BODY MEASUREMENTS AND CRITICAL DIMENSIONS OF SINGLE SEAT FIGHTER COCKPIT FOR I. A. F.*

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Summary

An attempt is made to work out the space requirements in a single seat fighter aircraft for the pilots of I. A. F. The method adopted is the same as that adopted by the R. A. F., "Mock-up Approach" which is based on dynamic anthropometry. The mock-up was obtained from H. A. L. and was fitted with an adjustable seat and primary controls. Trials were carried out with 20 I. A. F. pilots of varied experience and covering the full range of heights. The final results were obtained by referring the resultant data to the known distribution of height measurements of a randon sample of 503 I. A. F. pilots. The results are compared with those of the R. A. F. "standard" single seat fighter cockpit.

Introduction

We have reached a stage in military aviation in India, where we shall increasingly depend on indigenous production for our operational aircraft. In so progressing, we must keep in view the larger aim that man must be integrated with the aircraft in such a manner that the man-machine team operates at peak efficiency. The realisation of the full potential of this team can only be effected if full consideration is given to factors, which facilitate handling of the aircraft and ensure the safety and comfort of the operator. Of these factors one of the most important is the efficient design of the workspace.

The workspace assumes a critical importance in fighter aircraft, as the weight and size affect both the performance and the economics of flight. The main effort in the design of a fighter workspace is therefore focussed on the necessary compromises between human comfort and efficiency and the optimum space for aircraft performance. It is true that the

* Project completed at A. F. S.A.M. in April 1961.

aircraft designer must exercise judgement in the choice of design limits. The general rule the Air Force design of cockpits is that it accommodates at least 90% of personnel. Accordi to Hertzberg[7], experience shows that the remaining 10% can also manage by accepting sor extra discomfort, especially the last 2%.

It is generally known and confirmed by sporadic anthropometric surveys[4] that t average Indian is smaller than the average European. The aim of this project is to dete mine optimum size of a fighter cockpit, which would not only accommodate our pilots various body sizes, but would also ensure them ease of operation, safety and comfort.

Static Anthropometry

Morant[7] considers the following body measurements to be of greatest value connection with workspace in aircraft:

a) Stature
b) Sitting height
c) Arm length
d) Thigh length
e) Leg length
f) Seat breadth

The measurements relate to bodies in stiff attitudes. Allowance must be made f slumping as estimated by Samuel.[10] Generally, static body measurements do not give exa assessment of the space within which bodies can perform essential movements, and are th not functional measurements.

Dynamic Antropometry

The hand and the foot are the specialised utility agents of the limbs. For any positic of the body, the effective reach of these parts defines the space available for potential activit The development of effective workspace calls for a study of the population.

The pilot, who must be fitted in the aircraft, represents a large population that can b measured only through samples. This means that the dimensions of the extreme deviate cannot be predicted. The mean, however, may be estimated with reasonable accuracy, an it is possible to designate individuals who would be included within certain percenti ranges[1].

The labour involved in dynamic measurements precludes studies on large populatio groups. According to Dempster[1] dynamic data on samples of even five large, five mediur and five small subjects selected on the basis of static measurements form a fair function approximation to what would be shown by the whole group. In such a manner th overall potential range of motion can be defined, and carefully selected representatives ar studied in actual or well designed mock situtions.

The R. A. F. standard fighter cockpit evolved out of the above considerations. Th idea is well summarised by Morant[7] as the " Mock-up Approach ". Measurements and ob servations of a number of selected subjects seated in a mock-up cockpit were recorded. By correlating the information collected, the best arrangement possible to accommodate all pilots can be inferred. The solution reached can be described completely by drawings of an imaginary cockpit and there is no need to burden the aircaft designer with any information regarding body measurements.

The Conditions Regarding Single Seat Fighter Cockpit

Among the more specific conditions accepted the following are the principal ones concerning cockpit dimensions :—

a) The pilot should have a forward and downward range of vision of 15° below the horizontal, completely unobstructed.

b) With the seat harness tight, all pilots should be able to reach and use the controls efficiently during flying.

c) An ejection seat should be used.

d) If a gyro gunsight is to be installed the pilot should be able to bring his eyes to within 8 ins. to 10 ins. of its reflector.

e) There should be proper regard for the safety, ease in operation and comfort of the pilots.

f) While complying with other conditions, the dimensions of the cockpit should be made as small as possible to ensure better performance of the aircraft, 'and also to economise by reducing weight and size of the aircraft.

It is difficult to interpret such conditions as ease in handling, safety and comfort. The three factors are necessarily closely interrelated. If an obstruction, such as the gunsight, is installed close to pilot's head, his range of vision is restricted and the operation of the aircraft becomes more difficult; he is more likely to be injured in a crash landing and suffers discomfort.

For ease in handling there must be adequate elbow room ; it should be possible to reach all controls easily. The controls should have locations dependent on both the relative frequencies with which they are used, their relative importance in emergencies and physiological requirements for precision in operating controls. In designing a standard cockpit less abstract considerations must come first, and after satisfying the more immediate needs, a little latitude may be permitted for refinements.

To ensure safety, adequate clearance from the structure of the aircraft during ejection, and adequate clearances around him for crash landing, to minimise injury to the body are of paramount considerations. There should be no obstructions between legs. For this reason a horizontal control stick is better than a vertical one. The knees should be aft of the instrument panel for all positions of rudder pedals.

It must be borne in mind that tolerances in movements not only depend on body factors, but also on the sitting positions (inclination of the seat) and whether the seat harness is tight, or loose, or incorrectly positioned. The two relevant measurements, which are considered for deciding the clearance for ejection path are thigh length and shoulder breadth. Possible increases in the effective measurement of these due to badly worn harness, and due to jolting, could affect the safety of the pilot. Also, due to the same reasons, the advantage of selecting the pilots on account of their body size is much diminished.

Body Measurements of I. A. F. Pilots and some comparisons with those of R. A. F. and U. S. A. F. Pilots

Standards for Selection. A minimum height limit of 64 ins. is applied in the I. A. F. for selection of the pilots. There is no upper limit of height. This is similar to the practice in the R. A. F. The other measurement which is taken into consideration at the time of acceptance is the external leg length. The minimum requirement for this measurement is laid down as 39 ins.

Data Available. At present, no detailed body measurements are available for I. A. F. pilots, apart from the above two measurements, which are done at the time of the selection of the pilots. Some important body measurements were carried out at the Defence Science Laboratory (Iyer and Bhattacharya) [3] of 691 airmen. From this data, distribution and correlation of some measurements of greatest value in connection with cockpit workspace, can be reliably inferred and are given in Tables I and II.

TABLE I

Mean, S. D. and S. E. of Important Body Measurements of 691 I. A. F. Personnel

Sl. No.	Body Measurements (in cms)		Mean	S. D.	S. E.
1	Total height (stature)	...	168.4	5.2	0.2
2	Sitting height	...	87.2	3.1	0.12
3	Total arm length	...	82.2	3.5	0.13
4	Forearm length	...	54.5	3.1	0.12
5	Thigh length	...	58.2	2.5	0.09
6	Leg length	...	108.6	4.6	0.17
7	Seat breadth	...	36.8	1.8	0.17

TABLE II

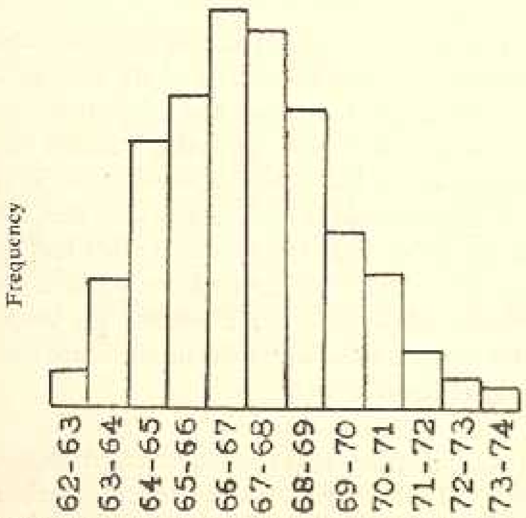
Correlation Between Important Body Measurements of 691 I. A. F. Airmen

Sl. No.	Body Measurements		(1)	(2)	(3)	(4)	(5)	(6)
1	Total height	...	1.0	0.72	0.68	0.38	0.69	0.81
2	Sitting height	...		1.0	0.37	0.29	0.40	0.48
3	Total arm length	...			1.0	0.34	0.44	0.47
4	Forearm length	...				1.0	0.53	0.56
5	Thigh length	...					1.0	0.78
6	Leg length	...						1.0

It can be seen from the Table II that there is a high correlation between total height and sitting height; total height and leg length; thigh length and leg length. The correlations between total height and arm length, and total height and thigh length are not very high.

Data for the total height and leg lengths were extracted from records, by random selection, of 503 I. A. F. pilots. The distribution of the total heights is shown in Fig. 1. It is almost symmetrical about the middle height (18.5% at 66 ins — 67 ins.). The distribution shows a moderate skew on the shorter side.

The possibility of being able to reduce the size of the cockpit by selecting pilots more stringently has often been mooted. The form of distribution of body measurements considered singly suggests that the space might be reduced considerably if a small percentage, *e.g.* 1 to 2 per cent, of the largest men are excluded. To estimate the practical advantage of doing so, it is necessary however, to examine the ways in which different body measurements are interrelated. Erroneous suppositions are often made regarding this matter. The correlation between total heights and leg lengths of the above sample of 503 pilots of I. A. F. are given in Table III.



Height in inches

FIG. 1 — Histogram showing the distribution of heights of 503 I. A. F. pilots

TABLE III

Correlation of height and leg length (in inches) in a random sample of 503 I. A. F. pilots. (Figures in the Table are percentage frequencies.)

Leg Length (in inches)	Total Height (in inches)												
	62–63–	63–64–	64–65–	65–66–	66–67	67–68–	68–69–	69–70–	70–71–	71–72	72–73–	73–74–	
37—38	0.8	0.2											1.0
38—39	0.6	2.8	3.1	0.6	0.2	0.2							7.5
39—40		2.2	6.4	6.0	4.0	1.4							20.0
40—41		0.4	2.0	4.8	8.0	3.5	2.0	0.4					21.1
41—42			0.4	2.3	5.1	8.0	6.0	1.6	0.8				24.2
42—43			0.4	0.6	1.2	3.4	4.5	2.8	1.6	0.2			14.7
43—44						0.4	1.0	2.2	2.5	0.4	0.2		6.7
44—45						0.2	0.2	1.0	0.6	1.0			3.0
45—46									0.2	0.2	0.4	0.4	1.2
46—47										0.2			0.2
47—48											0.2		0.2
48—49												0.2	0.2
	1.4	5.6	12.3	14.3	18.5	17.1	13.7	8.0	5.7	2.0	0.8	0.6	100.0

In this sample the range of total heights and leg lengths observed is 62 ins to 74 ins and 37.5 ins. to 49 ins. respectively. By excluding 1.4% of the extreme in total heights, only 1 in. of the range would be cut off at the shorter end and 2 ins. at the higher end. The study of the correlation shows that in spite of a high correlation between heights and leg lengths, one standard of measurement cannot be laid down for selection of pilots. For instance, applying a limit on account of one measurement, *e.g.*, height 64 ins., then 2.6% of the pilots whose leg lengths are above 39 ins. are liable to be excluded. If other body measurements are isolated and considered for laying down body size standards for selection, the proportion of the pilots who are liable to be excluded will be higher still, because the correlation of other measurements, *e.g.*, sitting heights, thigh lengths with total height is not so high. This consideration applies equally on the higher limits as well.

In dealing with cockpit space requirements, measurements of pilots only (the users) are required to be considered. Table IV gives comparison of distribution of heights and leg lengths of the sample of 503 I. A. F. pilots, with those of the U. S. A. F. and the R. A. F.

TABLE IV

Comparison of heights and leg lengths of U.S.A.F., R.A.F., and I.A.F. Pilots (Sample estimates)

	HEIGHT (IN INCHES)		LEG LENGTH (IN INCHES)	
	Mean	98% Range	Mean	98% Range
U.S.A.F.	69.1	64.1—74.5	not available	
R.A.F.	69.4	64.4—74.4	43.6	40.0—48.0
I.A.F.	66.1	63.0—73.0	41.1	38.0—46.0

The I.A.F. average pilot is shorter in total height and leg length. In total height he is about 3 ins. and in leg length about 2.5 ins. shorter compared with both U. S. A. F. and R. A. F. pilots.

Methods and Trials

Static body measurements give no exact assessment of the space within which bodies can perform requisite movements. The need is for a method of investigation which will take into account all the relevant considerations at the same time. The method adopted is on the lines of the "Mock-up Approach" outlined by Morant and Ruffell Smith [7,8,12] The method does not guarantee an ideal arrangement for all the sizes of the pilots. Some of the pilots falling within a certain range of body measurements are liable to be penalised.

The method consists in recording few body measurements of a selected group of pilots and then in recording certain measurements of reaches and body actions, and various other observations, after the subjects are seated in an adjustable mock-up cockpit. By relating all the information collected, the best arrangements to suit nearly all the pilots could be inferred. It is essential to choose pilots as subjects, as only they would understand the various conditions and requirements.

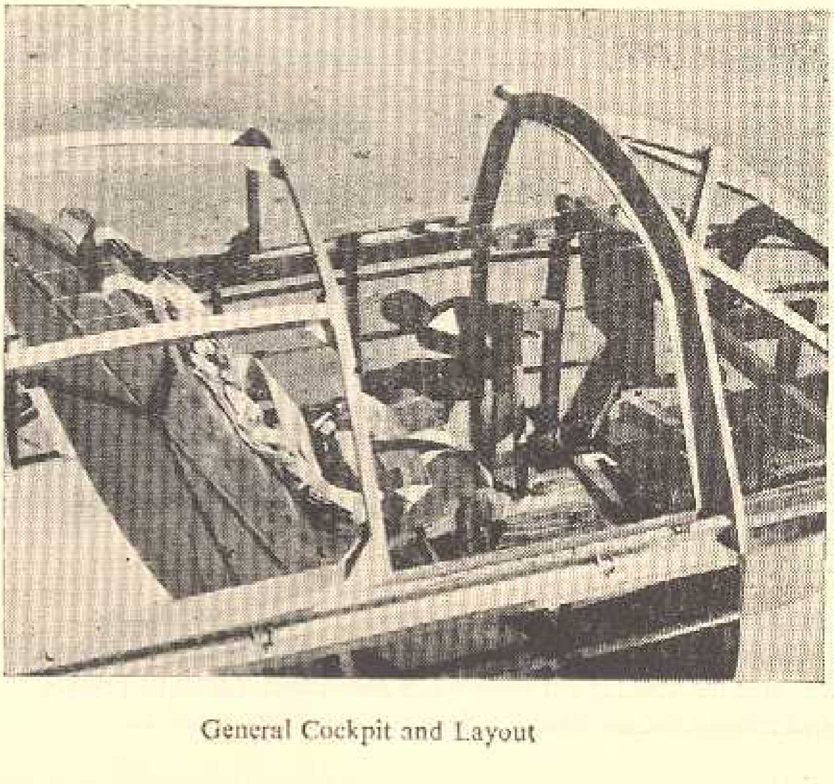
Variations in body size of the pilots remain a constant factor, and the dimensional features arrived at from the results of the trials help in securing uniformity in critical features, *e.g.*, relative position of seat and rudder pedals, and their relative adjustment. The results, however, would not be able to define the sizes and shapes of the cockpits of various aircraft, which would have to be examined individually for each aircraft at all its stages of development namely at design, mock-up and prototype.

The Mock-up

A mock-up was obtained from H.A.L. for purposes of the trials. After suitable modifications, it was used for working out various key dimensions for body reaches, as for rudder pedals, control column, escape clearance from the instrument panel, etc.

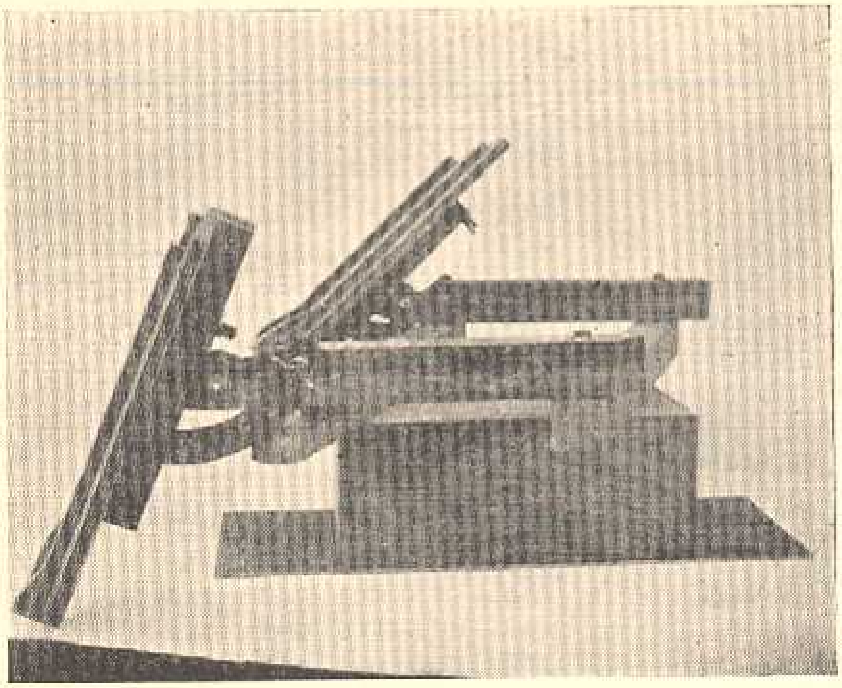
The various fittings in it were first removed, because they could not serve the purpose of trials, as they were at fixed positions and dimensions. A seat, which could be adjusted fore and aft, and vertically, and with the angles of the pan and back-rest adjustable was constructed and fitted. A stick type of control column, with enough play fore and aft, and sideways to suit all ranges of arm length, was fitted. The horizontal distance between its neutral position and the seat reference point was made adjustable. A set of rudder pedals, whose horizontal distance from seat reference point could be altered and fixed, was fitted in. The pedals were of 'foot print' type and their vertical distance from floor could be changed. The pedals had a range of movement of 4 ins. fore and aft of their neutral position. The pedal angles to the horizontal could be adjusted between 50° and 65°. A throttle control with adjustable height and horizontal distance, was fitted. The instrument panel was fitted on a railing so that its distance from eyes could be altered. The upper border could be altered by attaching extra pieces, and by an incorporated vertical adjustment in the panel to ensure standard vision below the horizontal for all heights of the pilots, seated at various ranges of seat adjustment. The lower limit of the panel was estimated, giving a clearance of 5 cms. above the knees. Figures 2 and 3 help, to some extent, to illustrate the layout.

FIG. 2



General Cockpit and Layout

FIG. 3



Adjustable Rudder Pedals

Subjects

Twenty subjects were dealt with. The group was chosen in such a way that not only extremes of sizes were represented, but also it represented pilots of various and varied experience. Of these four were test pilots and one an engineer pilot. Four of them represented short extremes, five tall extremes and the rest represented various range of heights in between. The random height subjects were given the first series of trials and the extreme heights the second series.

Some relevant body measurements were recorded for each subject. The measurements were taken by following the standard techniques which have been applied in the R.A.F. by Morant[5]. The measurements were overall projective ones of parts of the body taken, when the subjects adopted certain specified and stiff attitudes. They provide a frame of references, but they do not give any appreciation of the ranges of movements required when a pilot operates an aircraft. Certain correlations of results are worked out against the most relevant of the body measurements, and go to prove this. This will be discussed later in the paper. The ranges of movements, within tolerable limits, are assessed in mock-up trials. Table V shows the distribution of various important measurements of these subjects. The ranges for heights and leg lengths of these 20 subjects compared well with ranges of the same measurements of the 503 I. A. F. pilots mentioned earlier.

TABLE V

Body Measurements (in cms.) of Random, Short and Tall Sample of I. A. F. Pilots

	RANDOM		SHORT		TALL	
	Mean	Range	Mean	Range	Mean	Range
1. Total height ...	171.8	164.5-176.2	160.6	159.9-161.3	185.0	182.1-187.9
2. Sitting height ...	129.3	122.2-132.5	123.2	120.4-125.0	141.2	138.0-144.8
3. Eye height sitting ...	116.5	109.8-121.4	111.8	110.0-114.1	129.5	124.5-132.7
4. Shoulder height ...	99.8	93.5-104.1	93.5	92.7- 94.2	110.2	106.7-112.5
5. Elbow-rest height ...	66.3	63.8- 69.1	62.5	59.8- 65.6	73.0	68.6- 77.5
6. Patella height ...	51.8	48.3- 54.6	48.5	47.0- 49.3	56.2	54.9- 57.5
7. Bi-deltoid diameter ...	47.3	42.0- 52.1	46.3	42.7- 49.1	48.8	45.8- 52.1
8. Total arm length ...	78.3	74.2- 80.6	73.4	72.5- 75.2	84.8	82.1- 86.9
9. Max. arm reach from wall ...	90.2	84.1- 91.5	83.3	80.0- 87.6	96.0	92.9- 97.8
10. Forearm length ...	47.3	45.7- 50.4	44.8	44.0- 45.6	50.4	49.6- 52.1
11. Functional reach ...	80-0	77.5- 82.3	74.7	72.5- 77.5	86.6	83.8- 90.2
12. Leg length ...	110.3	101.6-115.6	99.3	98.5-100.3	120.2	115.0-124.5
13. Thigh length ...	60.7	56.0- 64-3	55.0	52.4- 57.7	63.0	61.8- 65.7
14. Foot length ...	27.2	26.5- 29.3	26.0	25.3- 27.0	29.0	27.6- 29.9
15. Hand breadth at meta-carpals ...	8.7	7.7- 9.0	8.5	7.7- 8.8	9.0	8.3- 9.6
16. Elbow span at rest ...	70.9	64.0- 76.2	65.1	64.8- 70.6	69.6	63.1- 73.7
17. Total weight (in lbs.) ...	158	114-188	137	124-157	173	158- 190

Table III of heights and leg lengths of the 503 I. A. F. pilots shows that 7% fall in the height range shorter than 64 ins., 84% fall in the range of 64 ins.-70 ins. and 9% in the range of above 70 ins.[3] In subjects for trials the range of short pilots was 62.9 ins.—63.5 ins. *i.e.*, shorter than 64 ins. and range for the tall pilots 72.1 ins.-74.0 ins. *i.e.* taller than 70 ins. The range of heights in the random sample of the subjects was observed to be 64.8 ins-69.4 ins. *i.e.*, 64 ins.-70 ins. When calculating the final results, weighted averages of the key dimensions were worked out on the basis of the percentage distributions in the 503 pilots sample and not those of the subjects in the trials.

Particulars of the Trials

In determining the critical dimensions of the cockpit, the aim was to determine an arrangement, if possible, which would mean that all pilots would be equally well accommodated.

Fixed Parameters—A number of points regarding dimensions could be settled before the systematic trials were started. As changes in pan and back angles of the seat would influence dimensions of the cockpit, these were fixed. The angles fixed were the included angle of the seat at 100° and the included angle of the ejection at 7°. The angle of the pan to horizontal was fixed at 7½°. Horizontal adjustment of the seat was not used, as it would not be incorporated in a fighter aircraft. The seat height for various subjects were fixed in such a way that the pilot would get 15° vision below the horizontal. The instrument panel was fixed at the distance worked out in accordance with the standard R. A. F. cockpit. The problem of dimensions was tackled keeping the gyro gunsight out of account.

Good first approximation could also be obtained for certain other dimensions. For all the subjects 3 or 4 settings were tried by raising the seat heights by intervals of two inches, with the harness tight at each position. The instrument panel at each position was adjusted in the vertical plane to give standard vision below horizon over the upper edge of the instrument panel. This helped the pilot to decide his best position. He was then tried again in his best position. All the adjustable parts were so adjusted as to give the pilot the best arrangement which depended mostly on his subjective feelings. The following measurements and observations were recorded for each subject whilst he was tightly harnessed in the seat.

a) The best setting for the rudder pedals as regards its angle to the horizontal, its height above the floor, its distance from the seat reference point most suited for operational ease and comfort. The lower limit of the instrument panel was judged to provide 5 cms. clearance for the knees. The knee angles were measured for the neutral, and the extreme positions of operation. The knee angles adopted by the subjects, served as good rough guides to cross check the acceptance of the comfort position in the various settings of the seat heights, tried by each individual and based on his subjective feelings.

b) The horizontal distance between the neutral position of the control column and the seat reference point was measured. The length of the control column (vertical distance) giving the upper limit of the grip from the heel level, and the forward limits of travel which he preferred were recorded.

c) The heights of the throttle above heel level and its reaches were measured.

d) Eye distances to the top and to the lower edge of the instrument panel were estimated.

e) The vertical width of the panel, and the height of lower edge above heel level were also measured. The upper edge, as stated above, was fixed to provide adequate below horizontal vision.

The first series of trials were carried out with 11 subjects. Average dimensions were worked out from the first series, and also the ranges of pedal adjustment, and travel of control

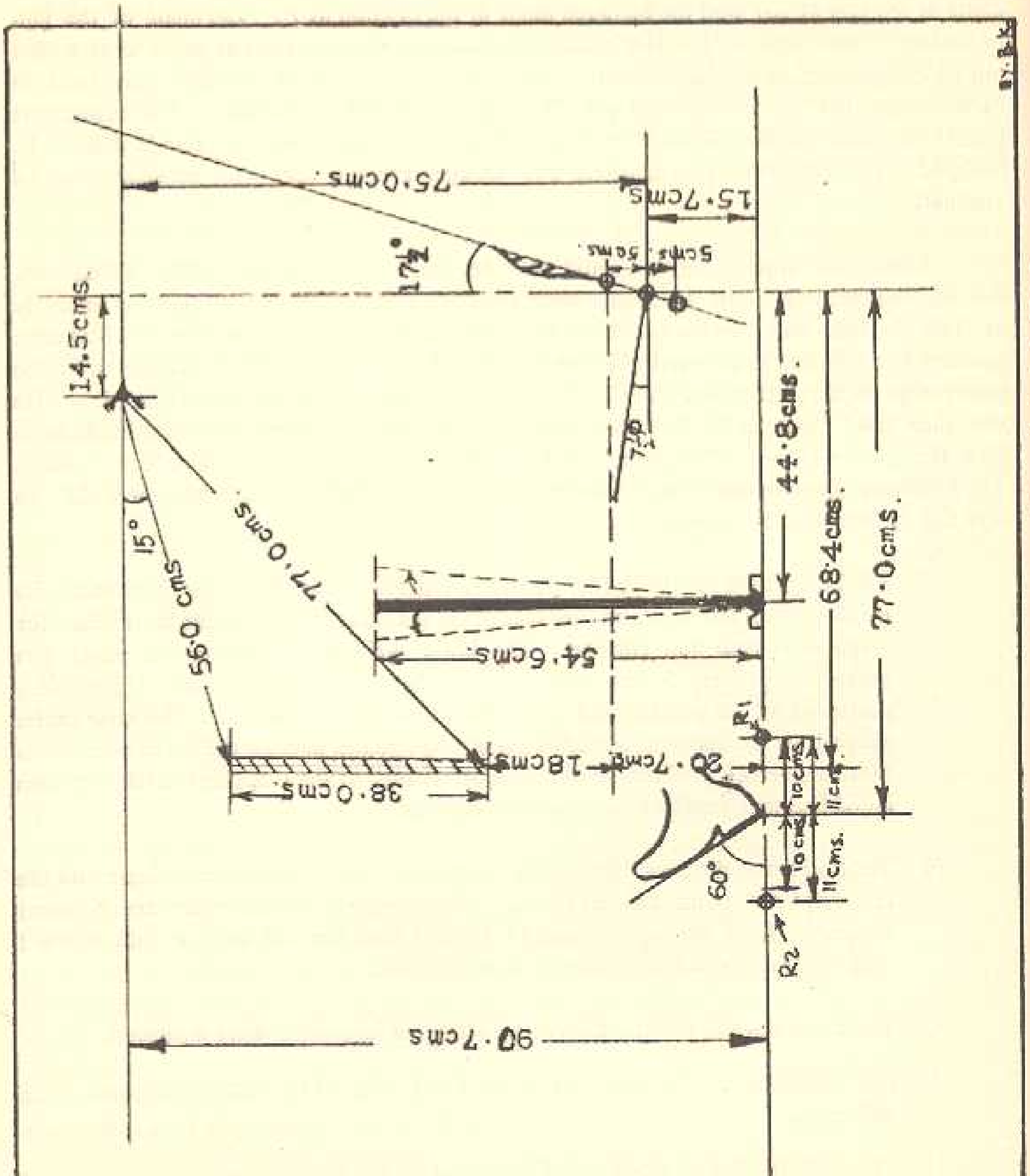


FIG 4

Recommended Dimensions of Single Seat Fighter Cockpit for I.A.F.

column and of the throttle control. In the second series of trials, with short and tall pilots, the average dimensions and ranges arrived at in the first series were tried and final results were obtained regarding dimensions and adjustabilities. In reaching the final results, due weightage was given for the tall subjects to the extent that it would not prejudice the reaches of the short samples so as to affect their safety of operation. The final results are in terms of measurements of structures without any reference to body measurements.

Results

The results of various critical dimensions of a fighter cockpit, reached in the trials are diagrammatically shown in Fig. 4. The size of the cockpit, as expected, from the static body measurements of an Indian pilot is shorter in all the dimensions than the standard R.A.F. or U.S.A.F. fighter cockpit. The measurements were recorded by a team which consisted of one officer and an assistant, the records were taken and analysed by a qualified statistician. The final results as stated earlier were obtained by relating all the information collected and referring to the known distribution of body measurements of the sample of 503 I.A.F. pilots, along with comparative figures of the R.A.F. standard fighter cockpit.

Vertical Dimensions—The various vertical dimensions worked out are:

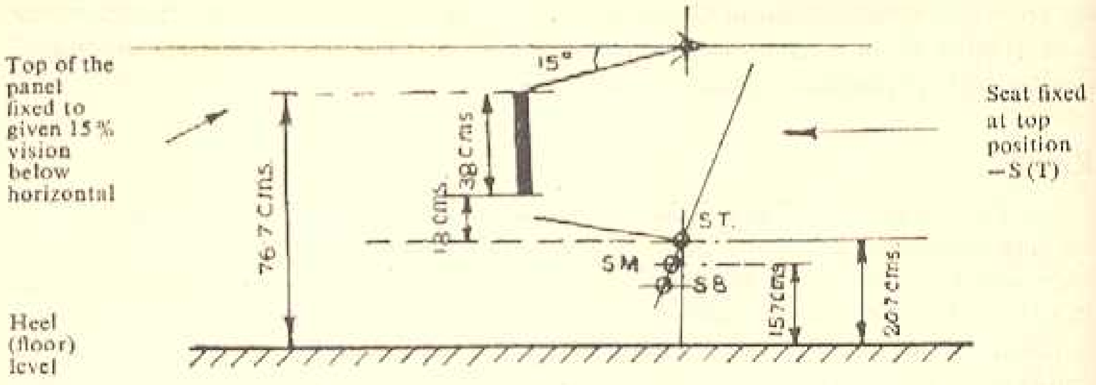
a) Vertical distance between the heel level and the eye datum is 90.7 cms. (35.7 ins). The R.A.F. figure for the same dimension is 39.25 ins.

b) The height of the seat reference point (SM) above the level of heel point works out to the average of 15.7 cms. The R.A.F. cockpit figure is 7.2 in. (18 cms).

c) The instrument panel was placed at a fixed distance, as worked out in the R.A.F. fighter cockpit, of 26.3 inches from the seat reference point at its most forward position. The height of the upper edge of the instrument panel from the heel level is 76.7 cms, providing the pilot with vision 15° below the horizontal. The average vertical width of the panel is 38 cms. (fig. 5). With this width the tallest subject had 3.5 cms of leg clearance from the lower edge of the panel. From the above figures the lower edge of the panel calculates to be 38.7 cms, above the heel level. The distance of the lower edge above the seat reference point, with the seat fixed at the top position, *i.e.* 2 inches higher than the mid position, would be 18.0 cms. The comparative figure for the R.A.F. cockpit with vertical stick is 6.3 inches (seat top 3 inches above the middle position.)

Rudder Pedals. The horizontal distance of the rudder pedals at the heel point from the seat reference point (seat at its middle position) is 77.0 cms. and the distance between the seat reference point to the foot middle point works to an average of 85.6 cms. The comparative distance for the R. A. F. fighter cockpit, seat reference point to the heel point, is 34.5 inches (87.6 cms.). Our range of adjustability of the rudder pedal to accommodate pilots of

FIG. 5



all sizes, seated at different seat heights to get the proper line of vision, is 22 cms. The range of rudder pedal adjustability in a standard fighter (R.A.F.) cockpit is 11 ins. The range of to and fro movements of rudder pedals from their neutral position was taken as 4 ins. — the same as in the R.A.F. cockpit.

Control Column. The vertical height of the control column measured to the upper point of the grip from the floor (heel level) is 54.6 cms. The neutral point of the control column from the seat reference point is 44.8 cms. The U.S.A.F. figure for the same distance is 19 in. (48.2 cms). Direct R.A.F. figures for these distances are not available. The forward reach of stick from its neutral position is 12.8 cms. in our trials.

Throttle Control. The distance from the seat reference point to the throttle is 34.0 cm. (closed position — easy reach). The height of the grip above the floor is 44.7 cm. These measurements are not critical and the R.A.F. figures are not available.

Various Angles. The angle, made by the foot pedals to the horizontal, averages to 60°. The figure for the R. A. F. fighter cockpit is 57°. The subjects also accepted 7° to 8° of flare out of the pedals from the vertical. The various knee angles adopted by various subjects at the neutral position of the rudder average 118° for random samples, 117° for the short and 107° for the tall subjects. The figures for the subjects in the R. A. F. cockpit trials range from 108° to 118° showing that the human comfort angles at knees for both the populations are the same.

Correlation Tables. Certain correlation of the key dimensions were worked out with the most related body measurements. They are given in Tables Nos. VI, VII and VIII.

TABLE VI

Correlation between total height, sitting height and cockpit size (in inches)

Sl. No.	Total height (X_1)	Sitting height (X_2)	Cockpit size (X_3)
1	67.2	51.8	35.3
2	67.8	50.3	34.7
3	67.4	51.0	35.7
4	69.4	51.6	35.8
5	68.4	51.3	37.6
6	64.8	48.1	35.4
7	68.3	51.4	37.0
8	67.3	51.0	34.2
9	68.1	51.8	37.4
10	68.9	52.2	35.4
11	66.3	49.7	33.4
12	63.5	49.2	33.2
13	63.0	47.4	33.0
14	62.9	48.2	33.2
15	63.2	49.0	35.5
16	72.3	54.3	36.8
17	72.3	55.3	35.5
18	72.1	55.4	38.5
19	74.0	55.8	39.0
20	73.8	57.0	38.5
Mean	68.05	51.6	35.75
SD	3.4	2.5	1.9

Correlation coefficient — between $X_1\ X_3 = +\ 0.81$

$X_2\ X_3 = +\ 0.77$

TABLE VII

Correlation between leg length and S.R.P. to heel point
(Figs. in cms.)

Sl. No.	Leg length X_1	S.R.P. to heel point X_2
1	101.6	70.9
2	115.5	82.3
3	110.5	74.5
4	111.0	71.0
5	109.3	79.2
6	108.0	77.4
7	98.6	75.3
8	100.3	74.0
9	98.6	72.7
10	99.8	77.0
11	122.5	88.0
12	115.1	81.3
13	121.0	89.3
14	124.5	89.5
15	118.1	88.4
Mean	110.3	79.25
S.D.	8.64	8.0

Correlation coefficient = + 0.91

TABLE VIII

Correlation between total arm length and control column distance
(Figs. in cms.)

Sl. No.	Total arm length	Control column distance
1	78.7	47.4
2	77.0	49.3
3	76.7	51.0
4	80.0	41.5
5	79.5	40.0
6	74.2	38.9
7	79.5	49.0
8	80.0	37.0
9	80.5	45.5
10	76.4	47.7
11	77.5	43.5
12	72.6	37.7
13	75.2	44.0
14	73.7	40.9
15	72.4	43.7
16	86.9	45.9
17	82.0	48.8
18	84.1	44.2
19	86.4	49.8
20	84.3	48.0
Mean	78.88	44.69
S.D.	3.81	4.03

Correlation coefficient = + 0.33
(not significant)

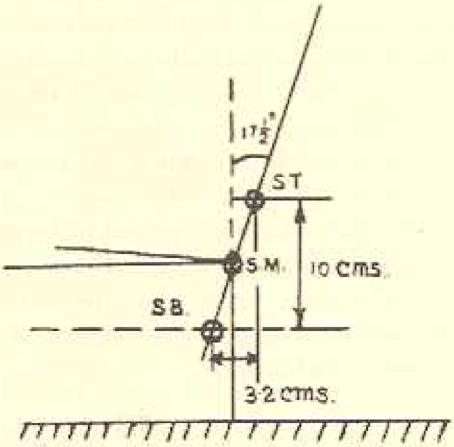
The tables show that there is a high correlation between total height and sitting height with the vertical size of the cockpit, the distance between heel point to horizontal line of vision. There is also high correlation between leg length and the rudder pedal reaches. But, in spite of these high correlations, it would not be possible to work out these dimensions from the static body measurements. The correlation between leg length, thigh length and the knee angles adopted, also the correlation between arm lengths and the distance of neutral point of control column from the seat reference point are not significant. Thus the comfortable reaches for the arm would not depend on the arm lengths entirely.

Adjustability

The range of distances from the seat reference point to the floor for all subjects, to provide them with the proper vision below the horizontal, is 11 to 19 cms. A total vertical adjustment of 10 cms, which is 2 cms more than the above range, would cover all the sizes of the pilots. Therefore, the recommended vertical adjustment of the seat is 5 cms. above and below the seat middle point, which is 15.7 cms above the floor.

The distances of the neutral positions of the rudder pedals from the seat reference point for all subjects varied from 71 cms to 89.5 cms, a range of 18.5 cms. To this should be added another 3.2 cms, caused by horizontal displacement of the seat when moving from the bottom to the top position at an inclination of 17½°. The total adjustment of the rudder pedals for all pilots and for all seat positions would therefore be 21.7 cms. Therefore a range of adjustability of 11 cms on each side of the neutral position of the rudder pedals would suffice for all our pilots.

FIG. 6



S T — Seat at top position
S M — Seat at middle position
S B — Seat at bottom position

3.2 cms. is horizontal displacement of seat from its bottom to the top position, with seat back and also the vertical line of adjustment of the pan 17½° inclined away from the vertical, the total vertical adjustment of the seat being 10 cms.

Distance from Normal Eye Line to the Inner Surface of the Canopy

Normally in a fighter aircraft the minimum clearance allowed between the inner surface of the canopy and the pressure helmet, with visor in up position, is 7.5 cms. The average vertical distance amongst our subjects between the eye and top of the head is 11.6 cms and allowing for 6-7 cms increase in distance from the head to the top of the helmet, the distance between normal eye levels and the inside of canopy surface will then be 26.1 cms.

Discussion

The mock-up trials with a selected group of subjects from the community of operators, and referring the results to the anthropometric data of the same community, showed that it is possible to work out the dimensions of an aircraft cockpit, which would be suitable for all our pilots. The space worked out will give them satisfactory conditions as regards ease in operation, safety and comfort. The conditions to be satisfied in fighter aircraft in India are supposed, for the purposes of the project, to be the same as in the R.A.F., namely adequate vision below horizontal, crash clearance for bad landing, escape and the minimum, size of the cockpit. Our dimensions are worked out around the fixed parameters of seat angles, distance between the instrument panel and the seat reference point, and 15° vision below the horizontal. So any change in these would modify the dimensions accordingly.

The key dimensions for other types of aircraft could be worked out by similar methods. The factors, which would modify these dimensions in other types of aircraft, are the different seat angles, the distance to the instrument panel from the seat which would be different if no seat ejection is used, and the requirements of the degree of vision below the horizontal. The relation between the various dimensions is complex and an alteration in one would affect the other, for example, if no ejection seat is used the distance to the instrument panel would be less, which would mean that either the vertical width of the panel should decrease, or the rudder pedals should be lowered to keep the adequate clearance for the legs. The latter would mean alteration in vertical size of the cockpit. So, if due to certain reasons the standard dimensions cannot be adhered to, it would be imperative to examine the workspace of that aircraft during its developmental stages to ensure the pilot efficiency and safety in operation of that aircraft.

The results of the project show that all our dimensions are smaller, although in close agreement, to that of the standard R.A.F. cockpit. This conforms to the average size of our pilots. The ranges of adjustability of the seat and rudder pedals are also smaller, and within these all sizes of our pilots can be accommodated satisfactorily. This smaller size of the cockpit would obviously result in aerodynamic advantage.

The pilots who acted as subjects in the project did not possess their full flying clothing equipment and were tested in their working dress. The allowance for flying with modern flying clothing can be worked out separately and would not materially alter the critical dimensions.

The knee angles which were adopted by the various subjects varied between 107°–118° for the neutral position of the rudder, for easy reach and comfortable operation. These figures are very close to those adapted for R.A.F. fighter cockpit trials with 29 pilots (108°–118°). As the knee angles would be adopted on subjective comfort, it can be stated the results obtained would be reliable only if reaches of the subject could be measured accurately. These measurements were taken from the calibrations which were repeatedly checked during the trials.

The correlation coefficients of key dimensions against corresponding body measurements (Tables VI, VII and VIII) indicate the close relationship between some of them. Correlation is very significant between the total height/sitting height and the cockpit, and similarly between leg length and rudder pedal reaches. From this relationship it is obvious that a rough estimate of cockpit dimensions could be evolved from static anthropometry, but actual distances suitable to all pilots cannot be calculated.

Standards for Selection. A study of the distribution of heights (fig. 1) of 503 I. A. F. pilots shows a skew on the shorter side and more so is the distribution of leg lengths (Table III). We have laid down height standards for entry of pilots in I. A. F. for the lower limits (64 ins.) but none for the higher, although the percentage above 72 ins. in height is only 1.4 (Table III). Assuming that our sample is fairly representative of the population of our serving pilots or persons who are desirous of joining the I. A. F. as pilots, it is felt that the rejection rate, due to our standards for minimum height, could be high. If, at any time, there is a requirement that cockpit space puts a still lower premium on the weight and size of a fighter aircraft, to improve its aerodynamic properties, a still smaller cockpit could be a possibility provided a small percentage of population (1.4%) at highest height range is barred for fighter flying. This cockpit would still be suitable for 98.6% of the pilots of I. A. F. as revealed by the present investigations.

Recommendations

The following recommendations are made :—

a) In this project secondary controls and the layout of various instruments and consoles have not been considered, and the problem of dimensions has been worked out keeping the gyro gunsight out of account. A further project should be undertaken with a cockpit made to the dimensions and adjustabilities worked out in this project, and with other adjustable arrangements so that the layout of various consoles, the maximum practical instrument area and the logical layout of the secondary controls could be worked out. This is important, because of the increased complexity of modern aircraft. Also, the effect of installation of the gyro gunsight on the dimensions worked out could be studied. The project recommended may also help in working out the standard workspace requirements for other types of aircraft.

b) A revision of physical standards, as far as the height and leg length, are concerned for pilots at the time of entry should be considered after anthropometric data of Indian population is available.

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References

1. Dempster, W. T., The Anthropometry of Body Action. WADD TR 60-18 Project 7214. Ohio, Wright-Patterson AFB, Jan. 1960.
2. Hertzberg, H. T. E.: Applied Physical Anthropology to Human Engineering. WADD TR 60-19 Project 7214. Ohio, Wright-Patterson AFB, Jan. 1960.
3. Iyer and Bhattacharya: Body Measurements in Relation to Cockpit Design. Delhi Defence Science Laboratory.
4. Martin, William B. and Edward, E. Johnson: Optimum Range of Seat Position. Extracts from Annotated Bibliography of Applied Physical Anthropology in Human Engineering. WADC TR 56-30. Ohio, Wright-Patterson, AFB, May 1958.
5. Morant, G.M.: A Report on Survey of Body and Clothing Measurements of R.A.F. Personnel. FPRC 633 (a), Aug. 1945.
6. Morant, G.M.: Dimensional Requirements for Seats in R.A.F. Aircraft. FPRC 682, Feb. 1947.
7. Morant, G.M.: "Body Measurements in Relation to Workspace." Anthropometry and Human Engineering. Agardograph No. 5, London, Butterworths Sc. Pub. 1955.
8. Morant G.M. and Ruffel Smith: Body Measurements of Pilots and Cockpit Dimensions. FPRC 689 Dec. 1947
9. Randall, Francis E.: Seat Comfort. Extracts from Annotated Bibliography of Applied Physical Anthropology in Human Engineering. WADC TR 56-30, Ohio, Wright-Patterson AFB, May. 1958.
10. Randall F.E., A. Damson, E.S. Benson & D.I. Patt: Human Body Size in Military Aircraft and Personal Equipment. AAF TR 5501 pp. 79—120 1946.
11. Ruffel Smith: "British Theory and Practice in the Layout of the Aircraft Cockpits." Collected Papers on Aviation Medicine. Agardograph No. 6. London, Butterworths Sc. Pub. 1955.
12. Ruffell Smith: Man and Aircraft Workspace. Farnborough, R.A.F., IAM Aug. 1954.
13. Samuel: Estimate of Allowances for Slumping in Standing and Sitting Heights. FPRC Memo 43, June 1953.