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THE CODING OF AIRCRAFT CONTROLS

DARWIN P. HUNT

AERO MEDICAL LABORATORY

AUGUST 1953

Statement A
Approved for Public Release

WRIGHT AIR DEVELOPMENT CENTER

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WADC TECHNICAL REPORT 53-221

THE CODING OF AIRCRAFT CONTROLS

Darwin P. Hunt

Aero Medical Laboratory

August 1953

RDO No. 694-17

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This is a summary report prepared by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center under Research and Development Order 694-17, "Functional Coding of Aircraft Controls," with Darwin P. Hunt acting as Project Engineer.

The assistance of the following people is gratefully acknowledged: Drs. C. W. Crannell and P. M. Fitts for permission to utilize their data concerning the accuracy of blind reaching; Lt. E. Ebert for developing the method of constructing Table III; Mrs. Jane McCulloch for drawing all of the figures and graphs; Mr. M. J. Warrick for reading and criticizing the report at various stages of its development; and Mr. D. R. Craig for his major contributions to the section dealing with shape coding.

ABSTRACT

This report summarizes the available information concerning several techniques of control coding which seem to be of value to the design engineers. Control coding means providing the operator with a way of identifying the controls. Five methods of control coding are discussed: Shape coding, size coding, location coding, color coding, and mode-of-operation coding. Information is given concerning each coding technique so that the design engineer can apply any of these methods as the need arises. Many of the advantages and disadvantages of each method are pointed out. The question of when to code and the type of coding to use are discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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SECTION I

INTRODUCTION

In operating any equipment it is desirable that the operator be able to locate quickly and identify accurately the various controls. This problem is particularly acute in the operation of military equipment. With more knobs facing the operator, with the space within which these knobs are placed becoming smaller, and with the time factor becoming more critical, it is apparent that some control knob coding or identification system is desirable.

The importance of correctly identifying controls was brought out clearly in a survey of pilot errors. Five hundred pilots were asked to describe an error that they had made or had seen someone make in using controls.[9] Of all the errors reported, 50% involved the operation of a <u>wrong</u> control. In an attempt to alleviate this situation, certain of the critical cockpit controls were functionally shape coded.[11] That is, certain shapes were assigned to particular functions so that whenever the operator saw or felt a particularly shaped knob he would know what function it controlled. Knob shapes that may be used for such functional shape coding are shown and discussed later in this report under Section III, "Shape Coding."

It is the purpose of this report to consolidate the presently available information and opinions concerning various techniques of control coding that seem to be of most value to the design engineer. These coding techniques are: (1) shape, (2) size, (3) position or location, (4) color, and (5) mode of operation. Labelling the controls is an equally useful method, but will not be discussed in this report.

Wherever possible, recommendations will be based on experimental results. However, much of the application of coding techniques has not been based on experimental data, but on "common sense". In areas in which results are not available or there are conflicting results or opinions, the conclusions will reflect the present views of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center.

SECTION II

GENERAL

The purpose of coding controls is to make them easy to identify. The ease with which a control can be identified enters as an important factor in at least three different situations. In the training situation, the ease with which the trainee can identify the different controls affects the speed with which he becomes familiar with the equipment and learns to use it efficiently and accurately. In the usual operating situation, requiring a multiplicity of adjustments and coincident operations of several control units, the ease and rapidity with which a control may be identified affects the speed and accuracy with which the total task can be performed. In the night operating situation, or in day operation in which the eyes are occupied with other tasks, the ability to identify a control, other than visually, may make the difference between serious error and successful accomplishment of the required task.

When considering the possible use of control coding, it is necessary to determine (1) which, if any, controls require coding and (2) what types of control coding are appropriate.

The decision as to which controls to code may be based upon some composite index of the frequency of use of each control, the importance of that control to the performance of the task, and the danger resulting from the operation of a wrong control. In a newly developed system it is difficult to obtain this information. Probably the most reliable preliminary information can be obtained from the engineers who designed and built the equipment and from operators of similar equipment. If the equipment is in operational use, there are numerous techniques such as photography and interviewing that may be utilized to get information regarding the frequency of use and the importance of the controls.

The decision as to which type or types of control coding to use must be based upon considerations of the specific situation in which it is to be used. Some of the factors to be considered are;

1. The demands placed upon the operator during the time that the controls must be identified.

2. The extent and types of control coding already being used.

3. The illumination of the operational situation. If the ambient illumination varies considerably or is very low, color coding might be inappropriate.

4. The rapidity and accuracy with which the controls are required to be identified.

5. The space available for the operation and placement of the controls. If space is quite limited, absolute position coding would not be applicable.

6. The number of controls that require coding.

7. The logistic problem that would arise as a result of using the various types of control coding. The magnitude of this problem depends upon such factors as the number of controls that are coded, the technique of coding employed, and the probability that replacements will be necessary. Usually adequate supply presents no difficulties if the controls are coded with respect to location or mode of operation.

Ultimately it is desirable that the control coding permit rapid and accurate identification of the control under all operating circumstances without interferring with the manipulability of the control, that the coding be pleasing to the operator and, finally, that it be easy and economical to apply and maintain. This report is concerned primarily with the first aspect; control coding for quick and accurate identification.

SECTION III

SHAPE CODING

This section is concerned principally with knob shapes for use on controls in which only modest force or torque is required. In addition to identification, there are two ways in which knob shapes may enter into the operator's task. It may affect the operator's ability (1) to make the required adjustments of the knob and (2) to monitor the knob's position. If a knob is to be functional, its design must be such that it can be manipulated properly. In addition, some knobs must be designed so that their settings can be determined by looking at or feeling them. A "gain" control, for example, might require more than one full turn to cover the adjustment range. An essentially round shape will facilitate this operation by allowing the operator to shift his grip readily and thus spin or twirl the knob to achieve the proper adjustment. In this instance, the fact that the shape does not allow the operator to check on knob position is not necessarily a disadvantage because the correctness of the adjustment can be monitored by hearing (or sight). On the other hand, a rotary selector switch, i.e., with detent positions, is not spun; but rather is adjusted by turning to particular positions. If the positions are displayed on a fixed scale, an elongated knob is indicated. The axis along which the knob extends may then be used for both visual and tactual checking of the knob position. Sometimes selector switches are provided with moving scales. In this case, an elongated knob may add little as a means of checking the knob position and could actually be the source of some confusion.

In general, the specific manner in which a given control is used is a factor that must be considered in deciding which knob shapes are satisfactory for that control. Specific recommendations are made in a later section, "Suggested Knob Shapes."

As was pointed out in Section II, the ease with which a control can be identified is an important factor in the efficient operation of equipment. A number of studies have shown that by using different knob shapes, properly selected, accurate identification of a control may be accomplished by tactual discrimination alone.[1,19] For greatest benefit, however, the knobs should be both visually and tactually discriminable.

The value of the technique of shape coding depends principally upon the tactual discriminability of the knob shapes that are used. As yet, there have been no general principles established that might be used to select or design discriminable knob shapes. Instead, it has been the practice to design a number of knob shapes on the basis of the final use to which they are to be put and then, by having a number of individuals feel them and/or look at them, select those that seem to be discriminable. This procedure limits the extent to which the conclusions may be generalized. That is, the conclusions must properly be restricted to the group of knob shapes among which the judgements of discriminability were made. If differently shaped knobs are added to the original group, the relative discriminability of any of the knobs may be changed. Therefore, in selecting a knob shape it is necessary to consider the knob shapes which will be around it.

One of the first studies aimed at selecting a number of discriminable knob shapes was conducted at the Psychology Branch, Wright-Patterson Air Force Base.[13] Forty blind-folded Air Force pilots tactually selected knobs, which they had felt, from a group of twenty-five differently shaped knobs. From an analysis of the pattern of errors that was obtained, two sets of eight knobs were selected among which there were very few errors of identification. These are shown in Figure 1. These results were confirmed in a follow-up study[14,15] employing a paired-comparison technique. A further survey was conducted in which pilot preferences were determined concerning (1) which of the aircraft cockpit controls should be coded and (2) which of the discriminable shapes should be used on the different controls.[16]

In 1948 the RAF Institute of Aviation Medicine conducted a somewhat similar study.[4,20] In addition to comparing shapes, the size was varied to find out if it had any effect on shape discrimination. This study resulted in the selection of a number of knob shapes from each size series. These are shown in Figure 2. Reducing the size from 1.5 to .6 inches did not appear to have much effect on the discriminability of the various shapes considered.

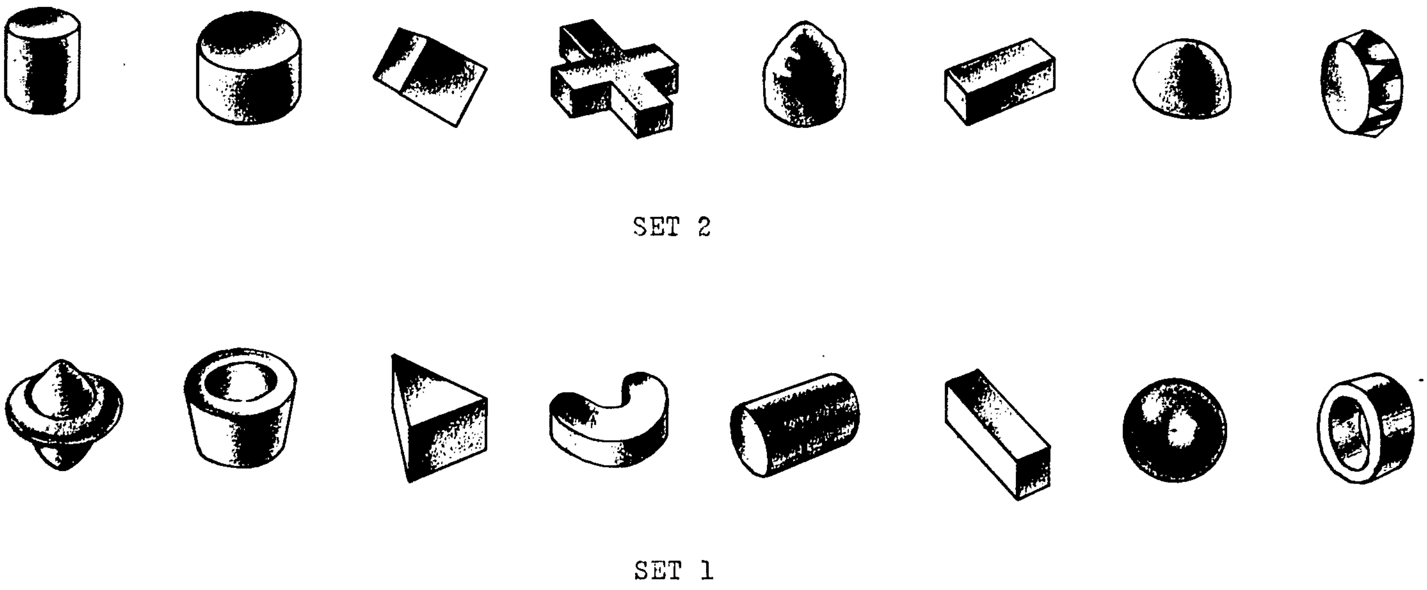


Figure 1: Two Sets of Knob Shapes That Are Distinguishable by Touch Alone. The Shapes of Each Set Are Rarely Confused With Each Other.

The effect of size on tactual shape discriminability was also investigated by the Aero Medical Laboratory.[2] It was found that size (1 in. to 2 in.) had no effect on the discriminability of the two knob shapes used. However, the authors cautioned against generalizing the results to other situations. It was pointed out that, in addition to a difference in the shape of the two knobs, there was also a difference in the orientation of their major dimension. Therefore, size may have been a relatively unimportant variable as compared to the other available cues.

The influence of training on the tactual discriminability of knob shapes was investigated by the Aero Medical Laboratory.[7] Three groups of subjects were used. One group was given no training. The other two groups were given two different kinds of training designed to increase the mutual discriminability of the four knob shapes; then all of the subjects discriminated among the four shapes. The subjects given training discriminated significantly faster and more accurately than the group given no training. Therefore, most of the estimates of the mutual discriminability of knob shapes may be considered to be conservative since relatively untutored subjects were used.

That tactual discriminability improves with practice has also been reported.[1] Subjects used their finger tips to distinguish among seventeen letters, three numerals, and five geometric forms. These figures were cut from 1/4 in. Masonite sheeting and were the maximum size which could be inscribed in a half-inch circle. The stroke width was two mm. It was found that, not only did the accuracy improve from 87% (Trial 1) to 100% (Trial 7), but the time taken to make the judgement decreased from 9 seconds (Trail 1) to about 3.5 seconds (Trial 8). It was also noted that the accurate judgements were made quickly and, conversely, the erroneous judgements were made slowly. The fact that such finger tip discriminations can be made also suggests a possibility for coding push button type controls by placing raised symbols on the top of the control.

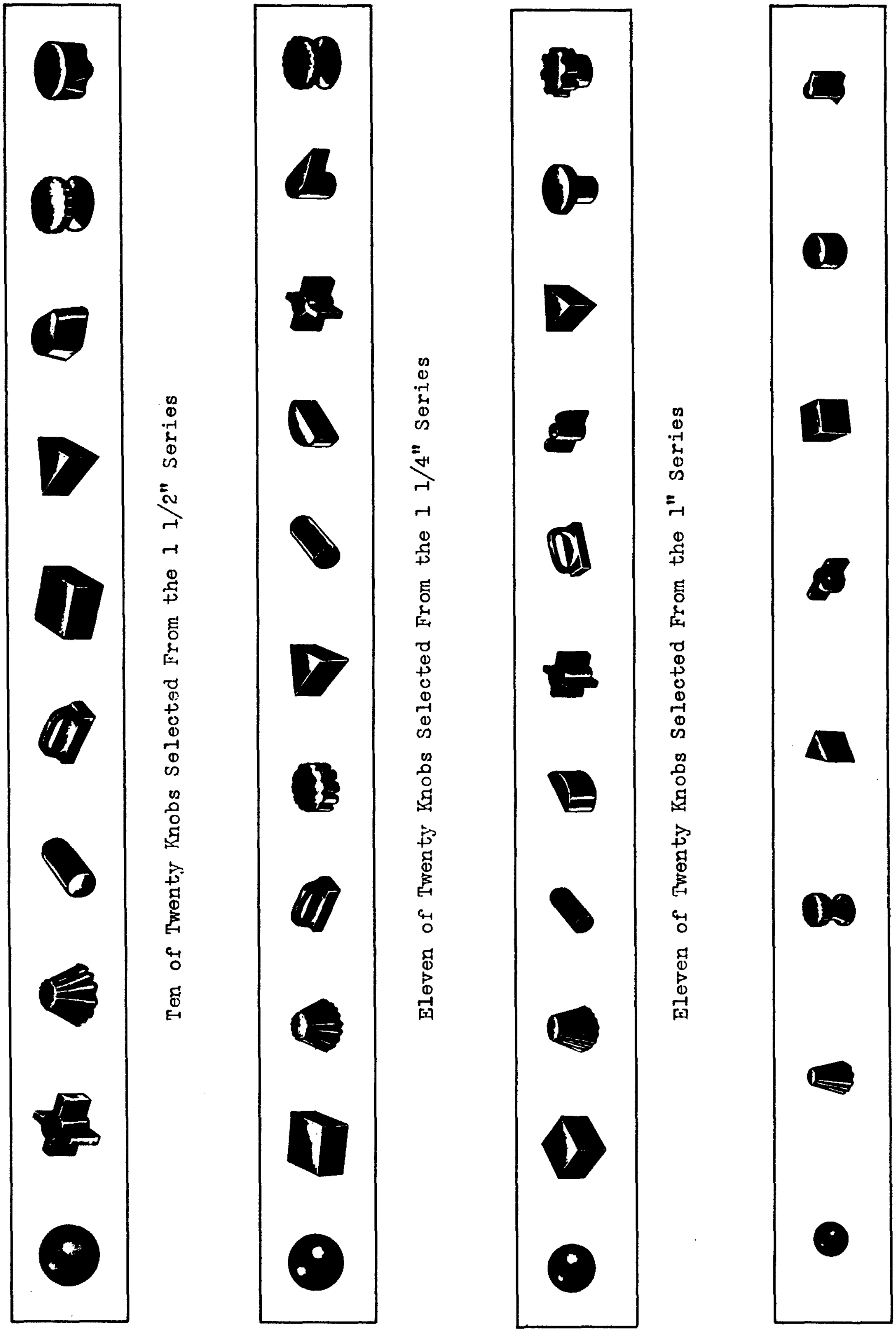
In another study by the Aero Medical Laboratory, 120 subjects felt the knobs and compared them with three-quarter-view pictures of the knobs.[6] The judgements were made with the bare hand and while wearing light-weight flying gloves (AF Type A-11-A). The subjects were allowed approximately 1.5 seconds for each comparison. The errors in judgements are shown in Tables I and II.

From the data presented in these tables, it is evident that each of the 31 experimental knob shapes may be classified as discriminable or not depending upon the knob shapes with which it is compared. The maximum number of knobs among which there were no judgement errors is ten. Twenty-eight such groups of ten knob shapes each are possible. These twenty-eight groups are presented in Table III. The knob shapes recommended in the following section were selected primarily on the basis of this study.

Suggested Knob Shapes: On the basis of two criteria, the task requirements and the identifiability, a number of knob shapes have been selected. Because of continual developments in manufacturing techniques, no knob shape was excluded because it might be difficult or costly to manufacture; nor were any excluded because it was suspected that they might not be preferred by the operators. It is to be emphasized, however, that both of these factors should be considered in the final selection of control knob shapes.

It may be noted in Table III that only sixteen different knob shapes are involved in the twenty-eight groups. These are the knob shapes that are suggested for application. The number of times each suggested knob was confused with another is shown in Table IV.

These knobs have been placed in one of three classes of control knobs depending upon their manipulative and position-monitoring characteristics (Appendix). Lacking experimental data on these characteristics of the variously shaped knobs, intuition and past experience have been relied on.



Ten of Twenty Knobs Selected From the 1 1/2" Series

Eleven of Twenty Knobs Selected From the 1 1/4" Series

Eleven of Twenty Knobs Selected From the 1" Series

Eight of Twelve Knobs Selected From the 0.60" Series

Figure 2: Tactually Discriminable Knob Shapes of Various Sizes

KNOB \ PICTURE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE
A									1																						
B	1									2															1						
C															1			4													
D																															
E									4																						
F								2																							
G																															
H																															
I										1																					
J	1	4																													
K																2		5													
L										2			1	6	1		3														
M										3		6		3			7	1							1						
N												2					1														
O										4																					
P											1			1																	
Q										5		2	5		1							1									1
R			3														1														
S																							4						1		
T																													3	3	
U																									1					1	1
V																							6	1	2	1		1			
W																1		1				3		2		2					
X																						1	2		3	2	1				
Y													1								1		1	2		2					1
Z				2										1							1		2		3		1	1			
AA																					1			2	3				1		1
BB																							1		1	1	1			1	
CC																											1			6	
DD																			2	5	1		1						4		2
EE																									1					1	

Table 1: The Relative Discriminability of Thirty-One Experimental Knob Shapes. Errors Made in Visual-Tactual Comparisons of Knob Shapes With the Bare Hand.

KNOB \ PICTURE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE
A									1									4													
B	1									4																					
C															2			3													
D			1												1			1													
E								1	1																						
F								2																							
G						1																									
H						3	1																								
I		1			1	1	2																								
J		5										2		1																	
K																3		2													
L													2	2			4														
M		5								9		6		2	1		6				1			1							
N										1		5					2							1							
O			1							2		2																			
P											1			1	2																
Q		1								5		4	9			1					1			1	2						1
R		1			2					1	1											1									
S																							6				2			3	
T																													1	2	
U																														1	
V																							7	3	2	1					
W																						6		6	1	1			1		1
X																		2	2			1	2		4	3	3				
Y											1		1								2			1		3	3				2
Z				1									1	1			1				1		4	2	4		1			1	
AA																			1			1	1	1	5	1			1		1
BB																			2				3	1	4	2				2	
CC																			2	2		1	2							6	1
DD																			5	2	1		2					1	8		
EE																			4		1				1	1	1				

Table 2: The Relative Discriminability of Thirty-One Experimental Knob Shapes. Errors Made in Visual-Tactual Comparisons of Knob Shapes While Wearing Gloves, AF Type A-11-A.

TABLE III

Knob Shapes That Are Discriminable By Touch Alone.
The Knobs of Each Set Were Never Confused with Other Knobs of the Same Set.
(Refer to Appendix to Identify the Knob Shapes).

1.	AEFKNOSTUV	15.	BCEGKLSTUV
2.	AEGKNOSTUV	16.	BCEGKNSTUV
3.	BEFKNOSTUV	17.	BDEFKLSTUV
4.	BEGKNOSTUV	18.	BDEFKNSTUV
5.	ACEFKLSTUV	19.	BDEGKLSTUV
6.	ACEFKNSTUV	20.	BDEGKNSTUV
7.	ACEGKLSTUV	21.	ACEFLPSTUV
8.	ACEGKNSTUV	22.	ACEGLPSTUV
9.	ADEFKLSTUV	23.	ADEFLPSTUV
10.	ADEFKNSTUV	24.	ADEGLPSTUV
11.	ADEGKLSTUV	25.	BCEFLPSTUV
12.	ADEGKNSTUV	26.	BCEGLPSTUV
13.	BCEFKLSTUV	27.	BDEFLPSTUV
14.	BCEFKNSTUV	28.	BDEGLPSTUV

Class A. These knobs are for use on controls:

1. which require twirling or spinning,
2. for which the adjustment range is one full turn or more, and
3. for which knob position is not a critical item of information in the control operation.

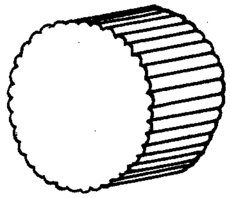


Figure 3: A Class "A" Knob Shape.

Example: North-south and east-west cursor controls are used in conjunction with radar scopes to adjust the intersection of two lines to specific positions. In instances in which knobs that control these functions are multi-revolutional, a Class "A" knob, e.g., Knob "A" (See Figure 3) is suggested.

I. Judgements Made With the Bare Hand

KNOB	A	B	C	D	E	F	G	K	L	N	O	P	S	T	U	V
A																
B	1															
C											1					
D																
E																
F																
G																
K												2				
L										6	1					
N									2							
O																
P								1		1						
S																
T																
U																
V																

II. Judgements Made While Wearing a Glove.

KNOB	A	B	C	D	E	F	G	K	L	N	O	P	S	T	U	V
A																
B	1															
C											2					
D			1								1					
E																
F																
G					1											
K												3				
L										2						
N									5							
O			1						2							
P								1		1	2					
S																
T																
U																
V																

Table 4: The Relative Discriminability of the Sixteen Selected Knob Shapes. Errors Made in Visual-Tactual Comparisons Between Sixteen Experimental Knob Shapes.

Remarks: Normally, the diameter of the knobs should not be less than 1/2 in. nor more than 4 in. However, recent research indicates that further reduction in knob diameter is feasible and, in some instances, desirable.[18] The height of the knob should normally be not less than 1/2 in. and need not be more than 1 in. The specific size will depend upon such factors as available space, force required to manipulate the control, fineness of setting required, the control-display movement ratio, etc.

Class B. These knobs are for use on controls:

1. which do not require spinning or twirling,

2. for which the adjustment range is less than one full turn or, if the adjustment range exceeds one full turn, operating requirements rarely, if ever, call for rapid adjustment over a large proportion of the range, and

3. for which the knob position is not a critical item of information in the control operation.

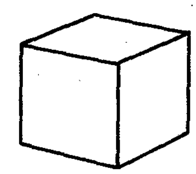


Figure 4: A Class "B" Knob Shape.

Example: On rotary control knobs that are used for tuning and have an operating range of less than one full turn, it is suggested that Class "B" knobs, e.g., Knob "K" (See Figure 4) are most appropriate.

Remarks: If the operating range of the control is less than one revolution, it is desirable to have a mark at the periphery of the knob, thus affording some qualitative information regarding the knob's position. The sizes of the knobs in this class should conform to the suggestions made for Class "A" control knobs. It might be noted that Class "A" control knobs may be used for Class "B" functions. The reverse is not true.

Class C. These knobs are for use on controls:

1. which do not require spinning or twirling,

2. for which the adjustment range is not more than one full turn, and

3. for which knob position is a critical item of information in the control operation.

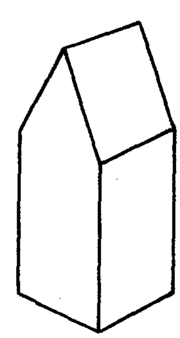


Figure 5: A Class "C" Knob Shape.

Example: On much equipment there is a multi-position function switch which controls the operating circuits of the system. If the positions are displayed on a fixed scale, a Class "C" knob, e.g., Knob "S" (See Figure 5) may be used advantageously. The elongation that is a characteristic of this class of knobs affords not only a visual and tactual check of the knob-position, but also aids in making settings, especially tactual.

Remarks: It is suggested that a mark be placed on the tip of the knob. As a result of adding a mark, however, the problem of parallax arises. In such cases, it is suggested that the knobs be tapered as shown in Figure 6. The height of the knob need not be more than 1 in. and should not be less than 1/2 in. The width should be sufficient to withstand the forces which may be applied to it and not so large as to be inconvenient to grasp. Normally, the width should be between 1/2 in. and 1 in. The length should be between 3/4 in. and 4 in. If blind settings are to be made with a knob of this class, it is desirable to use a parallel-sided knob.[12]

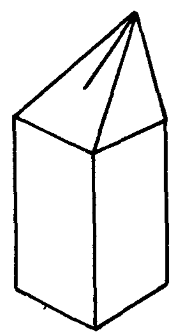


Figure 6: Tapering A Control Knob to Reduce Parallax.

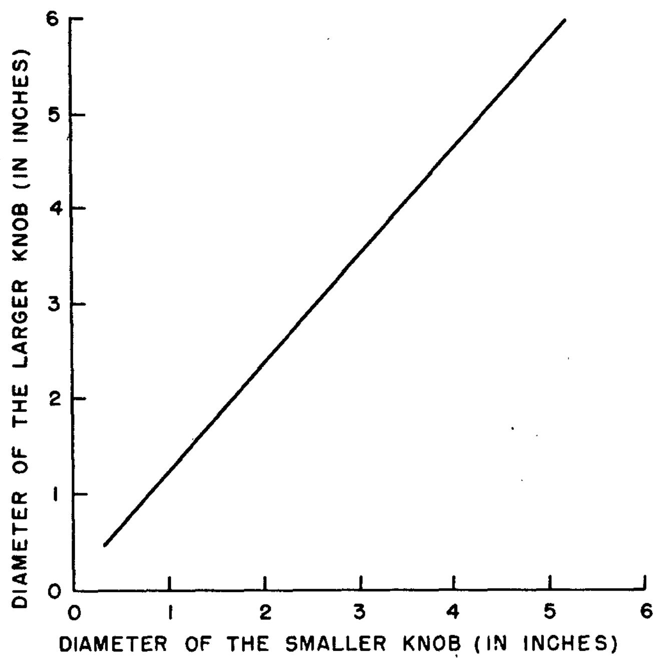


Figure 7: Diameters Required for Two Round Knobs To Be Discriminated by Touch Alone.

SECTION IV

SIZE CODING

Another way that the controls might be made distinguishable is by using different sizes. A disadvantage of coding this way, when considered alone, is that the number of tactually discriminable steps that may be used in the operational situation is probably quite small. That is, if we begin with a small control knob and then take the next largest knob which can be tactually discriminated from the first --- then select the next largest --- etc., we soon arrive at such a large knob that it is impractical to use it.

A distinction should be made between two kinds of size discriminability. One is "relative" size discriminability; the other, "absolute." By "relative" size discriminability is meant the ability to tell the difference between two different sizes by comparing one with the other. "Absolute," on the other hand, means that no such comparison is made. The operator simply remembers that a knob is of a particular size. There has been no research completed dealing with "absolute" size discriminability.

One study dealing with "relative" size discriminability[21] has resulted in data from which the necessary increment in size can be determined for knob sizes from one to five inches. The data are summarized in Figure 7. If we are given a 1.5 in. knob and want to select the next largest knob that will be distinguishable from it ninety-nine percent of the time, we would, according to Figure 7, select a 1.8 in. knob. It is to be re-emphasized that application of these data assumes that the operator makes comparisons between two or more knobs before deciding which is the correct one. For purposes of application we may assume that such a situation does exist in the use of concentrically ganged controls. That is, it is very easy for an operator to compare one size knob with another if the knobs are mounted on concentric shafts. Such an application is illustrated in Figure 8.

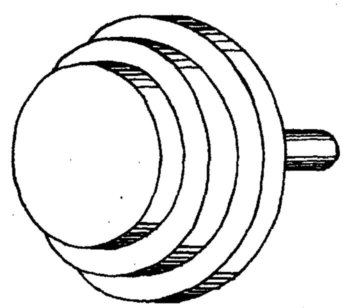


Figure 8: An Application of Size Coding to Ganged Control Knobs.

SECTION V

LOCATION CODING

Another way that one might make controls distinguishable is by placing them far enough apart so that an operator can identify the controls by their "absolute" location. An obvious and critical question that might be asked is, how close can we put the controls to each other and still expect the operator to reach out, without looking, and grasp the correct control. Fitts and Crannell undertook a research program aimed at, among other things, answering just this question.[8] The apparatus they used was a large plywood housing, octagonal in shape as regards the ground plan, and with a flat roof overhead. The subjects were seated in an airplane seat within this structure and were surrounded in front, on the sides, and overhead by 24 fourteen-inch square panels upon which paper targets were fastened. Figure 9 shows a photograph of the right quadrant of the apparatus with the upper four panels in place. When the subject was seated in the chair and centered in the apparatus, all twelve targets on either side were approximately equidistant (about 28 in.) from the subject's shoulder joint on the same side. In all cases, vision of the targets and the body was excluded.

In the first series of experiments, the subjects were required to reach out as accurately as possible and punch holes in the twenty-four paper targets. Also the number of targets was reduced to four and the reaching distance to about 21 in. The results of two representative targets (Positions A and C in Figure 9) are partially summarized in Figure 10.

Figure 9: Right Quadrant of the Apparatus Used to Investigate the Accuracy of Blind Reaching.

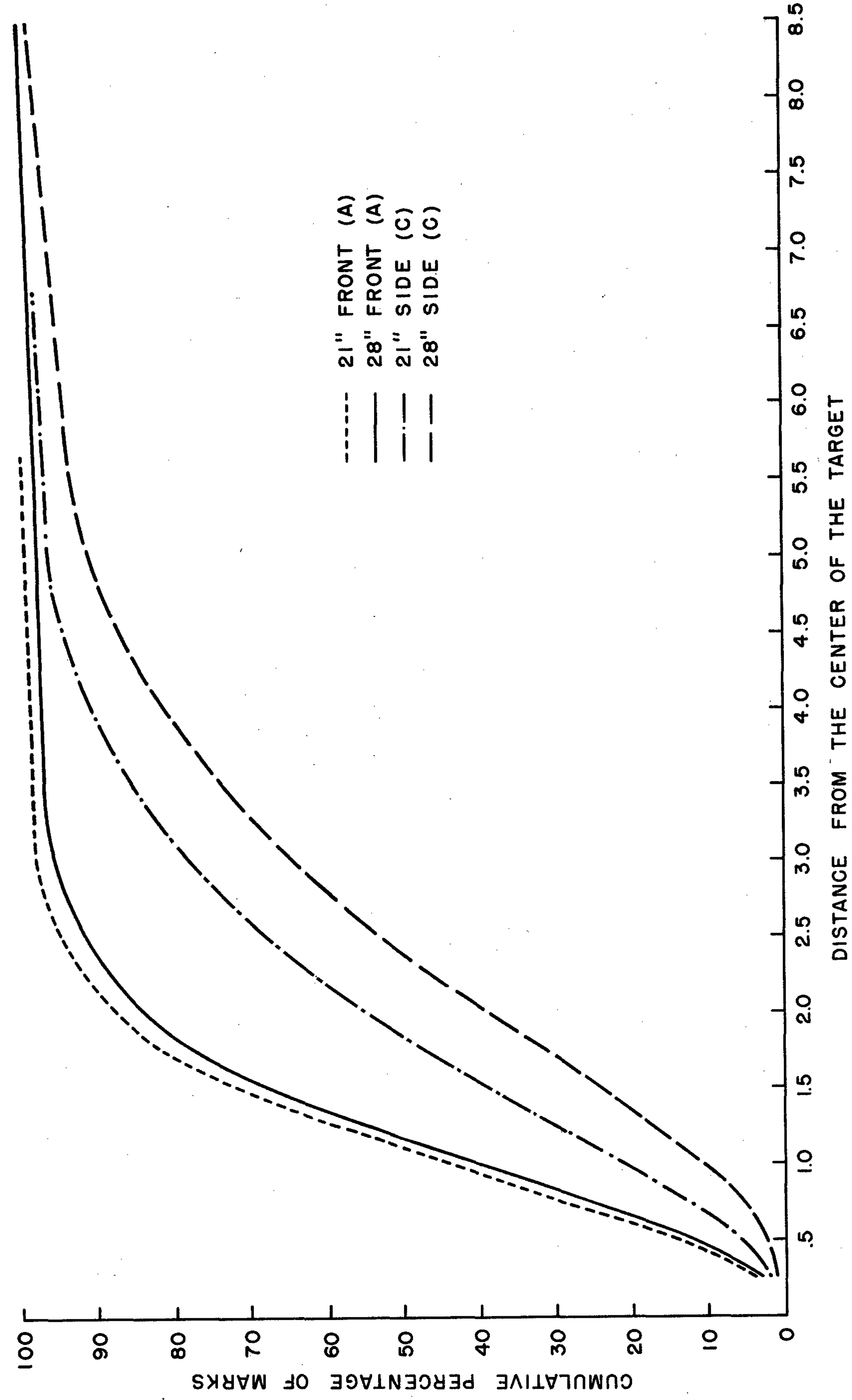


Figure 10: Accuracy of Blind Reaching. (Adapted From Fitts and Crannell)

It may be seen by inspecting this figure that accuracy is enhanced by either decreasing the reaching distance or by moving the aimpoint to the forward position. It might be noted, however, that the increase in accuracy that is obtained by decreasing the reaching distance appears not to be in direct proportion to the reduction in distance. They also found that blind reaching accuracy increases slightly when the number of targets used is reduced.

In a second series of experiments some of the target panels were replaced with switch boxes (Figure 9). Each box had a row of nine toggle switches, one inch apart. The boxes were placed so that the switches formed either a vertical or horizontal row. The task of the subject was to reach out, without looking, and activate the designated toggle switches.

A number of variables were investigated, but for purposes of application the data may be summarized as shown in Table V.

TABLE V

Accuracy of Blind Reaching to Switches
Percentage of Reaches in Error by More Than Specified Amounts
(Adapted from Fitts and Crannell)

	HORIZONTALLY ORIENTED SWITCH PANELS				VERTICALLY ORIENTED SWITCH PANELS			
ERROR	A	B	C	D	A	B	C	D
IN EXCESS OF ONE INCH	24.1	51.2	50.7	36.8	12.8	19.0	18.5	20.0
IN EXCESS OF TWO INCHES	6.5	25.4	20.8	18.1	1.0	3.5	5.3	4.5
IN EXCESS OF THREE INCHES	1.0	12.7	9.1	6.0	0.3	1.3	1.0	1.5
IN EXCESS OF FOUR INCHES	0.0	5.0	4.0	2.5	0.0	0.0	0.3	0.3

It may be seen from this table that the subjects were consistently more accurate in reaching to the switches which were vertically oriented. Other data indicate that this relative superiority of the vertical dimension does not hold true when reaching from directly below the objectives. Also, consistent with the results of the previous series of experiments, there was a loss of accuracy when the number of objectives (switch boxes) was increased.

In general, then, in any practical situation which requires an individual to reach to one among several objectives - such as airplane controls - arranged in a row, and in which vision is absent or seriously restricted, it is better to place these objectives in a vertical row. Until modified by further research a "safe" distance between such objects if located at shoulder level, and within easy reach, is believed to be at least five inches. It should be noted though, that this estimate would become increasingly too small as one departs from shoulder level and, presumably, as the "g" forces increase. However, the effects of various "g" forces on blind reaching has not been thoroughly investigated.

Of course, there are certain disadvantages to this technique of coding. Recently, it has been required that the size of the control panels be reduced, thus putting a maximum number of controls in a minimum amount of space. This, of course, has decreased the applicability of absolute position coding considerably. Secondly, consideration should be given to the extent to which a change in the location of a control will interfere with previously learned behavior. For example, if we were to interchange the positions of the wheel control and the flap control, we should not be surprised if a veteran pilot, given little training with the new locations, unintentionally raised the wheels instead of the flaps.

SECTION VI

COLOR CODING

Controls may be made more distinguishable by making them different colors. Obviously, the value of color coding is primarily dependent upon the number of discriminable colors. If one includes all the various hues with varying degrees of saturation (vividness) and various degrees of lightness or darkness, the number of discriminably different colors is enormous---perhaps as many as 300,000.[3] In the practical situation, however, the pilot has neither the time nor the facilities to identify colors by comparison. He must identify them rapidly, accurately, and usually in the absence of any very complete or convenient reference. The problem, therefore, is how many colors can be easily and positively identified. Previous to any systematic research, Parker and Wallis suggested, "ten as the order of number of colors that can be distinguished quickly and accurately by an average observer"[17] and Chapanis stated, "such a large number as ten or twelve colors would be too many for most operators to keep in mind and use effectively."[5] However, some research has been completed recently from which it was concluded that there are probably between ten and twelve "absolutely-identifiable" spectral hues.[10] With a series of twelve hues, appropriately selected, about 96% of the total number of judgements of four observers were correct; with ten hues, about 98% were correct. The hues in each series were of the following wave lengths (in $m\mu$):

Twelve-hue Series		Ten-hue Series
642 $m\mu$	Red	642 $m\mu$
617		
603		610
592	Orange	596
582		582
570	Yellow	556
530		515
504	Green	504
492		494
476	Blue	476
456		430
430	Violet	

If sufficient training is given, however, this number might be increased somewhat. Furthermore, it should be noted that this estimate pertains only to monochromatic spectral hues and excludes the psychological colors, the grays, metallic colors, etc.

One significant factor that would appear to affect the number of absolutely identifiable colors is the operator's ability to attach names to the colors.

There are many disadvantages to the use of color as a means of coding. Many colors already have meanings attached to them. Cockpit warning lights are usually red or amber. In the case of oxygen equipment, a red light signifies some imminently dangerous malfunctioning of the system. Green lights are used in the cockpit to indicate the position of the landing gear. On some instruments, the appearance of a red flag indicates that the instrument is not operating properly. The green area on the face of some instruments indicates their operating range, whereas the red area indicates a dangerous operating condition. In common with the conventional traffic signals, red is used as a warning and green an an "OK" indication. Unfortunately, such usage prejudices the use of color for the coding of controls. For example, the reds might rather naturally be interpreted as indicating controls that should be used either with caution or only under emergency situations. Of course, such stereotyped interpretations would not necessarily be universal as is evidenced by the color coding of electrical wiring and various fluid transmission lines. It should be noted, though, that some training or experience usually precedes this modified interpretation. Of equal importance is the fact that the nature of the work in which this color coding is involved is such that rapid critical discriminations are usually not required.

If color coding is contemplated, consideration must be given to the variation in ambient illumination. The seeing of color requires that there be light present and both the intensity and color of this light affect the color as seen. This subject is too complicated to discuss thoroughly, but a few examples may serve to illustrate the point. Under low levels of illumination, color is greatly modified and at times lost. Red may become a dark gray, and blue, a light gray. Under red lights, colors lose their identity and appear grayish, possibly tinged with red or green. For example, light blue, under red light, may appear black, while yellow might appear redish white, etc. In general, the greater the variation in the ambient illumination, the less the value of color coding.

SECTION VII

MODE-OF-OPERATION CODING

Another method of making controls distinguishable is by varying the way in which the controls operate. For example, we might have two controls identical with respect to color, size, shape, and, even, position. However, if one of the controls is a push-pull type and the other a rotary control, they will tend to be distinguishable to the operator. For example, the operator may want to perform a function which he knows, from past experience, is handled by a rotary control knob. Thus, when he grasps the control he thinks is the correct one, he will attempt to turn it. If he has inadvertently grasped a push-pull type control, he will know that it is the wrong one because he is unable to turn it. It is seen, then, that a control may be designed so that the movement required to operate it can be used as a cue to its identity.

Although the operator must attempt to activate the control before determining whether it is the correct one, its identification should not depend upon its actual activation. For instance, a smooth turning rotary control and a detented rotary control may be distinguishable to an operator, but would have the disadvantage of relying on activation for its identification.

The number of controls that may be coded using this method is partially dependent upon the number of discriminable control movements. A systematic search of the literature revealed no experimental data concerning this question. There are certain movements, however, that seem to be distinctive and might be utilized in the application of this coding technique: Up-down, right-left, in-out, and rotary. There are probably intermediate movements that would be distinctive to an operator, e.g., movements along the axes which are displaced 45° from the vertical, but experimental verification is lacking.

If this technique of control coding is being contemplated, the following four factors should be considered:

1. Available space. The amount of space available for the control operation may dictate to some extent the optimal mode of operation. For example, if space is seriously limited, a long sweep lever-type control would be inappropriate.

2. Control-display relationships. In many instances the control-display relationship is of such importance to the efficient operation of the equipment that it should not be altered for coding purposes.

3. Control placement. It may be inconvenient or impossible for an operator to make certain movements if the control is placed in certain locations, e.g., a pushing movement at the extreme reach of the operator.

4. Engineering feasibility. If a control and the function which it serves are mediated by a 360° potentiometer, it would usually be impractical to use a right-left moving control

All of these factors impose serious limitations on the extent to which it is feasible to use this coding technique. In addition to these limitations and the lack of adequate information upon which to base the application of this technique of control coding, there is another disadvantage; since the operator must attempt to activate a control before determining whether it is the correct one, the chances of unintentional activation are increased.

SECTION VIII

DISCUSSION

Although each of five different methods of coding controls has been discussed separately, it should be noted that any of the methods may be used in combination. For example, two controls could be made very distinguishable by making them different colors, different shapes, different sizes, by placing them far apart, and by designing one for "in-out" operation and the second "up-down".

In addition to the five methods discussed, there are other coding techniques which utilize vision, audition, and/or proprioception. Labeling, for example, is used quite extensively. The use of homing positions might be very useful in many situations. That is, if one control can be easily identified, the controls immediately surrounding it might be identified by their position relative to the initially identified control. Push button type controls might conveniently be coded by this technique. In some situations, the contours and edges of the panels may be designed such that certain controls located in the extreme corners might be easily identified by the operator.

In general, the decision as to which method or methods of coding to use must be based upon considerations of the specific situation in which it is to be used, the cost of manufacture and the probable logistical requirements.

SECTION IX

SUMMARY

Five design techniques that may aid the operator in identifying controls were discussed. Previous to applying any of these techniques, two questions must be answered: (1) Which, if any, controls require coding, and (2) which coding techniques should be used. The primary factors which should be considered in answering these questions were enumerated.

The pertinent points of each coding technique are as follows:

1. Shape coding

   a. Tactual discriminability can be improved by training[7] and by practice[1].

   b. Knob shapes may be selected that are discriminable, even while wearing gloves.[2, 4, 6, 13, 15, 19]

   c. Within limits, reducing the size of control knobs does not have much effect on their discriminability.[2, 4]

   d. The height of rotary control knobs should normally be between .5 and 1 in. For essentially round knobs, the diameter should usually be between .5 and 1 in., but may be smaller in some instances.[18] For elongated knobs, the width should normally be between .5 and 1 in. and the length between .75 and 4 in.

   e. Primarily on the basis of a study conducted at the Aero Medical Laboratory[6], a number of knob shapes have been presented which may be used if shape coding is indicated (See Table IV).

   f. Three classes of knobs have been designated on the basis of their manipulative and position-monitoring characteristics. Thirty-one experimental knob shapes[6] have been placed in their appropriate classes (See Appendix).

2. Size coding

Data have been presented from which the identifiable increments in size can be determined for knob sizes from one to five inches (See Figure 7).[21] Application of these data to the practical situation assumes that the operator compares two or more knobs before deciding which is the correct one.

3. Location coding

If one requires an operator to reach without looking with a high degree of accuracy, to one of a number of controls, it is best to arrange the controls in a vertical row at shoulder level.[8] A "safe" distance between these controls is at least five inches. As one departs from shoulder level, this distance must be increased.

4. Color coding

The number of discriminatively different colors, if one includes all the various hues with varying degrees of saturation and various degrees of lightness or darkness, has been judged to be 300,000.[3] However, in the practical situation, the operator has neither the time nor the facilities to identify colors by comparison; rather, he must be able to identify the colors individually without comparing one with another. Estimates of the number of such absolutely identifiable colors suggest that there are no more than ten or twelve.[5, 10, 17] Some absolutely discriminable spectral hues are given in terms of wave length and color names.

However, there are many disadvantages to using color for coding controls. For example, many colors already have meanings attached to them, and the variations in ambient illumination greatly affect the colors as seen.

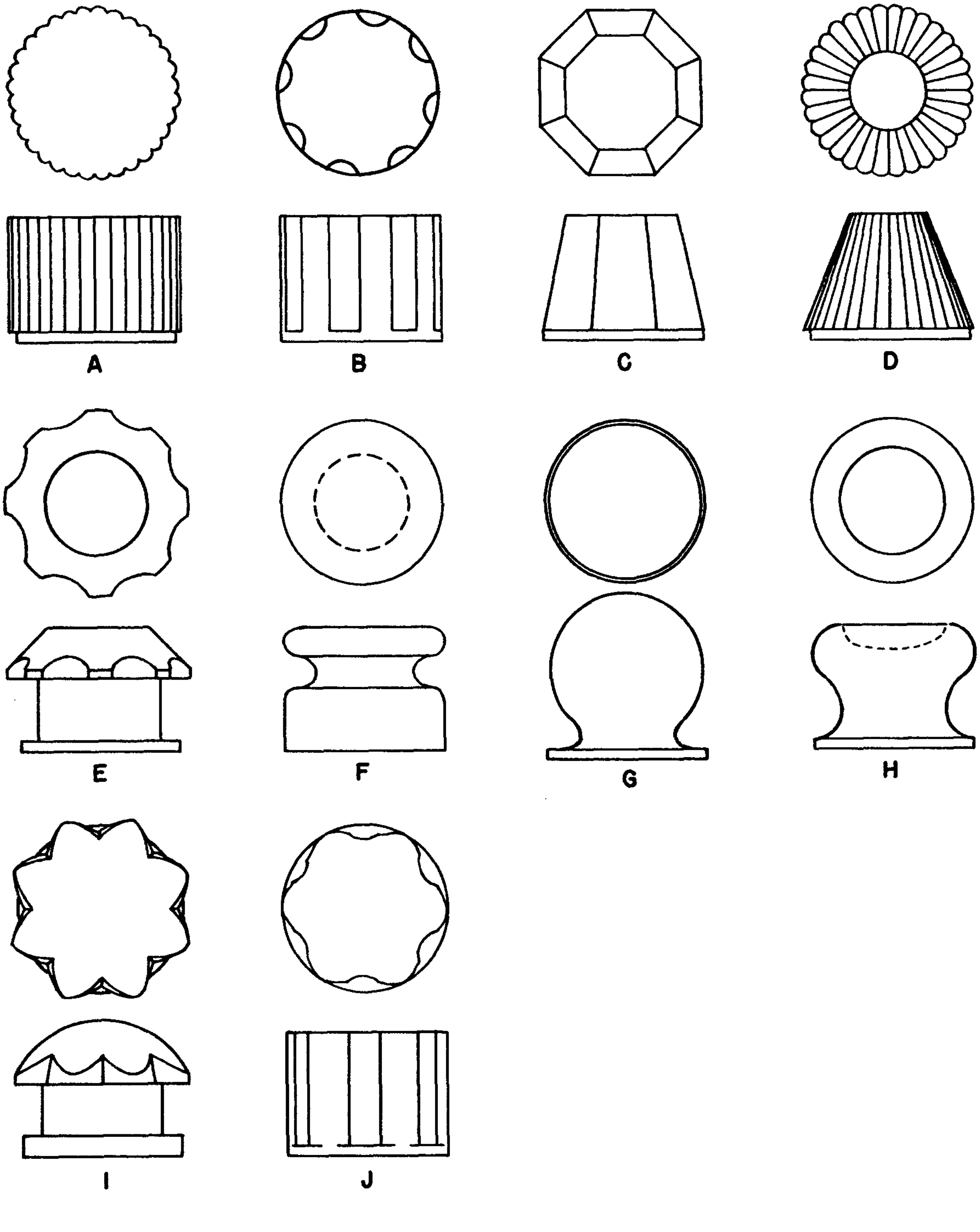
5. Mode-of-Operation coding

Although it is possible to code controls by varying the way in which they are operated, the usefulness of this technique is limited. In addition to lacking adequate information concerning discriminable movements, there are other factors that may need to be given precedence in determining the mode of operation of a control. Some of these factors are (1) control-display relationships, (2) engineering feasibility, (3) control placement and (4) space availability.

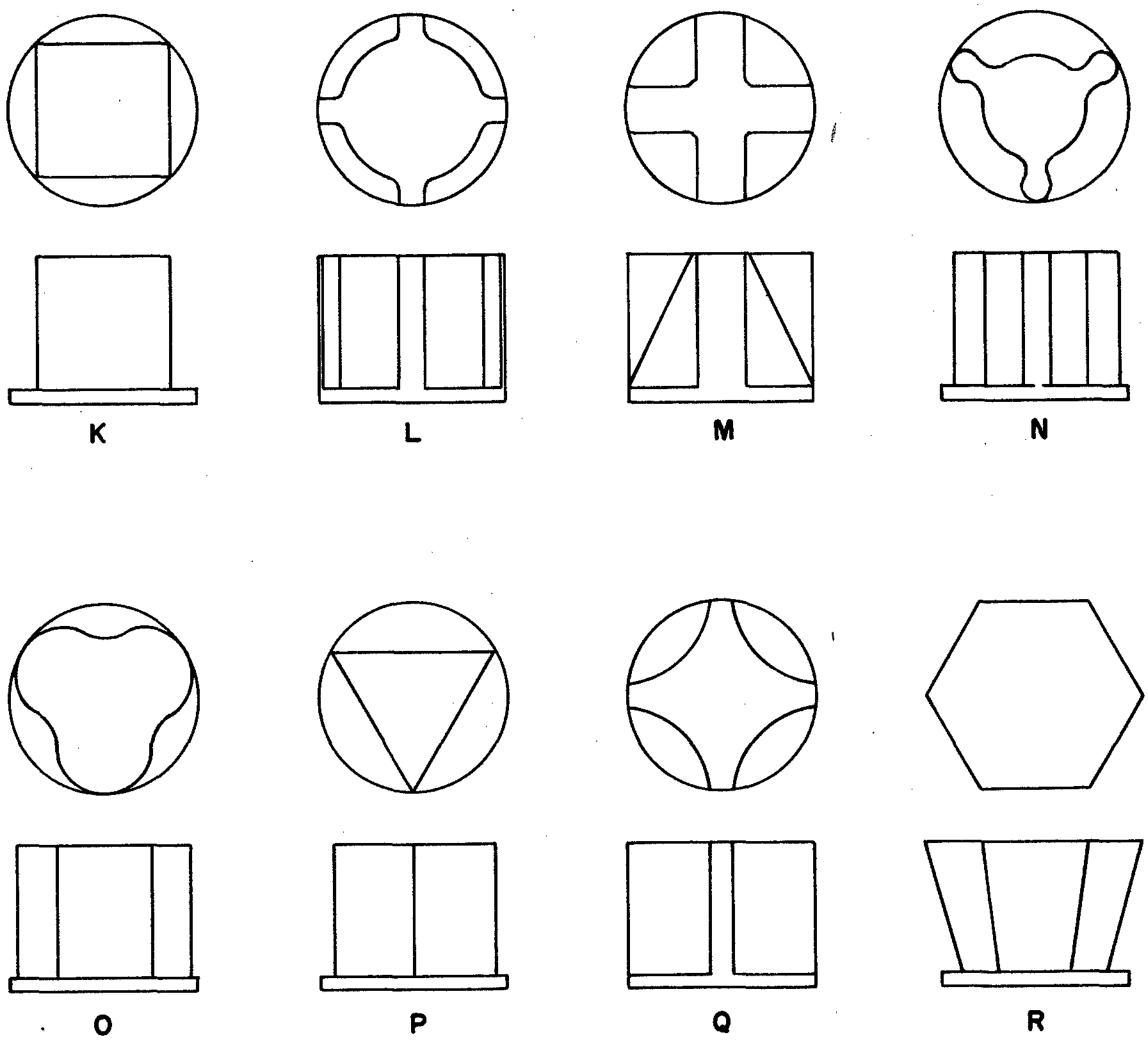
APPENDIX

All knobs are drawn to actual size

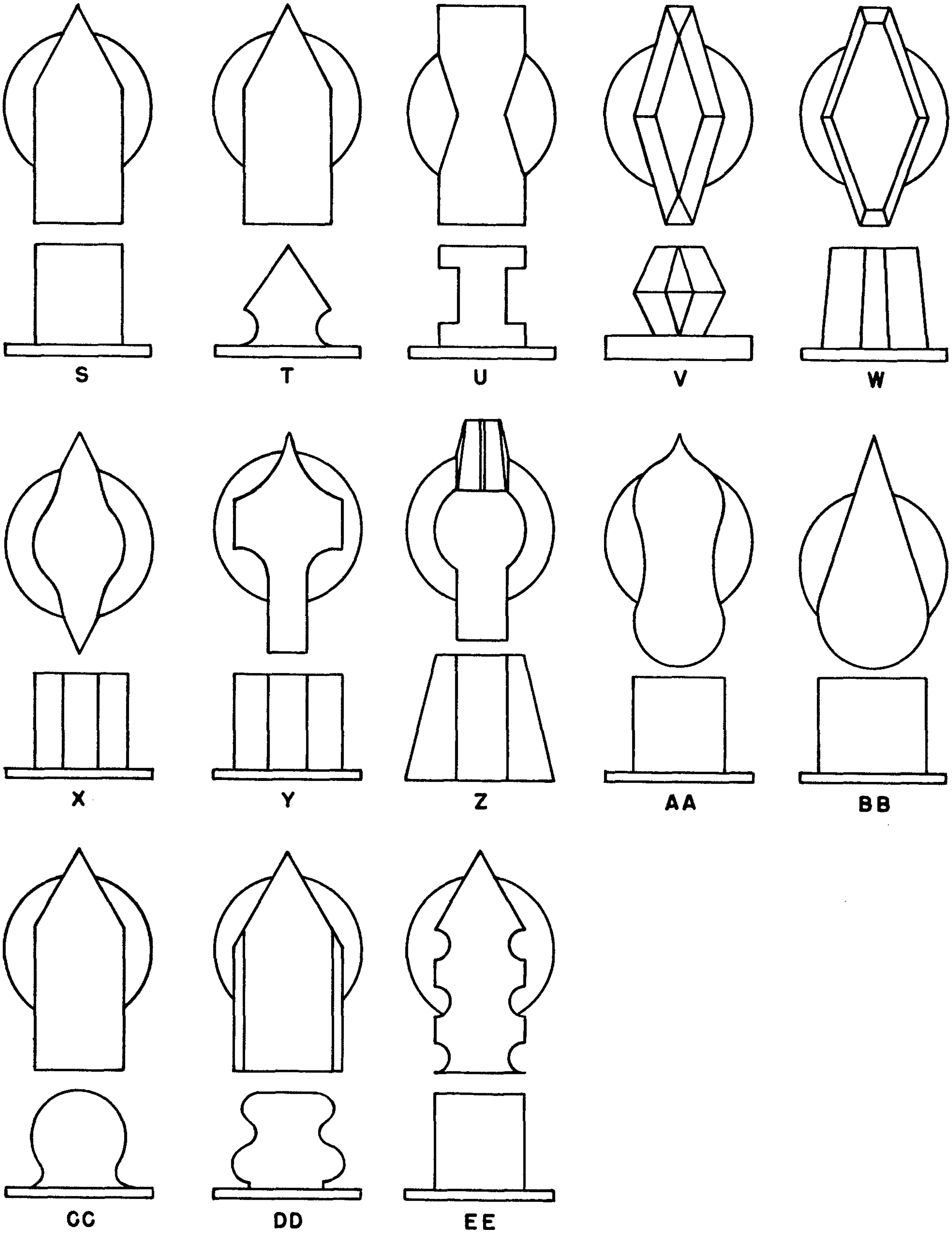
CLASS A



CLASS B



CLASS C



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