within the first 15 days of flight, and return to the nominal after returning

Stature Change



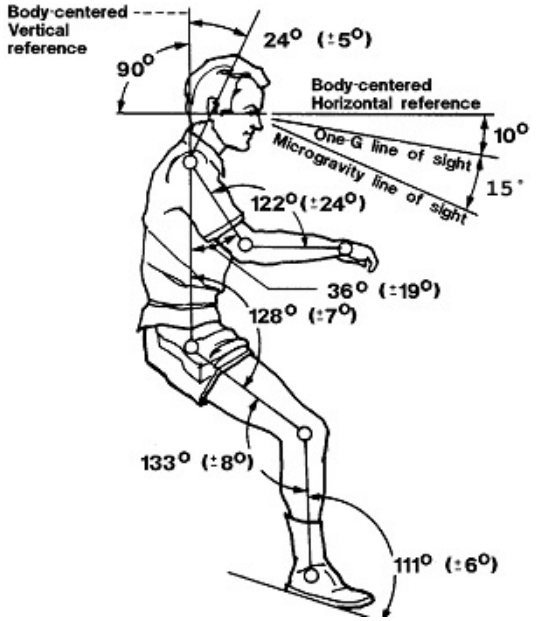
Calf Circumference Change



Measurement Sessions

Neutral Body Posture (NBP)

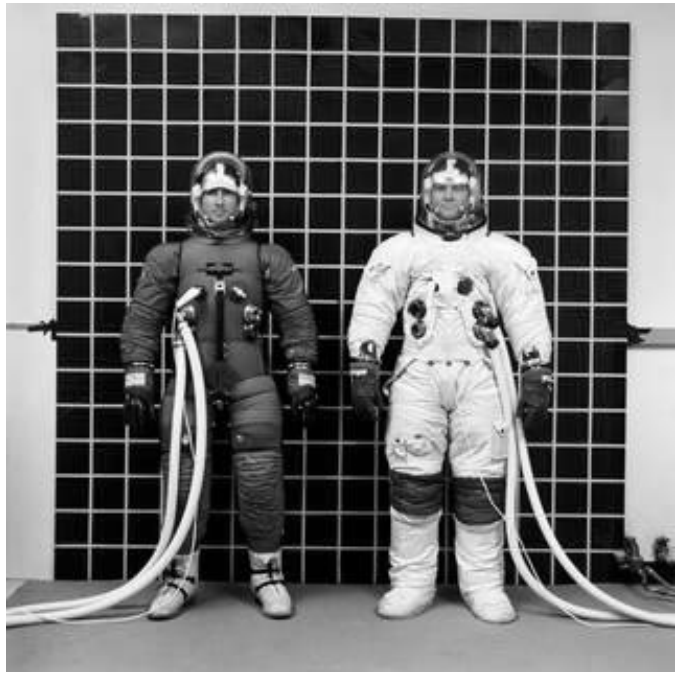
- Human body in 0-g exhibits a unique posture (neutral body posture; NBP), when relaxed and no external forces are applied
- The early designs for spaceflight hardware were based on upright standing or sitting postures without consideration of NBP, resulting in crew discomfort. Maintaining a body posture other than NBP requires significant strength exertions
- The NBP patterns were measured from ISS using photogrammetry techniques and used to build corresponding 3D manikins
- Only 0-g measurements are available. NBP or anthropometry changes in Lunar or Martian gravity environments are unknown

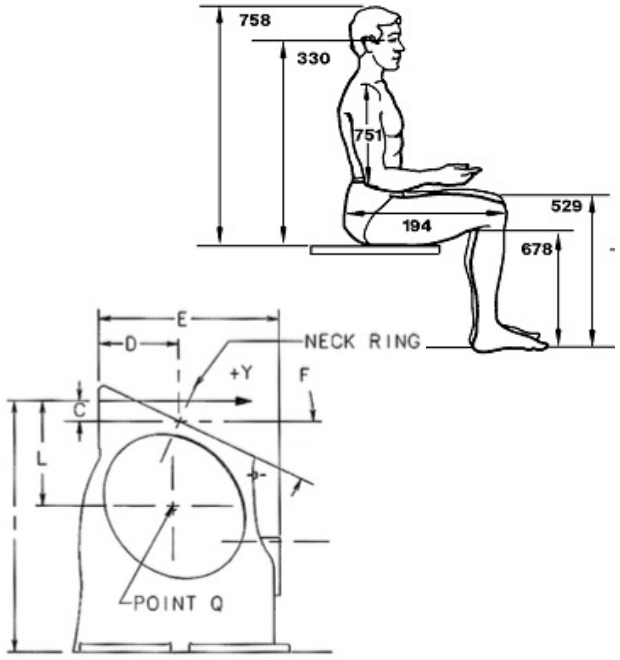


NASA STD-3000

Case Study: 3D Volumetric Assessments as New Approach

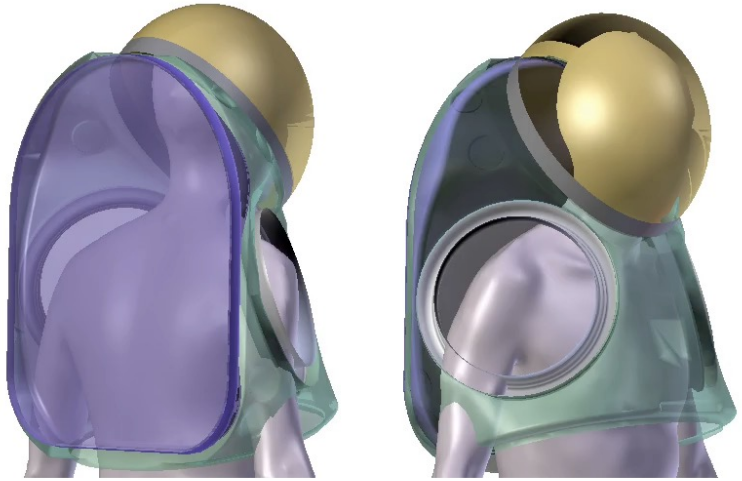
- Linear measurements guided the design of the past and currently deployed suits (Extravehicular Mobility Unit; EMU)
- However, linear measurements do not capture the complex 3D geometry of the human body
- For more complex designs like spacesuits, a lot more critical measurements can be involved
- Thus, matching with 1-99th percentiles for all measurements can be costly and sometimes overly conservative

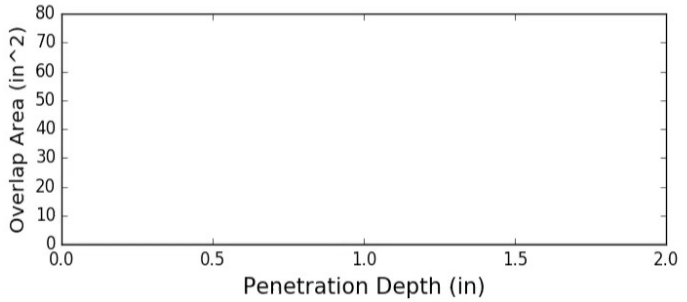




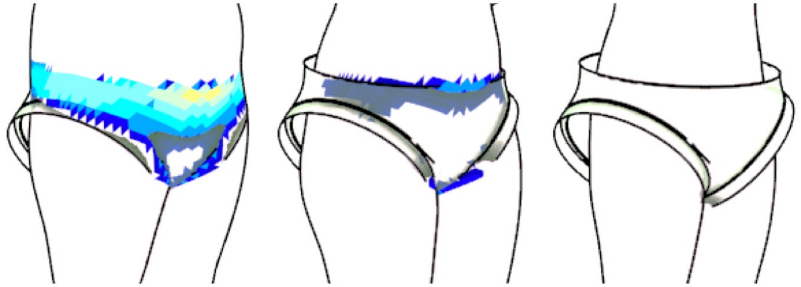
Case Study: 3D Volumetric Assessments (Cont'd)

- Question: can we assess fit directly using 3D body manikins, without relying on linear measurements?
- The next generation government reference design Exploration EMU (xEMU) was developed using volumetric virtual fit tests
- 3D scans overlaid with CAD. Suit-to-body contact location and magnitudes were calculated for hard upper torso (HUT) and lower torso assembly (LTA)

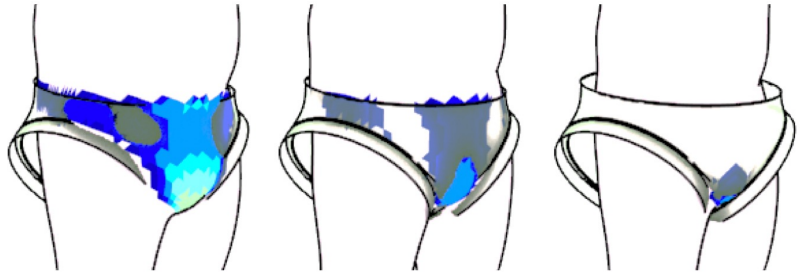




Female Cases



Male Cases

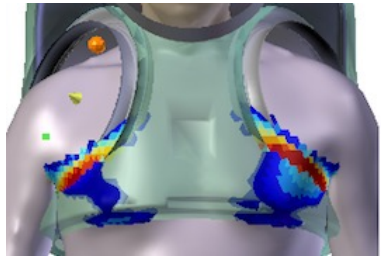


Davis et al., 2020

Case Study: 3D Volumetric Assessments (Cont'd)

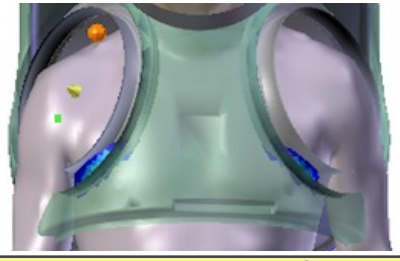
- The contact patterns were used as parameters for a fit probability model, which was trained by physical fit test outcome
  Probability(Fit) = f(suit-to-body contact patterns)
- Physical fit test subjects were selected from the "borderline fit" group and assessed for fit using 3D printed mockup

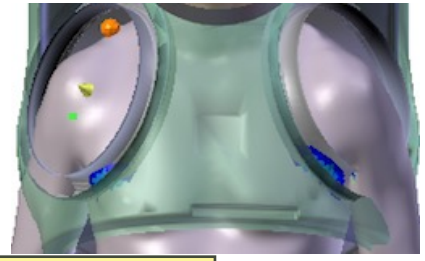
Maximum Overlap



Unlikely to fit

Intermediate Overlap



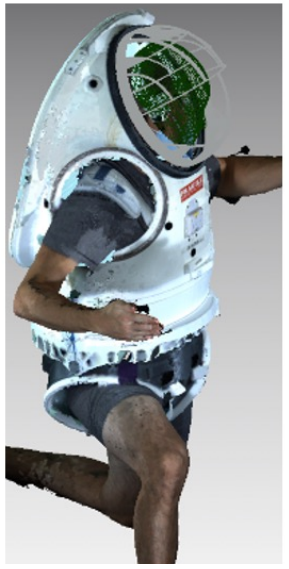


Borderline fit

Selected for physical tests

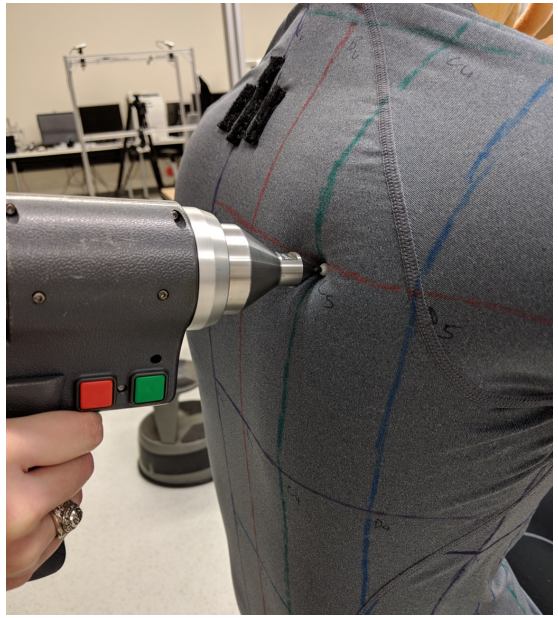
Minimum Overlap

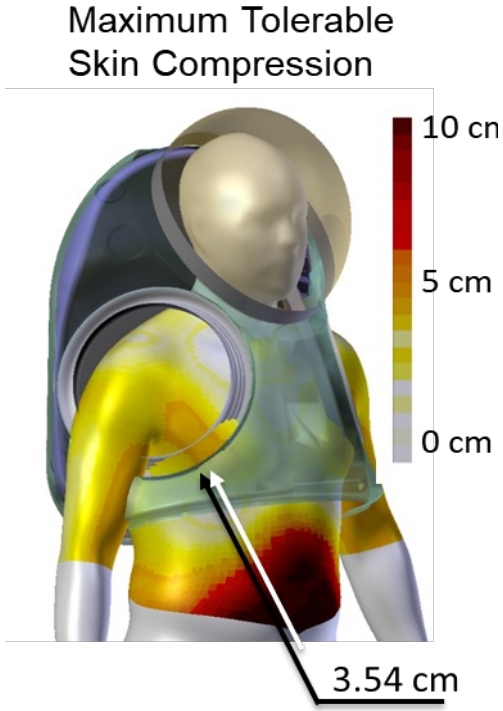
Likely to fit

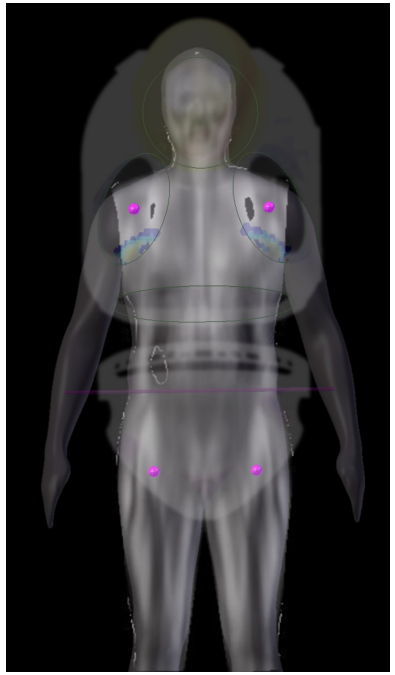


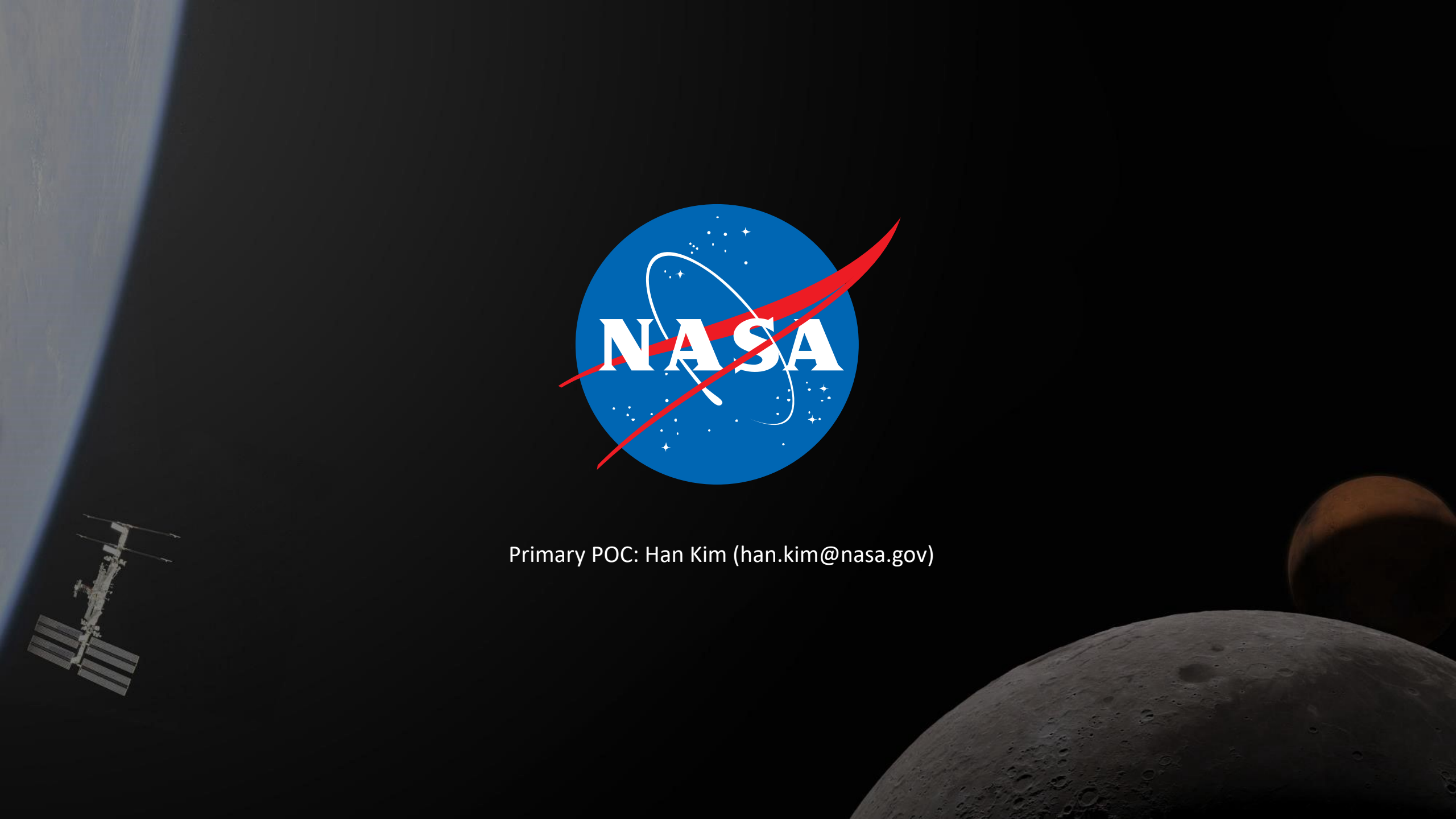
Case Study: Suit-to-Body Contact Measurements

- 3D scans quantifies the outer surfaces only, without considering of skin compressibility or individual tolerance. However, body compressibility often matters for spacesuit and hardware designs
- A NASA study explicitly measured body compressibility, and matched with suit-to-body contact assessments
- Suit-to-body contacts were “virtually” assessed through 3D scans. However, a new technique used different imaging systems, for example, DEXA (dual x-ray absorptiometry) scanning, which allowed for direct contact measurements









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