

# Anthropometry and Workspace Design

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## Normal Man?

## Cranfield Man!

- ♀ Ideal operator for lathe controls should be 4.5' (1.37m) tall, 2' (0.61m) across shoulders, and 8' (2.35m) arm span!

## Anthropometry

- ♀ Anthropometrics - measurement of the dimensions of the body and other physical characteristics. There are two types of measurement:

- ♀ Static.

- ♀ Dynamic.

### Static (Structural) Anthropometry

- ♀ Static (structural) anthropometry:

- ♀ Skeletal dimensions - measures distance of bones between joint centers

- ♀ includes some soft tissue measures in contour dimensions (includes the wobbly stuff that covers our bodies - muscle, fat, skin, bulk).

- ♀ Doesn't include clothing or packages.

- ♀ Measures refer to a naked person (with some adjustments)

- ♀ Birth of static anthropometry - First measurements were done by a Belgian mathematician (Quetelet, 1870) who tried to fit data to a Gaussian curve.

### Dynamic (Functional) Anthropometry

- ♀ Dynamic (functional) anthropometry:

- ♀ distances are measured when the body is in motion or engaged in a physical activity.

- ♀ Includes:

- ♀ reach (e.g. could be arm plus extended torso)

- ♀ clearance (e.g. two people through a doorway)

- ♀ volumetric data (**kinetosphere**)

## Distributions

- ♀ Distribution of Measurements - Any distribution (set of measurements) can be represented by three statistics:

- ♀ mean (the average)

- ♀ median (midpoint at which 50% >, 50% < than value)

♂ mode (most frequently occurring number).

## Normal Distribution

♀ Normal distribution - in a normal distribution all three statistics, the mean, median, and mode are the same. 68% of values in a normal distribution are within a standard deviation (SD) of either side of the mean ( $SD = \sqrt{\sum(X - \text{Mean})^2/n-1}$ ).

♀ 95% are within two SD, and 99% are within 3 SD.

♂ Example: Mean = 60", SD =4",

♂ ±1 SD = 56-64" - covers 68% of sample

♂ ±2 SD's = 52-68" - covers 95% of sample

♂ ±3 SD's = 42-72" -covers 99% of sample

## Non-normal Distributions

♀ Kurtosis - relates to the shape of the distribution. It's important to plot the data, as it's crucial to know it's shape for analysis. Types of distribution shapes include:

♂ Bell curve, Gaussian curve (named after Gauss, a physicist), normal distribution

♂ Bimodal

♂ Leptokurtic

♂ Platykurtic

## Skewed Distributions

♀ Skew - occurs when one tail of a distribution is disproportionate to the other tail:

♂ Positive skew

♂ Negative skew

## Stature Distributions

## Stature Distributions

♀ Within a gender, the 5<sup>th</sup> through 95<sup>th</sup> percentile range covers 90% of people (the top 5% and bottom 5% are excluded).

♀ In a mixed total population (50% men, 50% women) the 5<sup>th</sup> through 95<sup>th</sup> percentile range covers 95% of people (the top 5% of men and bottom 5% of women are excluded, but because only half the sample are men and half are women this = 2.5%+2.5%=5% total sample excluded).

## Anthropometric Diversity

- ♀ Ergonomic designs cannot accommodate every user, the extremes will always be special cases to be uniquely accommodated.
- ♀ Anthropometric extremes can be structural dimensions (bones) or contour dimensions (soft-tissues)

## Anthropometric Diversity

- ♀ Ergonomic designs must accommodate a range of user dimensions, typically from a 5th percentile woman to a 95th percentile man.
- ♀ This range will accommodate 9.5 out of 10 users.

## Sitting Height Differences

- ♀ Neutral sitting posture for 5th and 95th percentiles (Congleton, 1999).
- ♀ Sitting head height for 5th and 95th percentiles.

## Sitting Height

- ♀ Sitting height - Stature differences are reduced when sitting down.
- ♀ Sitting height - relative sitting stature = sitting height ~ 53% stature, but varies by ethnicity.
- ♀ Different ethnic groups have proportionally different physical characteristics.
  - ♀ Many native African peoples have proportionally longer legs than Europeans.
  - ♀ Eastern peoples (Asians) have proportionally shorter lower limbs than Western Europeans, in order: Japanese, Chinese, Korean, Thai, and Vietnamese. However, there is some evidence that this situation is changing e.g. modern Japanese youth have proportionally longer legs and wider faces than their parents.
  - ♀ In recent years the Dutch have become the tallest ethnic group (used to be the Dynka people of South Sudan).

## Coefficient of Variation

- ♀ Coefficient of variation (CV) - useful index of variability of a dimension ( $CV = sd/mean$ ). A low value means that the data are normally distributed (<10). A high value indicates increasing skewness of data.
  - ♀ Typical values are:

	US
♀ Stature	3-4%
♀ Body heights (sitting height etc.)	3-5%
♀ Body breadths	5-9%
♀ Dynamic reach	4-11%
♀ Weight	10-21%
♀ Joint ranges	7-28%
♀ Muscle strength (static)	13-85%

- ♀  $68\% \pm 1 CV$ ;  $95\% \pm 2 CVs$ ;  $99\% \pm 3 CVs$

## Calculating Percentiles

- ♀ Z scores (standard scores)

$$Z = (\text{Value} - \text{Mean})/\text{SD}$$

♀ For any %ile:

$$X_p = \text{mean} + (\text{SD} \times Z)$$

e.g. for US adults:

mean stature = 1755mm

SD = 71mm

Z (for 90<sup>th</sup> %ile) = 1.28

90%ile stature =  $1755 + (71 \times 1.28) = 1755 + 90.88$

90%ile stature = 1845.88 mm (~72.6")

## Normal Probability Graphs

♀ Mean and SD can be plotted on normal probability graph paper to determine any %ile value.

♀ Mean + 1 SD = 84<sup>th</sup>%ile (84.13)

♀ Mean - 1 SD = 16<sup>th</sup>%ile (15.87)

## Design Myths

♀ Design for the "average" person - since there are no people whose body dimensions are all at the 50th percentile.

♀ Body dimensions aren't linearly correlated so people with short arms don't necessarily have short legs, etc. After about 4 dimensions there's no highly consistent correlation.

♀ While the use of the 5th and 95th percentiles on one body dimension for one homogenous population (e.g. all men) may exclude 10% of the population, the use of these on 13 dimensions actually can exclude 52% of the population.

## Design Myths

♀ Myth of designing for 5-95th percentile - designing to include the ranges between the 5th and 95th percentiles of anthropometric data fits **most** people.

♀ 5 - 95 percentile for one population is only 90% ( $95 - 5 = 90\%$  of people), and only 95% for a 50/50 mixed gender population. If you design for 90%, you'll fit 9 out of 10, 90 out of 100, 900 out of 1000, etc.

♀ Goodness of fit depends upon relevant anthropometric dimensions (e.g. height won't necessarily predict arm length).

♀ Anthropometrics are based on population "norms" - must consider differences if dealing with specific subpopulations, such as a group of Dutch people or a pro-basketball team.

## Design Myths

♀ Anthropometric data are universal.

♀ Untrue. They are only specific to the populations which they describe. If the population is poorly specified the percentiles may be biased. Also, percentiles are only specific to the dimension which they describe.

♀ Design for an adjustable range.

- ‡ There can be significant cost/benefit tradeoffs as the percentile range is extended. Each successive percent of the population to be accommodated increases the costs relative to the benefits, i.e. there are diminishing returns.
- ‡ Many aspects of adjustability are only necessary if the users cannot be specified.
- ‡ Usability is most important.

## Body Morphology

- ‡ Sex differences - shape differences (hip breadth, breast size, abdomen depth) have important ergonomic consequences. Separate data are usually used for men and women.
- ‡ Age differences - body grows then stoops with age
- ‡ Body shape - soft tissue varies in shape and these variances may create differences in clearance and mobility requirements. Sheldon proposed 3 somatotypes
  - ‡ mesomorphic - wide thorax, smaller abdomen, strong, muscular body
  - ‡ ectomorph - thin, slender, bony, flat chested
  - ‡ endomorph - round, soft, large fat storage, pear shaped, full abdomen, smaller thorax, short limbs, fine hair, smooth skin.

## Sheldon's Somatotypes Sheldon's Somatotypology Somatotypes and Temperament Design Aids


- ‡ Data tables - tabular anthropometric data can be difficult to read and use.
- ‡ Humanscale - a series of templates are used by a computer to change relevant attributes as populations change. Values are printed. Unfortunately, it's still necessary to draw the figures from the data values.
- ‡ Mannequins - a two-dimensional drawing or figure which articulates like ADAM (Anthropometric Data Applications Mannequin) with plastic parts snap together like clear moveable paper dolls or overlay transparencies.
- ‡ Models - three-dimensional surface models like "George" can be useful as examples of anthropometric data. Models have often been used by clothing manufacturers.
- ‡ Computer generated models - three-dimensional models of a user at a specified percentile in certain respects. Can see elevation, plan, or perspective. An example is "SAMMIE" (System for Aiding Man-Machine Interaction and Evaluation). Image can be changed to simulate motion. Can also use strength/force predictions, but we don't have good data for most biomechanics.


## Stature Considerations

- ‡ Height - Average height of adults steadily declines with age after 20 years of age. Around 40 years of age most people start to shrink in stature. Women shrink more than men and shrinkage accelerates with age. This shrinkage occurs in the intervertebral discs of the spine, possibly causing rounding of the back. Some reduction in height may also result from shrinkage of lower limbs around the joints.
- ‡ Time of day - Because the cartilaginous discs of the spinal column get compressed by body weight throughout the day we tend to be slightly shorter in the evening (up to 0.9").


Additionally, extremities (like feet) swell throughout the day.

## Body Weight + Strength


 **Weight** - The average weight of adults increases from ages 20-45. From age 50 onward men's weight declines. From age 60 onward women's weight declines. Until 55 years of age weight increases and there is an increase in hip breadth. Fat is redistributed from subcutaneous areas to deeper positions especially around abdominal organs. Lean body weight decreases with age as muscles waste away.




 **Strength** - There is a decrease in muscular strength and the mechanical tensile breaking strength of bone, muscle, and connective tissue decreases with age.

## Pregnancy


 **Pregnancy** - Later stages of pregnancy decreases in the ability to lift, bend, reach, stand or walk for long periods, turn head, etc. so it is a form of temporary disability. Assuming a 0.02% pregnancy rate and 50,000,000 women of childbearing age, means an estimated 1,000,000 pregnant women at any time. Only recently have anthropometric surveys of pregnant women begun to be conducted (in Japan).

## Wheelchair User

 **Wheelchair Users** - Chairbound people actually suffer three limitations:


-  Condition which necessitates wheelchair use.
-  Lower eye-level - eye-level is 15 -16" below that of most standing people and the seated posture also influences reach, controls, and access.
-  Possession of a cumbersome, awkward, space-consuming, distinctive and inelegant vehicle. While a standing person occupies 25" by 15" of floor space, requires 16" to 26" aisle width and can turn on the spot, a wheelchair user occupies up to 57" by 25" of floor space, requires minimum aisle clearance of 31.5" and needs a turning circle of between 59" and 67".


## Wheelchair Users


 Design standards, such as ANSI A1171.1-1980, are available to assist with designs for wheelchair users.

## Wheelchair Users

## Dynamic Anthropometrics

 **Clearance** – the minimum space required for the body or body segment to pass through (or not). Maximum breadth and depth dimensions are used (person or technology – e.g. wheelchair).

 **Inclusion** – clearance to allow access (e.g. doorway, bathtub, crawlspace, hatch)

 **Exclusion** – clearance to prevent access (e.g. safety guard, cage, fan cover, air vents)

## Clearance Dimensions

## Body Ellipse

- ‡ Body ellipse – in plan view the human body occupies an elliptical shape. So clearance values depend on postural orientation (e.g. in corridors, turnstiles, buses, aisles etc.)

## Dynamic Anthropometrics

- ‡ Reach – dynamic reach envelope (kinetosphere) influenced by:

- ‡ Posture (sitting < standing).
- ‡ Footbase (increased reach with increased footbase).
- ‡ Weight in hands (heavy weight decreases reach).
- ‡ Type of grip (pinch > power).
- ‡ Proximity to obstacles (wall/obstacle behind person decreases reach).

- ‡ Reach envelopes are highly specific to situations.

## Zones of Convenient Reach

### Measuring Zone of Convenient Reach (ZCR)

- ‡ Measure:

- ‡ a = shoulder (acromion) – grip (center of hand) length.
- ‡ d = horizontal distance from shoulder to surface.

- ‡  $r = \sqrt{a^2 - d^2}$

- ‡ r = radius of ZCR.

- ‡ ZCR defines the maximum working area.

### Zones of Convenient Reach + Optimal Visual Zones

## Normal Work Area (NWA)

- ‡ Area described by the arms and hands with the elbows flexed at ~ 90°.

- ‡ Typically, the comfortable limit of outward rotation is about 25 °.

## Grip Strength and Reach

## Kinetosphere

- ‡ Volumetric reach envelope - used to model optimal workspace layout (e.g. SAMMIE CAD)


## Workspace Layout


- ‡ Importance - most important items should be most central and closest.

- ‡ Function - items with similar functions should be closest together.

- ‡ Frequency-of-use - position most frequently used items in

optimal locations.

 Sequence-of-use - position items in optimal locations for sequence of use.

 Normal Posture - position items to be accessible from a normal posture.