HUMAN ENGINEERING

Putting people into the system

Every engineered system has substantial interaction with human beings. There are various aspects to this with buzz words such as "ergonomics" and "human factors".

In theory we have a dilemma. If the system involves a man operating it, is the man part of the system or not?

Since our practical viewpoint is that a system comprises those items that are delivered, and that since the abolition of slavery we are unable to supply a man as part of the deliverables we must conclude he is not part of the system.

However when designing the system it some times makes sense to essentially view the human as a system element - other times it does not. So use common sense and be pragmatic. Either ' way the interfaces between the artificial elements in the system and the human remain similar - and complex, difficult, awkward etc..

WHY HAVE HUMANS IN THE SYSTEM?

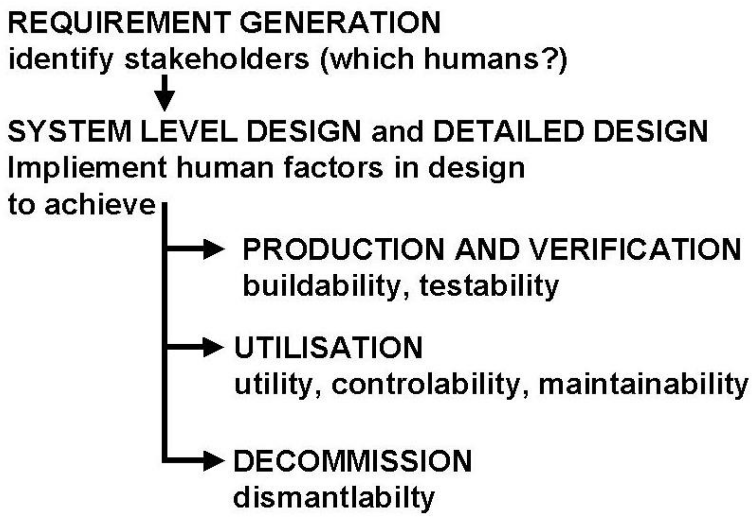
Humans can play three roles within an operational system, these are:

1 Customers of the system services.
For almost all engineered systems the purpose is some support to human activity -e.g. passengers on an aircraft.

2 Essential part of the system function.
That is the human is the only, or the most economic, way to meet the objectives - e.g. the cabin crew on a passenger aircraft to handle passengers.

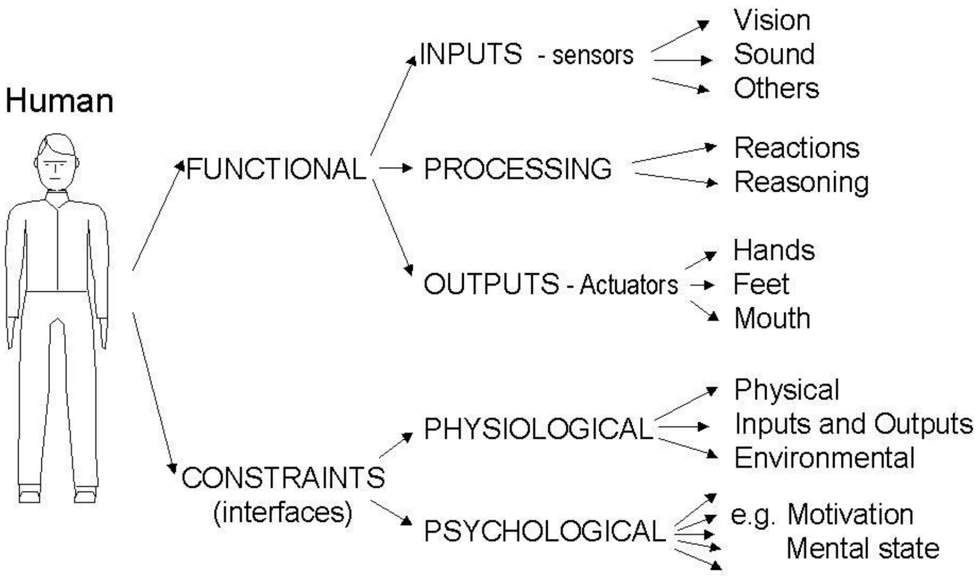
3 Where human psychology requires humans.
Even if in pure engineering terms they are not the optimum solution or even required at all - e.g. the cockpit crew of a passenger aircraft.

HUMAN FACTORS IN THE LIFECYCLE



FACTORS IN INTEGRATING HUMANS INTO SYSTEMS

Treating the human as a hard system element of the systems – we can generate an interface definition as shown in the following function breakdown



HUMAN SENSORS

Classically human beings are supposed have five basic senses by which we are aware of the outside world, but in reality there are at least seven and more dependent on how you define a sensor, how you subdivide the skin's sensors and whether you count the bodies internal sensors.

Property measured by	**Sense** using	**Organ**
light	vision	eyes
sound	hearing	ears
chemical (gas)	smell	noise
chemical (liquid)	taste	tongue
solid surface	touch	skin
temperature	-	skin
gravity	balance	inner ear

Dependant upon the complexity of the relation of the human/system interaction some, most or even all will be used to feed data to the human, to process and then to change the system state in accordance with the information.

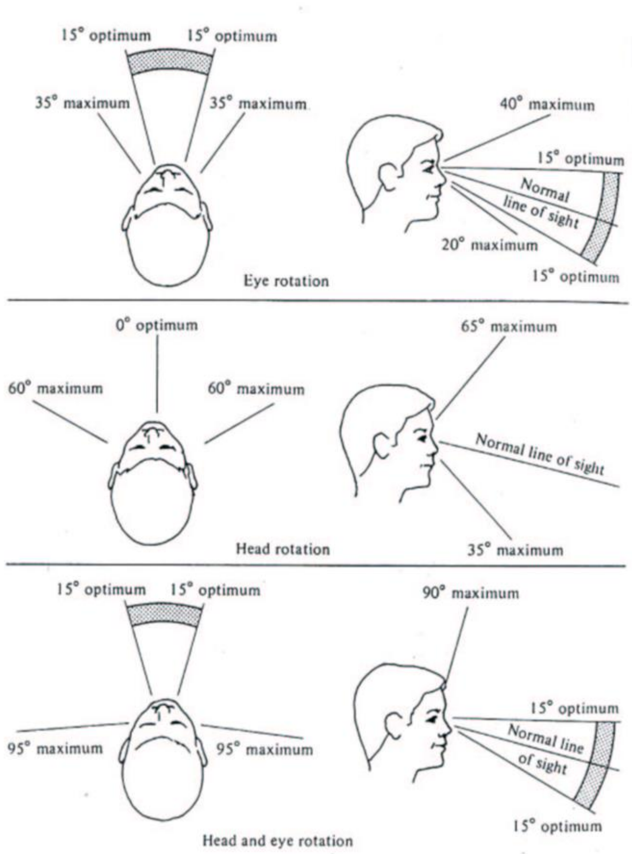
Human sensors have exactly the same of limitations as artificial sensors, and are subject to the same problems.

They only work over a limited range
They have thresholds
They cannot detect a signal if the noise ratio gets high

We will look at the most important.

LIGHT - VISION

The most important human sense. The eyes are a three band electromagnetic radiation detector covering about an octave centred on where the sun's light provides the most energy and the atmosphere is transparent.



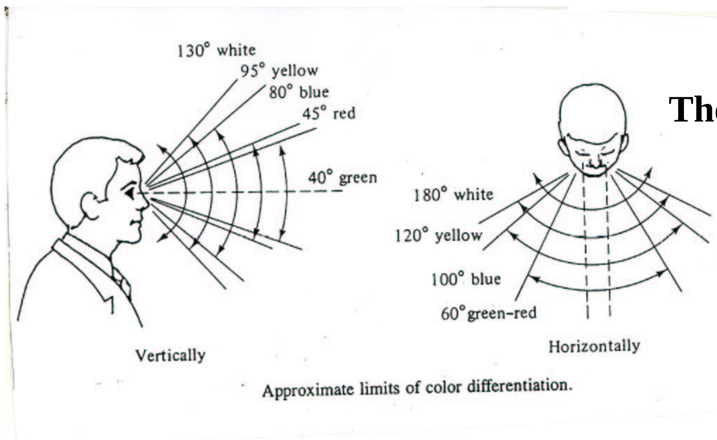
The Performance of the Human Eye (varies from human to human)

Typical resolution about 1 arc minute.

Lighting levels required for comfortable vision

General	400 – 800 Lux
Drafting	750 - 1500 Lux
Fine assembly	1000 - 4000 Lux

Above 1000 lux glare can be a problem.



The Limits of Vision

UNITS OF LIGHT

luminous intensity is measured in **candela.** One candela is emitted by a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

luminous flux is measured in **lumens**. It is calculated from candela x steradian**.** So 1/683 watt in one steradian is one lumen.

Illuminance is measured in **lux**. 1 lux = 1 lumen /m^2

Illuminance	Example
0.00005 lux	Starlight
0.0001 lux	Moonless overcast night sky
0.001 lux	Moonless clear night sky
0.01 lux	Quarter Moon
0.25 lux	Full Moon on a clear night
1 lux	Moonlight at high altitude at tropical latitudes
10 lux	Candle at a distance of 30 cm
50 lux	Family living room
80 lux	Hallway/Toilet
400 lux	A brightly lit office
400 lux	Sunrise or sunset on a clear day.
1000 lux	Typical TV studio lighting
32000 lux	Sunlight on an average day (min.)
100000 lux	Sunlight on an average day (max.)

SOUND - HEARING

One of the two key human senses and the one by which language is naturally received (written language is only about 5 to 6 thousand years old). The human ear responds to a range of sound pressure levels that differs by 10^{14} (a hundred thousand billion) and a frequency range of a factor of a thousand.

To measure sound pressure levels we use the **decibel (dB).** The decibel is names after Alexander Graham Bell (1847-1922) credited with the invention of the telephone but whose main research interest was hearing and he used a scale of 1-10 for subjects to describe how loud they perceived sound. When instruments could measure sound this scale was rather crude and a tenth of a “Bell” was used instead - hence Decibel.

Human hearing perception is logarithmic and the decibel scale has become a general means of measuring relative power in electronics but it still applies to sound.

A Decibel value between two powers P_1 and P_2comes from the equation

$$dB = 10 \text{ Log } (P_1/P_2)$$

Decibels express a ratio of two powers but by making it a ratio against an absolute value then it can be used as an absolute measure. With sound 0dB is set as 10^{-12} W /m^2, which is the normal threshold of human hearing. So a conversation at 60dB represents a power density of 10^{-6} W /m^2.

The Range of Human Hearing

Prolonged exposure to levels above 85 dB can result in hearing loss.

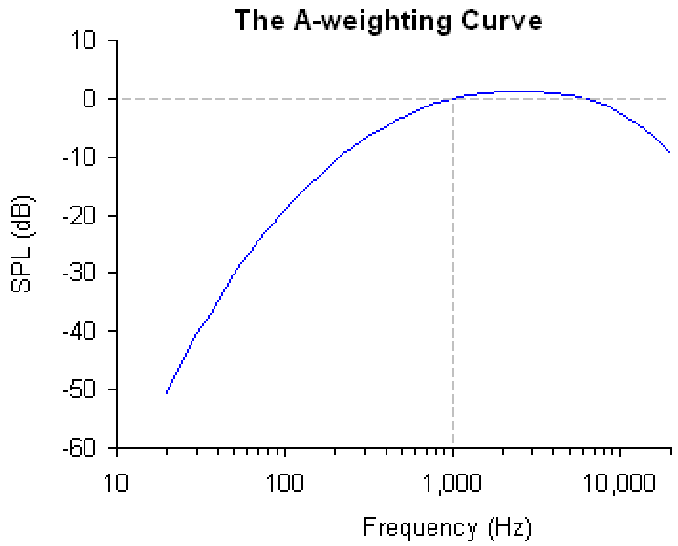
Around 8 hours continous exposure to 90dB can also cause ear damage

Any exposure to 140 dB can cause immediate ear damage.

140 dB -	**Gunshot or firecracker**	**100 W/m^2**
130 dB -	**Threshold of pain**	**10 W/m^2**
120 dB -	**Aeroengine**	**1 W/m^2**
110 dB -	**Thunder, Rock concert**	**0.1 W/m^2**
100 dB		**10^{-2} W/m^2**
90 dB -	**Symphony Orchestra**	**10^{-3} W/m^2**
80 dB -	**Door slamming**	**10^{-4} W/m^2**
70 dB -	**Loud Conversation**	**10^{-5} W/m^2**
60 dB -	**Street traffic, Conversation**	**10^{-6} W/m^2**
50 dB -	**Distracts attention**	**10^{-7} W/m^2**
40 dB -	**Quiet office**	**10^{-8} W/m^2**
30 dB -	**Average home**	**10^{-9} W/m^2**
20 dB -	**Whisper**	**10^{-10} W/m^2**
10 dB		**10^{-11} W/m^2**
0 dB -	**Threshold of hearing**	**10^{-12} W/m^2**

From this you can see for concentrated work the environment should be kept below 50dB, above 80dB even loud conversation is difficult, over 85 dB and health and safety issues start to be an issue.

There are also frequency limitations on hearing. The normal design range is 20 Hz to 20 kHz. But no human can hear all these frequencies at once. As humans age the higher frequency perception is lost but there is an increased lower frequency response (number of Rock Concerts etc. can also effect frequency response). Of course the response is not uniform over this range and typically it peaks (most sensitive around 2000 Hz).



Filters to mimic the average human ears response are used in sound meters when assessing noise levels. The curve used is called A -Weighted.

Suppression of echo is normally important - although over deadened environments can also distract

OTHER SENSES

Humans are not confined to sight and hearing. Other senses will also provide data to the brain - whether the system designer wishes it or not. Unlike an artificial system we cannot leave off the sensors we do not want.

Smell - strong smells (which are warning signals) will distract

Touch – significant feedback can be obtained by the feel of controls – which is why the hand controller on fly by wire aircraft (essentially operating like computer games controllers) have the response of the old mechanical joysticks artificially added

Gravity – often a nuisance in moving systems as the signals can cause nausea, also can give misleading signals that confuse the brain and contribute to incorrect decisions.

HUMAN DATA PROCESSING

Our eyes, ears, etc, are not good sensors what gives them their remarkable discriminatory ability is the brain processing which corrects for the deficiencies. As the sensors degrade with age the brain compensates by providing more processing.

Bad News

1) By the standards of artificial systems the human brain is a very slow processor

Data Input Speeds: Visual = 1/10 second. Hearing = 2-3 words a second

Trained reaction time can be around a quarter of a second but if a thinking reaction is required then can be several.

2) Programming in the brain is "close architecture". That is we don't know what it is or even how it works in principle. The interpretation features are very patchy for example face recognition is phenomenally good, brick recognition is very poor. The brain’s programming can play tricks. More extreme examples are optical illusions but less obvious interpretational errors can be made.

Good News

1) The main point of humans is the very complex evaluation capabilities that far exceed any machine capacity. Including the ability to make decisions in totally unfamiliar territory.

2) Also having humans in the system is the only way to enable the system to make ethical and aesthetic judgements.

CODING DATA

The human animal is adapted to a natural environment. Data provided by the system is not always best displayed in the most logical form if a quick human response is required. Coding data in a way that makes it easier for the brain to respond is often required.

Examples:

- Colour coding -lights, wires etc
- Use of rotation or linear dials rather than numerical displays
- Graphics and icons rather than text

With warnings obvious attention grabbing devices are alarms and flashing lights. Another technique for warnings and other unusual communications is placing the message in an out of context situation - example suggested for fighter aircraft was the use of a voice warnings recorded from the operator’s family (daughter, wife etc.).

HUMAN OUTPUTS - ACTUATORS

Most important are

Hands. They are flexible, precise to a few mm, and fingers can exert a few 10's Newtons force, over all hand/arm a few 100 Newtons.

Pity there are only two of them!

Feet can also be used as additional actuators. If the body is properly held can legs/feet can apply more force than arms/hands but with less precision. e.g. rudder pedal, car accelerator/brake clutch.

Mouth Tends to be last resort actuator but can be used. When machines understand language this could become a key interface.

ANTHROPOMETRY

The human body does not come in one size nor does it stay in one position. The posh word for dealing with the variability of the human body is "anthropometry".

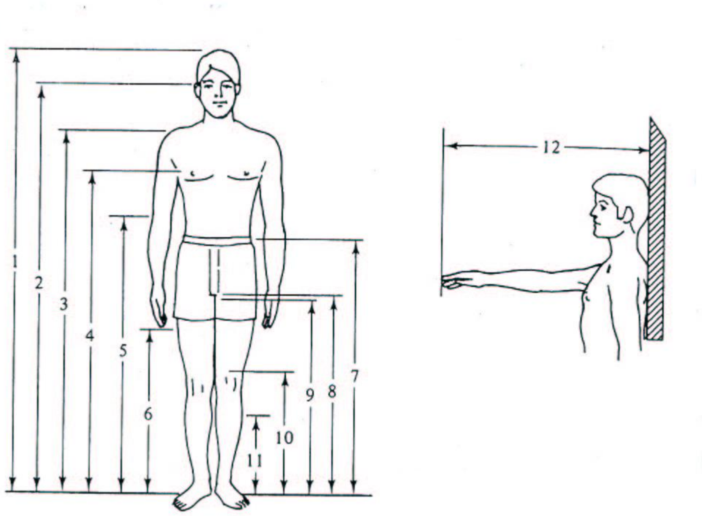
Anthropometry is from the Greek for "measurement of humans", A subject with a rather dubious past But in the late nineteenth and early twentieth centuries. It was studied because:

a) The measurement of a person’s key features (that remain constant over their adult life) was used by police to fix a person's identity (early biometrics) which was useful but time consuming - fingerprints proved quicker and more reliable also criminals tended not to leave their nose bridge to tip measurement at the scene of a crime.

b) There was an attempt to link a person’s features to character and ability and then by extension to argue differences in character and ability between various human races (now thoroughly discredited).

Today the value of the subject is in statistical data to ensure humans fit into and can use things designed to interact with them. The results are normally in the form of tables with various parameters and the 5th percent and 95th percent values from the studied population. Such as this example. These tables alter with country, and with time so industries that need this data (clothing for example) need to continually research how the target population has changed.

Typically a designer will work to fit 5th to 95th percentiles and it is normally argued when both sexes are accounted for that excludes about 5% of the population. However there are two problems with this.



Factors	Percentile values (cm)			
	5th Percentile		95th Percentile	
	Men	Women	Men	Women
Weight (kg)	57.4	46.4	91.6	76.5
Standing body dimensions				
1. Stature	163.8	152.4	185.6	172.2
2. Eye height (standing)	152.1	142.7	173.3	160.1
3. Shoulder (acromiale) height	133.6	123.0	154.2	143.4
4. Chest (nipple) height		110.0		127.3
5. Elbow (radiale) height	104.8		120.0	
6. Fingertip (dactylion) height	61.5		73.2	
7. Waist height	97.5	93.1	115.2	110.1
8. Crotch height	76.3	66.4	91.8	81.4
9. Gluteal furrow height		66.2		79.4
10. Kneecap height	47.5		58.6	
11. Calf height	31.1		40.6	
12. Functional reach	72.7	67.7	90.9	80.4

Anthropometric data—standing body dimensions.

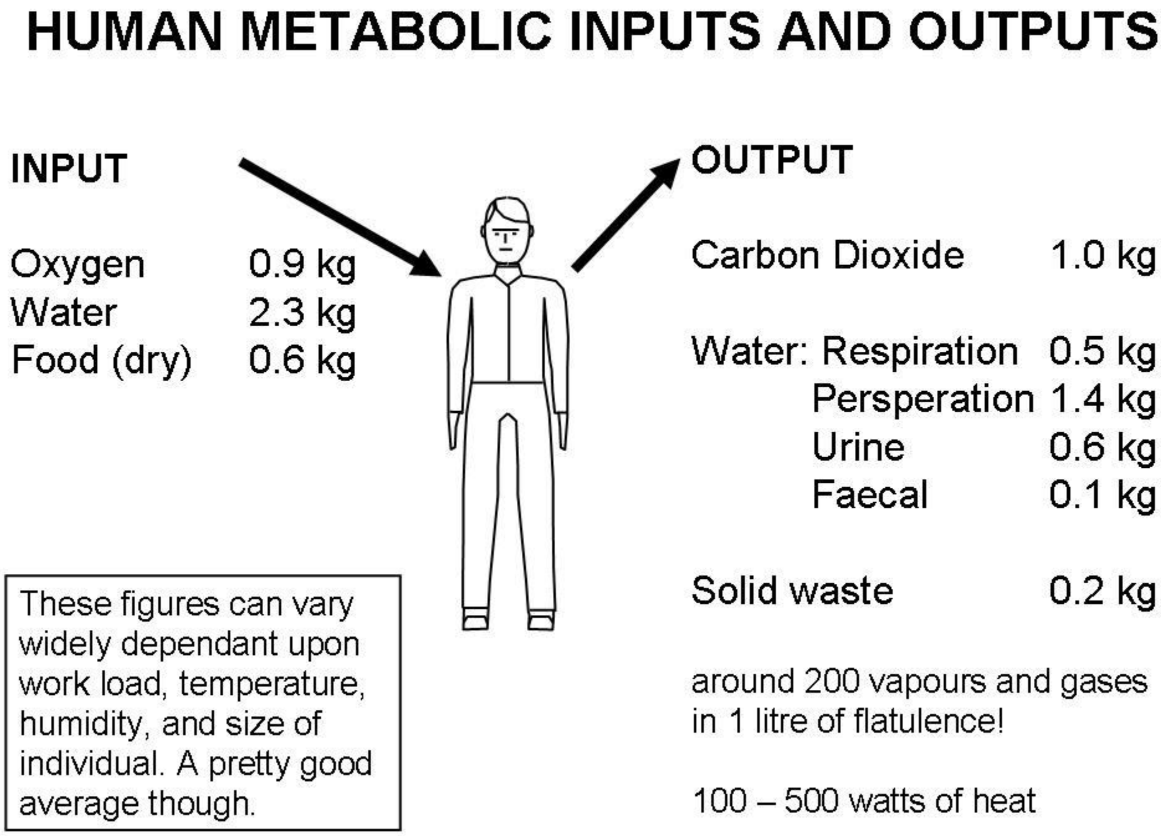
1) This is fine for things like aircraft cockpits and astronauts where the personnel can be selected but 5 % of the general public is a large population – on a Jumbo jet or A380 an average of 15 to 20 people will not fit the seats on every flight

2) People will not uniformly move into the extremes 5% in all the parameters. So while the use of the 5th and 95th percentiles on one body dimension may exclude 10% of the population, the use of these on 13 dimensions actually can exclude 52% of the population.

This suggests an argument that when designing for the "general public" is would be wiser to use something like the 99th percentile or above but these figures are not generally included in design tables.

METABOLIC REQUIREMENTS

Humans also need the equivalent of power supply – food and oxygen – and of course there are associated waste products.



ENVIRONMENT

Human performance is also affected by the environment he/she is in. There is a history of designing systems to control the environment the humans experience to maximise efficiency and increase safety.

ENVIRONMENT - ATMOSPHERE

Temperature and Humidity
These are linked - the higher the humidity the lower the temperature that can endured to any length of time.
Human tolerance to temperature. Optimum values are between 18 and 22 C and humidity below 50%

Drafts
Keep air speeds below 0.2 m/sec in an area intended for activities requiring concentration.

Carbon Dioxide
In enclosed spaces carbon dioxide partial pressure can build up. This can interfere with breathing even when the oxygen partial pressure is sufficient. Recommended maximum level for long term exposure 1% by volume. The normal atmospheric level is 0.03%.

Air Purity.
The human body gives off some 200 different gases and vapours. If allowed to build up most of these are unpleasant and can distract. There is therefore a need to processed or renewed the atmosphere at a rate of around 10 - 30 m^3/hour /person.

Pressure
Normal sea level atmospheric pressure = 100 kPa but the world's higher cities are around 2000 m = 80 kPa

Commercial aircraft cabins typically 75 - 85 kPa (1 500m 2000 m equivalent)

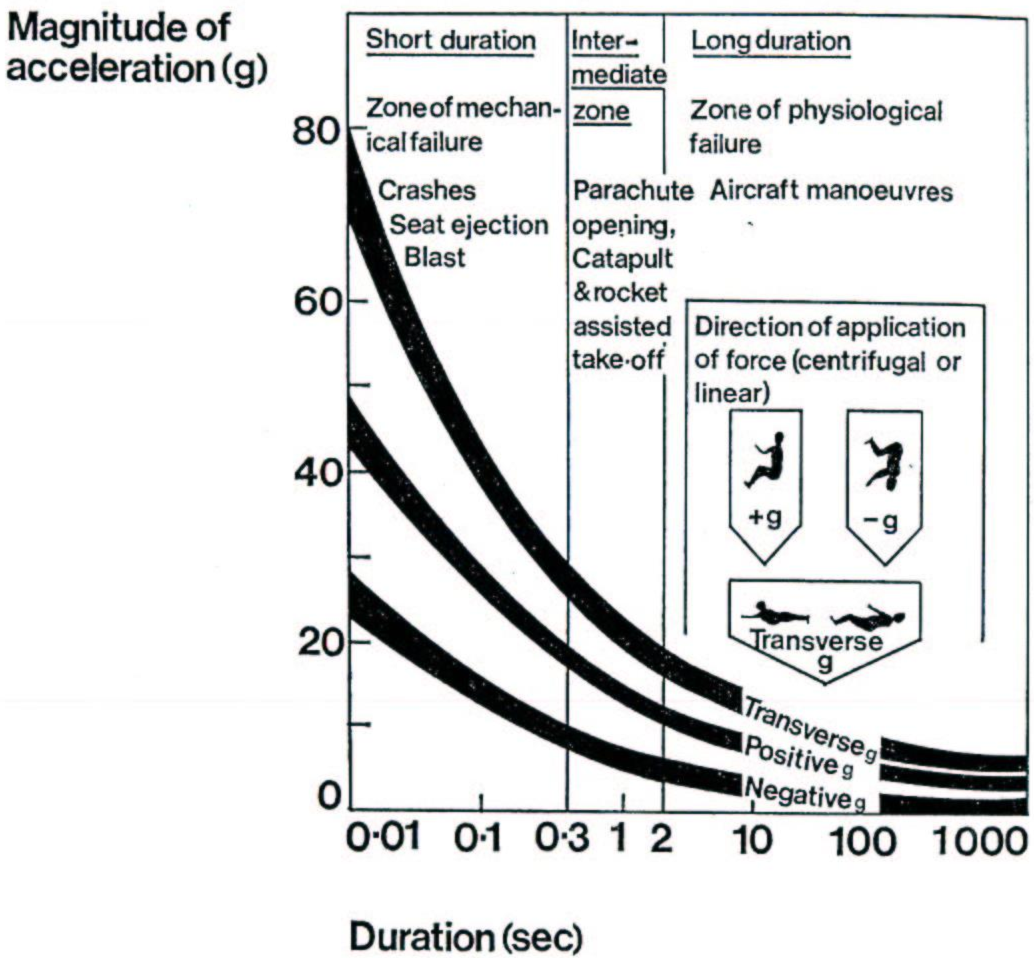
Higher than 3000 m (70 kPa) requires additional oxygen as its partial pressure falls below levels for humans to sustain efficiency and eventually life. This is why fighter aircraft pilots (and high altitude climbers) are fed supplementary oxygen.

Early American spacecraft and space suits operate on pure oxygen at around 30 kPa

The problem using this in spacesuits is the risk of Dysbarism (Decompression sickness or the bends) when going from sea level pressure oxygen/nitrogen mix as used in modern spacecraft.

On the ISS astronauts enter a special chamber with lower cabin pressure of 7 kPa for 24 hours before a spacewalk and the crew also do a half hour 'Prebreathing" of pure oxygen before decompression.

ACCELERATION FORCES



The graph shows g limits for humans in different postures.

Fighter pilots can sustain higher g (around + 9 g in seated position) by using G-suits and "Grunting" to delay blackout.

Negative g causes "Redout" which is more unpleasant more dangerous and more difficult to prevent.

ENVIRONMENT - DANGERS

Many other potentially dangerous environmental factors exist. In a normal everyday environment these are not a concern (yet) but where the system process creates high concentrations they must be controlled. Some examples:

RADIATION

Ionising: No definite knowledge of what constitutes a safe level exists, but general regulations covering this are probably very conservative and safe - unless you are an astronaut where permitted levels are 10 times greater.

Microwave: Western world regulatory "safe" levels are ludicrously high. The former Soviet Union had a much more realistic level which is sometimes used in the west when safety is really an issue.

Other Electromagnetic: Ultra-Violet, and Infra-red can cause burns if at high enough levels.

ELECTRIC

Ions: The ionic composition of the air can effect human performance.

Electric Fields: Debatable this one. But since a human body sends most of its data around by ions in fluids, it is logical to suppose electric fields would have some effect.

TOXIC SUBSTANCES

Gases, Dust, Biological: and other nasties floating in the air.

PSYCHOLOGY

Much more difficult to quantify and deal with but can be very important. Some issues like how data is presented we have already covered. Other factors to be considered include.

Colours
Dark, indistinct colours have depressant effect, Bright strong colours can stimulate. You mmay need to avoid primary colours if these are used for colour coding in the environment.

Privacy/Territorial space
Humans tend to need a defensible space and also some privacy particularly if permanently living in the system like submarines or space stations.

Motivation / Social status
Often within a system the social context of the human is an important factor in how they will behave. e.g. A uniform can impart authority and respect, useful if the humans function is to guide and control other humans (e.g. cabin crew).

EFFECTIVE HUMAN FACTORS

Human factors ought to be one of the easiest things to get right - after we are all human and know what we want? In practice it often goes wrong. So some suggestions to get it right.

1 - Use experienced engineers - in the end human factors is a bit of a black art so experience in the design team is essential.

2 - A simple suggestion for getting it right is to imagine yourself operating the system - it is amazing how many otherwise good designers seem unable to do this.

3 - A more formal technique for developing effective interactions is "fast prototyping" - used increasingly in cockpit design. A very crude mock-up is progressively up-graded as decisions are made until in the end a fully working demonstrator of the cockpit is made.

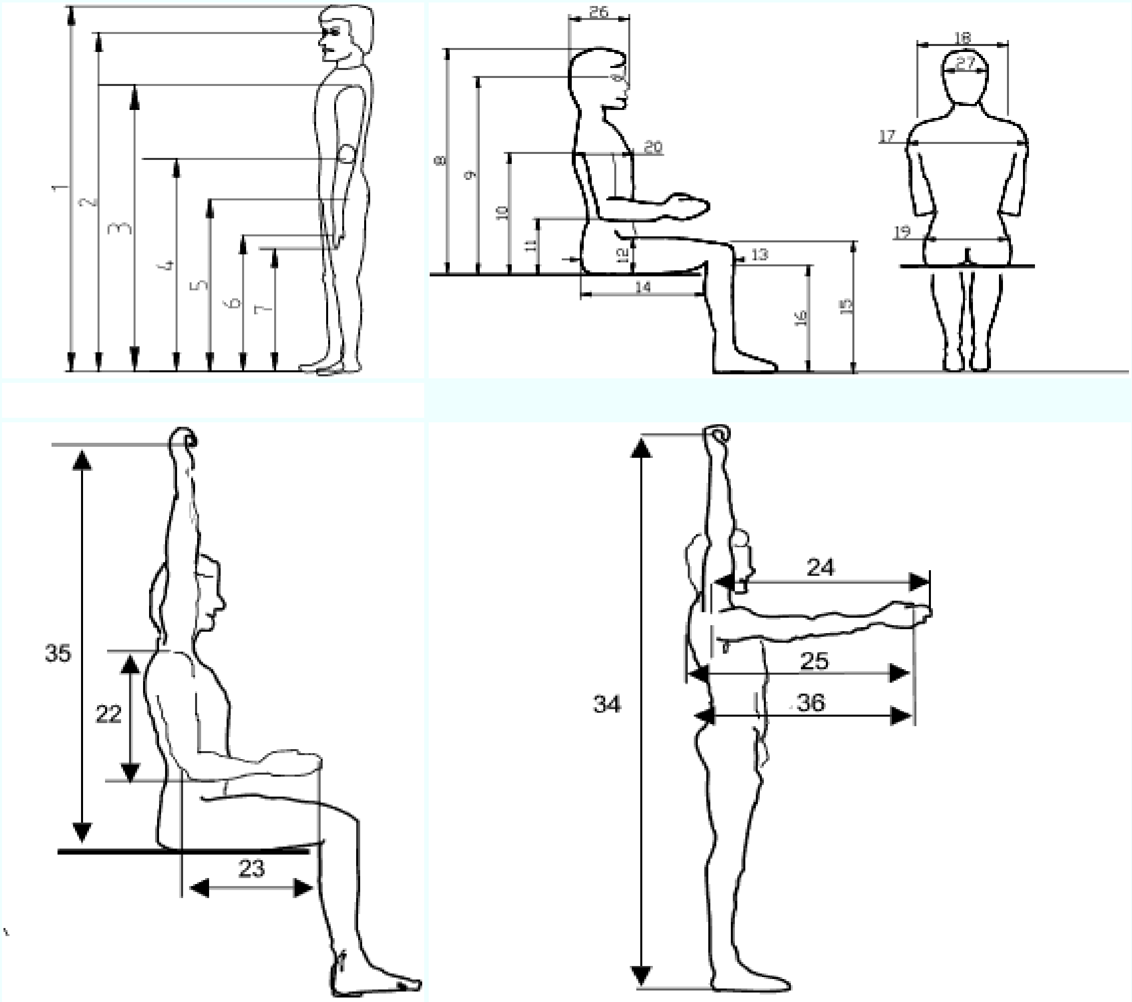
REFERENCES

Both "Aslaksen and Belcher" and "Blanchard and Frabycky" have good chapters on human interfaces.

Some Anthropometric Notes
(nicked off the Wikepedia entry on Anthropometry)

Anthropometric Data Standing Person

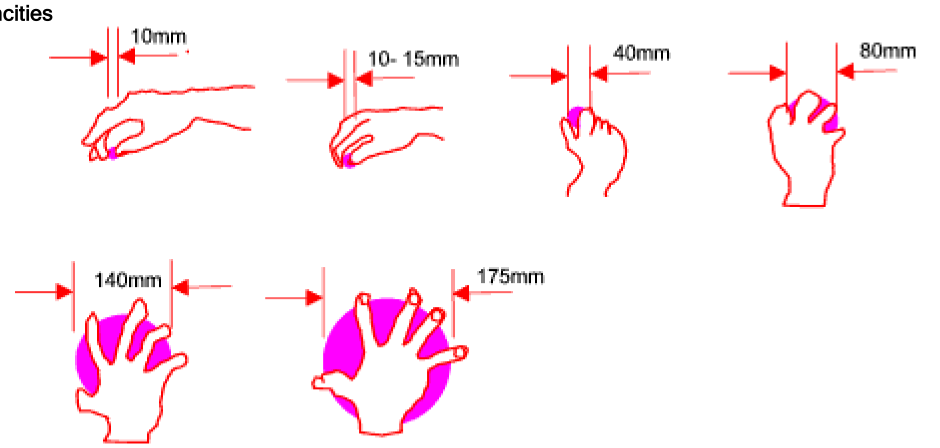
Note: The table relates to British person.
The 5% percentile indicates that 5% of people are smaller than the sizes given. The 95% percentile indicates that 95% of people are smaller than the sizes given. Therefore the size range show the mid 90% range of people sizes in the UK.



Dimension s	Man (Percentiles)		Women (Percentiles)	
	5%	95%	5%	95%
1- Height	1625	1855	1505	1710
2-Eye	1515	1745	1405	1610
3-Shoulder Height	1315	1535	1215	1405
4-Elbow Height	1005	1180	930	1085
5-Hip Height	840	1000	740	885
6-Knuckle Height	690	825	660	780
7-Fingertip Height	590	720	560	685
8-Sitting Height	850	965	795	910
9-Sitting Eye Height	735	845	685	795
10-Sitting Shoulder	540	645	505	610
11-Sitting Elbow Height	195	295	185	280
12-Thigh Thickness	135	185	125	180
13-Buttock-Knee Length	540	645	520	620
14-Buttock-popliteal length	440	550	435	530

15-Knee Height	490	595	455	540
16-Popliteal Height	395	490	355	445
17-Shoulder Breadth	420	510	355	435
18-Shoulder Breadth	365	430	325	385
19-Hip Breadth	310	405	310	435
20-Chest Depth	215	285	210	295
21-Abdominal Depth	220	325	205	305
22-Shoulder-Elbow Length	330	395	300	360
23-Elbow Fingertip Length	440	510	400	460
24-Upper Limb Length	720	840	655	760
25-Shoulder Grip Length	610	715	555	650
26-Head Length	180	205	165	190
27-Head Breadth	145	165	135	150
28-Hand Length	175	205	160	190
29-Hand Breadth	80	95	70	85
30-Foot Length	240	285	215	255
31-Foot Breadth	85	110	80	100
32-Span	1655	1925	1490	1725
33-Elbow Span	865	1020	780	920
34-Vertical Reach	1925	2190	1790	2020
35-Vertical Reach (sit)	1145	1340	1060	1235
35-Forward Grip Reach	720	835	650	755

Hand capacities



Maximum height of reach-

Note: As a very general rule the maximum height of reach = 1,24 x Body Length..

Sex	Stature	Percentile	To Fingertip(mm)	Grasping Height (mm)
Male	Tall	95	2310	2190
Male	Average	50	2180	2060
Male	Short	5	2040	1920
Female	Tall	95	2120	2020
Female	Average	50	2000	1900
Female	Short	5	1890	1790