BODY MEASUREMENTS IN RELATION TO COCKPIT DESIGN

Sqn. Ldr. M.K. Mookerjee,

AND

Shri M.N. Bhattacharya, Defence Science Laboratory.

It would be most expedient to take body measurements into account in designing machines of war. If they have been made without detailed regard to the sizes of their occupant, then it is desirable that body measurements should be taken into account in selecting the man for particular duties, so that no discomfort or strain is experienced in the functions of normal duties and movements. Majumdar (1) from the analysis of observations on 371 normal subjects representing seven different States found that for more than 95% of the subjects the ratio W/A was within 66-85 lb/m². European figure given by Forbes (2) being 77.4-93.9 lb/m². Patwardhan (3) from the analysis of available data, which he admits to be "pitifully inadequate" showed that an average Indian boy is about 64" in height at the age of 16 years. Taking normal growth curve into consideration it may be said that average Indian height is round about 66½", as compared to American and British figure which is about 68½" (4). It is obvious from the foregoing facts that shape and size of an average Indian is different from that of other countries and that the cockpit designed and constructed in our country must take into consideration body measurements of its occupant.

Owing to dearth of adequate information, data available from other countries is utilised by aircraft designers in this country in working out dimensions of cockpit work area for operation of manual controls of aircraft. It was, therefore, felt that basic data must be collected to have a knowledge on variation of body measurements of average population in India, which would obviously help the designer to introduce changes in the dimensions of cockpit.

Method and Analysis

Altogether twenty body measurements and body weights were taken of 691 airmen other than pilots, belonging to local Air Force Stations. Definitions of the measurements and method adopted are given below:

Technique of Body Measurements

Measuring Board

This has two vertical wings adjusted firmly at right angles to one another in the corner of the room, on which scales are marked in ½ cm. interval. The subject adopts a specified position with his body in contact with one or both wings, according to the nature of the particular measurements. The triangular block is in contact with the board. Alignment with the scale ensures that the working surface of the block is horizontal or vertical as the case may be and the measurement required is taken from the zero plane of the floor or from

the vertical zero line for the wing joints. The stool is used in taking measurement of the subject seated. It is 13½" in height, blocks of woods (½" thick) provided are placed on it until it appears that the subject's thighs are as nearly as possible horizontal.

Definitions of all the Measurements

1. **Top head to Floor.** The height of the seat is first adjusted by adding to or reducing the number of pieces of wooden blocks on it until the thighs of the subject appear to be as nearly as possible horizontal. He sits erect in the corner with the back against one wing of the board and his right side touching the other wing. The height from the floor when the block is placed on the subject's head is noted.

2. **Sitting Height.** The height of the seat is subtracted from the first measurement to give the sitting height.

3. **Seat to Floor.** Height of the stool and height of the pieces of wooden block added to make thigh appear horizontal (each block ½" thick).

4. **Shoulder to Seat.** Sits erect in the corner as in (1). arm touching against the side of the body and the fore-arm at right angle and arm with palm stretched facing inwards. The block is placed on the shoulder point. The height noted and the seat height is subtracted to give this height.

5. **Elbow to Seat.** Subject in the same position (4). Height from floor when the block is placed at the lower edge of fore-hand is noted and substracted from seat height.

6. **Knee Height.** Subject in the same position, block is placed on the right thigh, the height is noted from the floor to the mid point of the thigh.

7. **Eye to the top of the Head.** By the help of improvised measuring scale, height from the lable of the outer canthus of left eye to the top of the head is measured.

8 **Thigh.** Subject in the same position. The subject presses his right thigh against the wing of the board and sits back into the corner as "hard" as possible. His lower right leg should be vertical and his legs slightly seperated. The block is brought into contact with the most advanced point on the right knee. Measurement is noted. Mid point of the thigh is also noted.

9. **Total Leg.** Subject in the same position with his back, shoulder and buttocks against one wing of the board, both legs being fully extended over another stool kept at the same height before him and felt vertical. He is asked to sit as hard as possible and even when doing this his lumber region of contact will usually be near the upper edge of the sacrum and not on the buttocks. The block is brought into contact with the planter aspect of the right foot.

10. **Heel on the Floor with Leg Extended.** Subject sitting in the same position as before, the stool is removed, stretched leg is kept on the floor and the foot at right angle

with leg with the knee completely extended. This resulted in slight forward movement of the pelvis. This was done to get the effective leg length.

11. **Fore-arm.** Subject sits back "hard" at the corner, right arm pressed at the board, arm along the art plane of the body, fore-arm at right angle with the palm facing inward, finger stretched, block placed against farther most point of the tip of the finger.

12. **Arm.** Subject same position, hand completely stretched at right angle to the body and pressed against the board, palm open facing inward. Block placed against the tip of the middle finger.

13. **Chest.** Subject in the same position block placed at the nipple level.

14. **Abdomen.** Subject in the same position block placed at the umbilical level.

15. **Head.** Width between two temporal region by the help of anthropometer or block.

16. **Shoulder.** Subject maintains the same position as for sitting height with his shoulder pressed with back against the board. The block is brought in contact with the outer surface of the left arm over the deltoid. This was found one of the least accurate of the body measurement, lack of precision in determining it being due to slight difference in posture which is difficult to control.

17. **Elbows.** Subject maintaining the same posture as for shoulder with his fore-arm at right angle to the body, the block is brought into contact with the most advanced point at the left elbow.

18. **Seat-maximum below Hips.** Subject presses his right thigh against the wing of the board and sits back into the corner as "hard" as possible. His lower leg should be vertical and slightly separated. Block placed against the left thigh.

19. **Span Akimbo.** Subject stands with the back pressed against the broader wing of the board. Elbows are stretched out and at right angle to the body pressing against the board, palms over the breast plate. Subject adjusts his position till his left elbow touches the other board. Block is brought in contact with the advanced point of the right angle.

20. **Maximum Span.** Same position both hands are stretched pressing against the board at right angle to the body, with his palm facing out. Measurement from finger tip to finger tip.

21. **Weight.**

For purposes of statistical analysis of the data, subjects have been grouped into five State groups. The names of the State groups with the number of subjects belonging to each one of them are given below.

TABLE I.

Mean Standard Deviation and Standard Error for the Different body measurements (in cm) and body weight (in lbs) of 691 I.A.F. Personnel, Grou

Index No.	Body measurement (in cm)	No. of Sub-ects.	Bengal-Bihar-Assam			Bombay-C.P.				Punjab-Delhi				Madras, T.C., Mysore				U.P.			
			mean x	D.S. 6	Stand-ard $6/\sqrt{n}$ error	n	$\bar{x}$ mean	6 S.D.	$6/\sqrt{n}$ SE	n	x mean	6 S.D.	$6\sqrt{n}$ S.E	n	x mean	6 S.D.	$6/\sqrt{n}$	S.E. n	Mean $\bar{x}$	S.D. 6	S.E. $6/\sqrt{n}$
1.	Top of head to floor	94	126.67	3.23	.32	59	125.59	3.93	.51	199	128.06	3.83	.27	283	125.44	4.10	.24	56	126.77	4.26	.57
2.	Sitting height	,,	87.89	2.77	.28	,,	86.79	2.73	.36	,,	88.56	2.95	.20	,,	86.12	2.92	.18	,,	87.52	2.71	.36
3.	Seat to floor	,,	38.71	2.21	.22	,,	38.74	2.12	.28	,,	39.41	2.07	.14	,,	39.22	2.16	.13	,,	39.17	2.37	.32
4.	Shoulder to seat	,,	59.53	2.68	.28	,,	58.81	2.07	.27	,,	60.07	2.45	.17	,,	58.39	2.65	.16	,,	59.48	2.74	.37
5.	Elbow to seat	,,	23.87	2.02	.20	,,	22.60	2.33	.30	,,	23.67	2.22	.16	,,	22.74	2.38	.14	,,	23.95	1.97	.26
6.	Knee height	,,	54.13	2.20	.22	,,	54.64	1.94	.25	,,	55.37	2.24	.16	,,	54.65	2.06	.12	,,	54.45	2.43	.33
7.	Eye to top of head	,,	10.84	0.83	.06	,,	10.85	0.67	.08	,,	11.11	1.28	.09	,,	10.91	0.94	.05	,,	10.96	1.00	.13
8.	Thigh	,,	58.17	2.48	.26	,,	58.11	2.47	.32	,,	58.77	2.32	.17	,,	58.01	2.42	.14	,,	57.81	2.63	.35
9.	Total leg	,,	107.68	4.48	.46	,,	108.54	4.50	.58	,,	109.76	4.51	.33	,,	108.23	4.42	.26	,,	107.71	4.88	.66
10.	Heel on floor with leg extended	,,	93.21	4.61	.48	,,	94.31	4.27	.56	,,	95.53	4.45	.31	,,	93.49	4.30	.26	,,	93.94	4.44	.59
11.	Fore arm	,,	54.15	3.10	.35	,,	54.71	2.74	.36	,,	55.20	3.19	.22	,,	54.07	2.98	.18	,,	54.21	3.09	.41
12.	Total arm	,,	82.57	3.14	.32	,,	82.99	2.81	.36	,,	84.23	3.29	.23	,,	82.83	3.71	.22	,,	83.13	3.86	.52
13.	Chest	,,	22.63	1.25	.13	,,	22.12	1.29	.17	,,	22.40	1.33	.09	,,	22.29	1.30	.24	,,	22.17	1.37	.18
14.	Abdomen	,,	23.46	1.68	.18	,,	22.78	1.70	.22	,,	23.15	1.58	.11	,,	22.98	1.81	.11	,,	22.83	1.61	.22
15.	Head	,,	15.46	0.64	.06	,,	15.30	0.55	.07	,,	15.25	0.83	.05	,,	15.34	0.72	.04	,,	15.18	0.63	.08
16.	Shoulder	,,	42.38	1.93	.20	,,	42.59	1.94	.25	,,	42.38	1.90	.13	,,	41.74	2.02	.12	,,	41.94	1.88	.25
17.	Elbow	,,	42.65	2.90	.30	,,	42.84	2.44	.33	,,	42.87	2.10	.14	,,	42.20	2.47	.14	,,	42.29	2.02	.27
18.	Seat maximum below hips	,,	36.64	1.87	.19	,,	36.78	1.76	.22	,,	37.39	1.77	.13	,,	36.38	1.79	.11	,,	36.73	1.89	.25
19.	Span Akimbo	,,	106.64	3.78	.39	,,	106.97	3.23	.42	,,	108.25	3.92	.28	,,	106.13	3.73	.22	,,	106.82	4.12	.18
20.	Maximum span	,,	171.60	6.60	.68	,,	172.74	5.69	.76	,,	174.45	6.91	.49	,,	171.09	6.34	.37	,,	171.23	8.13	1.09
21.	Body weight (in lbs)		125.01	16.52	1.70		122.93	12.88	1.68		126.71	13.25	1.08	,,	122.51	14.08	0 84	,,	123.71	16.54	2.21

It has been noticed from the above analysis that for all body measurements except seat to floor, eye to top of head, fore arm, chest, abdomen, head, shoulder and elbow the P
the other groups. For the above measurements no significant difference exists between the State groups.

ped into Five State-Groups.

	Overall			
n	Mean x	S.D. 6	S.E. $6/\sqrt{n}$	Remarks
691	126.48	4.02	.15	Punjab-Delhi Grp. significantly higher than the average.
,,	87.23	3.11	.12	
,,	39.16	2.18	.08	
,,	59.15	2.73	.10	do
,,	23.25	2.32	.09	
,,	54.77	2.18	.08	
,,	10.96	1.00	.04	
,,	58.24	2.54	.09	do
,,	108.58	4.57	.17	
,,	94.15	4.41	.17	
,,	54.47	3.13	.12	
,,	82.23	3.50	.13	
,,	22.34	1.38	.05	
,,	23.06	1.78	.07	
,,	15.23	0.59	.02	
,,	42.10	1.99	.07	
,,	42.52	2.35	.09	
,,	36.77	1.82	.07	do.
,,	106.94	3.82	.14	
,,	172.23	6.79	.25	
,,	124.20	14.93	.57	Slightly higher than average

njab-Delhi group is significantly higher than

State Group	Number of subjects
Bengal, Bihar and Assam	94
Bombay and Madhya Pradesh (C.P.)	59
Punjab and Delhi	199
Madras, Travancore-Cochin and Mysore	283
Uttar Pradesh (U.P.)	56
Total	691

From the point of view of stature each State group was supposed to be homogeneous. Purpose of this grouping was to test whether there is any significant difference between the groups so far as the body measurements are concerned. Because in case of hetrogeneity among groups a dimensional limit based on the results of pooled data will be misleading. In that case the best solution will be to calculate say 95% upper and lower limits for each State group separately and take the lowest of the lower limits and highest of the higher limits as the preliminary dimensional limits for design. The final limits will be determined after proper trials and technical considerations. As the present analysis is intended for fixing up the preliminary limits we shall give limits as indicated above in the report. Result of statistical analysis of the data are given in Table I.

TABLE II

Ninety-five percent limits (IC$\pm$1.966) for different body measurements and body weight for five State groups

Sl. No.	Body measurements (cm).	State Groups I 95% limits Lower limit	I 95% limits Upper limit	II 95% limits Lower limit	II 95% limits Upper limit	III 95% limits Lower limit	III 95% limits Upper limit	IV 95% limits Lower limit	IV 95% limits Upper limit	V 95% limits Lower limit	V 95% limits Upper limit
1.	Top of head to floor	120.34	133.00	117.90	133.28	120.55	135.57	117.40	133.48	118.42	135.12
2.	Sitting height	82.45	93.33	81.44	92.14	82.78	94.34	80.41	91.83	82.22	92.82
3.	Seat to floor	34.37	43.05	34.59	42.89	35.35	43.47	34.98	43.46	34.52	43.82
4.	Shoulder to seat	54.29	64.77	54.75	62.87	55.28	64.86	53.19	63.59	54.11	64.85
5.	Elbow to seat	19.91	27.83	18.04	27.16	19.32	28.02	18.08	27.40	20.08	27.82
6.	Knee height	49.83	58.43	50.83	58.45	50.98	59.76	50.61	58.69	49.70	59.20
7.	Eye to top of head	9.22	12.46	9.53	12.17	8.61	13.61	9.07	12.75	9.01	12.91
8.	Thigh	53.30	63.04	53.27	62.95	54.23	63.31	53.26	62.76	52.66	62.96
9.	Total leg	98.91	116.45	99.73	117.35	100.92	118.60	99.56	116.90	98.15	117.27
10.	Heel on floor with leg extended	84.17	102.25	85.95	102.67	86.82	104.24	85.06	101.92	85.24	102.64
11.	Fore arm	48.07	60.23	49.34	60.08	48.94	61.46	48.23	59.91	48.16	60.26
12.	Total arm	78.42	88.72	77.49	88.49	77.78	90.66	75.56	90.10	75.57	90.69
13.	Chest	20.18	25.08	19.60	24.64	19.79	25.01	19.73	24.85	20.01	25.30
14.	Abdomen	20.16	26.76	19.44	26.12	20.06	26.24	19.44	26.52	19.68	25.98
15.	Head	14.21	16.71	14.23	16.37	13.63	16.87	13.93	16.75	13.94	16.42
16.	Shoulder	38.60	46.16	38.80	46.38	38.66	46.10	37.79	45.69	38.25	45.63
17.	Elbow	36.97	48.33	38.05	47.63	38.75	46.99	37.35	47.05	38.34	46.24
18.	Seat Maximum below hips	32.98	40.30	33.34	40.22	33.93	40.85	32.87	39.89	33.03	40.43
19.	Span Akimbo	99.23	114.05	100.65	113.29	100.56	115.94	98.82	113.44	98.74	114.90
20.	Maximum span	158.67	184.53	161.59	183.89	160.90	188.00	158.67	183.51	155.30	187.16
21.	Weight (lbs)	92.61	157.41	97.69	148.17	96.82	156.60	94.91	150.11	91.29	156.13

Appended Table II gives the 95% limits for all the body measurements and body weights for each State group separately. Table III gives the lowest of lower limits and highest of the upper limits of the State groups for each measurement.

TABLE III

Limits for Different Body Measurements

Sl. No.	Body measurement (cm.)	Lower limit	Upper limit
1.	Top of head to floor	117.40	135.57
2.	Sitting height	80.41	94.34
3.	Seat to floor	34.37	43.47
4.	Shoulder to seat	53.19	64.86
5.	Elbow to seat	18.08	28.02
6.	Knee height	49.70	59.76
7.	Eye to top of head	8.61	13.61
8.	Thigh	52.66	63.31
9.	Total leg	98.15	118.60
10.	Heel on floor with leg extended	84.17	104.24
11.	Fore arm	48.07	61.46
12.	Total arm	75.56	90.66
13.	Chest	19.60	25.08
14.	Abdomen	19.44	26.76
15.	Head	13.63	16.87
16.	Shoulder	37.79	46.38
17.	Elbows	36.97	48.33
18.	Seat maximum below hips.	32.87	40.85
19.	Span akimbo	98.74	115.94
20.	Maximum span	155.30	188.00
21.	Body weight (lbs.)	91.29	156.60

Table III gives the lowest of lower limits and highest of the upper limits of the Appended Table II gives

Conclusion

It may be mentioned, that static body measurements can seldom be trusted to give all the answers to the problem of determining the best dimensions of work space. For example, arm reach increases as it is moved from 0° to 105° from the mid-sagital plane of the body at the shoulder level and is decreased when the arm is raised or lowered at any angle. Similarly, distance of rudder pedals from the seat reference point and its range of movements can be better appreciated in a trial than from static measurements of leg length in any particular position. Experimental trial in a "mock -up" cockpit having the lay out accepted for standardisation purpose is essential before any decision is reached regarding cockpit dimension.

References

1. Majumdar N.C. Thermal Insulation of Clothing and Tolerance Time to Cold Stress —J. Ind. Physiol, 7, 205 (1953).
2. Forbes W. H. Appendix Physiology of Heat Regulation and the Science of Clothing by L.H. Newburgh (1949).
3. Patwardhan V.N. Nutrition in India (1952).
4. Sunderman F.W. and Boerner F. Normal Value in Clinical Medicine (1949)