ANTHROPOMETRY AND GLIDER COCKPIT DESIGN

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ABSTRACT

A range of important measurements of the human body, male and female, are given in table form. It is intended that this information will assist glider designers in building safer and more comfortable glider cockpits.

1. INTRODUCTION

Anthropometry is defined as the comparative study of the size and proportions of the human body. Most measurements of human characteristics vary according to a Gaussian distribution. It is more convenient to use a cumulative distribution, this giving an integral shaped curve. A percentile value is the figure indicating the percentage of people falling at or below (or above) a particular value.

Any one individual will have different percentile values for each of his body measurements. This complicates matters for the glider designer. Gliding is carried out all over the world. Different races differ in their physical measurements (Figure 1) (Ref. 1).

2. ANTHROPOMETRY AND AVIATION

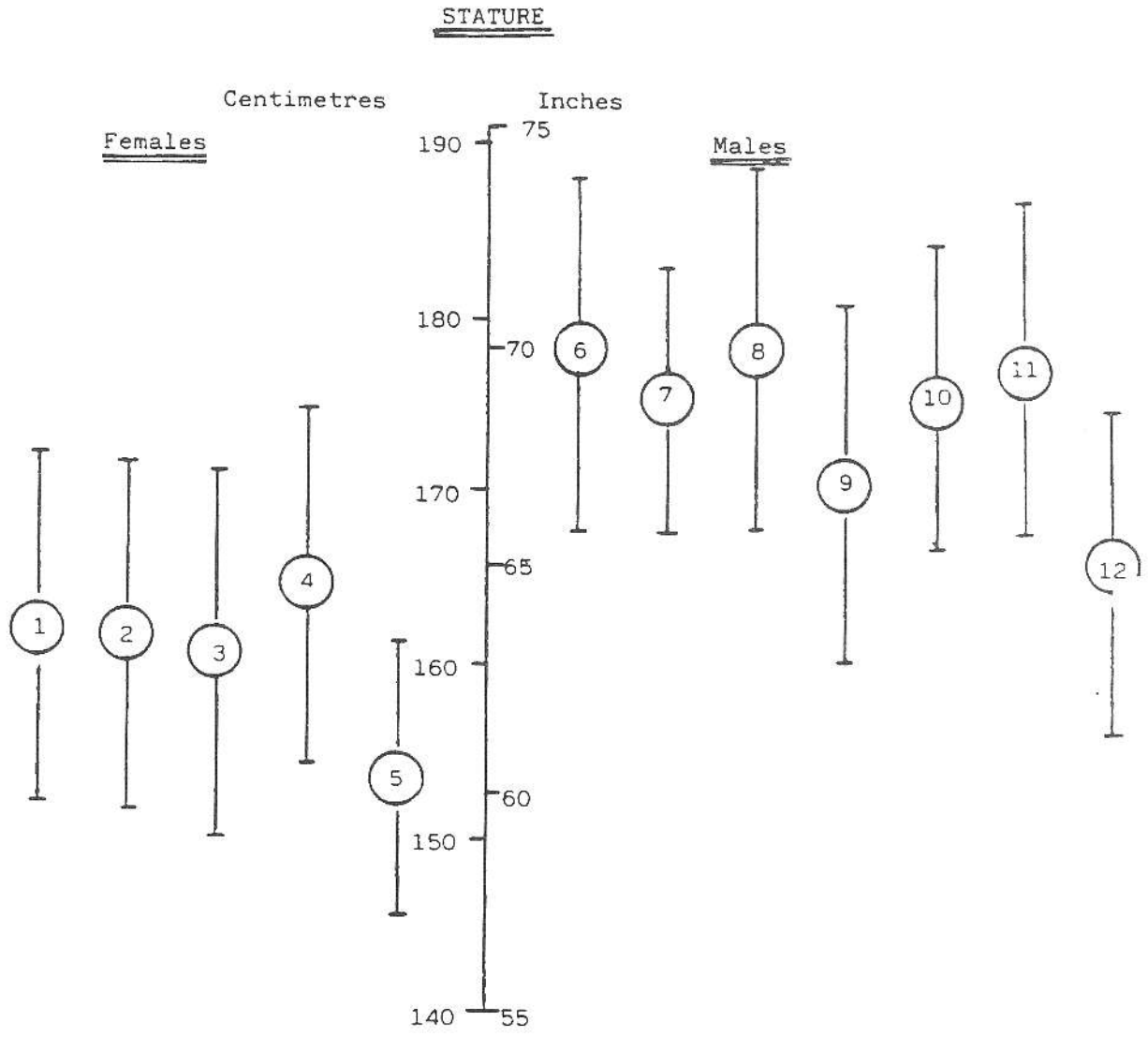
Anthropometry is of importance in military, commercial and sporting aviation.

In military aviation it is used in the initial selection of air crew, in deciding the type of aircraft they can fly, and in fitting the complex clothing and air crew equipment assemblies. In a new type of aircraft, the cockpit workspace has to be designed; in a current aircraft, the workspace may have to be re-evaluated. Military aircraft have special problems, such as providing a safe emergency ejection path, and the intrusion of heads up displays into the field of view.

In commercial aircraft limitations in the anthropometric aspects of design considerably reduce the pool of potential pilots. A study of the Boeing 737, 747, 757 and the Lockheed Tristar was carried out (Ref. 2). The selection criterion was the functional seated eye height. Considering a British population of 19-65 year olds, 13% of the male population and 73% of the female population would be excluded.

In gliding clubs considerable discontent has been voiced by tall and small pilots concerning cock-

FIGURE 1.



1. USAF
2. US Civilians
3. British Civilians
4. Swedish Civilians
5. Japanese Civilians
6. USAF Aircrew
7. NASA Astronauts
8. British Aircrew
9. Italian Military
10. French Aircrew
11. German Air Force
12. Japanese Civilians

Range of Variability (5th-95th Percentile) in Stature of Selected Populations

Source: NASA Anthropometric Service Book

pit workspace and ergonomic design; weight limits are also a problem. Tall pilots have to sit flexed forward under the canopy, with the consequent risk of spinal strain and injury. Their thighs may be pressed against the lower edge of the instrument panel. Full backward movement of the pilot's elbow may be limited by the cockpit structure, thus restricting full operation of the airbrake lever.

Small pilots, many of whom are women, have other anthropometric problems. To reach the controls and carry out full control movements, they have to sit forward on the seat. This usually entails placing a large

TABLE 1 - EXTRACT FROM ANTHROPOMETRIC SURVEY OF 2000 MALE RAF AIRCREW 1970/71
RAF INSTITUTE OF AVIATION MEDICINE, ROYAL AIRCRAFT ESTABLISHMENT TECHNICAL REPORT 73083, FARNBOROUGH, U.K.

PER-CENT-ILE	STATURE	WEIGHT	SITTING HEIGHT	SHOULDER HEIGHT SITTING	FUNCTIONAL ARM REACH	BUTTOCK KNEE LENGTH	BUTTOCK HEEL LENGTH	CROTCH HEIGHT	HIP BREADTH SITTING	BIDELTOID BREADTH	FOOT LENGTH	HAND LENGTH
	mm	kg	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	1638.0	55.8	864.7	604.3	722.0	549.6	974.5	758.0	323.7	418.7	238.5	168.7
2	1651.6	58.4	871.4	609.6	729.7	554.6	989.6	769.0	328.3	423.5	241.5	171.2
3	1660.5	59.5	876.2	614.3	735.6	557.9	997.9	775.3	332.1	426.8	244.0	172.7
5	1672.7	61.5	883.4	621.4	744.6	563.9	1007.1	785.0	337.1	431.7	246.9	174.8
10	1683.7	64.0	895.3	630.0	756.6	573.4	1021.9	798.6	343.5	439.3	250.2	178.7
15	1708.6	65.9	903.0	636.7	763.5	583.5	1035.0	807.7	348.0	443.8	253.0	180.9
20	1721.1	67.5	909.1	642.0	770.2	583.5	1045.2	817.5	351.4	447.8	255.1	182.8
25	1732.4	68.9	914.6	647.1	776.6	588.0	1054.1	823.7	354.3	451.4	257.0	184.2
30	1741.3	70.0	919.6	651.1	782.0	592.4	1062.1	830.5	356.8	453.8	258.8	185.5
35	1750.8	71.0	924.7	655.5	787.3	596.6	1069.5	836.1	359.5	457.1	260.4	186.8
40	1758.4	72.0	928.8	659.5	791.5	599.9	1075.8	842.5	362.5	459.6	261.8	188.1
45	1766.0	73.4	932.6	662.6	795.7	603.3	1082.5	847.3	364.8	461.9	263.3	189.5
50	1774.8	74.5	936.2	665.6	800.1	606.5	1087.9	853.4	367.0	464.8	264.9	190.6
55	1781.6	75.8	939.5	668.6	804.7	609.7	1094.8	857.9	369.6	467.5	266.5	191.6
60	1789.2	76.9	934.7	671.2	810.0	613.6	1100.5	862.9	371.8	470.2	268.5	193.3
65	1796.4	78.4	947.4	675.5	815.2	617.4	1109.1	868.4	374.5	473.7	270.1	194.5
70	1805.6	79.5	951.7	679.4	820.1	621.3	1115.8	873.7	377.6	476.3	271.8	195.8
75	1814.2	81.0	957.3	683.2	825.1	625.7	1125.3	880.3	381.3	479.3	273.6	197.4
80	1824.4	82.5	962.2	688.2	830.5	629.9	1134.9	888.0	383.9	482.8	275.7	199.2
85	1838.5	84.4	967.8	693.4	837.5	634.7	1143.8	896.1	388.1	486.7	278.0	200.9
90	1854.3	86.4	973.9	699.0	845.9	641.4	1155.2	906.2	393.2	491.9	280.9	203.5
95	1897.3	90.1	986.1	708.8	859.2	652.4	1173.1	926.8	400.3	499.7	285.4	206.9
97	1892.8	92.5	992.3	714.7	871.1	658.5	1188.1	936.2	406.1	505.4	289.1	209.3
98	1905.0	94.0	998.0	719.0	878.0	663.8	1201.7	948.0	409.5	509.8	291.0	211.8
99	1924.0	96.6	1007.0	727.0	889.4	671.7	1210.7	960.0	414.7	513.7	296.5	215.6
MEAN	1774.4	75.1	936.0	665.7	801.7	607.6	1089.9	853.5	368.3	465.8	265.9	191.4
STAND. DEV.	62.3	8.8	31.0	26.7	35.8	26.9	51.4	43.0	19.5	20.8	12.1	9.8
RANGE												
MIN:	1514.0	51.0	824.0	577.0	678.0	515.0	889.0	700.0	310.0	396.0	219.0	157.0
MAX:	2009.0	109.0	1026.0	754.0	946.0	693.0	1276.0	1011.0	436.0	547.0	309.0	229.0

number of cushions behind the pilot. This seating position is unstable, and the pilot may also be pressed back under "g-loading." With the control column fully back, lateral movement may be restricted by the pilot's thighs. The field of view is usually not a problem as gliders have excellent one-piece canopies, and the landing approach path is steep.

Two recent fatal accidents in the United Kingdom involved short female pilots. Both accidents had considerable anthropometric aspects in their causation (Ref. 3).

3. MEASUREMENTS

The following measurements were used. The test subjects were lightly clothed, so allowance should be made for flying clothing. The descriptions of the measurements are taken from the RAF study (Ref. 4); the USAF study may differ in detail (Ref. 5).

Stature. Standing erect head facing forward. Measurement from floor to datum probe at vertex.

Weight. Standing on spring scales.

Sitting height. Sitting erect with head forward facing and shoulders relaxed, back clear of rear wall. Elbows held lightly against sides with hands on mid-thighs. Measurement from floor to datum probe at vertex. Sitting height derived by subtraction of stool height from this measurement.

Shoulder height sitting. Sitting erect with shoulders relaxed, back clear of rear wall. Elbows held lightly against sides with hands on mid-thighs. Measurement from floor to datum probe at 90mm mark on left shoulder. Shoulder height derived by subtraction of stool height from this measurement.

Functional arm reach. Sitting erect with back and buttocks firmly against perspex panel; equal pressure of shoulders against panel (monitored from mirror). Arms extended horizontally with forefinger and thumb opposed, thumb in line with extended arms. Measurement from end wall to datum probe at tip of left thumb.

Buttock-knee length. Sitting erect with back and buttocks firmly against end wall, thighs parallel to rear wall and feet flat on floor. Knee block placed vertically on left knee against patella. Measurements from end wall to datum probe at knee block datum face.

Buttock-heel length. Sitting on rig floor, back to end wall. With both legs straight, buttocks pushed back to wall as far as possible. Measurement from end wall to heel block in light contact with left heel, using scale along rig floor.

Crotch height. Standing erect, back to rear wall, feet approximately 150mm apart. Datum probe placed firmly into perineum without accommodating upper thigh, or buttocks. Measurement from floor to datum probe.

Hip breadth, sitting. Sitting erect with knees together. Measurement with datum faces of caliper in light contact with buttocks at widest point.

Thigh-to-thigh breadth, sitting (Study of USAF women). Subject sits erect, thighs parallel and completely sup-

TABLE 2 - EXTRACT FROM ANTHROPOMETRIC SURVEY OF 1905 USAF WOMEN (NON-AIRCREW), 1968.
AEROSPACE MEDICAL RESEARCH LABORATORY, WRIGHT-PATERSON AFB, USA, REPORT NO. AMRL-TR-70-5 (1972)

PER CENT-ILE	STATURE	WEIGHT	SITTING HEIGHT	SHOULDER HEIGHT SITTING	FUNCTIONAL ARM REACH	BUTTOCK KNEE LENGTH	BUTTOCK HEEL LENGTH	CROTCH HEIGHT	THIGH BREADTH SITTING	BIDELTOID BREADTH	FOOT LENGTH	HAND LENGTH
	mm	kg	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	1495.2	43.71	786.9	522.7	652.7	517.5	*	657.5	321.3	366.7	215.3	163.6
2	1505.2	44.54	793.4	528.3	661.8	523.3		667.0	328.3	373.0	217.8	165.8
3	1512.6	45.25	797.8	532.0	668.0	527.1		673.0	332.6	376.9	219.5	167.2
5	1523.7	46.40	804.3	537.3	676.7	532.4		681.3	338.4	382.2	221.9	169.0
10	1542.8	48.47	814.8	545.8	690.7	540.8		694.4	347.1	390.1	225.8	171.9
15	1556.7	50.02	822.3	551.9	700.4	546.7		703.4	353.0	395.3	228.6	174.0
20	1568.1	51.30	828.3	556.7	708.1	551.5		710.7	357.8	399.4	230.7	175.6
25	1578.2	52.44	833.7	561.1	714.8	555.7		717.0	362.0	403.0	232.7	177.1
30	1587.3	53.48	838.5	565.0	720.8	559.6		722.8	365.8	406.2	234.4	178.4
35	1595.8	54.44	843.0	568.7	726.3	563.2		728.3	369.4	409.2	236.0	179.6
40	1604.0	55.37	847.2	572.2	731.5	566.6		733.5	372.8	412.2	237.5	180.9
45	1611.9	56.28	851.4	575.6	736.5	570.0		738.6	376.3	414.8	239.0	182.1
50	1619.7	57.19	855.5	579.1	741.5	573.4		743.7	379.7	417.6	240.5	183.3
55	1627.6	58.10	859.6	582.6	746.4	576.8		748.9	383.3	420.4	241.9	184.5
60	1635.5	59.04	863.8	586.1	751.3	580.3		754.1	386.9	423.3	243.4	185.8
65	1643.7	60.02	868.1	589.8	756.4	584.0		759.6	390.8	426.3	244.9	187.1
70	1652.3	61.07	872.7	593.7	761.7	587.8		765.5	395.0	429.6	246.6	188.5
75	1661.6	62.23	877.6	597.9	767.4	592.1		771.9	399.6	433.1	248.3	190.1
80	1672.0	63.57	883.1	602.6	773.8	596.8		779.1	405.0	437.2	250.3	191.8
85	1683.9	65.18	889.4	608.1	781.1	602.2		787.5	411.3	442.1	252.6	193.9
90	1699.0	67.35	897.3	615.0	790.5	609.1		798.1	419.7	448.5	255.5	196.5
95	1721.5	70.93	908.9	625.2	804.5	619.1		813.8	432.6	458.8	259.8	200.5
97	1736.2	73.57	916.4	631.7	813.9	625.4		823.9	441.4	465.5	262.7	203.0
98	1747.2	75.70	921.9	636.3	820.9	629.8		831.3	448.0	470.8	264.9	204.8
99	1764.8	79.47	930.5	643.6	832.5	636.6		842.5	458.6	479.5	268.3	207.6
MEAN	1621.0	57.73	856.0	580.0	741.3	574.3		745.0	381.9	418.7	240.7	183.8
STAND. DEV.	6.0	7.52	31.7	26.6	38.8	26.3		40.3	28.6	23.1	11.3	9.6
RANGE												
MIN:	1442.5	37.46	752.5	507.5	622.5	482.5		602.5	287.5	347.5	207.5	152.5
MAX:	1832.5	91.94	967.5	672.5	872.5	667.5		882.5	502.5	502.5	277.5	220.5

* see Table 3 for approximation

ported by the sitting surface. With a beam caliper, measure the maximum horizontal distance across the thighs.

Bi-deltoid breadth (shoulder breadth). Sitting erect with shoulders relaxed, back clear of rear wall. Elbows held lightly against sides with hands on mid-thighs. Light pressure exerted by right deltoid against perspex panel such that a circle of approximately 30mm diameter of the skin over the muscle is in contact with the perspex (monitored from mirror). Measurement from end wall to datum probe at maximum prominence of left deltoid muscle.

Foot length. Sitting erect with left foot in foot box, heel against back face and inner side of foot against side of box. Measurement from back face of box to datum face of slide in light contact with tip of longest toe.

Hand length. Elbow-fingertip length less elbow-wrist length.

(Elbow-fingertip length. Standing erect, back to end wall. Left upper arm horizontal with elbow touching end wall. Left forearm horizontal and parallel to rear wall with hand and fingers outstretched in line with forearm. Measurement from end wall to datum probe at tip of longest finger of left hand.)

(Elbow-wrist length. Standing erect, elbow touching end wall. Left forearm horizontal, parallel to rear wall and rotated so that back of hand faces rear wall with wrist mark uppermost. Measurement from end wall to datum probe at wrist mark.)

4. APPLICATION OF DATA

The classic study of 2000 male RAF air crew (Ref. 4) provides the anthropometric data for Table 1. This was a joint study by the RAF Institute of Aviation Medicine and the Royal Aircraft Establishment, Farnborough, England.

An interesting comparative study was carried out by the Army Personnel Research Establishment, Farnborough. This compared the anthropometric characteristics of Guardsmen (chosen particularly for their height), Royal Armored Corps servicemen, and Infantrymen. These figures were then compared with the above RAF air crew findings (Ref. 7).

Considering "Stature," the following table was drawn up.

	PERCENTILE			RANGE
POPULATION	3	50	97	
Guardsmen	171.60	178.80	194.40	170.60 - 197.20 cm.
Air crew	166.05	177.42	189.28	151.40 - 200.90 cm.
R.A.C.	162.10	173.88	185.80	155.30 - 196.00 cm.
Infantry	161.61	173.03	185.40	153.80 - 193.60 cm.

* It is clear that by using the upper figures from the RAF air crew study, a glider cockpit would fit tall large pilots.

TABLE 3

EXTRACT FROM ANTHROPOMETRIC SURVEY OF 17 FEMALE RAF AIRCREW, 1993. RAF INSTITUTE OF AVIATION MEDICINE, FARNBOROUGH, UK. UNPUBLISHED DATA.

SUBJECT NUMBER	CROTCH HEIGHT	BUTTOCK HEEL LENGTH	DIFFERENCE
	mm	mm	mm
7	700	945	245
13	717	984	267
15	720	1010	290
10	738	1014	276
17	742	989	247
12	746	1049	303
6	751	996	245
16	760	1016	256
11	762	1046	284
4	768	1049	281
5	772	1023	251
8	773	1056	283
1	776	1036	260
14	779	1025	246
2	796	1046	250
3	813	1116	303
9	834	1060	226
MEAN	761.5	1027.0	265.5

SURVEY OF USAF WOMEN (NON-AIRCREW), 1968. REPORT NO. AMRL-TR-70-5 (1972).

PER-CENT-ILE	(USAF) CROTCH HEIGHT	(RAF) DIFFERENCE MEASURED	(RAF) MEAN DIFFERENCE	(USAF) ESTIMATED BUTTOCK HEEL LENGTH
	mm	mm	mm	mm
1	657.5		265.5	923.0
2	667.0		265.5	932.5
3	673.0		265.5	938.5
5	681.3		265.5	946.8
10	694.4		265.5	959.9
15	703.4	245.0	265.5	968.9
20	710.7		265.5	976.2
25	717.0	267.0	265.5	982.5
30	722.8	290.0	265.5	988.3
35	728.3		265.5	993.8
40	733.5		265.5	999.0
45	738.6	276.0	265.5	1004.1
50	743.7	247.0	265.5	1009.2
55	748.9	303.0	265.5	1014.4
60	754.1	245.0	265.5	1019.6
65	759.6	256.0	265.5	1025.1
70	765.5	281.0	265.5	1031.0
75	771.9	251.0	265.5	1037.4
80	779.1	246.0	265.5	1044.6
85	787.5		265.5	1053.0
90	798.1	250.0	265.5	1063.6
95	813.8	303.0	265.5	1079.3
97	823.9		265.5	1089.4
98	831.3	226.0	265.5	1096.8
99	842.5		265.5	1108.0

The USAF study of non-air crew women provided the anthropometric data for Table 2 (Ref. 5). Although some of the measurement techniques differed slightly from those used in the RAF study, the results are comparable. In the female table, thigh breadth sitting was used, as against the male study in which hip breadth sitting was considered to be the suitable measurement.

It will be noted that in the female study buttock-heel length was not recorded. Crotch height was recorded, presumably for the purpose of measuring for uniforms. Knowledge of buttock-heel length is essential for establishing the position of the rudder pedals in the cockpit. It will be recalled that this study was of a non-air crew population.

A study of 17 female RAF air crew has been carried out by the RAF Institute of Aviation Medicine, Farnborough (Ref. 6). I have been kindly allowed to use unpublished data from this study. Table 3 shows the difference between the buttock-heel length and the crotch height of the subjects. These difference figures have then been placed against the comparable figures for crotch height from the USAF female study. It is clear that the difference figures are of random value as they go down the percentile table. I have therefore taken the mean value for the difference, 265.5mm. I have added this to the USAF crotch height measurement to obtain an approximate buttock-heel length. I consider this value is sufficiently accurate for the present study.

* By using the lower figures from the USAF female study, the cockpit would fit short women and short men.

The special value of some of the measurements is as follows.

Stature and weight. Self evident.

Sitting height. Height under the canopy. Allowance must be made for the pilot's semi-reclining position, and the resulting forward flexion of the pilot's head.

Shoulder height sitting. Establishing the position of the shoulder straps.

Functional arm reach. The hand operated controls and the instrument panel are within reach.

Buttock-knee length. This establishes the position of the knee in relation to the instrument panel.

Buttock-heel length. This determines the position of the rudder pedals.

Crotch height. Included in this study so as to calculate the female buttock-heel length. Of possible use in establishing the position of the 5th seat harness strap.

Hip breadth sitting.Thigh breadth sitting. Bi-deltoid breadth. These measurements determine the width of the cockpit.

Foot length. This gives the size and position of the rudder pedals.

Hand length. This helps determine the size of the hand

operated controls.

5. CONCLUSIONS

There is a traditional English song that goes as follows:

"Bless 'em all, Bless 'em all,
The long and the short and the tall."

It is to be hoped that the next generation of gliders will have cockpits that will enable long, short and tall pilots to glide in safety, comfort and joy.

An anthropometric study of an actual glider pilot population would enable the measurements given in this paper to be validated for that population.

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