Anthropometric Requirements for Constellation

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Outline

- **Anthropometry requirements for Constellation**
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  - Data sources
- **Comparison with legacy requirements and agency standards**
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  - Shuttle
  - ISS
- **Anthropometric Crew Selection Criteria**
- **Requirement History in CxP**
- **Effects of requirement reduction**
- **Current Cx Compliance Assessment**
  - Cx Project Feedback (Orion and EVA)
- **Forward Work**
- **Summary**

Executive Summary

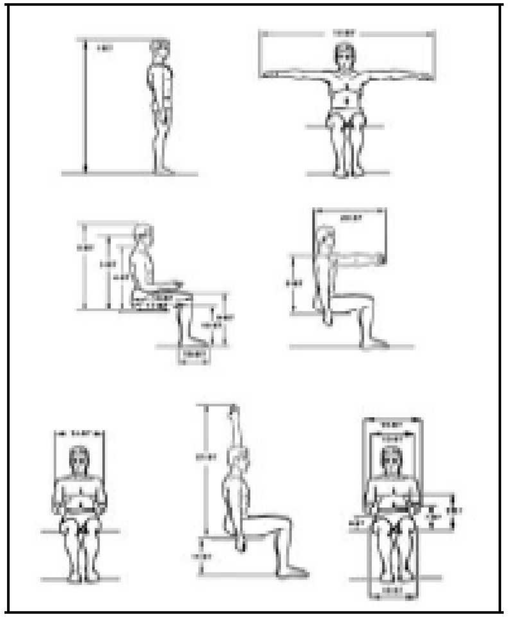
- **The NASA JSC Anthropometry and Biomechanics Facility (ABF) provides the subject matter expertise for Shuttle, Station, and Constellation Programs and Projects**
  - Develops Cx anthropometry, strength, mobility, and mass properties requirements
  - Gathers, interprets, manages and maintains the flight crew anthropometry database
  - Participates and provides input during crew selection
- **The Anthropometry Requirements are contained in the Human Systems Integration Requirements (HSIR) CxP70024**
  - Dimensional ranges are based on anthropometric database (NATICK ANSUR Survey, 1988) from Army personnel, NOT general population
  - Represents 1st to 99th percentile range so as to include the current crew (as of 2004) who otherwise would be outside the 5th and 95th percentile range
- **Constellation strategy is to maintain consistent requirements for vehicle and suit design as well as crew selection**
  - Projects to validate the requirements in design or push back with design data during early stages of development
  - Design requirements to be updated along with crew selection as individual design issues are elevated
  - Current crew selection limited by other systems today for ISS (EMU and Soyuz) in addition to HSIR
- **Recent CxP Content Scrub action closure recommended no blanket changes to the current requirement**
  - Projects are working toward compliance today, with only 3 known bounded issues
  - Requirements are NOT a significant mass driver for Orion
  - EVA has a standing ITA to address issues of anthropometric accommodation

Cx Anthropometric Requirements Overview

- **CxP70024, Constellation Human Systems Integration Requirements, (HSIR) Section 3.1**
  - **Anthropometric Dimensions**
    - **Unsuited Crewmembers [HS2001]**
    - **Suited Crewmembers [HS2002]**
  - **Mass Properties**
    - **Total Crew Mass (4 Unsuited Crew) [HS2010]**
    - **Mass Properties**
      - **Unsuited Crewmembers [HS2005]**
      - **Suited Crewmembers [HS2002]**
  - Range of Motion (Functional and Isolated)
    - Unsuited Crewmembers [HS2003]
    - Suited Crewmembers [HS2004]
  - Strength
    - Structural Integrity of Hardware
      - Unsuited [HS2007]
      - Suited [HS2007B]
    - Minimum Crew Operational Loads
      - Unsuited [HS2008]
      - Suited [HS2008B]
    - Equipment Damage Hazard ("kick loads') [HS2009]

Unsuited Generic Data AND Critical Dimensions for Design (unsuited, suited, and Pressurized suited)

Mass, CG, Moments of Inertia AND Maximum individual crew mass 80th percentile total crew mass



HSIR Anthropometry Requirements History

- **ABF maintains the HSIR Anthropometry Database**
  - Representative of a reasonable pool of future astronaut candidates, not limited to the current corps
  - Allows enough subjects for statistically significant analysis
  - Analysis findings are not attributable to individual flight crew members
  - Current astronaut database does not contain all crew or all dimensions

- **The HSIR Anthro database is based on the Natick U.S. Army Anthropometric Survey (ANSUR, 1988)**
  - Contains 132 body measurements and 48 head and face dimensions from 1774 males and 2208 females
  - Age-truncated to 30 and 51 so as to encompass the representative age range of astronaut corps
  - Chosen because military body type represents astronaut corps (in contrast to the CAESAR database of 2000 for general population)
    - Civilian American and European Surface Anthropometry Resource database (CAESAR) Range would have greatly increased due to larger variations in body type
  - Air Force data – no recent update for Air Force (1974)
    - HSIR Anthro Database mean height was adjusted to correspond with Air Force Pilots data who are statistically taller than Army personnel

HSIR Anthropometry Requirements History (continued)

- Requirements were derived from 1st percentile to 99th percentile from the Modified ANSUR database
  - NOT 1st to 99th percentile of the general population
    - The extremes of the general population (extremely tall, obese, and "little people" are neither factored into these percentiles nor driving HSIR requirements
  - The percentile range expanded from 5th – 95th to 1st – 99th to accommodate existing crewmembers (as of 2004)
    - Station Program was expected to accommodated an international Population (Japanese female to American Male)
    - Some crewmembers' dimensions were below the 5th or above the 95th percentile range
    - HSIR requirements were created to correct this issue, and vetted with the Space Life Sciences Directorate, the Constellation Program Office and with the Astronaut Office.
- The ANSUR database has been validated against the current Astronaut Corps during early CxP Integrated Design Analysis Cycles (IDACs)
  - IDAC-1: Established using the 1st and 99th percentile range as the starting point for design
    - Projects to validate the requirements in design or push back with design data during early stages of development
  - IDAC-2: Removed the TBRs associated with the anthropometry design values and removed the wording "1st" and "99th,"replacing it with "minimum" and "maximum"
    - Eliminated confusion over the requirement intent: Design to meet the accommodation requirements
    - CxP policy is to maximize crew accommodation within the constraint of budget/schedule, not necessarily to accommodate 1st to 99th percentile

Comparison with legacy Program requirements and standards

Apollo

- "Anthropometry: The vehicle design shall accommodate crewmen between the **<u>10th and 90th percentile</u>** for the following dimensions: weight, standing height, sitting height (erect), buttock- to- knee length, knee height (sitting), hip breadth (sitting), shoulder breadth (bideltoid), and arm reach from wall. Other body dimensions shall fall within the 5th and 95th percentiles as defined by WDAC- TR- 52- 321."

  Ref: APOLLO EXPERIENCE REPORT - CREW STATION INTEGRATION, Volume I - Crew Station Design and Development, NASA TN-D 8178, 1976

- Note: 8 critical vehicle dimensions and suits were custom built

Shuttle

- No suit factors were used in consideration for accommodation issues while designing the Shuttle
- *Ref: Anthropometric Source Book: Volume I and II: Anthropometry for Designers for Designers, NASA Reference Publication 1024, 1974.*

ISS

- "3.3.1.3 BODY SIZE DATA DESIGN REQUIREMENTS

  The data shown in Figure 3.3.1.3–1, dimensions of the projected year 2000, 40 year old American male and the 40 year old Japanese female, shall be used when designing all Space Station Intravehicular Activity (IVA) flight crew interfaces."

  Ref: International Space Station Flight Crew Integration Standard, SSP 50005, 1999

  Note: 56 critical vehicle dimensions and 17 critical suit dimensions

Dimensional Differences

- The difference between the 5th-95th percentile range used in ISS (SSP50005) and the 1st-99th percentile range currently in use for min and max (CxP 70024 HSIR) is often quite small, depending on the variability and range of sizes for that particular dimension

Dimensions (**in inches**)	1st		5th		95th		99th
Stature	58.5	-1.7	60.2	14.5	74.7	1.9	76.6
Eye height- sitting	26.2	-0.9	27.1	6.9	34	1.0	35
Hip breadth- sitting	12.4	-0.7	13.1	4.4	17.5	0.8	18.3
Bideltoid breadth	14.9	-0.7	15.6	5.7	21.3	0.8	22.1
Foot length	8.5	-0.3	8.8	2.8	11.6	0.4	12

- The key design challenge is not the BREADTH of the range, it is providing ADJUSTABILITY given the inherent variability between individuals

Anthropometric Crew Selection Criteria

- **The NASA JSC Anthropometry and Biomechanics Facility (ABF) coordinates with the crew office and CxP to determine the crew selection criteria**
- **In December 2008, Astronaut Candidates were evaluated against new anthropometric selection criteria**
  - Based on:
    - HSIR Critical Dimension (seat and suit critical dimensions)
    - Soyuz Critical Dimensions
    - EMU Sizing and Performance Accommodation
  - 121 Astronaut Candidates were measured
  - 35 Astronaut Candidates were eliminated based on these criteria
    - 15 due to HSIR
- **By Crew request, critical dimensions for crew selection were confirmed by Projects**
  - EVA System Project Office removed 1 Suit critical dimensions (16 to 15)
  - Orion Project Office removed 5 Vehicle critical dimensions (21 to 15)
- **HSIR critical dimensions list for design will be updated to reflect new crew selection criteria**

Accommodation effects of requirements reduction

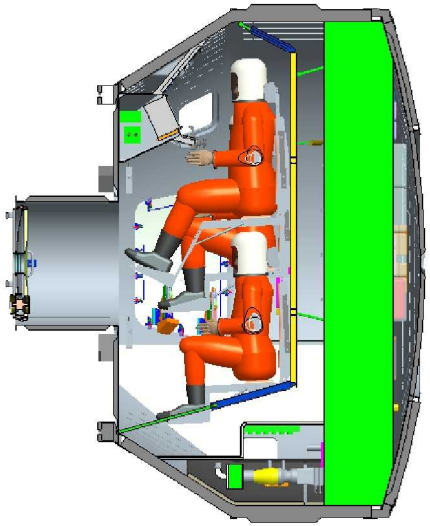
- Candidates for CxP Cost Reduction brainstorming suggested two actions assigned to HSIG relating to Anthropometry
  - Action 90: Relax anthropometric requirements to current design capability 5-95%
  - Action 90-b: Relax anthropometric requirements beyond 5-95%

- **Analysis Conducted by the Anthropometry and Biomechanics Facility (ABF) shows blanket reductions are not the correct course of action based on**
  - Crew accommodation reductions would be large, with low payoff to Projects
    - Highly constrained due to large number of critical dimensions
    - Low correlation among anthropometric dimensions
  - Only a few specific dimensions are currently design issues for the Orion team

- **Recommend NO blanket reduction in anthropometric requirements**
  - Orion and EVA Project concurrence
  - CxP SE&I Approval pending resolution of known design issues

- **Continue working within the Community of Practice on specific requirement compliance issues as they arise**

Requirement Reduction Analysis



- 37 critical (design driving) anthropometric requirements in HSIR
  - 16 dimensions required for development were identified in 2005 by the NASA-Suit team (utilized during the 2009 ASCAN selection, now 15)
  - 21 dimensions required for development were identified in 2005 by the NASA-CWG stakeholders (utilized during the 2009 ASCAN selection, now 15)

- When applying the current 1st percentile-99th percentile requirement for all 37 critical dimensions against the HSIR database (Modified ANSUR database)
  - 12% of the population is excluded due to suit considerations
  - 12% is excluded due to vehicle considerations
  - 18% is excluded due to a combination of suit and vehicle considerations (vs. 24% due to correlation between several suit and dimensions)

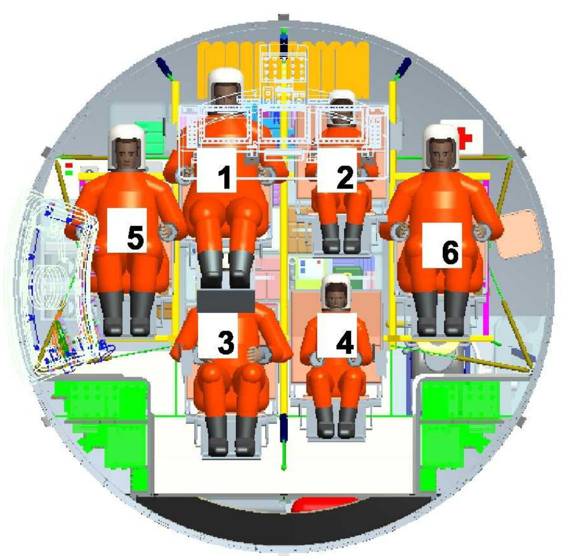


Table 1. Impact to Crew Population Accommodation for Global Relaxation of HSIR Anthropometry requirements

	Percent of the Population Excluded		
	1st - 99th Percentile	5th - 95th Percentile	20th – 80th Percentile
Suit (16 dimensions)	12	44	90
Cockpit/Seat (21 dimensions)	12	45	92
Combined (37 dimensions)	18	59	98

Orion Prime Contractor Response Dimensional Issues

- **Hip Breadth, Max, ACES unpressurized, sitting**
  - Accommodating this dimension may force a redesign of the seat mechanism and a reduction in overall occupant protection due to the amount of padding required to compensate for smaller hip breadth dimensions
  - some of the seat mechanisms between seats 3 and 4 may not be accessible with a gloved hand due to the close proximity of these two seats
  - Relaxing the unpressurized, suited sitting max hip breadth will allow a reduction to the seat pan width to increase the lateral spacing between the Seats 3 & 4 improving seat operations and crew comfort
    - ☑ **Being evaluated for validation as a joint Orion/EVA HSIG test objective during Orion Post DAC3 Analyses and CxP IDAC-5 Analysis**

- **Forearm-Forearm Breadth, Max, ACES unpressurized**
  - Two males with maximum forearm to forearm breadth cannot be seated side by side in seats 3 & 4 without overlapping (assuming HSIR posture)
  - Problem may be mitigated through the use of restraints that hold the arms across the body instead of leaving them at the side of the body.
    - ☑ **Primarily a posture issue, not a dimension issue. To be evaluated as a joint Orion/EVA HSIG test objective during Orion Post DAC3 Analyses and CxP IDAC-5 Analysis**

- **Sitting Height, Max, ACES unpressurized**
  - Each seat can accommodate a max suited seated sitting height, however two males with max sitting heights cannot be 'stacked' over each other (P1 & P3 or P2 & P4) without reducing the spacing between the upper and lower crewmember
  - Currently Orion assumes a 91st percentile sitting height can sit below a 99th percentile sitting height while retaining approximately 2.5 inches between the top of the lower crewmember's helmet and the bottom of the upper crewmember's seat pan.
  - Orion could accommodate four 99th percentile sitting height males by reducing the spacing between upper and lower crewmembers to approximately 0.5 inches.
    - ☑ **Can be resolved with NO design change per Crew consensus memo to accept limited crew compliment selection constraints due to seated height**

Outstanding Issues and Forward Work

- **HSIG and ABF Subject Matter Experts to perform data collection activity to validate the suited Hip Breadth max value, and sensitivity of arm posture (Bideltoid Breadth) to suit factors in an upcoming Human in the Loop Test**

- [redacted] **HSIG, Crew Office and Prime in discussions on analysis interpretation and application of crew complement requirements [HS2001, HS2001] for the single dimension of seated height**
  - Early analysis shows seated height is highly sensitive to suit factors (i.e Seat 3 could accommodate 38th percentile crew under max height crew in Seat 1 with helmet bailer bar (visor) down, and 95th percentile with bailer bar up.
  - From the crew consensus report CB-09-039:

    "The following crew anthropometric configurations are deemed acceptable:

    a) Orion must be able to accommodate placing a 91 percentile seated height male above or below a 99 percentile male.

    b) Orion must be able to accommodate placing a 95 percentile seated height male above another 95 percentile male."

- **EVA [redacted]roject office to continue to develop EVA system architecture and perform anthropometric accommodation analysis as part of a standing ITA with ABF**
  - Small EMU study in 1999 demonstrated that suit architecture can accommodate a broad range
  - Narrower range of current accommodation is due to economics of logistics, not design limitations

Crew Position

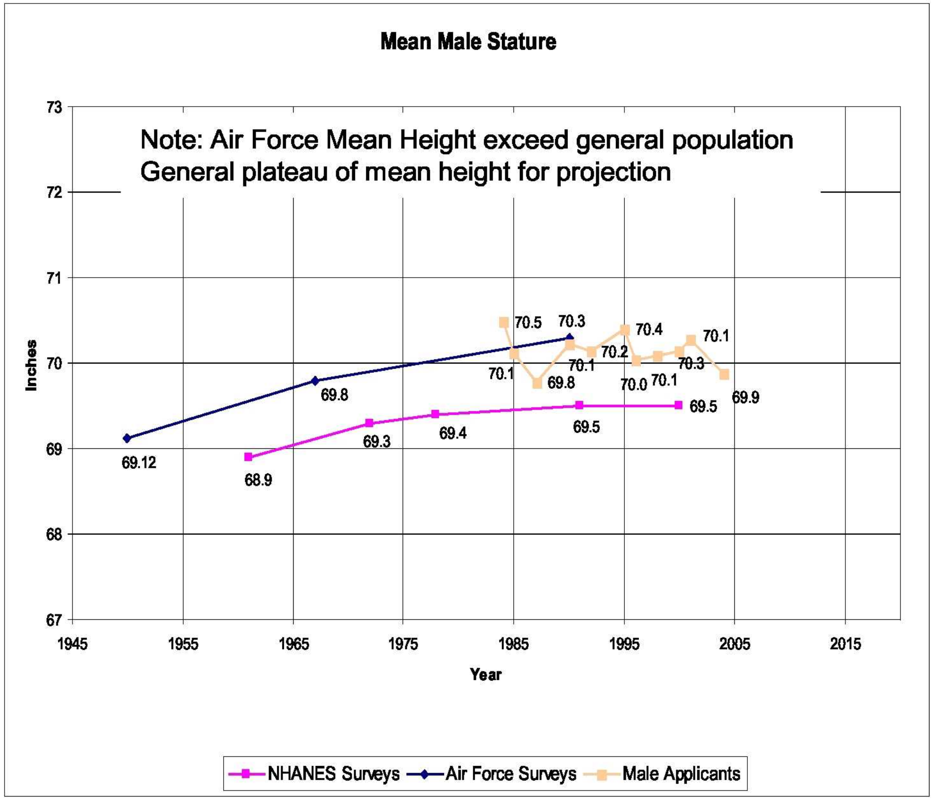
- *Pending input from Crew Office*

Conclusion/Recommendation

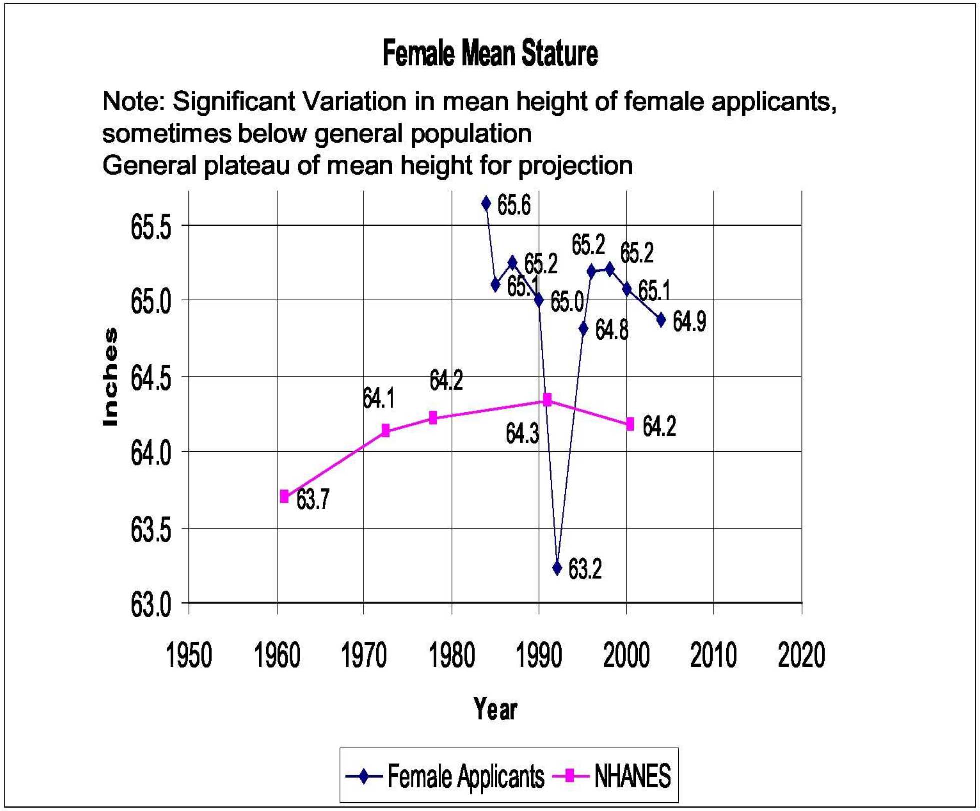
- **Current <u>design</u> requirements are representative of dimensions current astronaut corps, and inclusive of the likely future candidates**
  - Requirements are shown to be achievable by Orion
  - Small EMU study has shown that suit architecture can accommodate a broad range
- **Current <u>selection</u> requirements are consistent with Cx design requirements, but constrained by ISS assets (EMU and Soyuz)**
  - New crew selected to the Corps can fly on ISS or Cx missions
  - Impact to new crew is expected to be minimal as Cx EVA design matures
- **Recommend no blanket change to current requirements**
  - Gross reductions have high accommodation impact with low payoff
  - ABF and HSIG will continue to work design issues with Projects as they emerge
  - Manage design requirement <u>and</u> selection requirements together as new data becomes available

BACKUP

- The adjusted Army personnel database was projected forward in time to reflect a 2015 population based on 40 year growth trend data
- Minimal growth beyond for future years



Mean Height vs. Time
Male Astronaut candidates as compared to general population and Air Force



Mean Height vs. Time
Female Astronaut candidates as compared to general population

Impact of Global Relaxation of Accommodated Crew Population

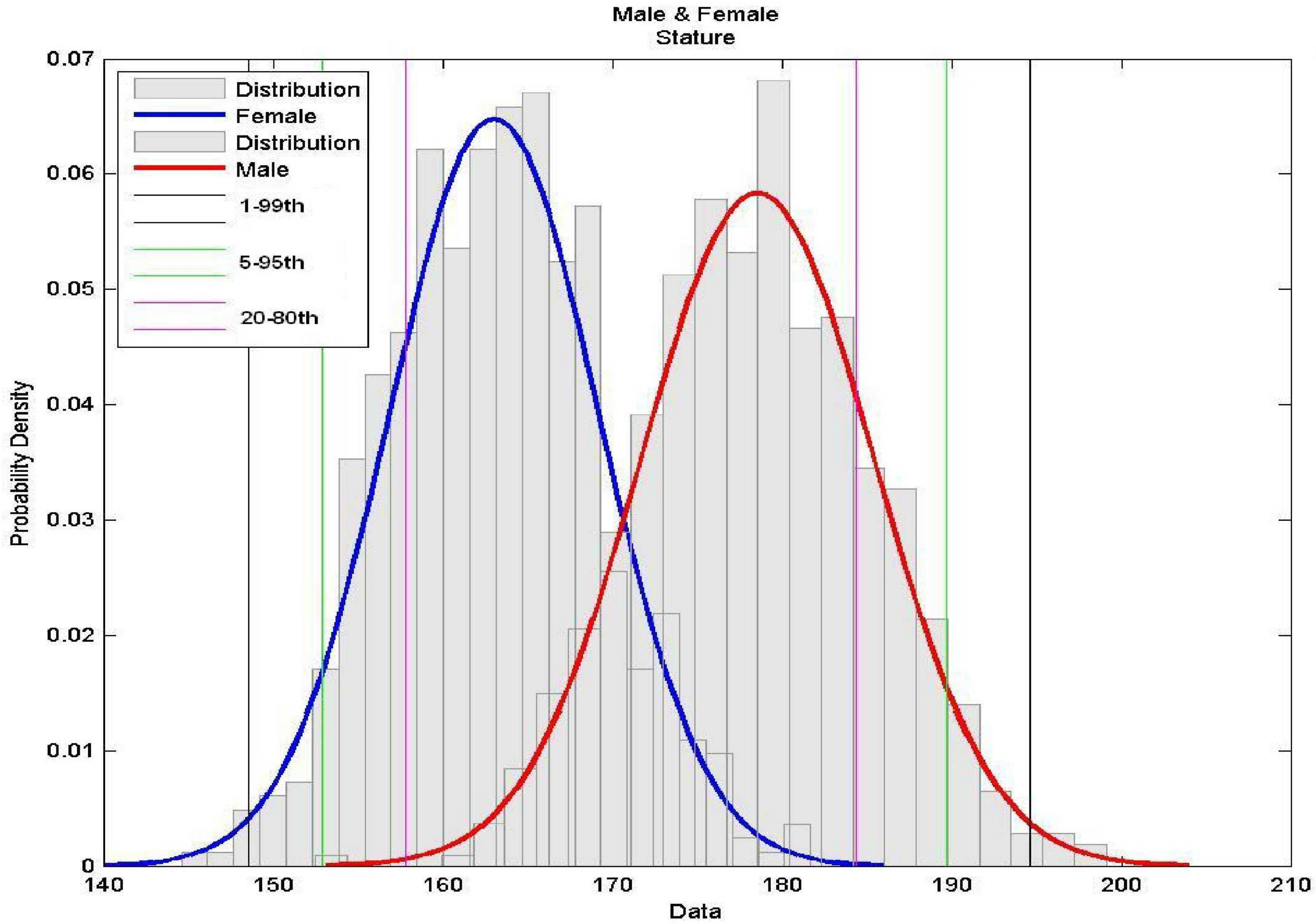


Figure 1. Bivariate Distribution for Stature and the associated percentiles

Note: Stature is a single critical dimension. When a reduction is made across 30 critical dimension, the problem becomes over-constrained. This results in near zero crew accommodation

HSIR Section 3.1 Requirements Cont…

3.1.1.1 Anthropometric Dimensions for Unsuited Crewmembers

[HS2001] The system shall provide fit, access, reach, view, and operation of human-systems interfaces in crew functional areas for unsuited crewmembers as defined in Appendix B, tables Anthropometric Dimensional Data for American Female and Male, Vehicle Design Critical Anthropometry Dimensions, and Suit Design Critical Anthropometry Dimensions.

Rationale: The full size range of an unsuited crewmember must be able to fit, reach, view, and operate all required human-systems interfaces in the crew functional areas that do not require protective suits. Because the current and future crewmembers' body dimensions could have a wide range, it is necessary to use the full range provided in these tables to ensure crew accommodation.

3.1.1.2 Anthropometric Dimensions for Suited Crewmembers

[HS2002] The system shall provide fit, access, reach, view, and operation of human-systems interfaces in crew functional areas for pressurized suited crewmembers as defined in Appendix B, table Vehicle Design Critical Anthropometry Dimensions and table Suit Design Critical Anthropometry Dimensions.

Rationale: The full size range of suited crewmembers must be able to fit, reach, view, and operate required human-systems interfaces involved in planned tasks in the crew functional areas that require protective pressurized suits.

TABLE B1-2 VEHICLE DESIGN CRITICAL ANTHROPOMETRY DIMENSIONS

Design Concern	Critical Dimension	Minimal Clothing		With ACES-Type Suit, Unpressurized		With ACES-Type Suit, Pressurized	
		Min (cm [in])	Max (cm [in])	Min (cm [in])	Max (cm [in])	Min (cm [in])	Max (cm [in])
Maximum vertical clearance	Stature, standing [1-B7]	148.6 (58.5)	194.6 (76.6)	157.7 (62.1)	203.7 (80.2)	158.0 (62.2)	200.2 (78.8)
Vertical seating clearance	Sitting height [2-B7]	77.7 (30.6)	101.3 (39.9)	83.6 (32.9)	112.8 (44.4)	85.9 (33.8)	110.7 (43.6)
Placement of panels to be within line-of-sight	Eye height, sitting [3-B7]	66.5 (26.2)	88.9 (35.0)	61.2 (24.1)	87.6 (34.5)	56.9 (22.4)	84.8 (33.4)
Placement of headrest	Cervicale height, sitting [4-B7]	56.6 (22.3)	76.2 (30.0)	58.9 (23.2)	81.5 (32.1)	59.7(23.5)	78.2 (30.8)
Top of seatback	Acromial height, sitting [5-B7]	49.5 (19.5)	68.1 (26.8)	48.8 (19.2)	68.8 (27.1)	48.3(19.0)	68.3 (26.9)
Placement of restraints	Chest height, sitting [6-B7]	33.8 (13.3)	50.3 (19.8)	32.5 (12.8)	48.3 (19.0)	31.8 (12.5)	47.2 (18.6)
Placement of restraining straps	Waist height, sitting (omphalion) [7-B7]	19.3 (7.6)	27.2 (10.7)	17.8 (7.0)	29.5 (11.6)	18.8 (7.4)	29.5 (11.6)
Placement of objects that may be over lap (panels, control wheel, etc.)	Thigh clearance, sitting [8-B7]	13.0 (5.1)	20.1 (7.9)	15.0 (5.9)	19.8 (7.8)	17.5 (6.9)	21.6(8.5)
Height of panels in front of subject	Knee height, sitting [9-B7]	45.5 (17.9)	63.5 (25.0)	47.2 (18.6)	66.3 (26.1)	51.3 (20.2)	69.9 (27.5)
Height of seat pan	Popliteal height, sitting [10-B7]	33.0 (13.0)	50.0 (19.7)	31.8 (12.5)	51.1 (20.1)	32.0 (12.6)	49.0 (19.3)
Downward reach of subject	Wrist height, sitting (with arm to the side) [11-B7]	39.6 (15.6)	54.6 (21.5)	41.1 (16.2)	62.5 (24.6)	45.0 (17.7)	63.5 (25.0)
Side envelope – maximum lateral reach	Span, sitting [12-B7]	147.8 (58.2)	204.7 (80.6)	147.6 (58.1)	210.6 (82.9)	142.7 (56.2)	207.5 (81.7)
Placement of restraint straps	Biacromial breadth [13-B7]	32.3 (12.7)	44.5 (17.5)	36.1 (14.2)	45.5 (17.9)	34.8 (13.7)	47.8 (18.8)
Width of seatback	Bideltoid breadth [14-B7]	37.8 (14.9)	56.1 (22.1)	53.1 (20.9)	66.3 (26.1)	58.4 (23.0)	70.9 (27.9)
Side clearance envelope, possible seatback width	Forearm-forearm breadth [15-B7]	38.9 (15.3)	66.0 (26.0)	69.3 (27.3)	87.6 (34.5)	82.3 (32.4)	100.6 (39.6)
Width of seat pan	Hip breadth, sitting [16-B7]*	31.5 (12.4)	46.5 (18.3)	36.3 (14.3)	54.4 (21.4)	38.9 (15.3)	55.6 (21.9)

HSIR Section 3.1 Requirements Cont…

TABLE B1-2 VEHICLE DESIGN CRITICAL ANTHROPOMETRY DIMENSIONS (CONCLUDED)

Design Concern	Critical Dimension	Minimal Clothing		With ACES-Type Suit, Unpressurized		With ACES-Type Suit, Pressurized	
		Min (cm [in])	Max (cm [in])	Min (cm [in])	Max (cm [in])	Min (cm [in])	Max (cm [in])
Length of seat pan	Buttock-popliteal length, sitting [17-B7]	42.2 (16.6)	57.2 (22.5)	47.2 (18.6)	62.2 (24.5)	50.0 (19.7)	68.6 (27.0)
Placement of panels in front of subject	Buttock-knee length, sitting [18-B7]	52.1 (20.5)	69.9 (27.5)	59.9 (23.6)	73.9 (29.1)	66.3 (26.1)	82.0 (32.3)
Rudder pedal design, foot clearance	Foot length, sitting [19-B7]	21.6 (8.5)	30.5 (12.0)	27.2 (10.7)	38.6 (15.2)	27.2 (10.7)	38.6 (15.2)
Placement of control panels, maximum reach	Thumb tip reach, sitting [20-B7]	65.0 (25.6)	90.9 (35.8)	67.3 (26.5)	103.1 (40.6)	52.8 (20.8)	100.6 (39.6)
Maximum vertical reach for controls	Vertical index fingertip reach, sitting [21-B7]	118.9 (46.8)	158.2 (62.3)	96.3 (37.9)	136.1 (53.6)	71.9 (28.3)	116.6 (45.9)

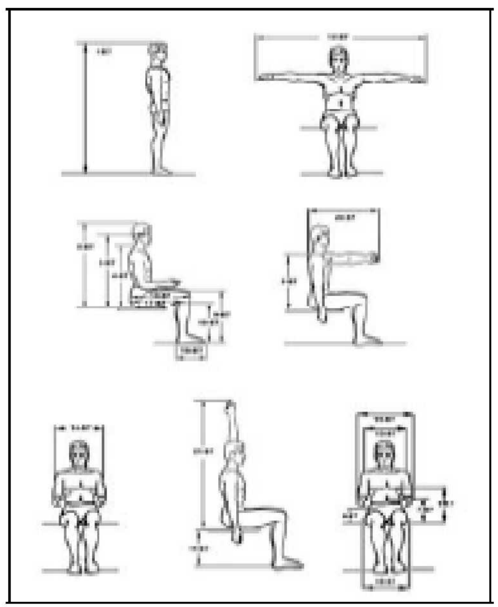


FIGURE B1-1 VISUAL INDEX FOR CRITICAL ANTHROPOMETRIC DIMENSIONS

HSIR Section 3.1 Requirements Cont…

TABLE B1-3 SUIT DESIGN CRITICAL ANTHROPOMETRY DIMENSIONS

Design Concern	Critical Dimension	Minimal Clothing	
		Min (cm [in])	Max (cm [in])
Maximum vertical clearance	Stature, standing [1-B7]	148.6 (58.5)	194.6 (76.6)
Placement of headrest	Vertical trunk diameter [22-B7]	55.9 (22.0)	75.9 (29.9)
Leg length	Crotch height [249-B3]	66.5 (26.2)	95.8 (37.7)
Knee break	Knee height mid-patella [873-B4]	39.6 (15.6)	57.9 (22.8)
Torso sizing	Chest breadth [223-B4]	23.6 (9.3)	39.4 (15.5)
Neck ring and helmet sizing	Head breadth [427-B4]	13.2 (5.2)	16.5 (6.5)
Torso sizing	Chest depth [236-B1]	19.1 (7.5)	30.2 (11.9)
Neck ring and helmet sizing	Head length [441-B6]	17.3 (6.8)	21.6 (8.5)
Maximum circumference of upper leg	Thigh circumference [852-B5]	47.8 (18.8)	71.9 (28.3)
Maximum circumference of upper arm	Biceps circumference flexed [111-B6]	22.9 (9.0)	40.4 (15.9)
Torso sizing	Chest circumference [230-B5]	75.7 (29.8)	118.6 (46.7)
Arm sizing	Inter-wrist distance [24-B7]	115.1 (45.3)	161.8 (63.7)
Functional arm break, arm length	Inter-elbow distance [25-B7]	72.6 (28.6)	101.3 (39.9)
Lower torso sizing	Waist depth [26-B7]	15.0 (5.9)	30.0 (11.8)
Lower torso sizing	Hip breadth [27-B7]	29.7 (11.7)	40.6 (16.0)
Arm sizing	Wrist-to-wall distance [28-B7]	54.6 (21.5)	77.7 (30.6)

HSIR Section 3.1 Requirements Cont…

3.1.3.1 Total Crew Control Mass

[HS2010] The system shall accommodate a total crew control mass, as shown in Appendix B, table Total Crew Control Mass, to mission destination through return.

Rationale: Total crew mass is based on a statistically derived value established to ensure, with high probability, that vehicle performance and mass allocations will be sufficient to accommodate crews selected from the astronaut corps without consideration of individual crew mass. Individual crew mass is already a criteria of individual crew selection to the corps. Insufficient total crew mass capabilities creates a burden for mission crew selection of larger crewmembers, requiring other crewmembers to be smaller and requiring backup crewmembers for smaller crewmembers to be similarly small. Total crew mass numbers are derived using a weight-truncated database based on the Natick U.S. Army Anthropometric Survey (ANSUR) data trended to show growth through 2015. The specification of crew mass uses this weight-truncated database for crewmembers using a Monte Carlo simulation to identify the 80th percentile total crew mass given a distribution of 18.5% of females in the population for four crew. For simplicity, this requirement assumes an average individual mass of 82 kg (180 lb), with a higher probability of meeting the total crew control mass for larger (six-person) crews and a lower probability for smaller (four-person) crews. Individual crew mass is the Max single crew mass per Appendix B, table Whole Body Mass of Crewmember. Crew masses specified are for unclothed or lightly clothed crewmembers and should be considered in addition to clothing and suit masses.

TABLE 3.1.3.1-1 TOTAL CREW CONTROL MASS

Vehicle	Four Crew (kg [lb])	Six Crew (kg [lb])
Orion	327 (720)	490 (1,080)
Altair	327 (720)	N/A

Six Crew Requirements Pending Deletion

HSIR Section 3.1 Requirements Cont…

3.1.3.2 Mass Properties of an Unsuited Crewmember

[HS2005] Aspects of the system with which an unsuited crewmember physically interacts during acceleration should accommodate crewmember mass properties as defined in all tables in Appendix B, Section B3.0 Mass Properties.

Rationale: Body support systems (seats, brackets, restraints, etc.) must accommodate forces exerted by an unsuited crewmember under all anticipated accelerations.

3.1.3.3 Mass Properties of a Suited Crewmember

[HS2006] Aspects of the system with which a suited crewmember may physically interact during planned tasks shall accommodate the mass of the suited crewmember provided in Appendix B, table Whole-Body Mass of Crewmember.

Rationale: All vehicle systems with human-systems interfaces need to be designed such that they will not be damaged after being subjected to the forces that a large suited crewmember can impart on that interface. Also, body support systems (seats, brackets, restraints, etc.) must accommodate forces exerted by a suited crewmember under all anticipated acceleration and gravity environments.

HSIR Section 3.1 Requirements Cont…

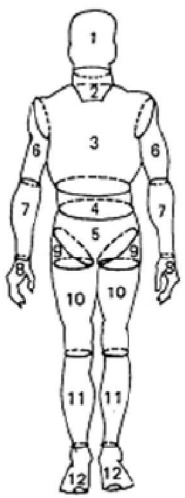
TABLE B3-1 WHOLE-BODY MASS OF CREWMEMBER

Crewmember Body Mass (kg [lb])		
	Unsuited	Suited*
Min	42.64 (94)	78.93 (174)
Max	110.22 (243)	146.51 (323)

* The crewmember body mass for "Suited" includes 36.29 kg (80 lb) for the pressure garment and does not include crew survival gear or EVA gear.

NOTE: Data are projected forward to 2015.

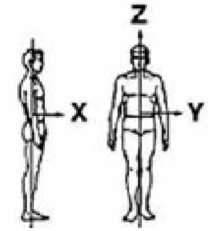
TABLE B3-2 BODY-SEGMENT MASS PROPERTIES FOR THE MALE AND FEMALE CREWMEMBER



Segment	Mass (kg [lb])	
	Min	Max
1 Head	2.99 (6.59)	5.03 (11.08)
2 Neck	0.49 (1.08)	1.39 (3.07)
3 Thorax	11.35 (25.02)	34.33 (75.69)
4 Abdomen	2.14 (4.72)	3.25 (7.16)
5 Pelvis	5.62 (12.4)	16.46 (36.29)
6 Upper arm	0.91 (2.0)	2.74 (6.04)
7 Forearm	0.59 (1.29)	1.86 (4.09)
8 Hand	0.24 (0.52)	0.66 (1.45)
9 Hip flap	2.22 (4.9)	4.79 (10.55)
10 Thigh minus hip flap	3.86 (8.12)	8.48 (18.69)
11 Calf	1.94 (4.28)	5.11 (11.27)
12 Foot	0.44 (0.98)	1.26 (2.77)
Torso (5 + 4 + 3)	19.11 (42.13)	54.05 (119.15)
Thigh (9 + 10)	5.91 (13.03)	13.26 (29.24)
Forearm plus hand (7+8)	0.82 (1.81)	2.51 (5.54)

NOTE: Data are projected forward to 2015.

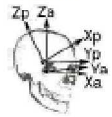
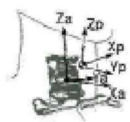
TABLE B3-3 WHOLE-BODY CENTER OF MASS LOCATION OF THE MALE AND FEMALE CREWMEMBER



NOTE: The axes in the figure above represent the anatomical axes.

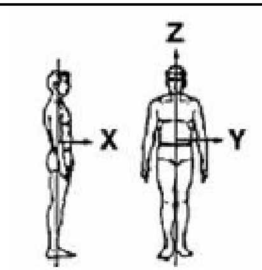
Dimension	Min (cm [in])	Max (cm [in])
$L(X_a)$	-15.27 (-6.01)	-6.40 (-2.52)
$L(Y_a)$	-1.22 (-0.48)	0.97 (0.38)
$L(Z_a)$	-3.81 (-1.5)	8.15 (3.21)

TABLE B3-4 BODY-SEGMENT CENTER OF MASS LOCATION OF THE CREWMEMBER

Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
Head 	X_a	-2.44 (-0.96)	0.53 (0.21)
	Y_a	-0.61 (-0.24)	0.61 (0.24)
	Z_a	2.24 (0.88)	4.04 (1.59)
Neck 	X_a	3.40 (1.34)	7.32 (2.88)
	Y_a	-0.56 (-0.22)	0.58 (0.23)
	Z_a	2.92 (1.15)	6.05 (2.38)
Thorax	X_a	3.76 (1.48)	7.06 (2.78)
	Y_a	-0.81 (-0.32)	0.48 (0.19)

HSIR Section 3.1 Requirements Cont…

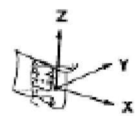
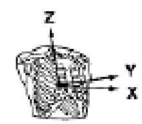
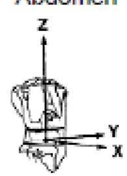
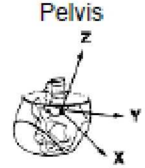
TABLE B3-5 WHOLE-BODY MOMENT OF INERTIA OF THE CREWMEMBER



NOTE: The axes in the figure above represent the principal axes.

Axis	Min (kg·m2 [lb·ft^2])	Max (kg·m2 [lb·ft^2])
X_p	6.59 (156.38)	17.69 (419.79)
Y_p	6.12 (145.23)	16.43 (389.89)
Z_p	0.73 (17.32)	2.05 (48.65)

TABLE B3-6 BODY-SEGMENT MOMENT OF INERTIA OF THE CREWMEMBER

Segment	Axis	Min (kg·m2x10-3 [lb·ft^{2}x10^{-3}])	Max (kg·m2 x10-3 [lb·ft^{2}x10^{-3}])
Head 	X_p	15 (351)	22 (512)
	Y_p	18 (424)	25 (587)
	Z_p	14 (322)	16 (379)
Neck 	X_p	0.7 (17)	2.2 (53)
	Y_p	1.0 (23)	2.7 (64)
	Z_p	1.1 (25)	3.4 (81)
Thorax 	X_p	183 (4,346)	680 (16,134)
	Y_p	135 (3,206)	505 (11,984)
	Z_p	119 (2,833)	431 (10,236)
Abdomen 	X_p	15 (347)	23 (540)
	Y_p	10 (241)	13 (309)
	Z_p	21 (500)	35 (826)
Pelvis 	X_p	46 (1,092)	148 (3,514)
	Y_p	34 (810)	137 (3,258)
	Z_p	61 (1,440)	173 (4,104)