Anthropometric Measurement Procedures at the Anthropometry and Biomechanics Facility

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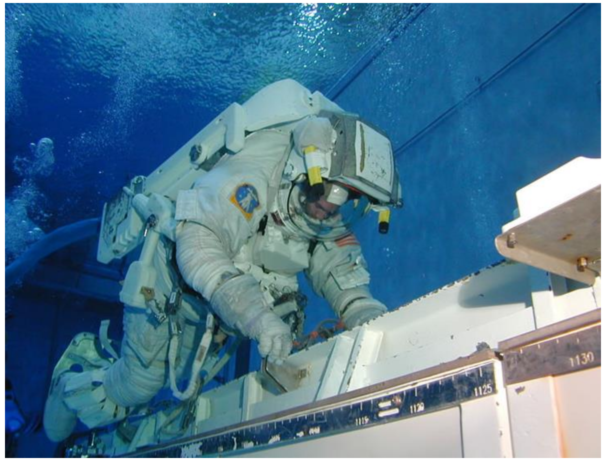
Background

Anthropometry and Biomechanics Facility (ABF) is the central source of crew and test subject anthropometry at NASA

- Anthropometry is essential for designing and verifying that spacesuits, vehicles, and equipment accommodate the physical size, shape, reach, range of motion, and strength of the crewmember population
  - Adjustments for external factors (e.g., gravity, clothing, suit pressurization, deconditioning) on crewmember anthropometry, biomechanics, and strength must also be included in the human-system integration

- Examples of anthropometric data usage at NASA
  - Spacesuit design, sizing, fit assessments, and reduced gravity simulation settings
  - Vehicle and habitat design, verification of crew accommodation
  - Test subject selection for Human in the Loop tests (HITLs)
  - Crew Selection



Suited testing in reduced gravity analogs (NBL to the left, ARGOS to the right)

HITL inside Orion mockup

ABF Measurements: Motivation

- ABF protocol was initially established as an outcome from the Shoulder Injury Tiger Team report (Williams et al., 2003)
  - Injuries were reported from microgravity analog training in Neutral Buoyancy Laboratory
  - Some injuries were associated with suboptimal suit fit
  - The report recommended developing and deploying a laser-based 3D body scanning protocol for sizing crew in spacesuits
  - The report also recommended establishing a consolidated and centralized group for anthropometry data
- Previously, anthropometry measurements were taken by different organizations/groups within NASA
- The different groups used a variety of definitions and protocols resulting in inconsistent measurements

ABF Protocol Evolution

- As ABF measurements became the standard dataset for NASA, more critical measurements have been identified and added to the database (e.g., suit-specific measurements, vehicle interface measurements, seat dimension related measurements)
- More programs have incorporated standards and requirements based on ABF measurements
  - Commercial Crew Program (CCP), Orion, Extravehicular Mobility Unit (EMU), Soyuz, Human Landing System (HLS), and Gateway

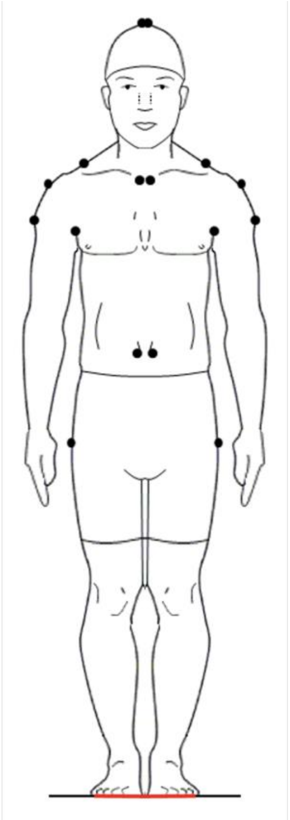
Seated Posture in Soyuz

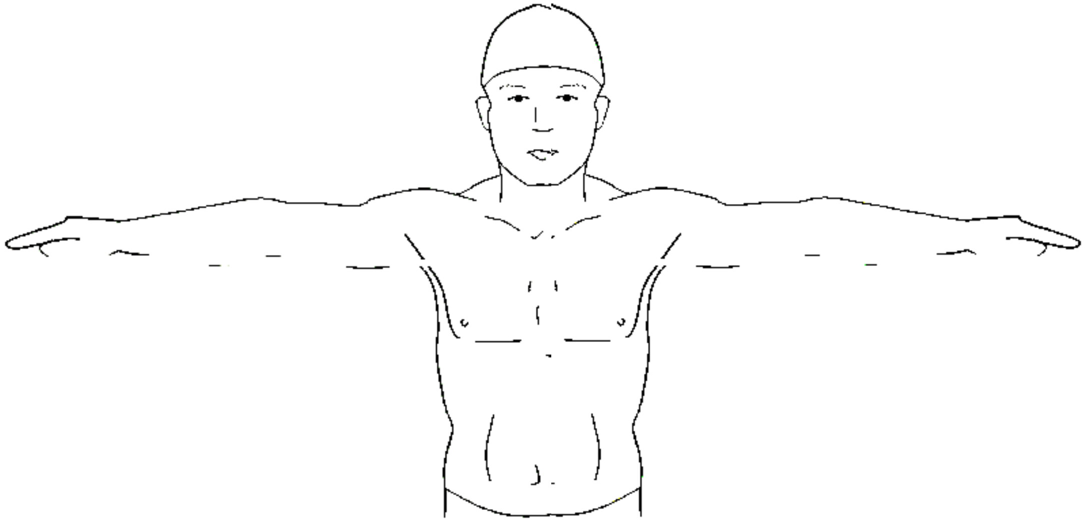
Training in EMU at NBL

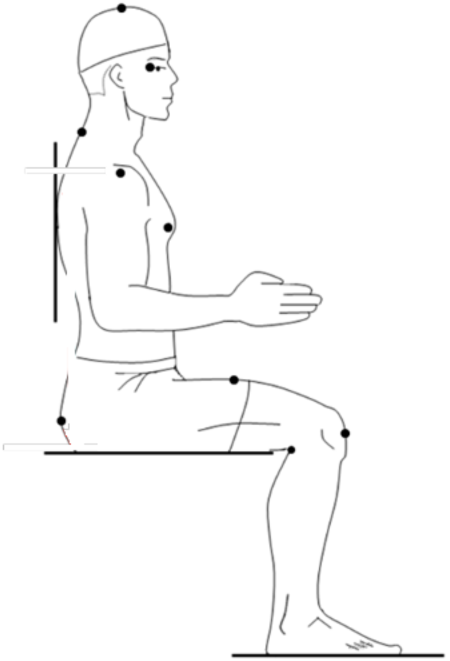
Evaluations in CCP Mockup Vehicle

ABF Database

- ABF collects measurements from crewmembers and test subjects
- ABF currently has a database of over 300 subject's anthropometry measurements
- Each person gets measured for approximately 100 dimensions in standing and seated poses
- Hands, fingers, and feet are also measured for lengths, breadths, and circumferences

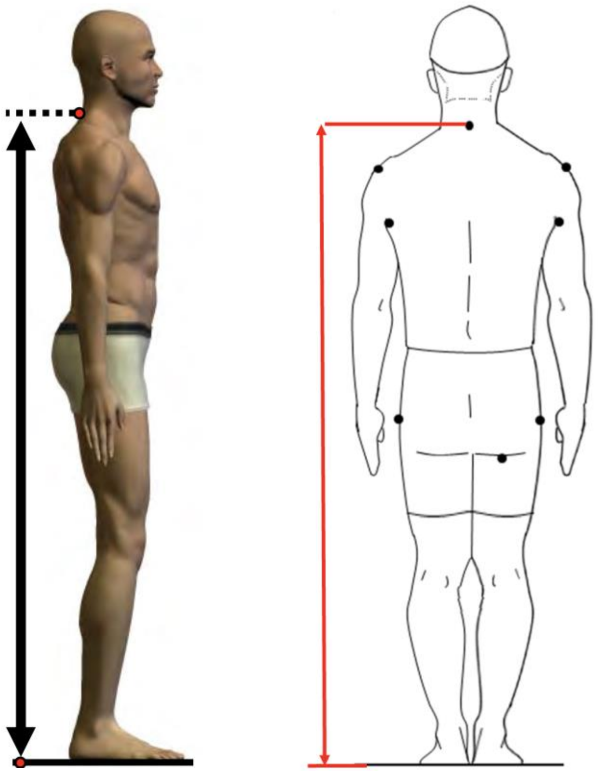




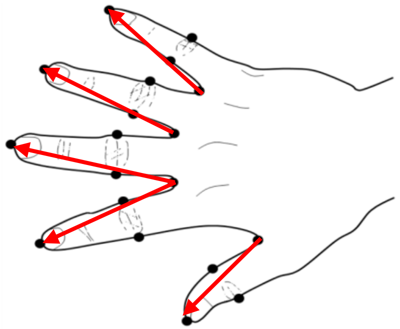


Measurement Definitions

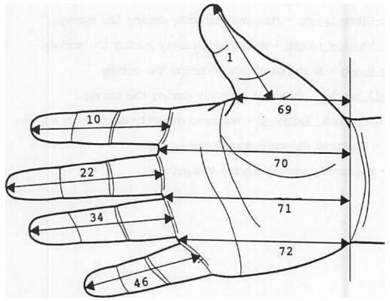
- Many measurements, including stature, cervical height, sitting height, etc., are defined similarly to US Army ANSUR 1988
  - ANSUR II 2012 data not used because
    - Does not include full set of measurements included in NASA requirements (e.g. seated postures)
    - Landmark definitions changed for some measurements (e.g., chest landmark)
- Some measurements are different from ANSUR, or newly created for spacesuits and space hardware. Some examples of these differences are:
  - Digit Length: measured from crotch, intended for glove fit
  - Maximum Circumference: measured at max circumference vs standardized landmark
  - Spacesuit Specific: measurement for communications carrier electric module (CCEM)



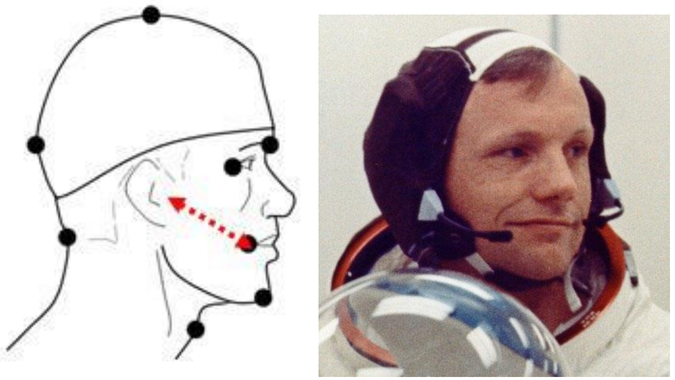
ANSUR (left) and ABF (right) cervical height are defined the same way



ABF Digit Length Definition



ANSUR Digit Length Definition



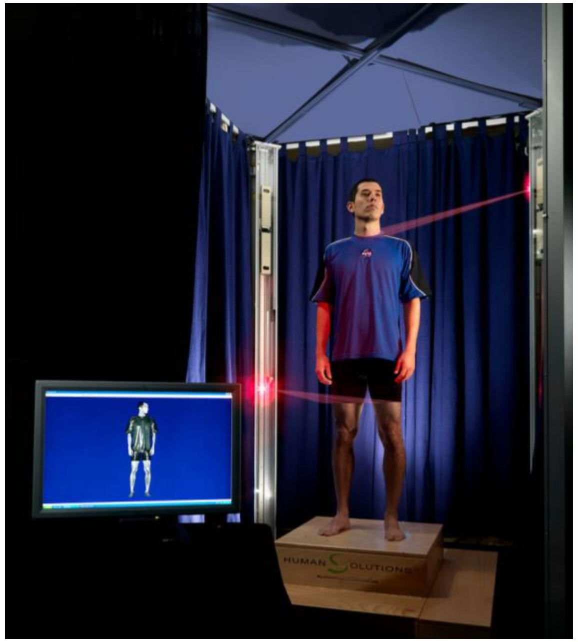
Measurement for CCEM

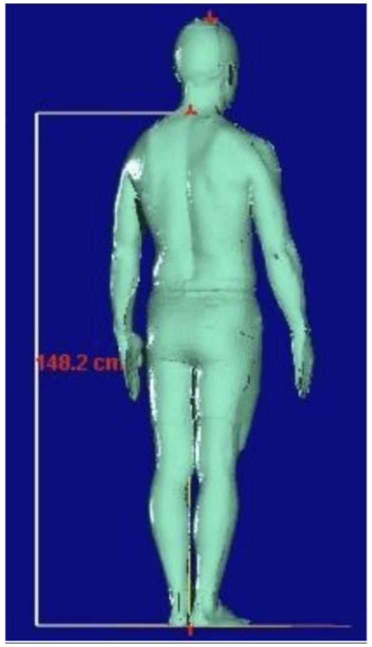
Specific Measurement Methods

ABF primarily uses laser scanning to collect data, then measurements are extracted from scans. However, select measurements taken manually without laser scanning.

Laser Scanning

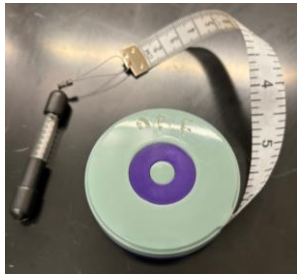
- Equipment
    - 3D laser scanner (whole body scanner, hand/foot scanner), bead markers, hair cap, scan wear consisting of biker shorts (+ sports bra for female subjects)
- Protocol
    - Bead markers are applied to subject's anthropometric landmarks
    - Subject is scanned multiple times in 12 whole body postures, 2 hand postures, and 1 foot posture
    - Measurements are extracted from scans and quality control applied
    - Finalized dataset is added to database





Specific Measurement Methods (Cont'd)

- Manual Measurements
  - Select suit-specific measurements are taken manually without scanning
  - Equipment
    - Anthropometer, measuring tape, scale
  - Protocol
    - Multiple measurements taken for each dimension and then remeasured if out of observer error
    - Spring-loaded tape measures are used to control tension
    - For crotch-related measurements, subjects self-measured and were instructed to raise the caliper blade maximally



Method Comparison

LASER SCANNING

Pros

- Allows remeasuring or taking new measurements without calling back subjects (e.g., crewmembers in flight)
- Better quality control - multiple measurements in the same posture and multiple measurers
- 3D geometric data available for modeling and virtual fit assessments

Cons

- Additional processing time for extracting data from scans and conducting quality assurance
- Skin compression may not be included

MANUAL MEASUREMENTS

Pros

- No separate data processing required after collection
- Measurements can be taken from direct contact with the body with controlled skin compression

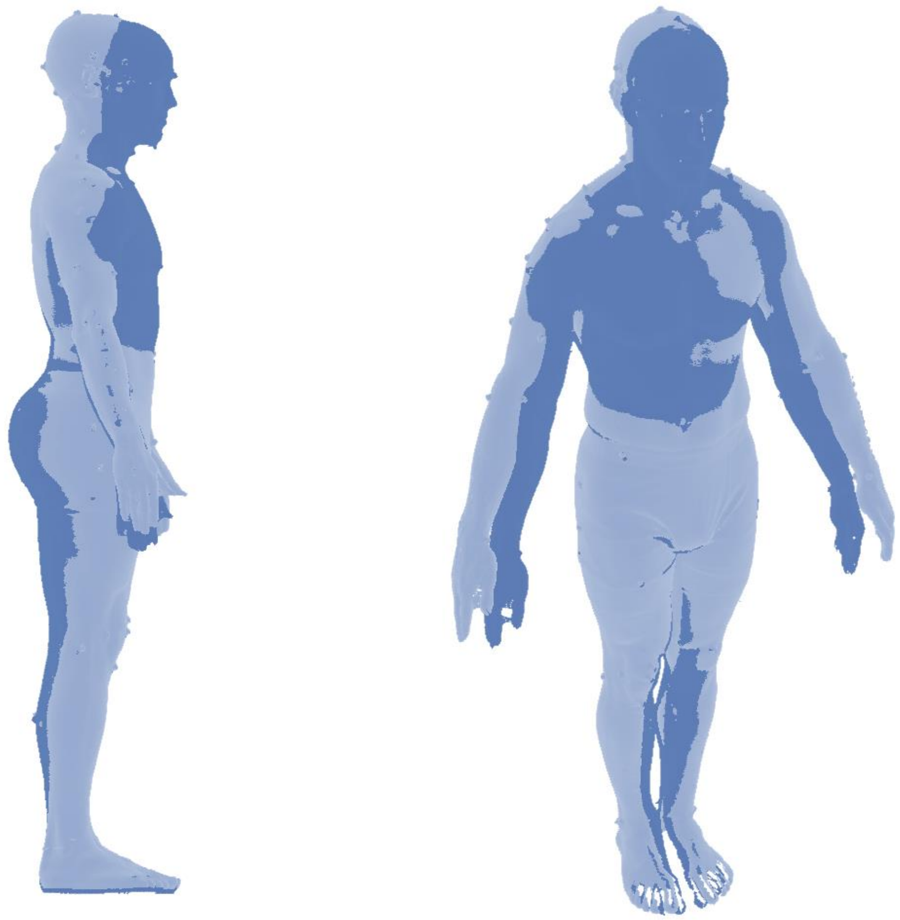
Cons

- Measurements may not be easily cross checked or validated
- Subjects need to be present in person for remeasuring or error correction
- 3D geometric data is not available for modeling and virtual fit assessments
- Posture differences are not easily identified

Potential Sources of Measurement Inconsistency

Multiple sources of inconsistency for both methods
- Misplaced marker/landmark identification
- Typos
- Postural changes
- Subject variability (hypermobile joints, spinal alignment/twisting, etc.)

These errors are more easily identified and corrected in the laser scanning process



Error Mitigation and Quality Assurance

Scan Measurements

- After each scan, landmarks are verified against a checklist; if any landmarks have fallen off or invisible, scan repeated
- Each dimension gets measured by multiple trained staff
- For each measurement, variations are assessed across the multiple measurers' measurements against predefined intra-observer and inter-observer tolerance limits
- If variations are above the predefined limit, extractions are iterated
- Once all variations are within the limit, the measurements are averaged for each dimension

Manual Measurements

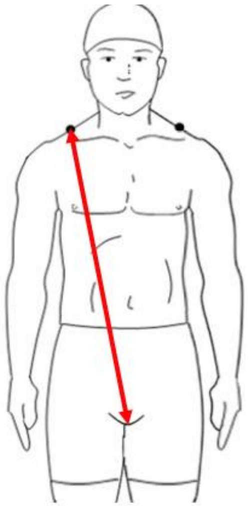
- Each measurement is taken several times and checked against expected observer error
- If variation is above the predefined limit, the measurement is remeasured

Case Studies:
Applications of ABF Measurements

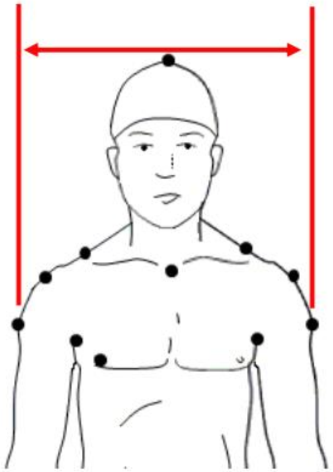
Test Subject Selection

- Test subjects are selected for human in the loop testing for suit or hardware
- Test subjects with extreme sizes and/or unique body shapes are prioritized
- Critical body measurements are first identified depending on the hardware types (e.g., spacesuit, seat, helmet),
- Selected measurements should sensitively influence accommodation, performance, or comfort/discomfort
- Measurements are sampled from the ABF database for specific subject types (crewmembers, non-crew subjects)

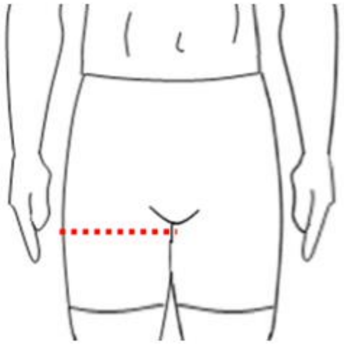
Torso Length



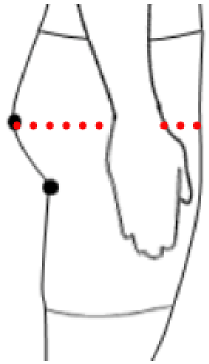
Shoulder Breadth



Thigh Circumference

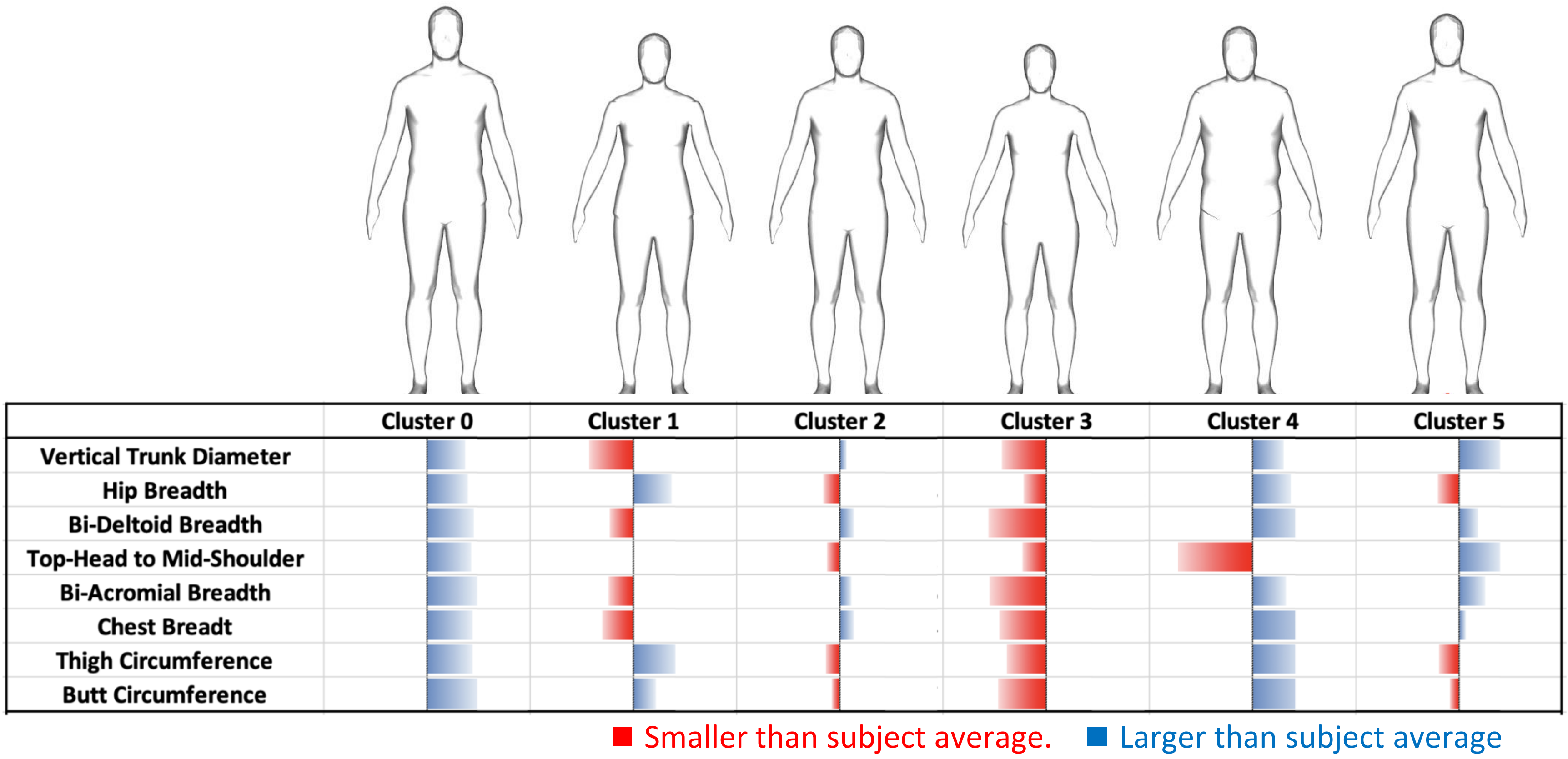


Buttock Circumference



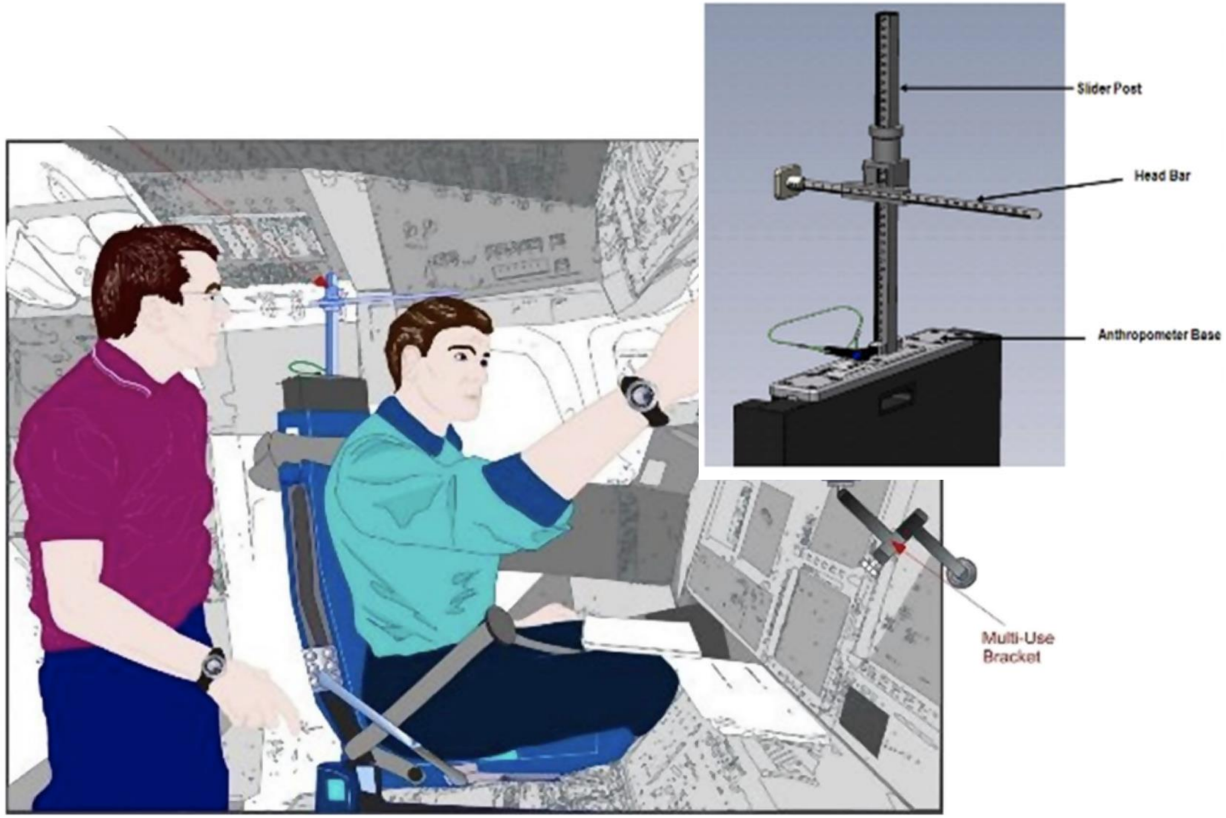
Test Subject Selection (Cont'd)

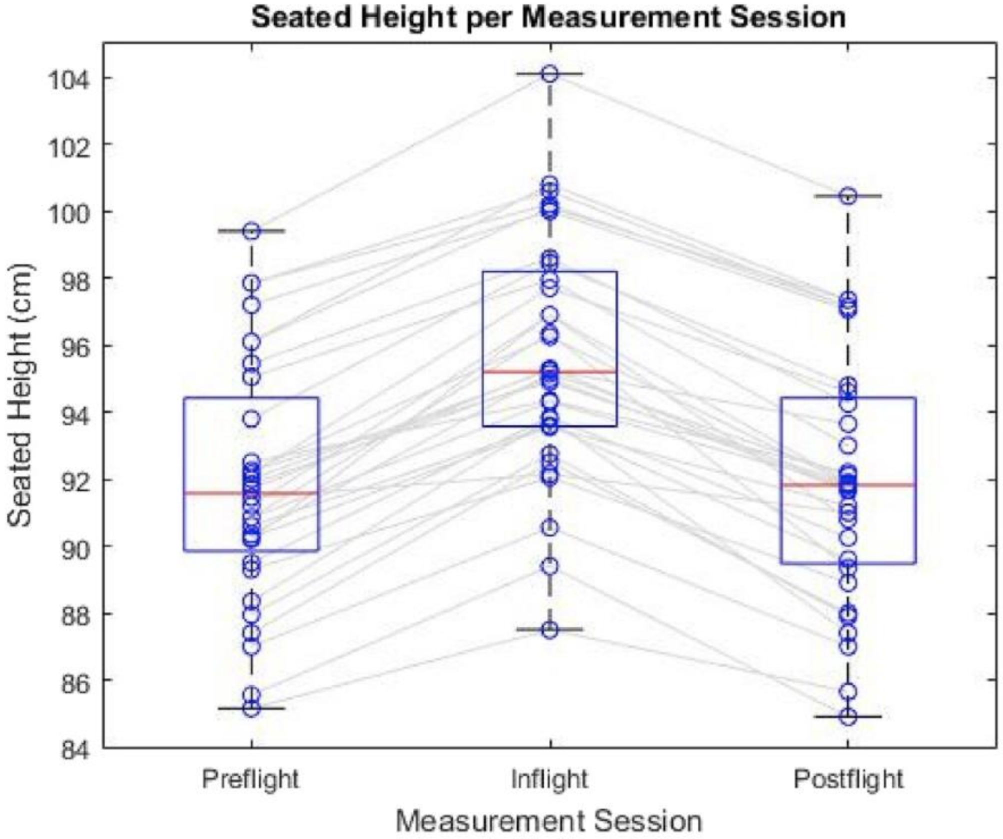
- Measurements were dimensionally reduced by principal component analysis (PCA) and grouped by a clustering method to identify "unique" body shapes and sizes
- The clusters determined the minimum number of subjects to be tested and corresponding test priority
- Subjects located in the extreme ends within the cluster were prioritized for testing



Measurement Variations in Microgravity

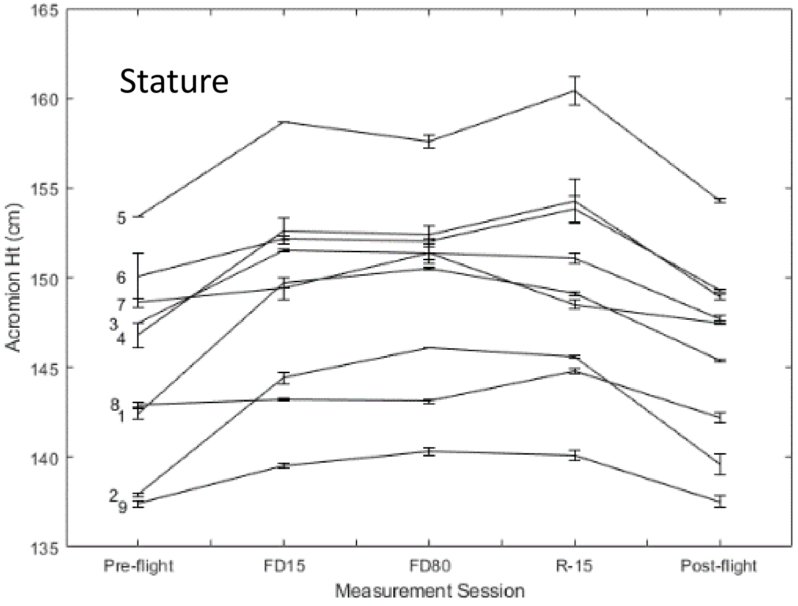
- Body shape and size tend to change in microgravity, due to fluid shift and spinal elongation
- Seated heights were measured from 29 astronauts in International Space Station and Shuttle flight, using the anthropometer installed in commander seat
- Seated height increased by 6% in microgravity flight compared to preflight and postflight conditions.

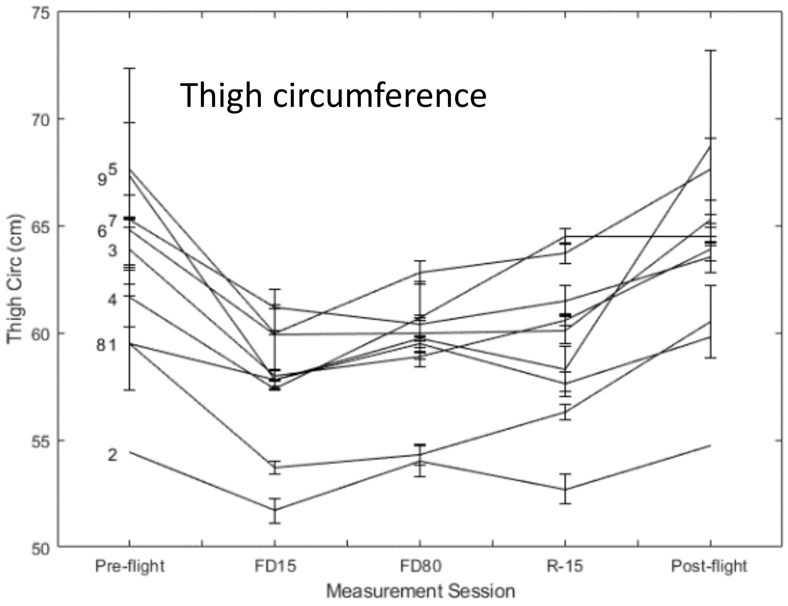




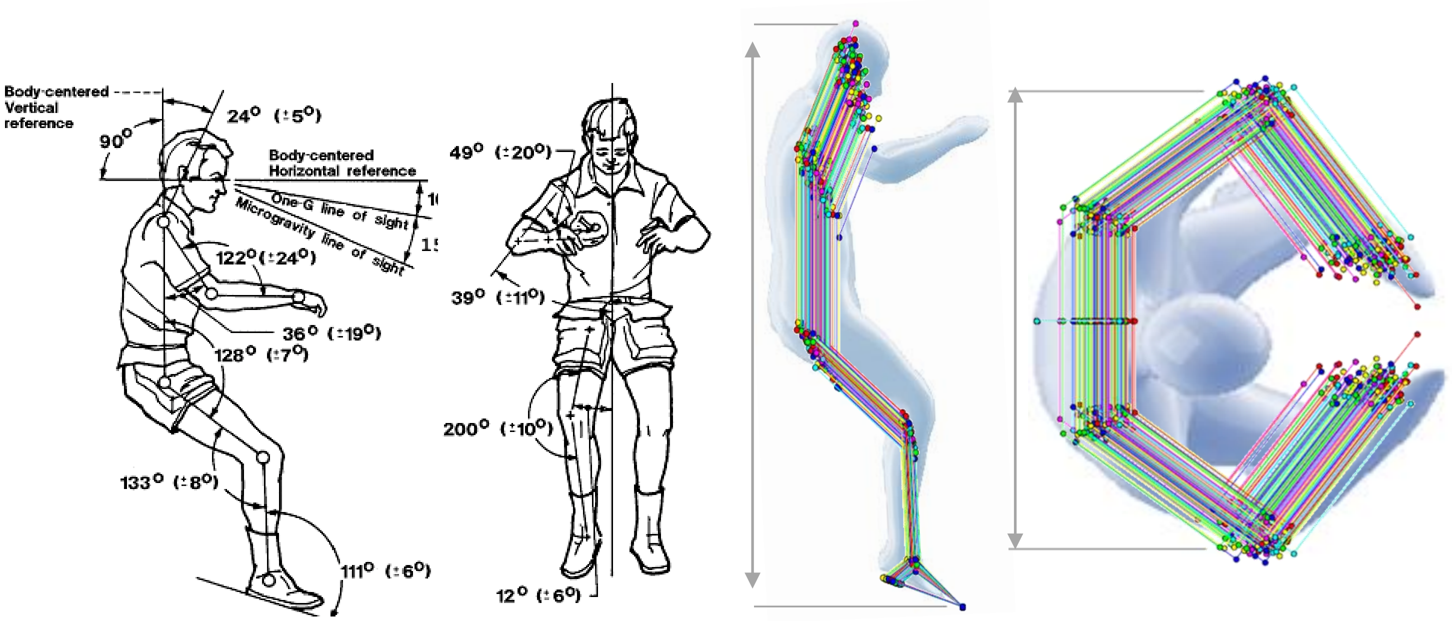
Measurement Variations in Microgravity (Cont'd)

- Standing height and other segment lengths were measured from 9 crewmembers in International Space Station
- Heights and lengths were measured using landmark-based photogrammetry; circumferences were self-measured using tape measure
- 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.
- Anthropometric changes take place within the first 15 days of flight, and return to nominal after return





Crew Accommodation in Vehicles



Whole body anthropometry for a crew population was used to determine microgravity vertical and horizontal clearances in a neutral body posture

Can apply a similar method of modeling population anthropometry to determine clearances in vehicles in other postures

Future Work

- Suited anthropometry in functional postures
- Anthropometry changes in Lunar and Martian gravity
- 3D body scanning in space

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