NASA-STD-3001 Technical Brief

Anthropometrics and Crew Physical Characteristics

OCHMO-TB-049

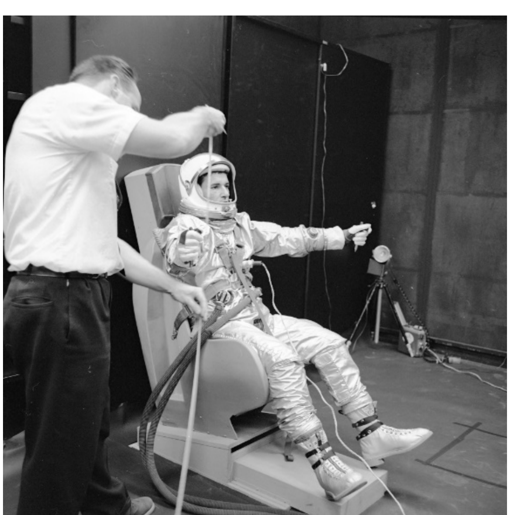
Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev E
[V2 3006] Human-Centered Task Analysis
[V2 3101] Iterative Developmental Testing
[V2 4102] Functional Anthropometric Accommodation
[V2 4103] Body Mass, Volume, and Surface Area Data
[V2 4104] Crew Operational Loads
[V2 4105] Withstand Crew Loads
[V2 4013] Muscle Effects
[V2 11024] Ability to Work in Suits
Appendix E: Physical Characteristics and Capabilities Data Sets

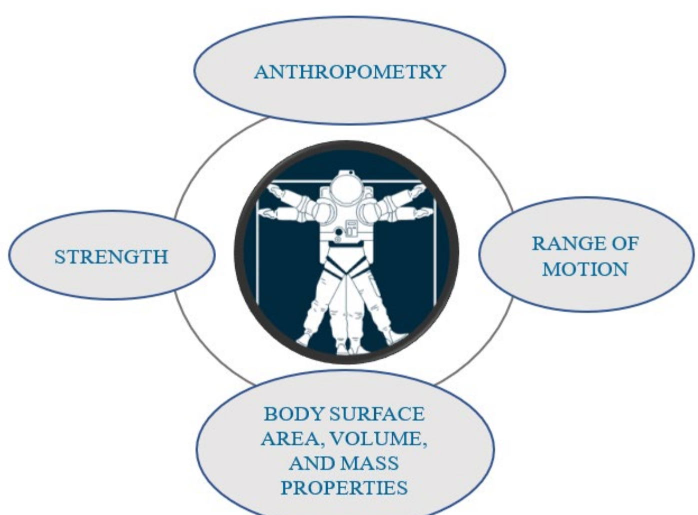
Reference OCHMO-HB-004 Anthropometry, Biomechanics, and Strength

Executive Summary

The design of human-inhabited spacecrafts, spacesuits, and equipment must accommodate for the physical size, shape, reach, range of motion, and strength of the crew population. Additionally, there must be considerations taken for the external factors that influence crewmember anthropometry, biomechanics, and strength including: the gravity environment, clothing, pressurization, and deconditioning during missions.
To determine which measurements and data sets are applicable to the design of a system, it is necessary to understand the tasks that are being performed, the equipment that will be used, and who will be performing the tasks.



Spacesuit Anthropometrics. Image from: San Diego Air and Space Museum



Background

Anthropometrics

Anthropometry refers to the measurement of human body lengths and circumferences, specifically relating to clearance and reach.

Clearance is described as the sufficient room necessary for crewmembers to fit through passageways and perform tasks safely and comfortably in the designated area, taking into account whether the crew will be suited/unsuited and the differences in performance and critical dimensions for body clearance when in a microgravity environment.

Reach is an important aspect that determines how controls, displays, and equipment should be positioned so that they can be accessed by the crew as required for specific tasks.

Anthropometry data drives the guidelines for the design of a system, considerations include:

- Selection of the user population and associated database.
- Use of 1st percentile female to 99th percentile male. Deviations from this range quickly reduces the number of people able to be accommodated.
- The nature, frequency, safety, criticality, and difficulty of the tasks to be performed.
- The position of the body during performance of these tasks.
- The mobility and flexibility requirements imposed by these tasks.
- Where design limits based on safety and health considerations are more conservative than performance criteria, they must be given preference.

When collecting anthropometric data, the following guidelines help ensure the data collected is useful and accurate:

- Subject clothing – In addition to basic anthropometric measurements that are normally taken in minimal clothing, include additional measurements for mission-appropriate scenarios such as pressurized suits.
- Consistency and accuracy of measurements – Measurements of subjects must be taken with a precise and consistent approach while ensuring measurement devices are properly aligned and calibrated.
- Identify needs for additional measurements to build up the anthropometric database, including the need for increased focus on unpressurized and pressurized suited conditions and zero and partial (i.e., 1/6th and 3/8th g) gravity conditions.

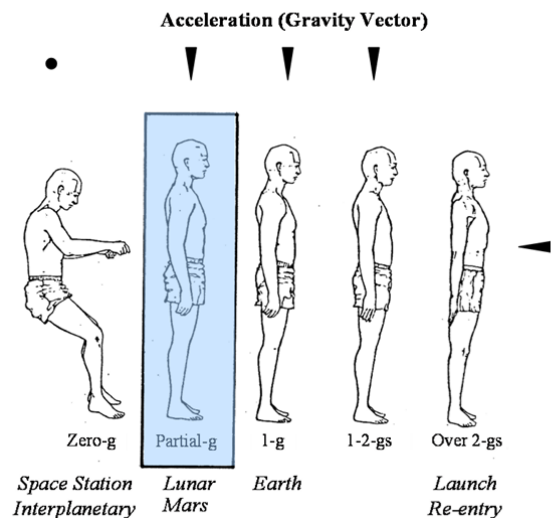
Other Anthropometric Considerations:

- Anthropometric databases do not contain percentile information on all possible critical dimensions for every design situation. Military databases, such as the ANSUR, that heavily influence NASA's designs do not include specific suited dimensions thus special studies or estimations must be used.
- When two or more individuals are located near each other, such as in a cockpit, consider all combination of sizes (i.e., a higher percentile person and a smaller percentile person with the ability to reach common control).
- Different human physical attributes of an individual rarely have the same percentile ranking (i.e., 5th percentile female in stature could have a 40th percentile arm length). Additionally, there is a lack of correlation between anthropometric dimensions and strength or reach capabilities.

Application

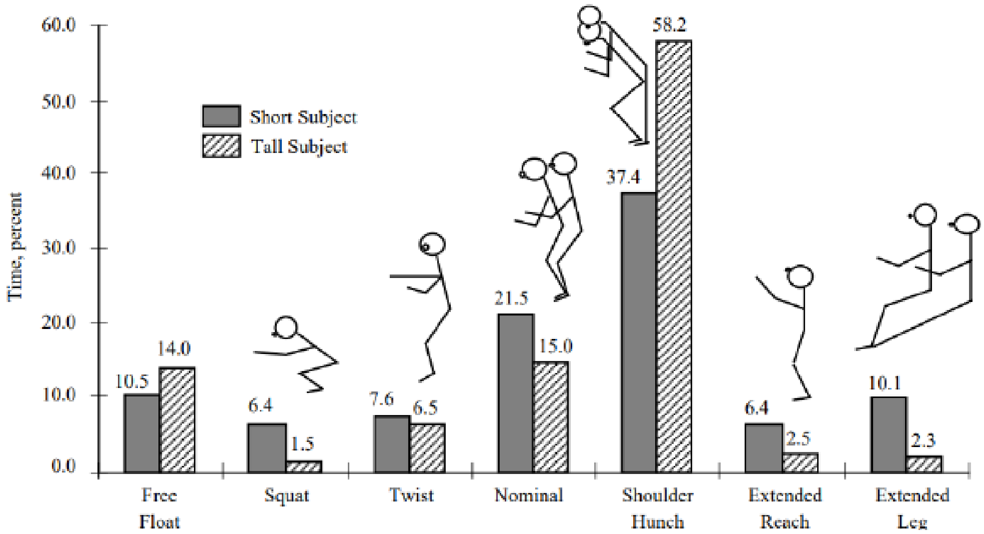
Clearance & Reach/Access

1. Identify the critical physical clearance dimension (using mock-ups, if necessary).
2. Define possible human body movements and positions relative to the critical dimension (consider the task being performed, including rescue operations or possible errors in an emergency, such as improper orientation for passage through a hatch).
3. Select the worst-case body position(s) that would cause clearance or reach problems. Consider the effects of other body dimensions or body positions. For example, a person with a long torso may have to lower their seat to properly position their eyes.
4. Determine the worst-case body postures or body dimensions. Determine relevant factors such as clothing, pressurization, gravity (such as spinal elongation in 0g), and any other environmental factors before using the data charts for the relevant data.



Postures in Response to Acceleration
From: *Creating a Lunar EVA Work Envelope*
(Griffin, Howard, Rajulu, & Smitherman, 2009)

5. Use the appropriate database to determine the value of the worst-case dimension(s) for the largest expected person. Also determine the full range (smallest person to largest person) that will define the position of the human.
6. Define the worst- case (bulkiest and largest) possible clothing and equipment worn or carried by the human and add this dimension to the worst-case body dimension. The results will define the design dimensions required to meet the clearance and reach requirements



Percentage of time primary crewmembers spent in each posture category

Task analysis and human-in-the-loop (HITL) testing are used to define planned crew tasks and include potential anthropometric and strength requirements. See OCHMO-TB-018 HITL and OCHMO-TB-005 Usability, Workload, & Error for additional information.

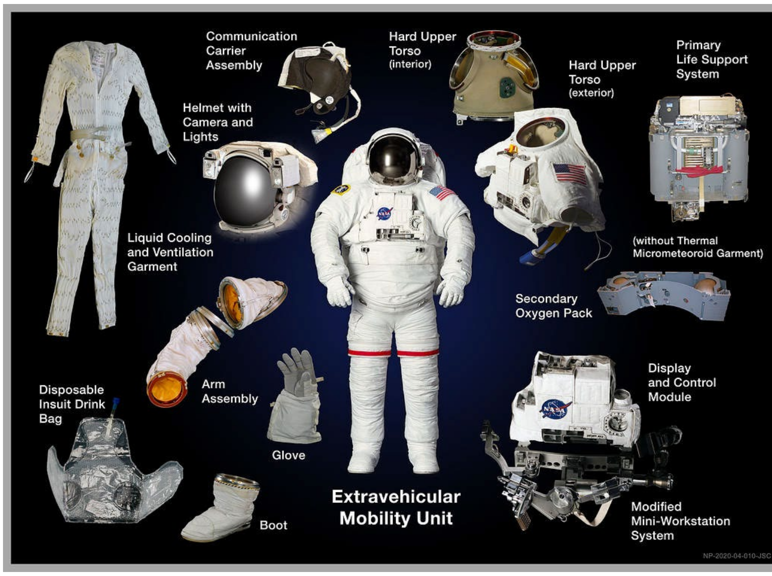
Reference Data

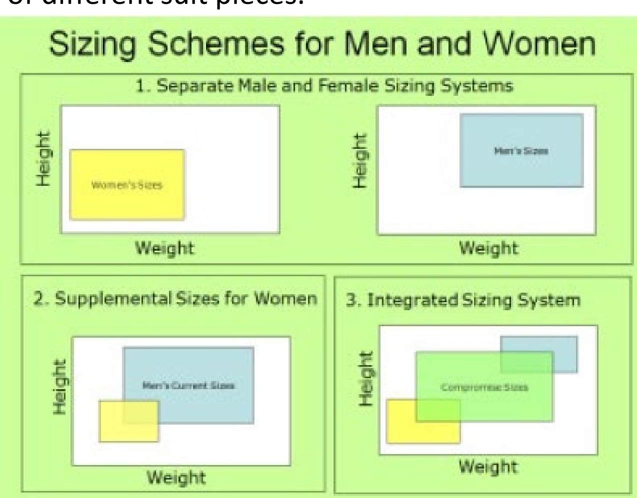
All crewmembers need to be able to perform any planned tasks efficiently and effectively. The intent is to accommodate the entire potential user population, not just meet the criteria in the datasets, which provide the most frequently used values in standard reference postures. When a design requires a posture outside of the standard reference posture, such as rotation from upright to recumbent seating, minimum and maximum values for the new posture must be developed for the unique design posture. When a system must accommodate a suited crewmember, an additional suited dataset can be provided that accurately identifies suited human dimensions. A tailored data set may be provided by NASA based on program or mission specific criteria, especially when a specific spacesuit has been identified.

Reference NASA-STD-3001 Volume 2 [V2 4102] Functional Anthropometric Accommodation and Appendix E: Physical Characteristics and Capabilities.

Lessons Learned

Shuttle-era Extravehicular Mobility Unit (EMU) spacesuits were designed using individual mix-and-match pieces to fit a population to include everyone from a 5th percentile female to 95th percentile male. Original designers made the assumption that a woman could fit the same size as a small man. This strategy did not take into account other factors, such as a woman in similar height and weight as a man is likely to have much broader hips and narrower shoulders. The overall lack of properly strategized suit design led to issues with suit fit and mobility while suited, as well as extravehicular activity schedule constraints based on the availability of different suit pieces.





Another example of how different body dimensions for an individual can affect design seated vehicle interactions. Often only the minimum and maximum dimensions are evaluated, however interferences can occur when there are variations in body size. During developmental evaluations, the variation between torso length and leg lengths identified instances when the knees would impact a display panel and the feet would impact hardware along the vehicle wall. The minimum and maximum was not an issue but the middle population who had odd variations of body dimensions were impacted.

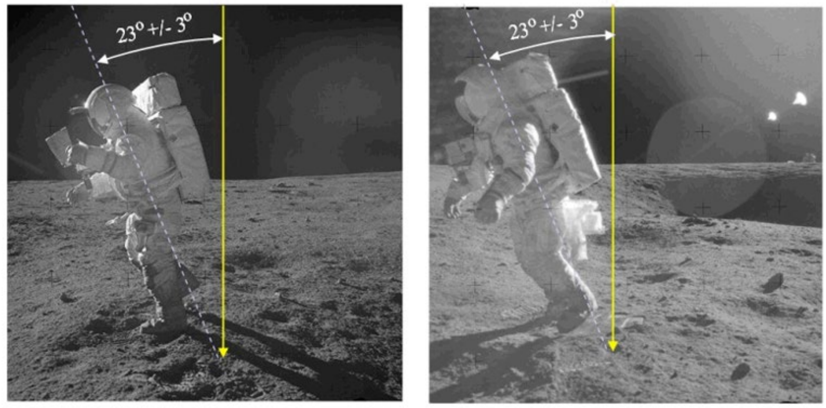
Example sizing schemes for men and women with the same gear. From: *Benson, E. & Rajulu, S. Complexity of Sizing for Space Suit Applications*

Background

Range of Motion and Reach Envelope

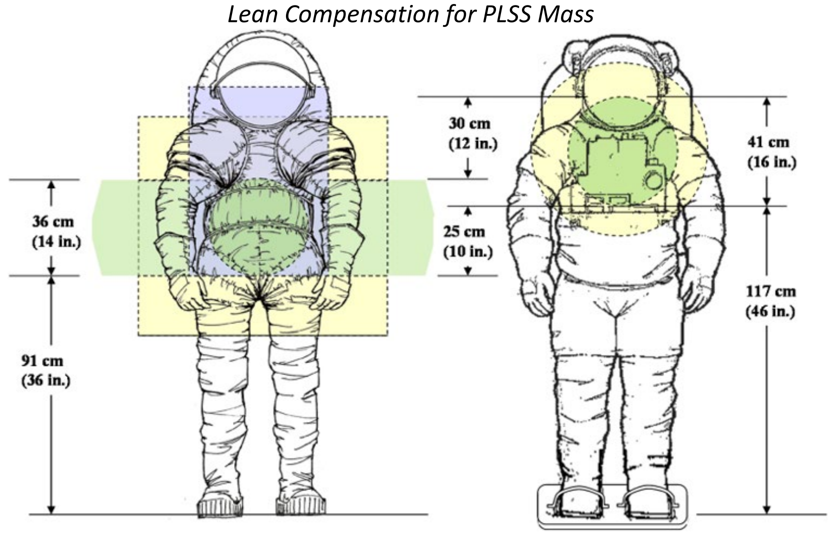
Range of motion (ROM) is how far a person can move or stretch parts of the body, such as a joint or muscle. Human movement varies from whole-body movement (e.g., locomotion or translation) to partial body movement (e.g., controlling a joystick with the right arm) to a specific joint or segment movement (e.g., pushing a button with a finger while holding the arm steady).

- Frequently, human motion involves two or more joints and muscles. The movement range of a single joint is often drastically reduced by the movement of an adjacent joint, meaning joint movement ranges are not always additive.
- Generalities can be made regarding body physique and its relationship to joint mobility, however as with other physical properties, variability always exists and must be considered on an individual basis.
- Fatigue, injury, and pain can affect a person's ability to maintain their normal ROM. Additionally, awkward and constrained body postures or loads carried by a person will restrict mobility.



Edgar Mitchell, Apollo 14 Al Bean Apollo 12

Lean Compensation for PLSS Mass



Lunar Weightless

Lunar and Weightless Envelopes

Examples from: *Creating a Lunar EVA Work Envelope (Griffin, Howard, Rajulu, & Smitherman, 2009)*

Reach envelope is the area that a crewmember can reach from a seated or standing position used for design requirements to define hand or foot controls. Gravity transitions can alter reach envelope conditions and impact design considerations such as crew interfaces for flight control.

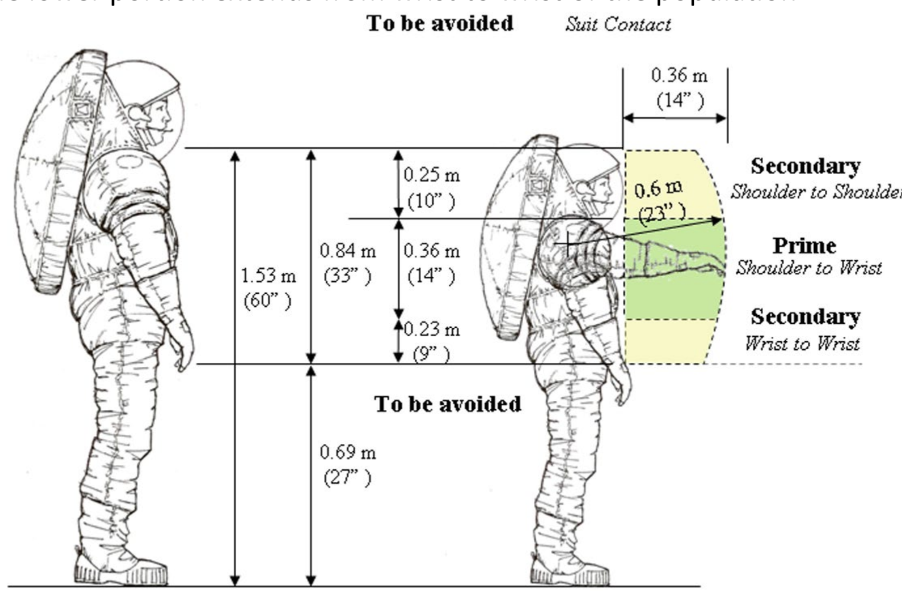
- Within the reach envelope, some locations are visible and simple to reach requiring minimal stretching; these areas are within the *optimal reach envelope*.
- In determining reach envelopes, designers need to define two boundaries: maximum functional reach from the body, and area close to the body that cannot be reached due to physical restrictions such as lack of elbow room.
- The crewmember who has the shortest functional reach should be used to define the maximum functional reach boundary. The worst-case condition for a constrained (e.g., seated with shoulder harness tight) person may be a combination of a long shoulder height and a short arm. These statistical variations in proportions should be accounted for in reach limit definitions.

Application

ROM and reach are greatly affected by restricted postures, bulky flight suits, pressurization, and restraints. When placing controls and access panels, designers must ensure they account for the reduction in crewmember reach capabilities.

Advances are being made in developing a new spacesuit for Lunar surface activities. The work envelope is slightly different from the reach envelope in that at maximum reach, little work can be done with the hands. The work envelope measures to the grasp area of the glove. The objective is to create a large work envelope but because of the extremes in the design population, this has been divided into prime and secondary envelopes. The prime EVA work envelope is the simplified geometry described when both hands are in a fixed field-of-view for the entire design population. The secondary envelope provides extended reach with the upper portion spanning from the shoulder height of the tallest crewmember to shoulder height of the shortest, and the lower portion extends from wrist to wrist of the population extremes.

Lessons Learned
Due to the location of the Soyuz instrument panel, crewmembers utilize a 'pointer' instrument to reach and push buttons during spaceflight due to their restricted posture and reach envelope while seated in their pressurized suits (see images below). This increases risk to the crewmember performance in a variety of ways and is not an ideal solution to the inadequate design and implementation of reach and range of motion data.



Primary and Secondary Reach Envelopes
From: *Creating a Lunar EVA Work Envelope (Griffin, Howard, Rajulu, & Smitherman, 2009)*

Background

Body Surface Area, Volume, and Mass

Body Surface Area (BSA) measures the total surface area of the human body. Estimated BSA of the crewmember is based on: Female 5th percentile in height with light weight and Male 95th percentile in height with heavy weight.

- The gravity environment BSA estimation equations apply to 1g conditions.
- Fluid shifts and spinal elongation due to microgravity conditions are not accounted for in BSA databases.
- The BSA data available is limited to specific populations in which the data is collected and may not be applicable to the entire astronaut pool being designed to.

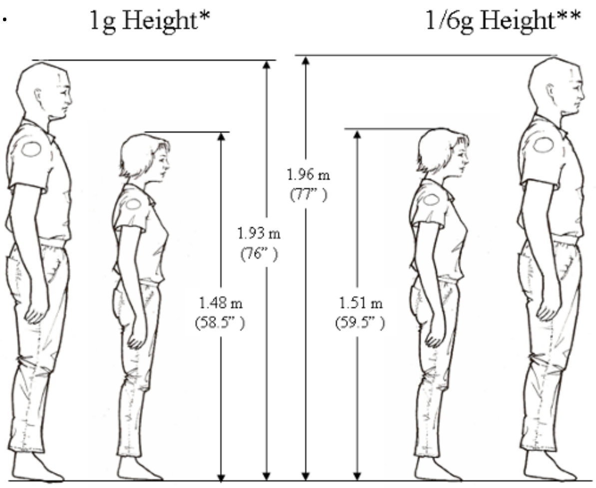
Body volume refers to the volume displaced by the body as a whole and by body segments. Both whole-body mass and body-segment mass data are based on 1g measurements.

The center of mass refers to the position that is the mean location of a distribution of mass in space.

- The 0g environment causes fluids to shift upward in the body and leave the legs. This results in an upward shift of the center of mass for the whole body and a loss of mass in the leg segments. The data does not account for the fluid shifts and spinal lengthening in 0g.
- In 0g, the body mass properties define body reaction to outside forces including: reactive to forces exerted by the crewmember or a hand tool; active forces from devices such as the Manned Maneuvering Unit; and the reaction of the body to a force depends on both the mass and the relative positions of the body segments.
- The whole-body center-of-mass and moment-of-inertia data is provided for standing posture only. Whole-body mass properties for other positions would have to be determined by mathematically combining the mass properties of the individual segments and the appropriate postures maintained by these segments.

Depending on mission or design requirements, system developers could need body mass, volume, and BSA data that accurately describe the entire size range of potential crewmembers. This data is used to make calculations for things such as radiation exposure, designing of body contact cooling systems, gravity or buoyancy, force and exertion for body support systems, or understanding how loads are distributed during accelerations.

Spinal elongation due to microgravity is an important consideration. Crewmembers tend to increase in stature by up to 3 percent (6% of seated height), which drives current requirements to allow for such growth in dimensions such as body surface area/stature, eye height, and seated height when designing crew interfaces, vehicle seats, and suits.



From: *Creating a Lunar EVA Work Envelope* (Griffin, Howard, Rajulu, & Smitherman, 2009)

Background

Strength

The term strength is often used to refer to a person's ability to generate force. Because of the difficulty in measuring strength, it is hard to formulate a clear definition of the term. Unlike anthropometric data, strength data from different populations is not readily available. Therefore, strength data often shows maximum and minimum values based on the weakest and strongest members of the population.

Strength Data Considerations	
User Population	The database selected should reflect the likely user population in terms of age, gender, fitness, and other characteristics as closely as possible.
Activity Type	The type of activity and interactions between the human and environment will dictate whether minimum or maximum strength is of concern. The level of criticality will also determine if factors of safety are needed.
Weakest Crewmember	In most cases, the goal of understanding strength data is to ensure that the weakest crewmember can perform a task.
Structural Limits	In some cases, structural limits are in place to prevent accidental damage from crewmembers. For example, the torque required to break a piece of equipment might be required to be more than the maximum torque produced by the strongest crewmember.
Duration	The duration of the activity has a major effect on the strength a person can exert. Strength drops off significantly with the extended duration of an activity.
Anthropometry	Because of the low correlation between strength and size, anthropometry should not be used to determine accommodation of strength and endurance.
Counter-Reactive Forces	Lack of gravity leads to the absence of counter-reactive forces that allow people to effectively perform physical work in 1g. Traction (friction force) is also absent, as are forces that result from using body weight for counterbalance. Without proper restraints, a crewmember's work capabilities are reduced and time to complete tasks increased.
Restraints	Even with foot restraints, the strength exhibited by subjects in 0g is about 17% less than their strength in 1g.
Body Position	Situations do exist in which a crewmember can achieve improved strength performance in 0g, such as when the crewmember uses the greater maneuverability in 0g to achieve a more efficient body position to be able to push off solid surfaces.
Deconditioning Effects	Strength is reduced with longer missions because of the deconditioning of muscles. Experience in space indicates that both the strength and aerobic power of load-bearing muscles in crewmembers decreases during missions exposing them to 0g. Exercise countermeasures have been used to counter these deficits, but to date have been only partially effective.
Exercise	Spaceflight may cause greater muscle atrophy than bed rest, with greater loss of leg strength than arm strength because locomotion is performed with the upper body in 0g. Refer to OCHMO-TB-031 Exercise Overview for information on crew strength requirements and spaceflight countermeasures used to preserve strength in-flight.

Application

Selection and Validation of a Database

One of the most important considerations in human-centered design is the user population. The question of who will be using the hardware must be addressed. It is especially important to determine the range of critical dimensions or values that are significant to overall layout and design of the spacecraft and key equipment used. Users should be defined in terms of age, gender, and ethnicity. This information is critical for selecting an appropriate database. Other considerations might include the timeframe for hardware use. If hardware is intended to be used far into the future, this may affect the anthropometry needs, because attributes of populations tend to change over time. Though it may be ideal to collect data for each subject who will use a piece of hardware, it is rarely feasible to do so. Thus, the selection of a database that closely represents the expected user population is crucial to good ergonomic design.

No matter which population range is selected, developers must consider the implications of not accommodating users outside the design limits. It is important to pick a dataset closest to the user population and is (a) current, (b) large enough to overcome statistical issues, and (c) representative of the anticipated user population.

To validate that the selected anthropometric database is the proper one to represent the user population, the analyst must address the following two questions:

1. Does the database represent who will use the system? Consider: Age, Ethnicity, Sex, Physical Fitness, and Education Level.
2. Is there a sufficient number of subjects in the database? System developers normally rely on data from surveys funded by large organizations. These surveys are sufficiently large (at least 1,000 subjects) to account for population variances.

Past experience indicates that historical changes have occurred in anthropometric dimensions such as height, weight, and other physical measurements. These changes that occur from generation to generation are referred to as secular change, and the impact of such changes can be significant for hardware design. To predict secular change, the first step is to select a population that is representative of the future user of the system under development. A database of dimensions should exist for this population. Next, use trend analysis to estimate the stature of a future user population. Finally, use the estimated future stature and the relationships between stature and other dimensions (including mass, body volume, and surface area) to calculate estimated future body segment lengths and other needed dimensions.

Percentiles are often used to report values from a norm-referenced database. When estimating percentiles, the data is represented graphically as a normal curve. At the peak of the normal curve stands the mean (50th percentile) and median of the distribution. The mean (μ) and standard deviation (σ) define a normal distribution used to calculate percentiles. The percentile can be estimated by the percentile equation: $X(p) = \mu + \sigma(z)$ Values of *Z* are constant for a given percentile and can be found in a standard normal (*Z*) distribution table.

Example: When 1st to 99th percentile limits are imposed, 10% of the population is eliminated. If 5th to 95th percentile limits are imposed for all criteria, 37% of the potential population wouldn't fit in the hardware. A short person may have long arms, or a wide person may be tall. The more restrictions, the greater the overall impact.

Back-Up

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision E

[V2 3006] Human-Centered Task Analysis Each human spaceflight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 3101] Iterative Developmental Testing Each human spaceflight program or project shall perform iterative human-in-the-loop (HITL) testing throughout the design and development cycle.

[V2 4102] Functional Anthropometric Accommodation The system shall ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix E, Physical Characteristics and Capabilities, Sections E.2 and E.3.

[V2 4103] Body Mass, Volume, and Surface Area Data The system shall accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix E, Physical Characteristics and Capabilities, Sections E.4, E.5, and E.6.

[V2 4104] Crew Operational Loads The system shall be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in E, Physical Characteristics and Capabilities, Section E.7.

[V2 4105] Withstand Crew Loads The system shall withstand forces imparted by the crew during all phases of flight, including but not limited to prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix E, Physical Characteristics and Capabilities, Section E.7 without sustaining damage.

[V2 4013] Muscle Effects The effects of muscle endurance and fatigue shall be factored into system design.

[V2 11024] Ability to Work in Suits Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

Appendix E: Physical Characteristics and Capabilities Data Sets

Reference List

1. OCHMO-HB-004 Anthropometry, Biomechanics, and Strength. https://www.nasa.gov/wp-content/uploads/2023/12/ochmo-hb-004-rev-a-dec2023.pdf?emrc=c689c2
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