A REPORT OF RESEARCH

UNDER CONTRACT WITH SPECIAL DEVICES CENTER

OFFICE OF NAVAL RESEARCH, U.S. NAVY

AND

THE JOHNS HOPKINS UNIVERSITY

REPORT NO. 166-1-8

MAXIMUM LIMITS OF WORKING AREAS ON VERTICAL SURFACES

BY

K. O. WILLIAM SANDBERG
AND
HAROLD L. LIPSHULTZ

This study was conducted at the Systems Research Field Laboratory of The Johns Hopkins University, Jamestown, Rhode Island, under a subcontract between New York University and The Johns Hopkins University, the prime contractor with the Office of Naval Research.

INDUSTRIAL ENGINEERING LABORATORY
NEW YORK UNIVERSITY

Reprint - April 1952

AD-639369

MAXIMUM LIMITS OF WORKING AREAS ON VERTICAL SURFACES

SUMMARY

This experiment measured the maximum area which can be reached on a flat vertical surface by the two arms of eight male subjects seated at varying viewing distances away from the surface. The paper discusses the influence of some of the variables: viewing distance, arm length, and body distance between pivot centers.

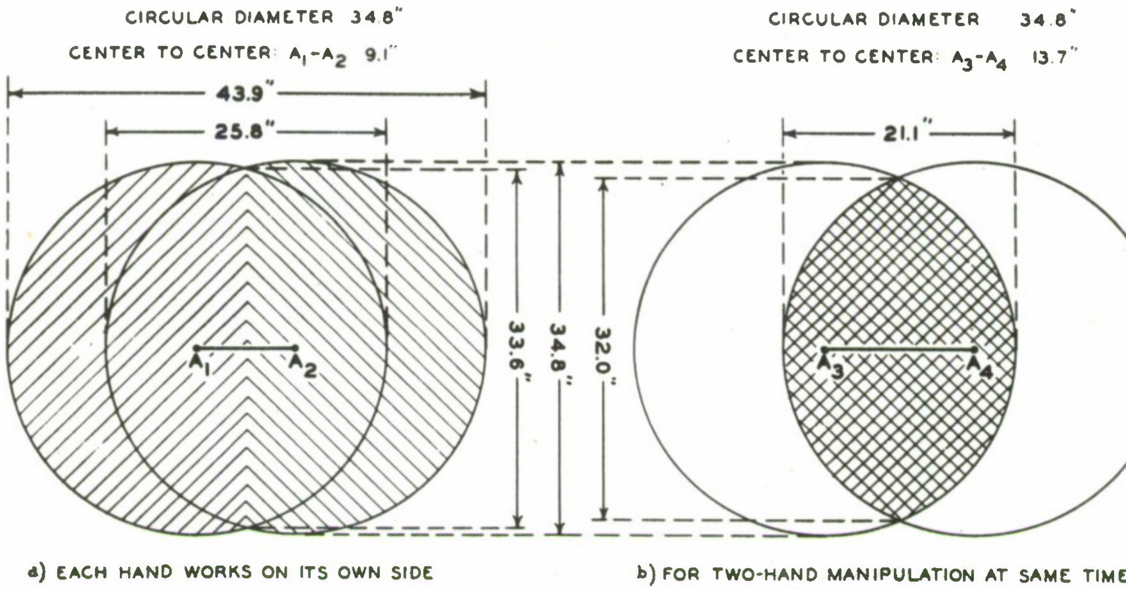
It was found that each arm described an approximate circle whose diameter decreased as the distance between the subject and the flat vertical surface was increased. The three viewing distances of 10 inches, 15 inches, and 20 inches were selected as representative of actual operating practice.

At the distance of 20 inches from eye to vertical panel, the average subject described a circle of 40.4 inches diameter with each arm. The two circle centers were approximately 12 inches apart, horizontally. When adjusted for the average anterior arm reach for almost 3000 AAF cadets, the circular diameter is 43.5 inches. The area enclosed by two such 43.5-inch circles is the maximum area of reach for operators of approximately average size.

At the same distance of 20 inches from eye to panel, a very small subject (short arms and of slight build) can describe two smaller overlapping circles of 34.8 inches diameter with centers separated horizontally by approximately 9.1 inches. These circles enclose the whole area of Figure 1a which takes the rough shape of an ellipse whose axes are 43.9 inches and 34.8 inches. It is estimated that 95% of all possible operators will be able to reach all points in this field.

When a manual task requires both hands to be at the same place simultaneously, the points which can be reached without a posture change are then limited to the common area of the two overlapping circles. These common points are shown for a subject of small size at 20 inches viewing distance by the inner hatched area of Figure 1a. This area approximates an ellipse whose major and minor axes are 33.6 inches and 25.8 inches respectively. However, it was found that a slightly smaller common area of two overlapping circles is described by a subject of short arms but broad build at 20 inches viewing distance. Figure 1b shows this ellipse as a double cross-hatched area with axes of 32.0 and 21.1 inches. Other values under different conditions are given in several tables in the report.

These area limits may be applied to layout design of such flat vertical surfaces as radar consoles and communication panels.



THE CONSERVATIVE LIMITS OF
MAXIMUM WORKING AREAS

Figure 1

ACKNOWLEDGMENT

The assistance of the experimental and administrative staff at the Johns Hopkins Field Laboratory at Jamestown, Rhode Island, in providing subjects and in preparing manuscript copy is hereby acknowledged.

AREA OF MAXIMUM REACH ON VERTICAL SURFACES

Purpose of Report This report is intended to determine the area of maximum reach without any kind of posture change for seated male radarmen working controls on a flat vertical surface. The characteristics of the areas encompassed by reaching are given for the average and for other subjects seated at varying distances from the vertical surface. The viewing distances considered are confined to those representative of actual practice in the operation of radar equipment.

Variables Other studies[1] have measured variations in body sizes. Stature varies by more than 12 inches, weight by more than a hundred pounds, anterior arm reach[2] by more than ten inches. Typical male anterior arm reach may range from 29.5 inches to 40.6 inches. The bi-deltoid[3] distance varies by five inches. Sitting height varies almost eight inches.

Inasmuch as radar operation may have to rely upon a high degree of interchangeability of personnel, it is not sufficient to consider maximum reach linits for only the average operator. Provision should be made to accommodate 95% of all possible male operators, including those with very short reach and small torso-size. Female dimensions are not included since women are not anticipated for this work.

Maximum Working Areas The selection of a maximum working area for practical use should be made so that the greatest number of potential operators can reach all points within that area without change of posture. Accordingly, in order not to sacrifice coverage because of a few extreme cases, the limiting values for the several variables have been established at the 5% and 95% percentile points. Recommendations are based upon the minimum areas possible for different combinations of operator characteristics within the range examined. The use of average or maximum values would prevent too many operators from reaching to the outer edges of such areas without posture change.

EXPERIMENTAL CONDITIONS

Methods Used The measurements reported were made under the following conditions:

1. The subject sat in a radar operator's chair and faced a chart hanging on a flat vertical wall. The head was maintained in approximately a constant position by means of a two-sided head guide mounted from the chair's back. (See Figure 2).

---

1. Army Air Forces Air Materiel Command, AAF Technical Report No. 5501, Human Body Size in Military Aircraft and Personal Equipment, 10 June 1946.
2. Definition of 'anterior arm reach': Heels together; heels, buttocks, middle of back (in lateral sense), and occiput against wall. Subject is required to attain maximum horizontal forward reach, with contacts maintained. Both arms horizontal, extended equally. Distance from wall to tip of right middle finger. (From AAF Report 5501)
3. Definition of 'bi-deltoid distance': Arms at side, palms forward. Maximum contact dimension across deltoids (large muscles around shoulders).

Figure 2
SUBJECT HELD IN POSITION BY HEAD GUIDE

2. The chart consisted of a sheet of white paper 48 inches by 72 inches in size, with radial black pencil lines interacting at a common origin and radiating in angular intervals of 15 degrees.

3. The head and body of the subject were so positioned that the midpoint of the distance between his eyes was coincident with a line perpendicular to the wall at the common origin of the radial lines. A carpenter's square was used to center the head on the vertical line and to align the eyes on the horizontal line. Adjustments for different operators were made by moving the chair to the left or right and by raising or lowering the chair.

4. The distance of the eyes away from the wall was established at 10 inches, 15 inches, and 20 inches, and sets of measurements were taken for each of these three distances. These distances were chosen because it was found that normal positions taken by ten radar operators who sat at the SG, SP, and SR radar consoles were no closer than 10 inches and no farther away than 20 inches from eye to panel (measured to the nearest 1/2 inch). Such distances evidently varied between operators due to individual differences in their preference for viewing distance. The viewing distance also varied according to the nature of the visual task; positions for close tracking of targets were closer than positions for casual search.

5. The subject, with fingertips touching the wall chart, rotated his outstretched arms simultaneously in opposite and symmetrical directions. This was only possible for a 210 degree arc. Beyond this the arms interfered with one another as they passed the vertical and progressed across the body. Hence to get the remainder of the reach data, a corollary condition was established.

6. The corollary condition required the subject to rotate both outstretched arms on the same side of the vertical at the same time. This was done for each side. In this position only one arm crossed over the body at one time, making a smaller locus which was measured to complete the arc.

7. The locus points were initially located to coincide with the finger tips at 15 degree intervals along the radial rays by fixing glass push pins on the chart and into the plywood wall. (See Figure 3). After the tracing, the locus-to-origin distance was measured by a flexible steel tape to the nearest 1/4 inch.

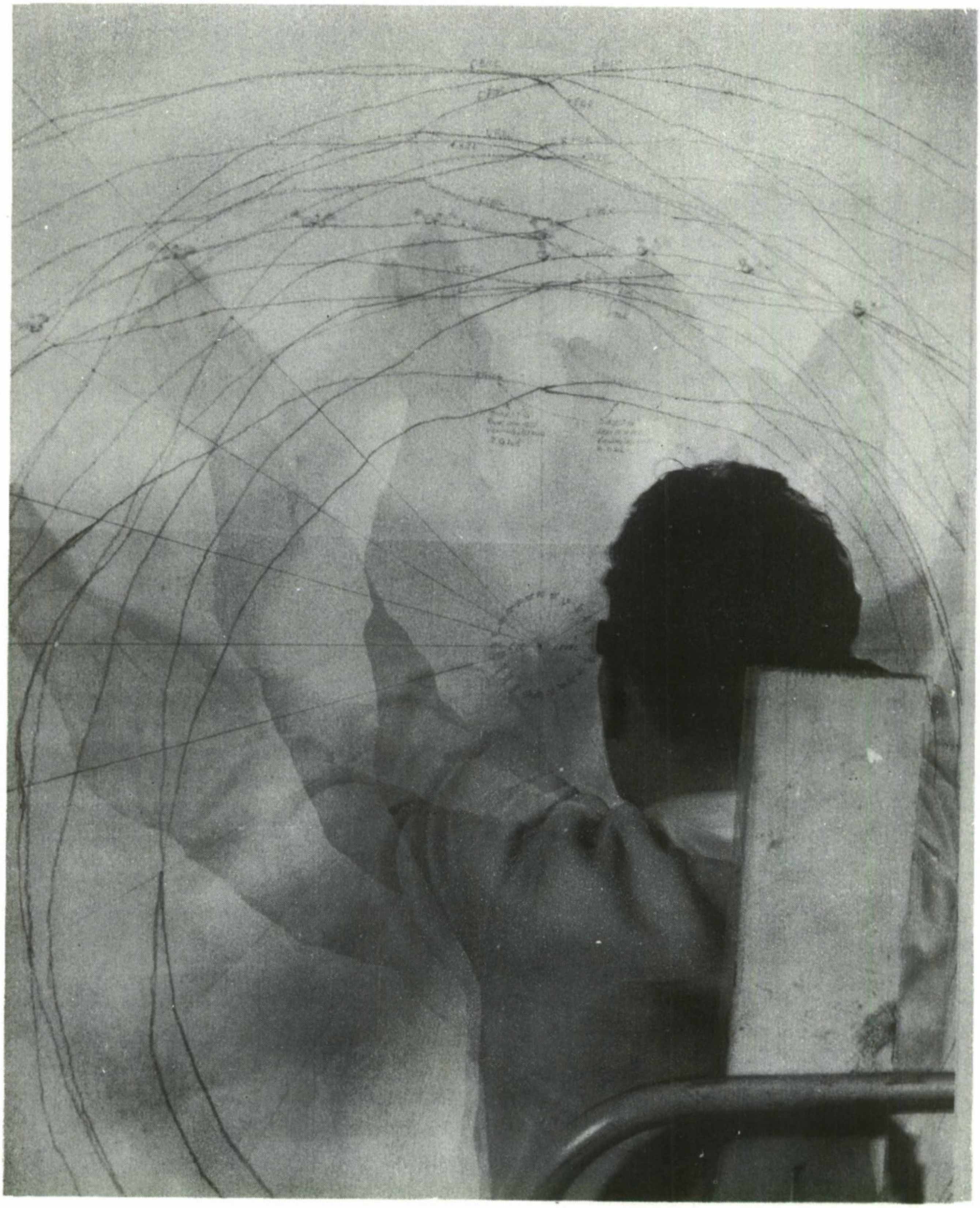


Figure 3

SUBJECT MOVES BOTH ARMS RADIALLY
GLASS PUSH PINS MARK OUTERMOST REACH

Data on Subjects Used Measurements were made and recorded for eight male subjects of various body structures according to the following tabulation:

TABLE I

BODY MEASUREMENTS MADE ON EIGHT SUBJECTS

Subject	Weight	Height		Anterior Arm Reach	
		Ft.	In.	Left Hand	Right Hand
A	210	5	11	37½	37-5/8
B	160	6	1-3/4	37-7/8	37-7/8
C	135	5	8	32-3/4	32-3/4
D	150	5	7-3/4	34-1/2	34-5/8
E	185	5	9-1/4	33-1/2	33-5/8
F	140	5	10-1/2	35-3/4	35-5/8
G	115	5	5-1/2	31-1/2	31-1/2
H	145	5	5-1/2	30-1/2	30-3/8
Average	155	5	9	34-1/4	34-1/4

Note: All subjects are right-handed except Subject C, who is ambidextrous.

EXPERIMENTAL RESULTS AND DISCUSSION

Circular Limits The arcs described by each arm of the individual subjects are approximate circles as indicated in Figures 2 and 3. The farther away the subject sits, the smaller the diameter of each circle. For any fixed distance from the wall, the circular diameters will vary among subjects, due to individual difference in arm length as indicated by the data for anterior arm reach in Table I.

The measurements taken along each radial line for the eight subjects were averaged. The mean distance was plotted at each 15-degree interval, and the several points thus determined were connected by a smooth 360 degree arc as shown in Figure 4. Table II summarizes the average circular diameters measured for the three viewing distances. Since these diameters are determined for an average arm of 34.5 inches in reach, corrections for a 35.2 inch arm are made to adjust the diameters to a population median.

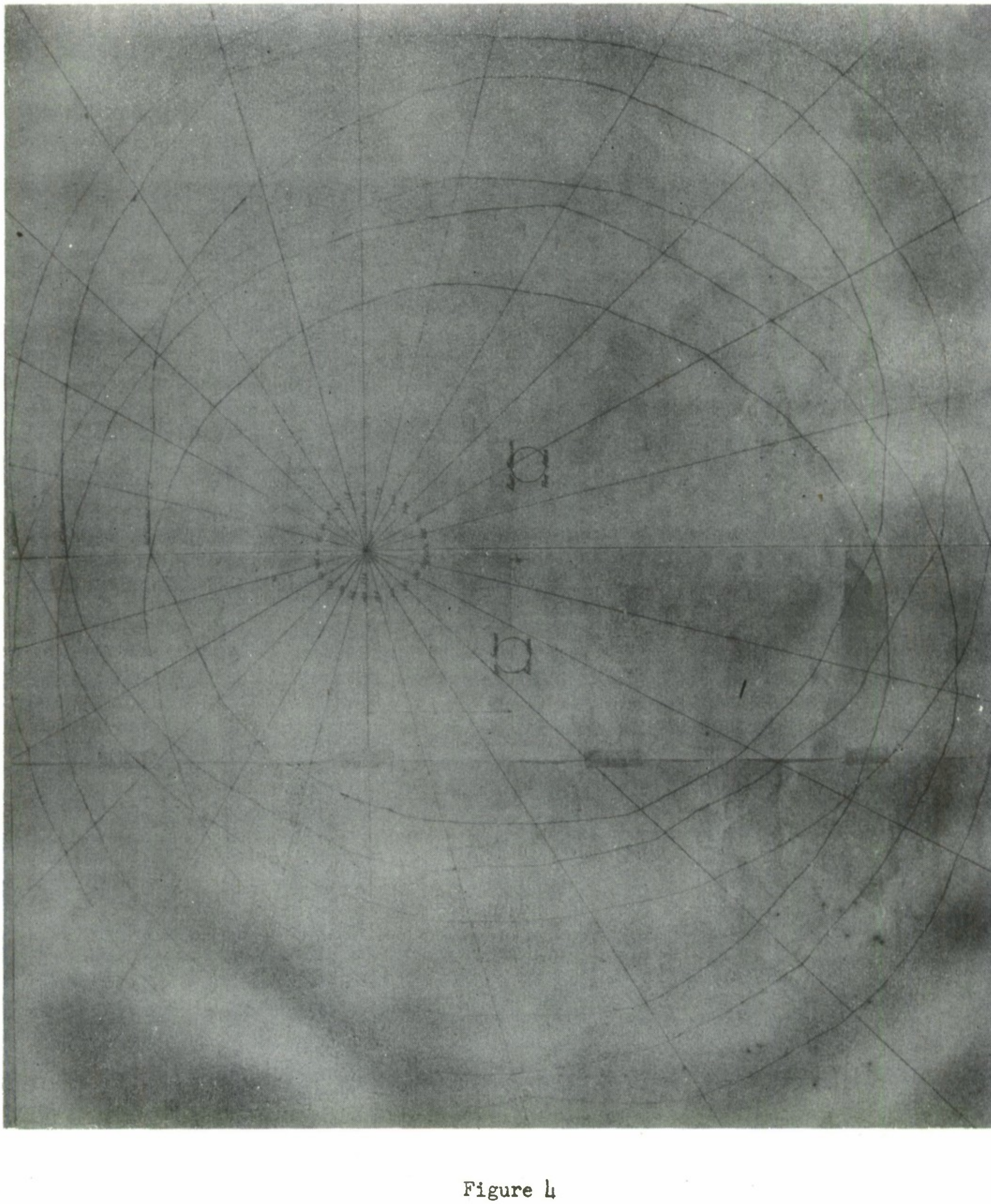


Figure 4

PLOT OF AVERAGE CIRCLES

TABLE II

DIAMETERS OF CIRCLES AVERAGED FROM EIGHT SUBJECTS WITH MAXIMUM REACH ON VERTICAL SURFACES AT THREE VIEWING DISTANCES

Viewing Distance	Left	Range	Right	Range	Selected	Corrected
10	53.07	51.3-54.1	53.13	51.9-54.5	53.1	55.5
15	48.04	47.1-49.0	47.42	46.0-49.1	47.7	50.4
20	40.09	38.9-41.1	40.74	39.8-41.5	40.4	43.5

All data in inches.

Note: The correction for a 35.2 inch average arm is based upon data in AAF Technical Report No. 5501.

Influence of Distance — It will be noted that the farther away the operator sits, the less vertical surface area he can reach. Table II shows that the greatest viewing distance of 20 inches yields the smallest circle of 43.5 inches diameter. Figure 5 shows the two overlapping circles of 43.5 inches diameter (circles B) which determine the area within which the average subject can work if he is no more than 20 inches from the working surface.

Influence of Arm Length — For a male whose anterior arm reach is less than the average, the outer fringes of the area enclosed by 43.5 inch circles will be beyond reach when he sits at the 20-inch viewing distance. Thus smaller areas to accommodate shorter arms should be considered. By reference to the data collected on almost 3,000 AAF cadets, only 5% of the group are found to have anterior arm reach distances less than 32.7 inches, and only 5% greater than 37.8 inches.

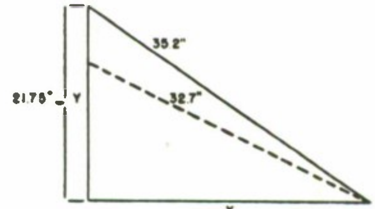
A computed circle using an anterior arm reach equal to 32.7 inches would permit the 95% group to sit at the observed maximum distance of 20 inches from eyes to panel and still reach all controls within the circumferences without shift of posture. The diameter of this smaller circle described by a shorter arm can be calculated as follows:

Given:

Average circle radius $= \frac{43.5}{2} = 21.75$ in.

Average anterior arm reach $= 35.2$ in.

Distance of panel to subject's arm pivot $= x$



The hypotenuse is reduced to 32.7 inches for a shorter arm. The distance x remains constant.

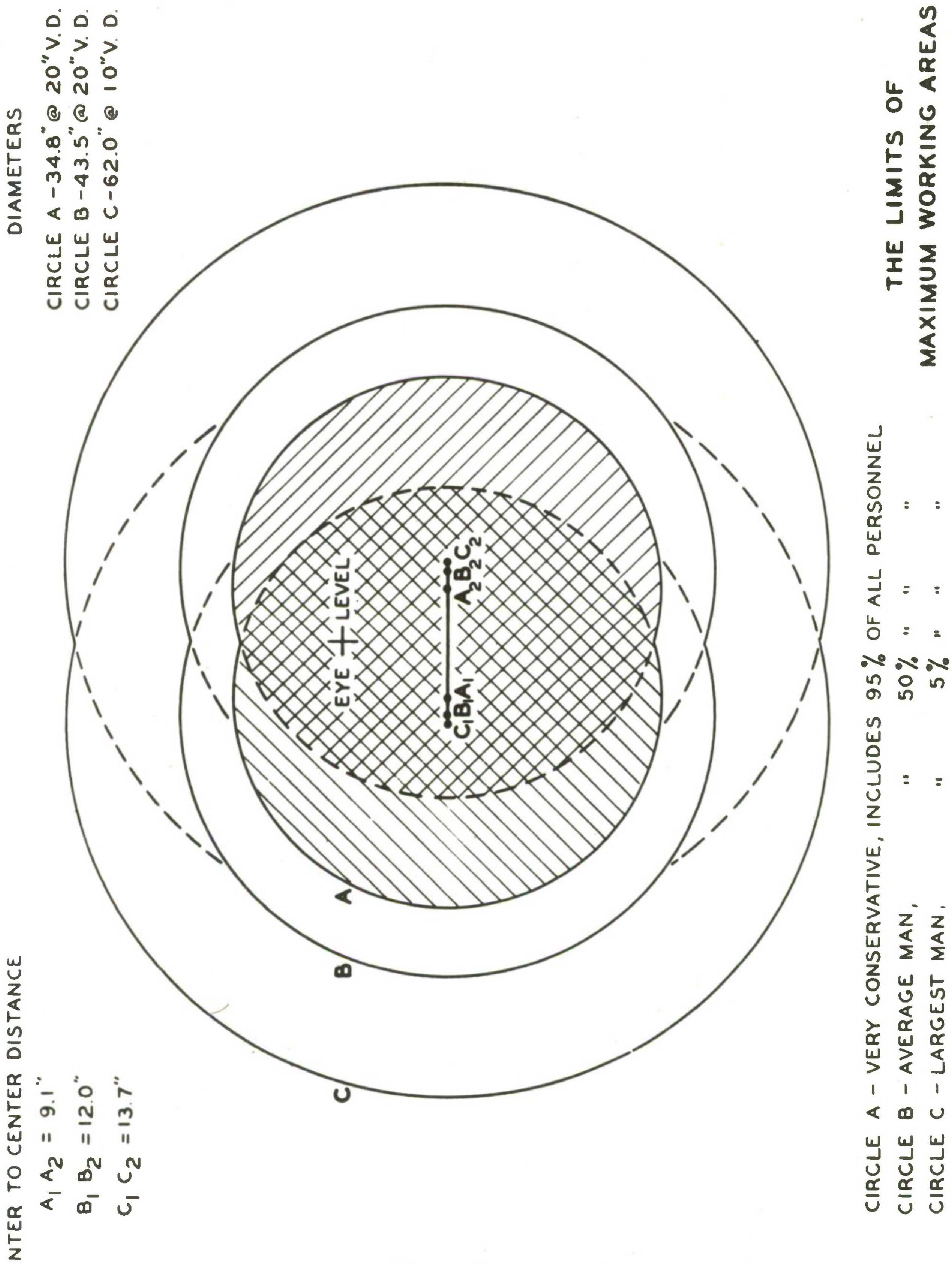

THE LIMITS OF
MAXIMUM WORKING AREAS
DIAMETERS
CIRCLE A – 34.8" @ 20" V.D.
CIRCLE B – 43.5" @ 20" V.D.
CIRCLE C – 62.0" @ 10" V.D.
CENTER TO CENTER DISTANCE
A1 A2 = 9.1"
B1 B2 = 12.0"
C1 C2 = 13.7"
EYE LEVEL
C1 B1 A1
A2 B2 C2
A
B
C
CIRCLE A – VERY CONSERVATIVE, INCLUDES 95% OF ALL PERSONNEL
CIRCLE B – AVERAGE MAN, " 50% " " "
CIRCLE C – LARGEST MAN, " 5% " " "

Figure 5

Problem: To find the new radius y

Solution:

$$x^2 = 35.2^2 - 21.75^2$$
$$x^2 = 32.7^2 - y^2$$

Thus: $35.2^2 - 21.75^2 = 32.7^2 - y^2$

$$y^2 = 32.7^2 = 21.75^2 - 35.2^2$$

$$y = 17.4 \text{ in.}$$

Hence, the diameter $2y = 34.8$ in.

This value of 34.8-inch diameter was checked against the wall chart measurements for a small subject, G, and was found satisfactory.

<u>Influence of Torso Size</u> The centers of the described circles were located by passing twelve diameters through the average circumference, and by determining the approximate geometrical center of the several intersections. These centers are called the pivot points. Since arm motion very often includes degrees of shoulder movement (particularly when the arm describes an inner arc across the body), centers of arm rotation shift about considerably.

Fluctuations in the horizontal distance between average pivot points are indicated in Table III. The data show that the major deviation is contributed by the body size of the subject.

TABLE III

SUMMARY OF PIVOT POINT LOCATIONS AS MEASURED FOR 8-MAN AVERAGE, SMALL SUBJECT AND LARGE SUBJECT

	Horizontal Distance Between Pivot Points			Vertical Distance From Eye Level		
Viewing Distance	Average	Small Subject	Large Subject	Average	Small Subject	Large Subject
10 in.	12.50	8.00	14.62	7.62	8.56	9.38
15 in.	11.37	9.84	14.13	9.44	8.69	8.44
20 in.	12.13	9.00	14.50	7.31	8.13	8.00
Selected for Any Distance	12.0	8.96	14.42	8.12	8.46	8.61

Note: Data on small subject are from Subject G; on large subject from Subject A.

The AAF tables show moderate correlation between-weight and bideltoid distance. Because of the similarity between bi-deltoid distances and the distance between pivot points, this relation also makes it reasonable to accept 12 inches from Table III as the average distance between pivot points applicable to a military population average.

It is desirable, also, to estimate the distance between pivot points for the 5% and 95% group, i.e., for the man of slight build and for the man of heavy build, Table IV presents the translation of individual subject data to the general military population data. Subjects G and A fall respectively beyond the 5% and 95% percentiles for weight. Hence the measured distances between pivot points for these individual subjects are corrected on the assumption of a linear proportion between bi-deltoid distances and distances between pivot points.

TABLE IV

ESTIMATION OF AVERAGE DISTANCES BETWEEN PIVOT POINTS FOR 5% AND 95% PERCENTILE GROUPS

	Wgt. in lbs.	Distance Between Pivot Points	Bi-Deltoids
Subject G	115	8.96 (a)	16.0 (a)
5% Group	128	9.07 (c)	16.2 (b)
Subject A	210	14.42 (a)	20.63 (a)
95% Group	184	13.70 (c)	19.60 (b)

Note: (a) Measured value.
(b) Tabular value, correlation with weight, AAF Report No. 5501.
(c) Calculated value.

Thus, from Table IV, the very small subject is assigned 9.1 inches distance between pivot points which will be exceeded by 95% of all possible operators. Similarly the very husky subject is assigned 13.7 inches distance between pivot points which will be exceeded by only 5% of all possible operators.

Influence of Pivot Height The height of the pivot points from the floor will establish the upper and lower positions of the circles and thus influence the location of the working areas. Several factors may act independently to modify the height of the pivot points. One change can be made by adjusting chair height. (The radar operator's chair used for this experiment could be adjusted from 19.7 inches to more than 34.7 inches. A second variable is the size range of operator whose sitting height may vary from 32.7 inches to 40.6 inches. Another change can also be made by alteration of operator posture, with a concurrent shift in the height of eye level because the two are dimensionally related. (Eye level was measured as 7-1/4 inches to 9-1/2 inches higher than pivot points for the eight subjects tested, with posture erect. See Table III.)

The vertical shift in pivot height (with fixed vertical working area) may cause a condition in which reach can be too short for certain controls. No special allowance for this shift is considered here because vertical accommodations are easily made through chair height adjustment.

The one partly controllable design variable is the location of visual tasks which in turn tend to change the height of eye level from the floor. Hence, any visual task should be properly located so as not to attract the operator from his central reach position.

Influences Combined — The several influences of viewing distance, of distance between pivot centers, and of arm reach may be combined. Accordingly, Table V summarizes the possible maximum working limits under various conditions.

TABLE V

DATA ON CORRECTED AVERAGE AND COMPUTED CIRCLES DESCRIBED ON A VERTICAL SURFACE

Eye-to-Panel Distance	Circle Diameter Corrected for Average Arm (35.2 in.)	Circle Diameter Computed for Very Short Arm (32.7 in.)	Circle Diameter Computed for Very Long Arm (37.8 in.)
10 in.	55.5 in.	49.0 in.	62.0 in.
15 in.	50.4 in.	43.1 in.	57.4 in.
20 in.	43.5 in.	34.8 in.	51.5 in.

Note: The circles may have their centers separated by 9.1 in., 12 in., and 13.7 in. for operators of very slight, average, and very heavy build respectively.

The most conservative maximum-area which will include 95% of all subjects is described by two overlapping circles at a 20-inch eye-to-panel distance whose centers are approximately 9.1 inches apart and whose diameters are 34.8 inches. This overall area is represented by the single cross-hatched pattern in Circles A of Figure 5.

When only 50% of potential operators need be considered at 20-inch viewing distance, then the overall area of the two overlapping 43.5-inch circles should be used. Circles B of Figure 5 enclose the area for such conditions for an average sized operator. If the viewing distance were reduced to 15 inches, the circular diameters for the average operator would be increased to 50.4 inches. It is believed that such values obtained for average operators have only restricted application in situations providing for an estimated 50% of operators at each viewing distance.

Of academic interest is the maximum area that can be covered by subjects of long reach seated in close to the console and with a maximum spread of pivot centers. Circles C of Figure 5 enclose such an area, comprising two circles of 62.0 inches diameter separated by 13.7 inches at centers. Circles C describe the area beyond which no more than 5% of all possible operators might be able to reach when seated no closer than the 10-inch viewing distance.

The upper and lateral limits of the two overlapping circles envelope an approximate elliptical area whose major and minor axes have been computed. Table VI shows different combinations of viewing distance, arm length, and distance between pivot points. The smallest area, 43.9 inches x 34.8 inches, will give maximum coverage by 95% of potential operators. Other areas for difference percentages of coverage (other than 5%, 50%, 95%) likewise can be determined to suit special conditions.

<u>Two-Handed Manipulation</u> Some tasks require that two hands be used at the same place and at the same time. In such instances, the maximum area available to both hands without change in posture is much smaller than when each hand may work to its own side of the vertical. The limits of such a maximum area are indicated by the inner intersecting arcs of the overlapping circles as shown in Figure 5. (These arcs are shown dotted.) The enclosed area is approximated by the inner elliptical shape with its major axis along the experimental vertical and its minor axis on the eye level horizontal. Table VII shows a series of measurements of major and minor axes taken on those areas described for Table VI. The smallest area, which is double cross-hatched in Figure 1b, is available to a husky operator with short arms seated at the 20-inch viewing distance. Its elliptical axes are 32.0 inches vertical and 21.1 inches horizontal. It should be noted that, whereas the operator of slight build has the least overall spread for one-hand manipulations, he has greater reach coverage for two-handed manipulations than has a husky operator under similar conditions. Compare Figure 1b and Figure 5. Hence, in order to be most conservative and to obtain better coverage, the values obtained for a husky operator are selected for two-handed use.

TABLE VI

COMPUTED DATA ON MAJOR AND MINOR AXES

OF THE LIMITING ELLIPTICAL SHAPE

Outer Circular Arcs Used as Limits

Data in Inches

BODY SIZE VARIABLES		EYE-TO-PANEL DISTANCE		
Arm Length	Dist. Betw. Pivot Points	10 in. (Major Axis x Minor Axis)	15 in. (Major Axis x Minor Axis)	20 in. (Major Axis x Minor Axis)
		(55.5)	(50.4)	(43.5)
35.2 (avg)	9.1	64.6 x 55.5	59.5 x 50.4	52.6 x 43.5
	12.0	67.5 x 55.5	62.4 x 50.4	55.5 x 43.5
	13.7	69.2 x 55.5	64.1 x 50.4	57.2 x 43.5
		(49.0)	(43.1)	(34.8)
32.7 (Small)	9.1	58.1 x 49.0	52.2 x 43.1	43.9 x 34.8
	12.0	62.0 x 49.0	55.1 x 43.1	46.8 x 34.8
	13.7	62.7 x 49.0	56.8 x 43.1	48.5 x 34.8
		(62.0)	(57.4)	(51.5)
37.8 (Large)	9.1	71.1 x 62.0	63.5 x 57.4	60.6 x 51.5
	12.0	74.0 x 62.0	69.4 x 57.4	63.5 x 51.5
	13.7	75.7 x 62.0	65.2 x 57.4	65.2 x 51.5

Note: Figures in parenthesis are the diameters of circles used in computing each set of axes.

MEASURED DATA ON MINOR AND MAJOR AXES OF THE COMMON ELLIPTICAL AREAS

For Two-Handed Manipulation Using the Same Arcs Described for Table VI

Data in Inches

BODY SIZE VARIABLES		EYE-TO-PANEL DISTANCE		
Arm Length	Dist. Betw. Pivot Points	10 in. (Major Axis x Minor Axis)	15 in. (Major Axis x Minor Axis)	20 in. (Major Axis x Minor Axis)
		(55.5)	(50.4)	(43.5)
35.2 (Avg)	9.1	54.8 x 46.5	49.6 x 41.3	42.6 x 34.5
	12.0	54.4 x 43.8	49.2 x 38.8	42.1 x 31.8
	13.7	53.8 x 41.9	48.5 x 36.7	41.3 x 29.8
		(49.0)	(43.1)	(34.8)
32.7 (Small)	9.1	48.3 x 40.0	42.1 x 34.0	33.6 x 25.8
	12.0	47.5 x 37.1	41.3 x 31.1	32.8 x 22.9
	13.7	47.1 x 35.3	40.8 x 29.4	32.0 x 21.1
		(62.0)	(57.4)	(51.5)
37.8 (Large)	9.1	61.4 x 53.1	56.7 x 48.4	50.8 x 42.5
	12.0	60.8 x 50.0	56.3 x 45.5	50.4 x 39.8
	13.7	60.5 x 48.3	55.8 x 43.7	49.7 x 37.8

Note: Figures in parentheses are the diameters of circles used in computing each set of axes.

Assumptions The foregoing discussion of maximum reach limits is based on several assumptions which are indicated below:

1. Body posture should not have to be changed in order to reach any controls with the fingers.

2. Data on almost 3000 AAF cadets is sufficient for extension to larger groups.

3. Linear proportion exists between bi-deltoid distance and the distance between pivot centers.

4. Pivot points, for purposes of calculations of maximum reach under different conditions, do not change their position.

5. The distance of eyes to panel is dictated by the presence of a visual task on the same vertical surface.

OTHER CONSIDERATIONS

Other Types of Surfaces This report has been limited to flat vertical surfaces; a few additional comments are made herewith to indicate that only the simplest case has been considered. By combination of two or more flat vertical surfaces, the available instrument working surface can be increased several fold. This is indicated by the different shapes in Figure 6. The suggested width of horizontal sides is equivalent to the diameter of the smallest circle plus the distance between centers. A more open 'V' or 'U' type design, Figure 6 b, c, and d, can be allowed if the viewing distance to the closed end is less than 20 inches.

The increase in the number of flat vertical sides suggests a curved or semicircular vertical console, Figure 6 d, and even a hemispherical shape. If the position of the pivot regions in the shoulders is adequately considered, the effective reach for one-armed manipulations increases manifold.

Normal Working Areas This report has determined the maximum limits of working areas on vertical surfaces. Within such areas, there are other smaller preferred working locations known as "normal" working areas. This latter category is defined as those locations reached by the operator fastest and with most comfort. Such normal areas, rather than maximum areas, are generally utilized for the more important and more frequent duties of the operator. Work involving reach may be done anywhere within the periphery of the maximum-area circles. However, for most efficient work, the reach should be limited to work within the normal area.

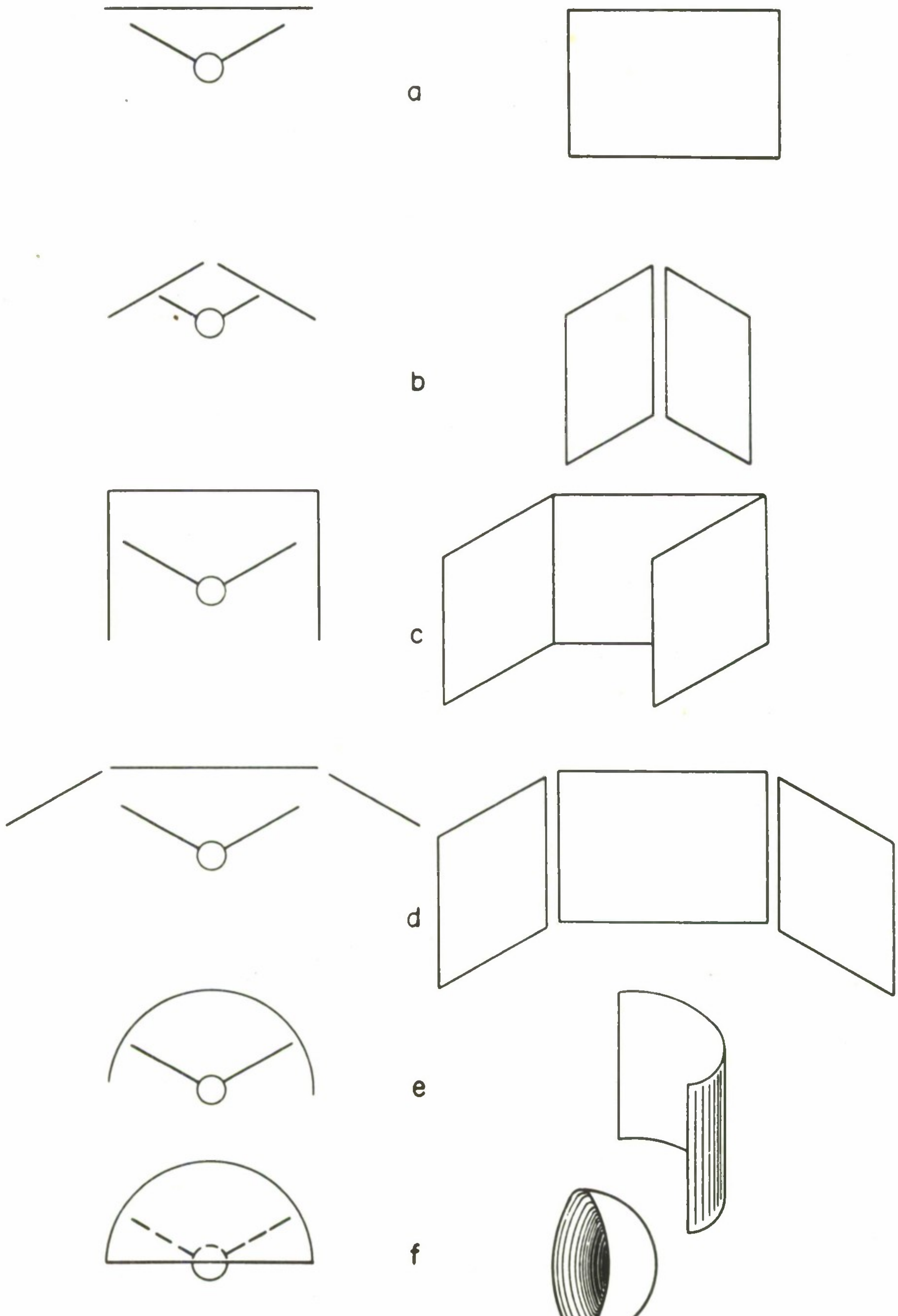


FIG. 6 — TYPES OF VERTICAL WORKING SURFACES

1. Approximate circles are described on a flat vertical surface by the arms of a seated male subject.

2. These circles decrease in diameter as the subject sits farther away from the vertical surface.

3. At the maximum viewing distance of 20 inches, the smallest average measured diameter for the eight subjects was 40.4 inches.

4. The measured distance between the centers of the two circles of average diameter of 40.4 inches was 12 inches.

5. Such measured values of circular diameters and distances between centers have been corrected for anterior arm reach and body distance between pivot centers as calculated on the basis of a population of 3,000 AAF Cadets.

6. These overlapping circles selected for different conditions of viewing distance, of arm reach, and of distance between pivot centers, enclose the maximum working area for those conditions.

7. The maximum working area for tasks requiring two-handed manipulation in the same place is limited to that area common to both of the overlapping circles and is smaller for husky men than for men of slight build.

RECOMMENDATIONS

The following recommendations are selected to include approximately 95% of an expected military population. The area enclosed by two overlapping 34.8-inch diameter circles whose centers are 9.1 inches horizontally apart on a line approximately 7-1/4 inches to 9-1/2 inches below eye level is recommended as the maximum working area. The area enclosed by these overlapping circles approximates an ellipse whose major axis is 43.9 inches and whose vertical minor axis is 34.8 inches. This is shown by the cross-hatched area of Circles A in Figure 5.

The recommended limiting area for work involving two hand manipulations at the same place is defined by the common area of two 34.8-inch diameter circles whose centers are separated horizontally by 13.7 inches. Its approximate elliptical shape has axes which are 32.0 inches vertically and 21.1 inches horizontally.

The above recommendations have their application to layout of instrument panels. Visual attractions or other means should be incorporated to keep the operator centered at his work place.