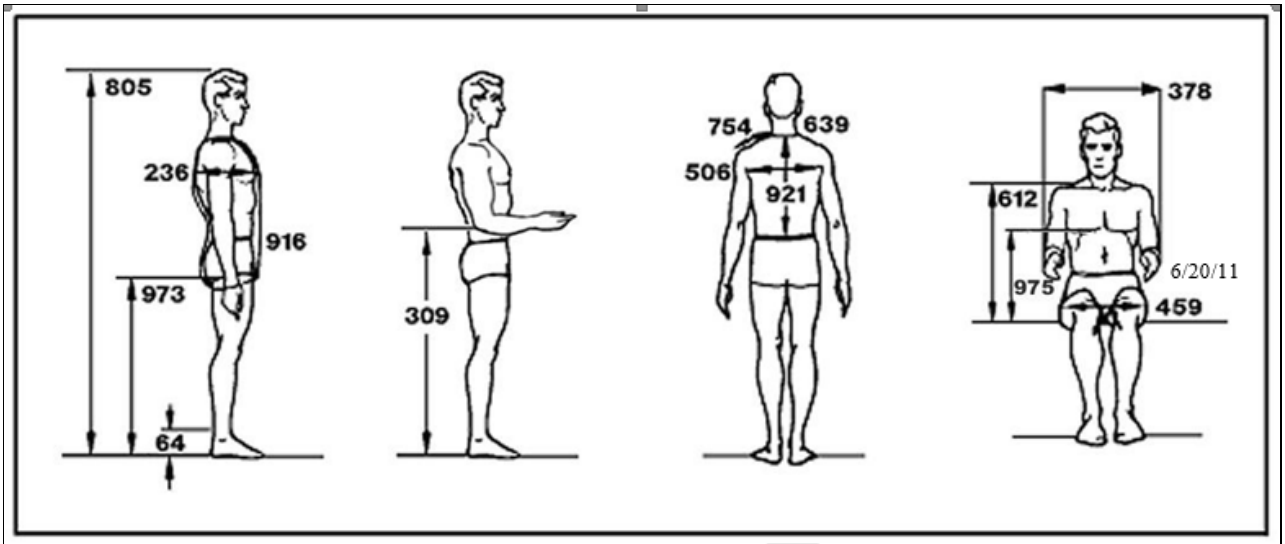
ANTHROPOMETRY

The data in this section are from the population in the 1988 Anthropometric Survey of US Army Personnel (ANSUR) (ref. Natick/TR-89/044), projected forward by NASA to 2015 to account for the expected small growth in the size of members of the US population. Note that for measurements that include the length of the spine, 3% of stature (for standing measurements) or 6% of seated height (for sitting measurements) must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation of 3% and 6% values can be found in NASA/SP-2010-3407 Revision 1, Human Integration Design Handbook (HIDH).

Table 1-1 Anthropometric Dimensional Data for American Female and Male contains a data range for general anthropometric dimensions under minimally clothed condition. The data in Table 1-1 does not account for clearances for operational movements crewmembers routinely perform while suited, e.g., helmet removal.

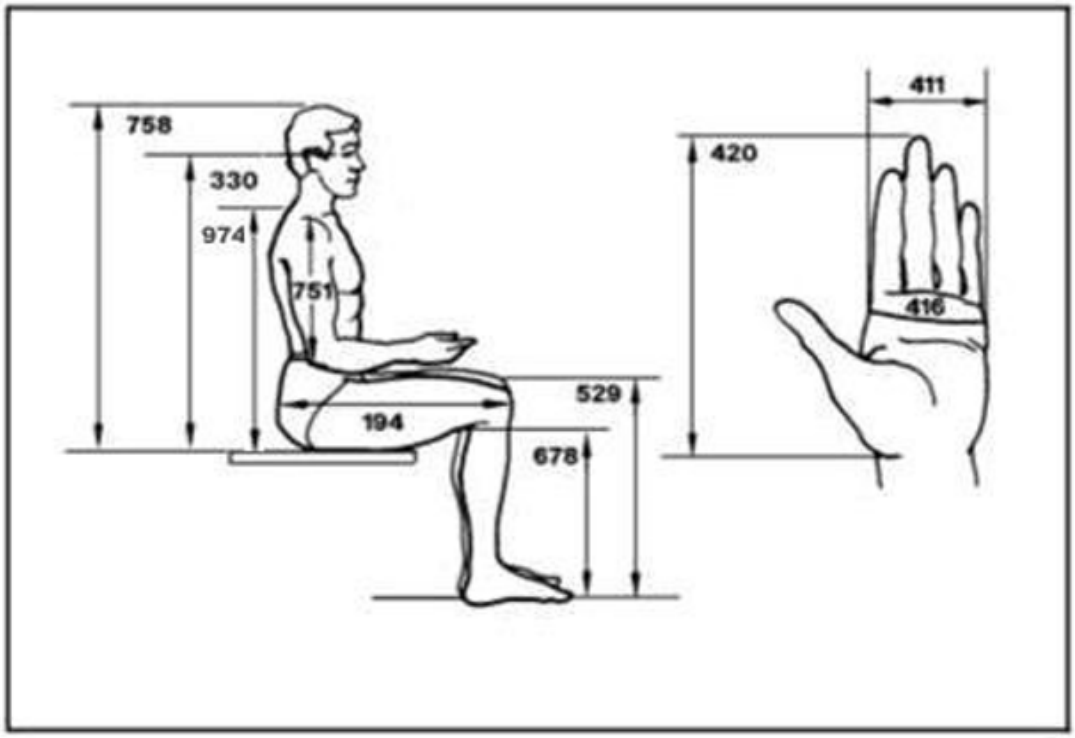
Table 1 ANTHROPOMETRY

TABLE 1-1 ANTHROPOMETRIC DIMENSIONAL DATA FOR AMERICAN FEMALE AND MALE

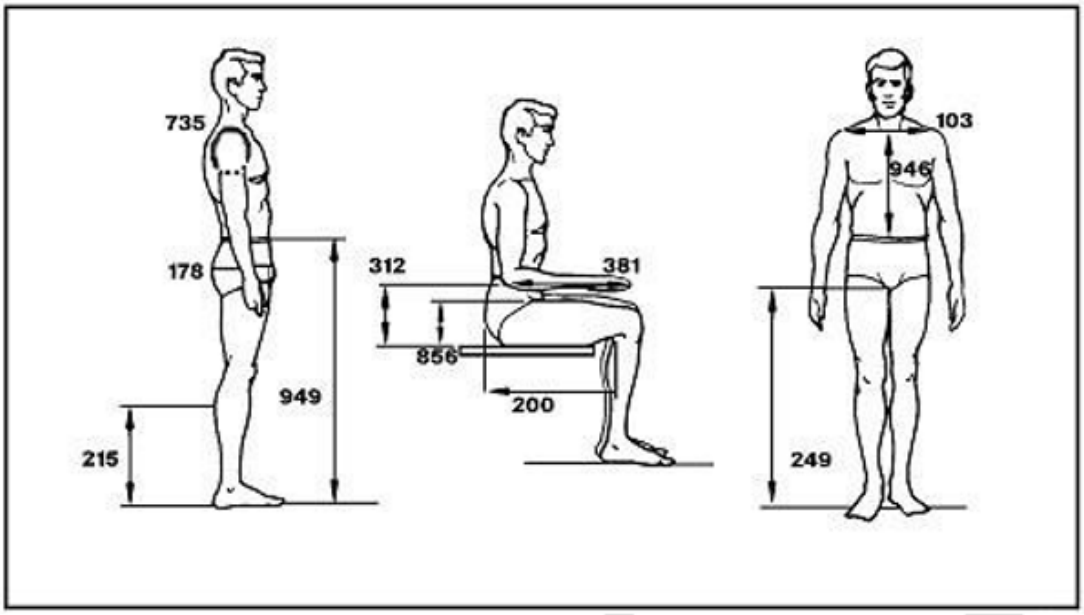


No.	Dimension	Min (cm, (in))	Max (cm, (in))
805	Stature	148.6 (58.5)	194.6 (76.6)
973	Wrist height	70.3 (27.7)	96.3 (37.9)
64	Ankle height	4.8 (1.9)	8.1 (3.2)
309	Elbow height (rest height standing)	89.9 (35.4)	120.7 (47.5)
236	Bust depth (chest depth)	19.1 (7.5)	30.2 (11.9)
916	Vertical trunk circumference	134.9 (53.1)	181.9 (71.6)
612	Mid-shoulder height, sitting	52.6 (20.7)	71.1 (28.0)
459*	Hip breadth, sitting	31.5 (12.4)	46.5 (18.3)
921	Waist back	39.1 (15.4)	55.9 (22.0)
506	Interscye	29.3 (11.5)	48.0 (18.9)
639	Neck circumference	27.8 (10.9)	43.4 (17.1)
754	Shoulder length (side neck-to-acromion horizontal distance)	12.0 (4.7)	18.0 (7.1)
378	Forearm-forearm breadth	38.9 (15.3)	66.0 (26.0)
975	Chest height, sitting	33.8 (13.3)	50.3 (19.8)

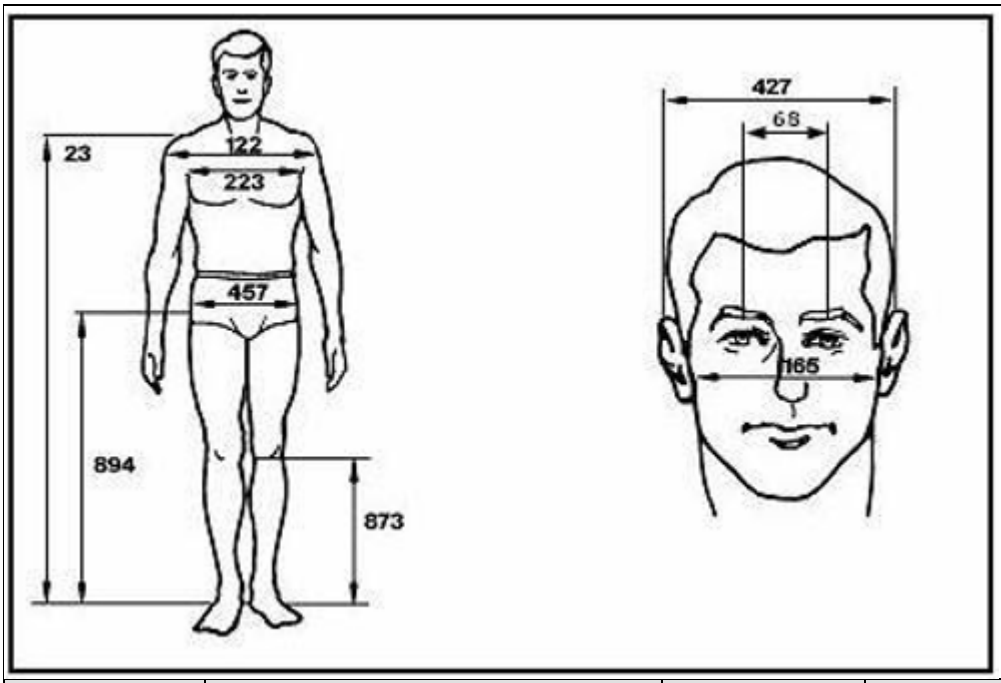
*For seated measurements, the largest female hip breadth is larger than the largest male hip breadth, and the smallest male hip breadth is smaller than the smallest female hip breadth; therefore, male data are used for the Min dimension, and female data are used for the Max dimension.



No.	Dimension	Min (cm [in])	Max (cm [in])
758	Sitting height	77.7 (30.6)	101.3 (39.9)
330	Eye height, sitting	66.5 (26.2)	88.9 (35.0)
529	Knee height, sitting	45.5 (17.9)	63.5 (25.0)
678	Popliteal height	33.0 (13.0)	50.0 (19.7)
751	Shoulder-elbow length	29.6 (11.6)	41.9 (16.5)
194	Buttock-knee length	52.1 (20.5)	69.9 (27.5)
420	Hand length	15.8 (6.2)	22.1 (8.7)
411	Hand breadth	7.1 (2.8)	10.2 (4.0)
416	Hand circumference	16.8 (6.6)	24.1 (9.5)
974	Cervicale height, sitting	56.6 (22.3)	76.2 (30.0)

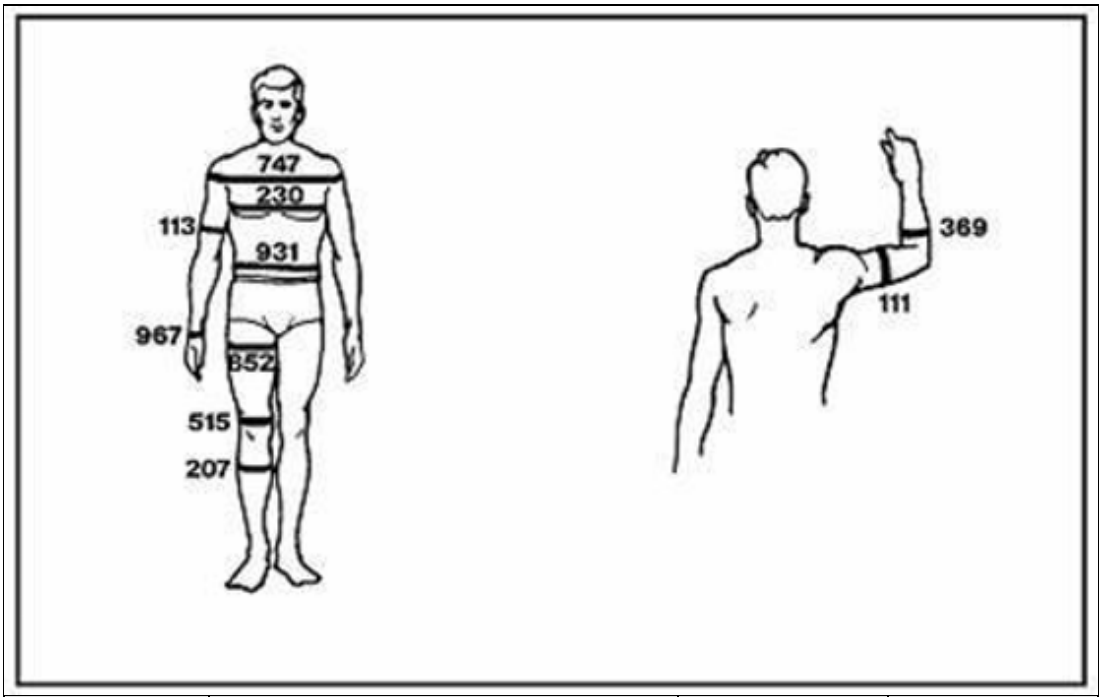


No.	Dimension	Min (cm [in])	Max (cm [in])
949	Waist height	86.6 (34.1)	119.6 (47.1)
249	Crotch height	66.5 (26.2)	95.8 (37.7)
215	Calf height	25.9 (10.2)	41.4 (16.3)
103	Biacromial breadth	32.3 (12.7)	44.5 (17.5)
946	Waist front	34.1 (13.4)	48.8 (19.2)
735	Scye circumference	31.9 (12.6)	52.1 (20.5)
178	Buttock circumference	84.1 (33.1)	114.8 (45.2)
312	Elbow rest height	16.2 (6.4)	30.0 (11.8)
856	Thigh clearance	13.0 (5.1)	20.1 (7.9)
381	Forearm hand length	38.7 (15.2)	54.6 (21.5)
200	Buttock-popliteal length	42.2 (16.6)	57.2 (22.5)

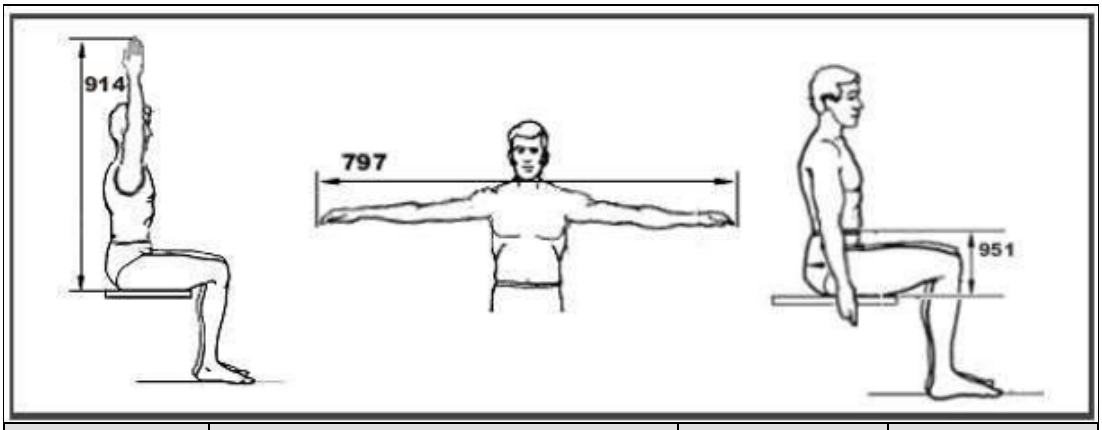


No.	Dimension	Min (cm [in])	Max (cm [in])
23	Acromial (shoulder) height	120.4 (47.4)	161.8 (63.7)
894	Trochanteric height	75.2 (29.6)	105.4 (41.5)
873	Knee Height, Midpatella	39.6 (15.6)	57.9 (22.8)
122	Bideltoid (shoulder) breadth	37.8 (14.9)	56.1 (22.1)
223	Chest breadth	23.5 (9.3)	39.4 (15.5)
457*	Hip breadth	29.8 (11.7)	40.6 (16.0)
165	Bizgomatic (face) breadth	12.0 (4.7)	15.5 (6.1)
427	Head breadth	13.3 (5.2)	16.5 (6.5)
68	Interpupillary Breadth	5.3 (2.1)	7.4 (2.9)

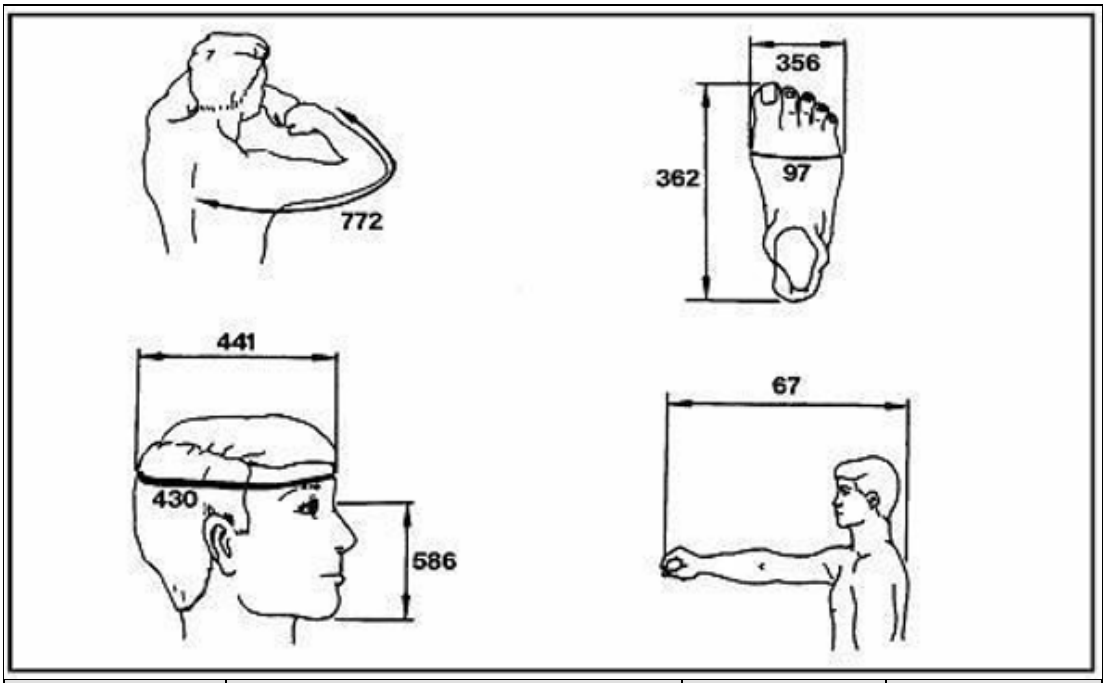
*For standing measurements, the largest female hip breadth is larger than the largest male hip breadth; therefore, female data are used for both the Min dimension and the Max dimension.



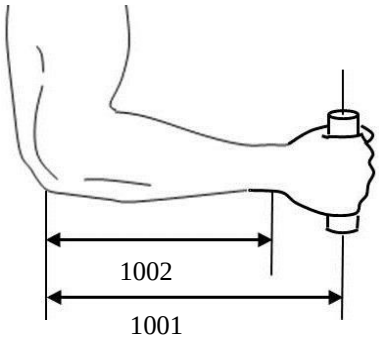
No.	Dimension	Min (cm [in])	Max (cm [in])
747	Shoulder circumference	90.4 (35.6)	133.9 (52.7)
230	Chest circumference	75.7 (29.8)	118.6 (46.7)
931	Waist circumference	61.2 (24.1)	110.5 (43.5)
852	Thigh circumference	47.8 (18.8)	71.9 (28.3)
515	Knee circumference	30.7 (12.1)	44.5 (17.5)
207	Calf circumference	29.5 (11.6)	44.5 (17.5)
967	Wrist circumference	13.5 (5.3)	19.8 (7.8)
111	Biceps circumference, flexed	22.9 (9.0)	40.4 (15.9)
369	Forearm circumference, flexed	21.6 (8.5)	35.3 (13.9)

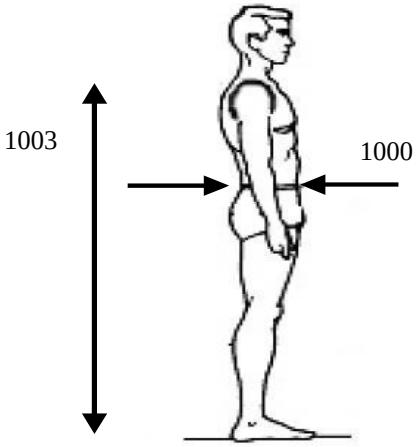


No.	Dimension	Min (cm [in])	Max (cm [in])
951	Waist height, sitting	19.3 (7.6)	27.2 (10.7)
797	Span, sitting	147.8 (58.2)	204.7 (80.6)
914	Vertical index fingertip reach, sitting	118.9 (46.8)	158.2 (62.3)



No.	Dimension	Min (cm [in])	Max (cm [in])
67	Thumb-tip reach	65.0 (25.6)	90.9 (35.8)
772	Sleeve length	72.4 (28.5)	99.1 (39.0)
441	Head length	17.3 (6.8)	21.6 (8.5)
430	Head circumference	51.3 (20.2)	61.0 (24.0)
586	Menton-sellion (face) length	9.9 (3.9)	14.0 (5.5)
362	Foot length	21.6 (8.5)	30.5 (12.0)
356	Foot breadth	7.9 (3.1)	11.4 (4.5)
97	Ball of foot circumference	19.6 (7.7)	28.2 (11.1)





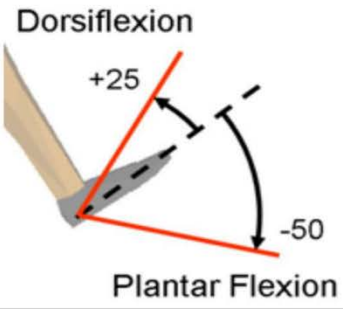
No.	Dimension	Min (cm [in])	Max (cm [in])
1000	Waist Depth	15.0 (5.9)	30.0 (11.8)
1001	Elbow to Center of Grip Length	28.7 (11.3)	40.8 (16.1)
1002	Elbow to Wrist Length	22.5 (8.9)	33.1 (13.0)
1003	Cervicale Height, Standing	127.7 (50.3)	169.8(66.9)

2 RANGE OF MOTION

The ranges of motion to be accommodated for crewmembers were collected in 1 g conditions as part of a 2007/2008 study in the NASA JSC Anthropometry and Biomechanics Facility. The values represented in these tables show the level of mobility that was needed to perform a variety of relevant functional tasks. These numbers do not necessarily indicate maximum level of mobility possible in a given configuration. Each table provides the range of motion for specific suited and gravitational conditions as described below.

Table D-2-1 Range of Motion (Unsuited) provides several joint measures that were present in old versions of this table but were not reinvestigated as a part of the 2007/2008 mobility study. These values are specifically called out when listed in the table.

TABLE 2-1: UNSUITED RANGE OF MOTION

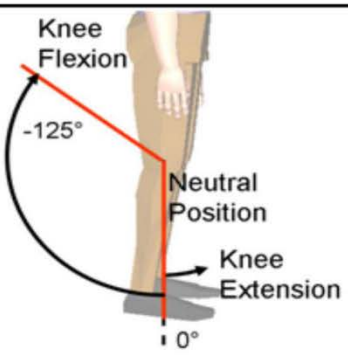


Ankle

Unsuited ROM

Dorsiflexion	Plantar Flex
25	-50

*All Units in Degrees

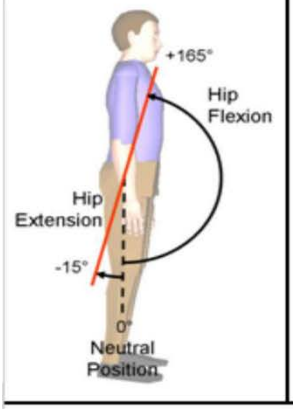


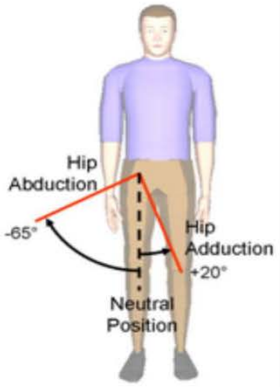
Knee

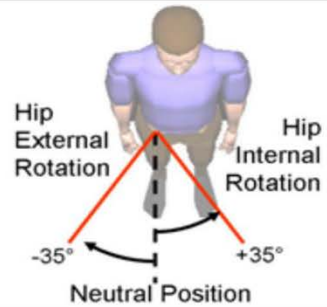
Unsuited ROM

Flexion	Extension
-125	0

*All Units in Degrees







Hip

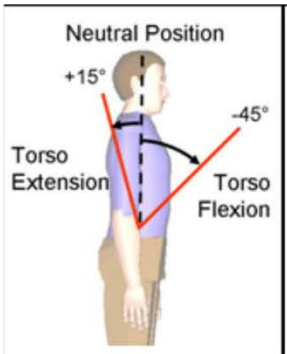
Unsuited ROM

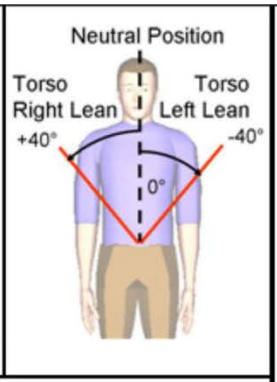
Flexion	Extension
165	-15

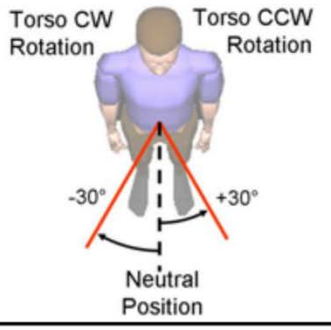
Abduction	Adduction
-65	20

Int Rotation	Ext Rotation
35	-35

*All Units in Degrees







Torso

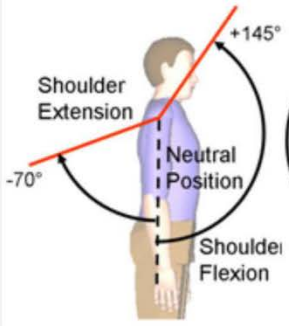
Unsuited ROM

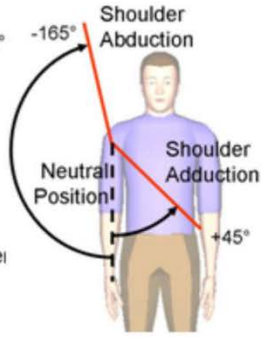
Flexion	Extension
-45	15

Right Lean	Left Lean
40	-40

CCW	CW
30	-30

*All Units in Degrees





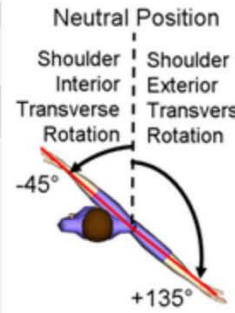
Shoulder

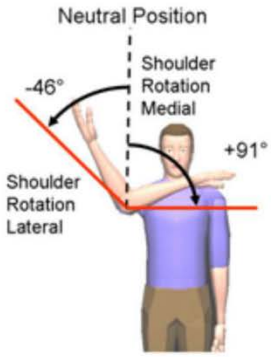
Unsuited ROM

Flexion	Extension
145	-70

Abduction	Adduction
-165	45

*All Units in Degrees





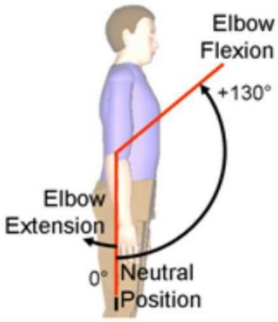
Shoulder 1979 Study

Unsuited ROM

Interior Transverse Rotation	Exterior Transverse Rotation
-45	135

Lateral	Medial
-46	91

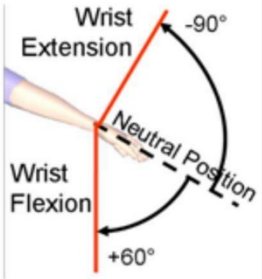
*All Units in Degrees

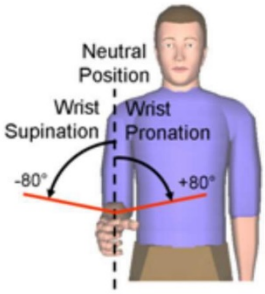


Elbow

Unsuited ROM	
Flexion	Extension
130	0

*All Units in Degrees



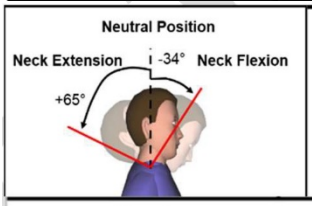


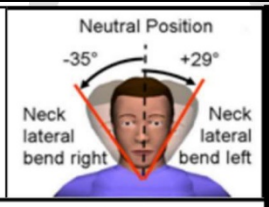


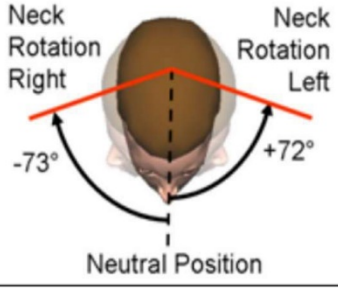
Wrist

Unsuited ROM	
Extension	Flexion
-90	60
Abduction (Radial Deviation)	Adduction (Ulnar Deviation)
30	-25
Supination	Pronation
-80	80

*All Units in Degrees



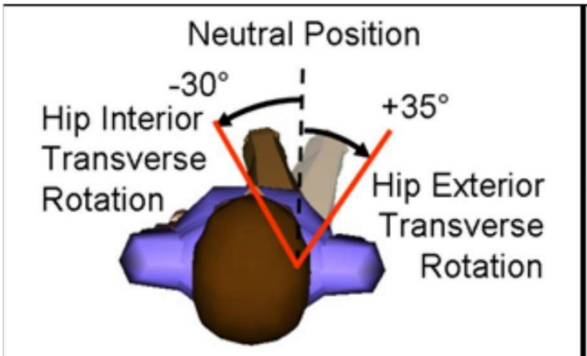




Neck 1979 Study

Unsuited ROM	
Flex	Ex
-34	65
Bend Right	Bend Left
-35	29
Rot R	Rot L
-73	72

*All Units in Degrees



	Unsuited ROM	
Hip 1979 Study	Interior Transverse Rotation	Exterior Transverse Rotation
	-30	35
	*All Units in Degrees	

“1979 Study” refers to data from SP-2-86L-064 Thornton, W, and Jackson, J. Anthropometric Study of Astronaut Candidates, 1979 to 1980, (Unpublished Data) NASA-JSC.

3 BODY SURFACE AREA

TABLE 3-1 BODY SURFACE AREA OF A CREWMEMBER

Crewmember Body Surface Area (cm^2 [$in.^2$])	
Minimum	13,831 (2,144)
Maximum	24,282 (3,764)

5 BODY MASS

TABLE 5-1: WHOLE BODY MASS

Crewmember Body Mass (kg[lb])	
	Unsuited
Min	42.64 (94)
Max	110.22 (243)
Data are projected forward to 2015	

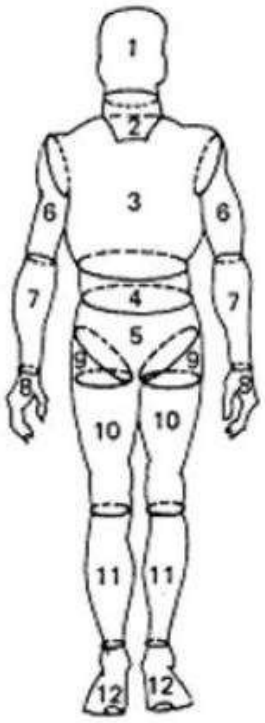
TABLE D5-2: WHOLE BODY MASS FOR MULTIPLE CREW, UNSUITED

Crew Number	Mean (kg(lbs))	Std. Dev (kg(lbs))	95th%tile (kg(lbs))	80th%tile (kg(lbs))	Per Crewmember Weight (kg(lbs))
1	X	X	110.2 (243.1)*	X	X
2	154.7 (340.3)	16.1 (35.4)	181.1 (398.4)	168.3 (370.3)	84.2 (185.1)
3	232.0 (510.4)	19.7 (43.3)	264.4 (581.6)	248.6 (546.9)	82.9 (182.3)
4	309.1 (680.0)	22.7 (49.9)	346.4 (762.2)	328.2 (722.0)	82.1 (180.5)
5	386.8 (850.9)	25.5 (56.2)	428.8 (943.3)	408.3 (898.3)	81.7 (179.7)
6	463.9 (1020.6)	27.8 (61.2)	509.6 (1121.2)	487.3 (1072.1)	81.2 (178.7)

*99^{th} percentile value

Given the low probability that a mission crew will be comprised entirely of 99^{th} percentile male crewmembers, a Monte Carlo simulation was performed to derive the above table. The Monte Carlo simulation generated total mass for the crew as a whole by randomly selecting groups of individuals from an existing population over a large number of iterations, generating a "population" of total mass values from which percentiles were derived.

TABLE 5-3: BODY SEGMENT MASS OF A CREWMEMBER, UNSUITED

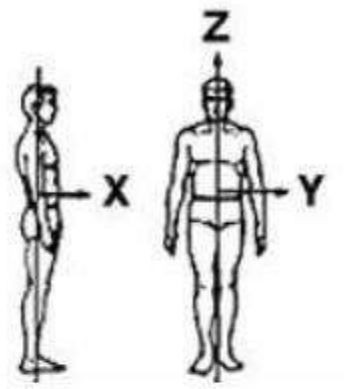


Segment	Mass (kg [lb])	
	Min	Max
1 Head	2.99 (6.59)	5.03 (11.08)
2 Neck	0.49 (1.08)	1.39 (3.07)
3 Thorax	11.35 (25.02)	34.33 (75.69)
4 Abdomen	2.14 (4.72)	3.25 (7.16)
5 Pelvis	5.62 (12.4)	16.46 (36.29)
6 Upper arm	0.91 (2.0)	2.74 (6.04)
7 Forearm	0.59 (1.29)	1.86 (4.09)
8 Hand	0.24 (0.52)	0.66 (1.45)
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)

Data are projected forward to 2015.

Whole Body Center of Mass: Assuming that the human flesh was homogeneous, it can also be assumed that the center of volume is at the center of mass location. McConville et al. (1980) and Young et al. (1983) provided ranges for the location of the center of volume for the male and female, respectively, in each study. Because regression equations were not given for the center of volume, the range values from the McConville et al. (1980) and Young et al. (1983) studies were used here. Specific values for the locations of the center of mass with respect to the anatomical axes were taken from each study to form the range; specifically, the upper range was set by the male upper range, and the lower range was set by the female lower range.

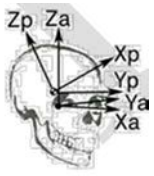
TABLE 5-4: WHOLE BODY CENTER OF MASS LOCATION

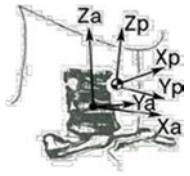
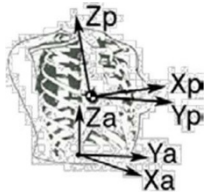
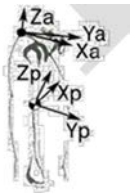


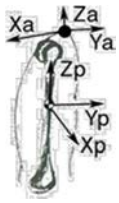
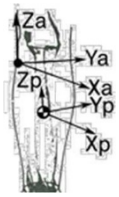
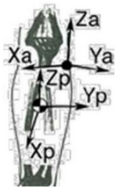
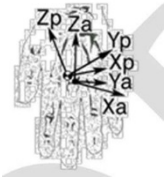
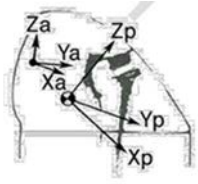
The axes in the figure above represent the anatomical axes.

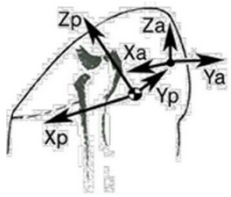
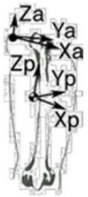
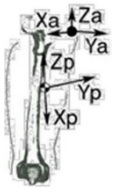
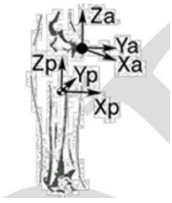
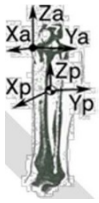
Dimension	Min (cm,(in))	Max (cm,(in))
L(Xa)	-15.27 (-6.01)	-6.40 (-2.52)
L(Ya)	-1.22 (-0.48)	0.97 (0.38)
L(Za)	-3.81 (-1.5)	8.15 (3.21)

TABLE 5-5 BODY-SEGMENT CENTER OF MASS LOCATION OF THE CREWMEMBER, UNSUITED

Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
Head 	Xa	-2.44 (-0.96)	0.53 (0.21)
	Ya	-0.61 (-0.24)	0.61 (0.24)
	Za	2.24 (0.88)	4.04 (1.59)
Neck	Xa	3.40 (1.34)	7.32 (2.88)
	Ya	-0.56 (-0.22)	0.58 (0.23)

Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
	Za	2.92 (1.15)	6.05 (2.38)
Thorax 	Xa	3.76 (1.48)	7.06 (2.78)
	Ya	-0.81 (-0.32)	0.48 (0.19)
	Za	13.44 (5.29)	21.97 (8.65)
Abdomen 	Xa	-1.47 (-0.58)	1.55 (0.61)
	Ya	-1.65 (-0.65)	2.26 (0.89)
	Za	-4.85 (-1.91)	-1.14 (-0.45)
Pelvis 	Xa	-12.17 (-4.79)	-6.96(-2.74)
	Ya	-1.32 (-0.52)	0.74 (0.29)
	Za	-0.76 (-0.30)	5.18 (2.04)
Torso 	Xa	-10.41 (-4.1)	2.49 (0.98)
	Ya	-1.52 (-0.60)	1.73 (0.68)
	Za	16.33 (6.43)	25.60 (10.08)
Right upper arm 	Xa	-0.71 (-0.28)	-0.91 (-0.36)
	Ya	1.85 (0.73)	-2.29 (-0.90)
	Za	-18.59 (-7.32)	-14.27 (-5.62)

Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
Left upper arm 	Xa	-0.64 (-0.25)	2.59 (1.02)
	Ya	-3.68 (-1.45)	-1.80 (-0.71)
	Za	-18.72 (-7.37)	-14.33 (-5.64)
Right forearm 	Xa	1.02 (0.40)	0.08 (0.03)
	Ya	-2.11 (-0.83)	4.14 (1.63)
	Za	-9.86 (-3.88)	-8.86 (-3.49)
Left forearm 	Xa	1.17 (0.46)	0.13 (0.05)
	Ya	-0.23 (-0.09)	-2.44 (-0.96)
	Za	-9.86 (-3.88)	-9.07 (-3.57)
Right hand 	Xa	-0.53 (-0.21)	0.03 (0.01)
	Ya	0.43 (0.17)	0.13 (0.05)
	Za	0.71 (0.28)	1.93 (0.76)
Left hand 	Xa	-0.71 (-0.28)	-0.23 (-0.09)
	Ya	-1.35 (-0.53)	0.89 (0.35)
	Za	0.84 (0.33)	2.03 (0.80)
Right hip flap 	Xa	-7.77 (-3.06)	1.70 (0.67)
	Ya	5.66 (2.23)	7.37 (2.90)
	Za	-6.73 (-2.65)	-6.05 (-2.38)

Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
Left hip flap 	Xa	-8.20 (-3.23)	2.41 (0.95)
	Ya	-10.67 (-4.2)	-5.18 (-2.04)
	Za	-6.96 (-2.74)	-6.20 (-2.44)
Right thigh minus flap 	Xa	-3.28 (-1.29)	2.36 (0.93)
	Ya	5.18 (2.04)	8.38 (3.30)
	Za	-24.84 (-9.78)	-23.34 (-9.19)
Left thigh minus flap 	Xa	3.10 (1.22)	2.21 (0.87)
	Ya	-9.60 (-3.78)	-5.28 (-2.08)
	Za	-24.87 (-9.79)	-23.62 (-9.3)
Right calf 	Xa	-4.24 (-1.67)	-0.10 (-0.04)
	Ya	-6.38 (-2.51)	-4.85(-1.91)
	Za	-16.18 (-6.37)	-12.01 (-4.73)
Left calf 	Xa	-4.34 (-1.71)	0.69 (0.27)
	Ya	4.04 (1.59)	6.83 (2.69)
	Za	-16.00 (-6.30)	-12.32 (-4.85)
Right foot 	Xa	-8.51 (-3.35)	-6.63 (-2.61)
	Ya	-0.28 (-0.11)	0.43 (0.17)
	Za	0.46 (0.18)	-0.05 (-0.02)

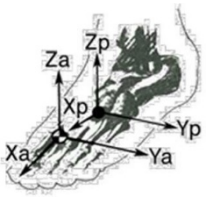
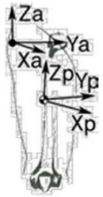
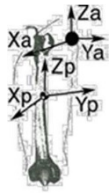
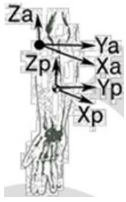
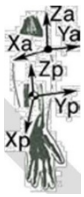
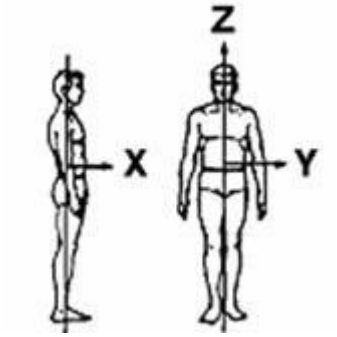
Segment	Anatomical Axis	Min (cm [in])	Max (cm [in])
Left foot 	Xa	-8.71 (-3.43)	-6.48 (-2.55)
	Ya	-0.86 (-0.34)	0.89 (0.35)
	Za	0.33 (0.13)	-0.10 (-0.04)
Right thigh 	Xa	-4.88 (-1.92)	2.11 (0.83)
	Ya	5.64 (2.22)	8.00 (3.15)
	Za	-17.55 (-6.91)	-17.55 (-6.91)
Left thigh 	Xa	-4.75 (-1.87)	2.29 (0.90)
	Ya	-9.65 (-3.80)	-5.26 (-2.07)
	Za	-17.91 (-7.05)	-17.83 (-7.02)
Right forearm plus hand 	Xa	0.43 (0.17)	-0.36 (-0.14)
	Ya	-2.29 (-0.90)	4.52 (1.78)
	Za	-15.54 (-6.12)	-14.99 (-5.9)
Left forearm plus hand 	Xa	0.43 (0.17)	0
	Ya	0.79 (0.31)	-2.82 (-1.11)
	Za	-15.37 (-6.05)	15.01 (-5.91)

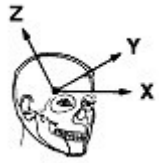
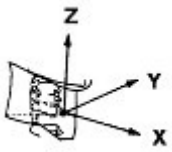
TABLE **5-6** WHOLE-BODY MOMENT OF INERTIA OF THE CREWMEMBER, UNSUITED

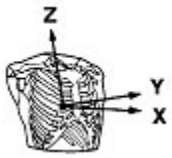
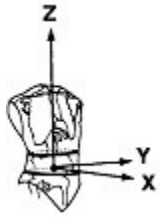
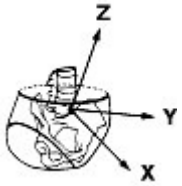
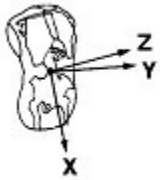
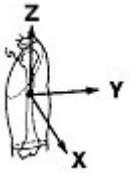


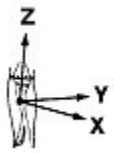
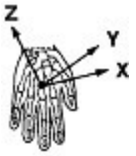
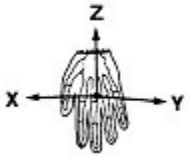
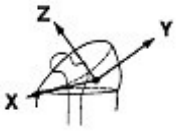
NOTE: The axes in the figure above represent the principal axes.

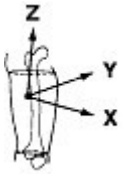
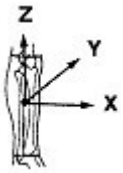
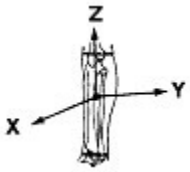
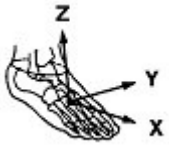
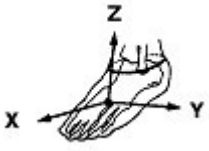
Axis	Min (kg·m2 [lb·ft2])	Max (kg·m2 [lb·ft2])
Xp	6.59 (156.38)	17.69 (419.79)
Yp	6.12 (145.23)	16.43 (389.89)
Zp	0.73 (17.32)	2.05 (48.65)

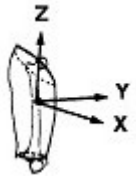
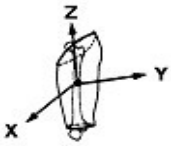
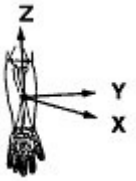
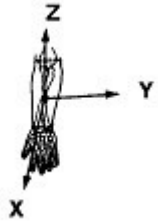
TABLE 5-7 BODY-SEGMENT MOMENT OF INERTIA OF THE CREWMEMBER, UNSUITED

Segment	Axis	Min (kg·m2x10-3 [lb·ft2x10-3])	Max (kg·m2 x10-3 [lb·ft2x10-3])
Head 	Xp	15 (351)	22 (512)
	Yp	18 (424)	25 (587)
	Zp	14 (322)	16 (379)
Neck 	Xp	0.7 (17)	2.2 (53)
	Yp	1.0 (23)	2.7 (64)
	Zp	1.1 (25)	3.4 (81)
Thorax	Xp	183 (4,346)	680 (16,134)

Segment	Axis	Min (kg·m2x10-3 [lb·ft2x10-3])	Max (kg·m2 x10-3 [lb·ft2x10-3])
	Yp	135 (3,206)	505 (11,984)
	Zp	119 (2,833)	431 (10,236)
Abdomen 	Xp	15 (347)	23 (540)
	Yp	10 (241)	13 (309)
	Zp	21 (500)	35 (826)
Pelvis 	Xp	46 (1,092)	148 (3,514)
	Yp	34 (810)	137 (3,258)
	Zp	61 (1,440)	173 (4,104)
Torso 	Xp	638 (15,143)	2,030 (48,178)
	Yp	577 (13,702)	1840 (43,654)
	Zp	205 (4,865)	644 (15,273)
Right upper arm 	Xp	5.4 (129)	18 (430)
	Yp	5.6 (133)	19 (462)
	Zp	1.0 (24)	3.9 (92)
Left upper arm 	Xp	5.3 (126)	17.7 (420)
	Yp	5.5 (130)	19 (449)
	Zp	0.9 (22)	3.8 (89)

Segment	Axis	Min (kg·m2x10-3 [lb·ft2x10-3])	Max (kg·m2 x10-3 [lb·ft2x10-3])
Right forearm 	Xp	2.8 (67)	12 (276)
	Yp	2.7 (65)	12 (282)
	Zp	0.5 (11)	1.8 (43)
Left forearm 	Xp	2.8 (66)	11 (257)
	Yp	2.7 (63)	11 (265)
	Zp	0.5 (11)	1.6 (39)
Right hand 	Xp	0.6 (14)	1.6 (38)
	Yp	0.5 (11)	1.3 (31)
	Zp	0.2 (4)	0.5 (13)
Left hand 	Xp	0.6 (15)	1.6 (37)
	Yp	0.5 (13)	1.3 (31)
	Zp	0.2 (4)	0.5 (12)
Right hip flap 	Xp	8.1 (191)	17 (412)
	Yp	10 (246)	22 (530)
	Zp	13 (318)	29 (696)
Left hip flap 	Xp	7.9 (188)	17 (398)
	Yp	11 (255)	22 (519)
	Zp	14 (324)	28 (671)
Right thigh minus flap	Xp	34 (800)	79 (1,885)

Segment	Axis	Min (kg·m2x10-3 [lb·ft2x10-3])	Max (kg·m2 x10-3 [lb·ft2x10-3])
	Yp	33 (785)	82 (1,941)
	Zp	14 (327)	32 (753)
Left thigh minus flap 	Xp	34 (798)	75 (1,784)
	Yp	33 (789)	79 (1,878)
	Zp	13 (317)	31 (729)
Right calf 	Xp	26 (615)	75 (1,790)
	Yp	26 (613)	76 (1,815)
	Zp	3.1 (73)	8.9 (210)
Left calf 	Xp	26 (614)	77 (1,826)
	Yp	26 (615)	78 (1,855)
	Zp	3.0 (70)	9.1 (215)
Right foot 	Xp	0.4 (9)	1.0 (24)
	Yp	1.6 (37)	5.5 (130)
	Zp	1.6 (39)	5.8 (138)
Left foot 	Xp	0.4 (9)	1.0 (24)
	Yp	1.6 (39)	5.4 (127)
	Zp	1.7 (41)	5.7 (134)
Right thigh	Xp	85 (2,009)	208 (4,940)
	Yp	87 (2,063)	220 (5,215)

Segment	Axis	Min (kg·m2x10-3 [lb·ft2x10-3])	Max (kg·m2 x10-3 [lb·ft2x10-3])
	Zp	27 (651)	59 (1,401)
Left thigh 	Xp	85 (2,022)	200 (4,757)
	Yp	88 (2,088)	212 (5,024)
	Zp	27 (649)	57 (1,350)
Right forearm plus hand 	Xp	11 (262)	40 (939)
	Yp	11 (257)	39 (935)
	Zp	0.7 (16)	2.4 (58)
Left forearm plus hand 	Xp	11 (260)	37 (887)
	Yp	11 (256)	37 (881)
	Zp	0.6 (15)	2.2 (53)
The axes in the figures above represent the principal axes.			

CREWMEMBER STRENGTH

Strength refers to a person's ability to generate force. Applying the following strength requirements will result in a minimum and maximum applied crew load to be used for operational and hardware design. The minimum load pertains to operational strength that accommodates the weakest person while the maximum load represents the force the hardware must be able to withstand without failure. It is important to note that these requirements apply to intentional forces applied by the crewmember. Durability is applicable to structural integrity of hardware due to non-intentional crew forces which is handled through the structural design process defined in JSC 65829, Loads and Structural Dynamics Requirements for Spaceflight Hardware.

Max Crew Loads - Vehicle components and equipment are to be designed to withstand large forces exerted by a strong crewmember during nominal hardware operation, without breaking or sustaining damage that would deem the hardware inoperable. Humans may also exert high forces when operating controls in emergency situations, such as attempting to open a hatch for emergency egress. The resulting possible damage to equipment could make it impossible to respond safely to the emergency. To avoid overdesign, a task analysis is performed to identify which interfaces must tolerate maximum crew operational loads. This includes identifying critical hardware that may be inadvertently used as a mobility aid or restraint. The data provided in the tables are for unsuited conditions. Data was derived from a collection of journal articles associated with human strength data.

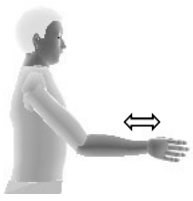
Minimum Crew Loads - The design must allow for all crewmembers to perform any of the requested tasks efficiently and effectively, thus ensuring task and/or mission success. The data provided is for unsuited conditions. A human-centered design process is to be used when implementing operational strength limits. Analysis of expected crew operations, activities, and tasks is to drive the design of human-machine interfaces. The analysis should evaluate and define activities/tasks in terms of criticality and required postures.

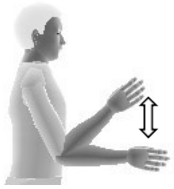
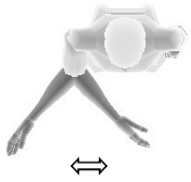
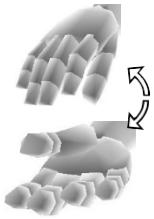
For this purpose tasks that involve the possibility of a single failure causing loss of life or vehicle have a definition of Criticality 1 Operations in the following tables. Tasks involving LOM alone have a Criticality 2 Operations. The values in the criticality 1 and 2 columns also include the decrement factor(s) to reflect the deconditioning effects on crewmembers after an extended duration of mission. All other tasks fall into the "Other Operations" category, and do not have deconditioning or a factor of safety applied over minimal anticipated crew strength. It is important to note that the designer should be careful not to implement multiple safety factors. For example, NASA-STD-5017 torque/force margin requirements (4.10.0) levy an extra safety factor on the applied torque/force to a given mechanism. Implementing this requirement along with the already built in safety factor (i.e., criticality) in the strength tables results in an overly conservative design.

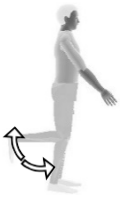
Data was derived from a collection of journal articles associated with human strength data. In addition, other references were used, such as the MIL-STD-1472F and the Occupational and Biomechanics textbook (Chaffin, D. B., Occupation Biomechanics, Second Edition, John Wiley & Sons, Inc., 1991), to set a standard for very specific strength data such as lifting strength.

TABLE 6-1: MAXIMUM CREW OPERATIONAL LOADS - UNSUITED

Type Of Strength		Maximum Crew Operational Loads (N(Lbf))
One-Handed Pulls		
Seated Horizontal Pull In[2] [Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement]		449 (101)
Seated Vertical Pull Down[2] [Subject in a seated position pulls downwards. Unilateral/Isometric measurement]		587 (132)
Seated Vertical Pull Up[2] [Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap]		756 (170)
Standing Vertical Pull Up[2] [Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side]		725 (163)
Two-Handed Pulls		
Standing Vertical Pull Down [2] [Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward]		707 (159)
Standing Pull in[2] [Standing erect with feet apart, with both hands holding handle located in front , pulling inward towards body]		391 (88)
Standing Vertical Pull Up[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward]		1437 (323)

Type Of Strength		Maximum Crew Operational Loads (N(Lbf))
Seated Vertical Pull Up[2] [Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders]		1188 (267)
One-Handed Push		
Seated Horizontal Push Out[2] [Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement]		436 (98)
Seated Vertical Push Up[2] [Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement]		280 (63)
Two-Handed Push		
Standing Vertical Push Down[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards]		525 (118)
Standing Horizontal Push Out[1] [Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body]		596 (134)
Standing Vertical Push Up[2] [Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders]		1094 (246)
Arm		
Arm Pull[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		249 (56)
Arm Push[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		222 (50)
Arm Up[2]		107 (24)

Type Of Strength		Maximum Crew Operational Loads (N(Lbf))
[Subject pushes and pulls handle in a various directions as shown by the figures]		
Arm Down[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		116 (26)
Arm In[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		98 (22)
Arm Out[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		76 (17)
Lifting		
Lifting Strength[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs]		1228 (276)
Elbow		
Flexion[2] [Subject moves forearm in a sagittal plane around the elbow joint]		347 (78)
Extension[2] [Subject moves forearm in a sagittal plane around the elbow joint]		249 (56)
Wrist and Hand		
Pronation[2] [Subject rotates hands and forearms so that the palms face downward or upwards]		876 (197)
Supination[2] [Subject rotates hands and forearms so that the palms face downward or upwards]		761 (171)
Wrist Flexion[2] [Subject bends the hand at the wrist in the sagittal plane as shown by the figure]		209 (47)
Wrist Extension[2] [Subject bends the hand at the wrist in the sagittal plane as shown by the figure]		85 (19)

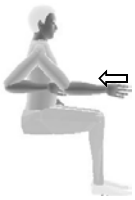
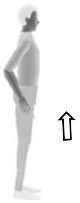
Type Of Strength		Maximum Crew Operational Loads (N(Lbf))
Pinch [1] [The act of squeezing between the thumb and a finger]		200 (45)
Grasp[1] [The acts of maintaining a tight hold of an object]		1219 (274)
Grip[1] [The acts of maintaining a tight hold of an object]		783 (176)
Leg		
Hip Flexion[2] [Subject moves upper and lower leg in a sagittal plane around the hip joint]		645 (145)
Hip Extension[2] [Subject moves upper and lower leg in a sagittal plane around the hip joint]		658 (148)
Leg Press[1] [Subject pushes a weight away from them using their legs]		2584 (581)
Knee Flexion[1] [Subject moves lower leg in a sagittal plane around the knee joint]		325 (73)
Knee Extension[1] [Subject moves lower leg in a sagittal plane around the knee joint]		783 (176)
Type Of Strength*		Maximum Crew Operational Loads (N(Lbf))
One-Handed Pulls		
Pronation* [Subject rotates hands and forearms so that the palms face downward or upwards]		11.3 (100)
Supination* [Subject rotates hands and forearms so that the palms face downward or upwards]		11.3 (100)

[1] Post space flight maximal measured strength decrement.

[2] Post space flight estimated strength decrement. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.

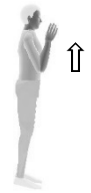
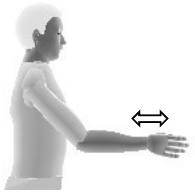
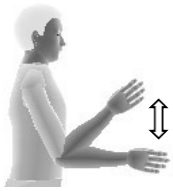
* Torque (rather than force) for unsuited pronation and supination. Torque units used

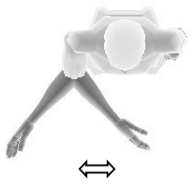
TABLE 6-2: MINIMUM CREW OPERATION LOADS - UNSUITED

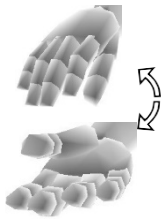
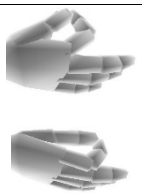
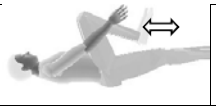
Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
One-Handed Pulls				
Seated Horizontal Pull In[2] [Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement]		111 (25)	147 (33)	276 (62)
Seated Vertical Pull Down[2] [Subject in a seated position pulls downwards. Unilateral/Isometric measurement]		125 (28)	165 (37)	311 (70)
Seated Vertical Pull Up[2] [Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap]		49 (11)	67 (15)	125 (28)
Standing Vertical Pull Up[2] [Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward		53 (12)	71 (16)	133 (30)

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
while keeping shoulders square and other arm relaxed at side]				
Two-Handed Pulls				
Standing Vertical Pull Down [2] [Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward]		138 (31)	182 (41)	343 (77)
Standing Pull in[2] [Standing erect with feet apart, with both hands holding handle located in front , pulling inward towards body]		58 (13)	80 (18)	147 (33)
Standing Vertical Pull Up[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward]		89 (20)	116 (26)	218 (49)
Seated Vertical Pull Up[2] [Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders]		93 (21)	125 (28)	236 (53)
One-Handed Push				

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
Seated Horizontal Push Out[2] [Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement]		89 (20)	116 (26)	218 (49)
Seated Vertical Push Up[2] [Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement]		67 (15)	85 (19)	160 (36)
Two-Handed Push				
Standing Vertical Push Down[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards]		102 (23)	133 (30)	254 (57)
Standing Horizontal Push Out[1] [Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body]		62 (14)	85 (19)	165 (37)

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
Standing Vertical Push Up[2] [Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders]		76 (17)	98 (22)	187 (42)
Arms				
Arm Pull[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		44 (10)	58 (13)	107 (24)
Arm Push[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		40 (9)	53 (12)	98 (22)
Arm Up[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		18 (4)	22 (5)	40 (9)
Arm Down[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		22 (5)	31 (7)	58 (13)

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
Arm In[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		22 (5)	31 (7)	58 (13)
Arm Out[2] [Subject pushes and pulls handle in a various directions as shown by the figures]		13 (3)	18 (4)	36 (8)
Lifting				
Lifting Strength[2] [Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs]		36 (8)	49 (11)	93 (21)
Elbow				
Flexion[2] [Subject moves forearm in a sagittal plane around the elbow joint]		13 (3)	18 (4)	36 (8)
Extension[2] [Subject moves forearm in a sagittal plane around the elbow joint]		27 (6)	36 (8)	67 (15)

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
Wrist and Hand				
Pronation[2] [Subject rotates hands and forearms so that the palms face downward or upwards]		165 (37)	222 (50)	414 (93)
Supination[2] [Subject rotates hands and forearms so that the palms face downward or upwards]		160 (36)	214 (48)	405 (91)
Pinch [1] [The act of squeezing between the thumb and a finger]		9 (2)	13 (3)	18 (4)
Grasp[1] [The acts of maintaining a tight hold of an object]		347 (78)	463 (104)	694 (156)
Grip[1] [The acts of maintaining a tight hold of an object]		49 (11)	67 (15)	102 (23)
Hip				
Hip Flexion[2] [Subject moves upper and lower leg in a sagittal plane around the hip joint]		116 (26)	156 (35)	289 (65)
Hip Extension[2] [Subject moves upper and lower leg in a sagittal plane around the hip joint]		191 (43)	254 (57)	476 (107)
Leg				
Leg Press[1]		618 (139)	827 (186)	1552 (349)

Type Of Strength		Minimum Crew Operation Loads (N(Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations
[Subject pushes a weight away from them using their legs]				
Knee Flexion[1] [Subject moves lower leg in a sagittal plane around the knee joint]		53 (12)	71 (16)	138 (31)
Knee Extension[1] [Subject moves lower leg in a sagittal plane around the knee joint]		142 (32)	191 (43)	383 (86)
Type Of Strength*		Minimum Crew Operation Loads (N·m(in-Lbf))		
		Crit 1 Operations	Crit 2 Operations	Other Operations

Hand and Wrist				
Pronation* [Subject rotates hands and forearms so that the palms face downward or upwards]	 \	0.8 (7.4)	1.1 (10)	2.1 (18.4)
Supination* [Subject rotates hands and forearms so that the palms face downward or upwards]		0.8 (7.4)	1.1 (10)	2.1 (18.4)

[1] Post space flight maximal measured strength decrement.

[2] Post space flight estimated strength decrement. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.

* Torque (rather than force) for unsuited pronation and supination. Torque units used.

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