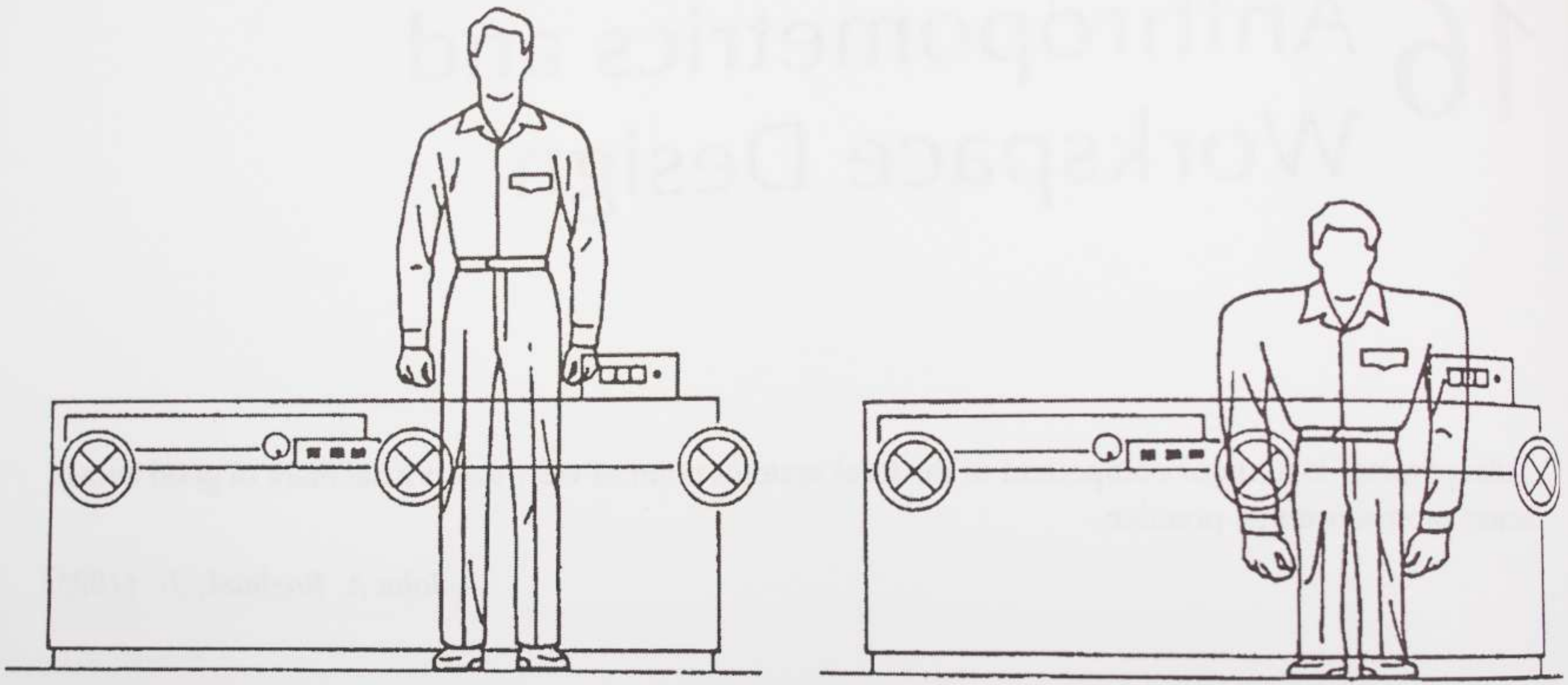
Anthropometry and Biomechanical for Ergonomic Design

Part 1

Robert W. Proctor and Trisha Van Zandt (2008). Human Factors in Simple and Complex Systems. 2nd Edition. Taylor & Francis.
Freivalds, A., & Niebel, B. (2013). *Niebel's Methods, Standards, & Work Design*. McGraw-Hill Higher Education.

Introduction

- The measurement of human physical characteristics is called *anthropometrics*.
- Engineering anthropometry refers to the design of equipment, tasks, and workspaces so that they are compatible with the physical characteristics of the people who will be using them.
- Ex the designing the envelope around the 5th percentile for reach distance insures that 95% of potential users can reach the controls within the envelope.
- *Biomechanics* is the field of study concerned with how the body moves.
- Human factor specialists routinely apply biomechanical data to equipment design so that equipment and tasks will accommodate the biomechanics of the user population.



(a) Most people look like this, but . . .

(b) Some designers think that people are shaped like this

Engineering Anthropometry

- *Anthropometrics* refers to measurements of the dimension of the human body.
- It is important that the sample be randomly selected from the target population.
- Our goal is to get as accurate a picture as possible of the distribution of the measurements of interest.
- All such measures are approximately normally distributed.
- The most commonly used anthropometric ranks are the 5^{th}, 50^{th} , and 95^{th} percentiles.

ANTHROPOMETRY AND DESIGN

- The primary guideline is to design the equipment to accommodate most individuals with regard to structural size of the human body.

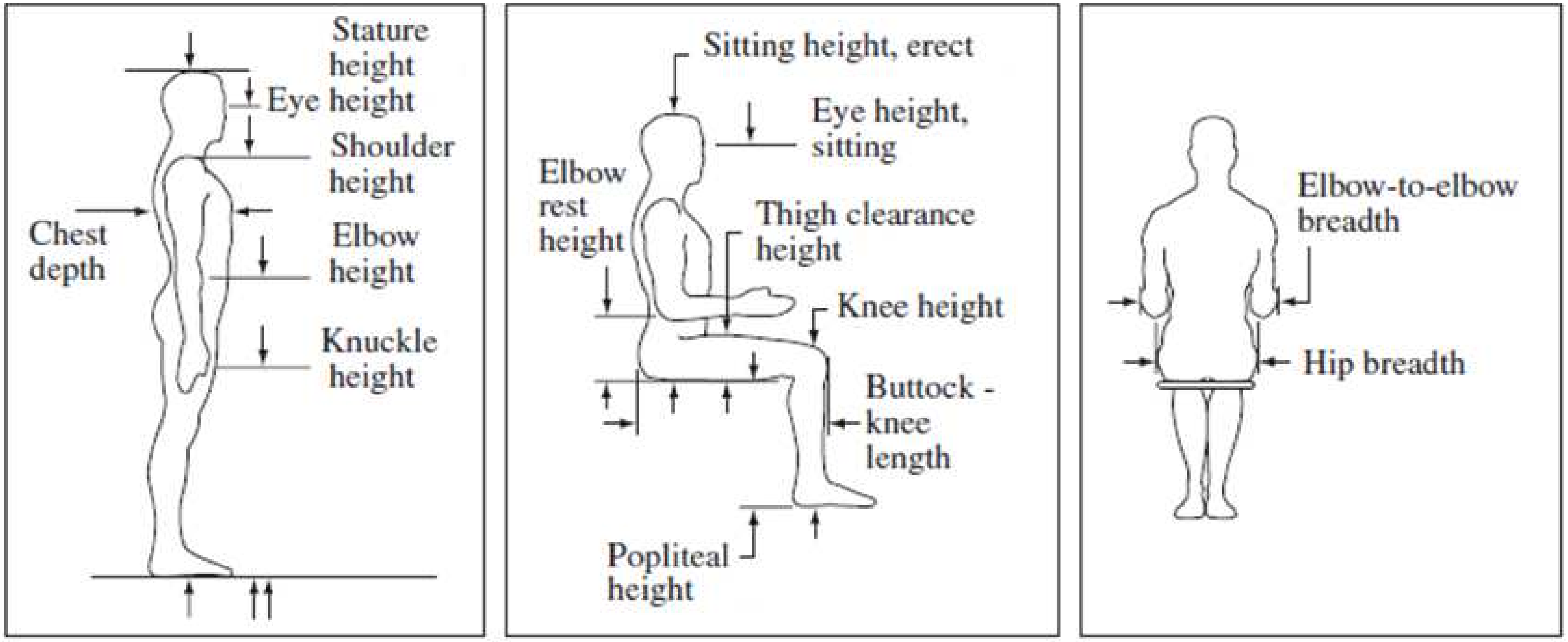


TABLE 10.1
Anthropometric Estimates for British Adults Aged 19 to 65 Years (all dimensions in millimetres, except for body weight, given in kilograms)

	Dimension	Men 5th %ile	Men 50th %ile	Men 95th %ile	Men SD	Women 5th %ile	Women 50th %ile	Women 95th %ile	Women SD
1.	Stature	1625	1740	1855	70	1505	1610	1710	62*
2.	Eye height	1515	1630	1745	69	1405	1505	1610	61
3.	Shoulder height	1315	1425	1535	66	1215	1310	1405	58
4.	Elbow height	1005	1090	1180	52	930	1005	1085	46
5.	Hip height	840	920	1000	50	740	810	885	43
6.	Knuckle height	690	755	825	41	660	720	780	36
7.	Fingertip height	590	655	720	38	560	625	685	38
8.	Sitting height	850	910	965	36	795	850	910	35
9.	Sitting eye height	735	790	845	35	685	740	795	33
10.	Sitting shoulder height	540	595	645	32	505	555	610	31
11.	Sitting elbow height	195	245	295	31	185	235	280	29
12.	Thigh thickness	135	160	185	15	125	155	180	17
13.	Buttock–knee length	540	595	645	31	520	570	620	30
14.	Buttock–popliteal length	440	495	550	32	435	480	530	30
15.	Knee height	490	545	595	32	455	500	540	27
16.	Popliteal height	395	440	490	29	355	400	445	27
17.	Shoulder breadth (bideltoid)	420	465	510	28	355	395	435	24
18.	Shoulder breadth (biacromial)	365	400	430	20	325	355	385	18
19.	Hip breadth	310	360	405	29	310	370	435	38
20.	Chest (bust) depth	215	250	285	22	210	250	295	27
21.	Abdominal depth	220	270	325	32	205	255	305	30
22.	Shoulder–elbow length	330	365	395	20	300	330	360	17
23.	Elbow–fingertip length	440	475	510	21	400	430	460	19
24.	Upper limb length	720	780	840	36	655	705	760	32
25.	Shoulder–grip length	610	665	715	32	555	600	650	29
26.	Head length	180	195	205	8	165	180	190	7
27.	Head breadth	145	155	165	6	135	145	150	6
28.	Hand length	175	190	205	10	160	175	190	9
29.	Hand breadth	80	85	95	5	70	75	85	4
30.	Foot length	240	265	285	14	215	235	255	12
31.	Foot breadth	85	95	110	6	80	90	100	6
32.	Span	1655	1790	1925	83	1490	1605	1725	71
33.	Elbow span	865	945	1020	47	780	850	920	43
34.	Vertical grip reach (standing)	1925	2060	2190	80	1790	1905	2020	71
35.	Vertical grip reach (sitting)	1145	1245	1340	60	1060	1150	1235	53
36.	Forward grip reach	720	780	835	34	650	705	755	31
	Body weight	55	75	94	12	44	63	81	11*

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3rd Edition. Taylor & Francis.

TABLE 10.15

Anthropometric Estimates for Hong Kong Chinese Industrial Workers (all dimensions in millimetres, except for body weight, given in kilograms)

Dimension	Men				Women			
	5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
1. Stature	1585	1680	1775	58	1455	1555	1655	60*
2. Eye height	1470	1555	1640	52	1330	1425	1520	57*
3. Shoulder height	1300	1380	1460	50	1180	1265	1350	51*
4. Elbow height	950	1015	1080	39	870	935	1000	41*
5. Hip height	790	855	920	41	715	785	855	42
6. Knuckle height	685	750	815	40	650	715	780	41
7. Fingertip height	575	640	705	38	540	610	680	44
8. Sitting height	845	900	955	34	780	840	900	37*
9. Sitting eye height	720	780	840	35	660	720	780	35*
10. Sitting shoulder height	555	605	655	31	510	560	610	29*
11. Sitting elbow height	190	240	290	31	165	230	295	38*
12. Thigh thickness	110	135	160	14	105	130	155	14
13. Buttock–knee length	505	550	595	26	470	520	570	30*
14. Buttock–popliteal length	405	450	495	26	385	435	485	29*
15. Knee height	450	495	540	26	410	455	500	27*
16. Popliteal height	365	405	445	25	325	375	425	29*
17. Shoulder breadth (bideltoid)	380	425	470	26	335	385	435	29*
18. Shoulder breadth (biacromial)	335	365	395	19	315	350	385	22
19. Hip breadth	300	335	370	22	295	330	365	21*(M)
20. Chest (bust) depth	155	195	235	25	160	215	270	34

Stephen Pheasant and Christine M. Haslegrave (2006). Bodyspace: Anthropometry, Ergonomics and the Design of Work. 3rd Edition. Taylor & Francis.

	Dimension	Men				Women			
		5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
21.	Abdominal depth	150	210	270	36	150	215	280	39
22.	Shoulder–elbow length	310	340	370	19	290	315	340	16*
23.	Elbow–fingertip length	410	445	480	22	360	400	440	24*
24.	Upper limb length	680	730	780	30	615	660	705	26
25.	Shoulder–grip length	580	620	660	25	525	560	595	22
26.	Head length	175	190	205	8	160	175	190	9
27.	Head breadth	150	160	170	7	135	150	165	8
28.	Hand length	165	180	195	9	150	165	180	9*
29.	Hand breadth	70	80	90	5	60	70	80	5*
30.	Foot length	235	250	265	10	205	225	245	11*
31.	Foot breadth	85	95	105	5	80	85	90	4*
32.	Span	1480	1635	1790	95	1350	1480	1610	80*
33.	Elbow span	805	885	965	48	690	775	860	51
34.	Vertical grip reach (standing)	1835	1970	2105	83	1685	1825	1965	86
35.	Vertical grip reach (sitting)	1110	1205	1300	58	855	940	1025	51
36.	Forward grip reach	640	705	770	38	580	635	690	32
	Body weight	47	60	75	9	39	47	62	7

Calculating Percentiles

Unless otherwise specified, when we refer to "percentile," we will be referring to this third definition of percentiles. Let's begin with an example. Consider the 25th percentile for the 8 numbers in Table 1. Notice the numbers are given ranks ranging from 1 for the lowest number to 8 for the highest number.

Table 1. Test Scores.

Number	Rank
3	1
5	2
7	3
8	4
9	5
11	6
13	7
15	8

The first step is to compute the rank (R) of the 25th percentile. This is done using the following formula:

$$R = P/100 \times (N + 1)$$

where P is the desired percentile (25 in this case) and N is the number of numbers (8 in this case). Therefore,

$R = 25/100 \times (8 + 1) = 9/4 = 2.25$. Therefore, the 25th percentile is 5.5.

From: http://onlinestatbook.com/2/introduction/percentiles.html

Calculating Percentiles: Probability Distributions and Percentiles

A *kth percentile* is defined as a value such that k percent of the data values (plotted in ascending order) are at or below this value and $100 - k$ percent of the data values are at or above this value. A histogram plot of U.S. adult male statures shows a bell-shaped curve, termed a *normal distribution*, with a median value of 68.3 in (see Figure 5.1). This is also the 50th percentile value; for example, one-half of all males are shorter than 68.3 in, while one-half are taller. The 5th percentile male is only 63.7 in tall, while a 95th percentile male is 72.6 in tall. The proof is as follows.

Typically, in a statistical approach, the approximately bell-shaped curve is normalized by the transformation

$$z = (x - \mu)/\sigma$$

where μ = mean
σ = standard deviation (measure of dispersion)

to form a standard normal distribution (also termed a z distribution; see Figure 5.2).

Once normalized, any approximately bell-shaped population distribution will have the same statistical properties. This allows easy calculation of any percentile value desired, using the appropriate k and z values, as follows:

κth percentile	10 or 90	5 or 95	2.5 or 97.5	1 or 99
z value	±1.28	±1.645	±1.96	±2.33

$$k\text{th percentile} = \mu \pm z\sigma$$

Example

Given that the mean stature for males in the United States is 68.3 in (173.6 cm), while the standard deviation is 2.71 in (6.9 cm) (Webb Associates, 1978), the 95th percentile male stature is calculated as

$$68.3 + 1.645(2.71) = 72.76 \text{ in}$$

while the 5th percentile male stature is

$$68.3 - 1.645(2.71) = 63.84 \text{ in}$$

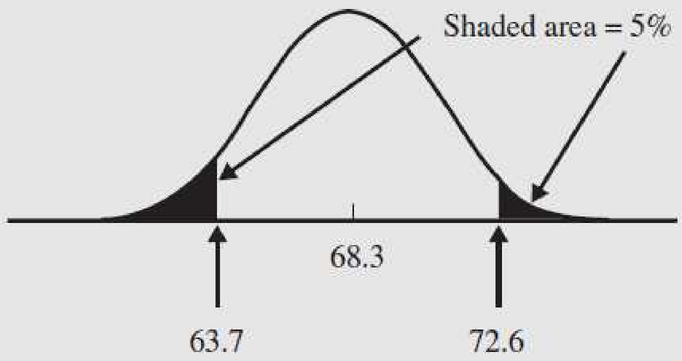


Figure 5.1 Normal distribution of U.S. adult male statures.

Note that the calculated values of 72.76 and 63.84 in are not exactly equal to the actual values of 72.6 and 63.7 in. This is so because the U.S. male height distribution is not a completely normal distribution.

Anthropometrics for Design

- The percentiles in a table of anthropometric data are used by design engineers to insure that equipment will be usable by almost all members of a population.
- Ex problems of “clearance” which include head room, knee room, elbow room and access to passageways and equipment, require the engineer to design for the largest or tallest individuals in the user population.
- Most commonly, the 95^{th} percentile values for height or breadth measurements will be used to insure adequate clearance.
- Ex problem of reach, which involve such concerns as the location of controls, the designer should be concerned with the smallest individuals in the user population, or the 5^{th} percentile.

Design for Extremes

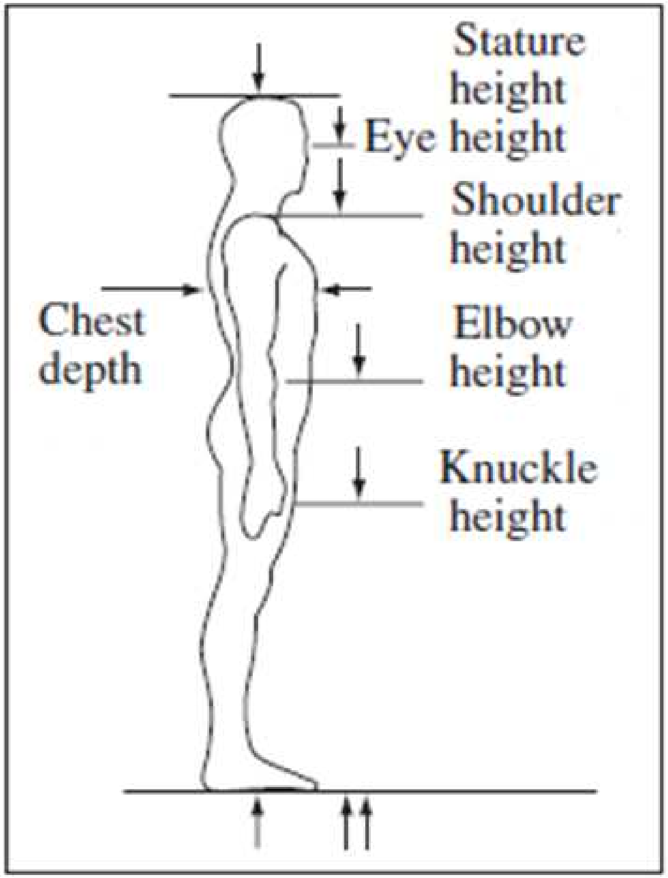
- *Design for extremes* implies that a specific design feature is a limiting factor in determining either the maximum or minimum value of a population variable that will be accommodated.
- For example, clearances, such as a doorway or an entry opening into a storage tank, should be designed for the maximum individual that is, a 95th percentile male stature or shoulder width.
- On the other hand, added space in military aircraft or submarines is expensive, and these areas are therefore designed to accommodate only a certain (smaller) range of individuals.
- Reaches, for such things as a brake pedal, is designed for the minimum individual, that is, a 5th percentile female leg or arm length. Then 95 percent of all females and practically all males will have a longer reach and will be able to activate the pedal or control.

Design for Adjustability

- *Design for adjustability* is typically used for equipment or facilities that can be adjusted to fit a wider range of individuals.
- Chairs, tables, desks, vehicle seats, steering columns, and tool supports are devices that are typically adjusted.
- These devices that are typically adjusted to accommodate the worker population ranging from 5th percentile females to 95th percentile males.

Design for the Average

- *Design for the average* is the cheapest but least preferred approach.
- For example, most industrial machine tools are too large and too heavy to include height adjustability for the operator.
- Designing the operating height at the 50th percentile of the elbow height for the combined female and male populations means that most individuals will not be unduly inconvenienced.
- However, the exceptionally tall male or very short female may experience some postural discomfort.

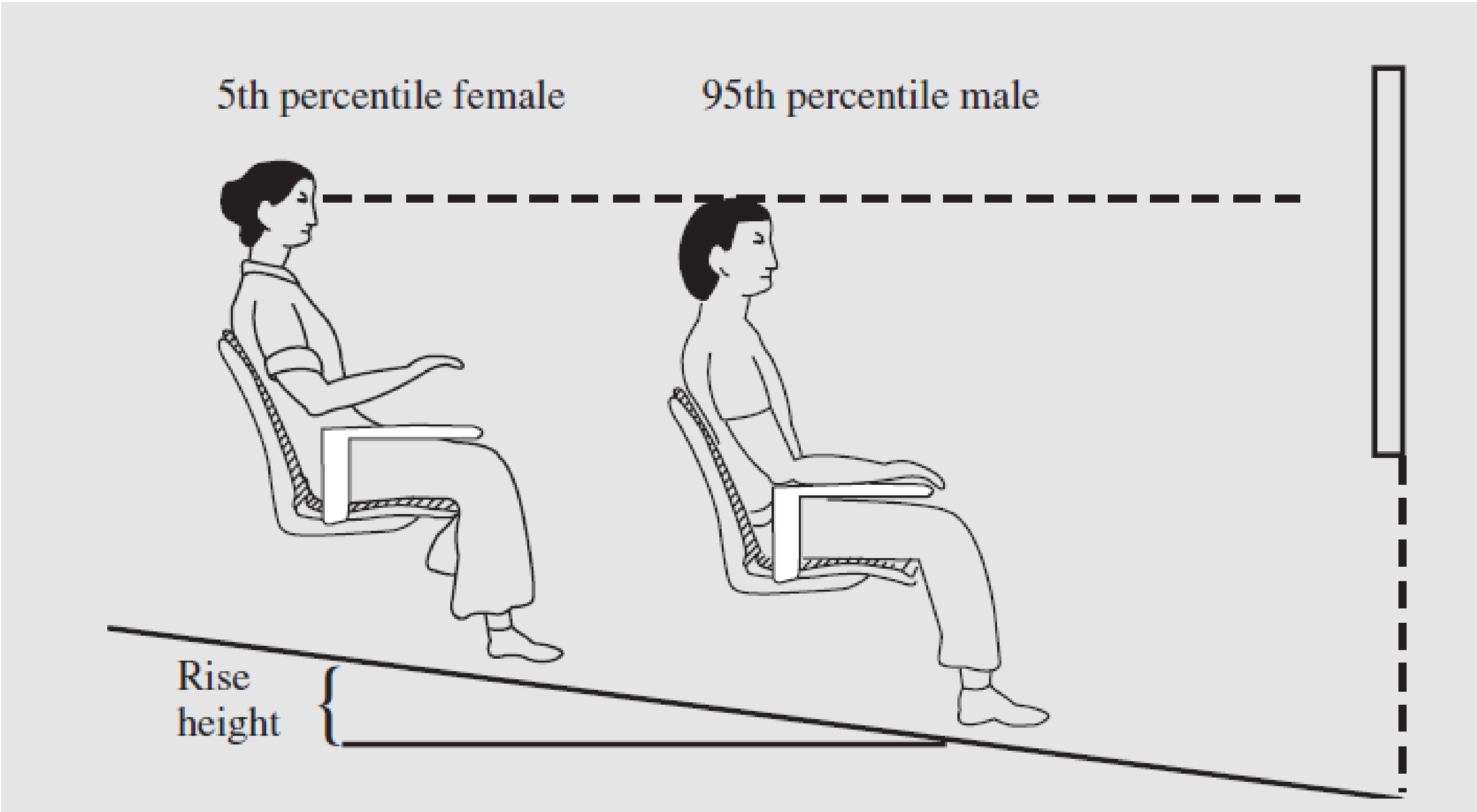


Example: Design Seating in a Large Training Room

This example will show the step-by-step procedures utilized in a typical design problem—arranging seating in an industrial training room such that most individuals will have an unobstructed view of the speaker and screen (see Figure 5.3).

1. Determine the body dimensions critical to the design—sitting height, erect; and eye height, sitting.
2. Define the population being served—U.S. adult males and females.
3. Select a design principle and the percentage of the population to be accommodated—Designing for extremes and accommodating 95 percent of the population. The key principle is to allow a 5th percentile female sitting behind a 95th percentile male to have an unimpeded line of sight.
4. Find appropriate anthropometric values from Table 5.1. The 5th percentile female seated eye height is 26.6 in (67.5 cm), while the 95th percentile male erect sitting height is 38.1 in (96.7 cm). Thus, for the small female to see over the large male, a rise height of 11.5 in (29.2 cm) is necessary between the two rows. This would be a very large rise height, which would create a very steep slope. Typically, therefore, the seats are staggered, so that the individual in the back is looking over the head of an individual two rows in front, decreasing the rise height by one-half.
5. Add allowances and test. Many anthropometric measurements have been made on nude human bodies. Therefore, allowances for heavy clothing, hats, or shoes may be necessary. For example, if all the trainees will be wearing hard hats, an additional 2 to 3 in might be needed for the rise height. It would be much more practical to remove the hard hats in the training room.

Design Seating in a Large Training Room

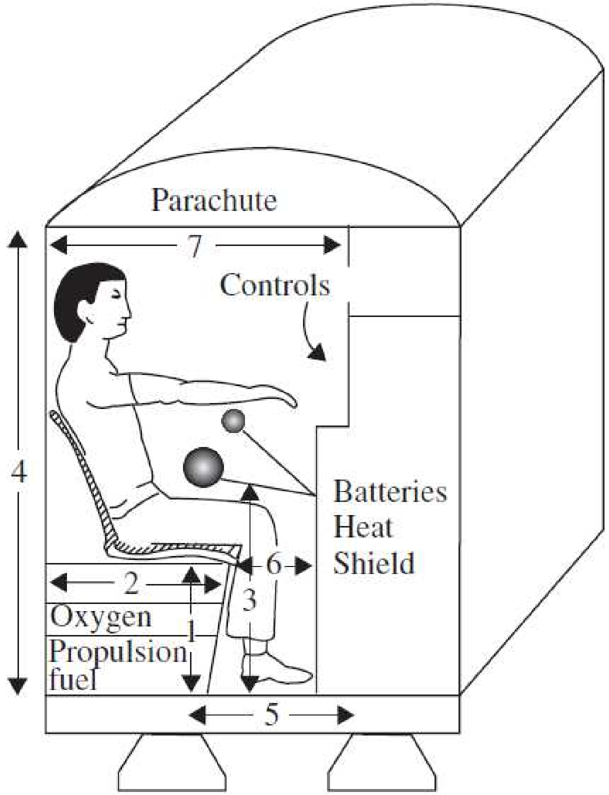


Recommend

- It is important to exercise care when designing for the minimum, maximum, or average.
- Robinette and Hudson (2006) caution, designing for the 5th percentile female to the 95th percentile male can lead to poor and unsafe design.
- One reason for these cautions is that when multiple dimensions are involved, some people will be large on some dimensions but small on others.
- If the design is based on given percentile values for the single dimensions independently, the percentage of people who will be able to use the equipment comfortably may be much less than the designer might intend.

Problems

Because of the Challenger disaster, NASA has decided to include a personal escape capability (i.e., a launch compartment) for each space shuttle astronaut. Because space is at a premium, proper anthropometric design is crucial. Also, because of budget restrictions, the design is to be nonadjustable; for example, the same design must fit all present and future astronauts, both males and females. For each launch compartment feature, indicate the body feature used in the design, the design principle used, and the actual value (in inches) to be used in its construction.



Launch Compartment Feature	Body Feature	Design Principle	Actual Value
1. Height of seat			
2. Seat depth			
3. Height of joystick			
4. Height of compartment			
5. Depth of foot area			
6. Depth of leg area			
7. Depth of chamber			
8. Width of compartment			
9. Weight limit			

Biomechanical Factors

- Good equipment design depends on more than accurate anthropometric measures.
- Most people spend their entire workday using the equipment for up to 8 h or more.
- People perform many actions, some repetitively and some infrequently. Consequently, biomechanical constraints are major factors in the design is called *occupational biomechanics.*
- *Occupational biomechanics* can be defined as "the study of the physical interaction of users with their tools, machines so as to enhance the user's performance while minimizing the risk of musculoskeletal disorders."

Biomechanical Factors

- By considering these biomechanical factors, as well as anthropometric factors, we can eliminate conditions that promote injury and discomfort quite early in the design.
- *The first category* deals with *posture.* Good posture minimizes skeletal and muscular stress, and can be encouraged by designing the equipment or product
- Good posture, so that a user can keep his or her elbows close to his or her body and minimize his or her head movement.
- *The second category* deals with the engineering considerations involved in the design of the *system interface.*
- Improperly designed or misused equipment can result in compression ischemia, or obstruction of the blood flow.

Biomechanical Factors

- Exposure to vibrations can cause tissue damage and psychological stress.
- A user's chair must provide proper support, especially if it is used for long periods of time. Repetitive task can concentrate stress on particular tissues, which may in turn result in chromic inflammation and permanent injury.
- The third category deals with *kinesiological factor*, or the type and range of movements that are performed. Long, forward reaches produce stress on the spinal column and so should be avoided.