

CHAPTER II VARIABILITY IN HUMAN BODY SIZE

by
James F. Annis
Webb Associates

A century ago, human engineering was a virtually unknown concept. In schools and homes, on assembly lines and military front lines, the item was paramount and its user secondary. If the operator could not be rammed into the workspace, then the operator was dispensable. Little notice was taken of the high cost in speed, efficiency, accuracy, endurance and safety which was paid in the use of tools and equipment ill-fitted to the hands, legs, eyes and backs of diverse operators. As late as World War II, the design of gun turrets for bombers was dictated so single-mindedly by the air frame configuration and performance requirements established for the aircraft that the number of men who could be found to fit into the turret was severely limited.

With the advent of ever more sophisticated technology, such a disregard for the human factor is no longer possible and a knowledge of man's size and its variability has become progressively more critical in the design of clothing, equipment and workspaces. Stresses involving posture, position and pressure imposed on an operator will result inevitably in an unhealthy body performing a far less than optimum job. We can no longer afford a random matching of men and machines; there are, after all, no dispensible operators on a space flight.

The problems of designing for a highly variable population are, of course, immense but not insuperable. The key to the solutions lies in a thorough acquaintance with the problem.

One has only to view a group of people to be struck by the range of diversity in the size and shape of mankind. This diversity, often visually aesthetic, can be a source of annoyance to the designer. For those involved in design problems, the human body seems to have an inordinate number of irregularly curved and angular depressions and projections, as well as an assortment of appendages, all of which tend to impede a straightforward design solution. Computer models have historically represented man as a series of cylinders, cones and spheroids, but ordinarily the designer should not.

Despite the quality of the subject material, the designer of equipment and systems must arrive at a design solution which will be adequate to accommodate the irregularities of size, shape and mobility of potential users. It is of value, therefore, to have as detailed a quantification of body size variability of the design population as possible.

One can, in general, classify the total human morphological variability into three broad categories: intra-individual, inter-individual, and secular variability. Intra-individual variability, as used here, pertains to those size changes or effective size changes that occur in an individual during his or her adult life. Some size changes such as those related to the aging process and nutrition occur slowly; others are temporary or transient such as those precipitated by movement or the environment. Intra-individual size variability also includes right side-left side asymmetry and the effect of personal protective clothing on functional body size. Of unique concern to the National Aeronautics and Space Administration (NASA) engineers are the changes which occur in the human body under zero-g and high-g conditions.

The differences between the sexes represent a major source of inter-individual variability with the female having, in general, a smaller overall body size, less strength and less rugged features than the male. A second source of such variability lies in ethnic and racial origins. The reader may obtain a general visual impression of the diversity of males and females of the three principal racial groups by examination of Figure 1. Although some artistic liberties have been taken in the figure, each representative body form was scaled to mean dimensional data utilized later in this chapter. Obviously a greater amount of difference could be demonstrated if extreme values had been used.

While all living people belong to a single biological species, the species, like other life forms, is not geographically uniform; it is differentiated into a number of local variants or breeding groups. These variants frequently differ in a number of morphological traits such as skin, eye and hair color, body size and proportions, with a particular trait often highly characteristic for a single variety. It is not necessary here to probe for the reasons behind these morphological differences between variants of man but only to acknowledge their existence and attempt to deal with them in terms of sizing and design requirements. This variability is of some importance here because of the many ethnic and racial groups that constitute the American population as well as the potential design population in the NASA space program.

For reasons that are not always very clear, dimensional differences also occur between persons of different occupations even in a single heterogeneous population. It is most commonly thought that selective pressures of a social, educational or physical nature act to produce the effect.

The third source of human variability which is here termed "secular" concerns changes which occur from generation to generation. Though not well understood this factor is of some importance in systems design. The lengthy lead time required for the production of modern spacecraft and systems is such that the crew members who may eventually use them are often not even of adult age when the design specifications are fixed. It is of more than casual interest, therefore, to estimate what the physical size and proportions of a particular design population will be at a given point in the future.

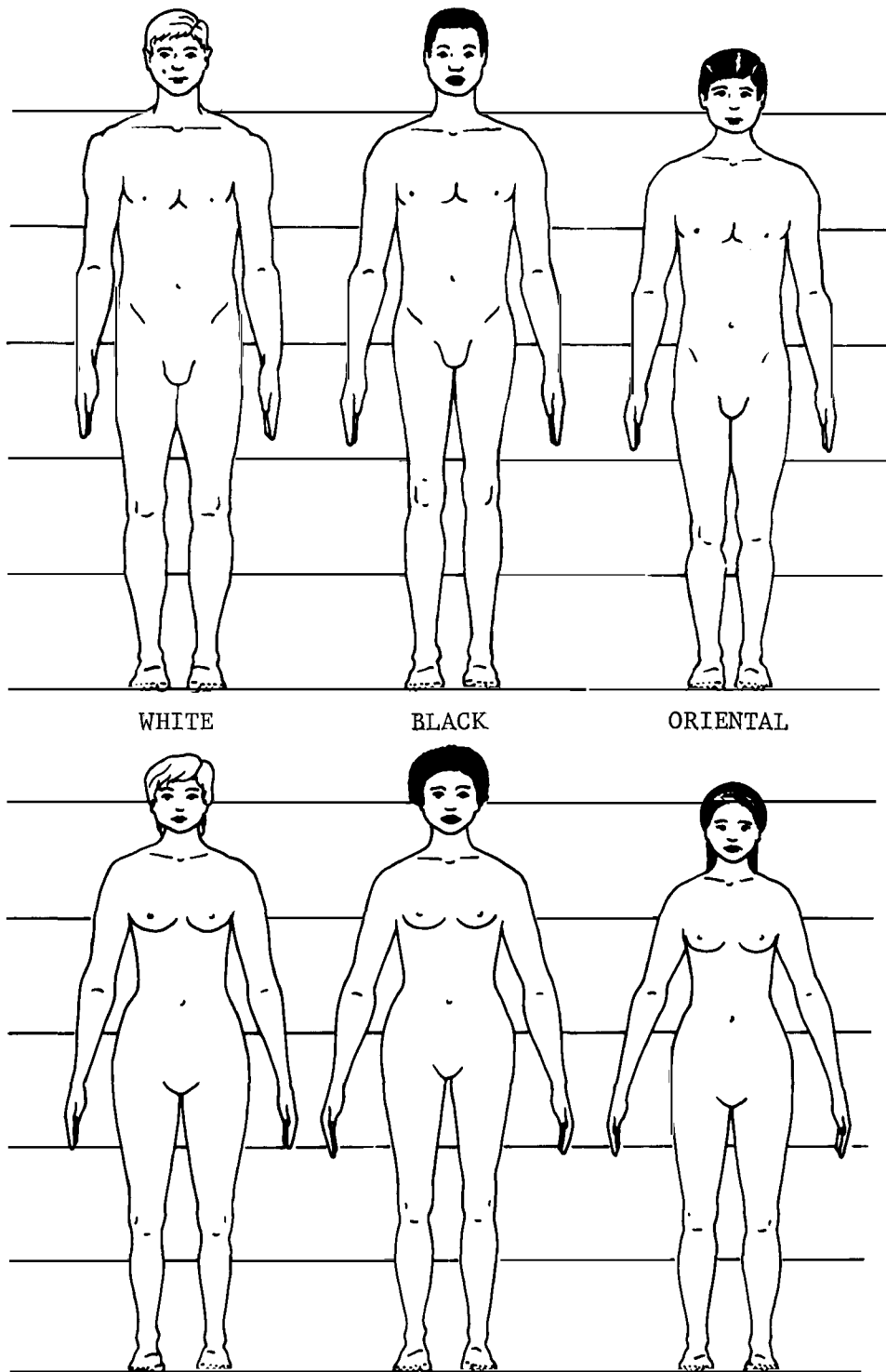


Figure 1. Body size comparisons of three principal racial groups: males and females.

Following a brief discussion of a few causes of size and shape variability of the individual we will offer in this chapter selected anthropometric data to guide the designer in statistically characterizing the variability of groups or populations as described above. Sections on the effects of aging, nutrition, right side-left side asymmetry, and transient changes in body size including day-to-day variations, the effect of posture and movement, and the effect of protective garments, will constitute the description of pertinent intra-individual variability. The effects of zero-g on body size, while noted in this chapter, have been covered in some detail in Chapter I. Variations between the sexes and among persons of different nationalities, racial groups and occupations will be discussed in sections on inter-individual variations. The concluding portions of this chapter will contain a discussion of secular changes recorded in the past century and suggest methods of predicting the size of astronauts and scientists a decade from now.

It should be assumed in all data presented that, unless otherwise noted we are dealing with adults for whom growth is complete. Obvious examples of extremes in size such as are found in Pygmy or Watusi populations have been ignored as have been pathogenetic examples of size extremes such as dwarfism or giantism. The data presented in this chapter represent "healthy" adults whose size variability (individually and in populations) reflect only the effects of "normal" genetic and environmental impact.

As we have attempted to do throughout this volume, an effort has been made to limit anthropometric data, wherever possible, to population surveys in which comparable measurement techniques and body landmarks were used. Obviously errors introduced by inter-anthropometrist differences cannot be altogether avoided and are endemic whenever comparative data presentations are made. Often, data presented in this chapter represents only selected dimensions for which more complete data from the same anthropometric survey is presented in more complete form elsewhere in the text.

Causes of Human Size Variability

No two individuals of a sexually reproducing species are exactly alike.* The statistical potential for individuality, in fact, verges on the incredible. Based on the weight of nucleotide pairs, Muller, the Nobel Prize winning geneticist, has estimated that there are $10^{2,400,000,000}$ possible combinations in the mass of DNA equivalent to that contained in the 46 human chromosomes (Dobzhansky 1962). Muller's staggering number would have to be further increased by unknown factors based on the number of possible combinations of environmental conditions which exert an influence on an individual's phenotypic expression.

*Monozygotic or identical twins have the same genotype, but somatic mutations, the environment, etc., will act to produce dissimilarities in adults.

At conception, the genetic endowment composes the individual's genotype which directs the formulation of the distinctly human, distinctly individualized proteins from which a given person's cells are built. Instructions guide cellular differentiation into special organ systems, the size, if not the shape, of component organs and blends everything together into a distinctly human and a distinctly individual morphology. The resultant expression of genotype is called the phenotype, which includes those physical characteristics that can be observed, described or measured by the human biologist.

There is little direct evidence to describe the genetic impact upon the development of body dimensions. The inheritance of a number of body deforming syndromes (e.g., Marfan's syndrome, Laurence-Moon-Biedl syndrome) appear to be controlled by single genes; most continuously quantitative dimensional traits, on the other hand, are considered to be polygenic. With a number of genes acting as a "system," the resultant phenotypic expression becomes as varied as the number of mathematically possible combinations. The situation is made more complex by the potential for pleiotrophic effects (multiple effects of a single gene), mutations and both internal and external environmental effects.

Whether or not physical characteristics of differing humans, racial or otherwise, are adaptive or non-adaptive has not been completely settled by physical anthropologists. It is clear, however, that certain selected phenotypic characteristics find higher incidence in given environments. For example, the natural occurrence of black skin in tropical areas of the globe cannot be refuted.

Such factors as (1) climate, including temperature, amount of sunlight, and humidity, (2) altitude, (3) topography, and (4) soil type have been shown to be correlated with various physical traits. Of the meteorological criteria, temperature is perhaps the factor most frequently related to types of people. Simply stated, man tends toward linearity in warmer climates and to be more spheric in colder climates. Related to this phenomenon are the so called rules of Bergman (warmer climates=smaller body size) and Allen (body protrusions and/or extremities shorter=colder climate). Both rules are interpreted to be adaptations to body heat exchange needs of a homeotherm. A compilation of stature-weight ratios for inhabitants of different parts of world is given in Table 1. Although not wholly consistent, the data tend to show a lower stature-weight ratio in cold areas of the world and a higher ratio in those that are hot.

Some other relationships between environment and various human traits which have been described include:

- (1) lighter skin at higher altitudes.
- (2) stockier build at higher altitudes, more linear at low.
- (3) greater incidence of epicanthic fold at altitude.
- (4) calf size greater in mountains than flat areas.
- (5) low nasal index in cold-dry environments.
- (6) high nasal index in hot-humid environments.
- (7) basal metabolic rate increases as mean annual temperature decreases.

TABLE 1
 STATURE, WEIGHT, AND STATURE:WEIGHT RATIO AMONG INHABITANTS
 OF DIFFERENT PARTS OF THE WORLD (DOBZHANSKY, 1962, AFTER BLACK)*

MEAN VALUE					
<u>Population</u>	<u>Stature</u>		<u>Weight</u>		<u>Ratio</u>
White					
Finland	171.0	(67.3)	70.0	(154.4)	2.44
United States (Army)	173.9	(68.5)	70.2	(154.8)	2.48
Iceland	173.6	(68.4)	68.1	(150.2)	2.55
France	172.5	(67.9)	67.0	(147.7)	2.57
England	166.3	(65.5)	64.5	(142.2)	2.58
Sicily	169.1	(66.6)	65.0	(143.3)	2.60
Morocco	168.9	(66.5)	63.8	(140.7)	2.65
Scotland	170.4	(67.1)	61.8	(136.3)	2.76
Tunisia	173.4	(68.3)	62.3	(137.4)	2.78
Berbers	169.8	(66.9)	59.5	(131.2)	2.85
Mahratta (India)	163.8	(64.5)	55.7	(122.8)	2.94
Bengal (India)	165.8	(65.3)	52.7	(116.2)	3.15
Black					
Yambasa	169.0	(66.5)	62.0	(136.7)	2.73
Kirdi	166.5	(65.6)	57.3	(126.4)	2.90
Baya	163.0	(64.2)	53.9	(118.9)	3.02
Batutsi	176.0	(69.3)	57.0	(125.7)	3.09
Kikuyu	164.5	(64.8)	51.9	(114.4)	3.17
Pygmies	142.2	(56.0)	39.9	(88.0)	3.56
Efe	143.8	(56.6)	39.8	(87.8)	3.61
Bushmen	155.8	(61.3)	40.4	(89.1)	3.86
Oriental					
Kazakh (Turkestan)	163.1	(64.2)	69.7	(153.7)	2.34
Eskimo	161.2	(63.5)	62.9	(138.7)	2.56
North China	168.0	(66.1)	61.0	(134.5)	2.75
Korea	161.1	(63.4)	55.5	(122.4)	2.90
Central China	163.0	(64.2)	54.7	(120.6)	2.98
Japan	160.9	(63.4)	53.0	(116.9)	3.04
Sundanese	159.8	(62.9)	51.9	(114.4)	3.08
Annamites	158.7	(62.5)	51.3	(113.1)	3.09
Hong Kong	166.2	(65.4)	52.2	(115.1)	3.18

*Data given in centimeters and kilograms with inches and pounds in parentheses.

Presented in the following sections are data which will alert the NASA engineer to the nature, extent and magnitude of human body size variability which will confront him in dealing with design problems for the astronauts of today and tomorrow and help him to solve some of the problems of designing for a range of users as potentially diverse as Japanese women and Scandinavian men. For a more complete presentation of specific dimensions for many populations the reader is referred to Volume II of this data book.

Intra-individual Variations in Size

The Effect of Aging

A number of physical and physiological changes occur in the adult body between the ages of 20 and 60 years as a result of the aging process. This phenomena has been recorded by Hooton and Dupertuis (1951) and a number of others. Among the changes of importance to the design engineer are the following:

- (1) Stature increases up to the age of 25 and decreases after the age of 30 at a progressively increasing rate each decade.
- (2) Body weight increases through 60 years (with the greatest increase among those between 30 and 40), then may decrease below the 30-year-old level.
- (3) Chest circumference tends to increase at least through 60 years.
- (4) Abdominal circumference tends to increase at least through 60 years.
- (5) Strength decreases.

Certainly there are many additional changes that could be listed (i.e., body compositional changes such as an increasing percentage of body fat with a tendency to shift to the central body); however, many are not well documented by longitudinal studies and are of limited importance in engineering anthropometry. A summary of the average change for certain variables studied over 10 years for each decade between 20 and 60 years of age is given in Table 2.

TABLE 2
AVERAGE BODY CHANGES WHICH OCCUR WITH AGING
BASED ON GSELL (1967)*

Age in years	Body Length	Body Weight	Chest Circ. (minimum)	Abdominal Circ.
20-30	+ till age 25	---	+6.8 (2.7)	+5.4 (2.1)
30-40	- 0.6 (0.2)	+3.4 (7.5)	+2.4 (0.9)	+4.6 (1.8)
40-50	- 1.4 (0.6)	+2.5 (5.5)	+1.7 (0.7)	+3.2 (1.3)
50-60	- 1.7 (0.7)	+2.1 (4.6)	---	---

*Data given in kilograms and centimeters with pounds and inches in parentheses.

Perhaps more to the point for NASA designers are the differences which are found when 20-30 year-old persons are compared to 30-40 year-olds in the same population. One such study on men was reported by Fry and Churchill (1956). The authors analyzed dimensional differences for 132 measurements on pilots under 30 years old and over 30 years old as subgroups of the 1950 Air Force survey. A selected group of 17 measurements which had mean differences greater than 1 mm. (.04 in.) was analyzed to see what differences existed between the older and younger pilots at the 5th, 25th, 75th and 95th percentiles. Results are shown in Table 3. The majority of the measurements selected are clearance dimensions in which small variations may have marked effects on the design of personal equipment and clothing. The percentile values demonstrate that in addition to noting the differences in the mean values, it is also important to know where and to what extent the "large" and "small" men change with age.

The Effect of Nutrition

After growth is complete, nutrition may continue to play a role in body size. Overeating and starvation represent nutritional extremes which clearly affect a person's size. Slight dietary excesses and deficiencies probably occur from time to time in every adult lifetime. How much fluctuations in dietary substance such as trace elements and the like affect body size as one ages is unknown. However, generalized overeating over a period of time usually results in obesity. The obesity development associated with middle age in industrialized nations is well known and does not require documentation here. Experimentally controlled studies in obesity furnishing dimensional changes associated with a known diet are rare. In one study (Sims et al. 1968) nine subjects increased body weight by an average of 24.8% over a 300-day test period. These investigators found from 0.4 mm (.016 in.) (calf) to 3.0 mm (.12 in.) (lower abdomen) increase in body radii for each percent increase in body fat.

Perhaps the most outstanding illustration of the effect of starvation on body size is found in a study by Ivanovsky(1923), who reported dimensional changes occurring in over 2,000 Russian adults during a two-year famine following World War I. Of the measurements reported, the most outstanding change occurred in stature, with average decreases of 4.7 cm (1.9 in.) and 3.8 cm (1.5 in.) in the men and women respectively. So far as can be determined, these rather significant losses cannot be attributed to technique, since near original statures were regained within six months following restoration of normal diet. The decrement in stature in starvation was thought to be principally due to vertebral shrinkage.

In a controlled short-term study of semi-starvation, Brozek et al. (1957) reported girth decrements up to 9.5% over a 24-day period. Data reflecting the changes in circumference measured in the study are shown in Table 4. Mean weight loss in the Brozek group was 7.58 kg. (16.7 lbs.). The importance of dimensional change from nutritional excesses or deficiencies

TABLE 3
 DIMENSIONAL DIFFERENCES AT SEVERAL PERCENTILE LEVELS BETWEEN USAF PILOTS
 AGED 20-30 YEARS AND USAF PILOTS AGED 30-40+ YEARS,
 BASED ON FRY AND CHURCHILL, 1956¹
 Older Pilots Minus Younger Pilots²

<u>Dimension</u>	<u>5%</u>	<u>25%</u>	<u>50%</u>	<u>75%</u>	<u>95%</u>
Weight	1.5 (3.2)	1.5 (3.2)	2.0 (4.4)*	1.7 (3.8)*	1.2 (2.6)
Stature	0.3 (0.1)	-0.5 (-0.2)	-0.5 (-0.2)	0.3 (0.1)	1.8 (0.7)
Nipple height	-0.5 (-0.2)	-0.3 (-0.1)	-0.5 (-0.2)	0.0 (0.0)	1.5 (0.6)
Crotch height	-1.8 (-0.7)**	-1.0 (-0.4)**	-0.3 (-0.1)	0.5 (0.2)	0.8 (0.3)
Buttock-knee length	0.0 (0.0)	0.0 (0.0)	-0.3 (-0.1)	0.3 (0.1)	0.8 (0.3)
Waist circ.	2.3 (0.9)*	2.5 (1.0)**	2.8 (1.1)**	2.8 (1.1)**	2.3 (0.9)
Chest circ.	1.5 (0.6)*	1.5 (0.6)**	1.8 (0.7)**	2.3 (0.9)**	2.3 (0.9)
Buttock circ.(sitting)	2.5 (1.0)**	1.8 (0.7)**	1.8 (0.7)**	1.3 (0.5)*	1.8 (0.7)
Buttock circ.(standing)	2.0 (0.8)**	1.5 (0.6)**	1.0 (0.4)*	0.8 (0.3)	-0.3 (-0.1)
Waist breadth	1.0 (0.4)**	0.5 (0.2)*	0.5 (0.2)**	0.5 (0.2)*	0.8 (0.3)
Chest breadth	0.0 (0.0)	0.3 (0.1)	0.5 (0.2)**	0.3 (0.1)	0.5 (0.2)
Hip breadth (sitting)	0.5 (0.2)	0.5 (0.2)**	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
Elbow-elbow breadth	1.3 (0.5)**	1.8 (0.7)**	1.5 (0.6)**	1.3 (0.5)**	1.8 (0.7)
Knee-knee breadth	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.1)*	0.0 (0.0)
Shoulder breadth	0.0 (0.0)	0.3 (0.1)	0.3 (0.1)	0.5 (0.2)**	0.3 (0.1)
Waist depth	0.8 (0.3)**	0.8 (0.3)**	0.8 (0.3)**	0.8 (0.3)**	1.0 (0.4)
Chest depth	0.8 (0.3)**	0.8 (0.3)**	0.5 (0.2)**	0.8 (0.3)**	0.5 (0.2)

¹Data given in kilograms and centimeters with pounds and inches in parentheses.

²Negative values (-) indicate younger group is larger.

* = Difference significant at 5% level ("Student's" t test)

** = Difference significant at 1% level ("Student's" t test)

TABLE 4
CHANGE IN BODY GIRTHS OF YOUNG MEN WITH SEMI-STARVATION
BASED ON BROZEK ET AL. 1957*

Body Part	Circ. at Start	S.D.	Change after 24 days: Intake=1010 kcal/day	% Change
Upper Arm	28.5 (11.2)	± 2.5 (± 1)	- 2.7 cm (1.1)	9.5%
Chest	92.5 (36.4)	± 7.9 (± 3.1)	- 4.4 (1.7)	4.8
Abdomen	80.3 (31.6)	± 7.4 (± 2.9)	- 7.1 (2.8)	8.8
Thigh	47.4 (18.7)	± 3.4 (± 1.3)	- 4.0 (1.6)	8.4
Calf	38.3 (15.1)	± 2.8 (± 1.1)	- 2.4 (0.9)	6.3

*Data given in centimeters with inches in parentheses.

for the designer is perhaps the fact that significant size changes can occur over a rather brief period of time although, unfortunately, such changes are highly individual.

Right Side-Left Side Asymmetry

People tend to believe that one side of their bodies is larger or longer than the other. Whether right side-left side asymmetry is real or imagined and therefore of any concern to the human engineer is the question. Laubach and McConville (1967) reported data for 21 paired measurements obtained from 42 to 117 young male subjects. Their data is summarized in Table 5. In 12 measurements the mean difference is less than one mm, well within the measurement error range. The authors question whether the statistically significant differences obtained in eight of the 21 measurements are of any practical significance.

A somewhat different study of right-left size variation was reported by Peters (1969), who measured some relaxed and erect, right and left side heights on 1166 women (German). A summary of this data is given in Table 6. Clearly in terms of work space (especially during seated desk work) the slumped versus erect differences are, on the whole, greater than the right-left differences.

TABLE 5
DIFFERENCES BETWEEN RIGHT SIDE AND LEFT SIDE MEASUREMENTS OF SELECTED DIMENSIONS
(BASED ON LAUBACH AND MCCONVILLE, 1967)*

Variable	Right Side		Left Side		RIGHT/LEFT DIFFERENCE
	Mean	S.D.	Mean	S.D.	
Arm circ. at axilla	30.36 (11.95)	2.68 (1.06)	29.64 (11.67)	2.62 (1.03)	.72 (.28)
Biceps circ., relaxed	28.71 (11.30)	2.66 (1.05)	28.16 (11.09)	2.62 (1.03)	.55 (.22)
Biceps circ., flexed	31.56 (12.43)	2.59 (1.02)	30.82 (12.13)	2.59 (1.02)	.74 (.29)
Forearm circumference	26.54 (10.45)	1.54 (.61)	25.99 (10.23)	1.48 (.58)	.55 (.22)
Wrist circumference	16.72 (6.58)	.82 (.32)	16.58 (6.53)	.82 (.32)	.14 (.06)
Upper thigh circumference	55.28 (21.76)	4.54 (1.79)	55.22 (21.74)	4.55 (1.79)	.06 (.02)
Lower thigh circumference	38.41 (15.12)	2.55 (1.00)	38.45 (15.14)	2.74 (1.08)	.04 (.02)
Calf circumference	36.58 (14.40)	2.32 (.91)	36.50 (14.37)	2.54 (1.00)	.08 (.03)
Ankle circumference	22.41 (8.82)	1.30 (.51)	22.45 (8.84)	1.37 (.54)	.04 (.02)
Acromial height	143.57 (56.52)	5.98 (2.35)	144.19 (56.77)	5.87 (2.31)	.62 (.24)
Trochanteric height	92.69 (36.49)	4.42 (1.74)	92.60 (36.46)	4.38 (1.72)	.09 (.04)
Lower thigh circ. height	52.46 (20.65)	2.97 (1.17)	52.63 (20.72)	3.01 (1.19)	.17 (.07)
Tibiale height	48.21 (18.98)	2.50 (.98)	48.23 (18.99)	2.46 (.97)	.02 (.01)
Ankle height	13.79 (5.43)	1.15 (.45)	13.50 (5.31)	1.00 (.39)	.25 (.10)
Sphyrion height	7.46 (2.94)	.59 (.23)	7.48 (2.94)	.60 (.24)	.02 (.01)
Acromion-to-radiale length	33.44 (13.17)	1.80 (.71)	33.51 (13.19)	1.79 (.70)	.07 (.03)
Rad.-ulnar styliion length	25.56 (10.06)	1.37 (.54)	25.61 (10.08)	1.34 (.53)	.05 (.02)
Hand length	19.21 (7.56)	.98 (.39)	19.20 (7.56)	.97 (.38)	.01 0
Hand breadth	8.49 (3.34)	.55 (.22)	8.43 (3.32)	.52 (.20)	.06 (.02)
Humerus breadth	7.13 (2.81)	.38 (.15)	7.13 (2.81)	.39 (.15)	0 0
Femur breadth	9.91 (3.90)	.97 (.38)	9.86 (3.88)	.92 (.36)	.05 (.02)

*Data given in centimeters with inches in parentheses.

TABLE 6
RIGHT SIDE-LEFT SIDE DIMENSIONAL DIFFERENCES IN WOMEN IN ERECT AND RELAXED POSTURES
(BASED ON PETERS 1969)*

<u>Measurement</u>		<u>Mean</u>	<u>S.D.</u>	<u>Diff. between erect & relax</u>	<u>Diff. between right & left</u>
Stature	(erect)	163.4 (64.33)	6.9 (2.7)		
	(relax)	163.2 (64.25)	4.6 (1.8)	0.2 (.08)	
Acromial ht.	(erect-R)	132.1 (52.01)	5.0 (2.0)		
	(erect-L)	132.4 (52.13)	3.9 (1.5)		0.3 (.1)
	(relax-R)	131.3 (51.69)	5.1 (2.0)	0.8 (.3)	
	(relax-L)	131.6 (51.81)	4.5 (1.8)	0.8 (.3)	0.3 (.1)
Elbow ht.	(erect-R)	100.1 (39.41)	4.6 (1.8)		
	(erect-L)	99.2 (39.06)	5.1 (2.0)		0.9 (.4)
	(relax-R)	99.4 (39.13)	3.4 (1.3)	0.7 (.3)	
	(relax-L)	99.2 (39.06)	4.2 (1.7)	0.0 0	0.2 (.08)
Sitting ht.	(erect)	83.7 (32.95)	2.6 (1.0)		
	(relax)	82.9 (32.64)	2.2 (0.9)	0.8 (.3)	
Eye ht. sitting	(erect)	74.2 (29.21)	3.7 (1.5)		
	(relax)	73.1 (28.78)	3.3 (1.3)	1.1 (.4)	
Acromial ht. sitting	(erect-R)	52.7 (20.75)	2.7 (1.1)		
	(erect-L)	52.9 (20.83)	1.4 (0.6)		0.2 (.08)
	(relax-R)	51.7 (20.35)	2.3 (0.9)	1.0 (.4)	
	(relax-L)	51.8 (20.39)	2.8 (1.1)	1.1 (.4)	0.1 (.04)
Elbow rest ht.	(erect-R)	20.3 (7.99)	2.3 (0.9)		
	(erect-L)	20.6 (8.11)	2.2 (0.9)		0.3 (.1)
	(relax-R)	19.3 (7.60)	2.5 (1.0)	1.0 (.4)	
	(relax-L)	19.6 (7.72)	2.4 (0.9)	1.0 (.4)	0.3 (.1)
Thigh diam. sitting	(R)	14.1 (5.55)	1.4 (0.6)		
	(L)	14.0 (5.51)	1.3 (0.5)		0.1 (.04)
Thigh ht. sitting	(R)	50.7 (19.96)	3.4 (1.3)		
	(L)	51.3 (20.20)	3.1 (1.2)		0.6 (.2)
Knee ht. sitting	(R)	39.3 (15.47)	2.3 (0.9)		
	(L)	39.6 (15.59)	2.3 (0.9)		0.3 (.1)

*Data given in centimeters with inches in parentheses.

Causes of Transient Body Size Change

While it is common knowledge that such long-term factors as aging, diet and disease have an effect on body size, it is much less well known that body dimensions fluctuate each day and that, wherever possible in the design of clothing and equipment, allowances for such changes should be made.

Many studies of day-to-day fluctuations in body weight have been conducted (Garrow, 1974; Khosla and Billewicz, 1964). Most such studies indicate that it is normal for weight to vary between 0.5 kg. (1.1 lb.) and 1.0 kg. (2.2 lb.) per day. This probably is largely the result of changes in total body water content during the day.

Decreases in stature occur during the course of a day as a result of compression of the fibrocartilaginous intervertebral disks and increased curvature of the spine as gravity and load-carrying strain the system. Loss in stature ranges from three to five cm. (1.2 to 2 inches) according to a number of investigators (Munipov and Zinchenko, 1970; DePuky, 1935; Ivanovsky, 1923) depending on the amount of standing, walking, or carrying which is done. In one study (Ivanovsky, 1923), stevedores were found to decrease 5 cm. (2 in.) by the end of the day. It is suggested that the best time to measure stature is at the beginning of the day, if "maximum" stature is critical to the problem at hand.

Normally stature, eye height and sitting height are greatly affected by posture. For example, the erect versus "slumped" difference may range from 2 cm. (.75 in.) to 4.5 cm. (1.75 inches) for stature and sitting height respectively (Hertzberg, 1972). Anthropometrists conducting a survey of Women's Air Force personnel in 1968 recorded a difference of 1.3 cm. (.51 inches) between erect and relaxed sitting height. An average difference of 0.4 cm. (.15 in.) was found between two erect posture techniques (i.e., the British Morant method mean stature is greater than the U.S. method) when measurements were made of 2,000 RAF aircrewmembers (Bolton et al. 1973). The higher figures are thought to be due to the straightening of the spine and tilting of the head which occurs when the subject is instructed to stretch to full height against a wall as he is in the Morant method. Damon (1964) found a stature difference ranging from .5 cm. (0.2 inches) to 2.0 cm. (0.8 inches) between subjects measured free standing versus those stretched against a wall. As expected, those measured against the wall were "taller." Head tilting (above the Frankfort plane) when subjects were backed against the wall added an average of 0.2 cm. (.08 inches) to the measurement.

All of the foregoing indicates the importance of controlled measurement conditions and suggests that users of such data should check, when possible, to determine by what means and under what conditions the measurements were made.

Obviously as a person moves within an imaginary three-dimensional static envelope which encompasses all possible body positions, size-related changes are constantly occurring. Considering that the spheroid envelope

itself moves through space as the individual walks, runs, jumps, climbs and reaches, a truly dynamic analysis of body size changes would be extremely complex. There are, however, a number of dimensional changes which result from movement but which may be treated as static size changes when only the maximum "end of the range of change" is considered for design purposes.

The effect of erect or slumped posture and of different techniques on stature and sitting height measurements have already been mentioned. Related to these effects is the fact that standing height is less than prone or supine body length. Alexander and Clauser (1965) found supine length to average 2.59 cm (1 inch) more than stature. Buttock breadth and abdominal depth are examples of dimensions that increase from standing to sitting configurations of the body (Damon, Stoudt and McFarland, 1966). The chest, of course, moves and changes dimensions with each respiration. To some extent the abdomen will also change in girth during breathing. Although quite variable between individuals, especially between men and women, the abdominal wall may traverse a 2-3 cm (.79 to 1.2 inch) anterior-posterior distance with maximum breathing (Agostoni and Mead, 1964). Pregnancy, of course, results in significant dimensional changes on the torso of women.

One of the better known dimensional changes associated with movement is the increase in girth with flexion. What child has not been asked to "make a muscle" by flexing the biceps? Perhaps for this reason both relaxed and flexed biceps circumferences are frequently measured. A compilation of flexed-relaxed bicep measurements for U.S. and European military personnel is given in Table 7. The mean girth increase with flexion for the 11 male groups surveyed is 2.4 cm (0.95 in.). The single female sample averaged 1.18 cm (0.46 in.) increase, or approximately one half of the male value. The flexed-relaxed circumferences of the elbow and forearm for the same populations are also given in Table 7. The average of 18.8% increase in elbow circumference demonstrates why tightly fitting clothing may restrict motion or blood flow in the arm.

A dimensional change often overlooked is the increase or decrease in longitudinal dimensions on the convex and concave surfaces of joints during movement. Form fitting clothing, pressure suits, prosthetic devices, or anything that must allow a good range of body mobility requires consideration of these changes. Linear distance changes over the body surface resulting from various joint movements were studied by Emanuel and Barter (1957). A summary of the 49 measurements made on 30 subjects is given in Table 8. Measurements were made using a flexible tape. Two arbitrary points were marked on either side of a joint and distances between them measured, first in a neutral position and then in specified flexed, abducted, retracted or protruded positions. While there are definite and significant changes in bodily dimensions with joint movement, the authors found them to be "fairly constant in magnitude" and repeatable. The amount of change is fairly constant regardless of stature or weight of the person.

TABLE 7
DIFFERENCES (Δ) BETWEEN MEAN RELAXED ($\bar{X}_r$) AND MEAN FLEXED ($\bar{X}_f$)
BICEPS AND ELBOW CIRCUMFERENCE FOR SELECTED MILITARY POPULATIONS *

Population	Biceps Circumference				Elbow Circumference				Forearm Circumference			
	$\bar{X}_f$	$\bar{X}_r$	Δ_{f-r}	% $\uparrow^{**}$	$\bar{X}_f$	$\bar{X}_r$	Δ_{f-r}	% $\uparrow^{**}$	$\bar{X}_f$	$\bar{X}_r$	Δ_{f-r}	% $\uparrow^{**}$
USAF-'67	32.74 (12.89)	30.79 (12.12)	1.95 (.77)	6.3	31.24 (12.30)	27.67 (10.89)	3.57 (1.41)	12.9	29.77 (11.72)	28.16 (11.09)	1.61 (.63)	5.7
USAF-'65	31.05 (12.22)	27.90 (10.98)	3.15 (1.24)	11.3	31.02 (12.21)	26.11 (10.28)	4.91 (1.93)	18.8	28.82 (11.35)	26.93 (10.60)	1.89 (.74)	7.0
WAF	26.79 (10.55)	25.61 (10.08)	1.18 (.46)	4.6	26.98 (10.62)	-	-	-	24.98 (9.83)	23.48 (9.24)	1.50 (.59)	6.4
German AF	32.22 (12.69)	29.33 (11.55)	2.89 (1.14)	9.9	34.11 (13.43)	26.69 (10.51)	7.42 (2.92)	27.8	29.45 (11.59)	27.32 (10.76)	2.13 (.84)	7.8
NATO (military)	30.53 (12.02)	28.41 (11.19)	2.12 (.83)	7.5	30.63 (12.06)	25.96 (10.22)	4.67 (1.84)	18.0	28.63 (11.27)	26.86 (10.57)	1.77 (.70)	6.6
Turkish (military)	29.77 (11.72)	27.19 (10.70)	2.58 (1.02)	9.5	29.99 (11.81)	25.31 (9.96)	4.68 (1.84)	18.5	28.02 (11.03)	26.10 (10.28)	1.92 (.76)	7.4
Greek (military)	30.64 (12.06)	28.37 (11.17)	2.27 (.89)	8.0	30.19 (11.89)	25.86 (10.18)	4.33 (1.70)	16.7	28.64 (11.28)	26.97 (10.62)	1.67 (.66)	6.2
Italian (military)	30.95 (12.19)	29.27 (11.52)	1.68 (.66)	5.7	31.41 (12.37)	26.49 (10.43)	4.92 (1.94)	18.6	29.03 (11.43)	27.30 (10.75)	1.73 (.68)	6.3

*Data given in centimeters with inches in parentheses.

**Percentage change calculation based upon: $\frac{\Delta_{f-r}}{\bar{X}_r} \times 100$.

TABLE 8
LINEAR DISTANCE CHANGES OVER BODY JOINTS WITH MOVEMENT
(BASED ON EMANUEL AND BARTER, 1957)*

<u>Measurement</u>	<u>Mean Difference</u>		<u>Standard Deviation</u>	
ELBOW				
Flexion, Full	8.48	(3.34)	0.91	(0.36)
WRIST				
Dorsal Surface				
Volar Flexion	2.00	(0.80)	0.48	(0.19)
Dorsiflexion	-0.27	(-0.106)	0.74	(0.29)
Volar Surface				
Volar Flexion	-3.37	(-1.47)	0.74	(0.29)
Dorsiflexion	1.93	(0.76)	0.51	(0.20)
SHOULDER				
<u>Anterior</u>				
Suprasternale-Acromion				
Protrusion	-2.21	(-0.87)	0.66	(0.26)
Abduction, Horiz.	-1.22	(-0.48)	0.43	(0.17)
Sternum to Scye				
Protrusion	-2.88	(-1.13)	1.24	(0.49)
Retraction	2.79	(1.09)	1.09	(0.43)
Abduction, Horiz.	2.46	(0.97)	1.19	(0.47)
Scye to Mid-arm				
Protrusion	-0.84	(-0.33)	1.32	(0.52)
Retraction	1.83	(0.72)	0.51	(0.20)
Abduction, Horiz.	1.47	(0.58)	0.97	(0.38)
<u>Posterior</u>				
Cervicale to Acromion				
Protrusion	-0.53	(-0.21)	0.94	(0.37)
Retraction	-2.57	(-1.01)	1.27	(0.50)
Abduction, Horiz.	-4.93	(-1.94)	0.91	(0.36)
Abduction, Overhead	-8.74	(-3.44)	1.17	(0.46)
Vertebra to Scye				
Protrusion	-9.30	(-3.66)	1.65	(0.65)
Abduction, Horiz.	2.01	(0.79)	1.22	(0.48)
Abduction, Overhead	5.77	(2.27)	1.42	(0.56)
Posterior Scye to Mid-Arm				
Protrusion	4.78	(1.88)	0.97	(0.38)
Abduction, Horiz.	1.55	(0.61)	0.76	(0.30)
Abduction, Overhead	4.60	(1.81)	0.94	(0.37)
<u>Lateral</u>				
Acromion to Mid-Arm				
Protrusion	-3.18	(-1.25)	0.86	(0.34)
Retraction	-2.44	(-0.96)	0.64	(0.25)
Abduction, Horiz.	-3.71	(-1.46)	0.53	(0.21)
Abduction, Overhead	-5.72	(-2.25)	0.91	(0.36)

*Data given in centimeters with inches in parentheses.

TABLE 8 (continued)

<u>Measurement</u>	<u>Mean Difference</u>		<u>Standard Deviation</u>	
NECK				
<u>Anterior</u>				
Suprasternale to Menton				
Posterior Flexion	7.14	(2.81)	1.09	(0 .43)
<u>Posterior</u>				
Vertebra at Scye Level to Inion				
Anterior Flexion	6.12	(2.41)	1.14	(0 .45)
<u>Lateral</u>				
Acromion to Mastoid Tip				
Right Flexion	-5.05	(-1.99)	1.70	(0 .67)
Left Flexion	3.02	(1.19)	0.91	(0 .36)
HIP				
<u>Anterior</u>				
(Ant. Sup. Spine Level to 3/4 Thigh)				
Hyperextension	1.32	(0.52)	0.48	(0 .19)
Hanging, Sitting, 90°	-6.71	(-2.64)	1.12	(0 .44)
<u>Posterior</u>				
Flexion, Forced, Sitting	15.24	(6.00)	1.98	(0 .78)
Hyperextension	-0.91	(0.36)	1.17	(0 .46)
Hanging, Sitting, 90°	8.64	(3.40)	1.88	(0 .74)
<u>Lateral</u>				
Abduction	-3.12	(-1.23)	1.47	(0 .58)
KNEE				
<u>Anterior</u>				
(3/4 Thigh to Mid-Calf)				
Flexion, Forced	10.39	(4.09)	1.04	(0.41)
Flexion, 90°, Sitting	5.99	(2.36)	0.91	(0.36)
TRUNK				
(Coccyx Tip to Cervicale, Sitting)				
Flexion, Full Anterior	10.11	(3.98)	1.88	(0.74)
ANKLE				
<u>Anterior</u>				
(Mid-Calf Interphalangeal Joint I)				
Dorsiflexion	-1.75	(0.69)	0.97	(0.38)
Plantar Flexion	3.58	(1.41)	0.71	(0.28)
<u>Posterior</u>				
(Mid-Calf to Heel Line)				
Dorsiflexion	0.51	(0.20)	0.56	(0.22)
Plantar Flexion	-3.45	(-1.36)	0.81	(0.32)

Effects of Protective Garments on Body Size

Basic anthropometric dimensions are normally given for the nude or "shirt sleeved" conditions; however, in a number of situations personal protective garments or equipment which must be worn may grossly alter the effective size of the wearer. Not only may heavy winter clothing add over 9.1 kg. (20 lbs) to body weight, but it may also increase stature some 7 cm (2.8 in.) and will add up to 25 cm (10 in.) to other key dimensions. In addition to simple linear dimension increases, such clothing may significantly affect range of joint movement and thereby further complicate the design layout of work spaces. Therefore, modifications in body size and biomechanical characteristics of an individual should be given careful consideration by the designer in situations where special encumbering gear will be used.

The change in selected body dimensions for a variety of civilian clothing, U.S. Army uniforms and U.S. Air Force flight assemblies is given in Table 9. In a more recent study Alexander, Laubach and McConville (1976) obtained data on the effect of full flight clothing on body size. The incremental and percentage increases in five nude and suited body dimensions critical to aircraft ejection envelopes are given in Figure 2. Investigators also found that in order to maintain the eye reference point (the basic design datum for cockpits) at a constant level, the seat reference point would have to be lowered an average of 1.9 cm (.75 in.) when aircrew wear maximum flight assemblies.

As if the dimensional increases caused by ordinary protective clothing were not sufficient, even greater changes in dimensions are associated with full pressure suits. Pressure suits generally are anthropomorphic gas-tight bags, designed to protect a pilot or astronaut from the reduced atmospheric pressure of high altitudes or the vacuum of space. When pressure suits are inflated to operational pressure (usually about 1/3 atmosphere), they grow in size and become stiff, often making motion difficult. The effect of one type of pressure suit, both uninflated and inflated, on 33 body dimensions, was reported by Clauser and Hertzberg in 1964. Results can be seen in Table 10. Although many girths are increased significantly, the most outstanding increase is in knee-to-knee breadth. In a later study of a more advanced Air Force pressure suit (Alexander, et al. 1969) the greatest dimensional change was again found to be in knee-to-knee breadth. The mean incremental (uninflated to inflated) and percentage change in six dimensions when this pressure suit is worn is shown in Figure 3. As with the flight clothing, the legs are more dimensionally affected than are the arms.

During EVA (extra-vehicular activity) the astronaut must wear a pressure suit which may include a portable life support system (PLSS). (The total assembly has been termed by NASA an Extra-Vehicular Mobility Unit or EMU.) A number of functional envelope dimensions required for the fully suited 5th and 95th percentile astronaut carrying the PLSS and Backup Oxygen Supply (OPS) are given in Figure 4. The recommended design dimensions for access corridors, hatches and direction change for the suited astronaut* (Apollo EMU) are shown in Figure 5.

*Preliminary Design Requirements for Shuttle EVA/IVA Orbiter Support. NASA Internal Note MSC-EC-R-71-10, 1971.

TABLE 9
INCREASE IN DIMENSIONS FROM CLOTHING (BASED ON CLAUSER AND HERTZBERG, 1964)*

	Civilian		Army				Air Force		
	Men Street Clothing	Women Street Clothing	Summer Uniform	Fall Uniform	Winter Uniform	Winter Combat	Full Flight Gear	Light Flight Assembly	Winter Flight Assembly
Weight	12.70 (5.00)	8.90 (3.50)	23.88 (9.40)	29.98 (11.80)	47.24 (18.60)	58.17 (22.90)			50.80 (20.00)
Stature	2.54 (1.00)	1.27-7.60 (.5-3.0)	6.60 (2.60)	6.73 (2.65)	6.73 (2.65)	6.99 (2.75)	-5.08 (-2.00)	8.38 (3.30)	4.83 (1.90)
Abdomen depth			2.39 (.94)	3.0 (1.18)	4.95 (1.95)	6.45 (2.54)	12.70 (5.00)		3.56 (1.40)
Arm reach anterior			.10 (.04)	.20 (.08)	.51 (.20)	.94 (.37)			1.02 (.40)
Buttock-knee length			.51 (.20)	.76 (.30)	1.37 (.54)	1.78 (.70)	5.08 (2.00)		1.27 (.50)
Chest breadth							6.35 (2.50)		1.52 (.60)
Chest depth			1.04 (.41)	2.44 (.96)	4.57 (1.80)	3.91 (1.54)	11.43 (4.50)	2.03 (.80)	3.56 (1.40)
Elbow breadth			1.42 (.56)	2.64 (1.04)	4.67 (1.84)	5.38 (2.12)	27.94 (11.00)		11.18 (4.40)
Eye level ht. sitting			.10 (.04)	.20 (.08)	.41 (.16)	.56 (.22)			1.02 (.40)
Foot breadth	.80 (.30)		.51 (.20)	.51 (.20)	.51 (.20)	.51 (.20)			3.05 (1.20)
Foot length	3.05 (1.20)		4.06 (1.60)	4.06 (1.60)	4.06 (1.60)	4.06 (1.60)			6.86 (2.70)
Hand breadth						.76 (.30)			1.02 (.40)
Hand length						.38 (.15)			.76 (.30)
Head breadth			7.11 (2.80)	7.11 (2.80)	7.11 (2.80)	7.11 (2.80)			1.02 (.40)
Head length			8.90 (3.50)	8.90 (3.50)	8.90 (3.50)	8.90 (3.50)			1.02 (.40)
Head height			3.43 (1.35)	3.43 (1.35)	3.43 (1.35)	3.68 (1.45)			.51 (.20)
Hip breadth			1.42 (.56)	1.93 (.76)	2.74 (1.08)	3.56 (1.40)			3.30 (1.30)
Hip breadth sitting			1.42 (.56)	1.93 (.76)	2.74 (1.08)	3.56 (1.40)	13.97 (5.50)	7.37 (2.90)	4.32 (1.70)
Knee breadth			1.22 (.48)	1.22 (.48)	1.83 (.72)	4.27 (1.68)	2.41 (.950)		6.35 (2.50)
Knee height sitting			3.35 (1.32)	3.35 (1.32)	3.66 (1.44)	3.66 (1.44)			4.57 (1.80)
Shoulder breadth			.61 (.24)	2.24 (.88)	3.86 (1.52)	2.95 (1.16)	15.24 (6.00)	1.02 (.40)	3.30 (1.30)
Shoulder-elbow length			.36 (.14)	1.27 (.50)	2.39 (.94)	1.57 (.62)			.76 (.30)
Shoulder ht. sitting			.41 (.16)	1.47 (.58)	2.34 (.92)	2.03 (.80)			1.52 (.60)
Sitting ht.			3.53 (1.39)	3.63 (1.43)	4.09 (1.61)	4.24 (1.67)		5.33 (2.10)	1.52 (.60)

*Data given in centimeters with inches in parentheses.

Civilians, men: underwear, shirt, trousers, tie, socks, shoes.

Civilians, women: underwear, dress, or blouse or sweater and skirt, shoes.

Army, summer uniform: underwear, khakis or O.D.'s or fatigues, socks, shoes, helmet and liner.

Army, fall uniform: underwear, fatigues, field jacket, socks, shoes, helmet and liner.

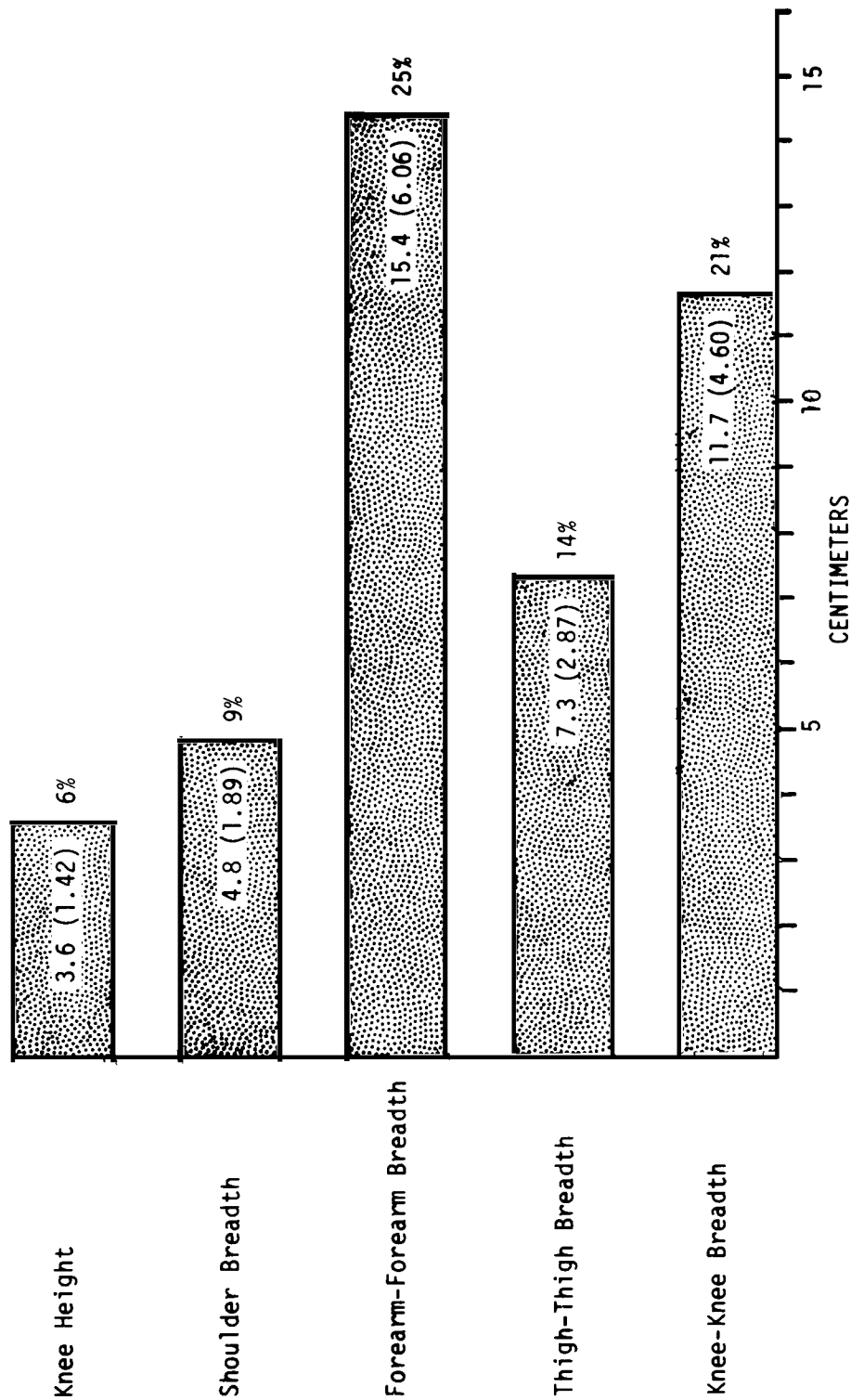
Army, winter uniform: underwear, fatigues, field jacket, overcoat, socks, shoes, helmet and liner.

Army, winter combat: underwear, fatigues, combat suit, overcoat, socks, shoes, gloves, wool cap, helmet and liner.

Air Force, full flight gear: T-1 partial pressure suit, inflated; ventilation suit, deflated, MD-1 anti-exposure suit and MD-3A liner, long cotton underwear.

Air Force, light flight assembly: T-5 partial pressure suit, uninflated; K-1 pressure helmet and boots.

Air Force, winter flight assembly: World War II heavy winter flying clothing, including jacket, trousers, helmet, boots and gloves.



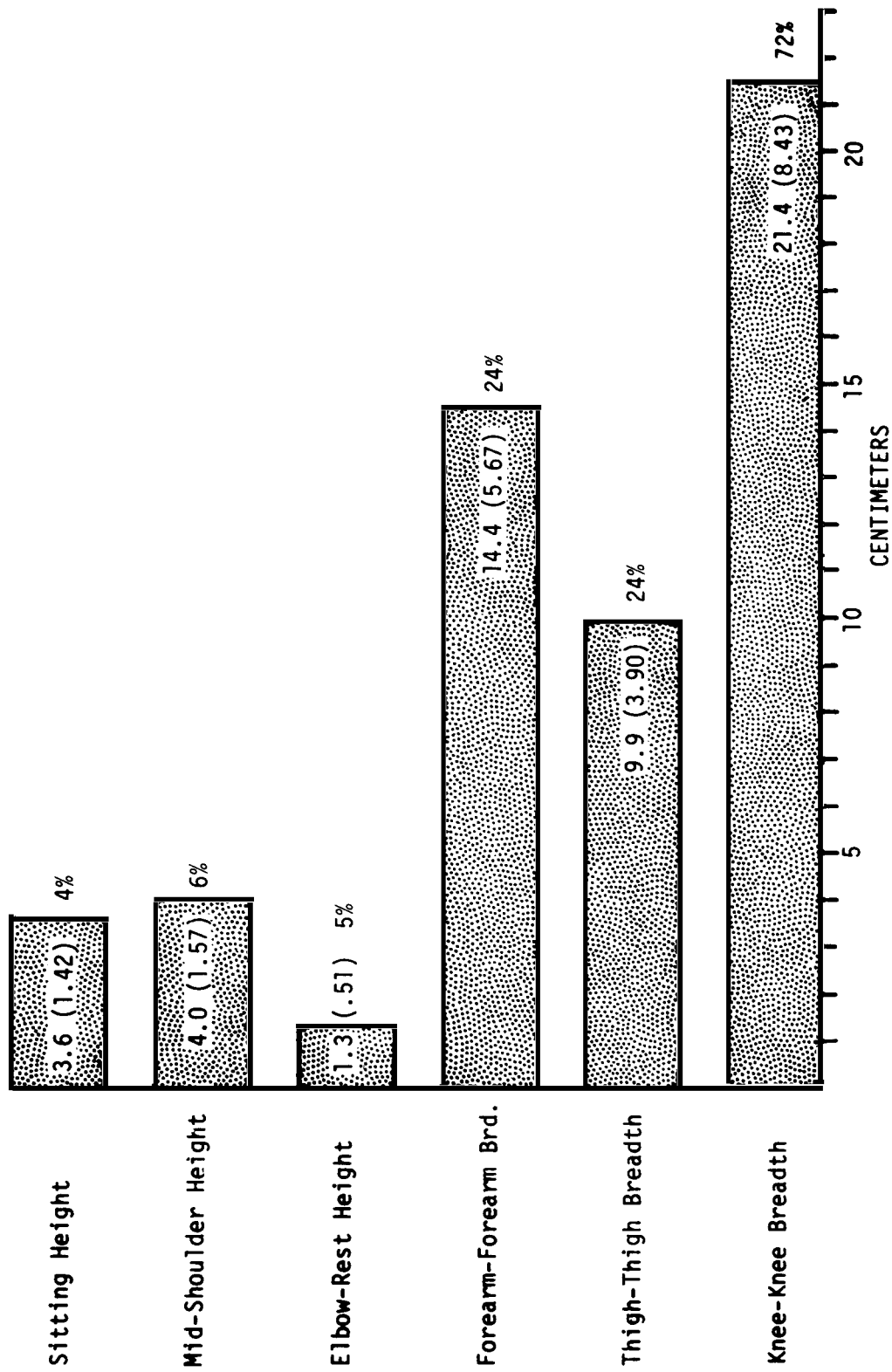
*Increments computed from 95th percentile values. Data given in centimeters with inches in parentheses. Measurements were made on 32 subjects in winter over-land and over-water assemblies.

Figure 2. Incremental and percentage growth changes in body size due to the effects of protective clothing and equipment (based on Alexander et al. 1976).

TABLE 10
INCREASE IN DIMENSIONS FROM PRESSURE SUIT
(BASED ON CLAUSER AND HERTZBERG 1964)*

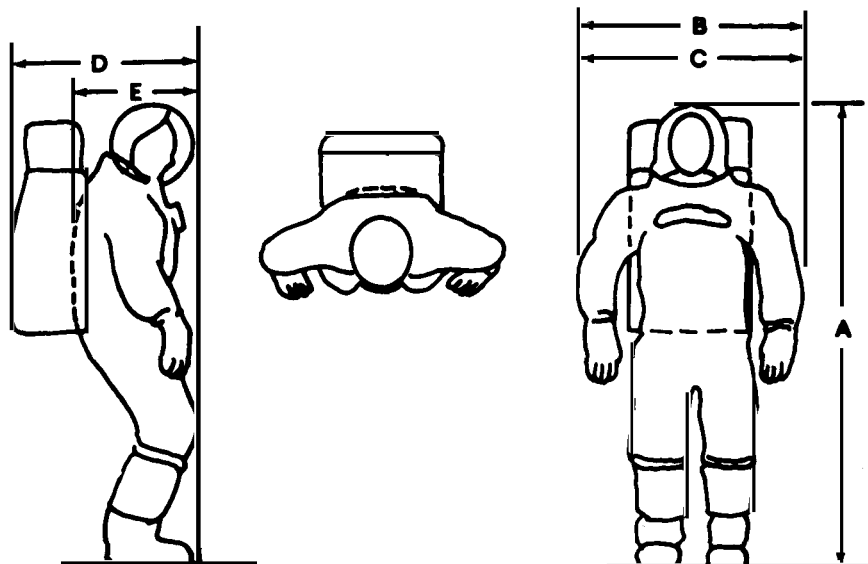
Measurement	Nude		Uninflated		Inflated	
	Median	Range	Median	Range	Median	Range
Shoulder circumference	122.68 (48.3)	114.55-128.27 (45.1-50.5)	142.49 (56.1)	138.94-154.9 (54.7-61.0)	160.02 (63.0)	152.40-165.10 (60.0-65.0)
Chest circumference	100.58 (39.6)	95.76-107.19 (37.7-42.2)	122.68 (48.3)	121.92-132.08 (48.0-52.0)	133.35 (52.5)	128.27-137.67 (50.5-54.2)
Waist circumference	87.12 (34.3)	81.28-98.55 (32.0-38.8)	112.78 (44.4)	106.68-119.89 (42.0-47.2)	120.14 (47.3)	114.81-127.00 (45.2-50.0)
Upper thigh circumference	63.75 (25.1)	56.64-66.04 (22.3-26.0)	65.28 (25.7)	65.52-71.12 (25.8-28.0)	68.58 (27.0)	64.26-73.66 (25.3-29.0)
Lower thigh circumference	43.18 (17.0)	39.62-46.99 (15.6-18.5)	52.83 (20.8)	46.23-59.94 (18.2-23.6)	56.13 (22.1)	53.59-62.23 (21.1-24.5)
Calf circumference	37.85 (14.9)	36.83-43.18 (14.5-17.0)	42.93 (16.9)	41.15-49.28 (16.2-19.4)	46.48 (18.3)	42.93-50.55 (16.9-19.9)
Ankle circumference	23.37 (9.2)	22.61-26.67 (8.9-10.5)	30.73 (12.1)	28.96-34.54 (11.4-13.6)	30.73 (12.1)	30.48-35.05 (12.0-13.8)
Biceps circumference	34.29 (13.5)	32.26-36.83 (12.7-14.5)	37.59 (14.8)	35.56-41.40 (14.0-16.3)	41.15 (16.2)	37.85-43.18 (14.9-17.0)
Wrist circumference	17.78 (7.0)	16.76-18.29 (6.6-7.2)	20.57 (8.1)	20.07-21.34 (7.9-8.4)	22.86 (9.0)	21.08-23.37 (8.3-9.2)
Vertical trunk circumference	171.20 (67.4)	163.58-181.61 (64.4-71.5)	169.67 (66.8)	165.07-177.80 (65.0-70.0)		
Knee circumference	40.39 (15.9)	38.10-43.43 (15.0-17.1)	56.13 (22.1)	50.80-58.42 (20.0-23.0)	55.37 (21.8)	50.80-59.44 (20.0-23.4)
Vertical trunk circumference	163.07 (64.2)	161.80-171.45 (63.7-67.5)	168.9 (66.5)	165.10-176.78 (65.0-69.6)	170.94 (67.3)	167.64-178.82 (66.0-70.4)
Buttock circumference	106.68 (42.0)	99.31-115.57 (39.1-45.5)	118.62 (46.7)	115.06-129.54 (45.3-51.0)	126.75 (49.9)	120.14-129.54 (47.3-51.0)
Shoulder breadth	48.77 (19.2)	46.23-50.29 (18.2-19.8)	52.32 (20.6)	47.24-55.88 (18.6-22.0)	60.20 (23.7)	35.05-64.77 (13.8-25.5)
Chest breadth	33.02 (13.0)	27.69-32.77 (10.9-12.9)	35.05 (13.8)	32.26-38.35 (12.7-15.1)	37.34 (14.7)	36.58-39.62 (14.4-15.6)
Hip breadth	34.80 (13.7)	32.77-36.58 (12.9-14.4)	39.12 (15.4)	35.81-41.40 (14.1-16.3)	44.20 (17.4)	41.15-47.24 (16.2-18.6)
Hip depth	26.16 (10.3)	24.13-30.48 (9.5-12.0)	28.96 (11.4)	27.43-29.72 (10.8-11.7)	38.10 (15.0)	38.10 (15.0)
Chest depth	25.90 (10.2)	24.89-27.18 (9.8-10.7)	33.27 (13.1)	30.73-34.29 (12.1-13.5)	37.85 (14.9)	36.07-38.61 (14.2-15.2)
Elbow-elbow breadth	50.55 (19.9)	47.24-56.13 (18.6-22.1)	58.93 (23.2)	52.58-63.75 (20.7-25.1)	70.36 (27.7)	65.53-76.45 (25.8-30.1)
Knee-knee breadth	20.83 (8.2)	19.81-23.62 (7.8-9.3)	30.48 (12.0)	27.18-34.29 (10.7-13.5)	54.10 (21.3)	47.24-57.40 (18.6-22.6)
Sitting height	90.68 (35.7)	88.14-95.76 (34.7-37.7)	88.39 (34.8)	85.60-91.95 (33.7-36.2)	93.47 (36.8)	90.42-97.79 (35.6-38.5)
Eye height	79.25 (31.2)	75.18-83.82 (29.6-33.0)	77.22 (30.4)	72.14-80.52 (28.4-31.7)	79.50 (31.3)	74.68-81.79 (29.4-32.2)
Shoulder height	59.69 (23.5)	57.66-63.25 (22.7-24.9)	59.69 (23.5)	56.13-62.23 (22.1-24.5)	61.72 (24.3)	59.44-64.26 (23.4-25.3)
Knee height	55.63 (21.9)	54.10-57.91 (21.3-22.8)	59.18 (23.3)	57.40-60.71 (22.6-23.9)	60.96 (24.0)	58.17-62.48 (22.9-24.6)
Popliteal height	44.45 (17.5)	43.69-50.29 (17.2-19.8)	45.97 (18.1)	43.18-46.74 (17.0-18.4)	46.23 (18.2)	42.67-48.01 (16.8-18.9)
Elbow rest height	19.8 (7.8)	19.05-23.11 (7.5-9.1)	20.83 (8.2)	16.00-25.65 (6.3-10.1)	25.40 (10.0)	24.13-27.94 (9.5-11.0)
Shoulder elbow length	38.1 (15.0)	36.07-39.12 (14.2-15.4)	39.12 (15.4)	36.83-40.89 (14.5-16.1)	40.13 (15.8)	38.61-40.64 (15.2-16.0)
Forearm-hand length	48.77 (19.2)	46.99-50.80 (18.5-20.0)	49.28 (19.4)	48.01-51.56 (18.9-20.3)	50.55 (19.9)	47.24-52.58 (18.6-20.7)
Foot length	26.67 (10.5)	26.16-27.94 (10.3-11.0)	32.00 (12.6)	29.97-32.26 (11.8-12.7)	31.24 (12.3)	29.72-32.00 (11.7-12.6)
Hand length	19.56 (7.7)	19.05-21.59 (7.5-8.5)	19.05 (7.5)	18.29-19.56 (7.2-7.7)	18.03 (7.1)	17.27-19.05 (6.8-7.5)
Palm length	11.43 (4.5)	11.18-11.43 (4.4-4.5)	8.89 (3.5)	9.91-10.92 (3.9-4.3)	10.16 (4.0)	8.13-14.99 (3.2-5.9)
Crotch height (standing)	84.58 (33.3)	78.99-88.39 (31.1-34.8)	82.30 (32.4)	78.23-84.84 (30.8-33.4)		
Thigh clearance	16.51 (6.5)	13.97-18.03 (5.5-7.1)	16.26 (6.4)	15.49-17.78 (6.1-7.0)	20.57 (8.1)	19.30-20.83 (7.6-8.2)

*All measurements were taken on seated subject, except crotch height. These measurements were taken on six subjects wearing the MC-2 (X-15 type) full pressure suit. Data is given in centimeters with inches in parentheses.



*Increments computed from 95th percentile values. Data given in centimeters with inches in parentheses. Measurements were made on 34 subjects wearing A/P22S-2 pressure suits.

Figure 3. Incremental and percentage growth changes in body size due to the effects of inflated pressure suits (based on Alexander et al., 1969).*



DIMENSION	PERCENTILE MAN	
	5%	95%
A - Height	171.45 (67.5)	191.77 (75.5)
B - Maximum breadth at elbows (arms relaxed)	--- --	74.68 (29.4)
C - Maximum breadth at elbows (arms at side)	--- --	67.06 (26.4)
D** Maximum depth with portable life support system (PLSS) and backup oxygen (OPS)	66.04 (26.0)	72.14 (28.4)
E** Maximum depth without PLSS/OPS	39.37 (15.5)	45.47 (17.9)
Weight (lb), with PLSS/OPS	143.31 (316.0)	174.73 (385.3)
Weight (lb), without PLSS/OPS	86.30 (190.3)	117.73 (259.6)

* Measurements made on A7L pressure garment assembly, pressurized to 3.75 psig. Data given in centimeters and kilograms with inches and pounds in parentheses.

** To obtain envelope dimensions, 2 inches have been added to maximum chest depth of suited/pressurized crewman for PLSS control box.

Figure 4. Functional envelope dimensions of the fully suited astronaut based on NASA Habitability Data Handbook (1971).*

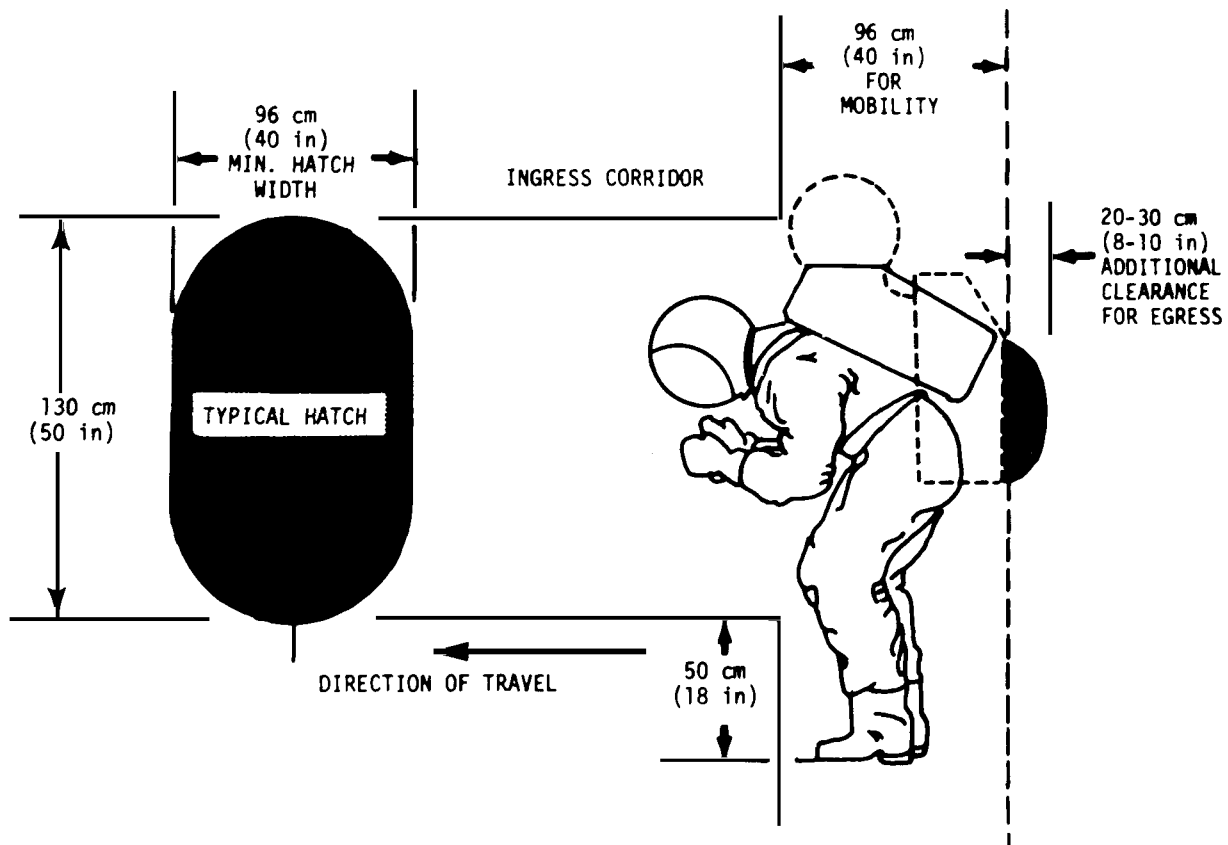


Figure 5. Recommended access corridor dimensions to accommodate fully suited astronaut (data obtained from NASA Internal Note MSC-EC-R-71-10, 1971).

It should be stressed, before leaving this subject, that body size changes caused by the addition of protective clothing, are suit-specific. Each suit or assemblage will result in somewhat different growth increments; the important point is that such growth is often significant and must be accommodated in the workspace design.

Effects of Zero-g on Body Size

Many features of man's form and structure resulted from having evolved in the earth's gravitational force (one-g). Our physiological functions are one-g adapted as are anatomical features related to our ability to maintain an erect posture. It is not surprising that when the force of gravity is removed for a period of time, changes in body size, shape, function and composition may occur since it is in opposing gravity that certain body features remain stable. Physicians since Hippocrates have known that immobility and disuse of the body (reduced dynamic opposition to gravity) result in tissue atrophy. Prolonged bedrest, a form of hypodynamism, also brings on a variety of deconditioning processes including muscular atrophy.

Not until space flight, however, were hypodynamic and hypogravic effects on body size of direct concern to the design engineer. Early concerns of medical specialists over the underlying pathology of body changes and the possibility of their progressive nature have largely been dispelled by the longer missions. The significance of zero-g body size changes for the design engineer is that many types of changes observed represent a class of intra-individual change not previously encountered. A pressure suit custom fitted at one-g may not be easily donned or comfortable for an astronaut "adjusted" to weightlessness. Work space carefully laid out and sized for "earthmen" may not be functional in space.

A discussion of the major anthropometric changes observed in astronauts during space flight can be found in Chapter I.

Inter-individual Variations in Size

Male-Female Size Differences

One of the primary sources of variability in size between individuals is the difference between the sexes, a matter of considerable importance to designers today since women are becoming more frequent participants in all forms of activity. Areas of design which a few years ago would not have required consideration of female size and strength no longer exist.

One need hardly point out that, in general, women tend to be smaller than men. In addition, the sexual tendency for females to deposit subcutane-

ous fat makes women more rounded. In attempting to assess quantitatively the size differences between men and women, care must be exercised in selection of data for comparison. Because of similarities in technique and proximity in time of completion of the studies, the best available data for comparison probably are from the 1967 male U.S. Air Force (AMRL unpublished) and the 1968 female Air Force (Clauser et al. 1972) surveys. The 5th and 95th percentile values for selected body dimensions are compared in Table 11 which shows that the male fliers are heavier and generally larger, as might be expected.

It has been an accepted rule of thumb that female measurements tend to average about 92% of comparable male values. The ratios shown in Table 12 indicate that for most linear measurements, the rule holds reasonably well for the general U.S. populations. A major exception is weight, a non-linear measurement. The table shows that women's weight is about three-quarters that of the men. To properly equate weight, an essentially three-dimensional quantity, with the linear measures, the cube roots of the weights should be computed. When this is done, the female to male ratio becomes 91.3%, a value clearly consistent with the 92% rule of thumb.

If male-female differences in the mean values for most body dimensions average only about 8%, what is their significance for designers? The answer to this question may be approached in several ways. One method is to examine the range of size differences, especially for dimensions commonly used in design, between a small female (5th percentile) and a large male (95th percentile). This is far from a merely academic exercise since persons representative of each extreme (in one or more dimensions) may be required to use or operate the same item or function in the same work space.

Examining again the data from the USAF surveys as shown in Table 11, it can be seen that the ratio of the 5th percentile females to the 95th percentile males for most dimensions is considerably lower (i.e., about 72%) than the ratio of the mean values. To illustrate the range of size difference, selected dimensions are graphed in Figure 6 to show not only the range of differences, but also the overlap of the 5th and 95th percentiles of each group. (The extreme range of differences, 40 cm. (16 in.) in waist circumference may be partially attributed to the age difference between the two groups. The women averaged 23.4 years and the men averaged 30 years of age.)

A second method that may be used to demonstrate the significance of sexual differences is through the use of bivariate distributions. When the distribution of the various height-weight combinations is plotted for the Air Force populations, two partially overlapping ellipses may be drawn which each encompass about 95% of their respective samples. Examination of Figure 7 will show that while there is considerable overlap, the two groups are nevertheless quite distinct in these two variables. Because of the well-known relationship of many other body dimensions to height and weight, it is apparent that the sexes are quite different in other aspects of body size as well.

TABLE 11
COMPARISON OF MALES AND FEMALES FOR SELECTED DIMENSIONS
5TH AND 95TH PERCENTILE VALUES*
(FROM 1967 USAF SURVEY UNPUBLISHED AND CLAUSER ET AL. 1972)

<u>Variable</u>	<u>Males</u>		<u>Females</u>		<u>Ratio**</u>
	<u>5th%</u>	<u>95th%</u>	<u>5th%</u>	<u>95th%</u>	
Weight	63.6 (140.2)	95.6 (210.8)	46.4 (102.3)	70.9 (156.3)	.49
Stature	167.2 (65.8)	187.7 (73.9)	152.4 (60.0)	172.1 (67.8)	.81
Sitting height	88.1 (34.7)	98.6 (38.8)	80.4 (31.7)	90.9 (35.8)	.82
Acromial height	135.7 (53.4)	154.8 (60.9)	123.0 (48.4)	141.1 (55.6)	.79
Waist height	98.7 (38.9)	114.3 (45.0)	93.1 (36.7)	107.9 (42.5)	.81
Crotch height	78.3 (30.8)	92.0 (36.2)	68.1 (26.8)	81.4 (32.0)	.74
Popliteal height	40.1 (15.8)	47.5 (18.7)	38.0 (15.0)	44.1 (17.4)	.80
Thigh clearance height	14.3 (5.6)	18.8 (7.4)	10.4 (4.1)	14.6 (5.7)	.55
Buttock-knee length	56.1 (22.1)	65.0 (25.6)	53.2 (20.9)	61.9 (24.4)	.82
Sleeve length	85.2 (33.5)	96.8 (38.1)	74.2 (29.2)	85.1 (33.5)	.77
Sleeve inseam	44.4 (17.5)	52.8 (20.8)	40.2 (15.8)	48.2 (19.0)	.76
Hand length	17.8 (7.0)	20.5 (8.1)	16.9 (6.7)	20.1 (7.9)	.82
Foot length	25.1 (9.9)	29.0 (11.4)	22.2 (8.7)	26.0 (10.2)	.77
Biacromial breadth	37.5 (14.8)	43.8 (17.2)	33.2 (13.1)	38.6 (15.2)	.76
Chest circ. (scye)	92.5 (36.4)	112.4 (44.3)	77.0 (30.3)	93.2 (36.7)	.69
Waist circ.	75.7 (29.8)	100.1 (39.4)	59.5 (23.4)	77.2 (30.4)	.59
Buttock circ. (sitting)	97.1 (38.2)	119.3 (47.0)	90.8 (35.7)	110.8 (43.6)	.76
Thigh circ.	51.5 (20.3)	66.2 (26.1)	48.7 (19.2)	62.6 (24.6)	.74
Calf circ.	33.3 (13.1)	40.6 (16.0)	30.6 (12.0)	38.1 (15.0)	.75
Hand circ.	20.0 (7.9)	23.1 (9.1)	16.8 (6.6)	19.8 (7.8)	.73
Head circ.	55.2 (21.7)	59.9 (23.6)	52.3 (20.6)	57.6 (22.7)	.87
Biceps circ. (flexed)	28.5 (11.2)	35.9 (14.1)	23.0 (9.1)	30.7 (12.1)	.64

*Data given in kilograms and centimeters with pounds and inches in parentheses.
**5th% Female/95th Male.

TABLE 12
SELECTED DIMENSIONS OF MALES AND FEMALES IN THE U.S. POPULATION
(BASED ON STOUT ET AL. 1965)*

<u>Variable</u>	<u>Males</u> (25.5-34.5 years)		<u>Females</u> (18.5-24.5 years)		<u>Ratio**</u>
	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	
Arm circumference (biceps)	31.14 (12.26)	3.20 1.26	26.10 (10.28)	3.40 (1.34)	.84
Biacromial diameter	40.1 (15.79)	2.10 (.83)	35.50 (13.98)	1.90 (.75)	.89
Buttock-knee length	59.79 (23.54)	2.95 (1.16)	56.67 (22.31)	3.18 (1.25)	.95
Buttock-popliteal length	49.81 (19.61)	3.18 (1.25)	47.80 (18.82)	3.15 (1.24)	.96
Chest circumference	99.2 (39.06)	8.30 (3.27)	83.7 (32.95)	6.20 (2.44)	.84
Elbow-elbow breadth	41.55 (16.36)	4.52 (1.78)	33.66 (13.25)	4.11 (1.62)	.81
Elbow rest height	24.64 (9.70)	2.77 (1.09)	22.76 (8.96)	2.69 (1.06)	.92
Knee height	54.84 (21.59)	2.82 (1.11)	50.09 (19.72)	2.59 (1.02)	.90
Popliteal height	45.34 (17.85)	2.69 (1.06)	40.59 (15.98)	2.46 (.97)	.90
Seat breadth	35.46 (13.96)	2.87 (1.13)	35.10 (13.82)	3.28 (1.29)	.99
Sitting ht. (erect)	91.44 (36.0)	3.45 (1.36)	85.29 (33.58)	3.20 (1.26)	.92
Sitting ht. (relaxed)	87.12 (34.30)	3.58 (1.41)	82.37 (32.43)	3.45 (1.36)	.95
Stature	175.3 (69.02)	7.00 (2.76)	162.0 (63.78)	6.20 (2.44)	.93
Thigh clearance height	14.71 (5.79)	1.78 (.70)	13.46 (5.30)	1.68 (.66)	.92
Waist circumference	86.69 (34.13)	10.69 (4.21)	69.55 (27.38)	9.35 (3.68)	.80
Weight	77.4 (170.45)	13.10 (28.95)	58.9 (129.8)	11.00 (24.33)	.76

*Data given in centimeters and kilograms (for weight) with inches and pounds in parentheses.

**Female $\bar{X}$ /Male $\bar{X}$.

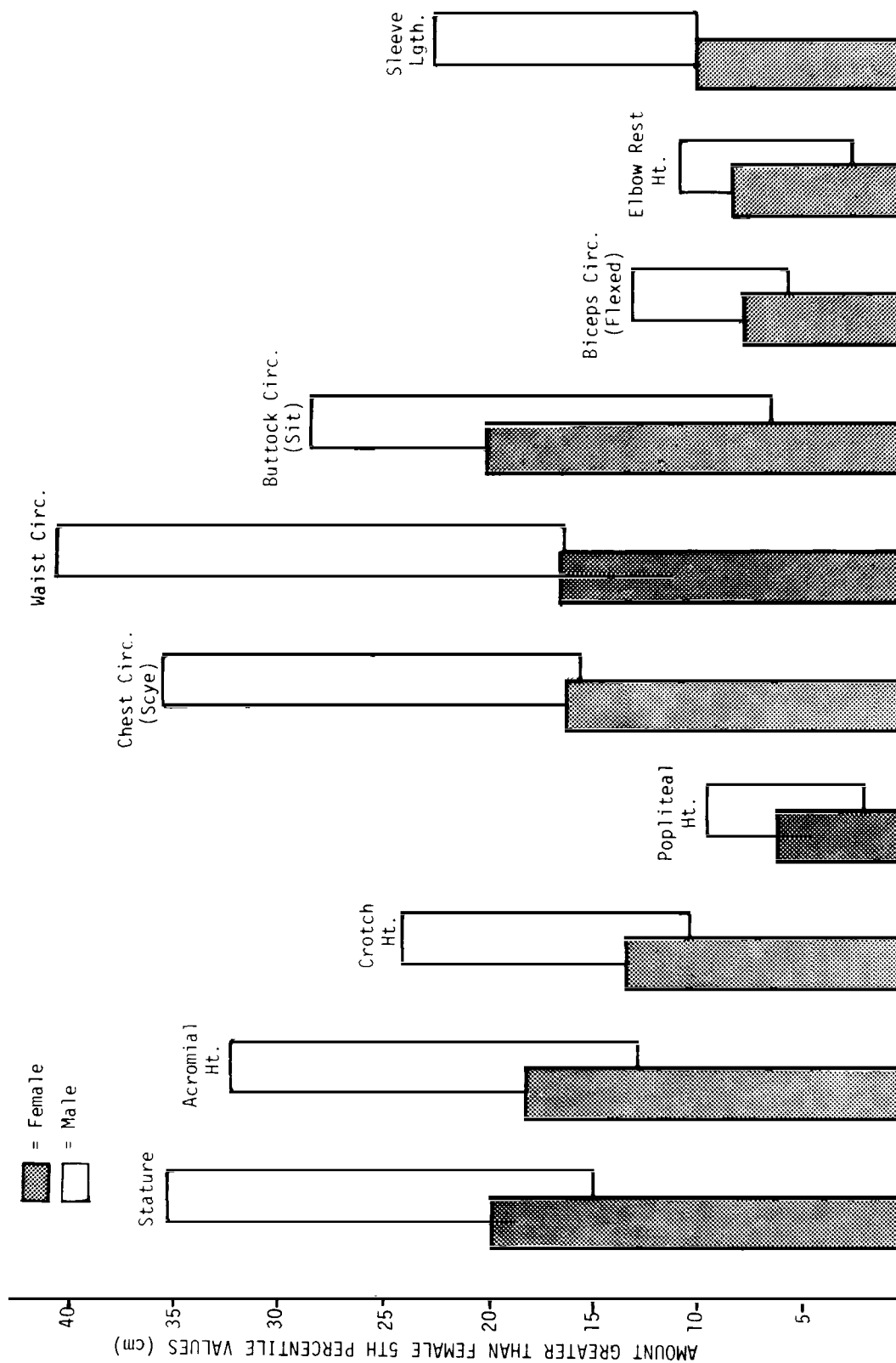
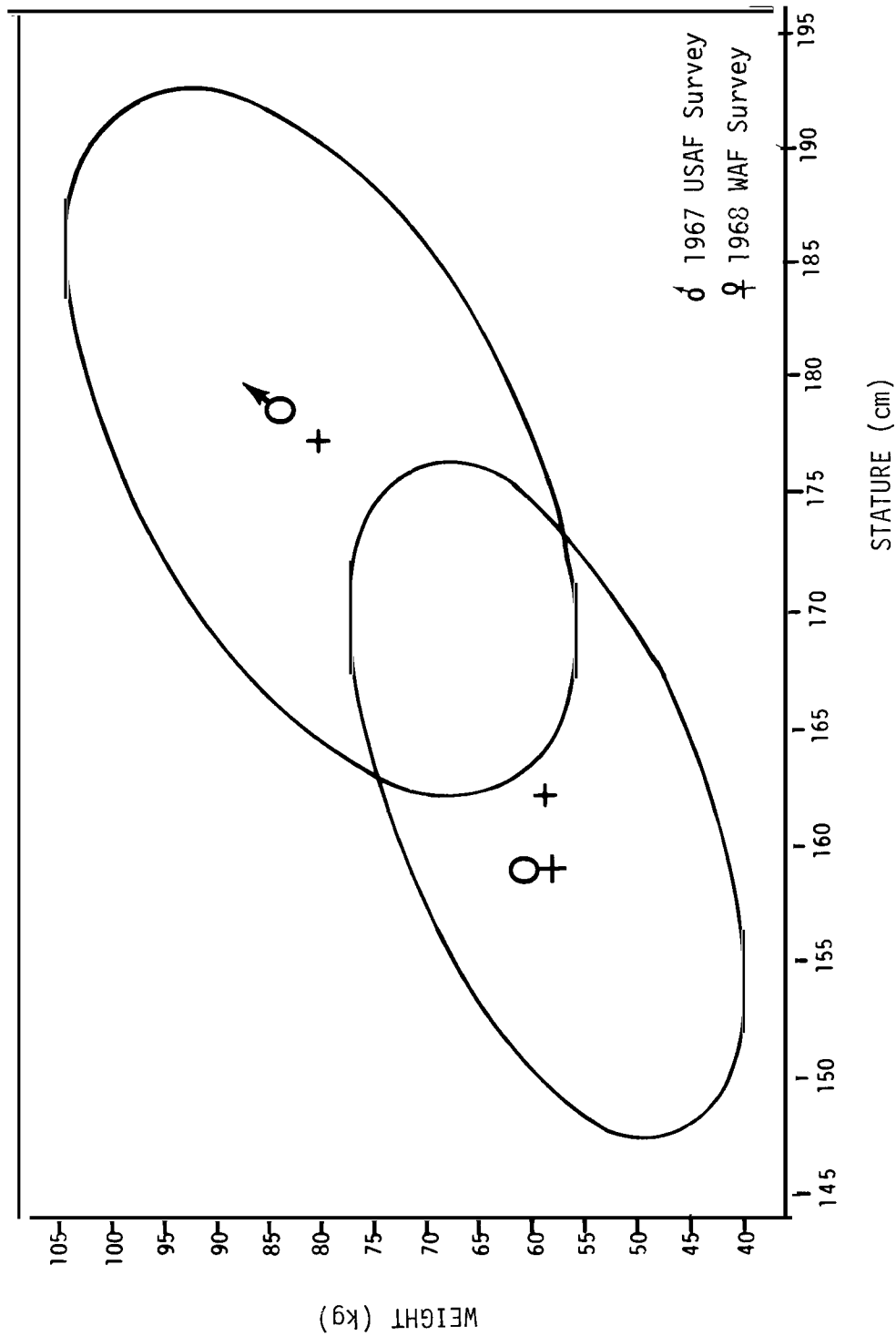


Figure 6. A comparison of 5th-95th percentile male and female values for selected dimensions showing the range of differences and overlap between the two groups.



* Approximately 95% of each group is contained within the appropriate ellipse.

Figure 7. Distributions of stature and weight for U.S. Air Force personnel - male and female.

Since the standard deviations of body size values, male or female, average about 5% of the mean, a difference of 8% would mean, in general, that the body size of females lying approximately one standard deviation above the female mean value would tend to match the body size of males lying approximately one standard deviation below the male mean value. From a design viewpoint this indicates that system or equipment specifications based on the anthropometry of male fliers, for example, would have to be modified if they are to accommodate the body size differences of female users.

Racial/Ethnic Variation in Body Size

To enter upon a lengthy discussion about the definition of "race" or "ethnic" is outside the purpose of this data book. The term "race" as used here will be equivalent to the subspecies usage although the conventional taxonomic names of Negro, Caucasian and Mongolian for the three major racial classes have been replaced by the more generalized terms, Black, White and Oriental respectively. We have included size data for selected examples of White, Black and Oriental populations. Only American Blacks have been considered. Whether they, as a population distinct from African Blacks, have formed or are forming a new race, has not been considered. "Ethnic" will refer chiefly to national origin of a subject or population.

Body size variability related to ethnic/racial groups is of considerable interest to Americans because of the broad spectrum of national origins that characterizes the American population. Some information on the ethnic and racial makeup of the U.S. population, as obtained from the 1970 census, is shown in Table 13 below.

TABLE 13
RACIAL/ETHNIC ORIGINS OF U.S. POPULATION*
(FROM CENSUS BUREAU DATA, APRIL 1970)

Group	Number in Thousands	Percent
White	177,784	87.5
Spanish Speaking	10,115	4.9
Black	22,580	11.1
Other	2,883	1.4
Indian	793	0.4
Japanese	591	0.3
Chinese	435	0.2
Filipino	343	0.2
Other	720	0.4

Racial/ethnic comparisons can be made by using the 1966 U.S. Army anthropometric survey data (White and Churchill). In this survey the subjects were asked to designate their ethnic derivation or national extraction. There were three categories in which national extraction was not otherwise specified: American White (29.3%); American Black (14.7%); and American Indian (1.8%). These categories represent approximately 45% of the total sample. The remainder of the sample was self-classified into 37 national origins. It is of some interest to compare these groups in terms of gross body size. Using only the dimensions of height and weight, such a comparison is given in Table 14. The table lists the mean and standard deviation for the total sample and shows the deviation of each group from these values. The sample sizes of some of the subsets are rather small, but they are adequate to indicate the diversity that exists in the various racial/ethnic components of the military population. These height-weight differences, while often quite large, still do not tell the complete story of body size differences.

Young adult males and females of the three principal races may be compared more broadly by examining the data presented in Tables 15 and 16 and Figures 8 and 9. The U.S. Air Force basic trainee survey of 1965 (Long and Churchill, 1968) and the Japanese Air Force survey of 1972 (Yokohori) are the sources of the male data. The female data are selected from measurements obtained from the 1968 survey of U.S. Air Force women (Clauser et al. 1972) and the Japanese civilian surveys of 1967-68 and 1972-73 (Yanagisawa 1974). In both cases the Black and White data are from the respective U.S. Air Force surveys. The mean values and standard deviations for selected measurements for the men and women are presented in Tables 15 and 16. Selected dimensions are plotted in Figures 8 and 9 in overlapping bar graphs to demonstrate the range of variation of the males and females of the three racial groups.

The 343 Black and White males that formed the comparative sample were selected from the total Air Force survey population (N=3,869) and matched on the basis of age, length of military service and region of birth; the females represent the total sample. Height and weight values for both racial groups are very similar. Despite this, there are significant differences in the mean values for about three quarters of the measurements. The Blacks have legs, arms, hands and feet which, on the average, are longer than those of Whites; the reverse is true for measurements of the torso. The Blacks tend to have longer heads, wider faces, and less body fat.

The Oriental samples cannot be so rigorously compared to the others as the Blacks and Whites can be to each other, since the Japanese survey was performed seven years later. The measurement techniques used in each survey are thought to have been comparable, however. As might be expected, the data show that the Orientals are on the average somewhat smaller. Despite the fact that for these samples the Japanese average nearly 10 cm (3.9 in.) shorter in stature, the sitting heights of all three groups are nearly the same. The limb lengths, especially the legs, apparently account for the vast proportion of the longitudinal difference in size. (See Figure 1) The majority of the circumferences do not appear to be significantly different. The Whites tend to be the most variable of the three groups.

TABLE 14
HEIGHT AND WEIGHT OF U.S. MILITARY MALES WITH DEVIATIONS OF THE RACIAL/ETHNIC SUBGROUPS
FROM THE TOTAL SAMPLE MEAN AND STANDARD DEVIATION
(FROM U.S. ARMY SURVEY, 1966)*

Ethnic Group **	No.	Height		Weight	
		$\bar{X}$	SD	$\bar{X}$	SD
Total Sample	6682	174.52 (68.71)	6.61 (2.60)	72.15 (159.09)	10.59 (23.35)
American White	1960	.58 (.23)	- .20 (- .08)	- .36 (- .80)	- .11 (- .24)
American Black	982	.02 (.01)	.04 (.02)	1.06 (2.34)	.28 (.62)
American Indian	120	- .08 (- .03)	0.00 0	- .89 (-1.97)	- .63 (-1.38)
Mexican	113	-4.05 (-1.59)	- .32 (-.13)	-1.28 (-2.82)	-1.31 (-2.89)
Puerto Rican	125	-6.09 (-2.40)	- .18 (-.07)	-5.95 (-13.11)	-1.28 (-2.82)
Spanish	74	-3.48 (-1.37)	- .02 (.01)	-3.55 (-7.83)	- .64 (-1.42)
Filipino	13	-7.02 (-2.76)	1.40 (.55)	-3.84 (-8.47)	.47 (1.04)
Hawaiian	10	-1.25 (- .49)	- .40 (-.16)	4.69 (10.35)	1.90 (4.18)
Japanese	26	-5.75 (-2.26)	- .55 (-.22)	4.36 (-9.61)	-1.43 (-3.15)
English	558	.61 (.24)	- .20 (-.08)	.53 (1.17)	.16 (.35)
Irish	864	.68 (.27)	- .44 (-.17)	.18 (.39)	- .19 (- .41)
Scottish	169	.94 (.37)	- .18 (-.07)	1.51 (3.32)	.67 (1.48)
Welsh	21	.96 (.38)	- .42 (-.17)	- .84 (-1.85)	.44 (.96)
French	273	-.82 (- .32)	- .42 (-.17)	-1.48 (-3.26)	.70 (1.54)
German	1080	.68 (.27)	- .19 (-.07)	1.11 (2.44)	.40 (.88)
Austrian	14	-.91 (- .3)	- .37 (-.15)	-2.15 (-4.73)	.92 (2.02)
Polish	218	.43 (.17)	- .27 (-.11)	.84 (1.86)	- .31 (-.69)
Swedish	134	1.61 (.63)	- .18 (-.07)	1.25 (2.75)	- .14 (-.31)
Dutch	147	-.28 (- .11)	- .38 (-.15)	-1.21 (-2.66)	-1.04 (-2.29)
Italian	319	-2.04 (- .80)	- .47 (-.19)	- .15 (- .32)	- .82 (-1.80)

*Data given in centimeters and kilograms with inches and pounds in parentheses.

**Subgroup classification self-assigned.

TABLE 15
MEANS AND STANDARD DEVIATIONS OF SELECTED DIMENSIONS FOR YOUNG MILITARY MALES OF THREE RACIAL GROUPS
(BASED ON LONG AND CHURCHILL, 1966, AND YOKOHORI, 1972)*

Variable	Black (U.S.)			White (U.S.)			Oriental (Japan)					
	Mean	S.D.		Mean	S.D.		Mean	S.D.				
Weight	68.39	(150.8)	9.16	(20.2)	68.07	(150.1)	10.84	(23.9)	60.59	(133.6)	6.49	(14.3)
Stature	175.1	(68.94)	6.6	(2.6)	175.2	(68.98)	6.9	(2.7)	165.9	(65.31)	5.31	(2.1)
Sitting height	88.2	(34.72)	3.1	(1.2)	91.6	(36.06)	3.6	(1.4)	90.4	(35.59)	2.8	(1.1)
Sitting eye height	77.1	(30.35)	3.0	(1.2)	80.3	(31.61)	3.3	(1.3)	78.6	(30.94)	2.8	(1.1)
Cervicale	149.8	(58.98)	6.3	(2.5)	149.6	(58.90)	6.5	(2.6)	140.3	(55.24)	4.9	(1.9)
Grotch height	86.1	(33.90)	4.7	(1.9)	83.0	(32.68)	4.4	(1.7)	73.9	(29.09)	3.7	(1.5)
Elbow rest height	20.5	(8.07)	2.4	(.9)	24.0	(9.45)	2.5	(1.0)	26.0	(10.24)	2.1	(.8)
Thigh clearance height	15.2	(5.98)	1.3	(.5)	14.9	(5.87)	1.4	(.6)	13.5	(5.31)	1.3	(.5)
Buttock-knee length	62.0	(24.41)	3.0	(1.2)	60.0	(23.62)	3.0	(1.2)	55.3	(21.77)	2.6	(1.0)
Shoulder-elbow length	36.9	(14.53)	1.8	(.7)	36.3	(14.29)	1.8	(.7)	33.1	(13.03)	1.9	(.7)
Elbow-wrist length	30.0	(11.81)	1.5	(.6)	28.6	(11.26)	1.4	(.6)	-	-	-	-
Hand length	20.3	(7.99)	1.0	(.4)	19.5	(7.68)	1.0	(.4)	18.2	(7.17)	-	-
Functional reach	81.2	(31.97)	4.4	(1.7)	78.6	(30.94)	4.0	(1.6)	-	-	-	-
Foot length	27.6	(10.87)	1.3	(.5)	26.6	(10.47)	1.3	(.5)	24.7	(9.72)	1.0	(.4)
Chest circumference	90.1	(35.47)	5.7	(2.2)	91.6	(36.06)	6.7	(2.6)	88.6	(34.88)	4.5	(1.8)
Waist circumference	74.9	(29.49)	6.0	(2.4)	78.0	(30.71)	7.8	(3.1)	75.0	(29.53)	5.4	(2.1)
Buttock circumference	90.6	(35.67)	5.8	(2.3)	92.1	(36.26)	6.4	(2.5)	89.1	(35.08)	3.9	(1.5)
Thigh circumference	54.3	(21.38)	4.9	(1.9)	53.8	(21.18)	5.3	(2.1)	52.6	(20.71)	3.4	(1.3)
Calf circumference	35.9	(14.13)	2.6	(1.0)	36.0	(14.17)	2.7	(1.1)	35.5	(13.98)	2.1	(.8)
Scye	41.9	(16.50)	2.2	(.9)	41.7	(16.42)	2.5	(1.0)	41.4	(16.30)	2.3	(.9)
Biceps circumference	30.7	(12.09)	2.6	(1.0)	30.0	(11.81)	2.7	(1.1)	29.8	(11.73)	2.0	(.8)
Forearm circumference	26.9	(10.59)	1.4	(.6)	26.3	(10.35)	1.6	(.6)	26.9	(10.59)	1.3	(.5)
Hand circumference	21.7	(8.54)	1.0	(.4)	21.3	(8.39)	1.0	(.4)	20.2	(7.95)	0.9	(.4)
Vert. trunk circumfer.	157.4	(61.97)	6.7	(2.6)	161.6	(63.62)	7.8	(3.1)	156.1	(61.46)	5.9	(2.3)
Sleeve inseam	51.2	(20.16)	2.6	(1.0)	49.4	(19.45)	2.5	(1.0)	-	-	-	-
Ankle circumference	22.5	(8.86)	1.4	(.6)	22.7	(8.94)	1.5	(.6)	21.4	(8.43)	1.1	(.4)
Head length	19.8	(7.80)	0.7	(.3)	19.5	(7.68)	0.7	(.3)	18.8	(7.40)	0.7	(.3)
Head breadth	15.1	(5.94)	0.5	(.2)	15.1	(5.94)	0.6	(.2)	15.8	(6.22)	0.6	(.2)
Vertex-menton height	23.2	(9.13)	1.0	(.4)	22.7	(8.94)	0.9	(.4)	23.4	(9.21)	1.1	(.4)
Bizygomatic breadth	13.6	(5.35)	0.6	(.2)	13.6	(5.35)	0.6	(.2)	12.8	(5.04)	0.9	(.4)
Head circumference	56.2	(22.13)	1.6	(.6)	55.8	(21.97)	1.6	(.6)	56.3	(22.17)	1.4	(.6)
Knee height sitting	56.6	(22.28)	2.6	(1.0)	55.1	(21.69)	2.7	(1.1)	49.4	(19.45)	2.1	(1.0)

*Data given in centimeters and kilograms with inches and pounds in parentheses.

TABLE 16
MEANS AND STANDARD DEVIATIONS OF SELECTED DIMENSIONS FOR YOUNG FEMALES OF THREE RACIAL GROUPS
(BASED ON CLAUSER ET AL. 1972)*

<u>Variable</u>	Black (U.S.)		White (U.S.)		Oriental(Japan)	
	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>
Age	20.9	3.9	20.3	3.6	25-39	(range)
Weight	56.4 (124.3)	7.1 (15.7)	57.1 (125.9)	7.0 (15.4)	51.3 (113.1)	7.0 (15.4)
Stature	161.3 (63.5)	5.8 (2.3)	161.9 (63.7)	5.9 (2.3)	153.2 (60.3)	4.8 (1.9)
Cervicale height	139.2 (54.8)	5.4 (2.1)	139.0 (54.7)	5.4 (2.1)		
Acromial height	131.7 (51.9)	5.4 (2.1)	131.7 (51.9)	5.4 (2.1)		
Sitting height	81.3 (32.0)	3.1 (1.2)	84.3 (33.2)	3.1 (1.2)		
Waist height	101.1 (39.8)	4.8 (1.9)	100.0 (39.4)	4.4 (1.7)	93.2 (36.7)	3.7 (1.5)
Crotch height	76.9 (30.3)	4.1 (1.6)	74.3 (29.3)	3.9 (1.5)	68.3 (26.9)	3.3 (1.3)
Tibiale height	42.8 (16.9)	2.4 (0.9)	41.9 (16.5)	2.3 (0.9)	38.6 (15.2)	1.8 (0.7)
Foot length	24.8 (9.8)	1.1 (0.4)	24.0 (9.4)	1.1 (0.4)	22.6 (8.9)	0.9 (0.4)
Hand length	19.2 (7.6)	0.9 (0.4)	18.3 (7.2)	0.9 (0.4)		
Head length	18.7 (7.4)	0.7 (0.3)	18.3 (7.2)	0.7 (0.3)		
Sleeve length	80.5 (31.7)	3.5 (1.4)	79.3 (31.2)	3.2 (1.3)	68.7 (27.0)	2.5 (1.0)
Head breadth	14.4 (5.7)	0.6 (0.2)	14.5 (5.7)	0.6 (0.2)		
Head circumference	55.8 (22.0)	1.5 (0.6)	54.6 (21.5)	1.6 (0.6)	54.5 (21.5)	1.4 (0.6)
Bust circumference	87.2 (34.3)	4.4 (1.7)	89.2 (35.1)	5.2 (2.0)	83.6 (32.9)	6.4 (2.5)
Waist circumference	66.4 (26.1)	4.7 (1.9)	66.9 (26.3)	5.0 (2.0)	67.1 (26.4)	6.3 (2.5)
Hip circumference	93.0 (36.6)	6.2 (2.4)	94.8 (37.3)	5.7 (2.2)	90.0 (35.4)	5.2 (2.0)
Thigh circumference	54.6 (21.5)	4.3 (1.7)	55.2 (21.7)	4.0 (1.6)	51.5 (20.3)	3.8 (1.5)
Knee circumference	36.1 (14.2)	2.3 (0.9)	36.2 (14.3)	2.1 (0.8)	33.5 (13.2)	2.2 (0.9)
Calf circumference	33.5 (13.2)	2.5 (1.0)	34.2 (13.5)	2.2 (0.9)	33.3 (13.1)	2.3 (0.9)
Ankle circumference	20.8 (8.2)	1.4 (0.6)	21.2 (8.3)	1.3 (0.5)		
Biceps circumference (relaxed)	25.0 (9.8)	2.2 (0.9)	25.4 (10.0)	2.1 (0.8)	26.7 (10.5)	2.5 (1.0)
Wrist circumference	15.0 (5.9)	0.8 (0.3)	15.0 (5.9)	0.7 (0.3)		
Vert trunk circumference	149.8 (59.0)	5.9 (2.3)	154.0 (60.6)	6.5 (2.6)	147.7 (58.1)	5.9 (2.3)

*Data given in kilograms and centimeters with pounds and inches in parentheses; age in years.

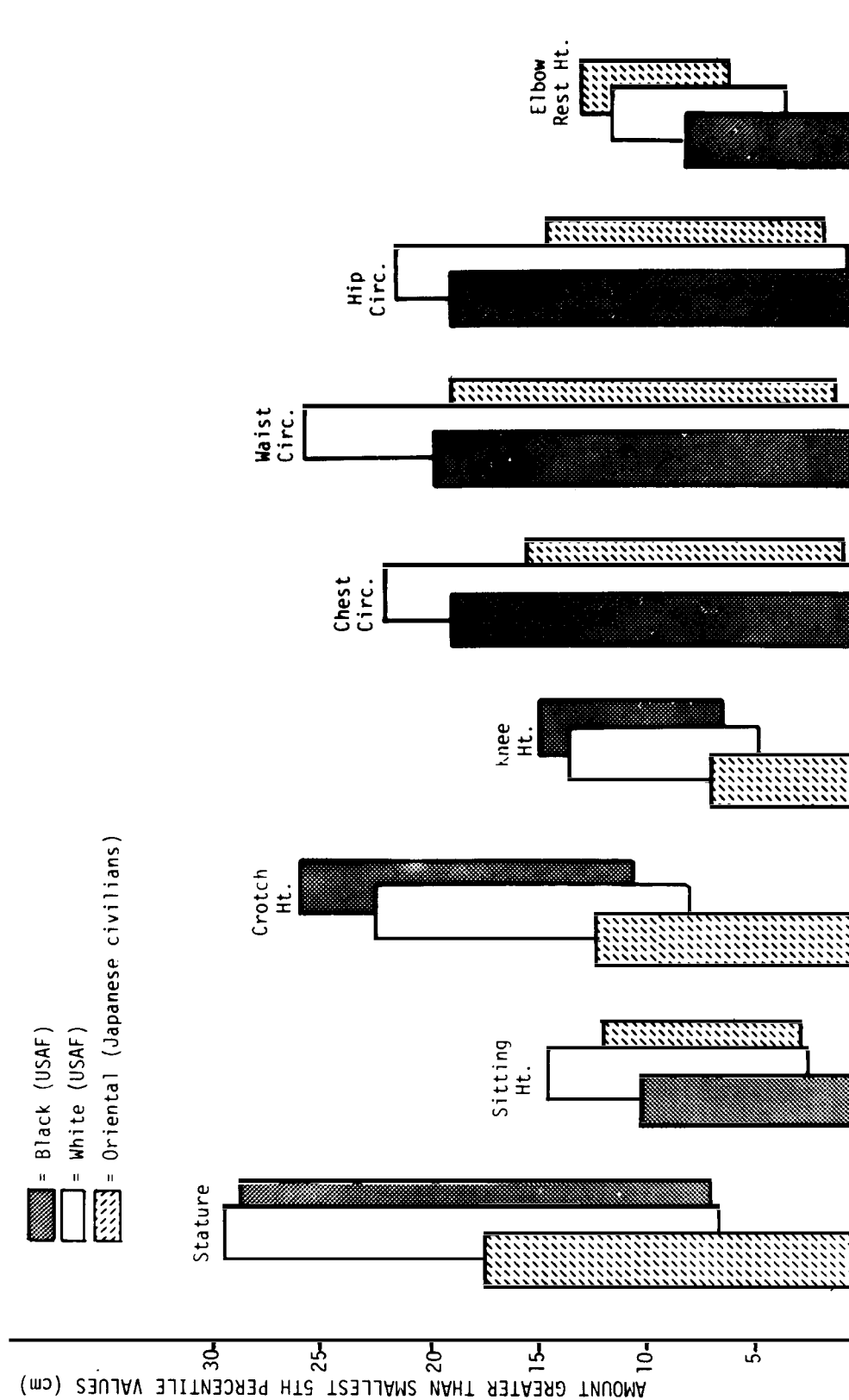


Figure 8. Range of variation between males of three racial groups for selected body dimensions (smallest 5th to largest 95th percentile).

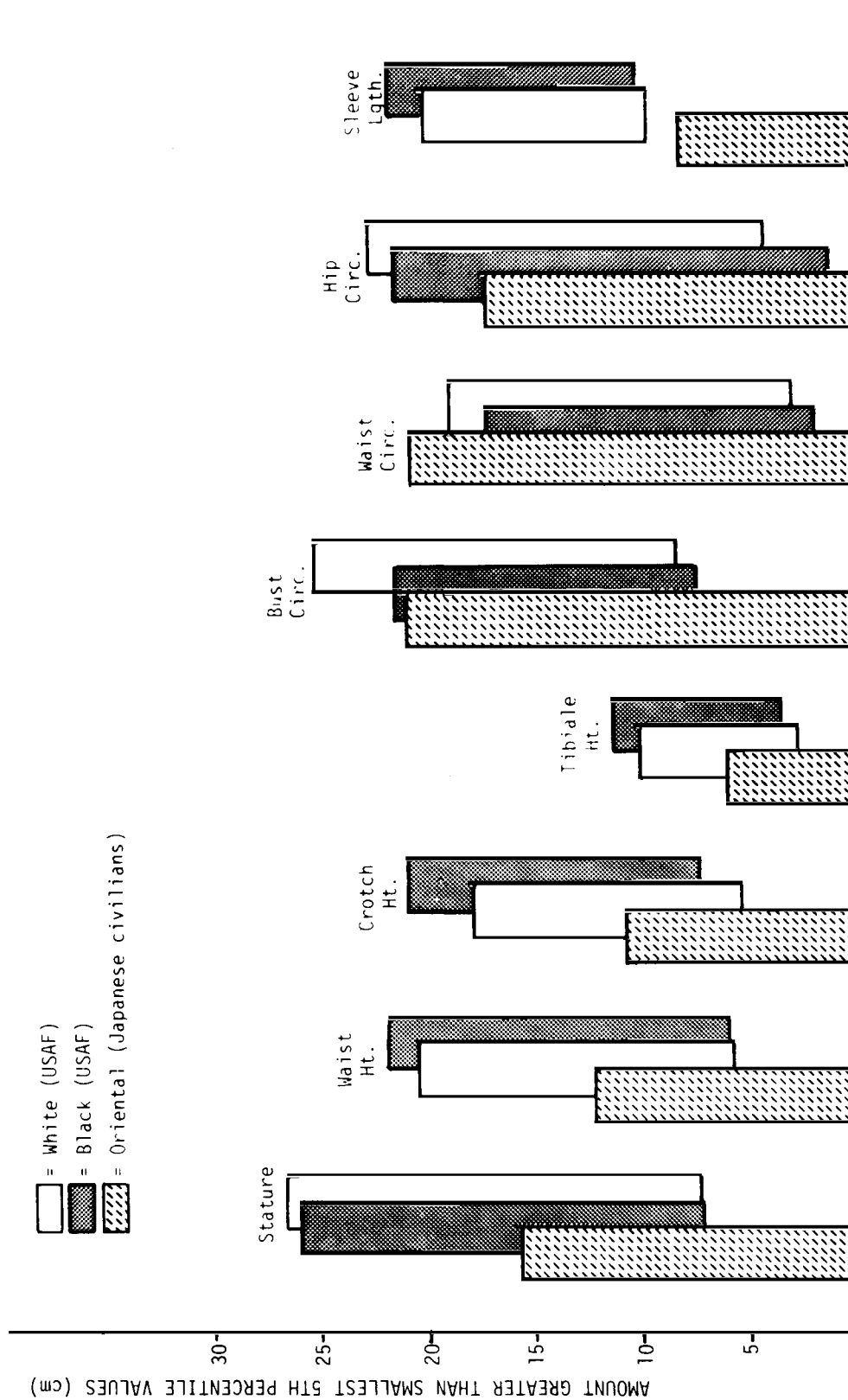


Figure 9. Range of variation between females of three racial groups for selected body dimensions (smallest 5th to largest 95th percentile).

While individual values for Whites and Blacks overlap to a large extent (partly as a result of greater variability in the White sample), the body size differences cited above are of sufficient magnitude to warrant consideration in the design of systems and equipment to be used by both Whites and Blacks.

National-Ethnic Size Variability

Without regard to racial composition of a given nation, there are demonstrable differences in body size when specific intra- or international groups are compared. This fact is easily ascertained by examination of the tables in Chapter III and the data in Volume II of this book. Selected portions of that material is presented graphically here in order to demonstrate national-ethnic variability. For convenience and brevity eleven common dimensions, as measured on the same 12 populations selected for presentation in Chapter III, have been chosen for presentation here. The 5th and 95th percentile range for each population (where available) are shown in Figures 10 through 20. The graphs clearly demonstrate the range of variability between subjects of different national origin and between groups of subjects of the same national origin (i.e., U.S. civilians and U.S. military personnel).

Size Differences Between Persons in Different Occupations

As noted above, dimensional differences are observed when anthropometric data from various vocational-professional populations are compared to data representing the general population. Utilizing the U.S. Health Examination Survey (HES) data (Stoudt et al. 1965) as a base, and data from surveys of several vocational-professional populations for comparison, Tables 17 and 18 were developed for males and females respectively. In comparing data, it should be remembered that the HES was performed somewhat earlier in time and the average age of the subjects was greater. It is recommended therefore that rigorous comparisons not be made. The purpose of this presentation is rather to alert the design engineer to the fact that if the user of the end item can be classed into a specific occupation, size data from the same or a similar population should be used wherever possible.

In comparing the male populations, the police are clearly larger than other individuals. The Air Force trainees are generally smaller but are also significantly younger. The group of stewardesses tends to be taller and slimmer than the other female groups. Again, the age of the HES population must be considered to affect dimensions such as waist circumference and elbow-elbow breadth.

Secular Changes in Adult Body Size

The fact that the size of the adult human body is thought to be increasing over time probably comes as no surprise. The man on the street will tell you that people are getting taller; older members of a community will recall "when people were smaller." Evidence shows that today's children

WAIST CIRCUMFERENCE

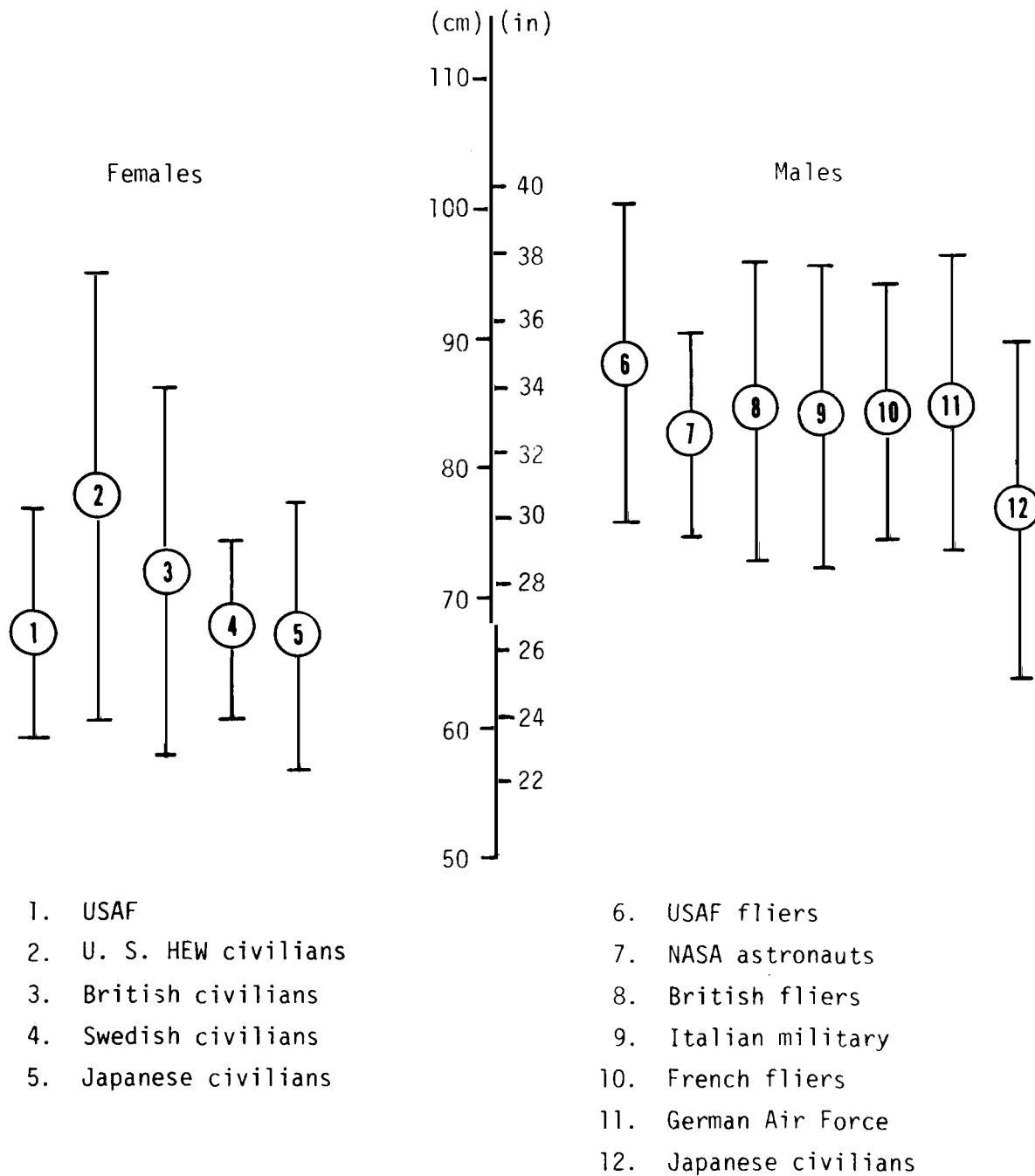
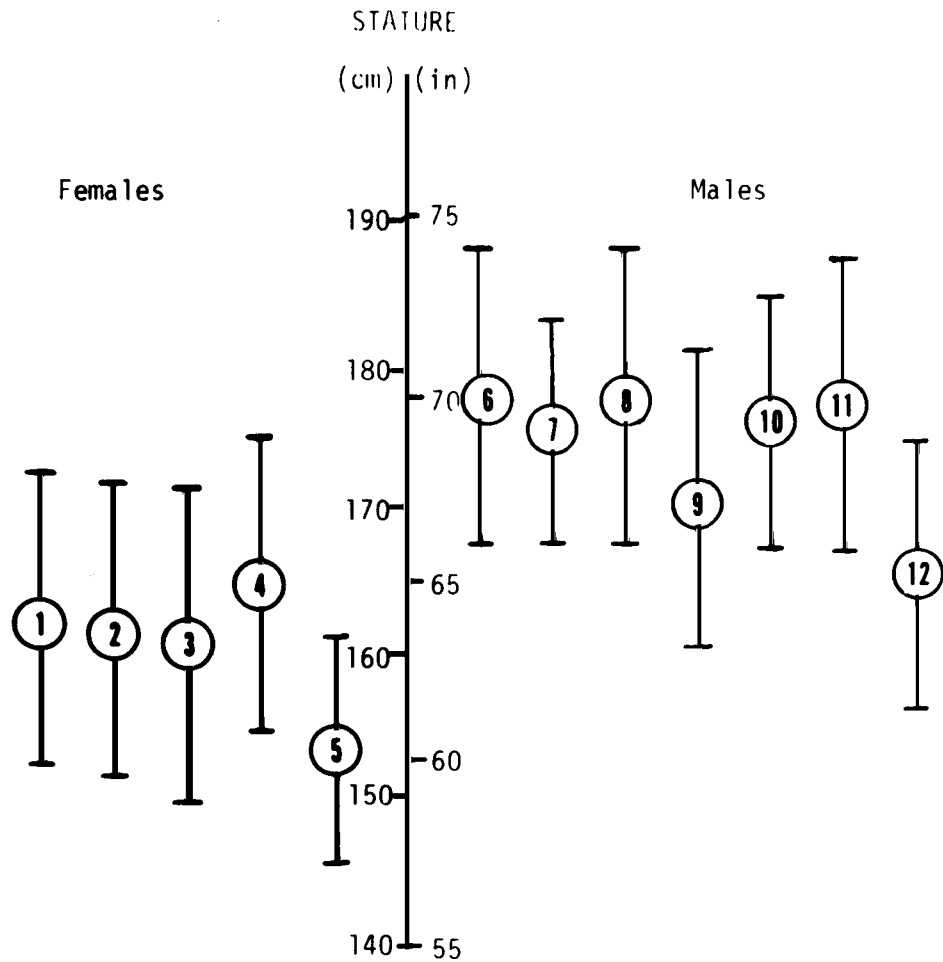
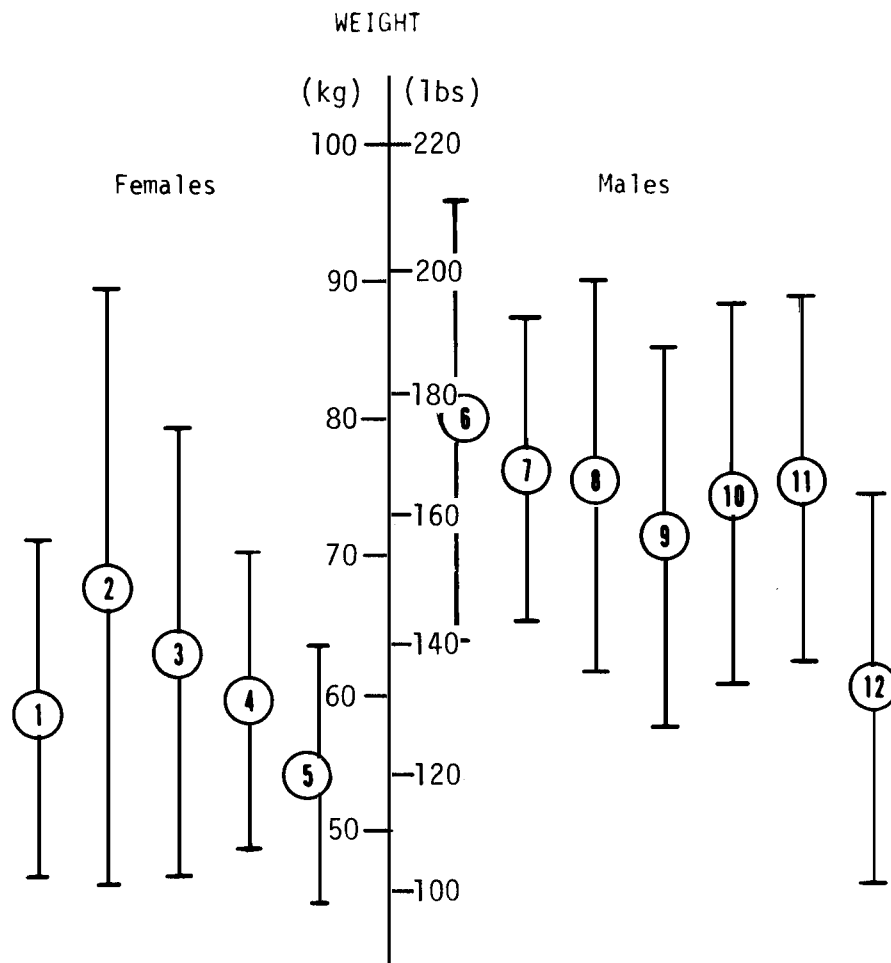


Figure 10. Range of variability (5th-95th percentile) in waist circumference for selected populations.



- | | |
|------------------------|------------------------|
| 1. USAF | 6. USAF fliers |
| 2. U. S. HEW civilians | 7. NASA astronauts |
| 3. British civilians | 8. British fliers |
| 4. Swedish civilians | 9. Italian military |
| 5. Japanese civilians | 10. French fliers |
| | 11. German Air Force |
| | 12. Japanese civilians |

Figure 11. Range of variability (5th-95th percentile) in stature for selected populations.



- | | |
|------------------------|------------------------|
| 1. USAF | 6. USAF fliers |
| 2. U. S. HEW civilians | 7. NASA astronauts |
| 3. British civilians | 8. British fliers |
| 4. Swedish civilians | 9. Italian military |
| 5. Japanese civilians | 10. French fliers |
| | 11. German Air Force |
| | 12. Japanese civilians |

Figure 12. Range of variability (5th-95th percentile) in weight for selected populations.

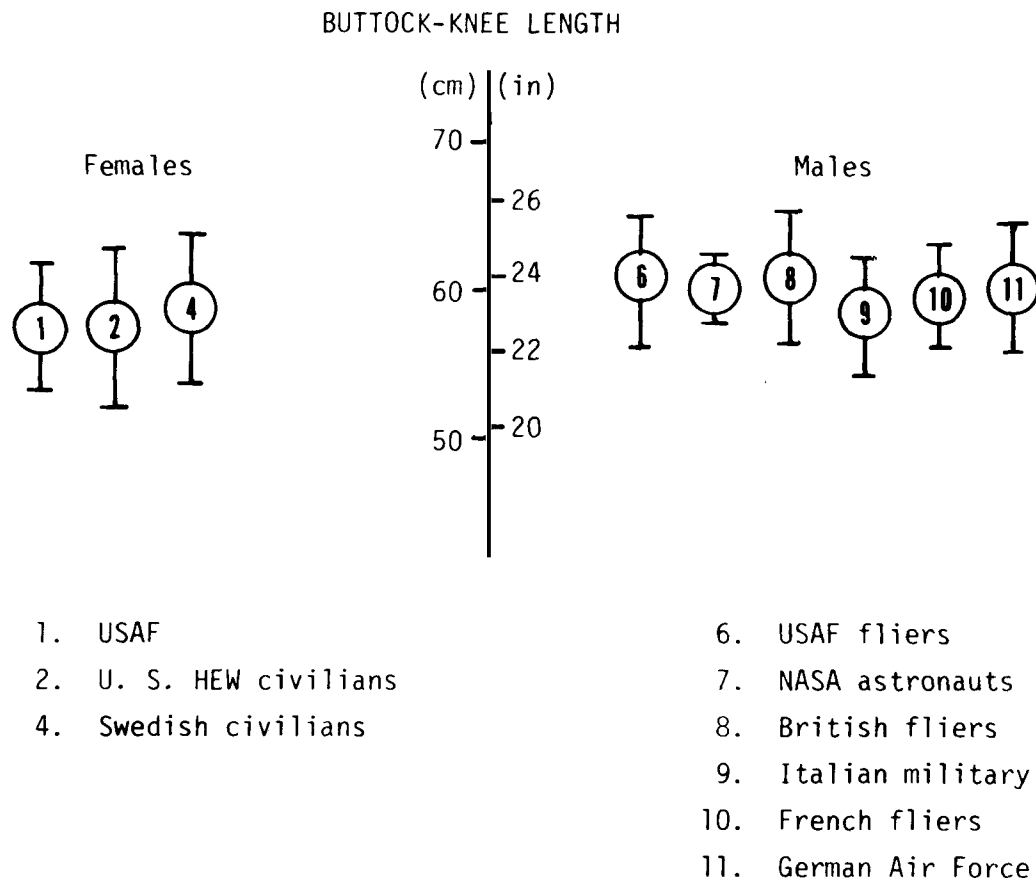
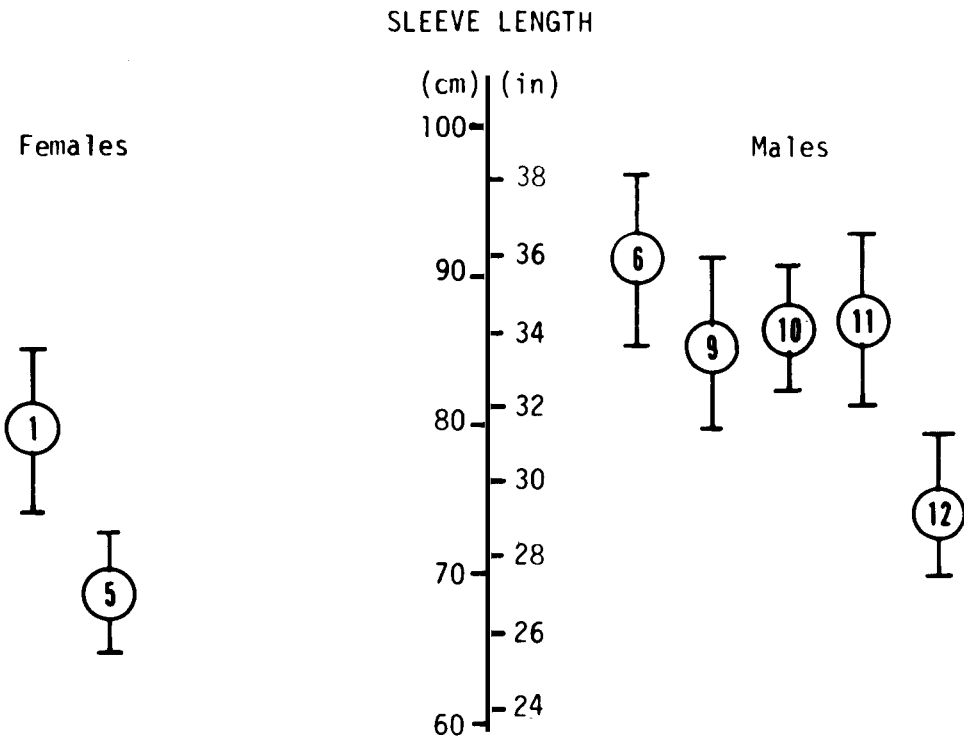


Figure 13. Range of variability (5th-95th percentile) in buttock-knee length for selected populations.



- 1. USAF
- 5. Japanese civilians

- 6. USAF fliers
- 9. Italian military
- 10. French fliers
- 11. German Air Force
- 12. Japanese civilians

Figure 14. Range of variability (5th-95th percentile) in sleeve length for selected populations.

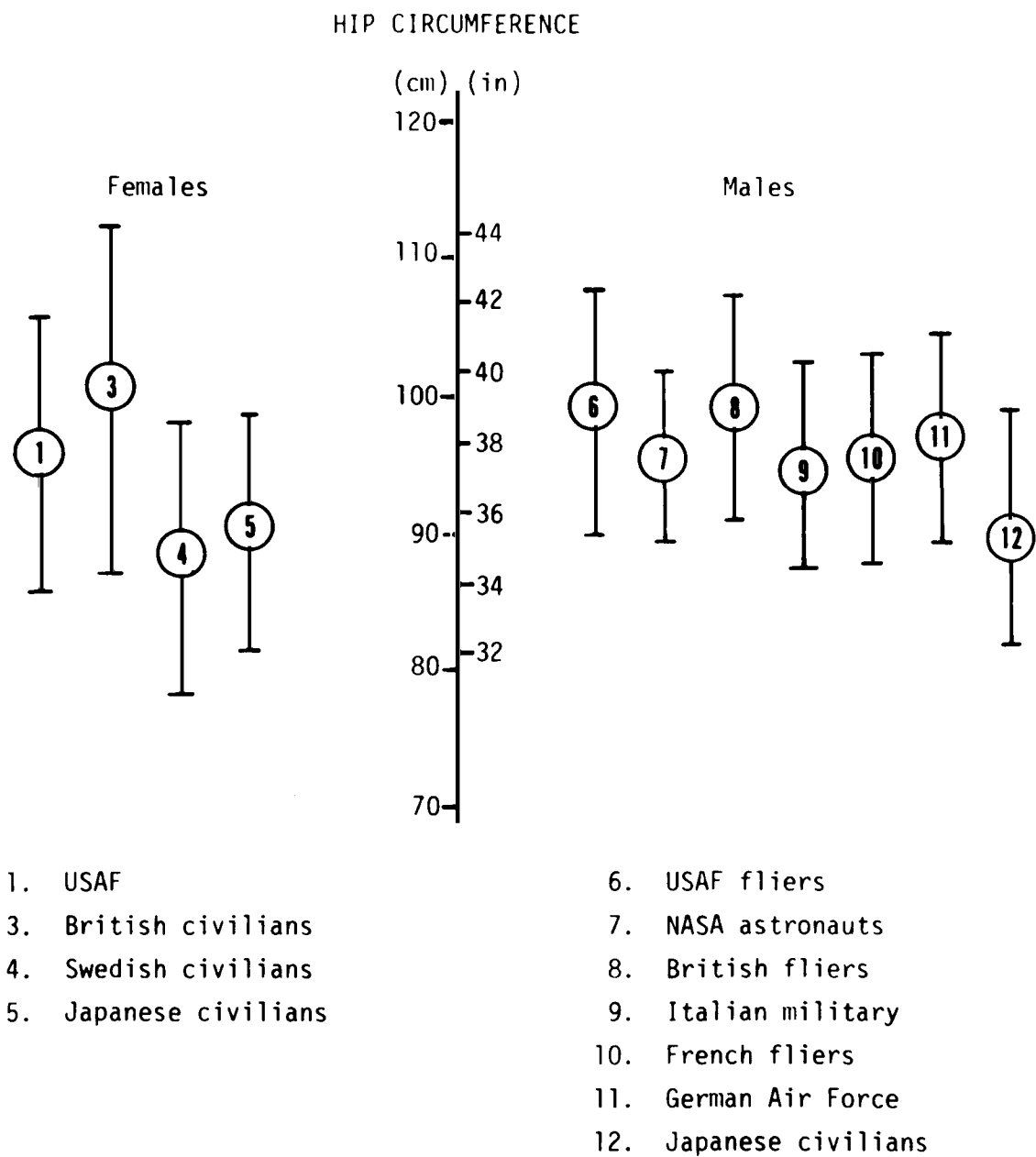
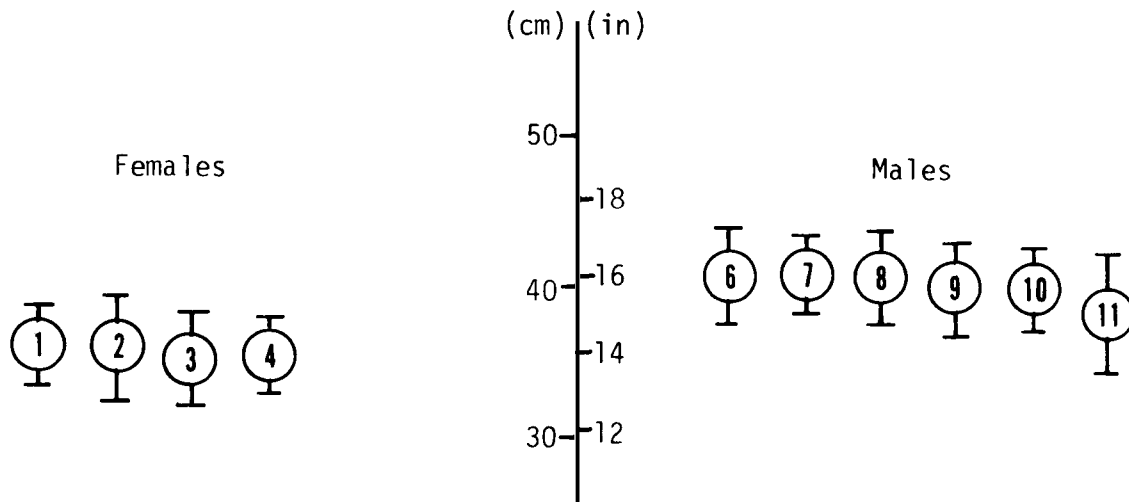


Figure 15. Range of variability (5th-95th percentile) in hip circumference for selected populations.

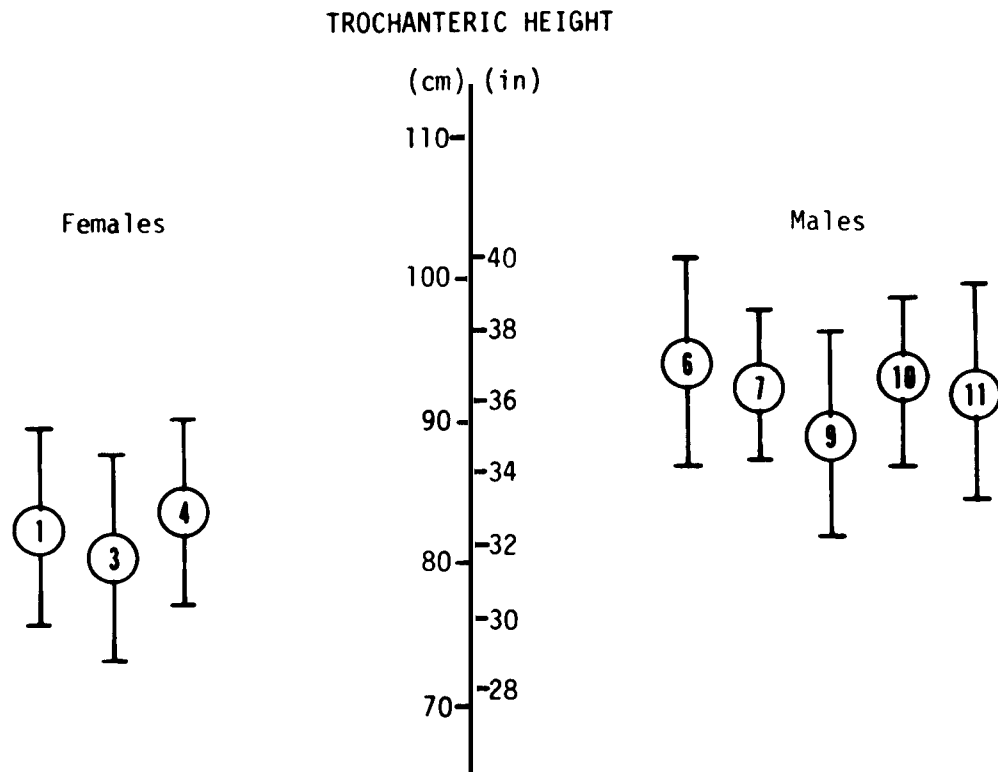
BIACROMIAL BREADTH



1. USAF
2. U. S. HEW civilians
3. British civilians
4. Swedish civilians

6. USAF fliers
7. NASA astronauts
8. British fliers
9. Italian military
10. French fliers
11. German Air Force

Figure 16. Range of variability (5th-95th percentile) in biacromial breadth for selected populations.



1. USAF

3. British civilians

4. Swedish civilians

6. USAF fliers

7. NASA astronauts

9. Italian military

10. French fliers

11. German Air Force

Figure 17. Range of variability (5th-95th percentile) in trochanteric height for selected populations.

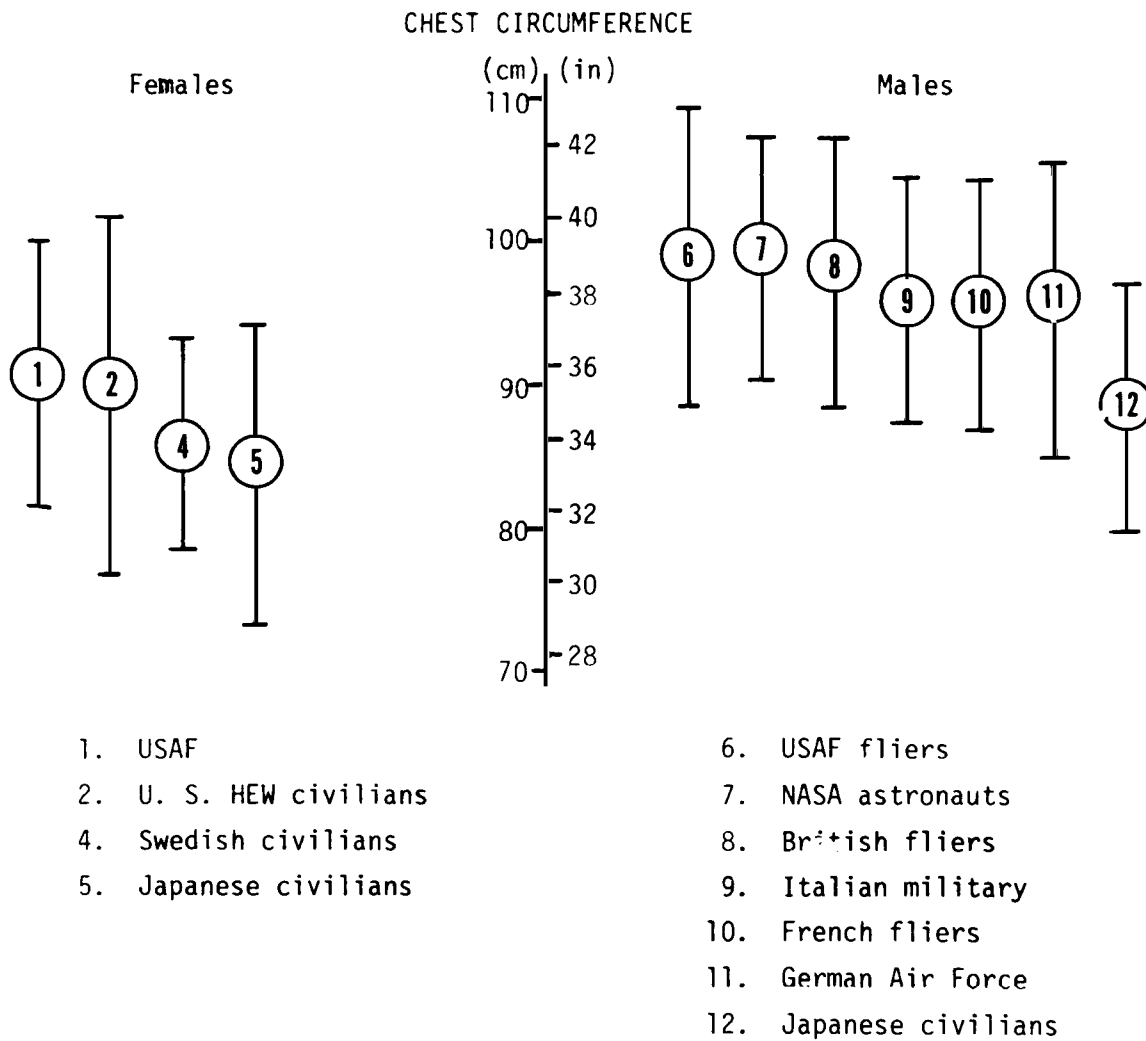
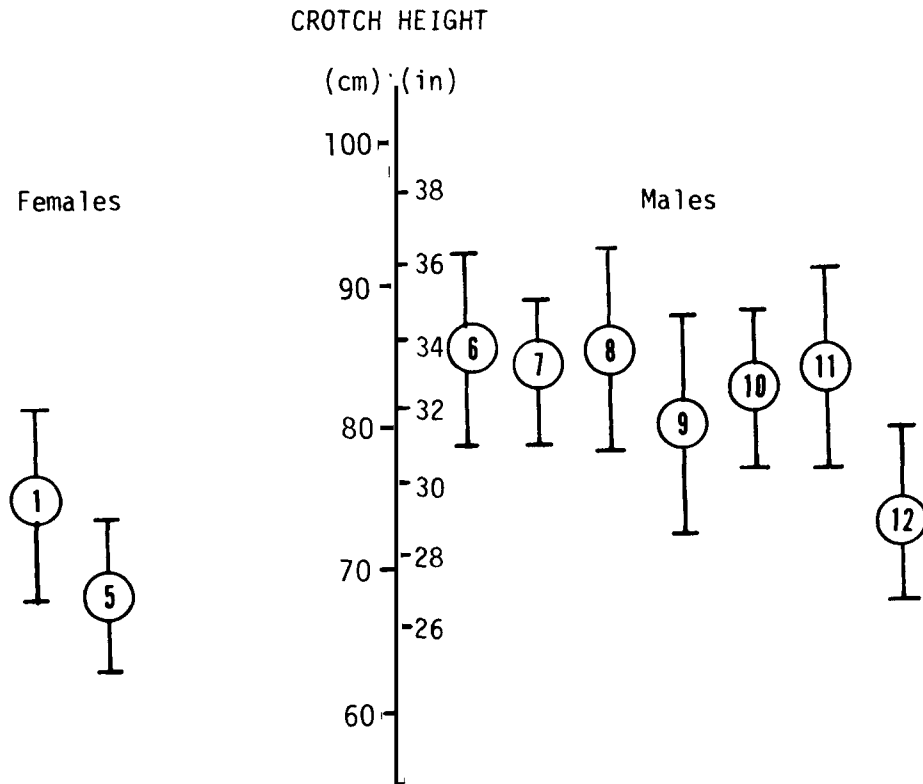


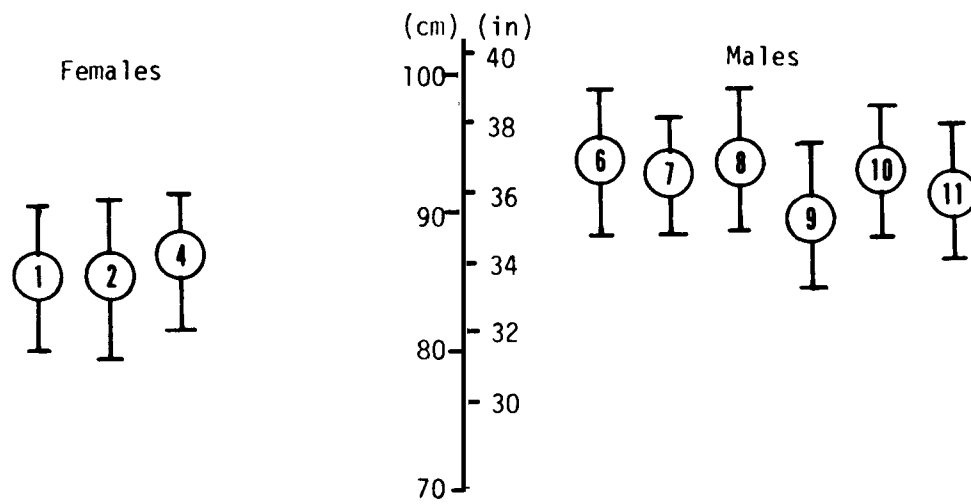
Figure 18. Range of variability (5th-95th percentile) in chest circumference for selected populations.



- | | |
|-----------------------|------------------------|
| 1. USAF | 6. USAF fliers |
| 5. Japanese civilians | 7. NASA astronauts |
| | 8. British fliers |
| | 9. Italian military |
| | 10. French fliers |
| | 11. German Air Force |
| | 12. Japanese civilians |

Figure 19. Range of variability (5th-95th percentile) in crotch height for selected populations.

SITTING HEIGHT



1. USAF
2. U. S. HEW civilians
4. Swedish civilians

6. USAF fliers
7. NASA astronauts
8. British fliers
9. Italian military
10. French military
11. German Air Force

Figure 20. Range of variability (5th-95th percentile) in sitting height for selected populations.

TABLE 17
SELECTED DIMENSIONS OF DIFFERENT VOCATIONAL-PROFESSIONAL GROUPS OF U.S. MALES¹

Variable	HES ²		'67 USAF ³		'75 POLICE ⁴		'65 AF TRAINEES ⁵		'55 BUS DRIVER ⁶		ASTRONAUTS ⁷	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	43.2	15.5	30.0	6.3	30.7	8.7	19.3	1.3	37.0	8.2	28-43 (range)	
Weight	75.9 (167.3)	12.6 (27.8)	78.7 (173.5)	9.7 (21.4)	83.3 (183.6)	12.0 (26.5)	68.7 (151.4)	10.2 (22.5)	75.9 (167.3)	12.7 (27.9)	74.5 (164.2)	6.9 (15.2)
Height	173.2 (68.2)	6.8 (2.7)	177.3 (69.8)	6.2 (2.4)	178.1 (70.1)	5.8 (2.3)	175.1 (68.9)	6.5 (2.6)	173.6 (68.3)	6.6 (2.6)	176.4 (69.4)	4.7 (1.9)
Biacromial breadth	39.6 (15.6)	2.0 (0.8)	40.7 (16.0)	1.9 (0.7)	-	-	39.7 (15.6)	1.9 (0.7)	40.0 (15.7)	1.6 (0.6)	40.5 (15.9)	1.7 (0.7)
Biceps circ.	30.7 (12.1)	3.3 (1.3)	30.8 (12.1)	2.3 (0.9)	-	-	27.3 (10.7)	2.6 (1.0)	-	-	-	-
Chest circ.	99.3 (39.1)	8.4 (3.3)	98.6 (38.8)	6.4 (2.5)	102.2 (40.2)	7.9 (3.1)	91.8 (36.1)	1.6 (0.6)	97.8 (38.5)	8.2 (3.2)	97.1 (38.2)	4.8 (1.9)
Waist circ.	88.6 (34.9)	11.4 (4.5)	87.6 (34.5)	7.4 (2.9)	90.6 (35.7)	9.4 (3.7)	78.0 (30.7)	7.5 (3.0)	-	-	82.1 (32.3)	4.5 (1.8)
Sitting height	90.4 (35.6)	3.8 (1.5)	93.2 (36.7)	3.2 (1.3)	92.2 (36.3)	3.4 (1.3)	91.1 (35.9)	3.5 (1.4)	92.0 (36.2)	3.3 (1.3)	92.4 (36.4)	2.6 (1.0)
Knee height	54.1 (21.3)	2.8 (1.1)	55.8 (22.0)	2.5 (1.0)	55.9 (22.0)	2.5 (1.0)	55.4 (21.8)	2.6 (1.0)	55.0 (21.7)	3.3 (1.3)	-	-
Popliteal height	43.9 (17.3)	2.8 (1.1)	43.7 (17.2)	2.3 (0.9)	-	-	44.8 (17.6)	2.4 (0.9)	-	-	-	-
Thigh clearance height	14.3 (5.6)	1.8 (0.7)	16.5 (6.5)	1.4 (0.6)	-	-	15.0 (5.9)	1.4 (0.6)	-	-	-	-
Buttock-knee length	59.2 (23.3)	3.0 (1.2)	60.4 (23.8)	2.7 (1.1)	61.5 (24.2)	2.7 (1.1)	60.3 (23.7)	2.9 (1.1)	60.3 (23.7)	3.3 (1.3)	60.4 (23.8)	1.5 (0.6)
Seat breadth	35.3 (13.9)	2.8 (1.1)	37.8 (14.9)	2.3 (0.9)	-	-	35.3 (13.9)	2.5 (1.0)	37.0 (14.6)	3.3 (1.3)	-	-
Elbow-elbow breadth	42.0 (16.5)	4.6 (1.8)	-	-	-	-	-	-	-	-	-	-
Elbow rest height	24.1 (9.5)	3.0 (1.2)	25.2 (9.9)	2.6 (1.0)	-	-	23.5 (9.3)	2.8 (1.1)	-	-	-	-
Buttock-popliteal length	49.3 (19.4)	3.0 (1.2)	50.4 (19.8)	2.6 (1.0)	-	-	49.4 (19.4)	2.7 (1.1)	-	-	-	-

¹ Data given in kilograms and centimeters with pounds and inches in parentheses; age in years.

² Stoudt et al. 1965.

³ Unpublished data.

⁴ Martin et al. 1975.

⁵ Long and Churchill 1968.

⁶ Damon and McFarland 1955.

⁷ Roth 1968.

TABLE 18
SELECTED DIMENSIONS OF DIFFERENT VOCATIONAL-PROFESSIONAL GROUPS OF U.S. FEMALES¹

<u>Variable</u>	<u>HES</u> ²		<u>STEWARDESSES</u> ³		^{'68} <u>WAF</u> ⁴	
	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>
Age	42.6	15.4	22.1	1.6	23.4	6.4
Weight	64.7 (142.6)	13.8 (30.4)	52.8 (116.4)	4.3 (9.5)	57.7 (127.2)	7.5 (16.5)
Height	160.3 (63.1)	6.6 (2.6)	166.2 (65.4)	4.8 (1.9)	162.1 (63.8)	6.0 (2.4)
Biacromial breadth	35.3 (13.9)	2.0 (0.8)	35.0 (13.8)	1.5 (0.6)	35.8 (14.1)	1.6 (0.6)
Biceps circumference	28.7 (11.3)	4.3 (1.7)	23.3 (9.2)	1.3 (0.5)	25.6 (10.1)	2.3 (0.9)
Chest circumference	88.1 (34.7)	8.1 (3.2)	85.6 (33.7)	4.0 (1.6)	89.7 (35.3)	5.7 (2.2)
Waist circumference	76.7 (30.2)	11.9 (4.7)	62.2 (24.5)	2.8 (1.1)	67.2 (26.5)	5.5 (2.2)
Sitting ht. (erect)	84.6 (33.3)	3.5 (1.4)	87.0 (34.3)	2.8 (1.1)	85.6 (33.7)	3.2 (1.3)
Knee ht. (sitting)	49.8 (19.6)	2.8 (1.1)	51.9 (20.4)	2.2 (0.9)	- -	- -
Popliteal height	39.6 (15.6)	2.5 (1.0)	43.5 (17.1)	2.1 (0.8)	41.0 (16.1)	1.9 (0.7)
Thigh clearance height	13.7 (5.4)	1.8 (0.7)	- -	- -	12.4 (4.9)	1.2 (0.5)
Buttock-knee height	56.9 (22.4)	3.0 (1.2)	57.5 (22.6)	2.3 (0.9)	57.4 (22.6)	2.6 (1.0)
Buttock-popliteal length	48.0 (18.9)	3.0 (1.2)	48.2 (19.0)	2.5 (1.0)	47.7 (18.8)	2.8 (1.1)
Seat breadth (hip)	36.6 (14.4)	3.8 (1.5)	36.8 (14.5)	1.8 (0.7)	33.7 (13.3)	2.1 (0.8)
Elbow-elbow breadth	38.9 (15.3)	5.3 (2.1)	33.0 (13.0)	2.3 (0.9)	- -	- -
Elbow rest height	23.1 (9.1)	2.8 (1.1)	24.1 (9.5)	2.5 (1.0)	22.7 (8.9)	2.5 (1.0)

¹ Data given in kilograms and centimeters with pounds and inches in parentheses.

² Stoudt et al. 1965.

³ Snow et al. 1975.

⁴ Clauser et al. 1972.

reach peak height velocity earlier in adolescence and each decade sees them reach puberty four to five months earlier than the last (Tanner, 1962). Growth tends to be completed at an earlier age today than it was at the turn of the century.*

This type of human variation, occurring from generation to generation over time is usually referred to as secular change by anthropologists. Whether the effect results from better nutrition, improved health care or some biological selection process has not been determined and is, in any case, of no practical significance to design engineers who need to know how much rather than why. The lengthy lead time required for the design and production of spacecraft, aircraft and other sophisticated devices is such that the persons who will eventually use them are, for the most part, only children when the design specifications are fixed. It is of more than casual interest, therefore, to anticipate the dimensions of physical size and body proportion which will exist at a given point in the future.

Records for height and weight for many of the nations of Western Europe go back as far as 200 years ago. Most of the early data was collected on military recruits and is therefore for young adult men only. Udjus (1964) has reviewed stature changes in Norwegian recruits over the past 200 years and Harbeck (1960) has accumulated stature data for a number of European countries and Japan extending back to the first half of the 19th century. The data from both sources are presented in Figure 21 which illustrates that the trend over time, although somewhat variable, has been for young adult men to become taller. The rate of increase in stature since 1900 in the European nations surveyed has ranged from .87 cm (.34 inches) to 1.29 cm (.51 inches) per decade in France and Switzerland respectively.

The demonstration of secular change in stature in the U.S. population, particularly for men, must also rely on military data. Height and weight data were collected on Union army personnel during the Civil War (Baxter, 1875; Gould, 1869). Since that time, military surveys of increasing complexity and accuracy have been conducted with increasing frequency. The mean stature and weight of U.S. soldiers at four points in time are listed in Table 19. The data indicate that there was little change in stature in the young American male between 1863 and 1919. In fact, data for recruits between 1906 and 1915 indicate that men were slightly shorter at that time than they were in the 1860's. Davenport (1921) suggests that this apparent reversal in the trend to increase in stature over time resulted from the influx of shorter Southern European immigrants into the U.S. population during the intervening period. Whether Davenport's suggestion is valid or not, it serves to point out the dangers in comparing temporally and technically disjointed data. Measurement techniques change, measurement personnel are different, military selection pressures vary and transient environmental factors affecting growth and development may be involved in influencing the data obtained at any given time. All these variables notwithstanding, the mean stature values for U.S. males since 1860 have shown a substantial increase, particu-

*A recent publication of the National Center for Health Statistics (Hamill et al. 1976) concludes that the secular growth trend appears to have stopped in American children born after 1955-56.

TABLE 19
MEAN STATURE, WEIGHT AND AGE OF U.S. ARMY SOLDIERS*

	<u>Stature</u>	<u>Weight</u>	<u>Age</u>
Northern Civil War Recruits (1863)	171.45 (67.5)	61.68 (136.0)	--
Northern Civil War Veterans (1865)	171.96 (67.7)	63.04 (139.0)	--
World War I Veterans (1919)	171.45 (67.5)	64.17 (141.5)	--
World War II Veterans (1942)	173.74 (68.4)	70.20 (154.8)	22.2
U.S. Army (1966)	174.50 (68.7)	72.15 (159.1)	24.3

*Data given in centimeters and kilograms with inches and pounds in parentheses.

TABLE 20
AVERAGE VALUES FOR SELECTED BODY MEASUREMENTS OF U.S.
FEMALES BORN 1903 to 1933 ¹

Year of birth	1903 - 4 ²	1927	1933 ³
Age	36 yrs.	41 yrs.	40 yrs.
Weight	60.5 (133.5)	63.3 (139.5)	63.7 (140.4)
Height	160.5 (63.2)	163.1 (64.2)	163.6 (64.4)
Hip Circumference	98.6 (38.8)	98.6 (38.8)	100.1 (39.4)
Waist Circumference	74.2 (29.2)	74.7 (29.4)	76.4 (30.1)
Mid-Thigh Circumference	49.8 (19.6)	50.6 (19.9)	- -
Knee Circumference	35.6 (14.0)	36.6 (14.4)	37.1 (14.6)
Calf Circumference	34.3 (13.5)	34.5 (13.6)	35.1 (13.8)
Ankle Circumference	21.1 (8.3)	21.3 (8.4)	21.6 (8.5)
Waist Height	102.0 (40.2)	- -	102.9 (40.5)
Crotch Height	72.4 (28.5)	- -	76.5 (30.1)
Foot Length	- -	24.1 (9.5)	24.6 (9.7)

¹Data given in centimeters and kilograms with inches and pounds in parentheses.

²Data from O'Brien (1941).

³Data from Cullipher and Delate (1974).

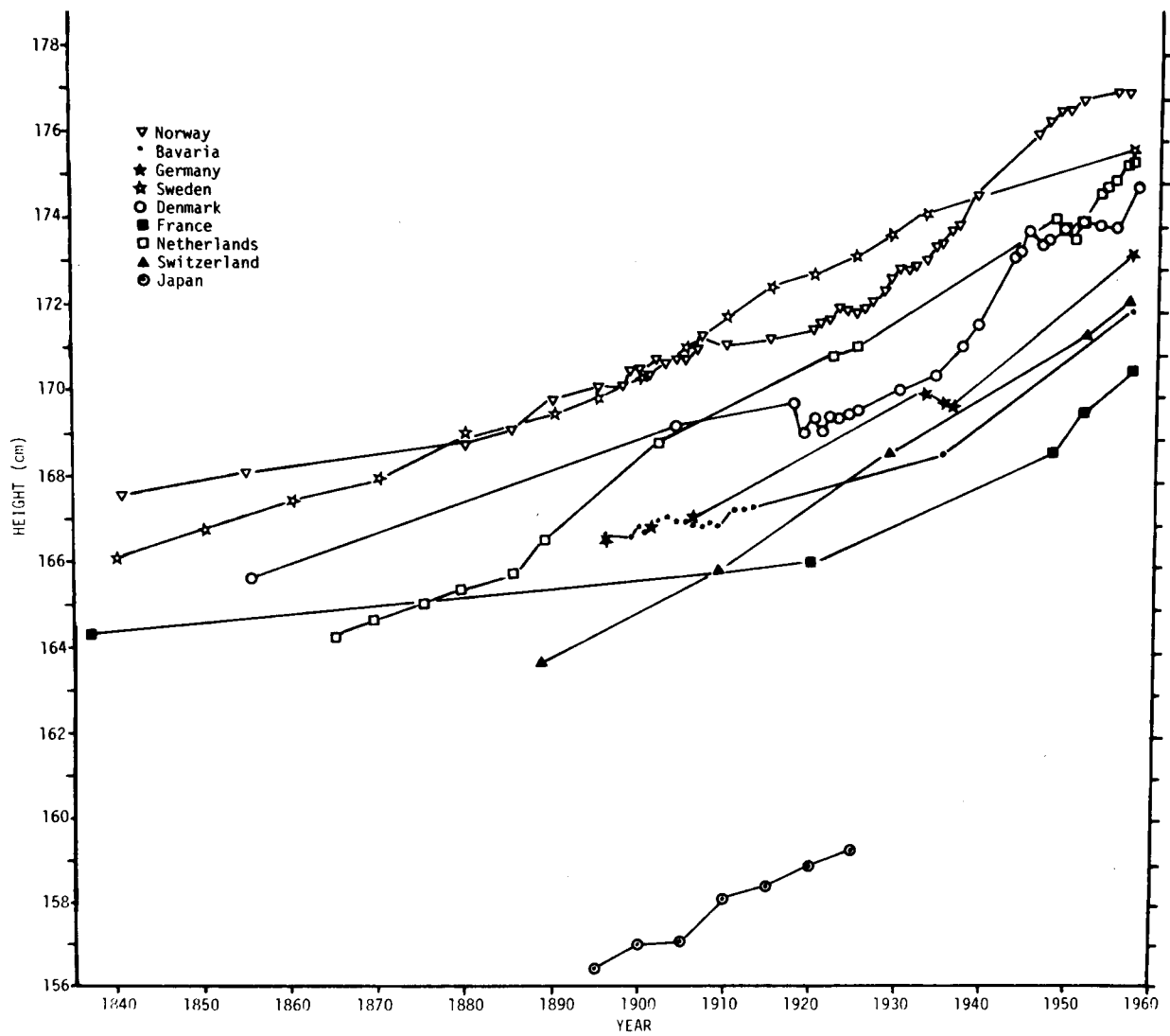


Figure 21. Secular increase in stature of young European and Japanese males: 1840-1960. After: Udjus (1964), and Harbeck (1960).

larly since the 1900's, and it is safe to assume that the trend is a real rather than artifactual one. Stature data for major U.S. surveys (male) are plotted in Figure 22. The rate of increase in stature since 1920 is nearly 1.0 cm (.4 in.) per decade, a finding which agrees fairly well with the European data.

Because most large surveys have historically been associated with the military, and because women were never drafted and rarely recruited until World War II, long term secular trends for women are more difficult to establish. Several dimensions obtained on fairly large and reasonably comparable samples of adult U.S. women are listed in Table 20. The survey covered a birth year period of 42 years (1903-1945) corresponding with the period during which U.S. men showed the most rapid increase in stature. The general trend is for today's women to be slightly larger for the dimensions listed, when women of the same age are compared.

Whatever the trend, the secular changes in body size are shown by the military surveys to be significant in systems and equipment design. As Kennedy (1972) noted, the USAF flying personnel measured in 1967 differed in a number of important respects from those measured in 1950, and, as a result, the "...Seat Reference Point to the cockpit eye line, as specified in MIL-STD-1333 (Cockpit Geometry, Department of Defense, 1969a), and MIL-STD-33574,5, and 6 (Basic Cockpit Dimensions, Department of Defense, 1969 b, c, d) was increased by 0.5 inches, from 31.0 inches to 31.5 inches. Such dimensions as sitting height, buttock-knee length, and knee height, sitting, to name just a few, are extremely critical in determining the basic vertical and fore-and-aft ejection clearance dimensions in the aircraft cockpit."

In summary, it is essential to recognize that body size, at least of military populations, is in a dynamic state, and that body size changes must be documented continuously if systems and equipment requiring long lead times are to be designed effectively.

Projection of Future Body Size

The chief application of data on secular changes is, of course, in predicting the size of a future design population. As noted above, the long lead time required for designing and building complex machines necessitates predicting size change in the human operator well in advance. Recognizing the importance of secular size variation and the consequences of ignoring such change, NASA recently asked the Aerospace Medical Research Laboratory (AMRL) at Wright Patterson Air Force Base to conduct a study to make predictions of body size through 1985.

The initial assumption of the AMRL study was that it could best be done by predicting the size of USAF pilots who will be in their mid-thirties in 1985 and accepting these predictions as being suitable for astronauts as well. Data from a half dozen past anthropometric surveys of flying personnel were analyzed to establish a trend for the stature and weight predictions while values for close to 200 additional dimensions were estimated by combining the height/weight data with appropriate regression equations. (For more complete data on projected anthropometry of 1985 flying personnel, see Chapter III, Appendix B).

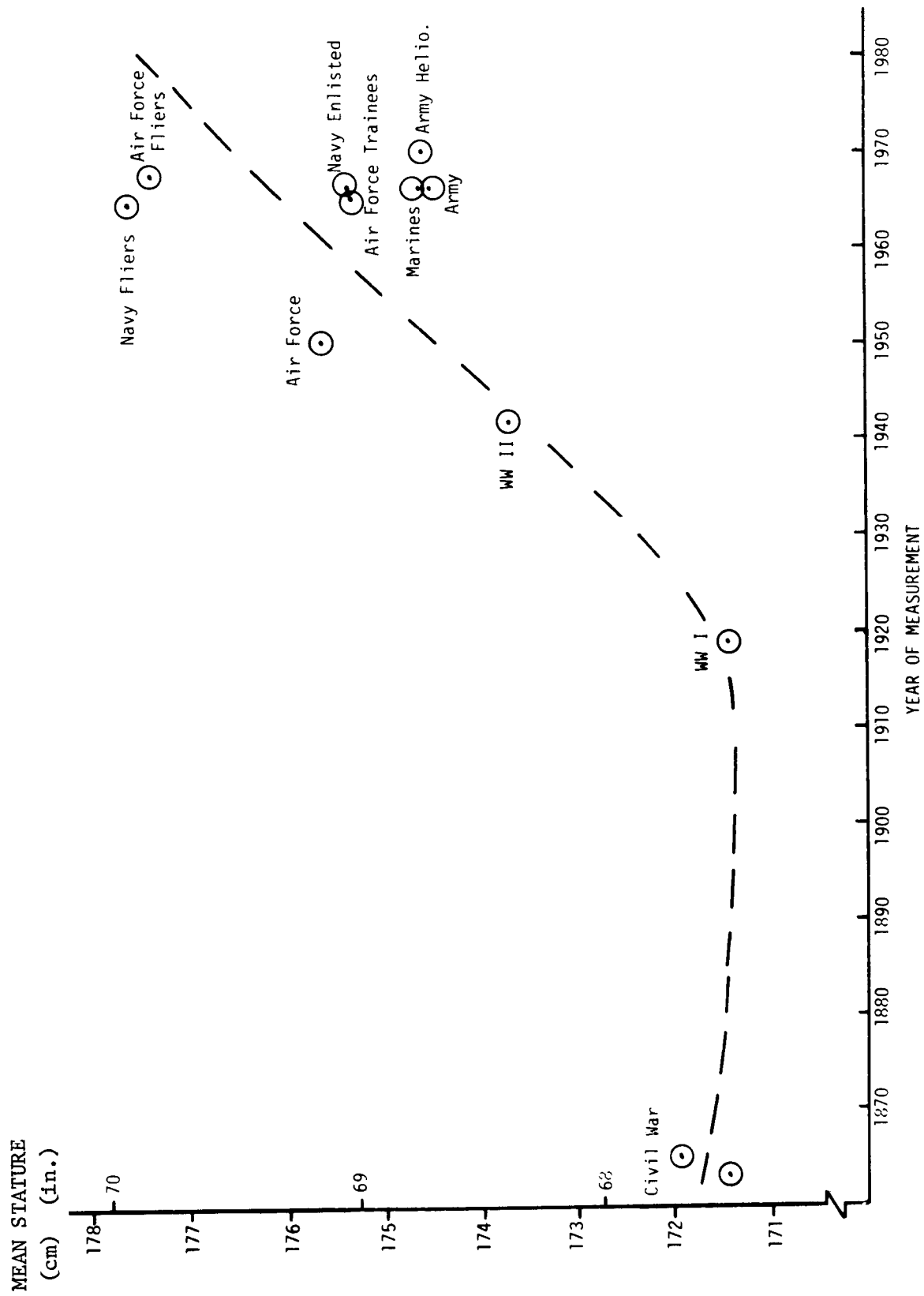


Figure 22. Secular trend in stature for young U.S. males: 1870-1980.

While analysis of past trends is a reasonable way for determining the dimensions of future astronauts, the process is both time-consuming and fraught with all the pitfalls that usually attend the manipulation of complex data. It could be pointed out, for example, that the rate of human "growth" since the turn of the century is not expected to continue indefinitely and, as noted above, there is some evidence that the trend toward earlier maturity and increased adult size is leveling off (Hamill et al. 1976).

One simple strategy, however, is available for predicting stature of air and space crews of the near future. In estimating astronaut statures for a decade hence, it can be assumed that the concern is with men who will be at least in their early and mid-thirties at that time, if not older. In a sense, it is not necessary to estimate these men's statures; one can go out and measure them. Men with appropriate birth years are already participating in USAF pilot and navigator training and other advanced military and space programs and can be measured at any given moment in time. In 1973 such a survey was carried out at two training bases. Statures and other data were quickly obtained for about 500 men, 23 to 27 years old, men, that is, with full growth who would be from 30 to 34 in 1980 and from 35 to 39 in 1985.

Summary

Invariably, a superior product will result if sizing factors related to the human operator are injected early in the design process. At present, anthropometric data are by far the best source of sizing information available to the designer. Once the relevant sizing factors and the target design population have been identified, the designer must ascertain whether reliable and recent anthropometric data are available for that population (See Volume II). If such data are available, the designer, armed with some understanding of statistical forms, must apply them knowledgeably to his problem. If such data are not available and an immediate survey of the population cannot be performed, the designer must adjust available data according to the types of size variability described in this chapter. While the various categories of variation dealt with here have been treated as though they were of equal importance, it must, of course, be remembered that each design problem is unique. Not all sources of human body size variability are equally relevant to every design task but none of them should be dismissed without careful consideration.

Although we have attempted to cover major areas of human size variability relevant to NASA designers, it is not possible in one chapter to cover exhaustively all sources of such variation. Thus it will be necessary from time to time for the design engineer to be innovative in the application of body size data. On occasion the designer will have to interpolate

and extrapolate data provided here as well as in other chapters and volumes of this data book. It has been the aim of this chapter to provide the design engineer with a sufficient background to stimulate greater awareness of the sources of body size variability and to guide his approach to the solutions of design problems. In the design of space flight hardware and equipment, consideration of human factors is not just important--it may be critical.

REFERENCES

- Agostoni, Emilio, and Jere Mead 1964. "Statics of the Respiratory System," Handbook of Physiology, American Physiological Soc. (Washington, D.C.), Vol. 1, sec. 3, pp. 387-409.
- Alexander, Milton, and Charles E. Clauser 1965. The Anthropology of Common Working Positions. AMRL-TR-65-73, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.
- Alexander, Milton, John W. Garrett, and Michael P. Flannery 1969. Anthropometric Dimensions of Air Force Pressure-Suited Personnel for Workspace and Design Criteria. Final Report, AMRL-TR-69-6, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.
- Alexander, Milton, Lloyd L. Laubach, and John T. McConville 1976. Effect of Encumbering Clothing, Personal Protective Equipment and Restraints on Body Size and Arm Reach Capability of USAF Airmen. Paper delivered at the Annual Meeting of the Aerospace Medical Association, May 1, 1976, Bal Harbour, Fla.
- Baxter, J. H. 1875. Statistics - Medical and Anthropological of the Provost-Marshall-General's Bureau Derived From Records of the Examination for Military Service in the Armies of the United States During the Late War of Rebellion of Over a Million Recruits, Drafted Men, Substitutes, and Enrolled Men. Government Printing Office, Washington, D.C.
- Bolton, C. B., M. Kenward, R. E. Simpson, and G. M. Turner 1973. An Anthropometric Survey of 2000 Royal Air Force Aircrew, 1970/71. TR-73083, Royal Aircraft Establishment, Ministry of Defense, Farnborough, Hants, England. (Also, AGARDograph No. 181, Dec. 1974.)
- Brozek, J., F. Grande, H. L. Taylor, J. T. Anderson, et al. 1957. "Changes in Body Weight and Body Dimensions in Men Performing Work on a Low Calorie Carbohydrate Diet," J. Appl. Physiol., 10(3):412-420.
- Clauser, Charles E., and H. T. E. Hertzberg 1964. "Size and Motion," Bioastronautics Data Book, Paul Webb, ed., NASA SP-3006, pp. 241-271.
- Clauser, Charles E., et al. 1972. Anthropometry of Air Force Women. AMRL-TR-70-5, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.
- Damon, Albert 1964. "Notes on Anthropometric Technique: I. Stature Against a Wall and Standing Free," Amer. J. Phys. Anthropol., 22:73-78.

- Damon, A., and R. A. McFarland 1955. "The Physique of Bus and Truck Drivers: With a Review of Occupational Anthropometry," Amer. J. Phys. Anthrop., 13(4):711-742.
- Damon, Albert, Howard W. Stoudt, and Ross A. McFarland 1966. The Human Body in Equipment Design, Harvard University Press (Cambridge, Mass.).
- Davenport, Charles B. 1921. Statistics: Army Anthropology. Vol. 15, Part One, Medical Dept. U.S. Army, in the World War, U.S. Government Printing Office, Washington, D.C.
- DePuky, P. 1935. "Physiological Oscillation of the Length of the Body," Acta. Orthop. Scand., 6:338-347.
- Dobzhansky, Theodosius 1963. Mankind Evolving, Yale University Press (New Haven, Conn.).
- Emanuel, Irvin, and James T. Barter 1957. Linear Distance Changes over Body Joints. WADC-TR-56-364, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.
- Fry, Edward I., and Edmund Churchill 1956. Bodily Dimensions of the Older Pilot. AMRL-TR-56-459, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.
- Garrow, John Stuart 1974. Energy Balance and Obesity in Man, American Elsevier Pub. Co. (New York).
- Gould, Benjamin A. 1869. Investigations in the Military and Anthropological Conditions Statistics of American Soldiers, Hurd and Houghton (Cambridge).
- Gsell, O. R. 1967. "Longitudinal Gerontological Research Over 10 Years," Geront. Clin., 9:67-80.
- Hamill, P. V. V., T. A. Drizo, C. L. Johnson, R. B. Reed, and A. F. Roche 1976. NCHS Growth Charts, 1976. Monthly Vital Statistics Report, Health Examination Survey Data, HRA 76-1120, Vol. 25, No. 3, supplement, June 22, 1976. National Center for Health Statistics, HEW, Public Health Resources Administration, Rockville, Md.
- Hertzberg, H. T. E. 1972. "Engineering Anthropology," Human Engineering Guide to Equipment Design, revised edition, Harold P. Van Cott and Robert G. Kinkade, eds., American Institute for Research (Washington, D.C.), pp. 467-484.
- Hooton, E. A., and C. W. Dupertuis 1951. "Age Changes and Selective Survival in Irish Males." Studies in Physical Anthropology No. 2, American Association of Physical Anthropologists and the Wenner-Gren Foundation for Anthropological Research, Edwards Bros., Inc. (Ann Arbor, Mich.).

- Ivanovsky, Alexis 1923. "Physical Modifications of the Population of Russia Under Famine," Amer. J. Phys. Anthropol., VI(4):331-353.
- Kennedy, Kenneth W. 1973. "Anthropometry and Kinematics in Crew Station Design," Crew System Design, Kenneth D. Cross and James J. McGrath, eds., Anacapa Sciences Inc. (N000 14-72-C-0105) (Santa Barbara), pp. 67-79.
- Khosla, T., and W. Z. Billewicz 1967. "Measurement of Change of Body Weight," Brit. J. Nutrit., 18:227-239.
- Laubach, Lloyd L., and John T. McConville 1967. "Notes on Anthropometric Technique: Anthropometric Measurements - Right and Left Sides," Amer. J. Phys. Anthropol., 26(3):367-370.
- Martin, J. I., R. Sabeh, L. L. Driver, T. D. Lowe, R. W. Hintze, and P. A. C. Peters 1975. Anthropometry of Law Enforcement Officers. TR-442, Naval Electronics Laboratory Center, San Diego, Cal. 92152.
- Munipov, V. M., V. P. Zinchenko, B. F. Lomov, P. Y. Shlayen, et al. 1973. Ergonomics: Principles and Recommendations, No. 1 (1970). All Union Scientific Research Institute for Aesthetic Styling in Engineering (Moscow), NASA-TT-F-716.
- O'Brien, Ruth, and William C. Shelton 1941. Women's Measurements for Garment and Pattern Construction. U.S. Dept. of Agriculture Miscellaneous Publication No. 454, U.S. Government Printing Office, Washington, D.C.
- Peters, Von T. 1969. "Anthropometrische und Physiologische Grundlagen zur Gestaltung von Büroarbeitssitzen," Ergonomics, 12(2):162-170.
- Roth, E. M. 1968. "Anthropometry and temporo-spatial environment," Compendium of Human Responses to the Aerospace Environment, Vol. III, sec. 16, NASA CR-1205.
- Sims, E. A., R. F. Goldman, C. M. Gluck, E. S. Horton, P. C. Kelleher, and J. R. Elkinton 1968. "Experimental Obesity in Man," Trans. Assoc. Amer. Physicians, LXXXI:153-170.
- Snow, C. C., H. M. Reynolds, and M. A. Allgood 1975. Anthropometry of Airline Stewardesses. Report No. FAA-AM-75-2, Federal Aviation Administration Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Okla. 73125.
- Stoudt, Howard W., Albert Damon, Ross A. McFarland, and Jean Roberts 1965. Weight, Height, and Selected Body Dimensions of Adults, United States 1960-1962. Public Health Service Publication No. 1000 - Series 11, No. 8, Dept. of Health, Education, and Welfare, National Center for Health Statistics, Washington, D.C.
- Tanner, James M. 1962. Growth at Adolescence, 2nd ed., Blackwell Scientific Publications (Oxford, England).

- Udjus, Ludvig G. 1964. Anthropometrical Changes in Norwegian Men in the Twentieth Century. Norwegian Monographs on Medical Science, The Anatomical Institute Anthropological Dept., University of Oslo (Norway) and the Armed Forces Medical Services, Universitets forlaget.
- Von Harbeck, Major Rudolf 1960. "Die Korpergrossen 20 Jahriger Manner," Wehrdienst und Gesundheit, Abhandlungen aus Wehrmedizin, Wehrpharmazia, un Wehrveterinaerwesen, 1:308-345.
- Yanagisawa, Sumiko 1974. About Japanese Physique and Body Girth, Dept. of Home Economics. Ochanomizu Institute, Women's University, Bunkyo-Ku, Tokyo.
- Yokohori, E. 1972. Anthropometry of JASDF Personnel and Its Application for Human Engineering. Aeromedical Laboratory, Japanese Air Self Defense Force, Tachikawa Air Base, Tokyo.

BIBLIOGRAPHY

- Anonymous 1973. Etude Anthropometrique des Personnels Militaires des Armees (in French), Anthropologue Appliquees, 45 rue des Saints-Peres, Paris 6e, France.
- Churchill, Edmund, John T. McConville, Lloyd L. Laubach, and Robert M. White 1971. Anthropometry of U.S. Army Aviators - 1970. TR-72-52-CE, U.S. Army Natick Laboratories, Natick, Mass.
- Grunhofer, H. J., and G. Kroh, eds., 1968. A Review of Anthropometric Data of German Air Force and United States Air Force Flying Personnel 1967-1968. AGARDograph No. 205, Advisory Group for Aerospace Research and Development, North Atlantic Treaty Organization, Neuilly sur Seine, France.
- Hertzberg, H. T. E., Edmund Churchill, C. W. Dupertuis, Robert M. White, and Albert Damon 1963. Anthropometric Survey of Turkey, Greece, and Italy, NATO AGARDograph 73, The MacMillan Co. (New York).
- Ingelmark, B. E., and Thord Lewin 1968. "Anthropometrical Studies on Swedish Women," Acta Morphologica, 3(2):145-178.
- Karpinos, Bernard D. 1958. "Height and Weight of Selective Service Registrants Processed for Military Service During World War II," Human Biology, 30(4):292-321.
- Karpinos, Bernard D. 1961. "Current Height and Weight of Youths of Military Age," Human Biology, 33(4):335-354.
- Kemsley, W. F. F. 1957. Women's Measurements and Sizes, Cheltenham Press Ltd. (Cheltenham, England).
- Simons, John C. 1964. "An Introduction to Surface-Free Behavior," Ergonomics, 7:22-36.

ADDITIONAL DATA SOURCES

The following documents are not readily available because of limited distribution (unpublished or preliminary data). However, copies/information may be obtained by contacting the author/source.

Cullipher, James H., and Edward J. Delate 1974. A New Pantyhose Sizing System Based on Five Measurements of the Woman's Lower Body. Textile Fibers Dept., E. I. DuPont de Nemours and Co., Wilmington, Del.

Long, Lynda, and Edmund Churchill 1968. Anthropometry of USAF Basic Trainees - Contrasts of Several Subgroups. Paper prepared for the 1968 meeting of the American Association of Physical Anthropologists. Unpublished data, Webb Associates.

NASA Astronaut Anthropometric Data - 1976. National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Tex.

NASA Habitability Handbook 1971. Vol. I., Mobility and Restraint, MSC 03909, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Tex.

U.S. Air Force Anthropometric Survey - 1965. Anthropology Branch, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

U.S. Air Force Anthropometric Survey - 1967. Anthropology Branch, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Unpublished data.

White, Robert M., and Edmund Churchill 1966. The Body Size of Soldiers: U.S. Army Anthropometry - 1966. TR-72-51-CE, U.S. Army Natick Laboratories, Natick, Mass.