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LAYOUT OF WORKPLACES

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FOREWORD

This report was prepared under Research and Development Project Number 7180, Human Engineering Applications to Equipment Design, of the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Walter F. Grether as Project Scientist.

This report is being issued as a preliminary draft of a part of the Human Engineering Guide to Equipment Design being prepared under the direction of the Joint Services Steering Committee for this guide. After further review and revision it is planned that this material will become part of that guide. The purpose of the Human Engineering Guide to Equipment Design is to provide designers of military equipment with human engineering data and general design recommendations for maximizing efficiency of human operation and use.

Users of this report are invited to submit comments which would be useful in revising or adding to this material prior to its publication in the Joint Services Human Engineering Guide to Equipment Design. Comments should be sent to: Chief, Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

This report has been released to the Armed Services Technical Information Agency, Knott Building, Dayton 2, Ohio. This report has further been released to the Office of Technical Services, Department of Commerce Washington 25, D. C. for sale to the general public.

Throughout the preparation of this report the authors received considerable assistance and guidance from Dr. Walter F. Grether, Mr. John Senders, Mr. C. A. Baker, Mr. M. J. Warrick, and Mr. J. Bradley of the Psychology Branch, and Mr. H. T. E. Hertzberg of the Biophysics Branch, Aero Medical Laboratory. A preliminary report was distributed in November 1954. This report was reviewed by approximately twenty experts in the field, representing the following organizations: Psychology Branch and Anthropology Section, Biophysics Branch of Aero Medical Laboratory, Human Engineering Branch of Aeronautical Medical Equipment Laboratory, Human Engineering Laboratory of Aberdeen Proving Ground, Human Engineering Branch of Navy Electronics Laboratory, Engineering Psychology Division of Frankfort Arsenal.

The art work was provided by Mr. Sidney Winter and Mr. Harold Montaine. Preparation of the final manscript was aided considerably by the editorial assistance of Miss Ida Moore and the typing of Miss Raffaela Tarzia.

ABSTRACT

A critical factor affecting operator performance in any man-machine system is the layout of his workplace. This report provides a compilation of human engineering recommendations concerning various aspects of workplace layout. Whenever these recommendations are the direct outgrowth of research in this field, the appropriate research studies are cited. When no research has been done on a specific problem, the authors draw upon their own experiences to provide the necessary recommendations. All recommendations have been reviewed by a number of experts in the field prior to final publication.

The report is divided into four main parts, entitled: General Considerations, Workplace Dimensions, Location of Controls and Displays, Direction-of-Movement Relationships. Check lists, figures and tables are used frequently as means of presenting recommendations. A table of contents and a subject index are also provided as aids to the user.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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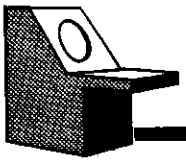
PART 1

GENERAL CONSIDERATIONS



Many details affecting men and equipment must be considered in the layout of workplaces. It is seldom possible to provide optimum conditions throughout the design. Therefore, the information and rules presented here are intended to guide the designer in making the best possible compromise in each case.*

a. Establish a clear and explicit set of requirements.

b. Make sure that all design requirements have been considered.

c. Keep the design "tentative" until you are sure about your facts.

d. Use mock-ups to evaluate alternative layouts and to check your final layout.

1.1 PRELIMINARY INFORMATION

Obtain information about requirements before beginning to design the workplace. Unless the following information is available, the designer may build in undesirable characteristics which are not detectable until late in the development stage.

a. requirements

1) Purpose or mission of the system.

2) Mission profile or detailed steps in conducting typical and atypical missions.

*These rules are presented as broad procedural guides and reminders to designers. It is not the purpose of this report to cover in detail the topic of systems analysis.

3) Tolerances allowable in the performance of the system (i.e., limits for accuracy, speed, force, etc.).

4) Effects upon system performance when various tolerances are not met.

b. job description

1) Specific tasks which the operator must perform--sequences to be followed, relative importance of each task, relative frequency and time duration for each task.

2) Inputs to the operator--information which he needs and is able to use to accomplish his specific tasks.

3) Outputs of the operator--data provided by the operator to influence the system (via controls).

c. design limitations

1) Anticipated environmental conditions--temperature, humidity, noise, illumination, vibration, ventilation, radiation, altitude, body position, accelerative forces, restrictions due to special clothing, etc.

2) Specific pieces of equipment already committed to the design.

3) Access and clearances.

4) Maintenance requirements.

1.2 DESIGN VARIABLES

A number of design factors must be considered in order to assure an optimum workplace arrangement. These are discussed below in accordance with the following outline:

Part 1: General Considerations. The workplace must be designed to accommodate the human body. Presented here are:

a. General rules which should be followed in accomplishing this.

b. Check list to insure that all rules are followed.

Part 2: Workplace Dimensions. Two general dimensions are given:

a. Optimum dimensions: Most desirable space for the location of controls and displays.

b. Limiting dimensions: Acceptable but not necessarily optimum space for the location of controls and displays. (This space will always include the space bounded by the optimum dimensions.)

Three workplace areas are included:

a. Visual areas--for the location of displays.

b. Manual areas--for the location of hand controls.

c. Pedal areas--for the location of foot controls.

Part 3: Location of Controls and Displays. All controls and displays to be used during normal operations should be placed within the space defined by the limiting dimensions. (This requirement does not apply to equipment which can be preset or which need not be monitored during normal operations.) The exact location of each control or display is determined by the following factors:

a. Priority: Place the most important equipment in the space defined by the optimum dimensions.

b. Grouping: Organize equipment on the basis of function and sequence of operation.

c. Associations: Establish correct and consistent positional relationships between controls and displays so that they may be identified in a systematic manner.

d. Spacing: Separate controls by distances recommended for the specific situation.

Part 4: Direction-of-Movement Relationships. All controls and displays should be designed and arranged so that direction-of-movement relationships are consistent. Thus, movements of controls, displays, and the vehicle itself must all be considered simultaneously. As far as possible, these movements should be standardized, should conform with existing design practice, and--most important--should follow natural habit patterns.

1.3 GENERAL RULES FOR WORKPLACE LAYOUT

General rules for workplace layout are presented in this section.[64] Specific rules for various aspects of the workplace are presented in Parts 2-4.

a. Standardize

1) Retain the same relative grouping for major controls and displays in all similar models of equipment.

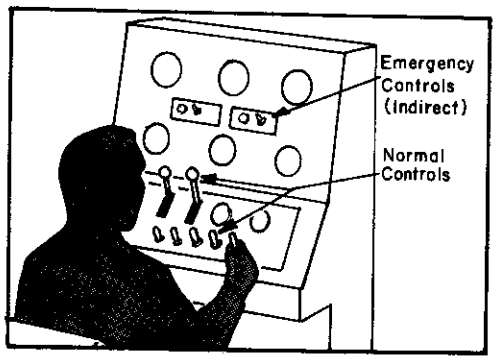
2) Design the controls and displays so that they operate in the same manner.

> Caution: If, for any reason, these cannot be done, make any exception obvious and drastic. This procedure reduces confusion in shifting from one device to another, thus minimizing chance for error.

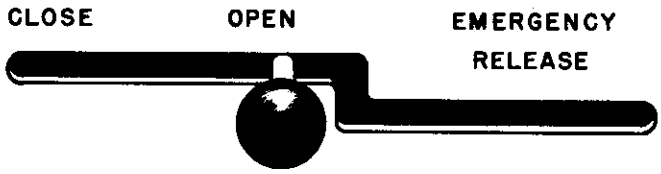
b. Make special provisions for emergency controls and displays*

1) Distinguish between emergency controls or displays and those used during normal operations.

Physically separate normal controls and displays from emergency ones.

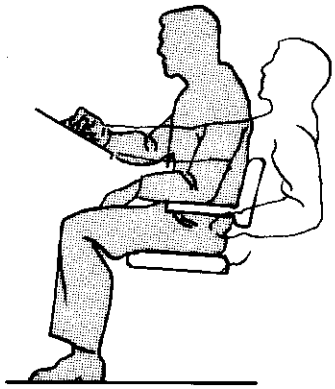


If separation would result in an inaccessible or poorly placed control, provide the normal control with an emergency mode or special operating position. This can be accomplished by adding an emergency release, going through a detent, exceeding a minimum force, etc.

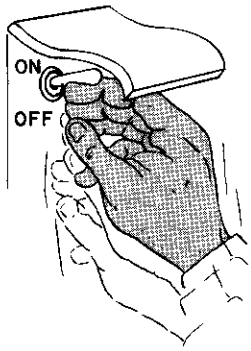


*Certain items of emergency equipment are covered by military specifications (MIL-STD-203) and design instructions (HIAD, pp. 6A 7-8).

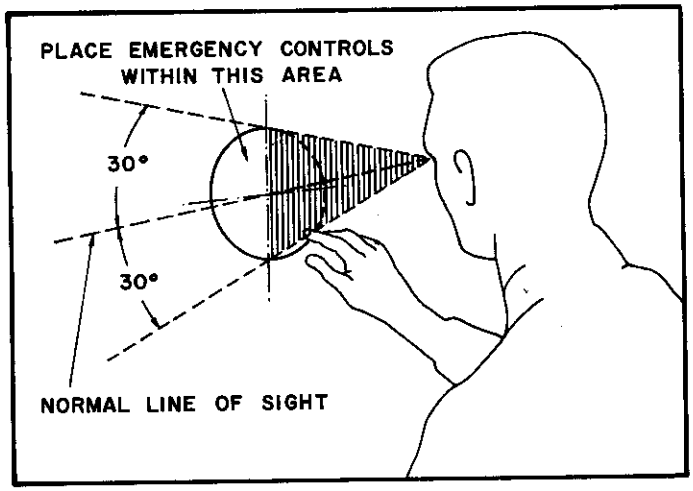
2) Place emergency controls in easily accessible locations, regardless of any momentary bodily attitude of the operator.



3) Provide special measures (guards, color coding, etc.) for emergency controls to aid in identification and to prevent inadvertent operation.



4) Place emergency controls within 30 degrees of the operator's normal line of sight.*



*For military aircraft this rule must conform with HIAD, Drawing AD 3001, or with superceding instructions.

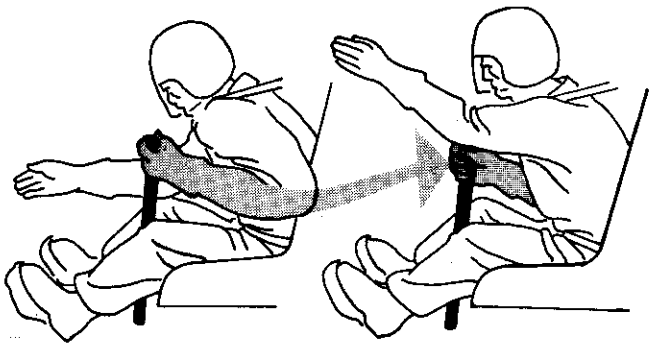
c. When one limb must operate two or more controls in sequence, arrange the controls to allow for continuous limb movement (from left to right, through an arc, etc.).

Note: This recommendation should not take priority over basic rules for locating controls (Part 3) and proper direction-of-movement relationships (Part 4).

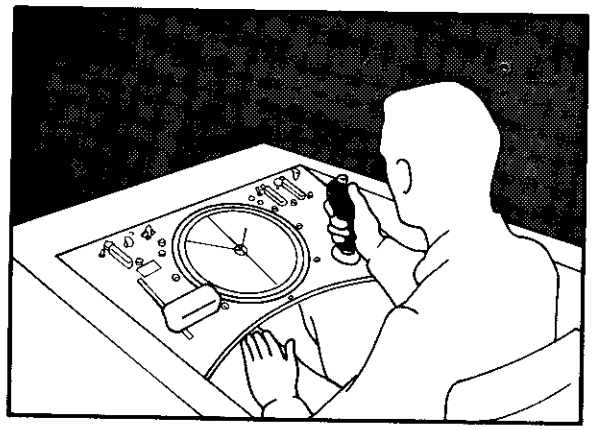
d. Distribute the controls in such a way that none of the operator's limbs will be overburdened and each will be used most effectively:

1) Assign to the hands controls which require high precision and/or speed of operation.

When there is only one major control which must at times be operated by either of the hands (steering wheel, etc.), place the control in front of the operator, midway between his hands.



When the major control is to be operated by one hand (e.g., formation stick), it should be located optimally for right-hand operation.



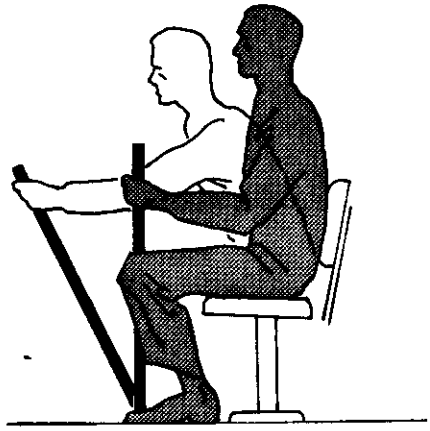
2) Assign the major load to the right hand since most persons are right-handed.

3) Assign to the feet controls which require large applications of force.

e) When the seated operator must apply a force of more than 5 pounds to a control by one hand, provide the operator with a support, e.g., back rest for pushing, foot rest for pulling.

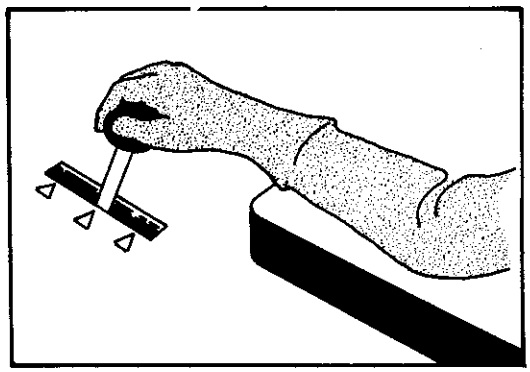
f. Design the workplace so that the operator can move his trunk or entire body, particularly when heavy forces (more than 30 pounds) or large movements (more than 15 inches in a fore-aft direction) must be made by the hands.

If seated, the operator should be able to bend forward from the waist. His movements should not be restricted unduly by clothing encumbrances.

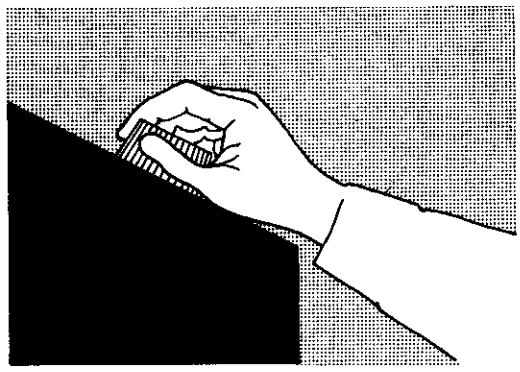


g. When controls must be positioned precisely, provide a support for the body part being used. The support should permit the limb to slide smoothly:

1) Hand controls: provide an elbow rest. Some controls (knobs, joysticks, etc.) provide partial hand support and may substitute for an elbow rest when space is severely limited.



2) Finger controls: provide a rest for the wrist or heel of the hand.



h. When the operator is on duty for long periods of time:

1) Arrange the workplace so that he can conveniently change his posture.

2) Design the workplace so that the larger body parts (arms, legs, trunk) as well as the hands and feet can be used.

CHECK LIST FOR LAYOUT OF WORKPLACES

When designing new equipment, engineers may use this check list to assure themselves that various human engineering principles are followed correctly.

FACTOR	ITEM	SECTION OF REPORT*
Identification Discrimination Localization	Workplace layout is standardized. Arrangement of controls and displays is consistent with other workplaces which these operators may use.	1.3, 4.1
	Displays and controls are located to insure quick and accurate identification.	2.6, 3.1, 3.3
	Controls are identifiable both by sight and by touch.	2.2, 3.4
	Controls are far enough apart to permit their location by "blind" reaching movements and to allow adequate clearance for operation (taking into account the clothing worn by the operator).	3.4
Efficiency of operation	Controls are located within easy working distance of the operator.	2.2, 2.3, 2.4, 2.6, 3.1
	The more important and frequently used controls and displays are given preferred positions.	2.2, 2.3, 2.4, 2.6, 3.1
	Controls and displays are grouped into patterns which aid in operation and observation.	3.2, 3.3
	No hand or foot is overloaded with work which could be performed adequately by another limb.	1.3, 2.4
	Controls operated in sequence are located in such a manner as to provide a minimum amount of limb movement compatible with an easily learned movement pattern from one control to the next.	1.3, 3.4

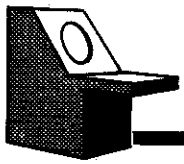
*Detailed information will be found in the section designated in this column.

FACTOR	ITEM	SECTION OF REPORT*
Vision	The most important and frequently used displays are located in the most favorable positions, normal to the line of sight.	2.1, 2.4, 2.6
	All displays are readable from the normal head position of the operator, allowing for normal head rotation and for restrictions imposed by helmets, goggles and other headgear.	2.1, 2.4, 2.6
	Miscellaneous equipment does not obstruct the view of displays.	3.2, 3.3
	Displays are not hidden or misread because of oblique viewing angles.	2.1, 2.4, 2.6
	Displays which are used together are grouped together.	2.1, 2.4, 3.2, 3.3
Interpretation	Direction-of-movement relationships between controls and controlled objects are consistent and conform with natural habit patterns.	4.1, 4.2, 4.3
	Displays and controls are patterned in a consistent functional arrangement.	3.2, 3.3
Team operation	Parts of consoles and panels used concurrently by more than one member of a team meet all the above recommendations for each member.	3.1, 3.3
	Operations by crew members who must use the same control do not interfere.	3.1, 4.1

*Detailed information will be found in the section designated in this column.

PART 2

WORKPLACE DIMENSIONS



Proper workplace layout requires that consideration be given to various workplace dimensions. Controls and displays should be located with due regard to the operator's size, his position (seated or standing), the directions in which he can most easily look, and the spaces in which he can best manipulate controls. Consideration should also be given to special influences such as protective clothing and g-forces. These factors are covered under the following headings:

2.1 Visual Areas (seated position): for the location of displays when the operator is seated.

2.2 Manual Areas (seated position): for the location of hand controls when the operator is seated.

2.3 Pedal Areas (seated position): for the location of foot controls when the operator is seated.

2.4 Standing Position: visual, manual and pedal areas when the operator is standing.

2.5 Comparison of Seated and Standing Positions: advantages of each position, body dimensions, recommended designs.

2.6 General Dimensions and Rules: location of displays relative to the line of sight, shape of panels, contour of panels, arm rests, g-forces.

Note: Supine and prone positions are used to counteract accelerative forces and/or to reduce the vertical height or silhouette of a vehicle. The fully supine position (flat-on-back) is not useful because it greatly reduces the operating capacity of the limbs and blocks off forward vision. The semi-supine position is equivalent to the seated position with a large backward

tilt; hence, dimensions for the seated position include positions varying from the upright to a backward tilt of 60° in order to include the semi-supine position. The prone position is not included here as there are too few applications at present to warrant special attention.[66]

The following dimensions are given for each area:

a. optimum dimensions

These dimensions define the most desirable space for the location of controls and displays. The most important controls and displays should be placed within this space.

b. limiting dimensions

These dimensions define the acceptable, but not necessarily the most desirable, space for the location of controls and displays. (The limiting dimensions will always include and be larger than the space bounded by the optimum dimensions.) Controls which are outside this space are either too close or too far from the operator; all normally used controls and displays should be located within this space.

Note: All dimensions include approximately 90 per cent of the operator population. Extreme dimensions are represented by the 5th percentile (small operator) and the 95th percentile (large operator). Operators outside this range are also accommodated but to a lesser degree.

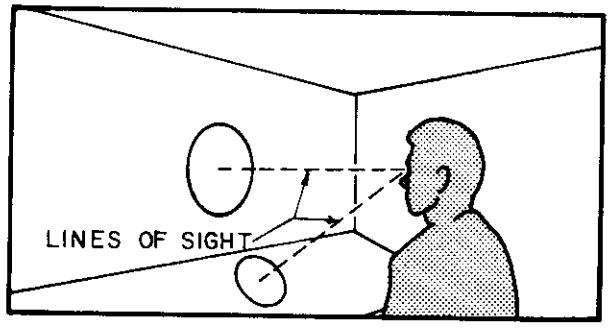
Dimensions of control areas are based upon personnel who are generally different from the population at large.[29] However, the techniques described for determining limiting dimensions are applicable to any population. The designer must choose dimensions from the appropriate population.[8, 10, 30, 31, 38, 45, 46]

2.1 VISUAL AREAS

2.1.1 Reference Terms

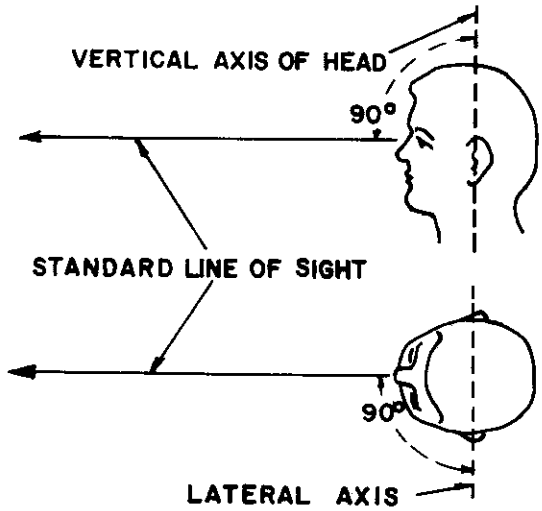
a. line of sight

A line from the bridge of the nose to the object on which the eyes are fixated, regardless of head position. For precise visual measurements this is measured from the cornea of the eye; however, since both eyes are involved simultaneously, the bridge of the nose is a satisfactory approximation for workplace layout problems.

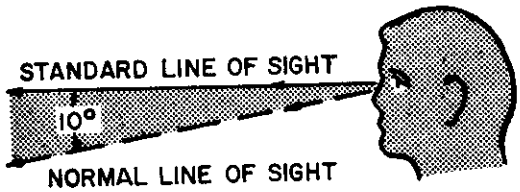


b. standard line of sight

The line of sight which is perpendicular both to the lateral and vertical axes of the operator's head, independent of eye movement. For a seated or standing operator, the vertical axis of the head is tilted slightly forward due to normal slouch (assumed to be about 5°), and therefore the standard line of sight is about 5° below the horizontal. For the supine operator, it is tilted upward from the horizontal, the exact amount depending upon the position of the operator's head.

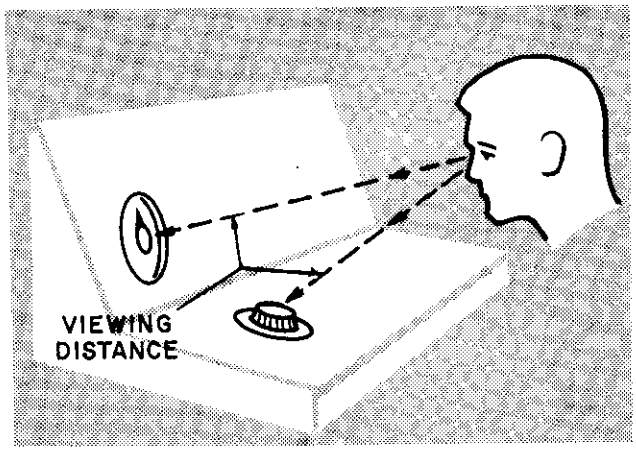


Note: The normal line of sight with eyes at rest is approximately 10° below the standard line of sight, i.e., the eyes naturally assume a small downward cast (approximately 15° downward for a seated operator).



c. viewing distance

Distance from the bridge of the nose to the object being viewed, i.e., the length of the line of sight.



d. optimum viewing angle

The solid angle through which the operator can view displays or controls with speed and accuracy by eye rotation alone*--measured horizontally and vertically from the standard line of sight.

*Shifts from one visual fixation point to another are accomplished most quickly by eye rotation alone when they involve: a) several such shifts in close succession, and b) only a small angular change (less than 15°). Changes in the point of fixation lasting more than a few seconds or requiring a greater angular change in the line of sight generally involve both head and eye motion. The operator generally prefers to hold his head stationary in order to establish a better orientation with respect to his surroundings, especially when he must maintain close contact with a main central display or with moving elements outside his operating cubicle (e.g., driving a truck, operating a crane) and at the same time make successive checks on other displays.[9,27]

The optimum dimensions of the visual area are defined by the optimum viewing angle when the viewing distance is known.

e. maximum viewing angle

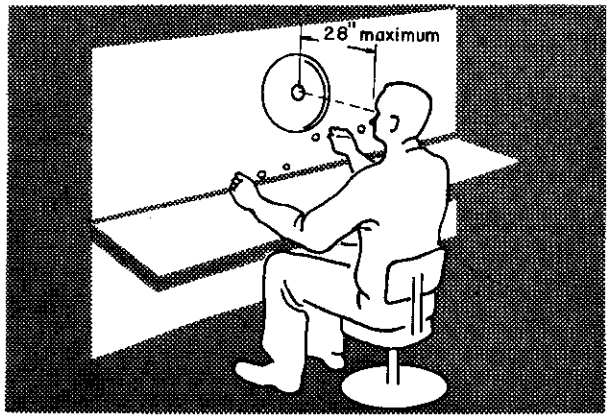
The angle through which the operator can view displays by combined head and eye rotation without straining his neck or eye muscles--measured horizontally and vertically from the standard line of sight.[28]

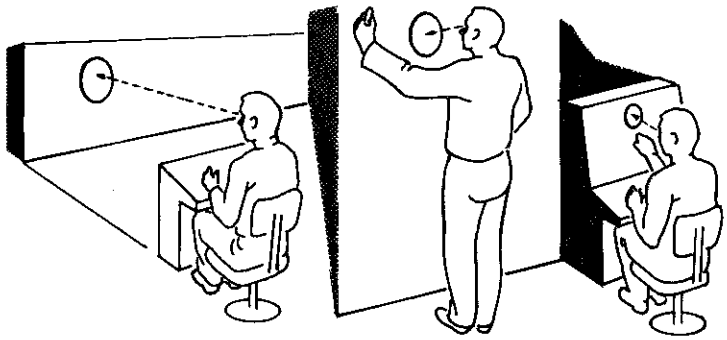
The limiting dimensions of the visual area are defined by the maximum viewing angle and the viewing distance.

2.1.2 Dimensions of the Visual Areas

a. viewing distance

For instruments whose displays are located close to their controls viewing distance is limited by reach distance and should not exceed 28 inches. Otherwise, there is no maximum limit other than that imposed by practical space limitations provided the display is properly designed.





Viewing distance to displays should never be less than 13 inches, and preferably not less than 20 inches. A small viewing distance places an undue strain on eye muscles controlling accommodation.[5,7,15,35]

b. optimum and maximum viewing angles

Table I gives optimum and maximum viewing angles for seated and supine positions. READ THE NEXT PARAGRAPH BEFORE USING THIS TABLE.

2.1.3 Restrictions to Visual Areas Caused by Equipment

Certain equipment can restrict the visual areas:

a. Head rotation may be reduced because of the weight and bulk of a helmet, mask, headphone, etc.

b. Eye rotation is unrestricted, but vision will be cut off by equipment which projects into the visual area.

c. In the seated and supine positions, upward head rotation will be restricted by a head rest, particularly when the operator is strapped to his seat so that his head is normally in contact with the head rest.

d. In the supine position, downward head rotation is unrestricted but vision may be cut off by the operator's knees. (See Figure 1 for knee positions.)

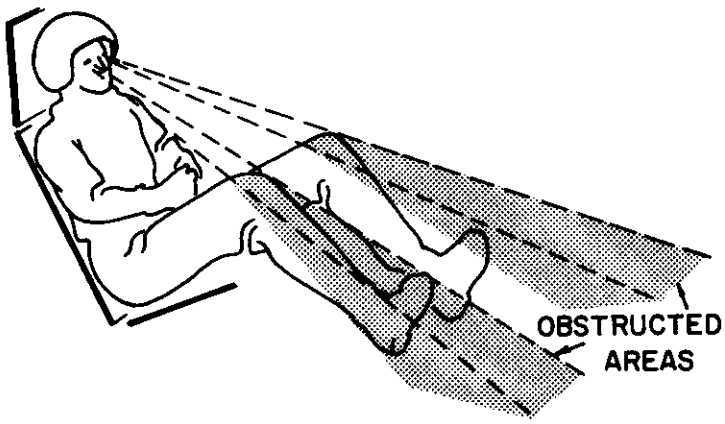
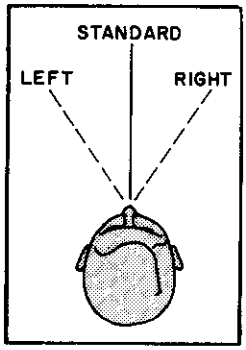
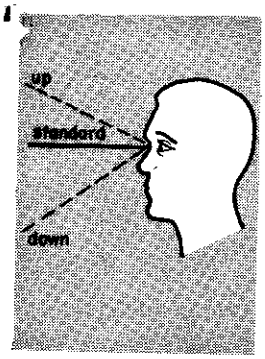
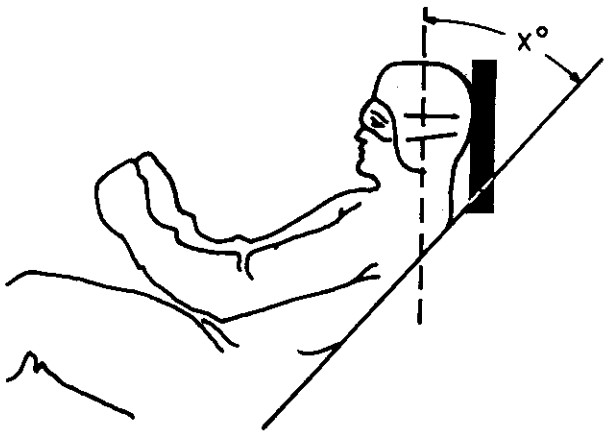


TABLE I

Viewing angle: seated, standing and supine* positions

TYPE OF MOVEMENT	VIEWING ANGLE					
	LATERAL			VERTICAL		
						
		Optimum	Maximum		Optimum	Maximum
Head rotation-only**	Left	0°	60°	Up	0°	50°
	Right	0°	60°	Down	0°	50°
Eye rotation only	Left	15°	35°	Up	0°	25°
	Right	15°	35°	Down	30°	35°
Head and eye rotation	Left	15°	95°	Up	0°	75°
	Right	15°	95°	Down	30°	85°

*In the supine position where the operator's head is tilted forward by a head rest, upward head rotation is eliminated, and downward head rotation is reduced by the amount (x°) the operator's head is tilted forward from alignment with his trunk.



**These angles assume that the standard line of sight is horizontal. Any shift in the normal line of sight from the horizontal will rotate these dimensions by a similar amount.

2.2 MANUAL AREAS (Seated Position)

2.2.1 Reference Terms

a. optimum manual areas

The space, as defined by optimum dimensions, which is most desirable for the location of hand controls both in their neutral position and when displaced in any direction. This is an "ideal" area (reserved primarily for manual controls which must be seen and used frequently) in which all of the following operating characteristics are optimized:

1) Speed and accuracy in locating (reaching for) the proper controls.

2) Speed and accuracy in operating controls.

3) Proximity of controls to visual areas. (Important controls should be designed so that they can be located and operated without being viewed; however, it should be possible to see them easily in emergency situations.)

4) Application of large muscular forces in all directions.

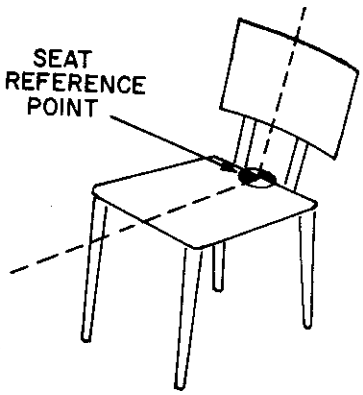
5) Efficient expenditure of energy in operating controls--minimizing fatigue when controls must be used over extended periods.

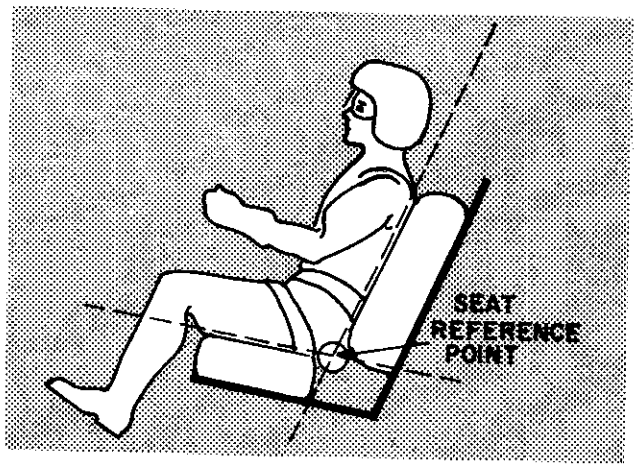
b. over-all manual areas

The space, as defined by the limiting dimensions, in which all hand controls should be located, both in their neutral position and when displaced in any direction.

c. seat reference point

The point where the middle lines of the seat and the back rest intersect. This point does not necessarily fall on the surface of the seat, e.g., in seats with recessed pans and backs for kits and chutes the seat reference point is a point in space which may not fall within the seat structure.





2.2.2 Dimensions of Optimum Manual Areas

a. recommended dimensions

Width is approximately 24 inches (based on a small informal sample by the authors). Other dimensions are given in Figure 1, which shows variations in seat tilt from the upright (0°) to 60°.

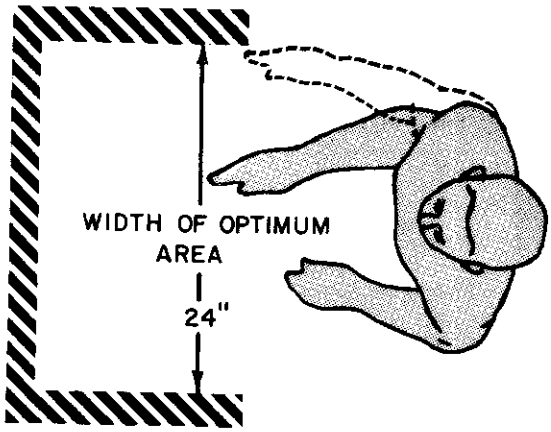
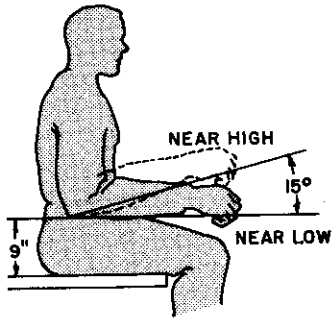


Figure 1 is a vertical, fore-aft cross section through the optimum manual area, bounded by four points (each represented as the center of the operator's fist):

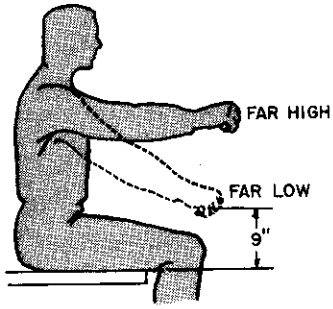
Near Low: operator's elbows next to body, forearms horizontal.

Near High: operator's elbows next to body, forearms flexed upward about the elbow 15°.

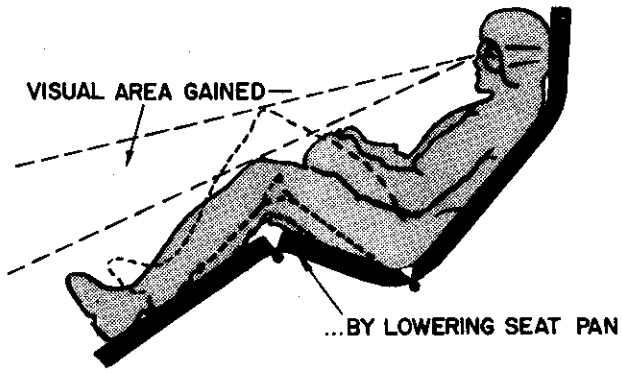


Far High: operator's arm extended horizontally from shoulder, operator sitting erect.

Far Low: operator's arms extended and lowered until hand is at level of elbow in "Near Low" position.

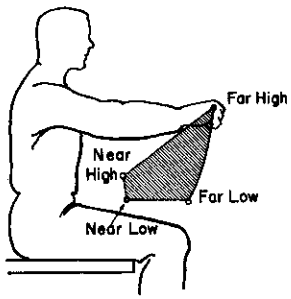


Note: When the seat is rotated, maintaining the same included angle between seat pan and back rest, the optimum area becomes smaller (see Figure 1) and the upper parts of the legs rise, blocking off portions of the working area. This effect can be partially corrected by lowering the front edge of the seat pan, thus increasing the angle between the seat and back rest. However, this angle should not exceed 120°.

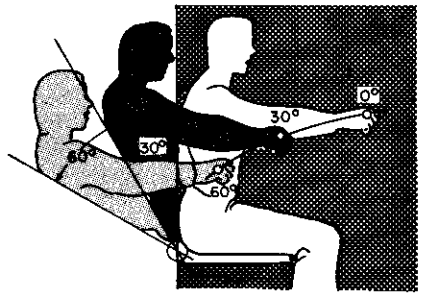


INSTRUCTIONS FOR FIGURE 1

The shaded areas in Figure 1 represent the vertical fore-aft cross sections of the optimum manual control area when the back rest of the operator's chair is at various angles of tilt. The optimum area is bound by four principal points: Near Low, Near High, Far High, Far Low. These bounding points are specifically indicated in Figure 1 for the optimum manual area when the operator is seated upright (0° tilt).



The heavy line marked "Far High" shows the arc generated by the center of the fist held at shoulder height with arm extended as the operator swings backward from the upright position (0°) through 60° of backward tilt. The position of the center of his fist is indicated at successive 10° intervals along the arc. Similarly, the arcs generated by the center of his fist at "Far Low," "Near Low" and "Near High" positions (as the operator's back rest swings from the upright to a 60° tilt) are shown, and these bounding points are also marked at successive 10° intervals.



At each 10° interval, the four bounding points have been joined and shaded in, showing the vertical cross section of the optimum manual control area for 0° (upright), 10°, 20°, 30°, 40°, 50°, and 60° of tilt.

Additional Information

Arcs, marked in 10° intervals, are also shown for the operator's Shoulder Pivot Point and Elbow (in resting position), as the back rest tilts from the upright position backwards 60°.

The Knee position is directly dependent upon the angle of the seat pan, i.e., while the seat pan remains set at a stationary position the operator's knees will remain in the same position regardless of the angle through which the back rest is tilted. The Knee position is therefore shown as the arc generated by the knee as the front edge of the seat pan is elevated from the horizontal. This will enable the designer to determine the clearance for the knees, and the amount by which the knees may block off the optimum manual and visual areas. From this he can determine the amount which must be deducted from the optimum area in order to provide leg clearance, or the amount which the front edge of the seat must be lowered in order not to interfere with the optimum manual or visual areas.

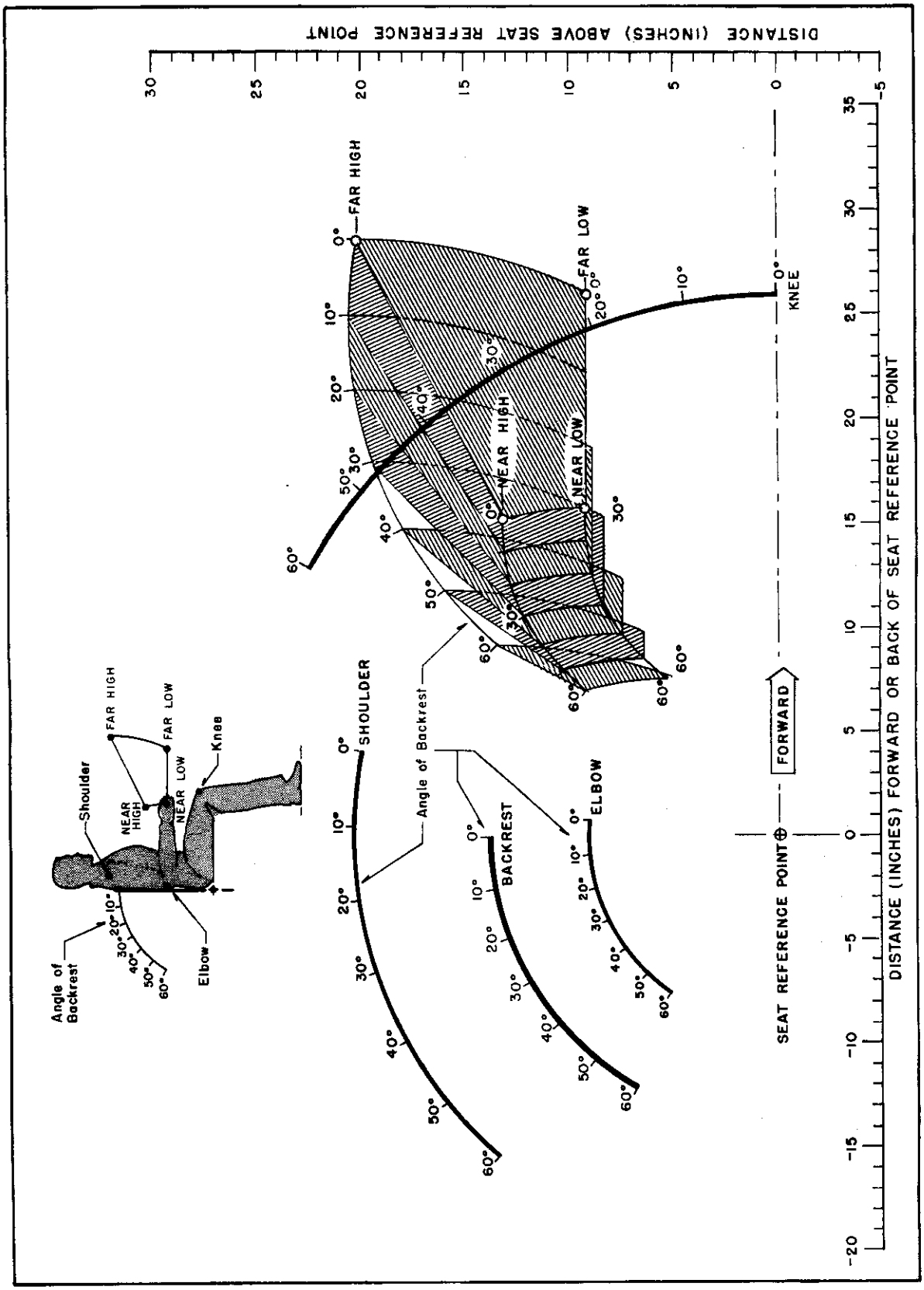


Figure 1. Optimum areas for seated positions (vertical cross-section).

b. critical measurements

The following measurements are critical in determining the optimum areas for manual controls:

Elbow to Center of Fist: use the 95th percentile to assure that controls are not placed too close for most operators.

Elbow to Seat Reference Point: use nine inches vertical distance; one inch forward of seat reference point (based on an informal study conducted by the authors).

Shoulder Pivot Point to Seat Reference Point: Use 5th percentile for vertical distance to assure that controls are not placed too high for most operators. The shoulder pivot point is located about one and one-half inches below the outer edge of the shoulder (used as the reference point for "Shoulder Height" measurements), and four inches forward (horizontal distance) of the seat reference point.

Shoulder Pivot Point to Center of Fist (arm extended): use the 5th percentile to assure that controls are not placed too far from most operators.

Knee to Seat Reference Point: use the 95th percentile for both horizontal and vertical distances to assure adequate knee clearance for most operators.

2.2.3 Limiting Manual Areas

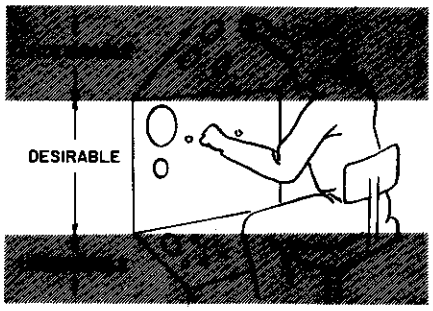
a. maximum dimensions

Maximum dimensions are shown in Figures 2-5. These figures represent maximum fingertip reach for the small (5th percentile) man. The dimensions should be reduced according to the type of control being used. Table II shows corrections to be applied for various types of controls which cannot be operated at fingertip reach.

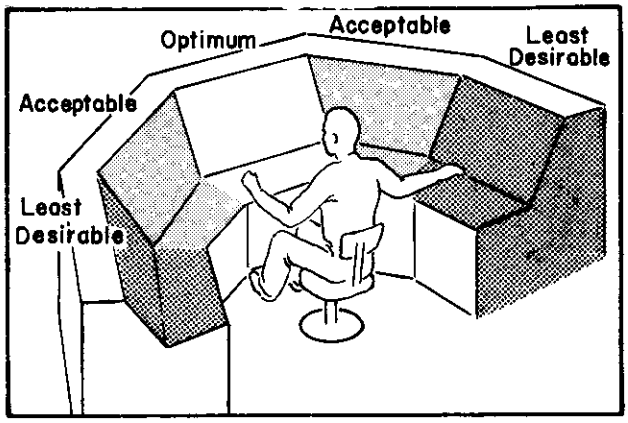
Figures 2-5 represent the case where the operator's shoulders are always against the back rest. Maximum reach dimensions should be increased according to the operator's freedom to move. Table III shows corrections to be applied.

Note: When all the controls cannot be placed within the optimum manual area, locations immediately adjacent to the optimum control areas are more desirable than those further away. As a general rule, the desirability of a control location decreases as either or both of the following distances increase: [6, 17, 18]

1) Distance above shoulder level or below waist level (seated position).



2) Distance sideward and rearward from the optimum control area.



b. minimum dimensions

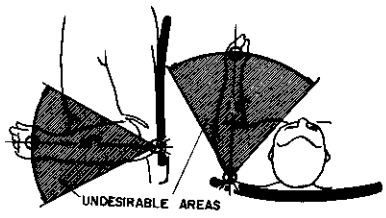
When movement of the operator's elbows is unrestricted, the surface of his body (or clothing) forms the minimum limits to manual reach. Thus, controls may be placed close to the operator with the following exceptions:

1) Tight or bulky clothing may prevent the operator from manipulating controls next to his body because he is limited in the extent to which he can bend his elbows.

2) Bulky clothing stands out from his body, filling in the space around his body.

3) Strength and accuracy of certain movements (especially rotary) close to the body are severely limited.[14]

If a back rest interferes with rearward movement of the elbows, no control should be placed within 16 inches (in any direction) of the resting position of the elbow.



2.2.4 Factors Affecting and Modifying Manual Areas

a. seat adjustments

All dimensions for the seated and supine positions are given with respect to the seat reference point. For these dimensions to be applicable in all cases, this reference point should be adjustable at least three inches horizontally and five inches vertically.

b. bulky clothing

Gloves, jackets, etc., reduce the movements of the limbs and trunk thereby reducing the manual areas (the precise amount depending upon the type of clothing being worn).

c. g-forces

When the operator is subjected to high g-forces, manual areas must be modified. (For further information, see page 55f.)

INSTRUCTIONS FOR FIGURES 2-5

Vertical dimensions are shown on the left marginal scale and indicate the vertical distance of the fingertips above or below the seat reference point. Horizontal dimensions are shown on the bottom marginal scale and indicate the horizontal distance of the fingertips forward or back of the seat reference point.

Each figure shows dimensions when the back rest is tilted the following angles from the vertical: 0°, 10°, 20°, 30°, 40°, 50°, 60°.

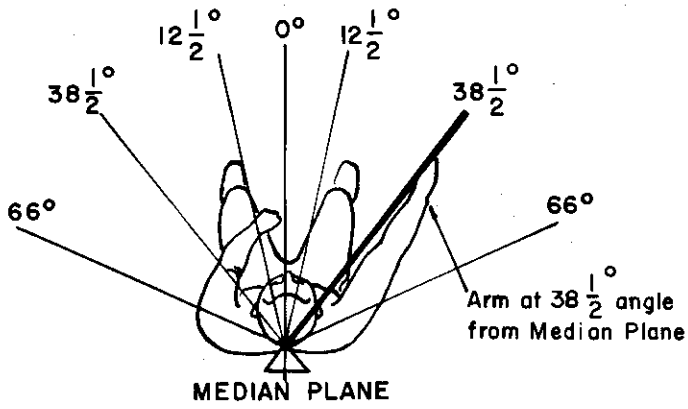
In each figure the arm is extended at a different angle from the median body plane (the angle between the median plane and a line formed by the intersection of the median plane with the seat back.

Figure 2: 0°

Figure 3: 12-1/2°

Figure 4: 38-1/2°

Figure 5: 66°



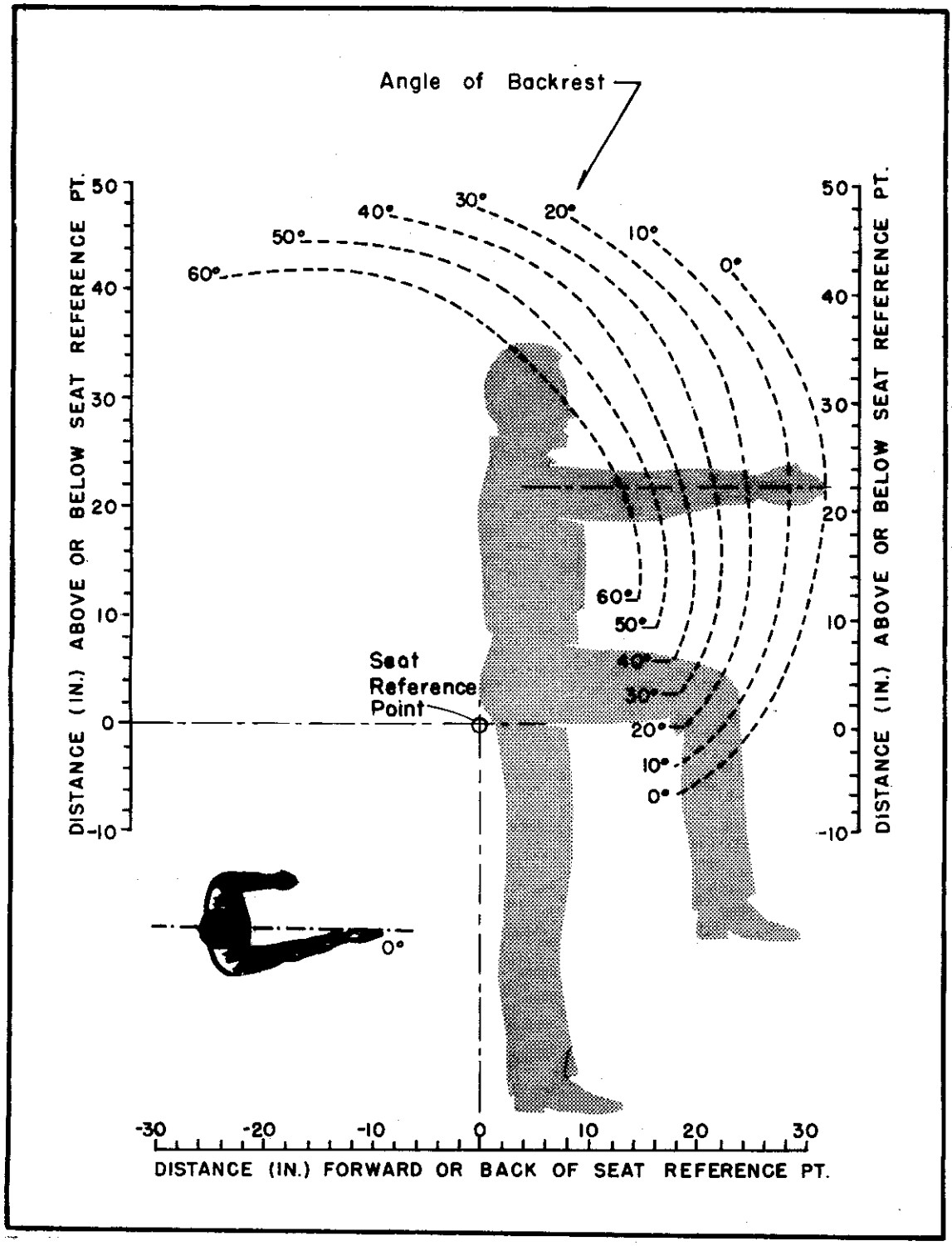


Figure 2. Maximum fingertip reach. (Seated and standing positions: 0°.)

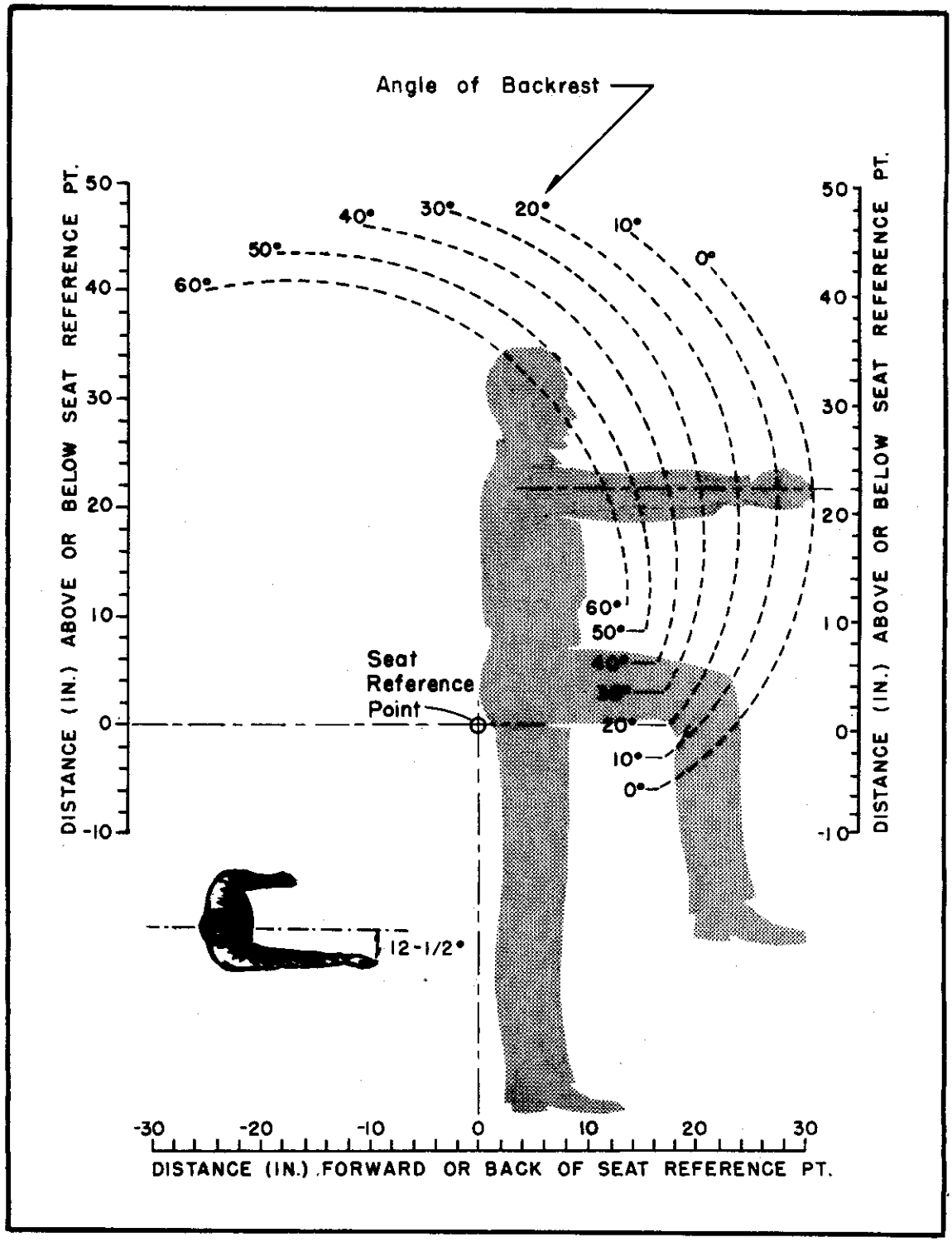


Figure 3. Maximum fingertip reach. (Seated and standing positions: 12½°.)

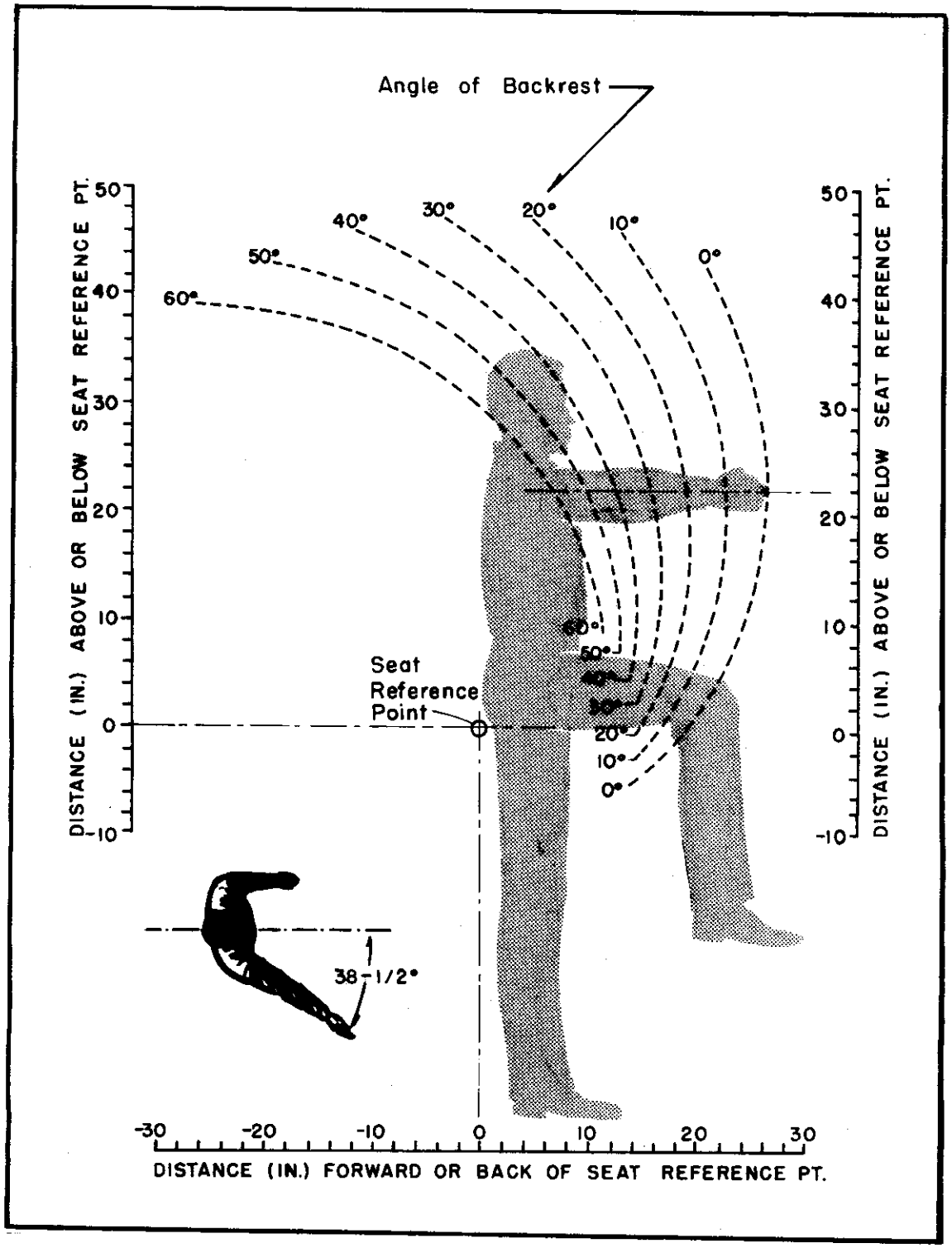


Figure 4. Maximum fingertip reach. (Seated and standing positions: 38½°.)

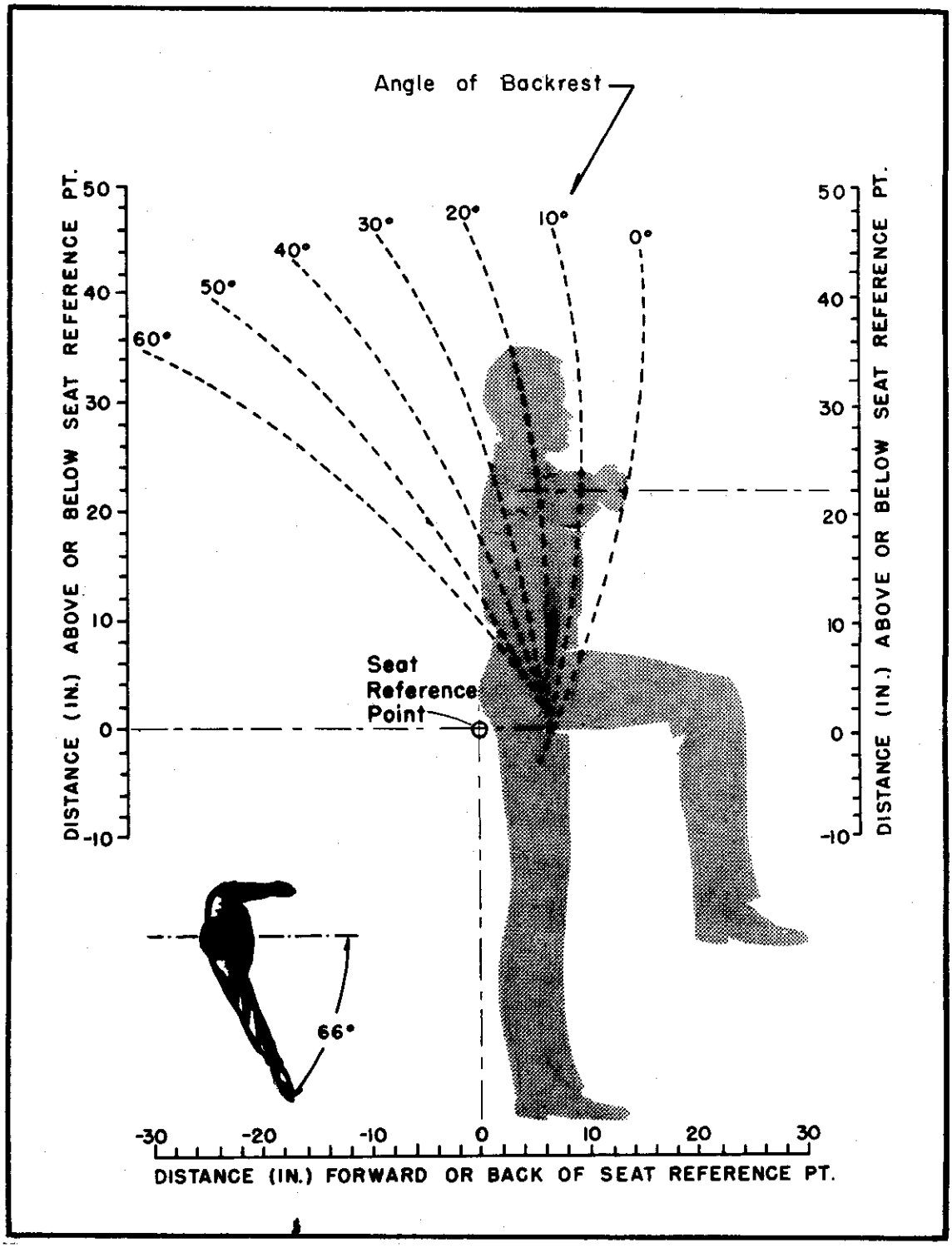


Figure 5. Maximum fingertip reach. (Seated and standing positions: 66°.)

TABLE II

Reductions in maximum reach dimensions for various types of controls (adjustments to Figures 2-5)

TYPE OF CONTROL	REDUCE MAXIMUM REACH DIMENSION IN FIGURES 2-5 BY:
Push-type (finger operated)	0 inches
Throw-type (finger operated)	2 inches
Small rotary selector (1-2 inches in diameter, finger-and-thumb operated)	4 inches
Large rotary selector (hand operated)	4-1/2 inches
Levers, cranks, etc. (requiring hand grasping)	5 inches

TABLE III

Additions to maximum reach dimensions for various body movements at different angles from median plane (adjustments to Figures 2-5)

BODY MOVEMENT	INCREASE MAXIMUM REACH DIMENSIONS IN FIGURES 2-5 BY AMOUNT INDICATED WHEN REACH IS DIRECTED:		
	0° straight ahead	45° oblique	90° straight out from the side
Shoulder extended*	4 inches	3 inches	2 inches
Shoulder extended, trunk rotated**	6 inches	4 inches	2 inches
Shoulder extended, trunk rotated, trunk bent***	16 inches	12 inches	8 inches

*The operator can extend his shoulders except when they are rigidly strapped to the back rest or his clothing or equipment are restrictive.

**The operator can rotate his trunk except when his shoulders or chest are rigidly strapped to the back rest or his clothing is restrictive.

***The operator can bend his trunk forward or sideward except when his shoulders or chest are rigidly strapped to the back rest, his waist is strapped to his seat or his clothing is restrictive.

2.3 PEDAL AREAS (Seated Position)

2.3.1 Reference Terms

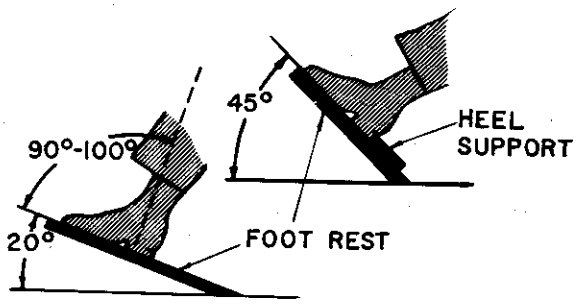
a. optimum pedal areas

The space, as defined by optimum dimensions, which is most desirable for the location of foot controls both in their neutral position and when displaced in any direction.

b. over-all pedal areas

The space, as defined by the limiting dimensions beyond which foot controls should not be located, either for their neutral position or when displaced in any direction.

Note: The operator should always be provided with a foot rest which allows each foot to be normal (90° - 100°) to the lower leg.[12]



If the foot rest is at an angle of more than 20° from the horizontal, * a heel support should be provided to prevent the foot from sliding downward. The heel support should be between 1 and 1-1/2 inches thick to minimize interference with leg movements.

*Based on informal experiment by authors.

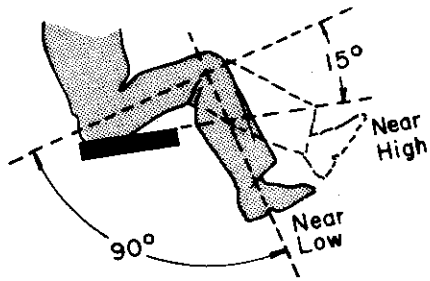
2.3.2 Dimensions of Optimum Pedal Areas

a. recommended dimensions

Figures 6 and 7 show, respectively, horizontal and vertical fore-aft cross sections of the optimum pedal areas. In each figure, separate areas are indicated for heel- and toe-operated controls. These areas are bounded by the following 4 points in Figure 6.

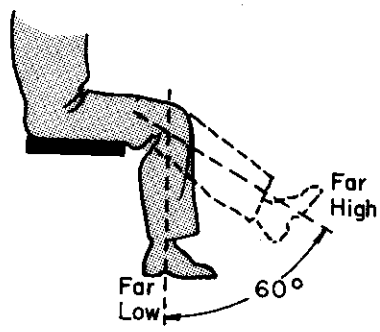
Near Low: Position of heel and retracted* toe with upper leg raised 15° from the seat pan, lower leg at 90° angle with upper leg.

Near High: Position of heel and retracted* toe with upper leg raised 15° from the horizontal, toe level with plane of seat pan.



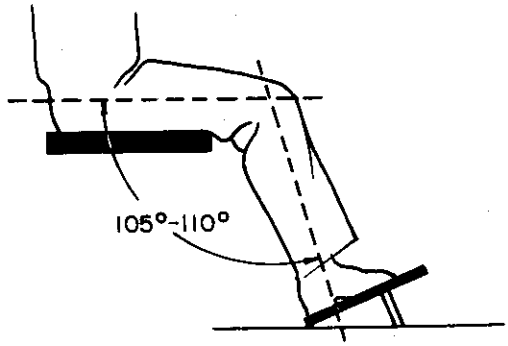
Far High: Position of heel and extended* toe with upper leg horizontal and lower leg extended 60° from the vertical.

Far Low: Position of heel and extended* toe with upper leg horizontal and lower leg vertical.



For the most comfortable position when operating controls which require the application of small forces (0 - 50 pounds), the upper and lower leg should form an angle of 105° - 110°.

When moderate forces (50 - 100 pounds) must be exerted, the upper and lower leg should form an angle of at least 120°.[44]

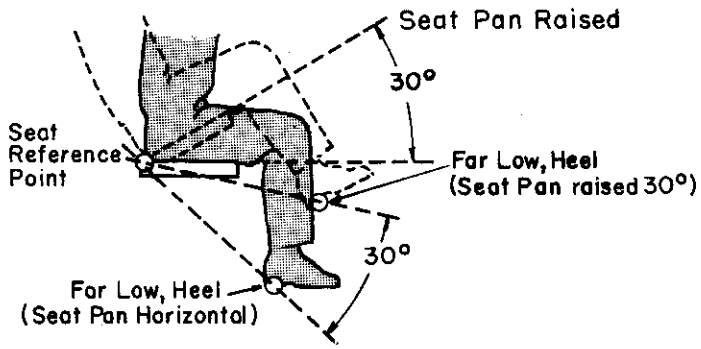


*Add 1 inch to normal knee pivot-to-toe distance for the extended toe, and subtract 1 inch for the retracted toe.

INSTRUCTIONS FOR FIGURE 6

The shaded areas in Figure 6 represent vertical cross sections of the optimum pedal areas for toe-operated and heel-operated controls when the back rest of the operator's chair is vertical (0° tilt) and the seat pan is horizontal. The optimum areas are bounded by the 4 principal points* described on page 33.

When the seat pan is tilted upward from the horizontal, the lower legs and feet swing upward and forward. The center of rotation is the Seat Reference Point. Thus, if the seat pan is raised 30° from the horizontal, a 30° arc with center at the Seat Reference Point, extending upward from the "Far Low, Heel" point in Figure 6 will locate the position of the "Far Low, Heel" point when the seat pan is tilted 30°. The remaining bounding points may be located by the same method.



*Technically, there is a fifth bounding point (Toe Retracted) for the toe-operated control area, which represents the position of the toe when the upper leg is horizontal, lower leg vertical, and toe raised (retracted). It has been included in this figure, although it has a negligible effect on the shape or extent of the optimum area.

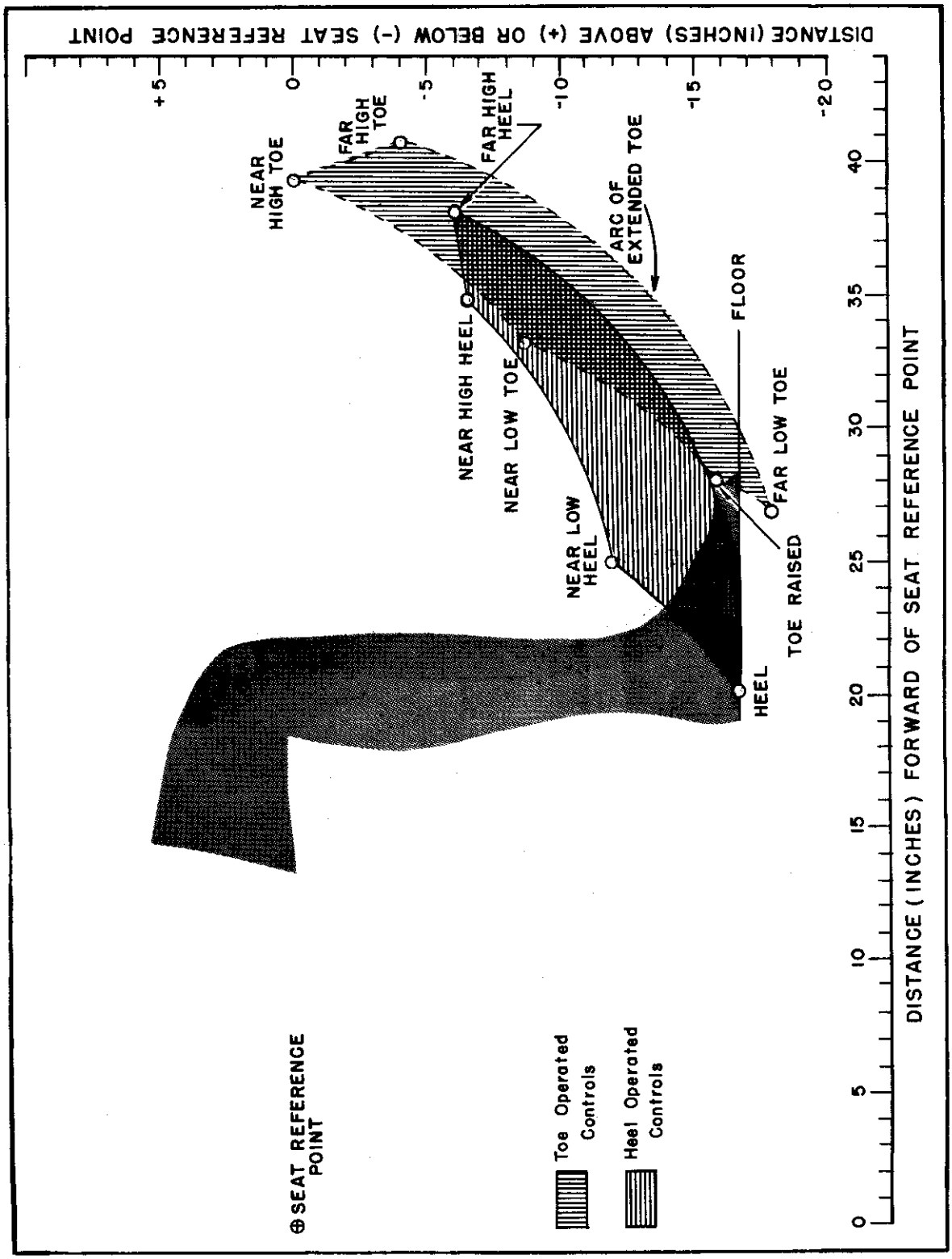


Figure 6. Optimum pedal areas for seated postion (vertical cross-section).

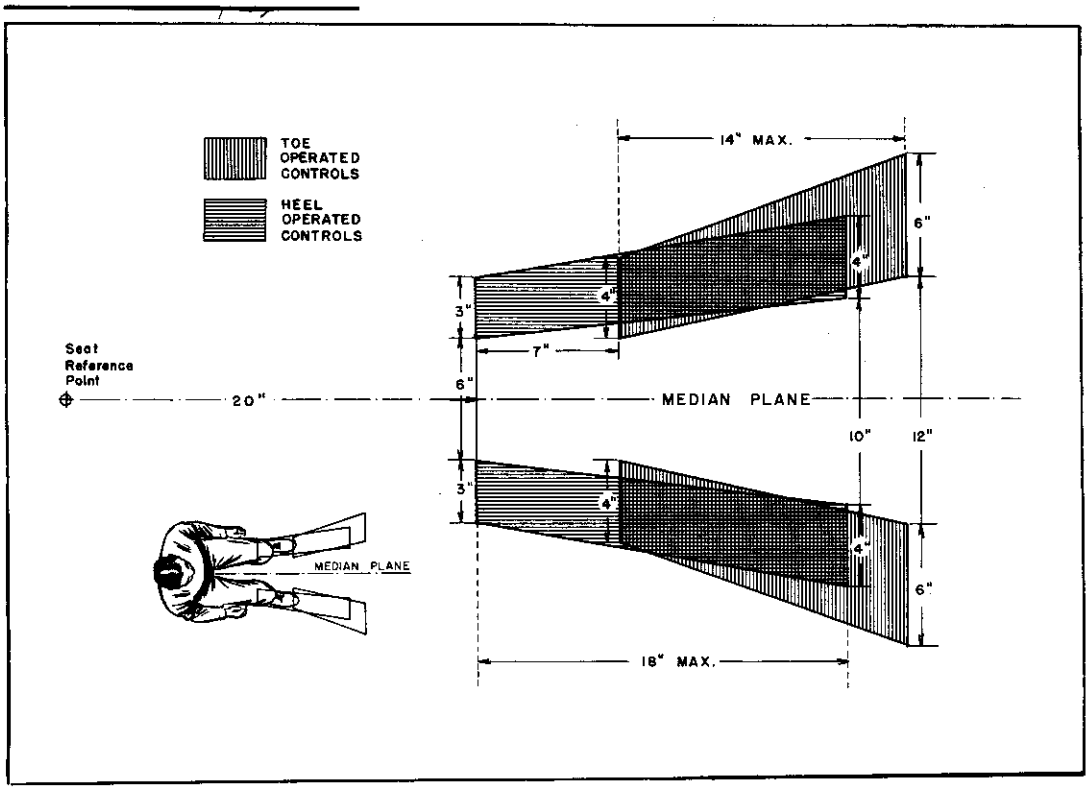


Figure 7. Optimum pedal areas for seated position (horizontal cross-section).

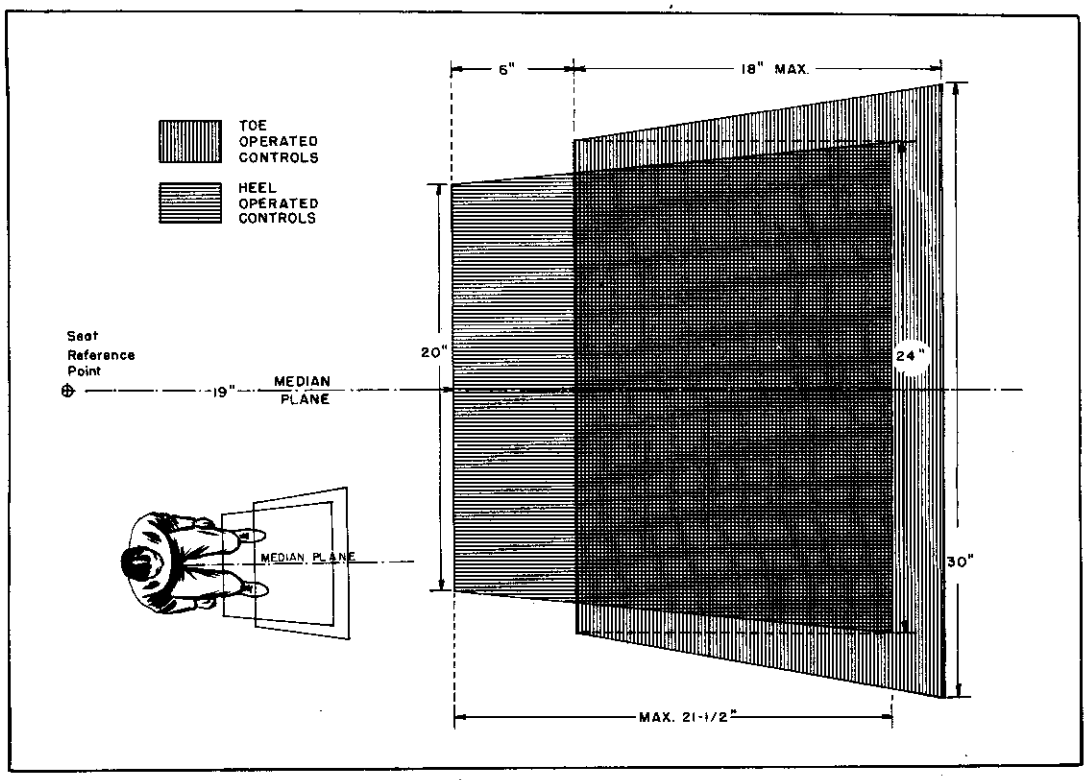
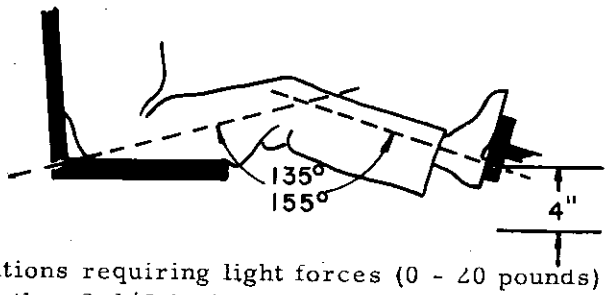


Figure 8. Over-all pedal areas for seated position (horizontal cross-section).

When large forces (over 100 pounds) must be exerted, the control should be located on a level with the seat pan or slightly below (not more than 4 inches). During maximum exertion of force, the upper and lower legs should form an angle of 135° - 155°.[39]



Control operations requiring light forces (0 - 20 pounds) over a short distance (less than 2-1/2 inches) are suitable for operation by ankle movements alone.[12,46]

b. critical measurements

The following measurements are critical in determining the optimum pedal areas:

Buttock-knee length: use 95th percentile to avoid placing controls too close to most operators.

Buttock-leg length (leg extended): use 5th percentile to avoid placing controls too far from most operators. Add 1.1 inches to nude dimensions to allow for heels.

Knee height (sitting operator): use 5th percentile to maintain vertical dimensions of pedal areas within capacities of most operators. Add 1.1 inches to nude dimensions to allow for heels.

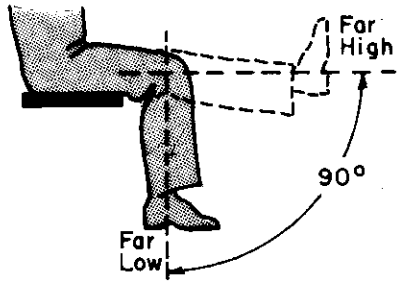
2.3.3 Dimensions of Over-all Pedal Areas

a. recommended dimensions

Lateral dimensions are shown in Figure 8,* and all other dimensions are shown in Figure 9. The vertical fore-aft cross section

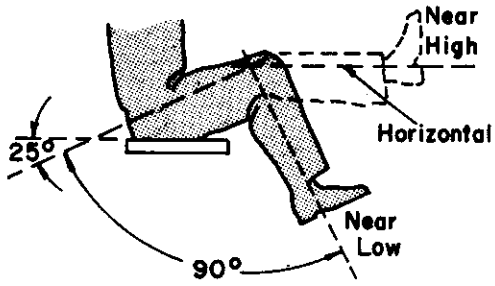
*Based on informal sample by authors. Measurements represent the lateral reach which 95% of the population can attain without strain and without altering the normal operating position of the body trunk.

of the over-all pedal area shown in Figure 9 is bounded by 4 limiting points:



Far High: position of heel or extended toe with upper leg resting on seat pan, lower leg horizontal.

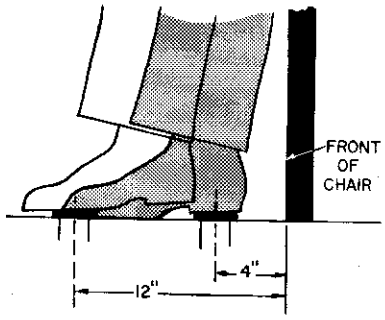
Far Low: position of heel or extended toe, upper leg resting on seat pan, lower leg at 90° angle with upper leg.



Near High: position of heel or retracted toe with upper leg raised 25°* from seat pan, lower leg horizontal.

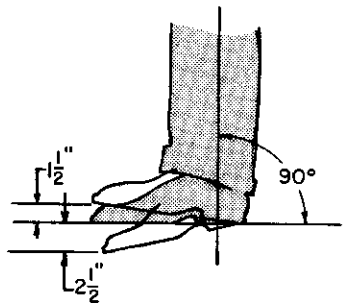
Near Low: position of heel or retracted toe with upper leg raised 25°* from seat pan, lower leg at 90° angle with upper leg.

When the chair is so constructed that the operator's feet cannot be placed under it, the following clearance should be provided between the front edge of the chair and the controls:



For heel-operated controls: 4 inches
For toe-operated controls: 12 inches

b. critical measurements



Add 2-1/2 inches to normal knee pivot-to-toe distance for the extended toe, and subtract 1-1/2 inches for the retracted toe.[12]

*Based on the recommendation that the operator's upper leg should not be raised to form an angle of less than 65° with the body trunk. Therefore, if the seat back is tilted 10° from the vertical, for example, the operator can raise his upper leg 35° from the horizontal seat pan.

For other specific measurements, use same distances given for Optimum Pedal Areas: critical measurements (page 37).

2.4 STANDING POSITION

The standing position is considered here to be a "standing-and-walking" position, i.e., the operator is free at all times to move in various directions. If this freedom is not available, the workplace should be designed so that the operator either sits at all times or shifts between a seated and standing position (see Section 2.5).

2.4.1 Visual Areas

a. optimum dimensions

See Visual Areas (Seated Operator), page 12, for reference terms and viewing distance. The optimum vertical viewing angles given in Table I (page 16) also apply to standing positions. The lateral dimensions in Table I apply only to groups of displays which are read in close succession or in conjunction with the operation of related controls. An optimum width need not be specified for the over-all lateral dimensions of unrelated displays because the operator can walk at will to the front of any display.

b. maximum dimensions

The operator can face equally well in any direction; therefore, as long as constant attention in any one direction is not always demanded, displays which require occasional reading may be placed (at the proper height) anywhere around him. In general, it is best to keep related displays together as a unit; thus, it is preferable to keep together a group of related displays (which may move some of the important displays out of the optimum visual area) rather than to take the important displays out of each group and concentrate them in one optimum position (as may be necessary in the seated position).

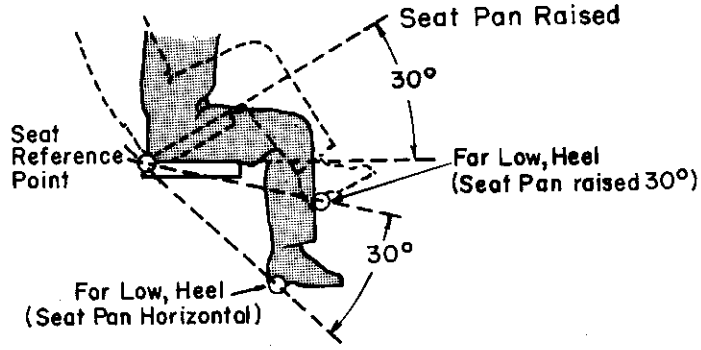
INSTRUCTIONS FOR FIGURE 9

The shaded areas in Figure 9 represent vertical cross sections of the over-all pedal areas for toe-operated and heel-operated controls when the back rest of the operator's chair is vertical (0° tilt) and the seat pan is horizontal. The control areas are each bounded by the four principal points* described on page 38.

When the seat pan is horizontal, as in Figure 9, a small portion of the maximum toe-operated control area is blocked off by the floor. This area becomes accessible to the operator when the front of the seat pan is raised.

Tilted Back Rest and Seat Pan

When the seat pan is raised, the lower legs and feet swing upward and forward (the angle between lower and upper legs should not be less than 90°). The center of rotation is the Seat Reference Point. Thus, if the seat pan is raised 30° from the horizontal, a 30° arc with center at the Seat Reference Point, extending upward from the "Far Low, Heel" point in Figure 9, will locate the position of the "Far Low, Heel" point with the seat pan raised 30°. The remaining bounding points may be located by the same method.



Similarly, when the back rest is tilted from the upright position (the seat pan remaining horizontal), the operator is free to raise his knee higher and still operate pedal controls throughout the entire shaded area. These extensions to the upper limits of the maximum pedal control areas may be located in the manner described in the previous paragraph. The angle between the seat pan and back rest should not exceed 120°.

*Note that there is a fifth bounding point (Toe Retracted) for the toe-operated control area which represents the position of the toe when the upper leg is horizontal, lower leg vertical, and toe raised (Retracted).

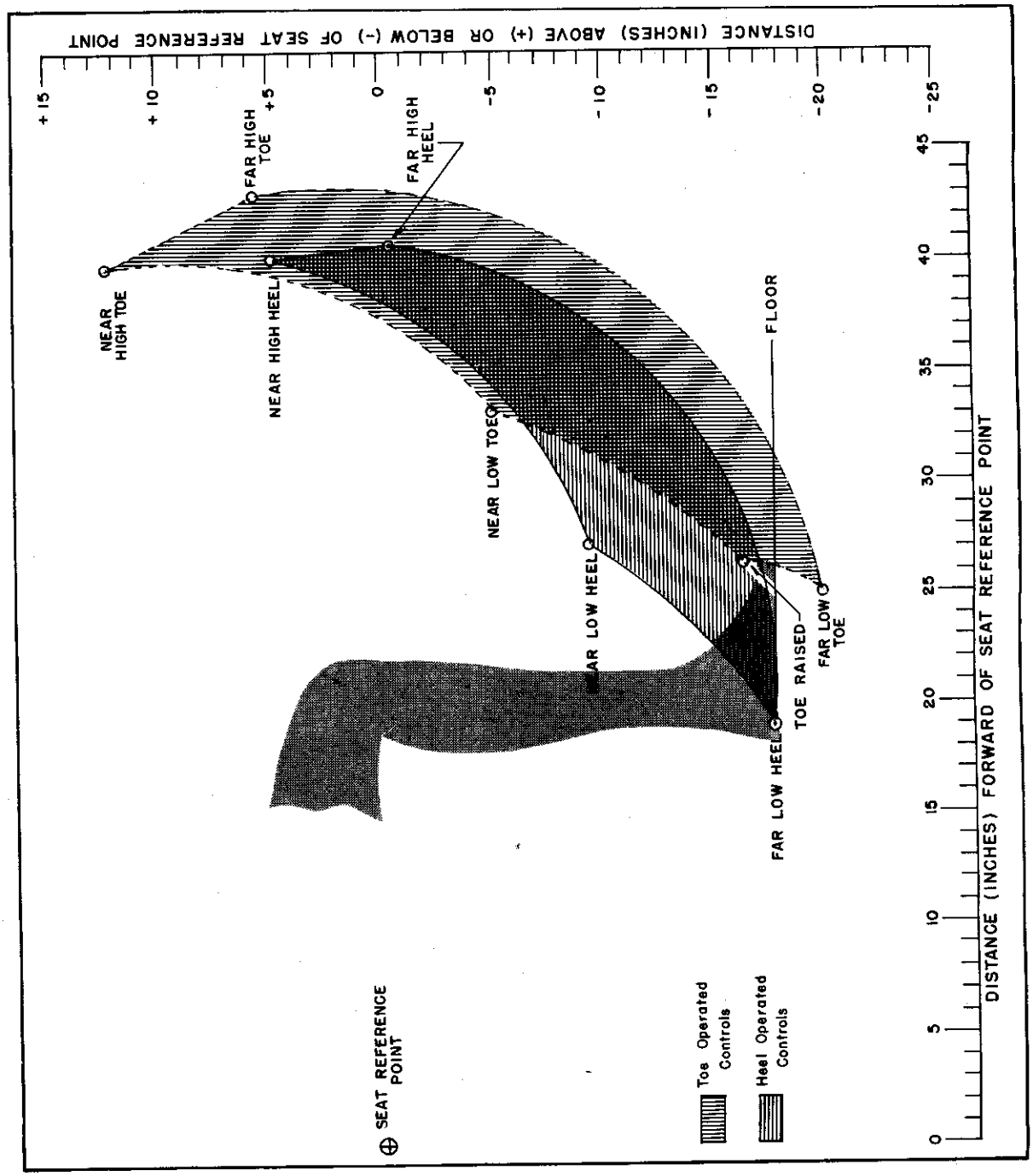


Figure 9. Over-all pedal areas for seated position (vertical cross-section).

2.4.2 Manual Areas

a. optimum manual areas

The upper and lower limits lie between the shoulder level and the elbow level with arms at side of the body. If this area were optimized for both the tall and short operators (lower limit: elbow height of tall operator; upper limit: shoulder height of small operator), the residual area would be too small for practical value. The best alternative is to use the dimensions of the average (50th percentile) operator; the limits of this area will be within easy operating range of all operators and will be near-optimum for most men (the middle 60 to 75 per cent of the population).

Figure 1 closely approximates this area. Height of "Near Low" and "Far Low" points should be approximately 43-1/2 inches above floor level. These points define the vertical fore-aft cross-section of the optimum manual area. The lateral dimensions of this area are approximately 30 inches for any one operating station* of the operator, i.e., groups of controls which must be operated simultaneously or in close succession should be placed within a lateral distance of 30 inches. When the operator can move back and forth between successive control operations, lateral dimensions are limited only by the time required to shift positions.

b. maximum manual areas

Theoretically, the limits of the maximum manual area extend from floor level (for an operator bending down) to the highest point which a small operator can reach and manipulate controls (78 inches).[67] In practice, the following limitations should be accepted:

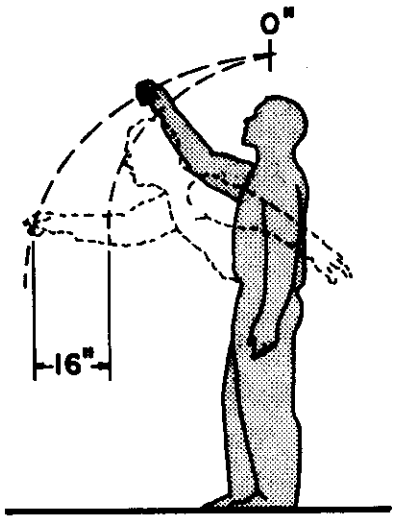
1) Minimum floor-to-ceiling clearance for a tall operator is 76 inches, leaving only 2 inches for overhead controls. Therefore, controls should not be placed on the overhead directly above passageways and/or working positions.

2) In its lowest position (maximum displacement), a control should be at least 32 inches above the floor (knuckle height of tall operator) to prevent excessive stooping. This is particularly important for controls which are used frequently or which require heavy forces for operation.

*In the standing position there may be more than one operating station for a single operator.

3) When the operator must reach over an object (table, console, work bench, etc.) to reach a control, the height which he can reach is limited accordingly. Figure 2 can be used to calculate this distance. Note that in Figure 2 the horizontal distance is measured from the Seat Reference Point; however, for a standing operator a better reference point is on the front of the operator's trunk (sternum, front of waist, etc.) which is about 10 inches forward of the Seat Reference Point.

Note: When the obstructing object is below waist level, the operator can bend over and increase his forward reach by about 16 inches. As the point of reach rises above shoulder level, the gain attainable by bending the trunk decreases progressively to zero at a point directly overhead.



2.4.3 Pedal Areas

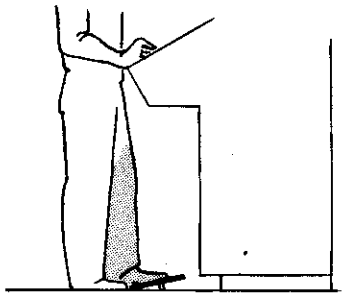
a. general

In the seated position, the feet should be used to exert large forces and to relieve the hands from repetitive, routine operations which do not require precise adjustment.[6] In the standing position the legs and feet are needed to maintain balance and to increase the operator's range of manual control capabilities. Hence, in the standing position, pedal controls should be avoided whenever possible except for occasional "in-between" operations.

b. recommendations

1) Pedal controls should be limited to operations which are performed while the hands are stationary and which relieve the hands from exerting large forces.

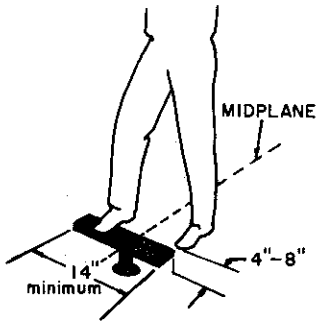
2) The operator should be able to reach the pedal by a natural short stepping or walking leg movement, i.e., with minimum lifting of the foot and knee.



3) Preferably only one pedal control should be assigned to an operator at any one operating station.*

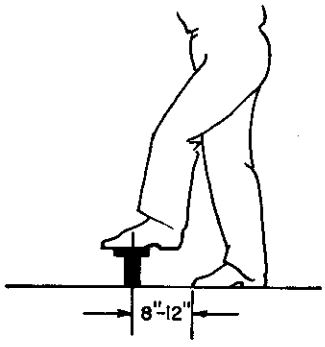
4) Pedals should be large enough so that each is operated by stepping in a general area without having to "seek" with the foot.

5) For normal forces (less than 30 pounds) the pedal should be located along the midplane of the station so that it can be operated by either foot (preferably a broad "tie-bar" control extending at least 7 inches laterally to either side of the midplane), or dual controls should be provided (with centers 4 inches from the midplane). The control(s) should be 4-8 inches forward of the toe in the normal standing position.



NORMAL FORCES

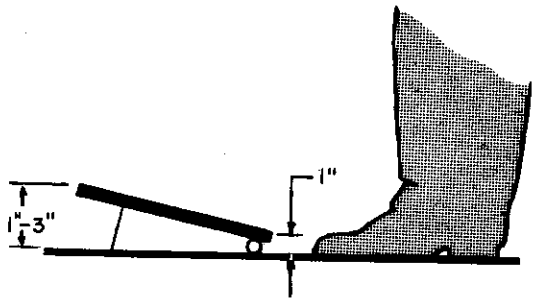
6) For heavy forces (greater than 30 pounds) the pedal should be designed as described above, but it should be 8-12 inches forward of the toe in the normal standing position.



HEAVY FORCES

*In the standing position there may be more than one operating station for a single operator.

7) The part of the pedal nearest the operator's foot should be raised at least one inch above the surrounding surface (to provide the operator with a good cue that his foot is in contact with it).



2.5 COMPARISON OF SEATED AND STANDING POSITIONS

2.5.1 Advantages of Seated Position

The seated position is superior to the standing position in the following ways:

a. reduction of fatigue

The operator can perform light work with his arms and heavy work with his legs for a much longer time than when standing.

b. increased stability and equilibrium

The operator's body is protected against vibration, rolling, jolting, etc., leaving his arms and legs free to operate controls. When the operator must undergo violent maneuvers and/or appreciable accelerative forces, some form of body support (seated, semi-supine, or semi-prone) is mandatory.

c. effective operation of pedal controls

The operator can use:

1) Both feet simultaneously.

2) Operate over a greater range with either foot.

3) Exert much greater force.

4) Operate pedal controls faster.

5) Operate more controls with either or both feet.

2.5.2 Advantages of Standing Position

The standing position is superior to the seated position in the following ways:

a. increased mobility

By taking one or more steps in any desired direction, the operator can bring within his visual and manual areas displays which he could not read and controls which he could not operate from a stationary position.

b. increased manual forces

The operator can position himself to exert large muscular forces on manual controls in any direction and over a wide range of control locations.

c. increased control movements

The operator can make large control movements such as those demanded by a large lever or handwheel. The standing position is of particular advantage when the operator must make a control movement which combines a large force over a long distance (e.g., ship's tiller without power boost, submarine diving planes).

2.5.3 Recommended Uses of Standing Position

The standing position is particularly useful in three situations:

a. when the operator must be free to walk

This may occur when controls and displays are so numerous, space consuming, or otherwise widely separated that they cannot be attended and operated from a single, stationary position.

b. as an alternative or change-over from the seated position

Designing a workplace which permits the operator to sit or stand allows him to shift posture at will, thereby reducing the muscular fatigue which results from prolonged effort in any one position. In this situation the workplace must be designed to conform with the operator's visual, manual and pedal areas in the more restricted of the two positions: seated position for visual and manual areas, standing position for pedal areas.

c. when no special provisions are made for leg room

This may occur either when all controls are mounted on a wall or bulkhead, or when the console is a solid with no indentations for knee room and too wide to be straddled. If the operator is seated directly facing the controls, few, if any, of them will lie inside the optimum manual area.

2.5.4 Important Anthropometric Data

When the workplace must accommodate both seated and standing operators, the most important anthropometric data (for standing operators) are presented in the following table:[29]

DIMENSIONS	HEIGHT (INCHES)		
	5th Percentile	50th Percentile	95th Percentile
Eye height	60.7	64.6	68.5
Shoulder pivot height*	51.2	55.0	58.6
Elbow height	40.5	43.4	46.3

Note: These data are corrected for shoe height (+1.1 inches) and for normal slump while standing (-1.2 inches).

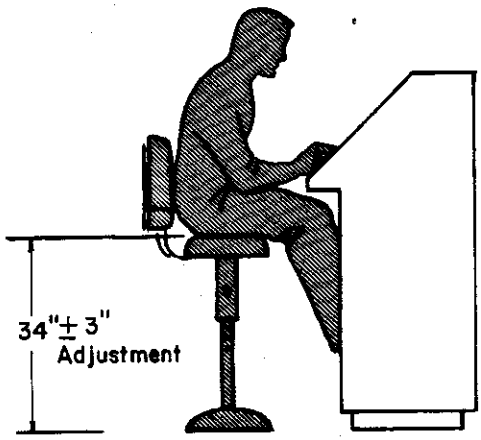
*Estimated from data in Hertzberg and Daniels.[29]

The size of the optimum visual and manual areas will be maximized for the entire operator population in both seated and standing positions if the dimensions of the average (50th percentile) operator are used rather than those of the short and tall operators. This increased operating area is slightly larger than the optimum manual area for the seated position; hence, the standing tall operator will have to reach slightly below elbow level for the lowest control, and the standing short operator will have to reach slightly above shoulder level for the highest control.

2.5.5 Recommended Design

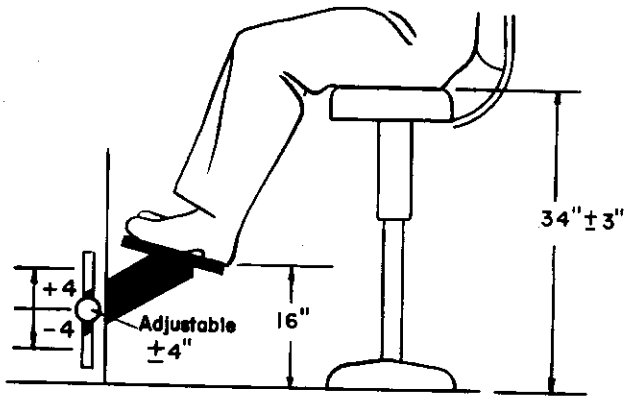
a. raised seat

When the operator alternates between seat or standing positions, a raised seat should be provided. The seat pan should be 34 inches above floor level and adjustable ±3 inches. The seat should be easily movable into and out of position; this can be done by a pull-out, swivel mount, etc.



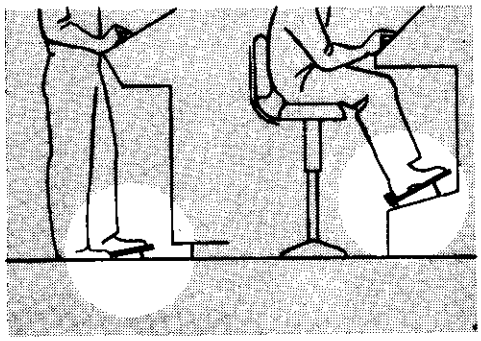
b. foot rest

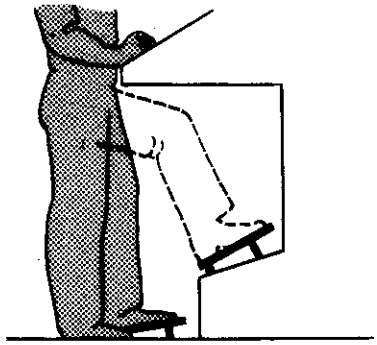
A foot rest should be provided for the seated position. The top of the foot rest should be 16 inches above floor level and adjustable ±4 inches. If the operator is working at a console-type workplace, the foot rest may be made part of the console (rather than the stool) in order to remove it as an obstacle to a standing operator.



c. pedal controls

The location of pedal controls for a seated operator should be higher than that for a standing operator. Hence, pedal controls should not be used when the operator is free to sit or stand, However, if pedal controls are imperative, two sets should be provided--one for the seated and one for the standing position.



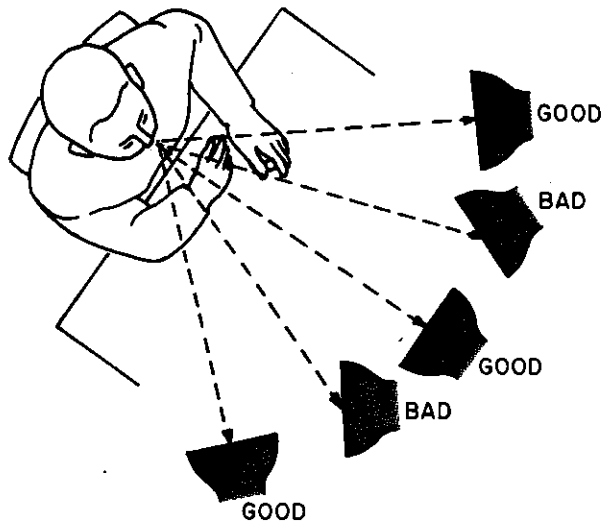


2.6 GENERAL DIMENSIONS AND RULES

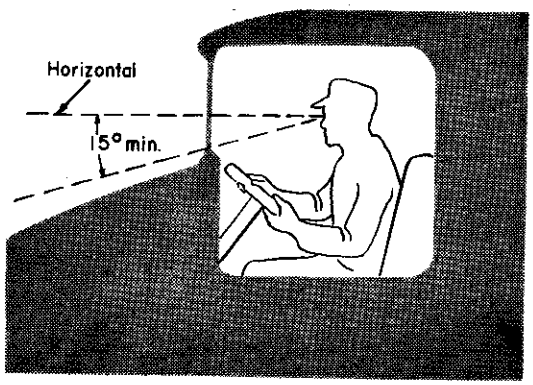
2.6.1 Location of Displays Relative to the Line of Sight

a. The plane in which the display lies should be perpendicular to the line of sight whenever possible, and the operator's view should be unobstructed by bezels and other projections.

In no case should the line of sight to the plane of the display be more than 45° from the perpendicular.



b. The optimum viewing angle is from 10° - 30° downward from the horizontal. In moving vehicles at least 15° downward vision is desirable. (HIAD specifies a minimum of 11° downward clearance for forward vision from cockpits.)[65]



The most important displays should be located at the eye-level of the small (5th percentile) operator. If additional vertical room is needed for displays, the location may be raised to the eye-level of the average (50th percentile) operator.

The dimensions for eye-height shown in the following table are representative of Air Force flying personnel. If the designer is to use these dimensions, he must be certain that they also represent the group for whom he is designing the workplace.[29]

DIMENSION	HEIGHT (INCHES)*		
	5th Percentile	50th Percentile	95th Percentile
Standing eye height**	60.7	64.6	68.5
Sitting eye height***	27.4	29.5	31.5

*These data have been corrected, as follows:

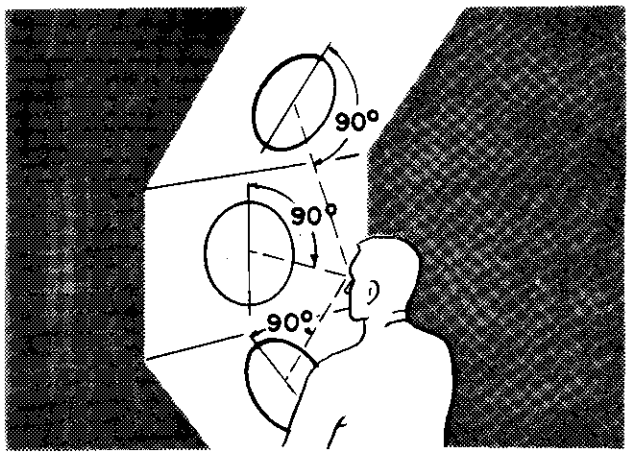
Average shoe height: +1.1 inches
Normal slump while standing: -1.2 inches
Normal slump while sitting: -2.0 inches

**Measured from the floor.

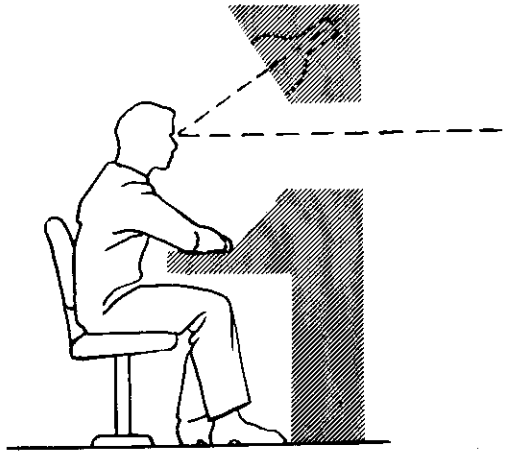
***Measured from a horizontal seating surface.

Note: A correction for clothing is not included because of wide variations in thickness and compressibility.

c. Cathode-ray tubes may be mounted in any location provided that the scope face is perpendicular to the operator's line of sight and that the display falls within the maximum visual area.[5, 60]



Cathode-ray tubes should not be mounted above the standard line of sight except when used for brief monitoring operations.[5]



Note: The above recommendations refer only to displays and not to controls, which should be located in the manual areas.

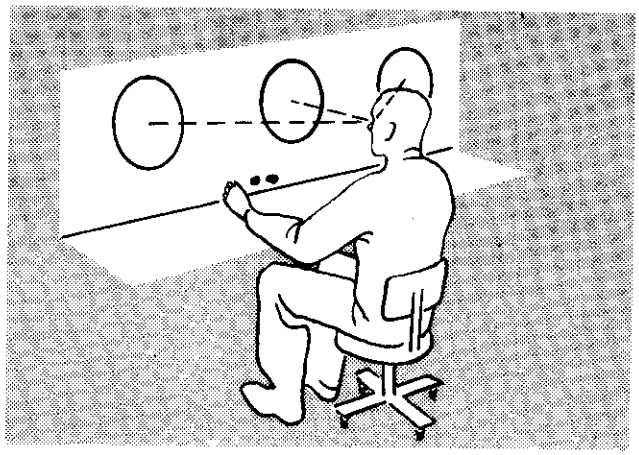
2.6.2 Shape of Panels*

The general shape of panels may be flat, curved or sectional;[32, 52]

*This section refers only to panel surfaces designed for a single operator. Workplace layout for team operation is not covered in these sections.

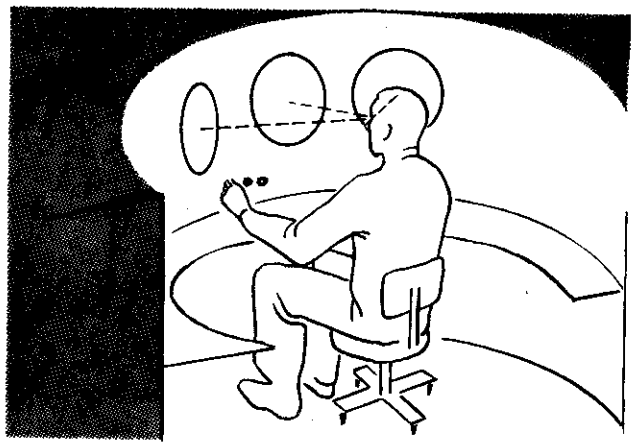
a. flat surface

Easy to construct but poorest to use when the panel is large. In the latter case, the outer edges may be beyond the maximum visual and manual dimensions, or the center of the panel may be too close to the operator (less than the minimum visual and manual dimensions).



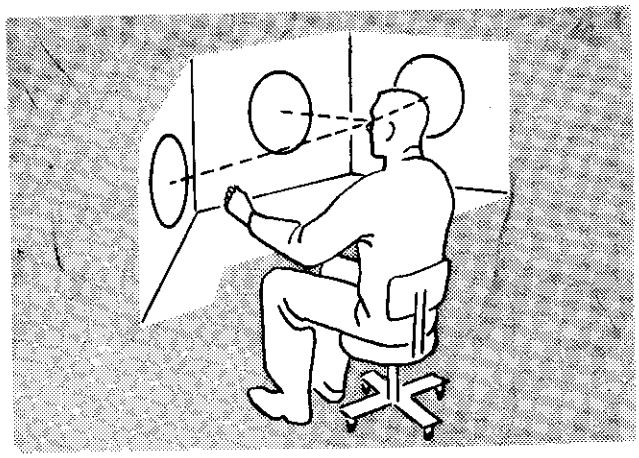
b. continuous curved panel

Difficult to construct but theoretically the best to use. It may be designed so that all points are within the limiting manual dimensions and all surfaces are perpendicular to the line of sight.



c. sectional panel

Panel in which several flat surfaces are mounted at appropriate angles. Easy to construct and has most of the advantages of a continuous curved panel.



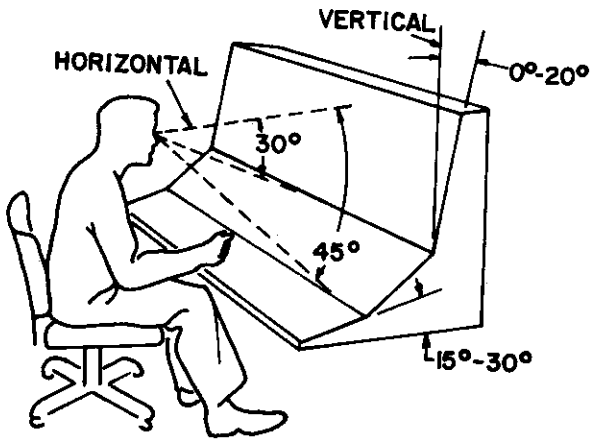
2.6.3 Contour of Panels

Note: The following recommendations apply only when the operator is standing or is seated with his back rest tilted from 0° (upright) to 20°.

The following method for designing panel contours is one of several which will aid the designer in determining the proper size, shape and slope of panels. In this method the contour of every panel, whether flat or sectional, is studied in three sections:

a. upper section

Vertical to 20° from the vertical, its lower edge being no more than 30° below the horizontal line of sight. This is the recommended instrument panel location and should be used primarily for displays. If direct vision to the outside or beyond the panel is required, the upper portion of this section must be omitted (see page 50). Controls can be located in this section if they are within reach, but should be restricted to instrument set-up or adjustment controls.



b. middle section

Slanting from 30° to 50° from the horizontal and extended downward to a maximum of 45° below the horizontal line of sight. This section should be used generally for displays and their associated controls. Controls located in this section should lie within the optimum manual area.

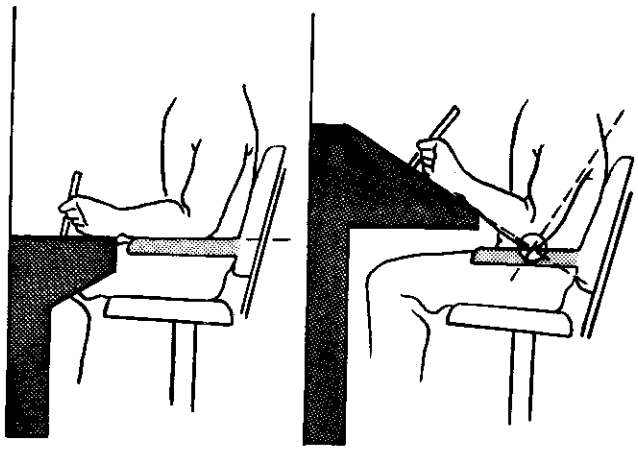
c. lower section

Slanting from 15° to 30° from the horizontal and extended from the middle section to the near limits of the optimum manual area. This section should be used for controls and miscellaneous equipment. As much of it as possible should lie within the optimum manual area.

The vertical edge of the panel nearest the operator is a recommended location for set-up and adjustment controls, light switches and other controls which are seldom used other than at the start or finish of the operating period. This surface can be recessed to safeguard against inadvertent operation.

2.6.4 Arm Rests

The operator's arm should be supported so that it lies in the same plane as the lower section of the panel. This will support the arm without forcing the operator to raise or depress his shoulder. Support may be provided either by the panel itself or by a special arm rest.



2.6.5 G-Forces [51]

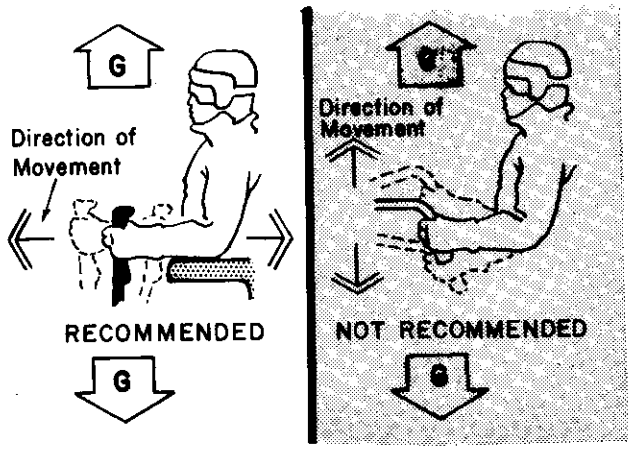
Note: The following statements apply only to the seated and supine positions. The standing position cannot be used when the operator is subjected to abnormal g-forces.

Controls which must be used while the operator is subject to acceleration forces above 2 g* should be placed so that:

a. The operator's limb is always in contact with the control, i.e., no reaching is required.

b. As many controls as possible are assigned to each limb. This is best accomplished by use of combined controls (several control functions mounted on a single shaft) so that movement from one control to another is avoided.

c. Linear controls operate perpendicularly to the direction of g-forces. This eliminates the necessity for the operator to compensate for g-forces acting along the line of control movement. When rotary control movements are made, limbs are least affected by g-forces.



*This applies to the relatively prolonged g-forces in one direction found in aircraft during sharp turns or pull-outs as well as the sudden changes in g-forces (jouncing, pitching) encountered in trucks, tanks, small naval craft, etc.

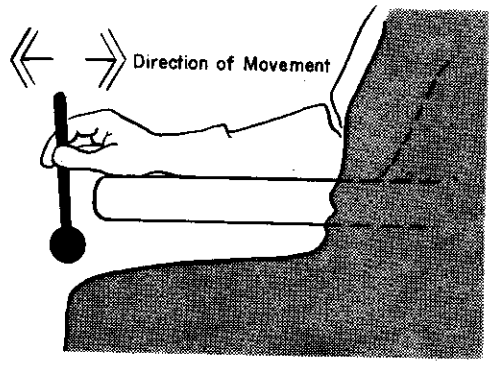
d. For hand controls, when the shoulder, elbow, forearm and wrist are supported:

Arm movements can be made up to 4 g.

Forearm movements can be made up to 4-5 g (up to 8-9 g if the arm is counterbalanced).

Hand movements can be made up to 8 g.

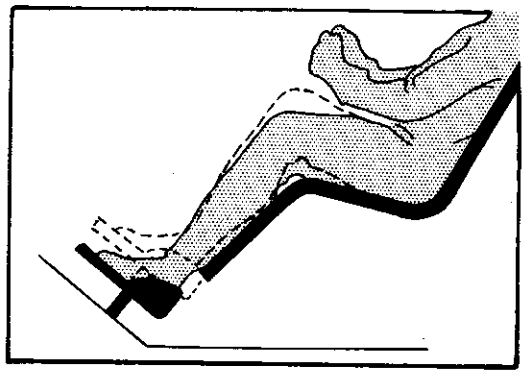
Finger movements can be made up to 10 g.



e. For foot controls, when the thigh, lower leg and heel are supported:

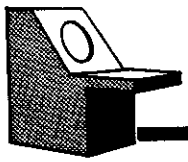
Lateral leg movements can be made up to 4 g.

Vertical, up-down leg movements can be made up to 2-3 g.



PART 3

LOCATION OF CONTROLS AND DISPLAYS



This part deals with the placement of individual controls and displays within the general spaces allotted to them. Four major factors will be considered:

3.1 Priority: assigning the most important controls and displays to the optimum areas (as determined in Part 2).

3.2 Grouping: organizing controls and displays into logical units.

3.3 Association: establishing a correct and consistent relation (correspondence) between each control and its related display.

3.4 Spacing: providing proper separation between controls.*

The rules presented in this part should aid the designer in establishing an optimum arrangement of controls and displays. After this layout has been established, it should, as far as possible, be used throughout the system and in all subsequent models of the same system.

These rules are general ones and cannot be expected to apply explicitly to all cases. In the event that two rules conflict with each other, the designer must determine a compromise based primarily upon the needs (or specific requirements) of the system being designed.

3.1 ESTABLISHING PRIORITY POSITIONS

3.1.1 Procedures

Analyze how the control or display is used by the operator and what its ultimate effect is upon system performance. Its priority may be measured in various ways. The most common ways involve determining one or more of the following:

*Recommended spacing of displays is covered elsewhere.

a. The frequency and extent of use of the control or display.

b. The accuracy and/or speed with which the display must be read or the control positioned.

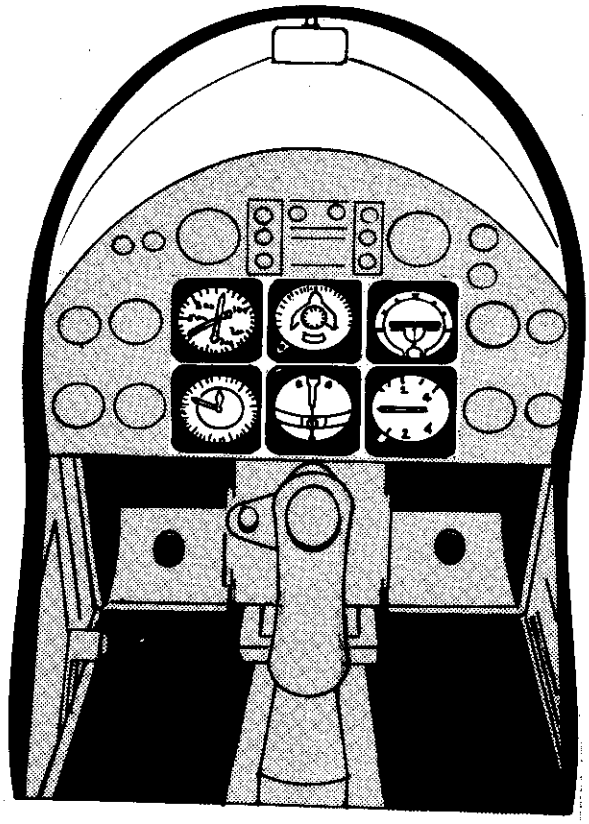
c. The decrease in system performance and/or safety resulting from an error or delay in using the control or display.

d. The ease of manipulating certain controls (in terms of force which can be applied, precision and speed of adjustment) in various locations.

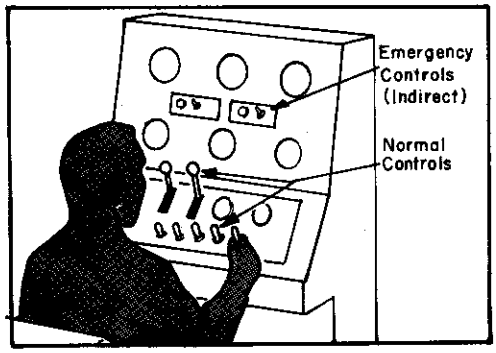
3.1.2 Rules[63]

a. Primary (highest priority) controls and displays should be placed within the optimum spaces (as defined in Part 2).

Example: At the pilot's position, primary flight instruments should be placed in the optimum visual area (center of the panel directly below the windscreen); primary flight controls should be in the optimum manual and pedal areas.



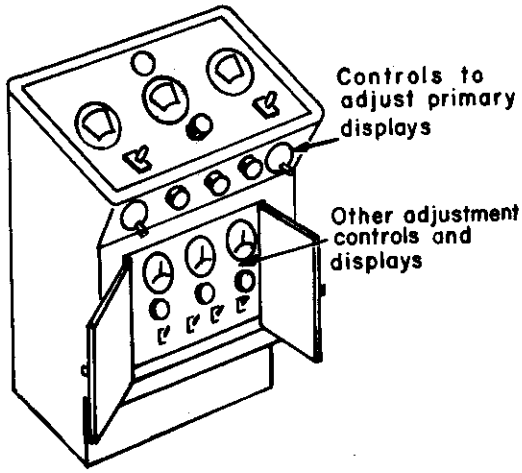
b. Emergency controls and displays should be placed in readily accessible positions. (See 1.3 for detailed information.) Emergency controls and displays will not usually be located in the optimum areas in preference to primary controls and displays. In some systems, however, the nature of an emergency is so critical that emergency equipment should be given top priority in location.



c. Secondary controls and displays (less important than primary ones but still used periodically during normal operations) should be placed within the limiting areas but not necessarily within the optimum areas. Their exact location should be determined primarily by proper grouping and associations (see Sections 3.2 and 3.3). Standardization is essential whenever a large number of such controls and displays must be used by one operator.

Example: On the pilot's panel of a single engine aircraft, such instruments as the tachometer, fuel flowmeter and fuel quantity gauge may be located anywhere around the primary instruments so long as these positions are consistent from one model of aircraft to another.

d. Set-up and calibration controls (which are used infrequently before the operator begins his primary tasks or during any convenient slack period) and their associated displays should normally be given lowest priority in assigning locations. They may be located outside of the operator's normal workplace unless they are used with other controls or displays.

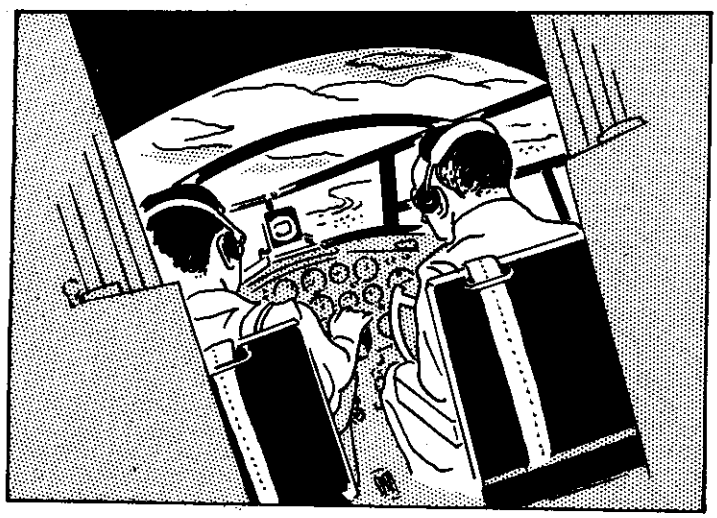


e. The shared use of controls and/or displays by more than one operator requires special consideration:

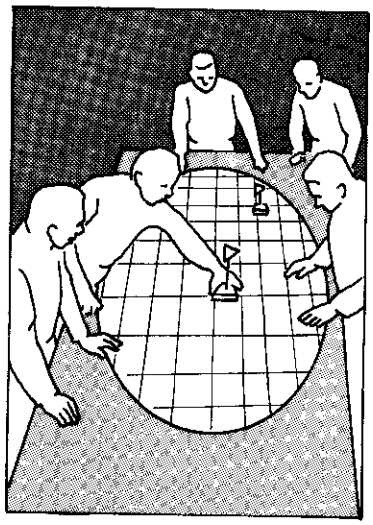
1) If primary controls or displays must be used by more than one operator, duplicate sets should be provided wherever there is adequate space; otherwise, controls or displays should be centered between the operators.

2) If secondary controls or displays must be used by two operators, they should be placed between the operators. If they are of equal importance to two operators, they should be centered between them; if they are more important to one operator, they should be nearer him.

3) Whenever direction-of-movement relationships are important and controls or displays must be shared by more than one operator, the operators should all face in the same direction.



4) When direction-of-movement relationships are unimportant, operators need not all face in the same direction.



3.2 GROUPING CONTROLS AND DISPLAYS

3.2.1 Procedures

There are two general ways of grouping--both should be followed whenever possible:[52]

a. functional grouping

Group together all controls or displays which are:

1) Identical in function (e.g., throttles).

2) Used together in a specific task (e.g., switches for arming a gun).

3) Related to one system component (e.g., all controls and displays pertaining to engine No. 1).

b. sequential grouping

Group together and arrange in normal order of use:

1) Controls which are operated in sequence (e.g., switches used in starting engines).

2) Displays which are observed in sequence (e.g., meters on an electrical distribution panel).

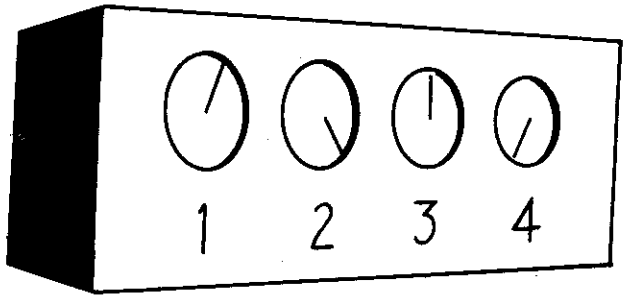
3.2.2 Rules

a. Displays should be grouped so as to facilitate check-reading.

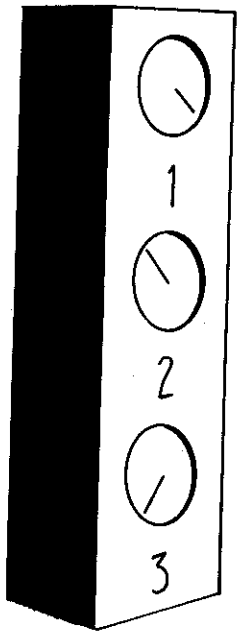
b. When displays are used sequentially:[62]

1) Displays should be aligned so that they are viewed in the following sequence:

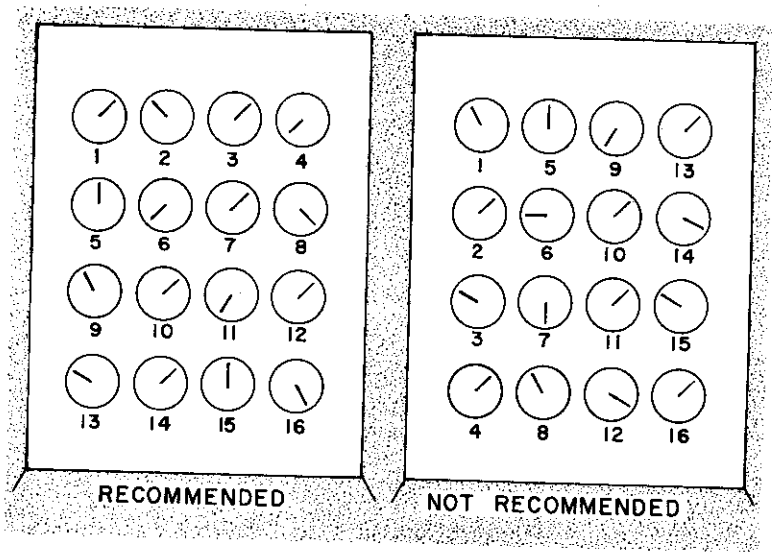
Horizontally: from left to right



Vertically: from top to bottom



Rows: from top row to bottom row and from left to right within a row



2) They should be grouped as close together as possible.

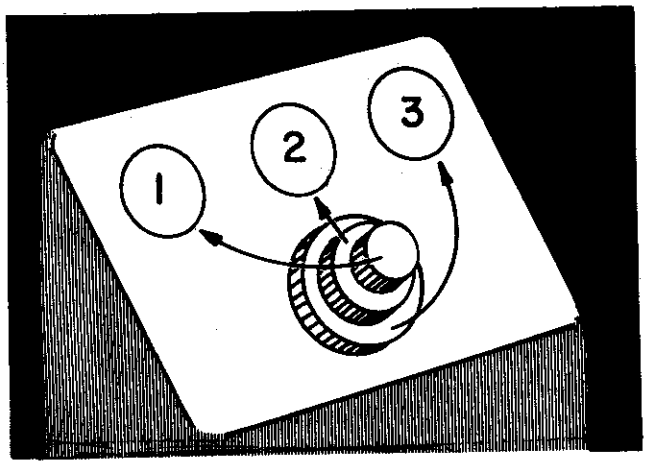
3) The direction in which they are aligned (horizontally, vertically or in rows) should be determined primarily by the correct control-display association (as covered in Section 3.3).

4) Unless important control-display associations are violated, the displays should be aligned horizontally provided they do not extend beyond the visual area. If a large number of displays must be viewed in sequence, they should be arranged in rows rather than columns.

c. When controls are used sequentially by the same hand, they should be arranged so that the operator moves his arm horizontally from one to the next (provided that control-display and/or control-component locations do not result in violations of associations, as covered in Section 3.3).[6]

d. When controls which are used sequentially cannot be aligned horizontally, they should be arranged in some other systematic manner, such as vertically from top to bottom.

e. When concentric (ganged) knobs are used sequentially, the front (smallest) knob should be used first, the back (largest) knob last.



Caution: Grouping of controls should not interfere with the division of major tasks among the various limbs of the operator.

3.3 ASSOCIATING CONTROLS AND DISPLAYS

3.3.1 Purposes

Whenever an operator must use a large number of controls and/or displays, their location and arrangement should aid him in determining:[19, 43]

a. Which controls are used with which displays.

b. Which equipment component each control affects.

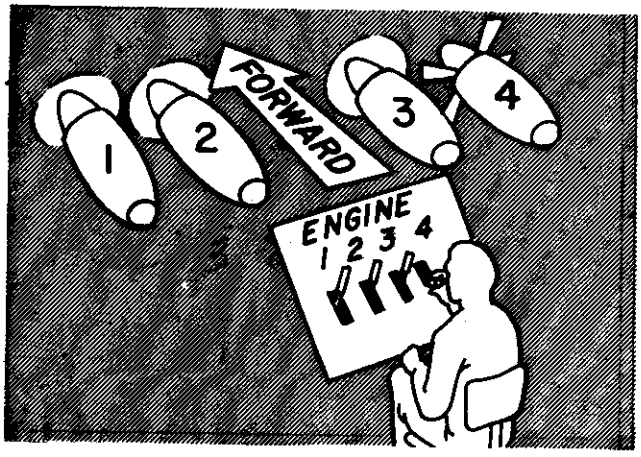
c. Which equipment component each display describes.

3.3.2 Rules

a. When a group of equipment components has the same function (e.g., the four engines of a multi-engine aircraft), the positions of the related (associated) controls and displays depend upon the direction the operator faces (relative to the normal direction of movement of the vehicle):

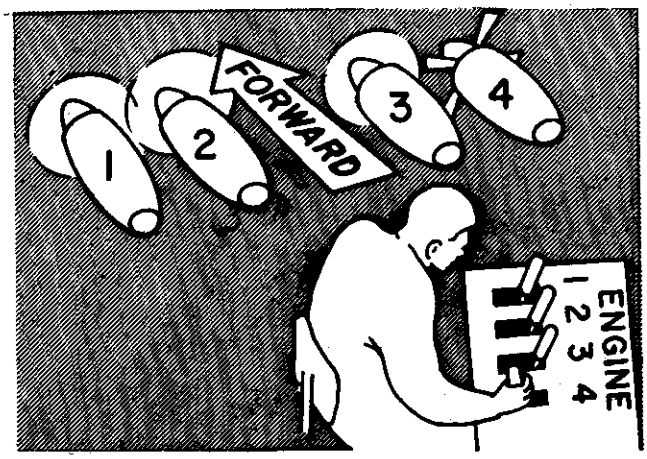
1) If the operator of a vehicle normally faces in the direction in which the vehicle moves: the positions of the controls and displays should correspond with the spatial orientation of their associated equipment components.

Example: The displays for each engine should be arranged from left to right to represent engines No. 1-4.

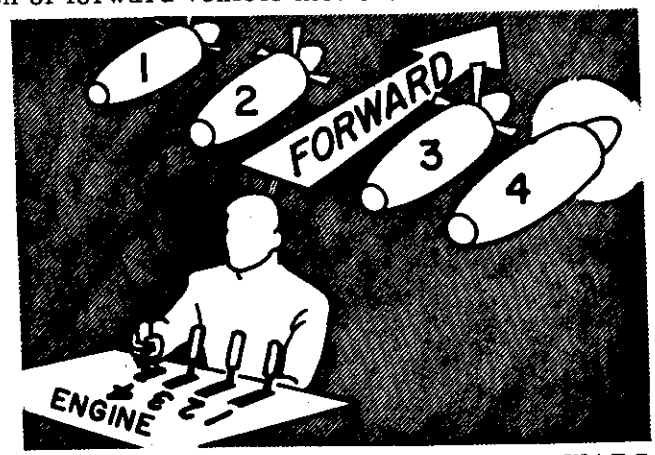


2) If the operator of a vehicle normally faces sideward: Controls and displays may be located in front of or on either side of the operator. When equipment components are arranged from left to right in the vehicle, their associated controls and displays should be located such that their arrangement would correspond spatially to their associated equipment components if both operator and panel were rotated to face in the direction of forward vehicle motion. When equipment components are arranged from front to rear in the vehicle, their associated controls and displays should be arranged to correspond spatially to their equipment components (without "rotating" operator and panel).

Example: The displays for each engine should be arranged from left to right as the operator faces them to represent engines No. 1 through 4.



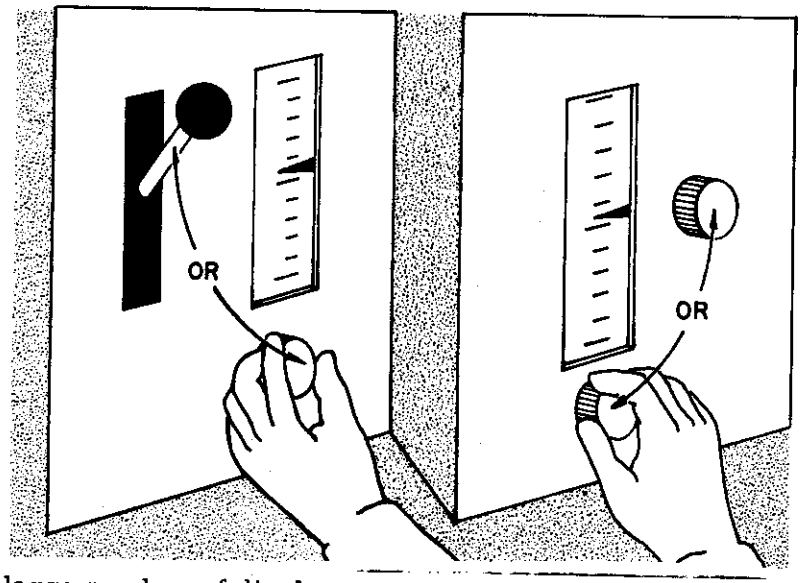
3) If the operator of a vehicle normally faces rearward: He should not control equipment components which have definite spatial orientations. However, if he must control equipment components which are arranged from left to right in the vehicle, the arrangement of controls and displays should be such that they would correspond spatially to their associated equipment components if both operator and panel were rotated to face in the direction of forward vehicle motion.[61]



b. When a control is always associated with a specific display, the control should be located so that the operator's hand does not block the display from sight.

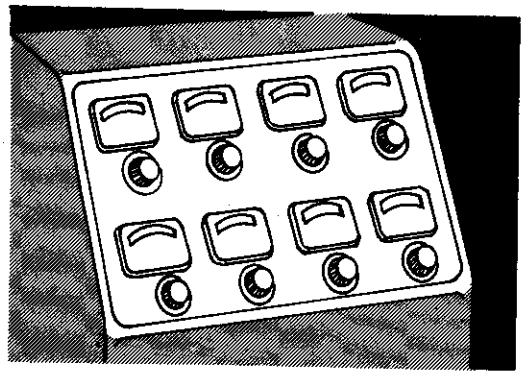
1) Controls operated by the right hand should be located below or to the right of their associated displays.

2) Controls operated by the left hand should be located below their associated displays. They may also be located to the left of their displays provided that direction-of-movement relations (see Part 4) are not violated.

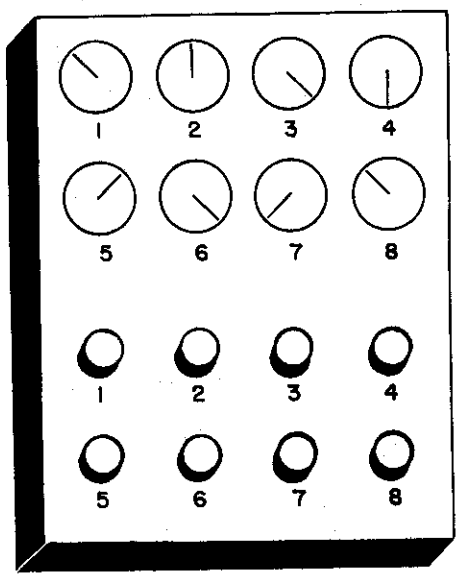


c. When a large number of displays are on the same panel, they should normally be arranged in either of the following two ways:[43]

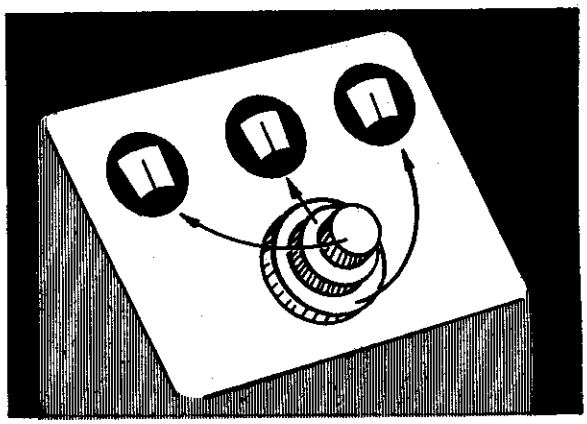
1) Each display directly above its associated control. All control-display combinations must be located close together so that wrong associations are not made (e.g., controls should be associated with the displays above them, not below them).



2) All displays in the upper portion and all controls in the lower portion of the panel. Each control occupies the same relative position as its associated display.*

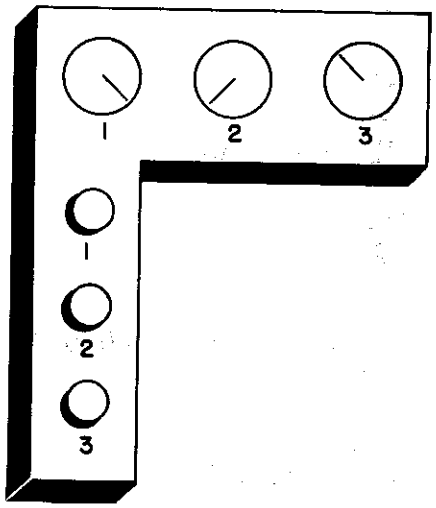


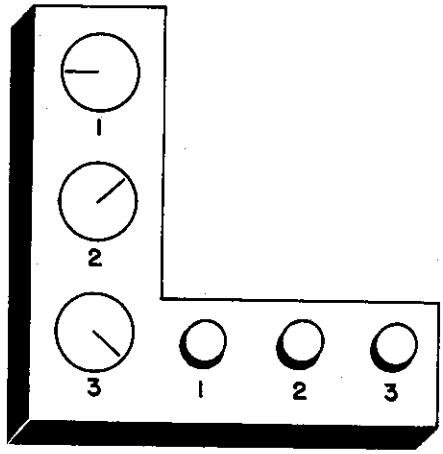
d. When concentric (ganged) knobs must be associated with displays, the displays should be arranged in a row from left to right: the front (small) knob controlling the left display, the middle knob the middle display, the back knob the right display.[11]



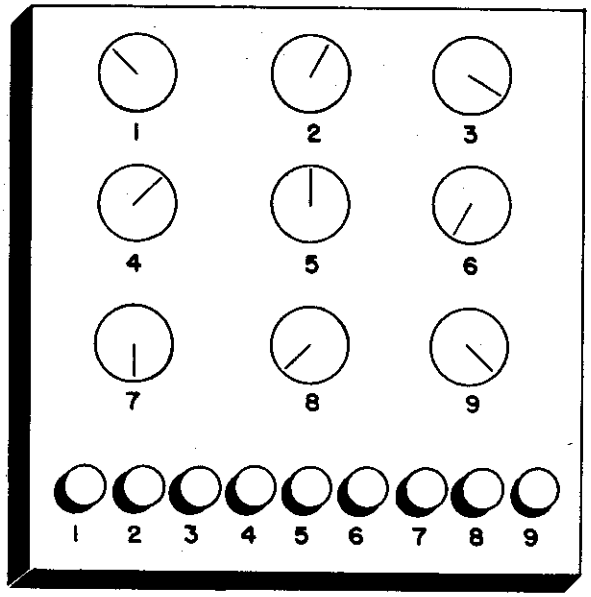
*Any rearrangement which changes the relative positions among controls or among displays (such as that resulting from reversing the positions of two controls) will seriously degrade operator performance. Such a change can result in a four-fold (or more) increase in both time and errors in selecting the proper control for a given display, either for skilled or unskilled operators.[43]

e. When rows of displays must be associated with columns of controls, and vice versa, left should correspond with top, and right with bottom. However, these arrangements should be avoided if possible.



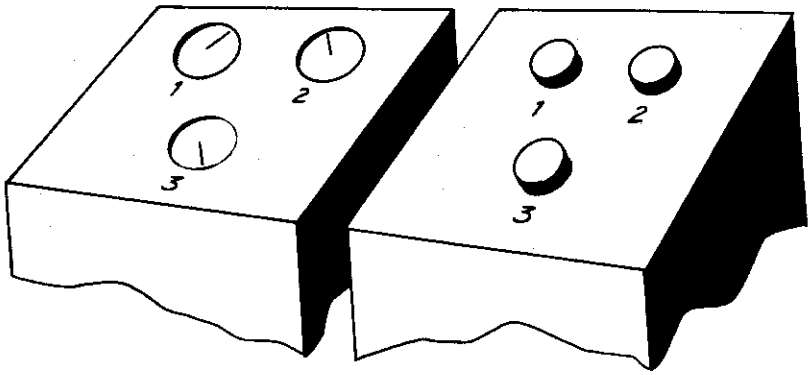


f. When two or more rows of displays must be associated with one row of controls, and vice versa, the general arrangement shown to the right should be used.

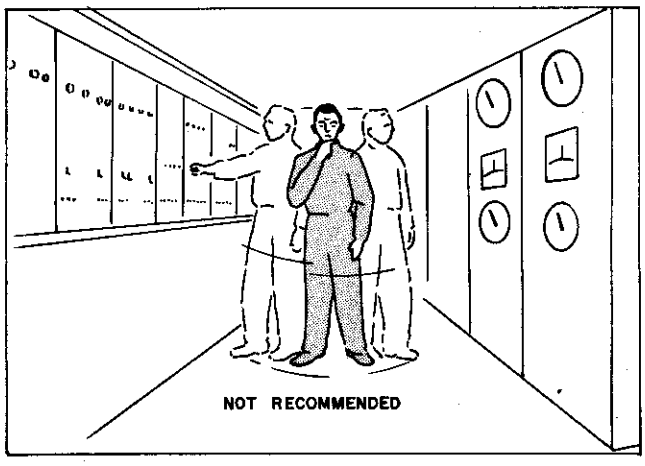


g. When all controls are on a control panel and their associated displays are on a display panel, good control-display associations can still be maintained:

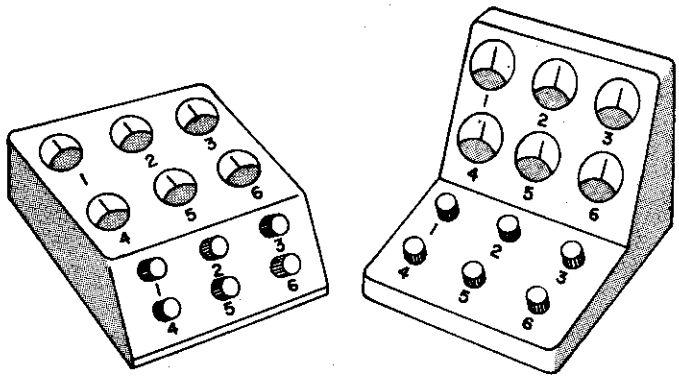
1) When both panels are mounted at approximately the same angle relative to the operator, the controls on one panel should occupy positions corresponding to those of their associated displays on the other panel.



2) The two panels should never face each other.



3) When one panel is at (or near) the horizontal and the other panel is at (or near) the vertical, the general arrangement shown here should be used.



3.4 SPACING BETWEEN CONTROLS

3.4.1 Factors Affecting Spacing

In determining the proper spacing between controls within a given area, the following factors should be considered:

a. Simultaneous use of controls.

b. Sequential use of controls.

c. Body part being used.

d. Size of control and amount of movement (displacement or rotation).

e. Need for "blind reaching" (i.e., being able to reach for and grasp the control without seeing it).

f. Effects upon system performance of inadvertently using the wrong control.

g. Encumbrances--pressure suits, gloves, boots, etc.

3.4.2 Rules

a. Foot controls should normally be spaced further apart than hand controls.

b. When blind reaching may be required, there should be greater separation between controls than when the operator looks at the control.[18]

c. When the effect of inadvertently using a wrong control (among several) is serious, the several controls should be widely separated.

3.4.3. Recommended Distances Between Controls

The specific distances separating controls is so much a function of the task being performed (and the space available) that rigid adherence to a single set of specifications is inadvisable. Minimum and desirable values are offered as guides.

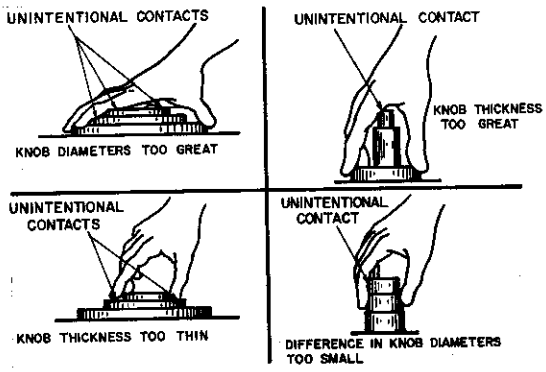
Minimum: The least acceptable distance between adjacent controls when the operator is in a stationary workplace with good environmental conditions and when controls are placed within the optimum manual (or pedal) areas.

Desirable: The preferred distance between adjacent controls which either are operated intermittently or are in a moving vehicle where the operator is subjected to jolting, vibration, etc.

Table IV presents recommended separations for various conditions of use. Unless stated otherwise, separations are measured between adjacent edges of two controls, regardless of control size.

Caution: If the operator is wearing gloves, heavy shoes, a pressure suit, or any other type of clothing which interferes with his movements, the specified separation between controls may have to be increased.

To conserve limited panel space, or aid in sequential operations, two or three knobs may be mounted on concentric shafts. Chances of accidental operation are increased if either the knob diameters or thicknesses are too large, too small, or differ by too small an amount. The drawing below (right) shows recommended dimensions for concentrically mounted knobs when accidental operation must be strongly guarded against.[11]



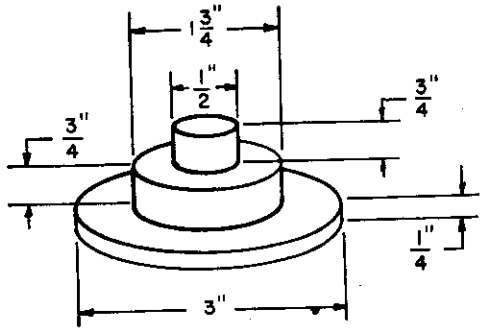
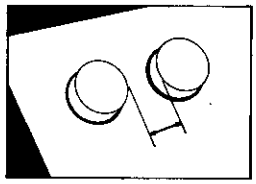
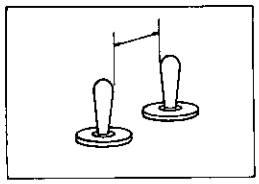
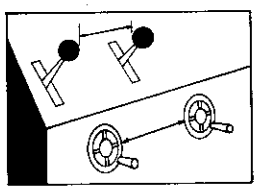
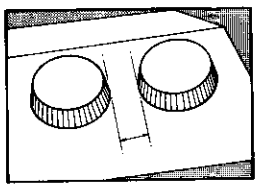
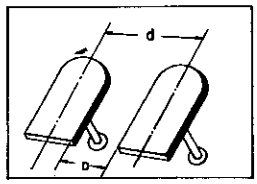
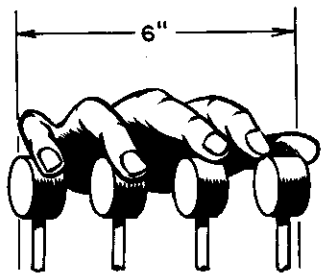


TABLE IV

Recommended separation between controls

CONTROL	TYPE OF USE	MEASURE OF SEPARATION	RECOMMENDED SEPARATION Minimum	Desirable
Push button	One finger--randomly*		1/2"	2"
	One finger--sequentially		1/4"	1"
	Different fingers--randomly or sequentially		1/2"	1/2"
Toggle switch	One finger--randomly*		3/4"	2"
	One finger--sequentially		1/2"	1"
	Different fingers--randomly or sequentially		5/8"	3/4"
Cranks and levers**	One hand--randomly*		2"	4"
	Two hands--simultaneously		3"	5"
Knobs	One hand--randomly*		1"	2"
	Two hands--simultaneously		3"	5"
Pedals***	One foot--randomly		a = 4"	6"
			b = 8"	10"
	One foot--sequentially		a = 2"	4"
			b = 6"	8"

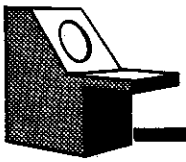
*When finger- or hand-operated controls are used randomly and are "blind positioned," they should be separated by at least 5 inches when mounted in the optimum manual area. This separation should be progressively increased to 12 inches as the location of the control approaches the periphery of the limiting manual dimensions.[18]



**When a group of levers are used simultaneously by the same hand, their maximum separation should be 6 inches or less.

***Either dimension a or dimension b should be met, preferably a.

PART 4



DIRECTION-OF-MOVEMENT RELATIONSHIPS

The direction in which a control should move is discussed in this part. In order to be correct, the direction of movement of the control must be related appropriately to the change which it induces in its associated display, equipment component and/or the system as a whole. Correct direction-of-movement relationships will improve system performance in:[1, 21, 57]

a. Precision of control adjustment.

b. Correctness of initial control movements (i.e., reducing movement in the wrong direction, called reversal error).

c. Speed of reaction or decision time.

d. Speed of control adjustment.

e. Speed of learning.

These improvements are relatively unimportant if the operator has a simple repetitive task. Their importance increases directly with:[3, 36, 37, 48, 53, 54, 55]

a. Task complexity.

b. Discontinuity or number of interruptions in the control sequence.

c. Degree of stress or anxiety.

The direction-of-movement relationships recommended here are made to satisfy one or more of three basic requirements:

a. Natural relationships.*

b. Existing design practice.

c. Standardization and consistency.

*Natural relationships refer to control movement habit patterns which are consistent from person to person without special training or instructions, i.e., they are responses which individuals make most often and are called "population stereotypes." For example: an upward movement of a toggle switch is almost always related to "on" as opposed to "off."[2, 4, 40]

4.1 GENERAL RULES

The following general rules are applicable in all situations:

a. The direction of movement of the control must be considered in relation to all of the following factors:[4, 40]

1) Operator position: His location and orientation relative to the control and to the moving vehicle.

2) Display position and response: The position of the display relative to the control; the nature and direction of the display response.

3) Equipment component response: The change exhibited by an equipment component as a result of the control movement--either in terms of motion for moving components (landing gear, gun turret, etc.) or in terms of power for stationary components (volume of a radio receiver, brightness of a radar scope, etc.).

b. Control movements should be consistent for all the equipment which one operator uses.[16, 22, 42, 58]

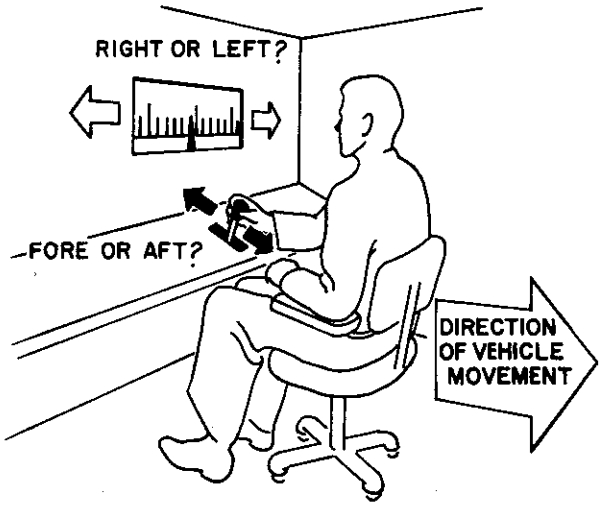
c. Controls and displays should be placed in front of the operator whenever possible.

d. The direction of movement of controls and displays should be related to the purpose underlying each control movement rather than to any particular mechanism or method of actuation used to perform the desired function.

> Example: If the operator wishes to lower temperature, opening a vent which will admit cool air or closing a vent which has been admitting hot air need not by itself be related to the control movement. The control movement should be related to the basic purpose: to raise temperature (upward movement, clockwise movement, etc.) or to lower temperature (downward movement, counterclockwise movement, etc.).

e. Direct movement relationships should be used whenever possible, particularly when they result in vehicle movement. Thus, a movement of the control to the right should result in a movement to the right of an instrument pointer, a right turn or right bank of the vehicle, etc. Recommended direct relationships are shown in Table V.[56, 57, 58]

f. Controls which are related to the direction of movement of the vehicle in which they are mounted should not be located so that the operator must face rearward to use them. In such situations, motion relationships are ambiguous with respect to left-right, clockwise-counter-clockwise and forward-rearward.



NOT RECOMMENDED

1) Operator inside a vehicle and controlling its direction of movement: He should face in the direction in which the vehicle normally moves.

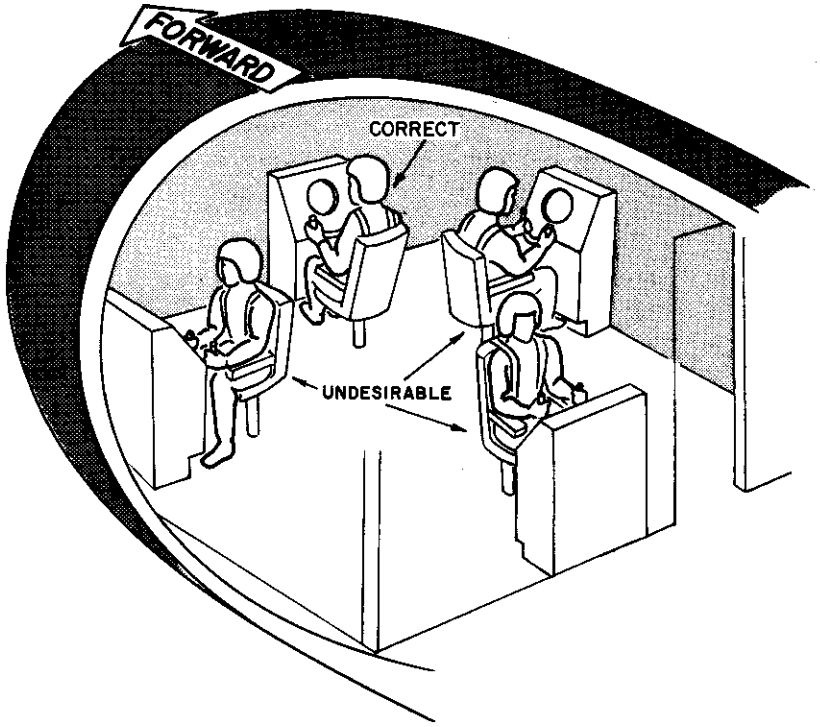


TABLE V

Recommended relationships between control and system

CONTROL MOVEMENT	SYSTEM (OR EQUIPMENT COMPONENT) RESPONSE — DIRECTIONAL: UP	RIGHT	FORWARD	CLOCKWISE	NON-DIRECTIONAL: INCREASE *
UP	RECOMMENDED	NOT RECOMMENDED	CONDITIONALLY RECOMMENDED	NOT RECOMMENDED	RECOMMENDED
RIGHT	NOT RECOMMENDED	RECOMMENDED	NOT RECOMMENDED	CONDITIONALLY RECOMMENDED	RECOMMENDED
FORWARD	SEE SECTION 4.2.4	NOT RECOMMENDED	RECOMMENDED	NOT RECOMMENDED	RECOMMENDED
CLOCKWISE	SEE SECTION 4.2.1	SEE SECTION 4.2.1	SEE SECTION 4.2.1	RECOMMENDED	RECOMMENDED

*Increase refers to increase in power output, brightness, rpm, etc., and to "on" or "start" as opposed to "off" or "stop."

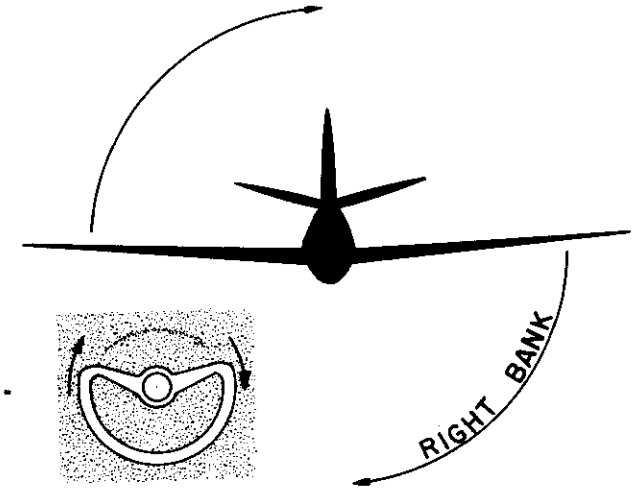
2) Operator inside a vehicle but not controlling its direction of movement: Direction-of-movement relationships are not affected by the orientation of the operator.

3) Operator controlling the direction of movement of a vehicle from a remote control station: He may face in any direction; however, he should mentally orient himself as if he were in the vehicle facing in the direction in which the vehicle is moving.

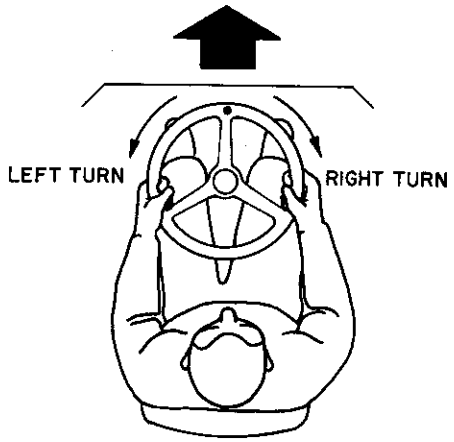
4.2 SPECIFIC RECOMMENDATIONS

4.2.1 Rotary Controls: Operator Orientation

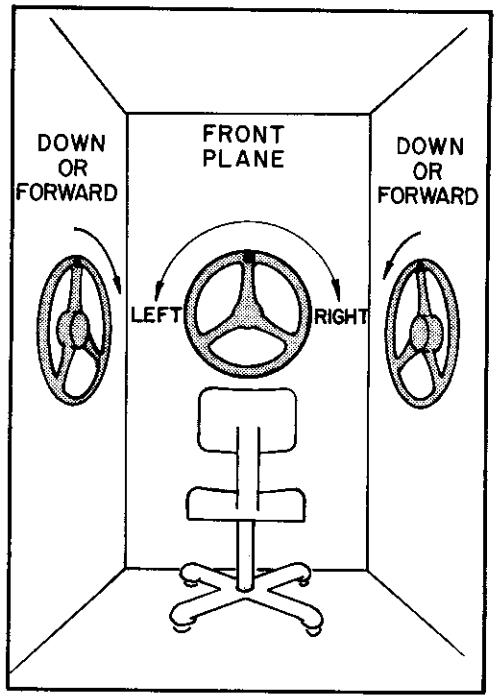
a. In using rotary controls, the operator orients himself with a certain point on the control; he perceives the control as moving in the direction which this point is moving. When the control affects the direction of movement of a vehicle, the point of the control with which the operator is oriented should move in the same direction as the desired direction of the vehicle.



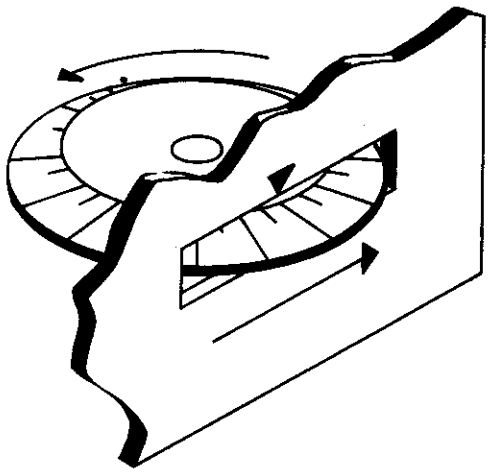
1) With rotary control movements in a horizontal plane: The operator orients himself with respect to the forward point of the control.



2) With rotary control movements in a vertical plane: The operator orients himself with respect to the top of the control.



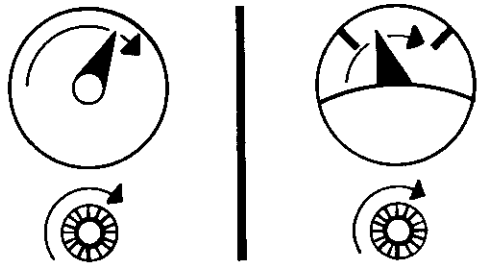
3) With a rotary control which is largely concealed: The operator responds to the exposed portion of the control as if it were a linear control.



b. The axis of rotation for the control should parallel the corresponding axis of rotation of the vehicle (provided the resulting control movements do not cause undue operator discomfort).

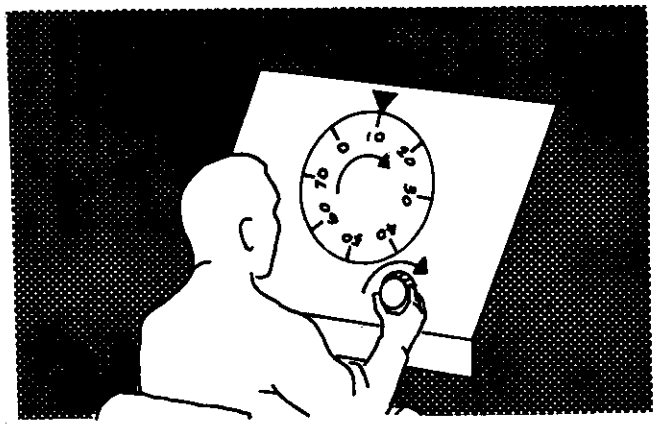
4.2.2 Rotary Controls: Use With Rotary Displays

a. When the display has a moving pointer and a stationary dial, a clockwise rotation of the rotary control should result in a clockwise rotation of the pointer.[34, 49, 57]

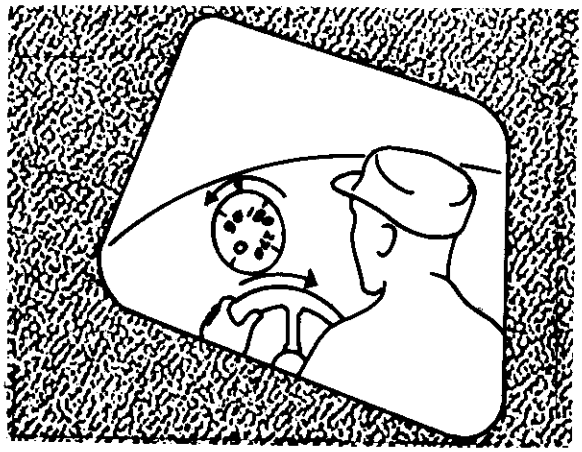


b. When the display has a moving dial and a fixed pointer or lubber line, it will usually cause direction-of-movement inconsistencies and should be replaced, when feasible, by a fixed dial and moving pointer. If it cannot be replaced, the following is recommended for the case where the indicator (pointer) is fixed at the 12 o'clock position:[11]

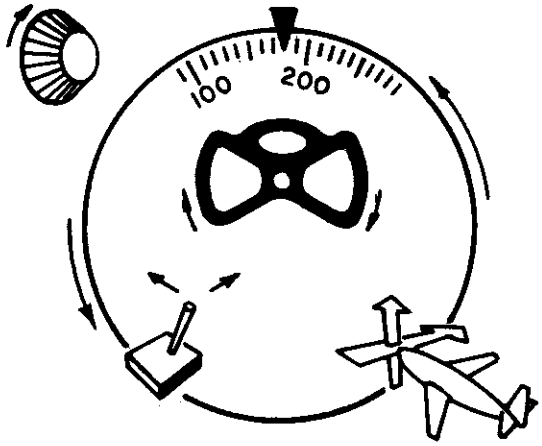
If the control-display combination is not related directly to the movement of the vehicle and if the operator always views the display when operating the control, scale numbers on the display should progress in a clockwise direction, and a clockwise rotation of the control (decrease) should result in a clockwise rotation of the display.



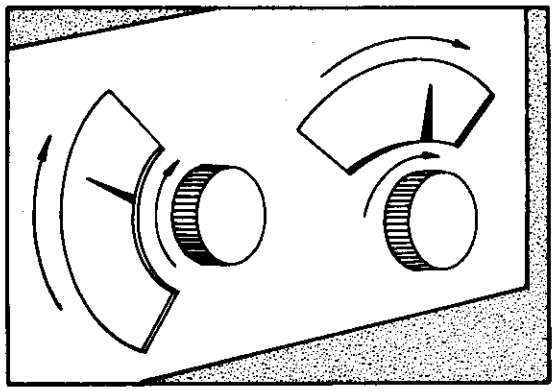
If the control directly affects the movement of the vehicle and if the operator does not view the display when operating his control, scale numbers on the display should progress in a clockwise direction, and a clockwise movement of the control (increase) should result in a counterclockwise movement of the display.



Note: If the associated control has a direct effect on the behavior of the vehicle (speed, direction, etc.) the scale should rotate counterclockwise (increase) with 1) clockwise movement of the associated knob, wheel, or crank; 2) movement forward, upward, or to the right of a lever; or 3) movement forward, upward, or to the right of the vehicle or component. Because of these ambiguities it is recommended that a moving pointer indicator be used for flight indications.[5, 33]

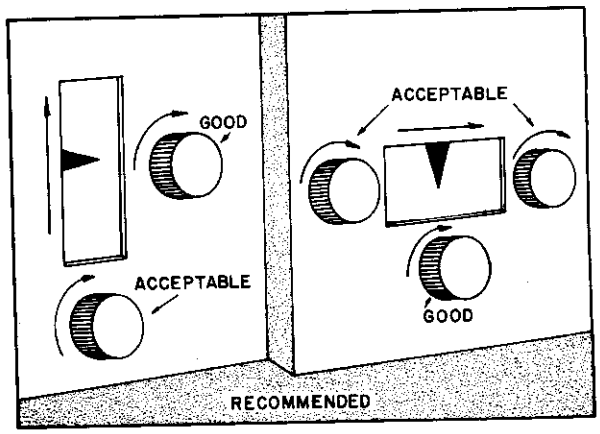


c. A rotary control should be on the concave side of a rotary display when the display movement traverses less than a full circle.[50, 56, 58]

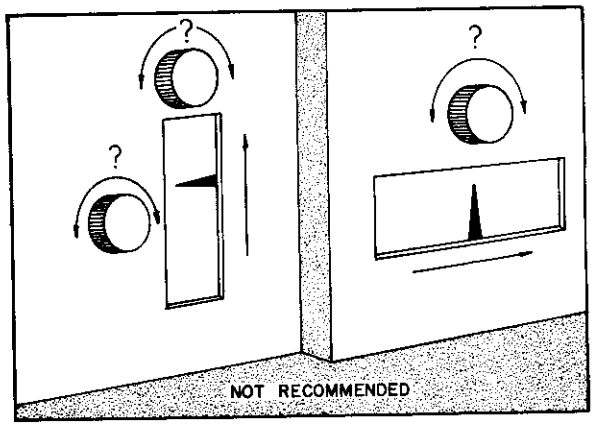


4.2.3 Rotary Controls: Use With Linear Displays

a. When a rotary control and a linear display are in the same plane, the part of the control adjacent to the display should move in the same direction as the moving part of the display.[20, 23, 24, 57]



b. A rotary control should not be placed above any display or to the left of a vertical display. This avoids conflict between principle (a) above and the principle that a clockwise control movement should result in either an upward or rightward pointer movement.[50, 56]



4.2.4 Linear Controls: Forward Movements

a. A forward control movement is generally associated with "increase" or "raise" as opposed to "decrease" or "lower."[1, 26]

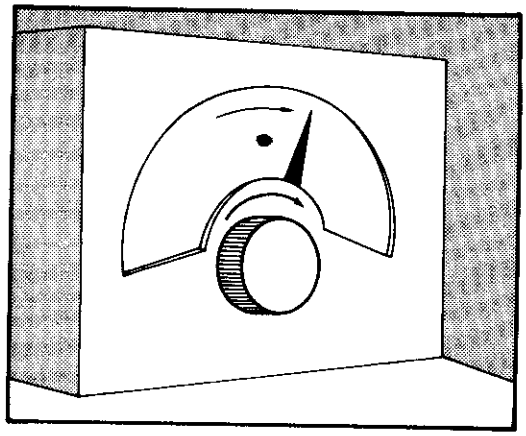
b. In aircraft, forward movement of the yoke or stick causes a nose-down movement of the vehicle and a downward or counterclockwise movement in associated displays. This particular reversal of normal control-display-system relationships may be continued for aircraft because it conforms with current standards.

4.2.5 Linear Controls: Use With Rotary Displays

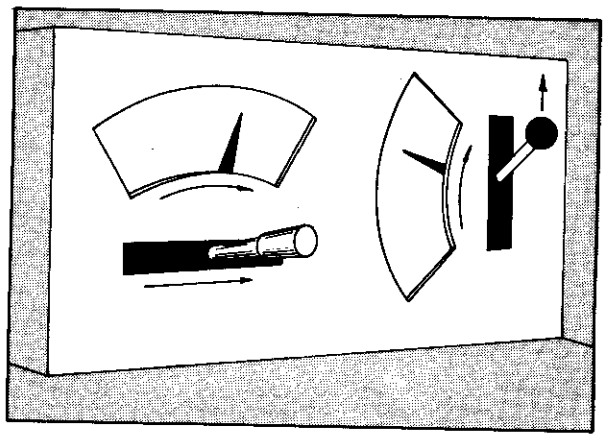
a. When there is no direct linkage between control and display (e.g., the joystick of an aircraft is not directly linked with the altimeter), a linear control may be used with a rotary display.

b. When there is a direct linkage between control and display (e.g., the frequency selector knob of a radio directly affects the pointer indicating each station):

1) If the indicator moves through an arc of more than 180°, a rotary control should be used.



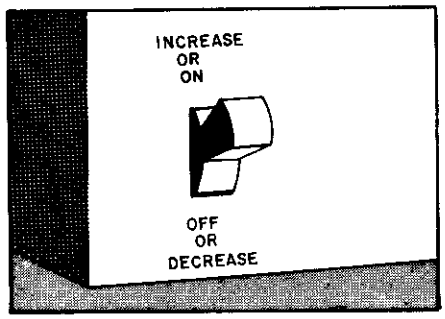
2) If the indicator moves through an arc of less than 180°, a linear control may be used provided the path of control movement parallels the average path of the indicator movement (i.e., is parallel to the chord subtending the entire arc of indicator movement) and the indicator and control move in the same relative direction.[57]



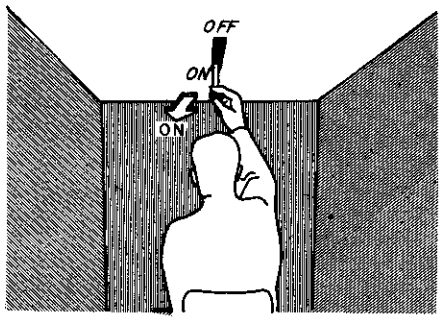
4.2.6 On-Off Controls

a. The direction of linear control movements for on-off (or increase-decrease) controls such as levers and toggle switches is determined by the location of the panel on which these controls are mounted.

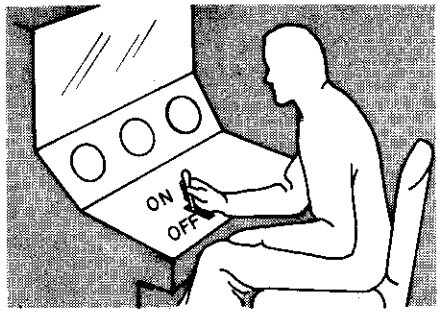
b. For controls mounted on vertical panels: "On" or "increase" should be an upward movement, "off" or "decrease" a downward movement.



c. For controls mounted on horizontal overhead panels: "On" or "increase" should be a forward movement, "off" or "decrease" a rearward movement.

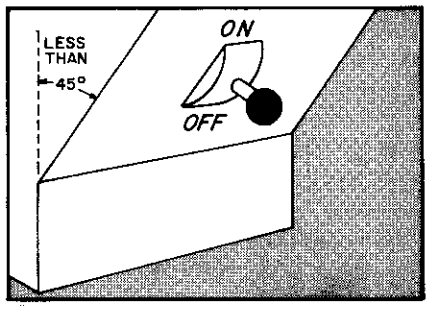


d. For controls mounted on upward facing horizontal panels: "On" or "increase" should be a forward movement, "off" or "decrease" a rearward movement.

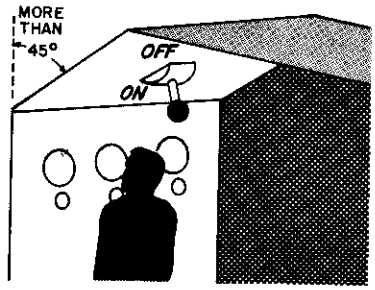


e. For controls mounted on sloping panels: There may be no sharply defined division between up-down and forward-rearward control movements. When panels are below eye-level, this is unimportant because forward and upward movements both require the operator to apply force in the same general direction. However, for panels above eye-level a forward movement is opposite that of an upward movement; therefore, to avoid ambiguous situations: [5, 63, 64]

1) For overhead panels tilted less than 45° from the vertical: Controls should be actuated as if the panel were vertical ("on" or "increase" should be an upward movement).

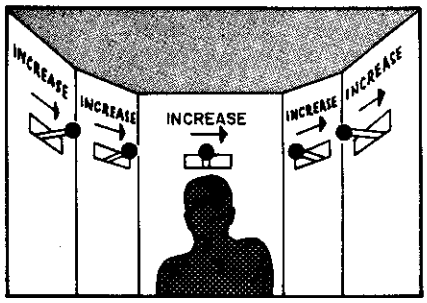


2) For overhead panels tilted more than 45° from the vertical: Controls should be actuated as if the panel were horizontal ("on" or "increase" should be a forward movement).



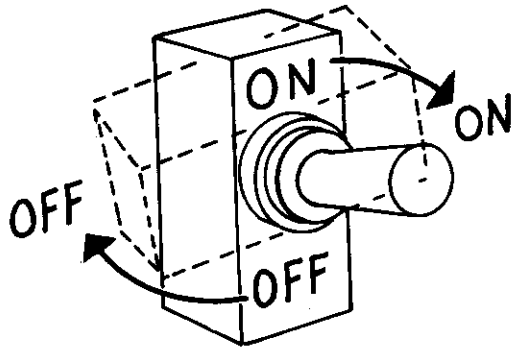
Note: Operators cannot make accurate estimates of tilt angles; therefore, overhead panels should not be placed at a 45° tilt. The best place to break directions is at an actual break in the panel (e.g., windscreen). If no such breaks occur, panels should be either less than 30° or greater than 60° from the vertical.

f. When surfaces at slight angles to each other are joined to form a continuous control panel (e.g., a console on which control panels are arranged radially about the operator), control movements should be consistent throughout the panel. All movement relationships should be the same as those established for the central panel.



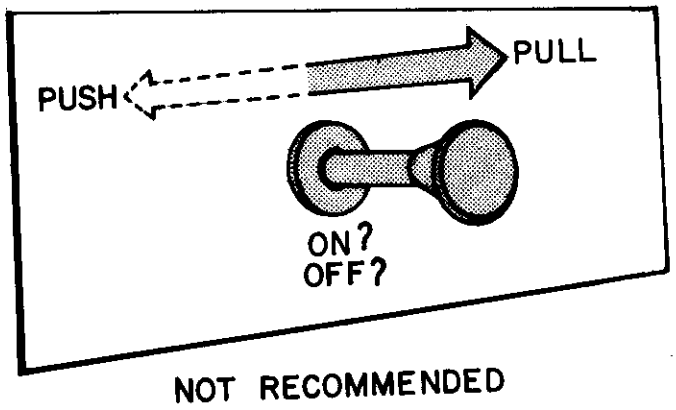
Note: However, in most instances, it is desirable to provide an artificial break in the panel surface (such as a conspicuous line), and follow recommendations (a) through (e) above.

g. When on-off controls are integral parts of an equipment unit which might be placed in various positions relative to the operator (e.g., in front of the operator, overhead, on either side), controls and labels should be constructed so that they can be rotated through 90°. In this way the control can always be oriented for the proper direction-of-movement relationship.



4.2.7 Push-Pull (Plunger-Type) Controls

a. Such controls which project from the panel surface on which they are mounted (e.g., hand choke on automobile, throttle on some types of small aircraft) are not recommended. The "pushed-in" position on these controls is generally associated with "off" or "decrease." This control movement, particularly when the control is mounted on the front plane, conflicts with the usual forward-to-increase control movement.

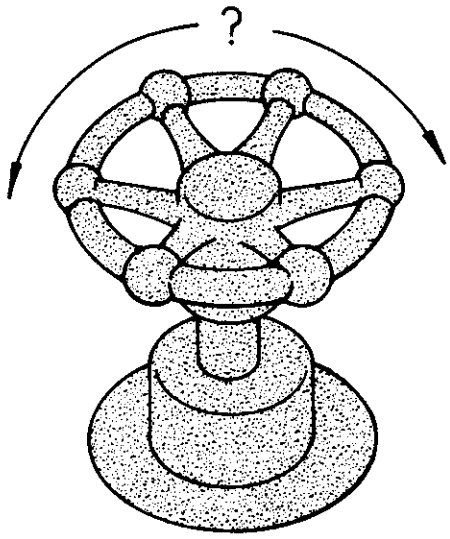


NOT RECOMMENDED

Note: This recommendation does not apply to push-button type controls.

4.2.8 Valves [41]

a. Valves generally turn clockwise for "close" or "off." This can be confusing to the operator in two ways:

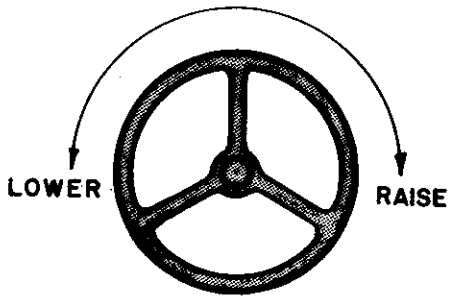


NOT RECOMMENDED

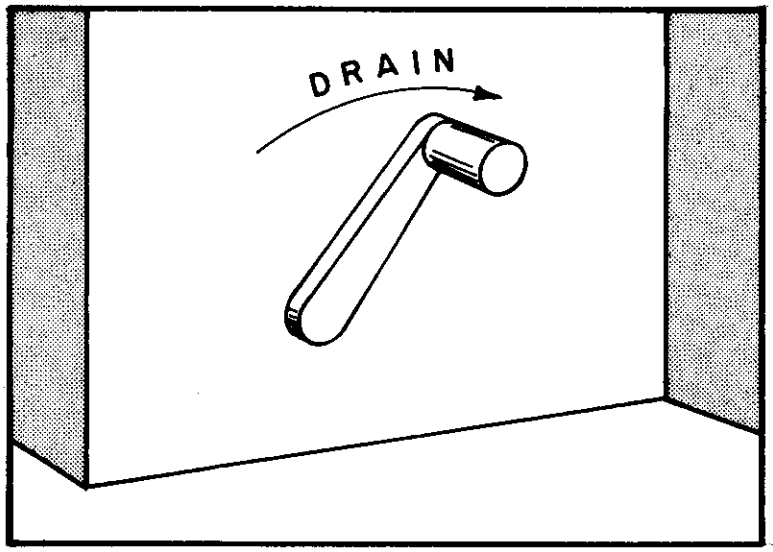
1) Clockwise-to-decrease conflicts with the consistent use in other controls of clockwise-to-increase movements.

2) Opening a valve may increase pressure in one instance and decrease pressure in another instance.

b. Valve controls should operate and be labeled according to the end purpose which they serve (e.g., "raise" or "drain"). In this way, direction-of-movement relationships for controls and displays can be consistent both with each other and with other control-display movements in the system.



Caution: Some individuals experienced with certain valves may have learned that "off" or "close" is a clockwise rotation. In order to aid their relearning, movement directions should be prominently labeled; and, whenever possible, the appearance of the redesigned valve should be changed drastically from the old one. One possibility is to replace the traditional valve-handle design with a lever, crank or crossbar.



4.2.9 Spring-Loaded Unidirectional Controls

a. Direction-of-movement relationships do not apply to simple on-off or reset controls (as a trigger or push button) which are spring-loaded, move in only one direction and are activated by applying force in that direction.

b. These controls may be mounted anywhere within the limiting dimensions. Their exact location should be determined primarily by the direction in which the operator can apply force most effectively.

4.2.10 Movement Relationships in Tracking Tasks

a. Direct control-display and control-equipment movement relationships are possible in tracking tasks where the position of the controlled object (marker, "hook" or target-follower) is directly dependent upon the position of the control; this is called position control. However, for other types of tracking (such as rate-control, acceleration-control, etc.) direct movement relationships do not apply to the usual position orientation.

> Example: In rate-control, the position of the control directly affects the velocity of the controlled object (and, indirectly, its position). Any movement of the control to the right of the null position imparts a rightward velocity to the controlled object; the farther the control is to the right (or left) of its null position, the greater the rightward (or leftward) velocity. Thus, a change in the direction of movement of the control may or may not result in a change in the direction of movement of the controlled object. In the case where a control is moved to the left, stopped, then returned rightward toward its null position, the control reversal causes the controlled object to reduce its velocity while maintaining its original direction. A change in the direction of movement of the controlled object will not take place until the control is moved rightward beyond the null position.

b. All direction-of-movement relationships can be made to apply to all tracking situations in the following manner:

1) With position-control, the direction of movement of the control must be related directly to the direction of change in position of the controlled object.

2) With rate-control, the direction of movement of the control must be related directly to the direction of change in velocity of the controlled object.

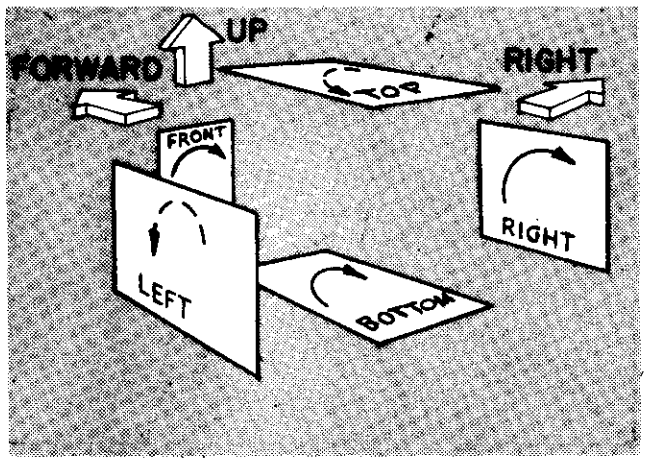
3) With acceleration-control, the direction of movement of the control must be related directly to the direction of change in acceleration of the controlled object.

4) With rate-aided control, the direction of movement of the control must be related directly to the direction of change in both position and velocity of the controlled object.

Note: In the special case of a rigid control where there is no perceptible movement of the control, the direction in which force is applied should be considered equivalent to "direction of movement."[25]

4.3 SUMMARY TABLE OF RECOMMENDATIONS

Table VI evaluates the major possible combinations of control movement and display response in five planes relative to the operator. "Front plane" is the direction in which the operator is seated. No displays or controls on the rear plane are considered because of the unlikelihood that they can be viewed or reached. Recommendations concerning the bottom plane are considered also to apply to horizontal side panels. The directions "forward," "right," "clockwise" in all five planes are illustrated below.



Only half of each pair of movements is listed in Table VI: "Up" is always paired with "down," "right" with "left," "forward" with "backward," "clockwise" with "counterclockwise." When one movement relationship is given, all other combinations can be inferred (e.g., if "up" is recommended for "increase," then "down" should go with "decrease"; "up" should not go with "decrease" nor "down" with "increase").

TABLE VI

Recommended direction of movement for controls and resulting display response

CONTROL PLANE		DISPLAY PLANE															
	TYPE OF MOVEMENT	Front			Left			Right			Bottom			Overhead		
		Up	Rt	Clock-wise	Up	Fwd	Clock-wise	Up	Fwd	Clock-wise	Fwd	Rt	Clock-wise	Fwd	Rt	Clock-wise
Front	Up	+	o	o	+	o	-	+	o	+	+	o	o	-	o	o
	Right	o	+	o	o	+	o	o	-	o	o	+	+	o	+	-
	Clockwise	o	o	+	+	o	+	-	o	+	o	-	+	o	+	+
Left	Up	+	o	+	+	o	o	+	o	o	o	-	o	o	+	o
	Forward	o	+	o	o	+	o	o	+	o	+	o	+	+	o	-
	Clockwise	-	o	+	o	o	+	o	o	o	-	o	+	+	o	+
Right	Up	+	o	-	+	o	o	+	o	o	o	+	o	o	-	o
	Forward	o	-	o	o	+	o	o	+	o	+	o	-	+	o	+
	Clockwise	+	o	+	o	-	o	o	o	+	+	o	+	-	o	+
Bottom	Forward	+	o	o	o	+	o	o	+	+	+	o	o	+	o	o
	Right	o	+	-	-	o	o	+	o	o	o	+	o	o	+	o
	Clockwise	o	+	+	o	+	+	o	-	+	o	o	+	o	o	o
Over-head	Forward	-	o	o	o	+	+	o	+	-	+	o	o	+	o	o
	Right	o	+	+	+	o	o	-	o	o	o	+	o	o	+	o
	Clockwise	o	-	+	o	-	+	o	+	+	o	o	o	o	o	+

Caution: In Table VI, only direction of motion relationships between control and corresponding display are considered. The meaning (whether increase or decrease, the direction of scale progression, or the effect on a vehicle's motion) is not considered. The designer must, therefore, exercise caution in applying these recommendations to insure that they result in control and display movements which are consistent with those of other controls and displays and with other human engineering considerations such as: a) the direction of motion of the vehicle or equipment, b) the convention that Right, Up, Forward or Clockwise movement of either a display or control is associated with an increase, c) the convention that numerical scales progress up, right or clockwise. If there are conflicts, alternative types and arrangements and locations of controls and displays should be examined.

It is assumed, in Table VI, that the recommendations of the preceding sections have been followed. Violation of the preceding recommendations negates the table. For example, the recommendation that clockwise control movement be associated with a rightward display movement applies only if the control is essentially below the display. (See Section 4.2.3.)

Ratings

Recommended (+): These are the obvious, "natural," movement relationships. They should always be used providing they do not result in undesirable conflicts with the convention that rightward, up, clockwise and forward movements of a display or control are associated with an increase. If such a conflict does result, one of the conditional (o) relationships should be considered.

Conditional (o): These relationships are acceptable if applied with caution. They are either:

a. Critically dependent on locating the control relative to the display so that adjacent parts of the control and display move in the same direction (e.g., a clockwise movement of a rotary control should result in rightward movement of the display if the display is above the control, but not if it is below the control), or

b. Sufficiently ambiguous that either motion relationship is acceptable providing that the convention of rightward, up, clockwise or forward for increase on both control and display are adhered to and providing that the direction of increase (and decrease) of both control and display is clearly indicated.

Not Recommended (-): A Not Recommended relationship should be avoided. Occasionally, it is the converse of a recommended relationship so that simply reversing the direction of motion of either the control or display (but not both) will result in an acceptable relationship. If the converse relationship is also not satisfactory and an acceptable recommended relationship cannot be found, a conditional (o) relationship should be used.

BIBLIOGRAPHY

1. Adams, J.A. The evaluation of "difficulty of task" under several different conditions of performance on the modified Mashburn apparatus. Office of Naval Research, Special Devices Center, Technical Report SDC 57-2-8, 1949.

2. Andreas, B.G. Bibliography of perceptual-motor performance under varied display-control relationships. University of Rochester, Scientific Report No. 1, AF Contract 30(602)-200, 1953.

3. Andreas, B.G., Green, R.F. and Spragg, S.D.S. Transfer effects between performance on a following tracking task (modified SAM Two-Hand Coordination Test) and a compensatory tracking task (modified SAM Two-Hand Pursuit Test). J. Psychol., 1954, 37, 173-183.

4. Andreas, B.G. and Weiss, B. Review of research on perceptual-motor performance under varied display-control relationships. University of Rochester, Scientific Report No. 2, AF Contract 30(602)-200, 1954.

5. Baker, C.A. and Grether, W.F. Visual presentation of information. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-160, August 1954.

6. Barnes, R.M. Motion and time study. New York: John Wiley and Sons, Inc., 1950.

7. Bartlett, N.R. and Williams, S.B. Signal mark size and visibility of radar signals on a plan position indicator. Systems Research Laboratory, The Johns Hopkins University, Report Number 166-I-30, 1947.

8. Benton, R.S. Body sizes of pursuit pilots. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Memorandum Report ENG-49-695-32B, 20 September 1943.

9. Bielschowsky, A. Lectures on Motor anomalies: the physiology of ocular movements. Amer. J. Ophth., 1938, 21, 843-854.

10. Brackett, F.S. Eye cups, head rests, head clearances. United States Army Service Forces-Army Medical Research Laboratory Partial Report, Subprojects No. 6-1, 6-2, 6-3, 6-4 and 6-6, September 1944.

11. Bradley, J.V. Control-display association preferences for ganged controls. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-379, August 1954.

12. Brown, C.W., Ghiselli, E.E., Jarrett, R.J., Minium, E.W. and U'Ren, R.M. Magnitude of forces which may be applied by the prone pilot to aircraft control devices. III. Foot controls. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report AFTR 5955, October 1949.

13. Carter, L.F. and Murray, N.L. A study of the most effective relationships between selected control and indicator movements. In Fitts, P.M. (Ed.) Psychological research on equipment design. Report No. 19, Army Air Forces Aviation Psychology Program Research Reports, Washington, D.C.: U.S. Government Printing Office, 1947.

14. Clarke, H.H., Elkins, E.C., Martin, G.M., Wakim, K.G. Relationship between body position and the application of muscle power to movements of the joint. Arch. phys. Med., 1950, 31, 81-89.

15. Craik, K.J.W. and Macpherson, S.J. The effect of certain operating conditions on the visibility of PPI radar echoes. Medical Research Council, Unit of Applied Psychology, University of Cambridge, England, Report No. APU 16, 1945.

16. Duncan, C.P. Transfer in motor learning as a function of degree of first-task learning and inter-task similarity. J. exp. Psychol., 1953, 45, 1-11.

17. Ellis, D.S. Speed of manipulative performance as a function of work-surface height. J. appl. Psychol., 1951, 289-296.

18. Fitts, P.M. and Crannell, C. Location discrimination. II. Accuracy of reaching movements to twenty-four different areas. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report AFTR 5833, 1950.

19. Fitts, P.M. and Seeger, C.M. S-R compatibility: spatial characteristics of stimulus and response codes. J. exp. Psychol., 1953, 46, 199-210.

20. Foxboro Company. A study of factors determining accuracy of tracking by means of handwheel control. National Defense Research Committee, Office of Scientific Research and Development Report No. 3451, 1942. Washington, D.C.: U.S. Department of Commerce, 1946.

21. Gagne, R.M. and Foster, Harriet. A study of transfer in a motor task with varying display-control relationships. Office of Naval Research, Special Devices Center, Report No. 316-1-3, 1948.

22. Gagne, R.M. and Foster, Harriet. Transfer to a motor skill from practice on a pictured representation. J. exp. Psychol., 1949, 39, 342-354.

23. Gardner, J.F. Direction of pointer motion in relation to movement of flight-controls--cross-pointer type instrument. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report No. 6016, 1950.

24. Gibbs, C.B. Transfer of training and skill assumptions in tracking tasks. Quart. J. exp. Psychol., 1951, 3, 99-110.

25. Gibbs, C.B. and Baker, J.C. Free-moving versus fixed control levers in a manual tracking task. In Tustin, A. (Ed.) Automatic and manual control. London: Butterworth, 1951.

26. Graham, Norah E., Baxter, I.G. and Browne, R.C. Manual tracking in response to the display or horizontal, vertical and circular scales. Brit. J. Psychol., 1951, 42, 155-163.

27. Hall, M.V. and Greenbaum, L.J., Jr. Industrial ophthalmology: areas of vision and cockpit visibility. Trans. Amer. Acad. Ophth. and Otol., September-October 1950, 74-88.

28. Hering, E. Spatial sense and movements of the eye. Baltimore: The American Academy of Optometry, 1942. (Translated by Carl R. Radde.)

29. Hertzberg, H. T. E., and Daniels, G. S. Anthropometry of flying personnel-1950. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 52-321, September 1954.

30. King, B. G., Morrow, D. J. and Vollmer, E. P. Cockpit studies--the boundaries of the maximum area for the operation of manual controls. Naval Medical Research Institute, National Naval Medical Center, Project No. X-651, Report No. 3, 15 July 1947.

31. King, B. G., Vollmer, E. P., Henson, M., Margolis, S. I., Pfaffman, C., Whaley, R. V., Newton, H. E. and Lewis, L. B., Jr. Measurements of aircrewmen and aircrew spaces in Naval aircraft. Naval Medical Research Institute, National Naval Medical Center, Project No. X-651, Report No. 1 15 December 1945.

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

33. Loucks, R. B. Interpretation of azimuth indicators by novices: I. Aircraft direction indicators with fixed lubber lines and azimuth cards that turn. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report No. 5957, 1950.

34. Loveless, N. E. Manual tracking in the four quadrants of a circular scale: II. Upper and lower quadrants. Flying Personnel Research Committee Report 867, HM Government Printing Office, Great Britain, March 1954.

35. McFarland, R. A., Holway, A. H. and Hurvich, L. M. Studies of visual fatigue. Graduate School of Business Administration, Harvard University, Boston, Massachusetts, 1942.

36. Mitchell, M. J. H. Direction of movement of machine controls: III. A two handed task in a discontinuous operation. Psychological Laboratory, Ministry of Supply, Cambridge, England, SM 10018 (S), 1947.

37. Mitchell, M. J. H. and Vince, M. A. The direction of movement of machine controls, Quart. J. exp. Psychol., 1951, 3, 24-35.

38. Morant, G.M. The heights and weights of Royal Naval pilots compared with those of R.A.F. pilots. Flying Personnel Research Committee FPRC 682, HM Government Printing Office, Great Britain, 1947.

39. Müller, E.A. Optimum arrangement of pedals operated from a seated position. (Distributed by The Armed Services Technical Information Agency, ATI 138 641, Document Service Center, U.B. Building, Dayton 2, Ohio.)

40. Murrell, K.F.H. Naval Motion Study Unit Report No. 61, London, England, October 1954.

41. Murrell, K.F.H. and McCarthy, C. Direction of motion relationships between valves and gauges when mounted in panels. Naval Motion Study Unit Report No. 51, London, England, 1952.

42. Nesberg, L.A. and Smith, K.U. Measurement of a complex psychomotor performance by means of a printed test. J. appl. Psychol., 1950, 34, 309-312.

43. Nystrom, C.O. and Grant, D.A. Performance on a key pressing task as a function of the angular correspondence between stimulus and response elements. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-71, January 1954.

44. Orlansky, J. The human factor in the design of stick and rudder controls for aircraft. Office of Naval Research, Special Devices Center, Technical Report SPECDEVCEN 151-1-8, 3 February 1948.

45. Patt, D.I. Cockpit dimensions in relation to human body size. Army Air Force, Air Technical Service Command, Engineering Division, TSEAL-3-695-32TT, 1945.

46. Randall, F.E., Damon, A., Benton, R.S. and Patt, D.I. Human body size in military aircraft and personal equipment. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report AFTR 5501, 10 June 1946.

47. Rulon, P.J., Sampson, P.B. and Schohan, B. The effects of "G" forces on the performance of teletype operators. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report No. 6568, October 1951.

48. Simon, C. W. Effects of stress on performance on a dominant and a non-dominant task. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-285, 1954.

49. Simon, C. W. Instrument-control configurations affecting performance in a compensatory pursuit task. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 6015, 1952.

50. Simon, C. W. The presence of a dual perceptual set for certain perceptual-motor tasks. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-286, June 1954.

51. Stauffer, F. R. and Cochran, L. B. Preliminary studies on the ease with which pilots can grasp and pull ejection seat face curtain handles. US Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida, NM-001059.22.02, 6 November 1951.

52. Stellar, E. Human factors in panel design. In Human factors in undersea warfare. Committee on Undersea Warfare, National Research Council, Washington, D. C., 1949.

53. Vince, M. A. Direction of movement of machine controls. Flying Personnel Research Committee, FPRC 637, HM Government Printing Office, Great Britain, 1945.

54. Vince, M. A. Learning and retention of an "unexpected" control-display relationship under stress conditions. Medical Research Council, Unit of Applied Psychology, University of Cambridge, England, Report No. APU 125/50, 1950.

55. Vince, M. A. and Mitchell, M. J. H. Direction of movement of machine controls. Psychological Laboratory, Ministry of Supply, Cambridge, England, SM 2861 (S), 1946.

56. Warrick, M. J. Direction of motion stereotypes in positioning a visual indicator by use of a control knob: II. Results from a printed test. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Report No. MCREXD-694-19A, 1948.

57. Warrick, M. J. Direction of movement in the use of control knobs to position visual indicators. In Fitts, P. M. (Ed.) Psychological research on equipment design. Report No. 19, Army Air Forces Aviation Psychology Program Research Reports, Washington, D. C.: U. S. Government Printing Office, 1947.

58. Warrick, M. J. Effects of motion relationships on speed of positioning visual indicators by rotary control knobs. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Technical Report No. 5812, 1949.

59. Warrick, M. J. and Grether, W. F. The effect of pointer alignment on check-reading of engine instrument panels. USAF, Air Materiel Command, Wright-Patterson Air Force Base, Memorandum Report MCREXD-694-17, 1948.

60. Williams, S. B. Visibility on radar scopes. In Human factors in undersea warfare, Committee on Undersea Warfare, National Research Council, Washington, D. C., 1949.

61. Wissel, J. W., Vandenberg, J. E. and Orlansky, J. A human engineering study of aircraft electrical distribution panels. USAF, Air Materiel Command Wright-Patterson Air Force Base, Technical Report No. 53-252, July 1953.

62. Woodson, W. E. Human engineering guide for equipment designers. Berkeley: University of California Press, 1954.

63. Cockpit Controls: location and actuation of, for aircraft. Department of Defense, Defense Supply Management Agency, Office of Standardization, Washington, MIL-STD-203, 1953.

64. Handbook of human engineering data. (2nd Ed.) Tufts College, Institute for Applied Experimental Psychology, Office of Naval Research, Special Devices Center, Technical Report SPECDEVCEN 199-1-2a, 1 November 1952.

65. Handbook of instructions for aircraft designers. Air Research and Development Command, Manual No. 80-1, Headquarters, ARDC, Baltimore, Maryland, November 1952.

66. Hertzberg, H.E. A prone position bed for pilots. USAF Air Materiel Command, Wright-Patterson Air Force Base, Report No. MCREXD-695-71D, 25 June 1948.

67. Hertzberg, H.E., Emanuel, I. and Alexander, G. Anthropometry of working positions: I. A preliminary study. USAF, Wright Air Development Center, Wright-Patterson Air Force Base, WADC Technical Report 54-520, 1954.

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