in a discontinuous task carried on with the right hand when the left hand was performing a fairly difficult but dissimilar and continuous task.[80]

"Expected" relationships probably originate in the previous experiences of individuals rather than in any anatomical organization. Even though the "unexpected" relationships may be learned quickly, in many cases the great amount of previous contrary experience probably contributes toward the rapid forgetting of these learned relationships. Certainly, the use of other controls with confusing similarities and differences between the particular "unexpected" display-control relationships would be likely to lead to errors in the operation of the latter. In addition, even though an operator has learned to make correct, "unexpected," display-control responses, he is very likely to respond in the way most natural to him when an emergency arises, and his response will therefore be in error. This, of course, will vary with the level of learning of the "unexpected" response.

In one panel arrangement, subjects first turned a knob in order to center a light in a semicircular display, and then turned a second knob in order to center a light in another semicircular display. This alternation between panels was continued for a series of responses. Time and error scores were not large when a clockwise control movement produced a clockwise indicator light movement on both panels, nor were they large when a counterclockwise control movement produced a counterclockwise indicator light movement on both. However, when a clockwise-clockwise relationship existed on one panel, and a clockwise-counterclockwise relationship on the second, time and error scores increased greatly for both.[81] Such data clearly indicate the importance of having standard display-control relationships on all equipment in order to avoid errors in rapid responses.

If the best arrangements and relationships are employed when controls are designed for situations in which visual displays must be responded to rapidly and accurately, speed of response will be increased, learning of the control task will probably be facilitated, and incorrect responses will be less likely to occur, particularly when the operator is working under conditions of boredom, fatigue, or emergency. If compromises must be made in the direction-of-motion relationships between display and controls, it is probably more important that all controls on the panel have the same direction-of-motion relation to the displays even though they may not be the most "expected" relationship. Another alternative is to make the dial having an "unexpected" relationship to a control a different type of display than the others (for example, a linear type if the others are circular), so that its differentiation is obvious.

In tasks where only one control is used continuously, the problem of the

[80] R. E. Jones, A survey of pilot preferences regarding knob shapes to be used in coding aircraft controls, *Memorandum Rept. No. MCREXD-694-4E*, Air Materiel Command, USAF, October 1, 1947.

[81] M. J. Warrick, Effect of motion relationships of speed of positioning visual indicators by rotary control knobs, *Tech. Rept. No. 6812*, Air Materiel Command, USAF, October, 1949.

direction-of-motion relationship does not appear to be significantly important unless the task is of short duration, when it more nearly approaches the discrete type of response situation. Even here, since these controls are likely to be operated in conjunction with others, it is better that "expected" relationships be used if possible.[2,24]

Knob Shape. The most efficient shapes for hand controls were determined by testing several types of knobs subjectively and objectively on the basis of maximum force applied, arc through which the knob turned, and time required for grasping and releasing. A two-pointed (cigar) shape and a four-pointed star gave the highest mechanical advantage and were also favored by the subjects. Of the two, the four-pointed knob is superior in that it is easier to obtain a new grip on this form when a partial turn has been made. Circular controls and three-, five-, six-, and eight-pointed controls were much less satisfactory.[82]

The use of different shapes has also been found to reduce the time required for the accurate operation of a series of controls. For instance, if the positions of controls are changed after individuals have learned one set of operations, the time required to perform accurately a series of tasks with the controls is increased.[57] However, if the control handles are coded with regard to shape, the detrimental effect of shifting the location of controls is minimized even when visual cues are reduced. If standardized, this type of coding would be of great value where new operators are learning to operate a machine with a large bank of controls, and it would be of particular value when a trained operator, or perhaps an older operator, shifts from one machine to another where the controls are in a different position. He could verify his choice of controls and avoid errors even though he might tend to reach for and operate the controls through force of habit without the aid of vision (see "Tactual Displays" on page 92).[2] Coding may also be achieved by the use of specific colors for certain controls or types of controls. Color coding may be used independently of, or in conjunction with, shape coding.

Knob Size. In controls requiring the exertion of negligible force, such as the setting of indicator pointers, the diameter of the knob has little influence on the time required to make the setting provided only that it can be conveniently grasped. A knob of about $2^3/_4$ inches in diameter appears to be a favorable size. The use of a crank handle does not aid, and possibly hinders, the speed of adjustment on a task of this type.[83] The same general finding has been reported for knobs used in tuning for maximum signal strength, as where bracketing would be used (moving the control approximately 30° to one side and then to the other, and attempting to halve the distance by feel). For a knob with the axis at right angles to the operator's forearm a diameter of 1 to 2 inches has been found superior. For

[82] A. Wallichs and F. Hulverscheidt, Die Bedienbarkeit von handgriffen Vorrichtungen, *Maschinentechnik und Werksleiter*, **29**, 193–197 (1935).

[83] W. O. Jenkins and M. B. Connor, Some design factors in making settings on a linear scale, *J. Applied Psychol.*, **3**, 395–409 (1949).