within a given reach zone. In general, this zone will approximate a circle whose size will vary depending on the arm reach of the operator.[23]

More often than not, however, a knowledge of arm reach to a three-dimensional region is required rather than to a vertical plane only or horizontal plane only.[24] Functional arm reach for many working areas will, in general, correspond to the illustration shown in Figure 4. One investigator who has dealt concretely with problems of this complexity is Dr. B. G. King. In the experimental method employed to determine the various reach measurements, a series of seated subjects reached for and touched successive points on a vertical measuring rod as it was brought forward along a horizontal support. Horizontal distances from the vertical line rising from the seat reference point to the vertical

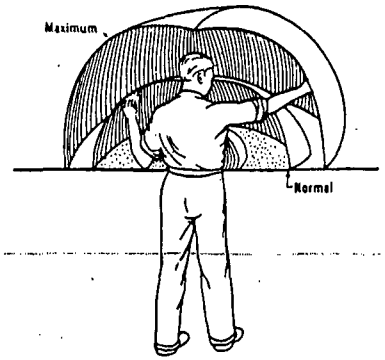


Figure 4. The normal and maximum working areas in three dimensions. (Reprinted with permission from Ralph M. Barnes, *Work Methods Manual*, 1944, John Wiley and Sons, Inc.)

measuring rod at extreme fingertip reach were measured for each of 99 points. The over-all pattern is such that the average reach increases as the arm is moved laterally from 0° to 15, 45, 75, 100, and 105° and decreases as the arm is raised or lowered from the trunk height of the subject (see Figure 5). The unequal radii of any arc describing various successive points of reach are attributable to the position of the shoulder joint in relation to the mid-sagittal plane of the body and to its architecture. Data on the maximum distance that could be reached by 97 per cent of a Navy male population are presented in Table 3.[25] Distances are

[23] H. L. Lipschultz and K. O. W. Sandberg, Maximum limits of working areas on vertical surfaces, Office of Naval Research, Special Devices Center, *Report No. 166-I-8*, 1947.

[24] A. Chapanis, W. R. Garner, and C. T. Morgan, *Applied Experimental Psychology, Human Factors in Engineering Design*. Wiley, New York, 1949.

[25] B. G. King, D. J. Morrow, and E. P. Vollmer, Cockpit studies—the boundaries of the maximum area for the operation of manual controls, *Project X-661, Report No. 8*, Naval Medical Research Institute, National Naval Medical Center, 1947.

TABLE 3
Maximum Reach with Right Arm
(In inches)

Level above reference point (in.)	Angle 0°	R 15°	R 45°	R 75°
46	11.6	13.7	15.0	17.0
40	18.9	20.5	22.4	24.1
34	22.9	24.9	26.6	28.0
28	25.5	27.1	29.1	30.1
22	26.7	28.2	30.3	31.4
16	26.6	28.0	29.7	31.6
10	25.3	27.0	29.3	30.4
4	22.6	24.2	26.4	27.9
−2	17.5	19.7	21.8	22.8

measured from the vertical line through the reference point with the subject's shoulders touching the back cushion; seat back 13° from the vertical. The reference point is at the upper level of the seat cushion at its line of intersection with the lower cushions of the back. Reach for the left arm can be outlined by using above measurements at corresponding points to the left (see Figure 5).[25]

Unfortunately, there are two limiting factors that prevent these data from having wide applications in general problems of equipment design. The first difficulty is that the sample consists only of male Naval personnel. Although King believes that they may be sufficiently representative to serve as a basis for specifying reach dimensions satisfactory for a relatively large percentage of a random sample of men in the armed forces, nevertheless they will not necessarily closely approximate other selected populations. For example, the functional reaches that can be maintained by 93 per cent of this Naval group might be achieved by only 75 per cent or perhaps by as many as 98 per cent of other groups.

It should be remembered also that reach dimensions will change with any alteration in the conditions of the working area, such as a difference in the inclination of the seat or seat back, thus necessitating either a new study under the new working conditions or the computation of correction values to be applied to the table of standard data. An additional point is that the dimensions in Table 3 are maximum reach measurements taken at the fingertip. Obviously controls cannot be operated at these extreme locations. Depending upon the characteristics of the control and the degree of movement and accuracy required, its maximally distant location may be up to 5 inches less than the outermost range of fingertip reach.[25]

The above necessary qualifications and restrictions point up the complexity of functional arm-reach problems and the difficulty of applying specific dimensions to practical situations. However, it should be remembered that a limited use of such correlations as exist between arm length or reach measurements and other body