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HUMAN FACTORS ENGINEERING DESIGN STANDARD FOR WHEELED VEHICLES

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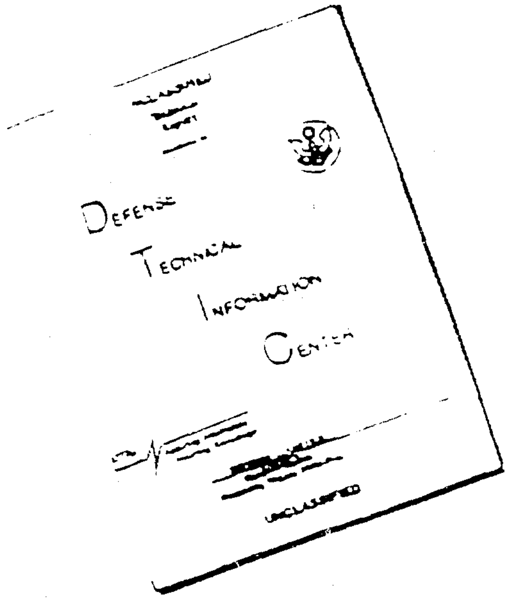

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HUMAN FACTORS ENGINEERING DESIGN STANDARD FOR WHEELED VEHICLES

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September 1966

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PROMULGATION SHEET

1. The data contained in this standard reflect the official position of the U. S. Army Human Engineering Laboratories (HEL) and supersede all other data issued by these laboratories that pertain to the subject of this standard. (Specifically, this standard supersedes Technical Memorandum 21-62.)

2. Human Engineering Laboratories standards are issued for use by the major subordinate commands of the Army Materiel Command (AMC) in the area of human factors engineering, in accordance with AMCR 70-1.

3. HEL standards guide the AMC major subordinate commands and project managers for the inclusion of human factors engineering requirements into research and development or procurement contractual documents.

4. HEL standards are the basis for the human factors engineering evaluations that HEL conducts in accordance with AMCR 10-4.

5. The use of HEL standards does not obviate the need for participation by human factors specialists during research, development, test, and evaluation, because neither the areas of interest in this standard nor the contents of these areas is exhaustive.

CONTROLS

DISPLAYS

FIGURES

TABLES

HUMAN FACTORS ENGINEERING DESIGN STANDARD

FOR WHEELED VEHICLES

INTRODUCTION

In order for equipment to be utilized most efficiently, it must be designed for the specific user population. This constraint upon design is obviously, although perhaps unconsciously, one of the designer's primary considerations.

Designers must design for men who, in tactical situations, will be under conditions of stress and fatigue from many causes. A performance decrement may arise in the tactical situation not so much because troops are basically unable to perform, but because the individual soldier is over-loaded, both physically and mentally.

Equipment must be designed so the procedures for using it are as simple as possible. Equipment should not require intellectual tasks like transforming data when personnel may be distracted. More complex equipment is likewise undesirable, because it is less reliable and less maintainable.

It is recognized that training can improve crew proficiency; however, training should not be considered a substitute for good design.

As a general comment about the design of Army equipment, more complex weapon systems mean the Army must either find more capable people or design equipment so the people who are available can use it. The latter technique is preferable.

It is important to have information about the men who serve as crew members. Their capabilities and limitations are among the basic considerations in designing equipment.

The official Army selection procedures are given in AR 611-201, "Manual of Enlisted Military Occupational Specialties," and AR 600-200, "Enlisted Personnel Management System."

This Standard gives the design engineer both human factors engineering design principles and detailed criteria. The design principles are stated as general rules to be applied during system-development programs or as essential items that must be considered during design to insure that sound human factors engineering practices will be incorporated. The detailed criteria consist of dimensions, ranges, tolerances, and other specific data. In some cases, the range of acceptable dimensions and other factors may be rather large. Where only the minimum and maximum are given, design engineers may select any part or item within the recommended range. But where optimum dimensions are given, designers should aim to approximate them whenever possible.

ANTHROPOMETRICS

BODY DIMENSIONS

1. The anthropometric data in this section (Tables 1, 2, and 3 and Figs. 1, 2, and 3) provide a basis for design decisions not specifically covered in other sections. In applying these data, users must consider the following areas:

a. The nature, frequency, and difficulty of related tasks.

b. The body's position when performing these tasks.

c. The task's requirements for mobility or flexibility.

d. Any special reasons for increasing design-critical dimensions: (a) to compensate for obstacles, projections, etc., and (b) to allow for protective garments, packages, lines, padding, etc.

e. Interference between two or more tasks the man must do at the same time.

2. General rules for selecting the appropriate data from Tables 1, 2, and 3 and Figures 1, 2, and 3 are:

a. Gross dimensions (passageways, accesses, safety clearances, etc.) which must accommodate or allow passage of the body should be based on the 95th percentile values.

b. Limiting dimensions (reaching distance, displays, test points, hand-rails, control movement, etc.) which are limited by extension of the body should be based on the 5th percentile values.

c. Adjustable dimensions (seats, safety goggles, belts, controls, etc.) should accommodate the range of personnel from the 5th through the 95th percentiles.

3. The 5th percentile for a particular dimension is the value that 5 percent of the personnel are smaller than, while 95 percent are larger. Conversely, the 95th percentile is the value that 95 percent of the personnel are smaller than, while 5 percent are larger. Thus a score's percentile indicates the percent of a group that scored below it.

4. Probably no individual matches either the 5th or the 95th percentile values exactly on all dimensions. For example, an individual may be at the 95th percentile in stature and seated eye-height, but have an arm reach or hand measurement well below the 95th-percentile dimensions.

5. When personnel relax -- slump -- they may reduce their seated eye-height measurements (Fig. 1, E-7) by as much as 2.5 inches. This slump factor must be considered in locating displays, in establishing the system's visual requirements, and in selecting a seat's range of adjustment. Note, however, that the slump factor is not a valid reason for lowering ceilings to save space.

6. Anthropometric data in Table 1 are taken on the nude figure. This is to avoid confusions caused by the wide variations in dress. It is necessary to make allowances for clothing. Table 2 shows increments added by the basic uniform.

NOTE:

The data for the arctic-clothed soldier (Table 1) were measured with 5th and 95th percentile soldiers dressed in the following:*

a. Headgear

Helmet, steel, with liner
Cap, field, insulating
Hood, field, insulating

b. Handgear

Mittens, lightweight, cold-dry

c. Footgear

Socks, men's, wool, cushion sole
Boots, combat, rubber, insulated, cold-dry (white)

d. Underwear

Undershirt, man's, cotton, short sleeve
Drawers, man's, cotton, shorts (boxer)
Undershirt, lightweight
Drawers, lightweight

e. Body Clothing

Coat, man's, shell
Trousers, man's, shell
Liner, CBR protective, coat, man's, shell
Liner, CBR protective, trousers, man's, shell
Shirt, man's, cotton
Suspenders, trousers
Liner, cold-wet, coat, man's, shell
Liner, cold-wet, trousers, man's, shell
Overgarment, man's, cold-dry, upper body
Overgarment, man's, cold-dry, lower body
Liner, cold-dry, overgarment, man's, upper body
Liner, cold-dry, overgarment, man's, lower body
Vest, armored

* Anthropometry of the Arctic equipped soldier. TR EPT-2, U. S. Army Natick Laboratory, Natick, Mass., August 1964.

TABLE 1

Body Dimensions

Dimension			Design Values (inches, unless otherwise noted) 5th Percentile Nude	5th Percentile Arctic[a] Clothed	95th Percentile Nude	95th Percentile Arctic[a] Clothed
Weight (pounds)			124	150	192	222
Standing						
A.	1.	Stature	64.3	67.3	72.6	75.3
	2.	Eye Height	59.9	61.4	68.1	69.2
	3.	Ear Height	59.1	--	67.0	--
	4.	Shoulder Height	52.0	53.7	59.8	61.3
	5.	Nipple Height	47.0	--	53.9	--
	6.	Kneecap Height	18.1	19.7	22.1	23.9
	7.	Penile Height	31.6	--	37.4	--
	8.	Substernale Height	45.6	--	52.1	--
	9.	Suprasternale Height	52.7	--	59.9	--
B.	1.	Nasal-Root Height	61.0	--	68.9	--
	2.	Chest Depth	7.2	11.8	9.6	12.6
	3.	Waist Depth	6.7	10.0	9.4	14.0
	4.	Buttock Depth	7.6	--	10.2	--
	5.	Crotch Height	30.0	28.6	35.8	32.6
C.	1.	Chest Breadth	9.9	--	12.4	--
	2.	Waist Breadth	9.4	--	12.3	--
	3.	Hip Breadth	12.1	15.8	14.5	18.3
	4.	Knuckle Height	27.7	--	32.4	--
	5.	Wrist Height	31.0	--	36.1	--
	6.	Waist Height	38.3	41.2	44.8	46.4
	7.	Elbow Height	40.6	--	46.4	--
	8.	Cervicale Height	54.8	57.5	62.7	64.6
Seated						
D.	1.	Sitting Height	33.5	35.1	38.0	39.9
	2.	Shoulder Height	21.0	21.8	25.0	25.8
	3.	Shoulder-Elbow Length	12.9	14.6	15.6	16.2
	4.	Waist Height	7.9	--	10.4	--
	5.	Thigh-Clearance Height	4.8	6.3	6.5	7.5
	6.	Buttock-Knee Length	21.5	23.5	25.2	26.4
	7.	Back-of-Knee Height	15.7	15.8	18.3	17.4
	8.	Knee Height	19.8	22.4	23.5	25.6
	9.	Buttock-Leg Length	39.4	--	46.1	--
	10.	Forearm-Hand Length	17.3	21.3	20.1	22.1
E.	1.	Shoulder Breadth	16.4	18.8	19.6	22.0
	2.	Elbow-to-Elbow Breadth	15.3	22.8	20.3	26.7
	3.	Hip Breadth, Sitting	12.7	17.0	15.5	19.7
	4.	Knee-to-Knee Breadth	7.2	--	8.8	--
	5.	Breadth of Both Feet	7.0	9.6	8.2	10.4
	6.	Elbow-Rest Height	7.1	6.4	10.8	10.7
	7.	Eye Height (see para 5, page 4)	29.1	29.9	33.5	33.8

[a] See description on page 5.

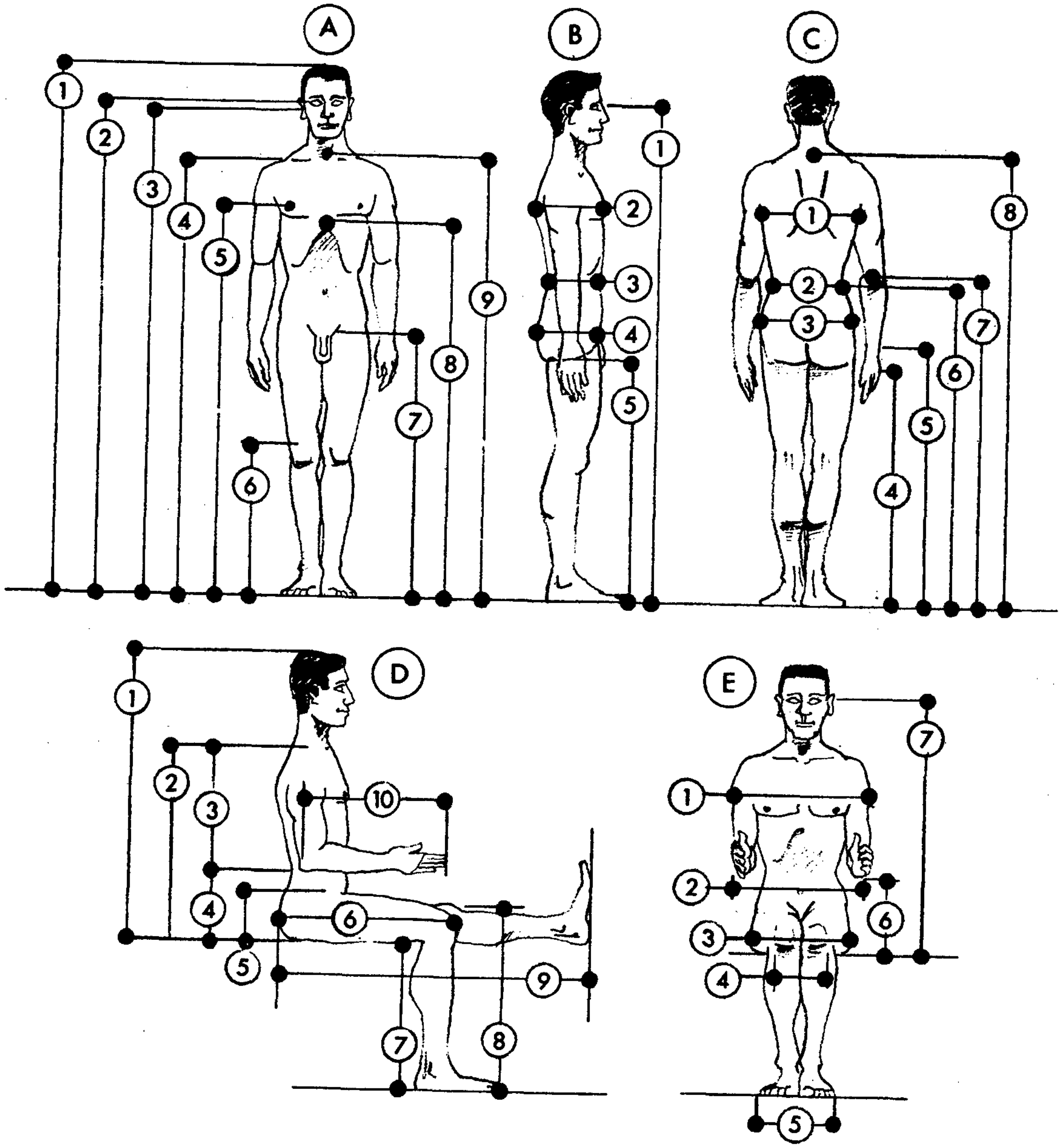


Fig. 1. BODY DIMENSIONS

TABLE 1 continued

Dimension	Design Values (inches)			
	5th Percentile		95th Percentile	
	Nude	Arctic Clothed	Nude	Arctic Clothed
F. Reach				
1. Functional Reach (from Wall)	29.4	30.5	34.9	36.6
2. Arm Reach (from Wall)	31.9	--	37.2	--
3. Maximum Reach (from Wall)	35.4	--	41.7	--
4. Span	65.0	68.0	75.2	76.6
G. Head				
1. Binocular Distance	3.3	--	4.0	--
2. Interpupillary Distance	2.3	--	2.7	--
3. Interocular Distance	1.1	--	1.5	--
4. Nasal-Root Breadth	0.4	--	0.7	--
5. Nose Breadth	1.2	--	1.5	--
6. Lip Length	1.8	--	2.3	--
H. Head				
1. Head Breadth	5.6	9.0	6.4	9.0
2. Edge of Right Ear to Edge of Left Ear	5.3	--	5.9	--
3. Minimum Frontal Diameter	3.9	--	4.7	--
4. Maximum Frontal Diameter	4.4	--	5.1	--
5. Breadth of Face	5.1	--	5.9	--
6. Width of Jaw	3.9	--	4.6	--
7. Ear Protrusion	0.6	--	1.1	--
I. Head				
1. Head Height (from Ear)	4.8	6.6	5.6	7.8
2. Minimum Frontal Arc	4.8	--	6.1	--
3. Chin-to-Nose Length	2.2	--	3.1	--
4. Nose Length	1.9	--	2.5	--
5. Chin-to-Hairline Length	6.8	--	8.0	--
J. Head				
1. Head Length	7.2	10.9	8.1	10.9
2. Nasal Root (to Wall)	7.2	--	8.2	--
3. Ear Breadth	1.3	--	1.6	--
4. Ear Length	2.2	--	2.7	--

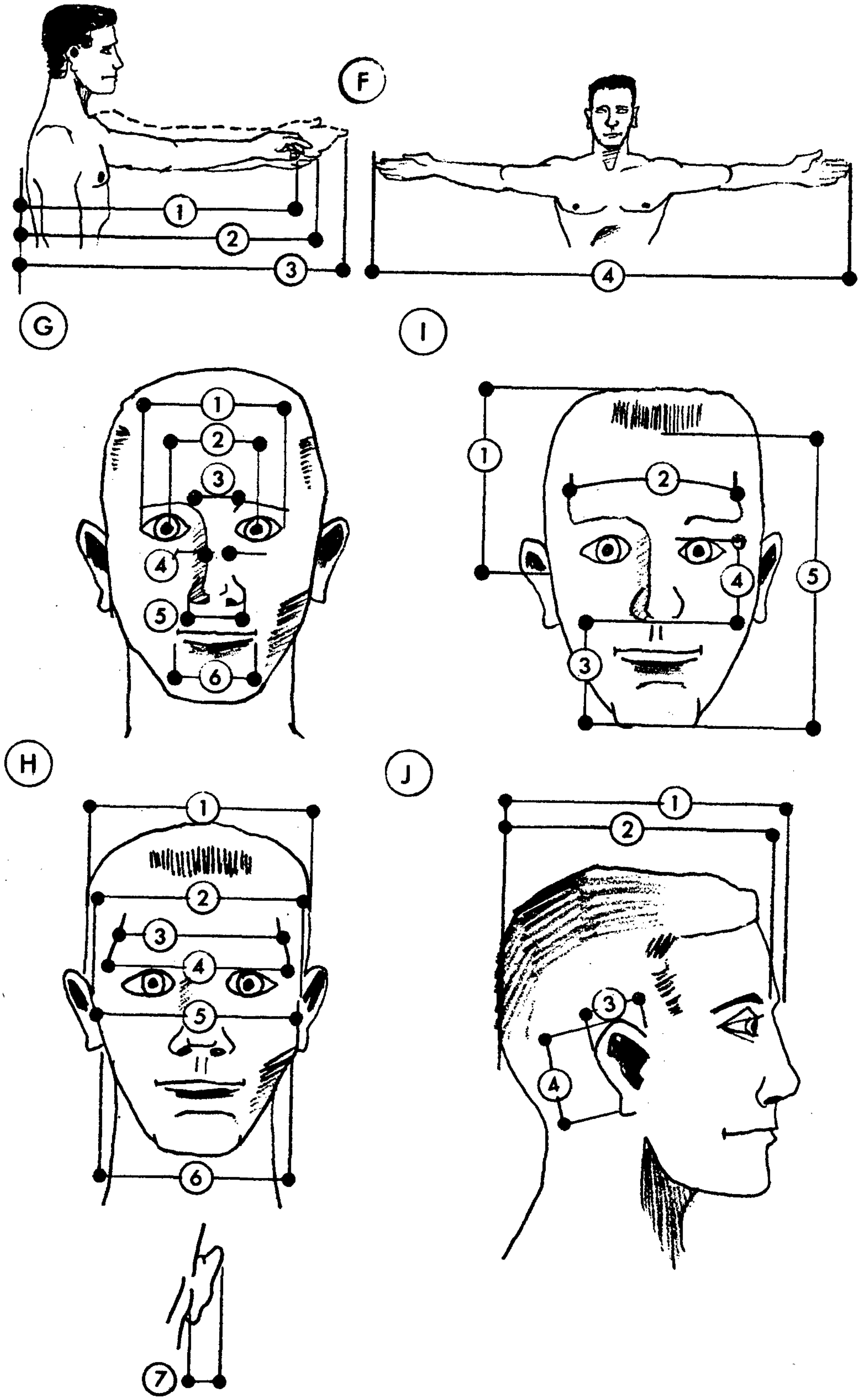


Fig. 1. Continued

TABLE 1 continued

Dimension	Design Values (inches)			
	5th Percentile		95th Percentile	
	Nude	Arctic Clothed	Nude	Arctic Clothed
K. Body Circumferences				
1. Neck	13.3	26.3	15.7	25.4
2. Shoulder	39.2	49.7	46.6	56.3
3. Chest	32.9	41.7	40.5	49.4
4. Waist	26.9	37.6	35.8	47.4
5. Buttock	33.3	46.0	40.5	54.1
6. Thigh	18.8	24.0	24.5	29.6
7. Lower-Thigh	13.1	--	16.6	--
8. Calf	12.6	19.4	15.6	22.0
9. Ankle	7.8	15.0	9.5	17.7
10. Wrist	6.0	11.8	7.4	13.0
L. Foot				
1. Ankle Breadth	2.7	--	3.2	--
2. Ankle Height (Medial)	3.1	--	3.8	--
3. Ankle Height (Lateral)	2.4	--	3.1	--
4. Foot Breadth	3.5	4.8	4.3	5.4
5. Ball-of-Foot Circumference	8.9	14.7	10.5	15.5
6. Foot Length	9.7	12.7	11.2	13.3
7. Instep Length	6.9	8.4	8.3	9.0
8. Heel Breadth	2.3	--	3.0	--
M. Hand				
1. Grip Diameter (Outside)	3.7	See	4.4	
2. Grip Diameter (Inside)	1.6	Fig. 3	2.1	
3. Fist Length (Phalanx III)	2.5		2.9	
4. Fist Circumference	10.7		12.4	
5. Thickness at Metacarp III	1.0		1.3	
6. Finger Diameter (Third Finger)	0.8		0.9	
7. Hand Length	6.9		8.2	
8. Hand Breadth at Metacarp	3.1		3.7	
9. Palm Length	3.9		4.6	
10. Hand Breadth at Thumb	3.7		4.4	
11. 1st Digit-to-Crotch Height	4.0		5.0	
12. Thumb Thickness	0.7		0.8	
13. Thumb Length	2.0		2.6	
14. Third-Finger Length	4.2		4.8	
15. Dorsum Length	2.8		3.2	

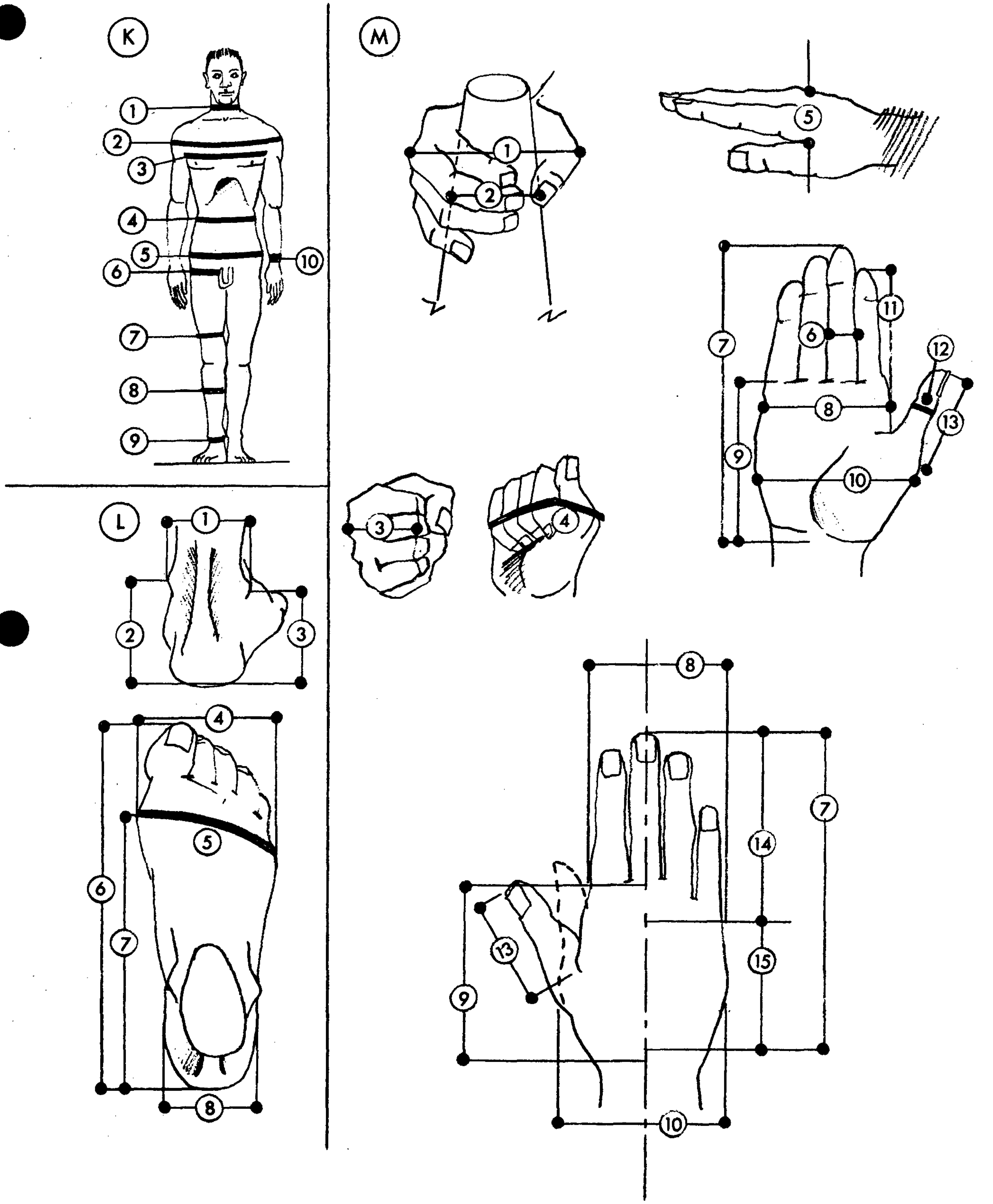


Fig. 1. Continued

TABLE 2

Body Dimensions of the 5th- and 95th-Percentile Soldier Wearing Temperate-Zone Clothing

	Basic Uniform: Underwear, Khakis or O.D.'s or Fatigues, Socks, Shoes, Helmet and Liner — Percentile 5th	Basic Uniform — Percentile 95th	Additions to the Basic Uniform: Field Jacket — Percentile 5th	Field Jacket — Percentile 95th	Overcoat — Percentile 5th	Overcoat — Percentile 95th
Weight (Pounds)	141.9	210.2	144.3	212.6	151.1	219.4
Body Dimensions[a] (Inches)						
A-1 Stature	67.8	75.8	67.8	75.8	67.8	75.8
D-1 Sitting Height	35.1	39.4	35.2	39.5	35.4	39.6
E-7 Eye Height, Sitting	29.4	33.5	29.5	33.6	29.6	33.7
D-2 Shoulder Height, Sitting	21.4	25.3	21.8	25.7	22.2	26.0
D-8 Knee Height, Sitting	21.4	24.6	21.4	24.6	21.5	24.7
D-6 Buttock-Knee Length	21.9	25.4	22.0	25.5	22.1	25.6
D-3 Shoulder-Elbow Length	13.3	15.5	13.7	15.9	14.1	16.3
E-1 Shoulder Breadth	16.7	19.6	17.4	20.3	18.0	20.9
C-1 Chest Breadth	11.0	13.6	11.1	13.7	11.3	13.9
E-2 Elbow Breadth	15.7	20.4	16.2	20.8	17.0	21.6
C-3 Hip Breadth	12.6	15.0	12.8	15.2	13.2	15.5
E-3 Hip Breadth, Sitting	13.2	16.0	13.4	16.2	13.8	16.5
E-4 Knee Breadth (both)	7.6	9.3	7.6	9.3	7.9	9.5
B-2 Chest Depth	8.4	10.8	8.9	11.4	9.8	12.2
L-6 Foot Length	11.0	12.7	11.0	12.7	11.0	12.7
L-4 Foot Breadth	4.0	4.5	4.0	4.5	4.0	4.5
M-7 Hand Length (See Fig. 3)						
M-10 Hand Breadth (See Fig. 3)						

[a] The letter and number with each body dimension refer to the drawings in Figure 1.

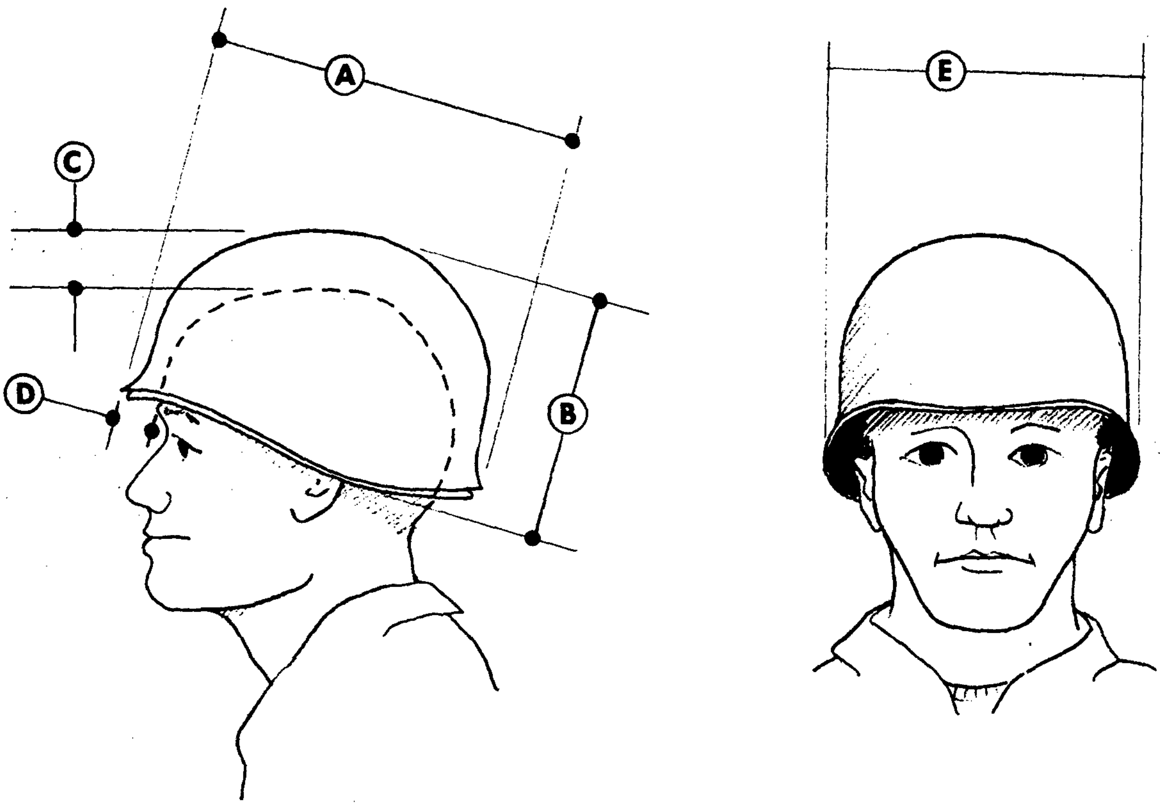
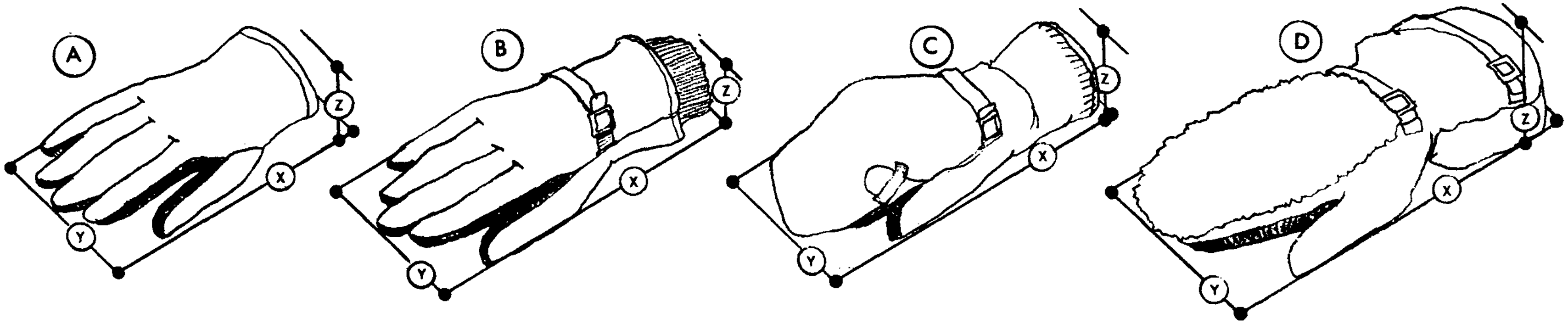


Fig. 2. M-1 HELMET

TABLE 3

Dimensions of the M-1 Helmet

Dimension	Size (Inches)
A. Length, front rim to rear rim	11 (maximum)
B. Height, at maximum angle	6 7/8
C. Top of head to top of helmet	2 (maximum)
D. Eyebrow ridge to front rim	2 (maximum)
E. Width, rim to rim	9 1/4 (maximum)



	Hand Dimensions (inches)											
	A Anticontact Glove			B Wet-Cold Glove			C Wet-Cold Mitten			D Arctic Mitten		
Hand Position	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Extended Flat	10.3	4.5	2.5	10.5	5.5	3.0	14.0	5.8	3.2	16.4	5.2	3.6
Closed as Fist	7.0	5.0	3.3	7.3	5.8	3.7	11.5	5.8	3.8	14.3	5.2	5.4
Grasping Handle												
.25" diameter	7.0	4.7	3.5	7.3	5.5	3.5	11.0	5.7	4.2	14.0	5.0	4.5
1.0" diameter	7.0	4.5	3.5	7.3	5.3	4.0	11.0	5.2	4.5	14.0	5.0	4.5
2.0" diameter	7.5	4.5	4.2	8.0	4.7	4.0	12.0	5.2	4.7	15.0	5.2	5.0
Grasping Knob												
.25" diameter	8.0	3.8	3.5	9.0	4.6	4.0	11.5	5.0	4.2	15.5	4.8	4.5
1.0" diameter	9.0	3.8	3.2	9.0	4.5	4.0	12.0	5.0	4.2	15.8	4.8	4.8
2.0" diameter	9.5	3.8	3.2	9.2	4.5	4.2	12.5	4.6	4.4	16.0	4.7	4.8

Fig. 3. GLOVED-HAND DIMENSIONS

1. It must not take more force to operate a control than the weakest person who is apt to use it can exert. How much force operators can apply depends on such factors as the type of control, the body member used to operate it, this body member's position when it operates the control, general position of the body, whether or not there are supports, such as back rests, etc.

2. Whenever possible, equipment should be designed so one man can lift it. Certain lifting tasks may require two men, but this is usually undesirable. Leg muscles -- not arm or back muscles -- should be used for heavy lifting. The approximate load that 95 percent of the population can lift safely is shown in Figure 4; however, it should be reduced when:

a. The object is very difficult to handle (e.g., bulky, slippery, etc.).

b. Access and work space are restricted.

c. Operators must exert force continuously for more than one minute.

d. The object must be positioned finely or handled delicately.

e. Operators must perform the task frequently (e.g., many times on a given day).

3. The optimum carrying load is normally about 35 percent of body weight.

4. Figure 5 shows how much force 95 percent of the male personnel can exert in different directions and with different body members.

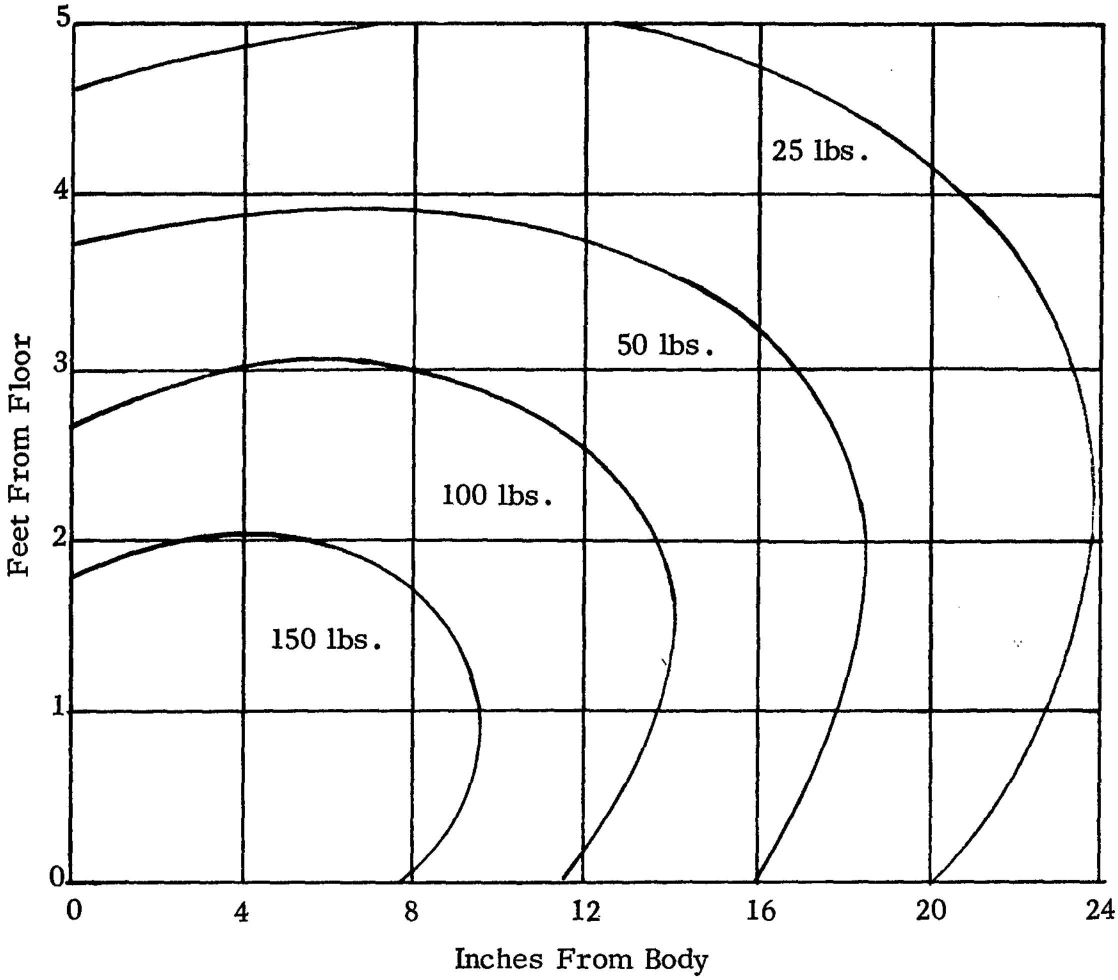
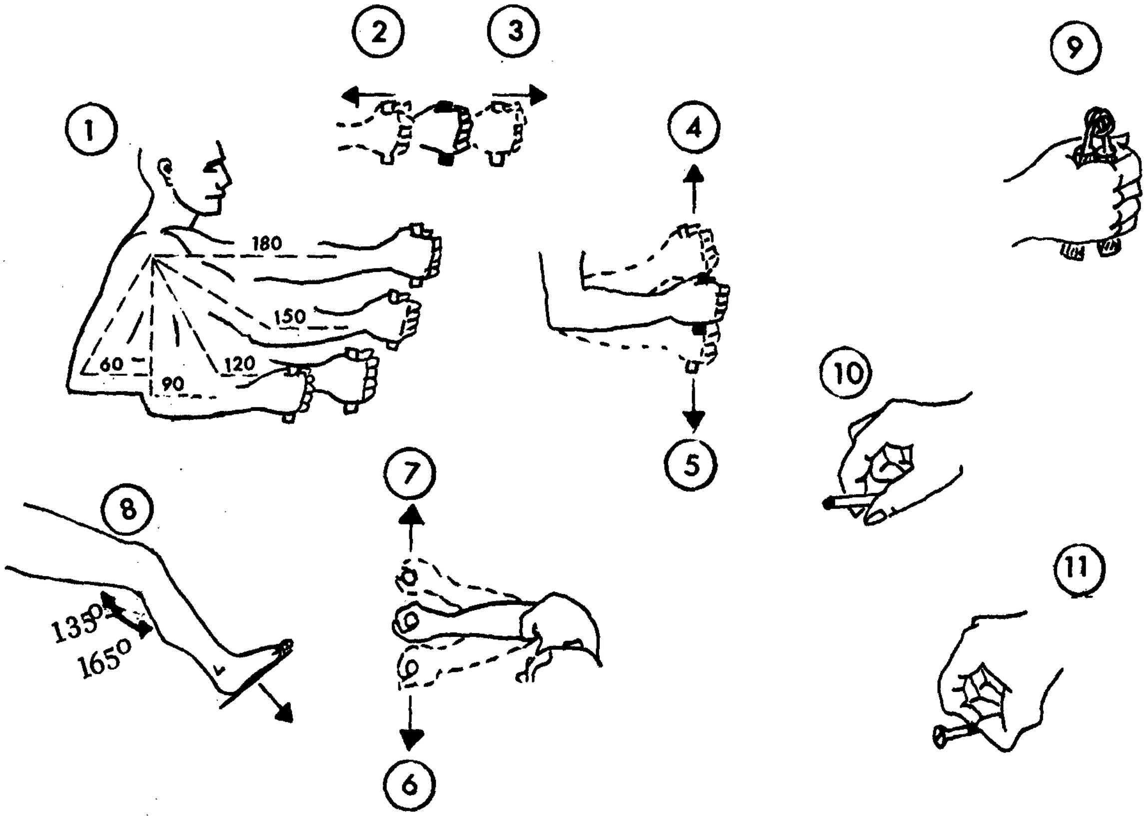


Fig. 4. MANUAL LIFTING CAPACITY
(using both hands)



ARM STRENGTH (POUNDS) FOR SITTING MAN

(1) Elbow Flexion	(2) Pull R[a]	(2) Pull L	(3) Push R	(3) Push L	(4) Up R	(4) Up L	(5) Down R	(5) Down L	(6) In R	(6) In L	(7) Out R	(7) Out L
180°	52	50	50	42	14	9	17	13	20	13	14	8
150°	56	42	42	30	18	15	20	18	20	15	15	8
120°	42	34	36	26	24	17	26	21	22	20	15	10
90°	37	32	36	22	20	17	26	21	18	16	16	10
60°	24	26	34	22	20	15	20	18	20	17	17	12

LEG, HAND, AND THUMB-FINGER STRENGTH (POUNDS)

Holding Time	(8) Leg Push R	(8) Leg Push L	(9) Hand Grip R	(9) Hand Grip L	(10) Thumb-Finger Grip (Palmar)	(11) Thumb-Finger Grip (Tips)
Momentary Hold	413	387	63	65	15	12
Sustained Hold	200	200	42	38	15	12

[a] R = Right L = Left

Fig. 5. HUMAN STRENGTH

RANGE OF HUMAN MOTION

1. All operating positions should allow space to move the trunk of the body. When the operator must exert large forces (over 30 pounds) or make large control movements (more than 15 inches in a fore-aft direction), he should have enough space to move his entire body.

2. Table 4 gives the ranges, in angular degrees, for all the voluntary movements the joints of the body can make, as illustrated in Figure 6. The designer must remember that these are maximum values; since they were measured with nude personnel, they do not reflect the restrictions clothing would impose.

3. Here is a general index for selecting appropriate dimensions from Table 4:

a. Use the lower limit if the movement is directly required in operating or maintaining the equipment.

b. Use the upper limit in designing for freedom of movement.

TABLE 4

Range of Human Motion[a]

Body Member	Movement	Lower Limit (degrees)	Average (degrees)	Upper Limit (degrees)
A. Wrist	1. Flexion	78	90	102
	2. Extension	86	99	112
	3. Adduction	18	36	27
	4. Abduction	40	54	47
B. Forearm	1. Supination	91	113	135
	2. Pronation	53	77	101
C. Elbow	1. Flexion	132	142	152
D. Shoulder	1. Lateral Rotation	21	34	47
	2. Medial Rotation	75	97	119
	3. Extension	47	61	75
	4. Flexion	176	188	190
	5. Adduction	39	48	57
	6. Abduction	117	134	151
E. Hip	1. Flexion	100	113	126
	2. Adduction	19	31	43
	3. Abduction	41	53	65
	4. Medial Rotation (prone)	29	39	49
	5. Lateral Rotation (prone)	24	34	44
	6. Lateral Rotation (sitting)	21	30	39
	7. Medial Rotation (sitting)	22	31	40
F. Knee Flexion	1. Prone	115	125	135
	2. Standing	100	113	126
	3. Kneeling	150	159	168

[a] These values are based on the nude body. The ranges are larger than they would be for clothed personnel.

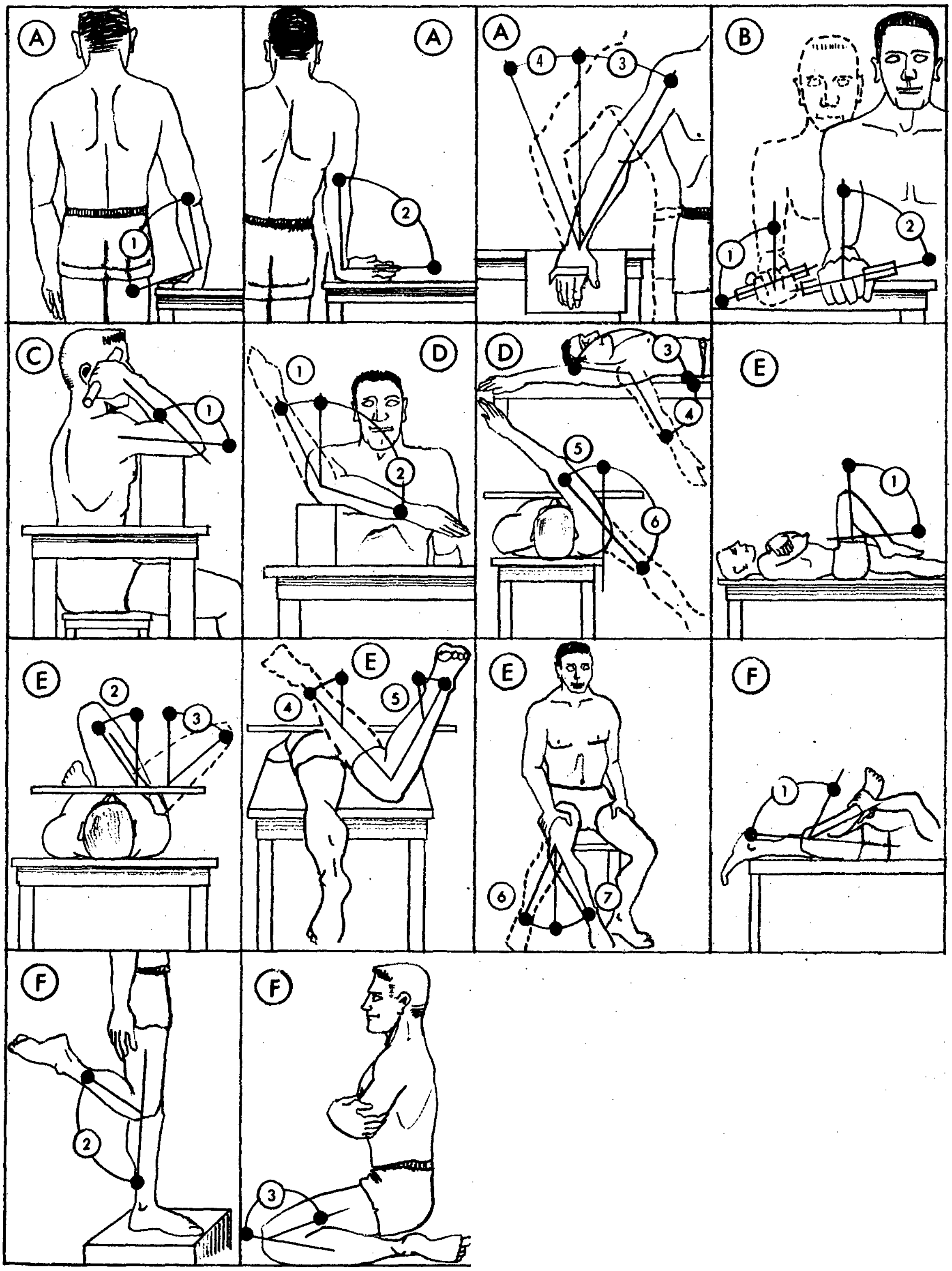


Fig. 6. RANGE OF HUMAN MOTION

TABLE 4 continued[a]

Body Member	Movement	Lower Limit (degrees)	Average (degrees)	Upper Limit (degrees)
G. Foot Rotation	1. Medial	23	35	47
	2. Lateral	31	43	55
H. Ankle	1. Extension	26	38	50
	2. Flexion	28	35	42
	3. Adduction	15	33	24
	4. Abduction	16	30	23
I. Grip Angle		95	102	109
J. Neck Flexion	1. Dorsal (back)	44	61	88
	2. Ventral (forward)	48	60	72
	3. Right	34	41	48
	4. Left	34	41	48
K. Neck Rotation	1. Right	65	79	93
	2. Left	65	79	93

[a] These values are based on the nude body. The ranges are larger than they would be for clothed personnel.

Flexion: Bending, or decreasing the angle between parts of the body.
Extension: Straightening, or increasing the angle between parts of the body.
Adduction: Moving toward the midline of the body.
Abduction: Moving away from the midline of the body.
Medial Rotation: Turning toward the midplane of the body.
Lateral Rotation: Turning away from the midplane of the body.
Pronation: Rotating the palm of the hand downward.
Supination: Rotating the palm of the hand upward.

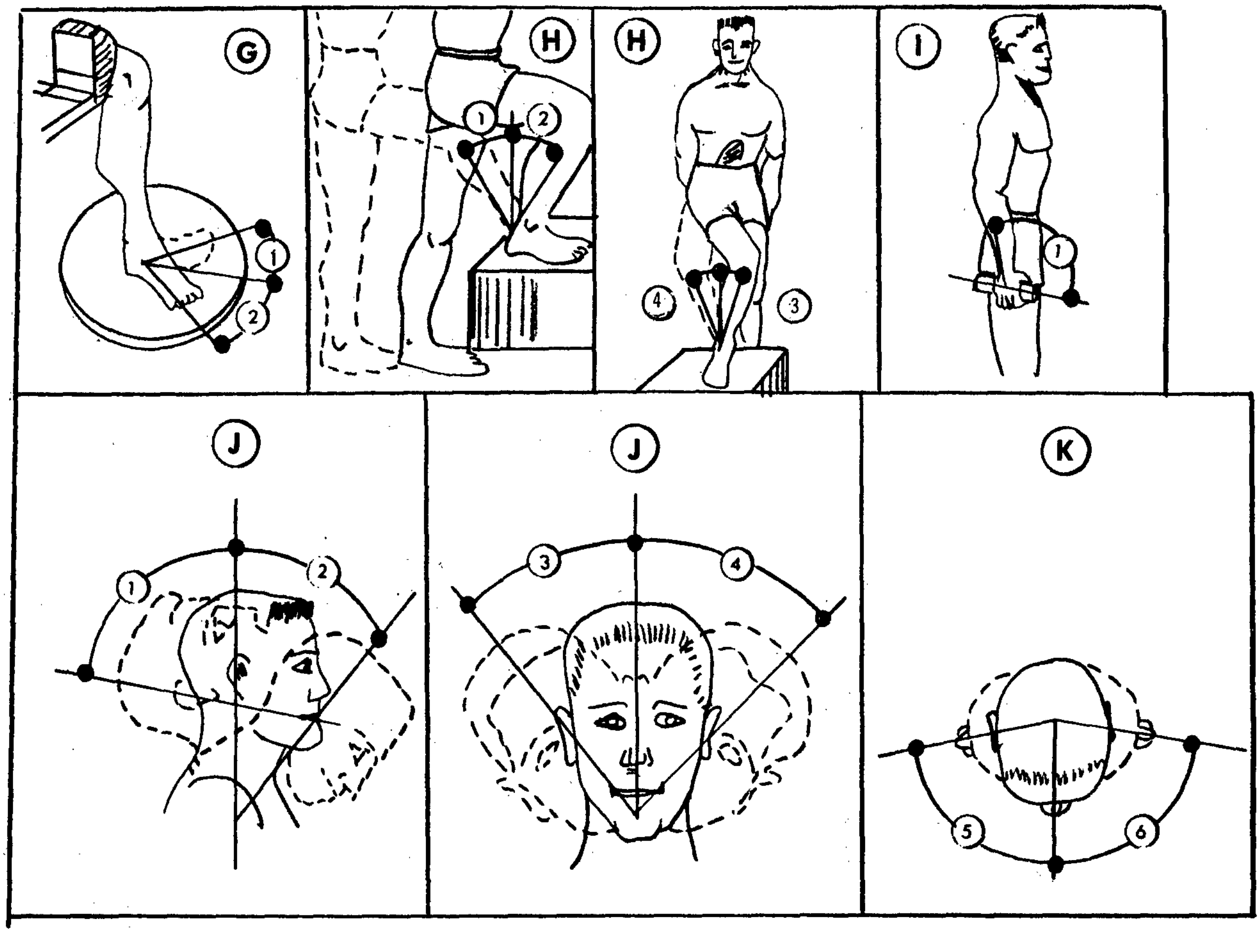


Fig. 6. Continued

ENVIRONMENT

GENERAL

1. There are three major categories of environmental factors which affect wheeled-vehicle design:

a. Environmental factors that design can control (e.g., illumination, ventilation rate, etc.).

b. Environmental factors that design cannot control (e.g., amount of solar radiation, dust, mud, rain, etc.).

c. Environmental factors that are a function of design (e.g, noxious substances, vibration, noise, etc.).

2. Throughout the design phase, designers should consider the environmental extremes the system will be subjected to and how these extremes can affect human performance.

3. Designers should consult the most recent issue of AR 705-15, "Operation of Materiel under Extreme Conditions of Environment," for criteria about designing for extreme operating conditions.

THERMAL REQUIREMENTS

1. Temperature requirements for personnel compartments depend on the nature of tasks, the conditions they are performed under, and the clothing operators wear.

2. The requirements for hot and cold environments, as specified below, must be met under all operating conditions.

Cold Environment

1. The reference temperature is measured 24 inches above the seat reference point of the operator's normal position. In cold environments (AR 705-15), cab compartments should be heated so the reference temperature does not fall below + 5° F dry bulb. In normal operating positions, air temperatures around the operator's body should be within the range from 15° F dry bulb above reference temperature to 10° F dry bulb below the reference temperature, e.g., if the reference temperature is + 20° F, then temperatures at various parts of the body should be between + 35° F and + 10° F. The heater should achieve these requirements within one hour after it is turned on.

2. There should be provisions for regulating the amount of heat the heater delivers, with devices like shutters, louvers, fan-speed controls, etc.

3. Vehicles used as ambulances should maintain a temperature of at least 50° F dry bulb throughout the patient compartment.

4. In vehicles used as troop carriers, the troop-carrying area should be heated as provided in paragraph 1 above.

5. Open cabs and machine-gun kits call for special consideration of how moving air can exaggerate the severity of cold environments. An empirical expression called the Windchill Index (WI) evaluates the way air movement and air temperature, together, affect the environment's total cooling power.

a. Figure 7 gives values of WI as a function of wind speeds and air temperatures.

b. In evaluating a windchill hazard, designers must consider air movement at personnel positions.

c. If personnel are exposed to a WI of 1200 or above while operating a vehicle, they must be protected. As Figure 7 shows, windchill indices this large are common even in temperate climates.

6. Surfaces that personnel touch -- i.e., gearshift levers, steering wheels, dash controls, seats, side panels, compartment walls, etc. -- should have surfaces with low heat conductivity.

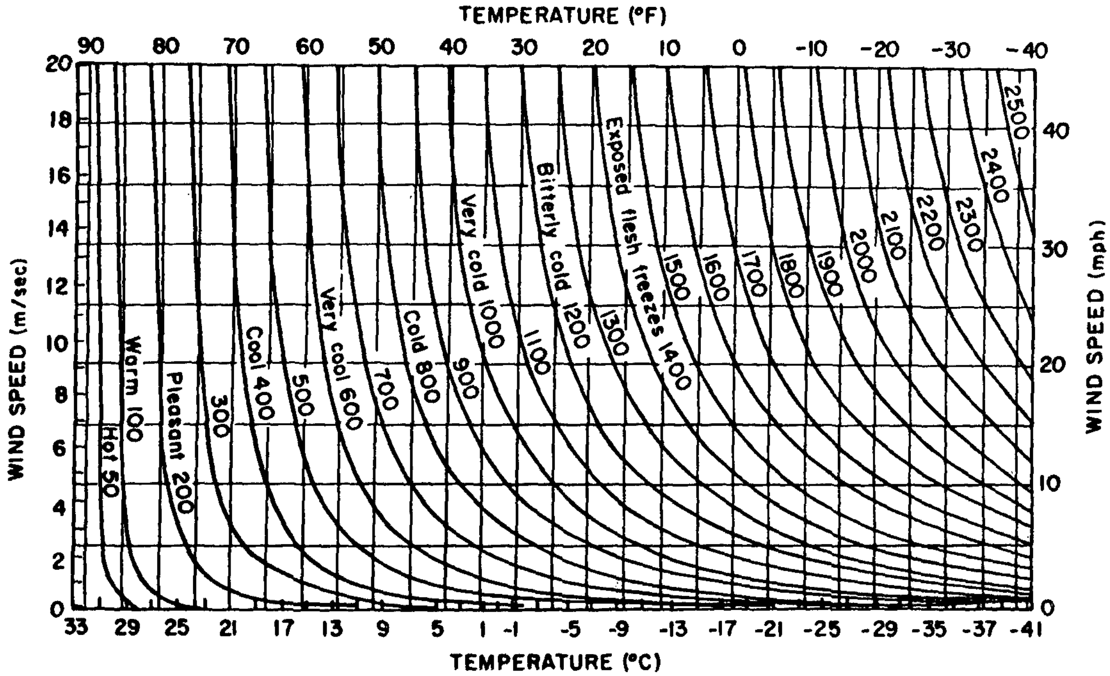


Fig. 7. WINDCHILL CHART
(Numbers on curves represent windchill in kg-cal/m^2/hr)

Hot Environment

1. Several environmental factors determine how much heat stress personnel can tolerate: dry-bulb air temperature, humidity, air movement, radiation, and direct conduction from objects.

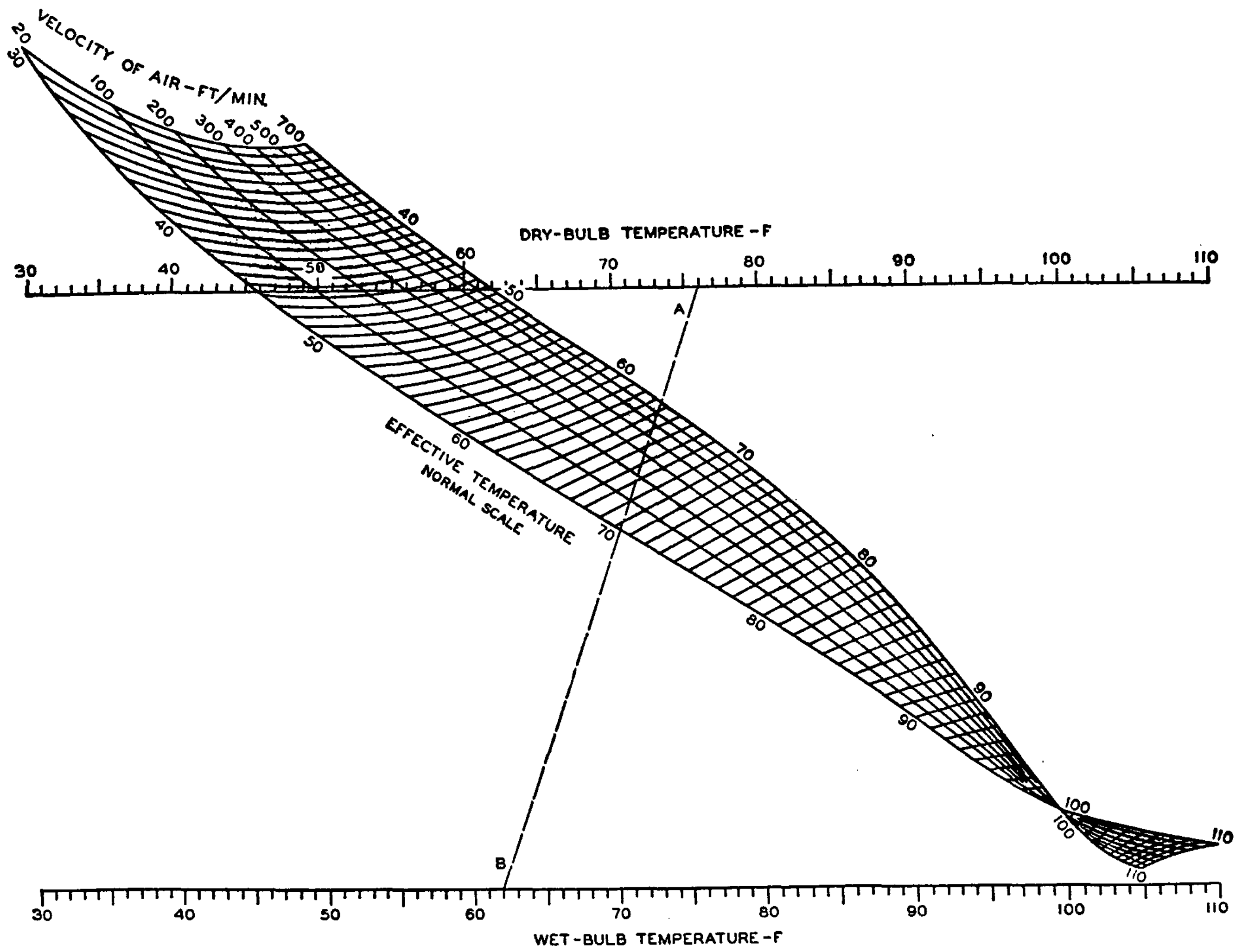
2. The effective temperature (ET) of an environment is an empirical thermal index that considers how combinations of dry-bulb air temperature, humidity, air movement, and clothing affect people. Numerically, it is equal to the temperature of still, saturated air which would induce the same sensation.

3. Effective temperature may be read from Figure 8. This chart is based on men wearing customary indoor clothing and doing sedentary or light muscular work. It does not include any additional heat stresses from special-purpose clothing, such as gas masks, chemical protective clothing, or body armor. Likewise, it does not consider radiant heat inputs, such as radiation from the sun or vehicle components.

4. The greater the input of radiant heat, the less reliably effective temperature measures heat stress. However, if there is a radiant heat problem, environmental heat stress can be assessed with the Wet-Bulb-Globe Thermometer Index (WBGT). This measure corrects the effective temperature for radiant-heat input; the apparatus and methods for measuring WBGT are described in Appendix 1 of TB Med 175.

5. The maximum ET (WBGT) at which humans perform reliably is 85^{o} F. Designers should make every effort to avoid conditions which expose the individual to ET (WBGT) above 85^{o} F for prolonged periods of time (one hour or more). Some effective methods for reducing the environmental heat stress are ventilation, insulation, and shielding.

6. If personnel can touch metal surfaces that may get as hot as 115^{o} F, special precautions are indicated: shielding, insulating, relocating components, or at least adding warning decals, signs, or labels.



A. Clothing: *Customary indoor clothing.* B. Activity: *Sedentary or light muscular work.* C. Heating Methods: Convection type, i.e., warm air, direct steam or hot water radiators, plenum systems.

Fig. 8. DERIVING EFFECTIVE TEMPERATURE

VENTILATION

1. Ventilation both cools personnel and controls air contamination. These two functions involve different problems, different measurements, and different solutions.

2. Cooling personnel with moving air should satisfy the requirements of the hot-environment section; however, the air should have even flow and distribution, so that it does not blow on one part of the body.

3. Personnel compartments require at least 10 cubic feet of fresh air per minute per occupant, to control air contamination by body products. If there are also other noxious substances in the compartment, this rate may not be sufficient.

4. Ventilation should provide air flow sufficient to dilute contaminants and divert them from personnel positions.

Noxious Substances

1. Noxious substances can enter personnel compartments from the outside environment, engine exhausts, heater exhausts, weapons, etc.

2. From the practical standpoint of controlling health hazards, the most important contaminants in wheeled vehicles are carbon monoxide, ammonia, aldehydes, and nitrogen oxides. In sufficient concentrations, these substances are lethal. In lower concentrations, they may incapacitate personnel through eye irritation, nausea, reduced mental alertness, and unconsciousness.

3. Carbon monoxide is particularly dangerous. Odorless, colorless, and tasteless, it cannot ordinarily be detected by the human senses. Its effects are cumulative, so concentrations which personnel can tolerate safely for short times may become dangerous in longer exposures.

4. The concentration of combustion products in the cab or troop area should not exceed the limits as published in the latest issue of "Threshold Limit Values," by the American Conference of Government Industrial Hygienists.

5. The composition of exhaust fumes varies with operating conditions. For example, concentrations of noxious substances are highest when starting and idling the engine in cold weather. In addition, exhaust composition depends on the engine's loading condition, the ambient temperature, and the type of fuel.

6. Temporary disabilities, such as eye irritation and nausea, commonly occur when personnel are exposed to exhaust streams from multi-fuel engines, as when transporting troops or in convoys.

7. Table 5 shows some of the noxious exhaust products of engine fuels.

TABLE 5

Noxious Exhaust Products of Engine Fuels

Fuel	Exhaust Products			
	CO	CO_2	N_2O_4	SO_2
CITE	X	X		
JP4	X	X		
Kerosene	X	X		
Diesel Fuel	X	X	X	X
Gasoline	X	X	X	X
KJJ	X	X	X	X

NOISE

General

1. Advancing technology has given Army equipment greater power and increased mobility, but with an accompanying increase in noise. When this noise, or sound-pressure level (SPL), becomes too great, a number of adverse effects occur: noise interferes with communications, it affects human performance, and it increases the probability of detection by an enemy.

2. The sensation of sound arises when certain frequencies of atmospheric-pressure fluctuations impinge on the ear. The intensity of these fluctuations is expressed in logarithmic units: decibels (dB). The decibel scale's reference pressure is defined as 0.0002 microbar, or 0.0002 dynes per square centimeter; at a frequency of 1000 Hertz (Hz), this reference is said to be the smallest pressure change that young men with good hearing can detect. A scale measuring pressure fluctuations in decibels referred to 0.0002 microbar is termed sound-pressure level (SPL).

3. Types of Noise. Noises may be classified into five general categories:

a. Steady-State Wide-Band Noise (continuous noise), e.g., tank noise, air moving through ducts, ambient noise.

b. Steady-State Narrow-Band or Pure-Tone Noise, e.g., circular saws, transformer noise, turbine whine.

c. Impulse (impact) Noise, e.g., drop forge, hammer, gunfire, door slamming.

d. Repeated Impulse (impact) Noise, e.g., riveting, pneumatic hammers, machine guns.

e. Intermittent Noise, e.g., aircraft flyovers, automobile traffic, passing train.

Speech-Interference Level

1. Communications may be affected by ambient noise -- both surrounding noise and noise in the communication system itself.

2. The speech-interference level (SIL) describes how effectively noise masks speech. SIL is defined as the average (in dB) of the masking noise's sound levels in three octave bands: 600 to 1200, 1200 to 2400, and 2400 to 4800 Hertz (Hz). Sometimes speech interference can be predicted better by also averaging in the 300-600 Hz band if it is 10 dB or more louder than the 600-1200 Hz band. The SIL cannot be used if the masking noise has intense low-frequency components or if it is concentrated in a narrow band. The distance and voice level which will permit reliable conversation (70 percent monosyllabic word intelligibility) for direct person-to-person (non-electrically aided) communications at various SIL without lip reading is shown in Figure 9.

3. Voice communication is the most common method of requesting and giving information. In military systems, voice messages are transmitted in two ways:

a. Electrically, by radio or telephone.

b. Person-to-person.

4. Electrically transmitted speech depends greatly on the characteristics of the microphone, transmission equipment, and the earphones. However, direct and electrically transmitted voice communications have certain limitations in common; one of these limitations is the acoustical environment of both speaker and listener, which has a very important influence on the effectiveness of communication.

5. The frequency range from about 200 to 6000 Hz contains most of the energy required for perfect speech intelligibility. However, this range may be narrowed to 300 to 4500 Hz with little loss in intelligibility.

6. Most of the information in English speech is conveyed by the consonants. Unfortunately, consonants are high-frequency sounds with relatively little energy, so they are more subject to masking than vowels. Conversely vowels have more energy but transmit a limited amount of intelligence. For example, the <u>s</u> sound is a high-frequency sound, whereas the vowel <u>o</u> is a low-frequency sound.

7. To measure how a noisy environment affects intelligibility, trained talkers and listeners should speak phonetically balanced word lists in accordance with the provisions and word lists established by the American Standards Association.*

* American Standard S 3.2-1960, American standard method for measurement of monosyllabic word intelligibility. American Standards Association, Inc., 10 E. 40th St., New York 16, New York.

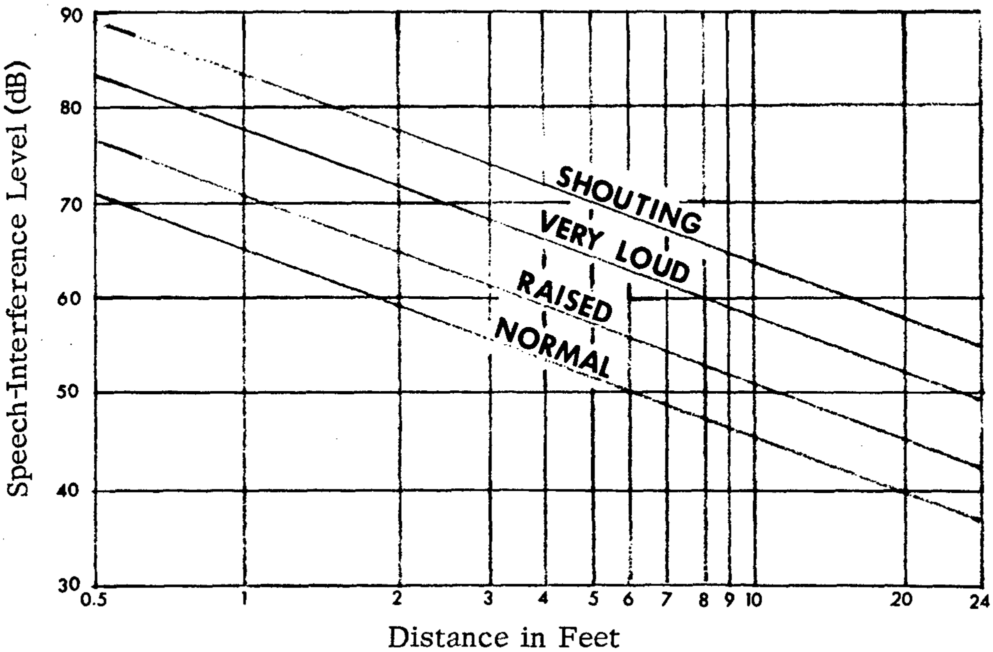


Fig. 9. PERSON-TO-PERSON COMMUNICATIONS

Equipment Design Criteria

1. When there are steady-state noise sources in the environment -- i.e., on-vehicle generators, air conditioners, etc. -- the maximum noise level for Army Materiel Command equipment should not exceed the levels set forth in the latest issue of HEL Standard S-1-63.

2. When the system requires continuous person-to-person communication (not electrically aided), the steady-state noise level should not exceed that shown in the latest issue of HEL Standard S-1-63.

VIBRATION

1. Vibration can affect performance adversely when:

a. At high levels, it causes critical body damage.

b. It makes dials, lettering, and sight reticles difficult to read.

c. It makes controls, tools, or other objects difficult to manipulate.

d. It contributes to increased fatigue, nervousness, and irritability that can lead to oversights, errors in judgment, etc.

2. In designing equipment, vibration should be:

a. Minimized wherever practical.

b. Kept below the "strongly noticeable" and "recommended limit" range of Figure 10 wherever possible.

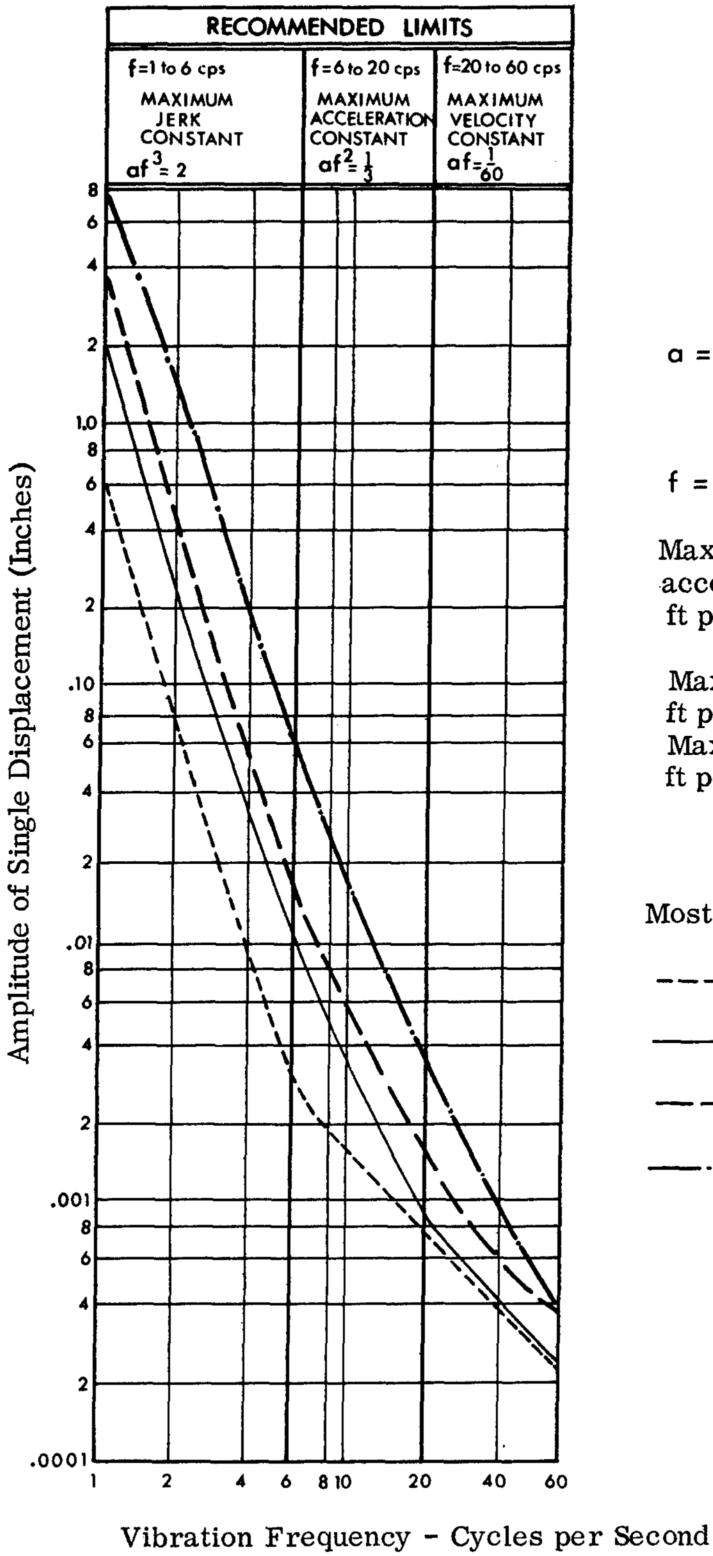
c. Always kept below the "uncomfortable" to "extremely uncomfortable" range of Figure 10.

3. Vibration can be reduced and controlled by:

a. Isolating equipment from vibration sources by shock mountings, fluid couplings, etc.

b. Properly balancing rotating elements of equipment.

c. Providing damping materials or cushioned seats for standing or seated personnel.



DEFINITIONS

a = Amplitude of vibration (inches)(max. displacement from static position)

f = Frequency of vibration (cycles/sec.)

Max. rate of change of acceleration (Jerk) $= \frac{2}{3}\pi^3 af^3$, ft per sec^3

Max. acceleration $= \frac{1}{3}\pi^2 af^2$, ft per sec^2

Max. velocity $= \frac{1}{6}\pi af$, ft per sec.

LEGEND

Most Sensitive Reactions

- - - - - - - Strongly Noticeable

———— Recommended Limit

— — — — Uncomfortable

—·—·— Extremely Uncomfortable

Fig. 10. HUMAN REACTION TO VERTICAL VIBRATIONS

RADIATION

1. Radiation problems are becoming increasingly important as new uses for radioactive materials and new methods for handling them are developed. Radiation is extremely dangerous, and its health hazards are well known.

2. Protective devices, permissible dosages, and dosage rates change as new data accumulate; therefore, designers should contact the U. S. Army Surgeon General for the latest available data.

3. Microwave radiation: The maximum microwave energy that personnel may be exposed to is given in AR 40-583.

4. Nuclear radiation: To find the maximum nuclear radiation that personnel may be exposed to, designers should consult the Atomic Energy Commission and the U. S. Army Surgeon General.

TABLE 6

Illumination Requirements for Wheeled Vehicles

Type of Vehicle	Illumination Levels (footcandles)	Light Source
Ambulance	30 (at work position) 1 (30" above floor level)	surgical lamp dome lamp
Trucks (Auxiliary light for map reading)	1 (one foot from light source)	auxiliary lamp
Bus	1 (30" above floor level)	dome lamp
Shop Van	1 (30" above floor level)	dome lamp

VISIBILITY

General

1. A vehicle driver should have a 180-degree field of forward vision (90-degree field of forward vision on each side of the vehicle's longitudinal centerline). A 220-degree field of forward vision is even more desirable.

2. In his normal driving position, the driver should be able to see the ground at a point 20 feet in front of the vehicle -- or, if at all possible, within ten feet in front of the vehicle. It is also very desirable to allow for looking upward at least 15 degrees above the horizontal.

3. Door posts, windshield-wiper motors, and other devices should not obstruct vision.

4. Transparent materials used for windshields or windows should neither distort nor obscure vision.

5. Interior surfaces should not reflect light or glare to the operator.

6. Side closures should operate easily so the driver and assistant driver can look to the rear on both sides of the vehicle.

7. When possible, there should be a rear window so the driver can see backward over the cargo bed.

Illumination

1. To perform their various tasks efficiently, vehicle personnel must have certain minimum amounts of light (Tables 6, 7, and 8).

2. Auxiliary lighting should be provided where it is needed for tasks like map reading, troubleshooting, etc.

3. Illumination of visual work areas is considered satisfactorily uniform if the minimum illumination of any point within the area is at least two-thirds as bright as the maximum illumination.

TABLE 7

Illumination Requirements for Representative Tasks

Task	Illumination Levels (footcandles) Recommended	Minimum	Light Source
Perceiving small details with low contrast for prolonged times, or where speed and accuracy are essential (examples: repairing small components, inspecting dark materials, layout drafting).	150	100	General Services plus supplementary
Perceiving small details with fair contrast where speed and accuracy are not so essential (examples: handwriting, electronic assembly).	100	50	General Services and/or supplementary
Prolonged reading, desk or bench work, general office and laboratory work (examples: assembly work, filing records).	70	50	General Services and/or supplementary
Occasional reading, recreation, reading signs where visual tasks are not prolonged (example: reading a bulletin board).	50	30	General Services or supplementary
Perceiving large objects with good contrast (example: locating objects in bulk supply warehouse).	20	10	General Services
Passing through walkways, handling large objects (example: loading from a platform).	20	10	General Services

TABLE 8

Specific-Task Illumination Requirements

Work Area or Type of Task	Illumination Levels (footcandles[a]) Recommended	Minimum
Assembly, missile component	100	50
Assembly, general		
coarse	50	30
medium	75	50
fine	100	75
precise	300	200
Bench work		
rough	50	30
medium	75	50
fine	150	100
extra fine	300	200
Business machine operation (calculator, digital, input, etc.)	100	50
Console surface	50	30
Corridor	20	10
Circuit diagram	100	50
Dial	50	30
Electrical equipment testing	50	30
Emergency lighting	--	3
Gage	50	30
Hallway	20	10
Inspection task, general		
rough	50	30
medium	100	50
fine	200	100
extra fine	300	200
Meter	50	30
Ordinary seeing task	50	30
Reading		
large print	30	10
newsprint	50	30
handwritten report, in pencil	70	50
small type	70	50
prolonged reading	70	50
Service area, general	20	10

[a] As measured at the task object or 30 inches above the floor.

Dark Adaptation

1. Dark adaptation is the process by which the eyes become more sensitive in dim light. The eyes adapt almost completely in about 30 minutes, but the length of dark adaptation depends on the color and intensity of the previous light.

2. Low-brightness red light is used to do visual work while maintaining maximum dark adaptation. This red light is obtained by passing white light through a filter that transmits only wavelengths longer than 620 millimicrons (red). A filter with a higher cut-off would maintain dark adaptation still more effectively, but it would waste too much of the available light energy.

3. Where dark adaptation is required, instrument or display markings should be illuminated with red light (620 millimicrons and above). The brightness of the markings should be between 0.02 foot-Lambert and 0.1 foot-Lambert.

4. White light is incompatible with dark adaptation. If it is dimmed enough that it does not interfere with dark adaptation, it will not be bright enough to workby. Where both white light and dark adaptation are to be required, the conflict should be resolved by evaluating the priorities of the operator's tasks (e.g., if night vision is more important than reading maps, use dim red lighting). Colors often appear different under different types of illumination; unless a display will always be used under white light, do not use color coding.

5. At low levels of illumination, red light degrades the eye's dark adaptation less than any other color.

6. Instrument panels should be designed and located for both day and night use.

Brightness Ratios

The brightness ratios between lightest and darkest areas and/or between task and surroundings should be no greater than specified in Table 9.

TABLE 9

Brightness Ratios

Comparison	Environmental Classification[a] A	B	C
Between tasks and adjacent darker surroundings	3 to 1	3 to 1	5 to 1
Between tasks and adjacent lighter surroundings	1 to 3	1 to 3	1 to 5
Between tasks and more remote darker surfaces	10 to 1	20 to 1	b
Between tasks and more remote lighter surfaces	1 to 10	1 to 20	b
Between luminaires and adjacent surfaces	20 to 1	b	b
Between the immediate work area and the rest of the environment	40 to 1	b	b

[a] A -- Interior areas where reflectances of entire space can be controlled for optimum visual conditions.
B -- Areas where reflectances of immediate work area can be controlled, but there is only limited control over remote surround.
C -- Areas (indoor and outdoor) where it is completely impractical to control reflectances and difficult to alter environmental conditions.

[b] Brightness-ratio control not practical.

Glare

1. One of the most serious of all illumination problems is glare or dazzle -- relatively bright light shining into the observer's eyes as he tries to observe a relatively dim visual field. Glare not only reduces visibility for objects in the field of view, but causes visual discomfort.

2. Direct glare arises from a light source within the visual work field. It should be controlled by:

a. Avoiding bright light sources within 60 degrees of the center of the visual field. Since most visual work is at or below the eye's horizontal position, placing luminaires high above the work area minimizes direct glare.

b. Using indirect lighting.

c. Using more relatively dim light sources, rather than a few very bright ones.

d. Using polarized light, shields, hoods, or visors to block the glare in confined areas.

3. Reflected glare refers to reflections from bright surfaces in the visual field. It should be controlled by:

a. Using surfaces that diffuse incident light, rather than reflecting it specularly.

b. Arranging direct-light sources so their angle of incidence to the visual work area is not the same as the operator's viewing angle.

4. These glare-control methods assume the operator is using unaided vision. Eyeglasses reflect glare into the eyes if a bright light behind the viewer is between 30 degrees above and 45 degrees below the line of sight -- or if it is within 20 degrees left or right of the line of sight.

5. Reflected glare from work surfaces is a common, but frequently overlooked, cause of reduced performance in visual tasks.

Reflectances

Large surface areas should be non-glossy. Some non-critical small areas, such as door frames and molding, may be glossy if ease of cleaning is essential.

COLORS

Vehicles should be painted as recommended in the most recent AR 746-5.

Where neither current regulations nor the procuring activity specify colors, the following colors selected from FED STD 595 should be used:

Interiors and Equipment

Ceiling	27875 White
Floors	36118 Gray
Handles	37038 Black
Lettering	37038 Black
Panels	26492 Gray
Walls	24410 Green

Exterior Equipment

Covers	24087 Olive Drab
Handles	24087 Olive Drab
Lettering	37038 Black or 37875 White (on Olive Drab surfaces)
Panels	24087 Olive Drab

BATTERIES

1. One man should be able to change a storage battery within ten minutes, using on-equipment materiel (OEM).

2. Batteries and their compartments should be designed so they can be cleaned and serviced without removing any other components.

3. To prevent incorrect connections, the battery's positive and negative terminals should be labeled and have different sizes or shapes.

4. Battery-retaining devices should use either fasteners that can be removed without hand tools, or nuts and bolts the same size as the battery-terminal clamps.

5. Batteries should be mounted on racks where they are protected yet easily accessible (i.e., under the hood, but within the operator's reach when the hood is open). Where such a location is not feasible, there should be corrosion-resistant, roll-out racks, slides, or hinges that can be pulled out conveniently without disconnecting them.

6. Battery-access covers should be fastened with quick-release fasteners. It should be readily apparent that an access cover is either loose or fastened. If the cover is hinged, there must be enough clearance to open the door.

7. The storage battery compartment itself, and any adjacent metal parts that battery leakage might corrode, should have an acid-resisting paint or coating. There should also be openings for ventilation and drainage.

8. Wherever the starter cable passes through a metal part, it should be insulated with an acid-proof and waterproof bushing to prevent grounding.

9. Wherever both battery and fuel tank are under the driver's seat, they should be partitioned from each other, and both compartments should have separate covers, ventilation, and drainage to the outside.

10. There should be a slave receptacle for auxiliary starting. It should be located near the front of the vehicle and away from areas where there may be fuel vapor.

11. Battery compartments should allow enough space for heating pads and insulation used to winterize the vehicle.

BRAKES

1. There should be two separate ways to apply the brakes on every vehicle. One such means should be an auxiliary parking brake. If the two separate brake systems are connected in any way, they should be constructed so a failure in one system will not degrade the other. (Ref. I.C.C. Regulation, parts 190-197, August 1963.)

2. Every truck used to tow a vehicle with full air brakes should have a means of activating the towed vehicle's brakes.

3. In buses, the front wheels and rear wheels should have separate brake systems, so that even if the connection to one set of wheels breaks, the driver can still apply the brakes to the other wheels.

4. Brake tubing and hose should be mounted so fittings are accessible with ordinary hand tools.

5. All connections for air, vacuum, or hydraulic braking systems should be accessible to the operator.

6. All vehicles using air or vacuum brakes should have a reserve capacity or a reservoir that insures full braking even with the engine off.

7. Every air or vacuum reservoir should have a check valve so that leakage in the air or vacuum supply line will not deplete the reservoir. Means should be provided to determine that the check valve is in working order.

8. All vehicles with compressed-air brakes should have warning signals that operate continuously as long as pressure is below a fixed threshold pressure (not less than one-half the cut-out pressure of the compressor governor). These warnings should be designed so they are readily audible or visible to the driver. In addition, each vehicle should have a pressure gauge indicating the braking pressure in pounds per square inch.

9. All vehicles with vacuum brakes should have a readily audible or visible warning signal which gives continuous warning as long as the vacuum in the supply reservoir is less than eight inches of mercury. In addition, each vehicle should have a vacuum gauge indicating the braking vacuum in inches of mercury or pounds per square inch.

10. The master cylinder should be located where it is easily accessible for servicing.

11. Air reservoir drains should be readily accessible.

CANVAS AND ACCESSORIES

1. When cargo vehicles are used for troop transport or workspace, there should be between 60 to 75 inches of clearance between the tarpaulins and bows covering the bed and the cargo floor.

2. One man should be able to gain access to the cargo compartment within three minutes, from front or rear, with the tarpaulin and curtains in place.

3. Tarpaulin bows and ropes should be easy to unfasten, and bows should be designed so personnel wearing gloves can remove them from sockets under wet, muddy, or freezing conditions.

4. Tarpaulin bows (especially wooden ones) should be designed so moisture, rust, or dirt will not make them seize in their sockets.

5. Tarpaulins and cab tops should be shaped and supported so they shed debris and do not form water or ice pockets, whether the vehicle is operating or parked.

6. Cab tops, tarpaulins, and curtains should be protected from chafing and flapping.

7. Tarpaulin and cab-top bow sockets should have adequate drain apertures.

8. The cab should be designed so one man can convert it from open to closed type, and vice versa, in ten minutes or less.

9. Tarpaulins, end curtains, and bows should be designed so two men can remove or install them in ten minutes or less.

NOTE: The time restrictions in 8 and 9 above do not apply to heavy padded arctic cabs and enclosures.

10. Tarpaulins and end curtains should be fire resistant.

11. Pins and other retaining devices should have the largest working clearances that still assure they will be retained properly.

12. Pins and other retaining devices should be designed so men wearing gloves can remove and replace them.

13. There should be chains to keep retaining pins and devices from getting lost.

14. There should be provision for rolling up the sides of cargo-area tarpaulins to ventilate the troop area.

15. There should be space to stow stakes and bows on the vehicle.

16. Vehicles that transport troops should have safety straps at the rear of the vehicle.

INTRA-VEHICULAR COUPLING DEVICES

1. Coupling devices should be long enough that they do not restrict a vehicle's maneuverability when it tows another vehicle.

2. Coupling devices should be designed so normal use will not damage them.

3. Coupling devices should be designed so they cannot be mismated.

4. Vehicles with air-over-hydraulic brakes or air brakes should have provisions at front and rear for connecting to another vehicle's brake system and controlling its brakes while towing it.

5. There should be suitable precautions to protect intra-vehicular couplings from accidental disconnection, kinking, entanglement, dragging, abrasion, or pinching during operation.

6. Every full trailer should be coupled to the towing vehicle's frame with a safety chain or chains.

7. Chains or cables should be connected so the tow-bar will not drop to the ground if it fails.

8. Each chain or cable should have an ultimate strength at least equal to the gross weight of a loaded trailer being towed.

DRAINS AND VENTS

1. Drain valves should be accessible, dependable, and have simple operating mechanisms.

2. Vents and drains should be designed so mud, ice, or other foreign matter will not clog them.

3. Drain plugs and valves should be designed to resist seizing, whether they are open or closed.

4. All drain plugs should be the same size, if possible; if not, the number of different sizes should be minimized.

5. Drains should be designed so they empty lubricants and hydraulic fluids completely.

6. Fluids should drain to the outside of the vehicle, without falling on obstructions or splashing onto vehicle components. Draining of fluids should not require any special equipment.

7. Drains that purge pneumatic-system reservoirs should be readily accessible, and they should drain tanks completely.

8. Drains and vents should be located where crew members can clean and check them easily.

9. Drains and vents should be easy to identify. They should be located where they are easy to close and check before floating or swimming operations.

10. Floating or swimming vehicles should have an instruction plate giving locations for drains and vents, and procedures for operating them.

11. Vehicles that swim should have bilge pumps.

12. Regardless of whether they are open or closed, drains in the cargo body should remain flush to the surface in which they are located so they do not interfere with the loading, stowage, or unloading of cargo.

EXHAUST SYSTEMS

1. Exhaust systems should be built so they are leakproof. They should be mounted to the chassis securely, yet loosely enough that flexion between components will not damage them.

2. The exhaust pipe should be attached to the exhaust manifold securely, yet so it can be disconnected quickly. It should not interfere with removing the engine.

3. The exhaust system should be located or protected so personnel will not contact hot surfaces.

4. The exhaust system and vehicle should be designed to keep exhaust fumes from entering the cab and troop compartments.

5. The exhaust system should reduce exhaust noise. It should not heat tires unduly, disturb road dust, or clog in mud or in swimming operations.

6. A bus' exhaust system should discharge to the atmosphere at least six inches in front of the bus' rearmost part so that exhaust gases are not drawn up and into open rear doors or windows.

7. Exhaust systems should be designed to eliminate any safety hazard, such as starting grass fires when operating in areas of high grass.

ENGINES

1. Air cleaners should be located where they are easy to remove, service, and install. It should be possible to service them with OEM tools and equipment.

2. Engine-timing marks should be easily visible.

3. Engine-timing marks should have a visible reference point on the engine, so timing can be checked when the engine is installed in the vehicle.

4. Where required, an air-restriction gauge should be located where it is visible to the operator.

5. Vehicles should have engine over-speed governors.

6. Over-speed governors should be made tamper-proof.

7. Fan belts and other drives that require adjustment should be simple and readily accessible.

8. Removing oil-drain plugs should allow the pan to drain completely if the vehicle is on a level surface, so the operator does not have to move the vehicle.

9. Fuel and coolant pumps, starter motors, generators, filters, and other engine accessories should be accessible without removing the engine from the vehicle. It should be possible to replace any engine accessory without removing more than one other engine accessory.

10. It should be possible to remove the engine from the chassis without first removing engine accessories such as starters, generators, pumps, manifolds, etc.

11. Fuel and oil filters should be located where they can be cleaned and replaced without disassembling other parts of the vehicle.

12. Spark plugs should be located in an accessible place. It should be possible to remove them with OEM tools.

13. Ignition-system wiring should be mounted and routed so vehicle vibration or personnel cannot break connections accidentally.

14. Engines that use diesel or multi-fuels should be designed so it is easy to drain the primary fuel filter daily.

15. Engines used as electric or pneumatic power sources, and vehicular engines on radio-carrying vehicles, should have tachometers and hand throttles which can be locked at part-throttle positions.

FUEL SYSTEM

1. Neither the fuel tank nor its supports or intake pipe should project beyond the vehicle's overall width. Ideally, these components should be located slightly inward of its overall width.

2. As a precaution in case of collision, the fuel tank should not be forward of the front axle of the power unit it is on.

3. The fuel tank and its intake pipe must not be inside or over parts of the vehicle that carry passengers.

4. The fuel container should be designed so that, if the vehicle turns over, fuel will not spill faster than one ounce per minute.

5. The fuel system should be constructed so gravity or syphoning cannot feed fuel directly to the carburetor or injector.

6. Some specific features of tanks for liquid fuels are:

a. Excess-flow valve: When fuel is forced from the tank with pressure devices, there should be a safeguard to stop the flow of fuel if the fuel feed line breaks.

b. Fueling rate: Tactical and combat vehicles' fuel tanks that hold 50 gallons or more should be able to accept fuel at 50 gallons per minute. Tanks that hold less than 50 gallons should accept fuel fast enough to be filled in one minute.

c. Air vent: Every fuel tank should have a non-spill air vent. It may be mounted separately or combined with the filler cap or safety vent.

7. The fuel tank's liquid capacity should be marked on it.

8. The fuel-tank drain plug should be accessible and located so it can drain the fuel tank completely. Personnel should be able to remove it with OEM.

9. The nozzle opening in the fill-pipe should be outside the cab or body. Its location must minimize the likelihood of spilling fuel on the exhaust system or battery.

10. The fuel fill-pipe should never be more than four feet above the ground or above the base of the work platform used for refueling.

HORN

1. Where horns are required, they should produce complex sound in the audio frequency band between approximately 250 and 2,000 Hz. Its sound-pressure level between these frequency limits, measured three feet from the exit of the horn and on its axis, should be 110 decibels.

2. Sound-level measurement should be made with instruments that comply with the latest revision of American Standard Z 24.3-1944.

3. Sound level should be measured with the horn installed in the vehicle. There should not be any reflecting walls or obstacles (other than the ground) within 100 feet of the horn when its sound level is measured.

HEATERS

1. Refer to the environmental section (page 24) for heating and ventilation requirements.

2. Heaters should be located or protected so personnel cannot touch parts that are hot enough to cause burns.

3. Van heaters should be fastened securely so they will stay in place during normal use or in case the vehicle overturns.

4. Van heaters should be built so they will not come apart -- exposing parts like exhaust stacks, pipes, or conduits -- if the vehicle overturns.

5. Any heater that burns oil, gas, liquified petroleum gas, or any other combustible material, must discharge its combustion products outside the vehicle.

6. Cab heater controls should be accessible to the vehicle operator.

7. The heater's air inlet should be positioned so it cannot take in either engine or heater exhaust gases.

8. It should be possible to replace ignitors, resistors, and other "high-mortality" items without having to remove the heater from the vehicle.

LADDERS -- TRAILERS AND VANS

1. Ladders should be used as follows:

a. Be provided wherever personnel have to change elevation abruptly by more than 16 inches in operating or maintaining the vehicle.

b. Be designed, installed, or provided to give the most immediate and efficient access to and between work places.

c. Be built sturdily enough to support the combined weight of the most men (assuming 250 pounds per man) and equipment that will be on them at once.

d. Have nonskid surfaces wherever personnel will step, walk, or stand.

e. Have no obstructions, edges, notches, or burrs which could injure personnel or damage hoses and cables.

f. Be adequately marked against any dangers their use involves (e.g., unavoidable low overhead, possible shock, etc.).

g. Wherever possible, be designed so one man -- but never more than two men -- can carry, handle, and position the ladder.

2. More specifically, ladder designs should consider:

a. Limited spaces and clearances.

b. Probable environmental conditions, particularly whether the structure is likely to get wet, icy, or snowy.

c. The type, direction, and frequency of traffic.

d. Loads or other encumberances personnel must carry.

e. The configuration and weight of other equipment that may have to be moved over the ladder.

3. The primary basis for selecting a ladder is the slope it must have to get enough structural strength in the available space. Figure 11 shows the preferred and critical angles of incline for various structures.

4. When operational or maintenance vans will remain in one location for a period of time, stair ladders should be used.

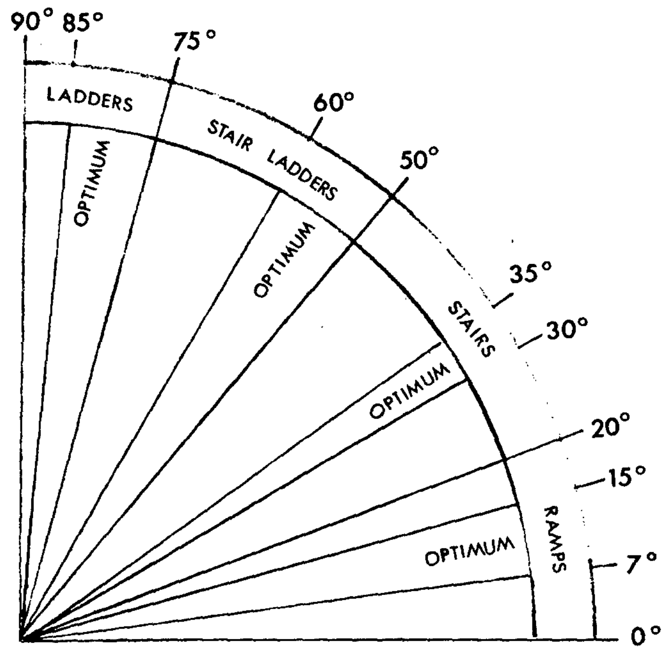


Fig. 11. INCLINE ANGLES FOR THE USE OF VARIOUS STRUCTURES

5. Ladders should have rubber-cleated, pivoted feet if used in non-freezing weather, and steel cleats if used in ice or snow.

6. Hinges and locks are preferable to bolts and nuts for assembling two-section extension ladders.

7. Catches and other mechanisms on folding ladders should be simple, easy to release, and easy to maintain, even for personnel wearing gloves (Fig. 3).

8. If one man must lift and store ladders manually, the ladder weights and lift distances from ground level should not exceed five feet for 25 pounds or six feet for 20 pounds.

9. Dimensions for stair ladders, fixed ladders and stairs are shown in Figures 12 and 13 and Tables 10 and 11.

TABLE 10

Stair-Ladder Dimensions

	Minimum	Maximum
A. Angle of rise	50°	75°
B. Tread depth		
For 50° rise	6"	10"
For 75° rise	3"	6"
C. Riser height	7"	12"
D. Height, step to landing	7"	12"
E. Width, handrail to handrail	21"	24"
F. Min. overhead clearance	68"	--
G. Height of handrail	34"	37"
H. Diameter of handrail	1.25"	1.75"
I. Min. hand clearance	3"	--

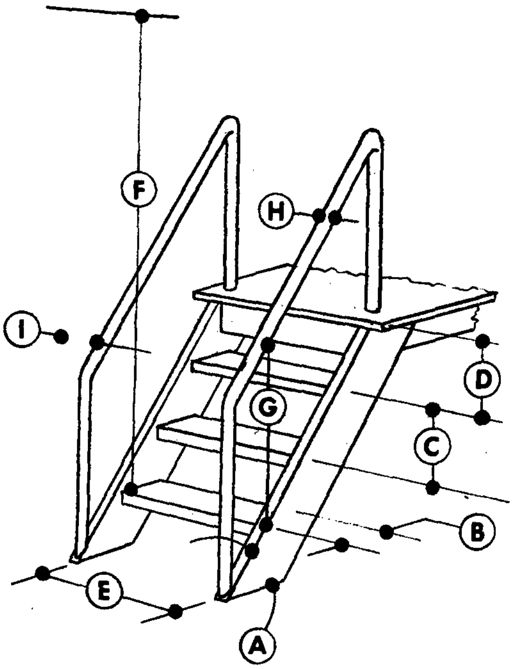


Fig. 12. STAIR-LADDER DIMENSIONS

TABLE 11

Fixed-Ladder Dimensions

	Minimum	Maximum
A. Angle of rise	75°	90°
B. Rung or cleat dia.		
Wood	1.00"	1.5"
Metal	.75"	1.5"
C. Rung spacing	9.0"	16.0"
D. Height, rung to landing	6.0"	16.0"
E. Width between stringers	12.0"	--
F. Climbing clearance width	24.0"	--
G. Min. clearance depth		
Back of ladder	6.0"	--
On climbing side	36" for 76°	30" for 90°
H. Height of string above landing	33.0"	--
I. Max. height of climb	--	10.0"

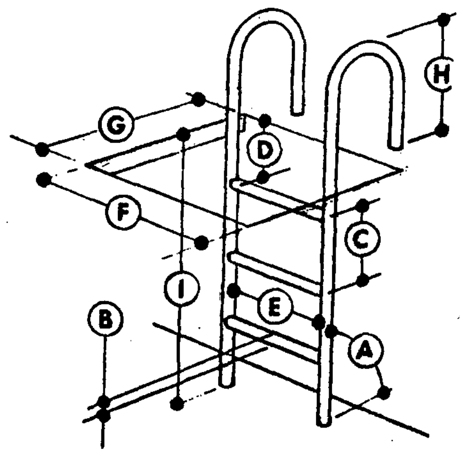


Fig. 13. FIXED-LADDER DIMENSIONS

LIGHTING SYSTEM

1. The headlights should allow the driver his choice of upper (bright) or lower (dim) distribution of light.

2. The regular headlight beam should be aimed straight ahead and so that, 25 feet away, the top of the high-intensity zone will be two inches below the lamp's height.

3. Headlights should be mounted so they will illuminate at least 500 feet of the road in clear atmospheric conditions.

4. The lighting system should be designed so driving lights and turn signals cannot be used when the blackout lighting system is on.

5. Reflectors should be mounted between 24 inches and 60 inches above the ground.

Blackout Lighting System

1. The blackout-light source and its housing should be mounted on the left-hand side of the vehicle, as far forward and aimed as near the driver's line-of-sight as practicable.

2. On a level road, the blackout beam should be 30 feet wide at a point 20 feet in front of the vehicle (decreasing density from 20 feet to a point 100 feet in front of the vehicle), with the top of the beam directed at least one degree below the horizontal.

3. Blackout marker lights should follow MIL-L-3976.

MIRRORS

1. Where there are two rear-vision mirrors, they should be located so the driver can look backward along both sides of the vehicle.

2. Mirrors should be braced and clamped so vibration will not obscure the view.

3. Buses with front-engine compartments should have cross-over mirrors (for viewing areas forward and to the side of the driver's position) mounted in front of them

RADIATORS

1. The radiator filler neck should be large enough to accept existing fillers.

2. The filler neck should be positioned so the operator can see the fluid level inside the tank. He should not have to add fluid to determine the fluid level.

3. There should be an accessible drain in the radiator's lower tank to drain it completely.

4. There should be a guard or grill to protect the radiator during travel through brush and during maintenance.

5. It should be possible to remove the radiator without having to remove the engine first.

6. Coolant tubing and hose should be:

a. Designed, constructed, and installed to insure they will continue functioning properly.

b. Sufficiently long and flexible to accommodate all normal motions of the parts they are attached to without damage.

c. Mounted so they are secure from chafing, kinking, or other mechanical injuries.

d. Mounted so clamps are accessible.

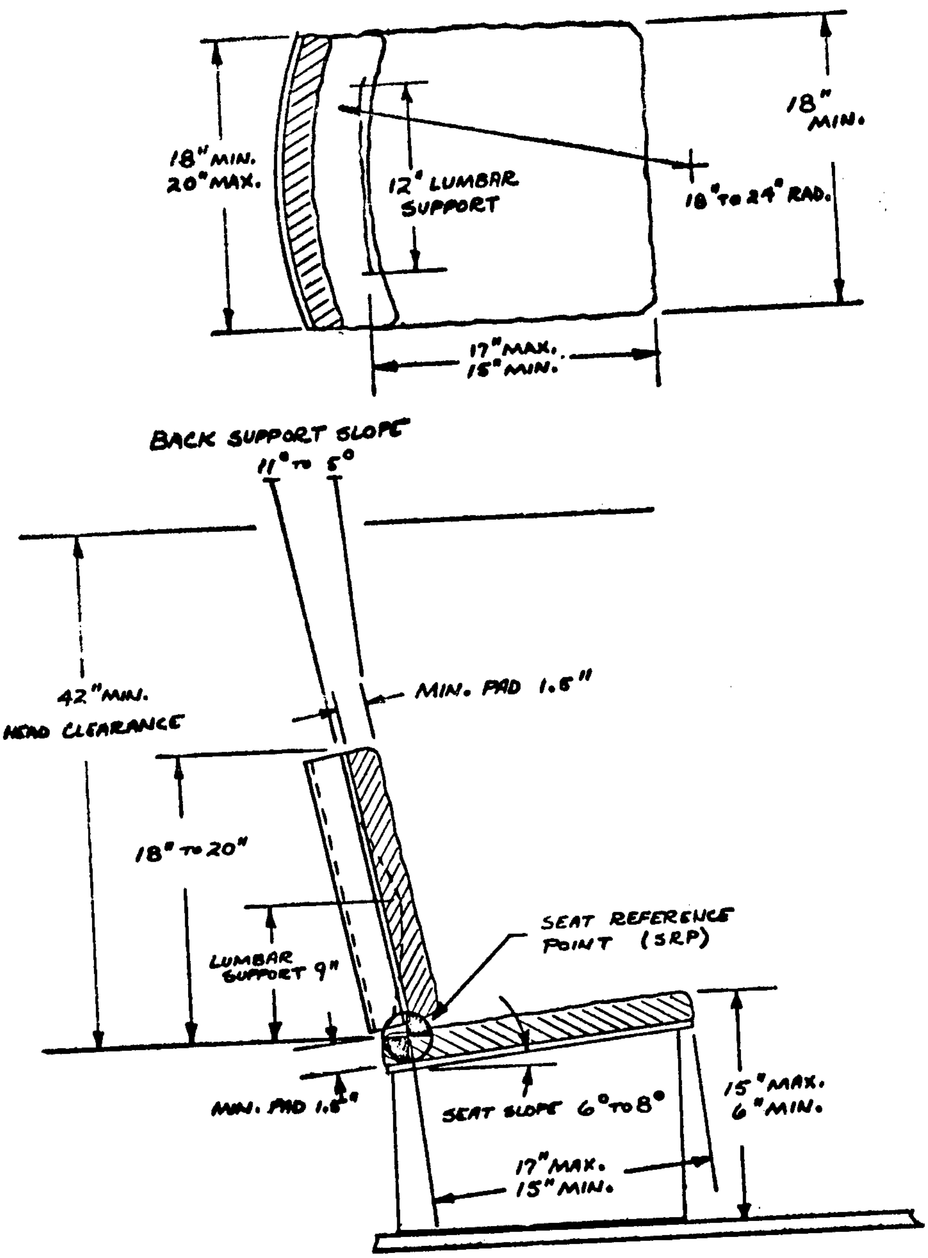


Fig. 14. DIMENSIONS FOR VEHICLE OPERATOR'S SEAT

SEATING

1. Seating for vehicle operators should follow the dimensions recommended in Figure 14.

2. If the seat's height above the floor is variable, requirements for leg room and foot rest will also vary. When the seat is adjusted higher, there will be more leg room and larger foot-rest angles.

3. Seats should adjust at least four inches in the fore-aft direction.

4. Back-rest angle should not be more than 105 degrees from horizontal.

5. If only the lumbar area is supported, the back-rest's angle of tilt should be 95 degrees to 100 degrees for operators in an alert position.

6. The seat pan should be flat. It should be made from a rigid material.

7. Seat padding should be kept to a minimum, but it should be resilient enough to keep the operator's body from contacting the seat bottom during severe vibration.

8. Seat padding made of foam-type material should be adequately ventilated.

9. There should be safety seat belts on all administrative-type vehicles.

10. The front edge of troop seats in the vehicle's cargo area should not be higher than 16 inches from the floor.

11. How deep cargo-area seats should be depends on the vehicle's mission; if personnel must wear packs, the seat should be at least 16 inches deep.

TIRES

1. The spare tire and tools for servicing it should be readily available. One man should be able to remove and stow a tire with OEM only.

2. Vehicles with air-over-hydraulic brake systems should have a pneumatic outlet and OEM pressure gauge for adjusting tire pressures.

3. The air hose should be long enough to reach all the tires, including the spare, from the air compressor on the same vehicle or another vehicle.

4. When there is no spare tire, the vehicle should have a "limp-home" device (to temporarily take on the function of the flattened tire) that will permit it to continue traveling for 50 miles after the tire failure.

5. It should be possible to inflate and check the spare tire with a standard air gauge without removing the spare tire from its mounting.

6. Dual-wheel tires should be designed so both outer and inner tires can be inflated and checked. Valves should be located so tires can be inflated and checked when they are interchanged.

7. Equipment for stowing and unstowing spare tires should be simple to operate and safe to use.

8. It should be possible to remove and replace the spare tire with the vehicle fully loaded.

WINDOWS

1. In addition to the windshield area, closed-cab vehicles should have at least one glass window or curtained aperture on each side of the driver's compartment.

2. Every bus that seats eight or more passengers should have adequate provision for passengers to escape through windows.

3. Each push-out window or other escape window should be clearly identified as such by prominent, legible signs, lettering, or decals. These markings should tell how to open the emergency exit.

WINDSHIELDS

1. Windshields should be flat glass sections wherever possible.

2. When windshields must be curved, the curve radius should be large to reduce distortion.

3. The critical visual area extends to, and often beyond, the vehicle's left corner post. It is better to use a narrow corner post -- 1 1/2 to 2 inches -- than to use a wrap-around windshield which severely distorts important visual areas.

4. Buses should have two sun visors, one to shield each half of the windshield, as standard equipment. Sun visors should be constructed to "fit" the areas they shield. Designers should especially avoid sun visors that leak light around the edges, which can be more annoying than no shielding at all.

5. Buses should have a strip of transparent filter material (generally green) along the top of the windshield, to reduce glare without totally blocking vision.

WINDSHIELD WIPERS

1. Use electrically operated windshield wipers, rather than vacuum-operated wipers.

2. Windshield-wiper motors should be at the bottom of the windshield.

3. Windshield wipers should return to the bottom of the windshield when they are turned off.

4. There should be an emergency handle for operating the windshield wipers manually if necessary.

5. Windshield wipers should clean the areas of the windshield that the driver must see through to operate his vehicle adequately.

CONTROLS

GENERAL

1. Handles, levers, pedals, knobs, and wheels should be designed so personnel ranging from the 5th through the 95th percentile in size, wearing arctic clothing, can operate them effectively.

2. There are two kinds of controls: discrete and continuous.

   a. Discrete controls can be set at any of several fixed positions.

   b. Continuous controls can be set at any position between the control's extremes.

3. All controls should be designed, oriented, and located in accordance with normal work-habit patterns, customary reactions, and human reflexes.

4. Certain stereotyped relationships between controls and displays should be followed to take advantage of the man's previous learning, maximize transfer of training, and minimize error (Table 12).

TABLE 12

Conventional Control Movements

Function	Direction of Movement
On	Up, right, forward, clockwise, pull (push-pull-type switch)
Off	Down, left, rearward, counterclockwise, push
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up, back
Lower	Down, forward
Retract	Up, rearward, pull
Extend	Down, forward, push
Increase	Forward, up, right, clockwise
Decrease	Rearward, down, left, counterclockwise
Open Valve	Counterclockwise
Close Valve	Clockwise

5. The direction a control moves in should be consistent with the direction the controlled object moves in.

6. Controls should be distributed so that no one limb will be overburdened.

7. Controls used most frequently should be placed between elbow and shoulder height. Where "blind" reaching is a requirement, the control should be located forward and slightly below elbow height.

8. Operating controls, instruments, and vision devices should be placed so their accessibility reflects their importance and frequency of use.

9. The most important controls may not be the ones that are used most frequently; therefore, the control's criticality must also be considered.

10. Controls used to perform the same function for different but closely associated equipment should be consistent in size and shape.

11. Functionally similar or identical primary controls should be arranged consistently from panel to panel and from operating position to operating position.

12. Controls should have labels (on panel or control) that:

a. Identify the control function.

b. Give the method of operation, if it is not obvious.

13. Controls should be coded so they can be identified easily by sight or touch, or both; controls may be distinguished from each other by color, size, shape, or location.

14. Using one control should not interfere with using another control unless they are purposely interlocked in sequence.

15. Controls should be designed and located so that they cannot be operated accidentally.

16. When operating critical controls can be dangerous to equipment or personnel, the controls should be guarded appropriately to prevent accidental operation.

17. Several methods can be recommended for guarding a control against accidental operation:

a. Separate it from the area used in the normal sequence of control movements.

b. Recess it or place physical barriers around it.

c. Cover it.

d. Interlock it so personnel must make an extra movement to operate it, or operate another control first.

e. Select controls that can be operated only by definite or sustained effort.

18. With proportional controls, including engine throttles, the force and movement of the control should parallel the action of the device which is controlled.

19. Proportional controls should not have off positions (dead spots), but control action may be disproportionately rapid where settings are not critical, or disproportionately slow where personnel must make fine adjustments.

20. Controls that are located and operated conventionally should have conventional purposes. Also, they must not require peculiar or unique coordination for proper, safe operation (e.g., brakes or shift).

21. Control locations and movements should be consistent for all the equipment the operator uses. There should be a logical relation between a control's location and movement, and the action of the equipment it controls.

22. Control operations should require a minimum of movements, particularly with gear shifting.

23. In successive control movements, the operator's hand should pass easily from sequence to sequence with a minimum change in position or direction.

24. Controls used in a rapid sequence should all operate in the same direction.

25. Control settings should be easy to find and identify.

26. Control knobs should be placed where personnel can operate them without covering associated indicators, particularly if operators must wear arctic clothing.

27. Control reference positions, such as neutral or maximum limits, should be indicated positively, so they are obvious even under blackout conditions.

28. Discrete controls, such as the gear-ratio selectors, should be marked so that at least every other step is identified.

29. Hand-operated controls should be positioned so they can be operated easily. There should be clearance for inserting and removing hands and for operating controls while wearing arctic mittens.

30. Performance envelopes -- the three-dimensional spaces an operator needs to perform assigned tasks -- must be adequate.

31. Neither the operator's use of controls nor their proper functioning should be affected detrimentally by the vibration of the vehicle.

32. Mechanical transmission controls, such as gear-shifting and parking-brake controls, should not be affected by dirt, mud, or ice.

33. Manual steering should be adequate for the driver to stop the vehicle safely and drive it slowly without any power assist.

Considerations in Selecting Controls

1. It is important to consider two basic factors in designing or selecting control devices:

a. Compatibility between the control's movement and location and those of the element it controls.

b. The operator's efficiency in using combinations of controls and displays.

2. When the primary considerations in selecting a control are its operating force and range of settings, use the recommendations in Table 13.

TABLE 13

Recommended Manual Controls

Actuation Force	Control Function	Control Type
Small	2 Discrete Positions	Key Lock Push Button Toggle Switch Legend Switch
	3 Discrete Positions	Rotary Selector Switch Toggle Switch
	4 to 24 Discrete Positions	Rotary Selector Switch
	Fine Adjustment	Crank Continuous Rotary Knob
Large	2 Discrete Positions	Foot Push Button Hand Push Button Detent Lever
	3 to 24 Discrete Positions	Detent Lever Rotary Selector Switch

3. The basic information designers need to select the proper control will include:

a. The control's function, purpose, and importance to the system; the nature of the controlled object; the type of change to be made, and its extent, direction, and rate of change.

b. The task's requirements -- precision, speed, range, and force required to use the control; and how the system is affected by sacrificing in one of these areas to improve another.

c. The information the operator needs, including his requirements for locating and identifying the control, determining its setting, and sensing any change in its setting.

d. The amount and location of space where the control can be placed.

e. The importance of locating the control in a certain position for proper grouping or proper association with other controls and displays.

4. Hand-operated controls should be used for rapid or precise adjustments.

5. When operators must make precise settings over a wide range, use multi-turn controls.

6. When the controlled object can be adjusted only in a limited number of discrete steps, use discrete-adjustment (detent) controls, rather than continuous-adjustment (non-detent) controls.

7. Controls may be combined to aid sequential or simultaneous operation, to reduce reaching, or to save space. However, designers should minimize the possibility of accidental operation.

8. Use foot-operated controls when the man must apply large or continuous forward forces. There should not be more than two foot controls, no matter how simple, for each foot.

MANIPULATION AND SEPARATION OF CONTROLS

1. The driver's control mechanisms should be located on the left side of the cab.

2. The driver should have support if he must make fine or continuous adjustments:

a. At the elbow (for gross hand movements).

b. At the forearm (for fine hand movements).

c. At the wrist (for finger movements).

3. When the operator uses controls to supervise an operation, locate them where he can supervise continuously while he operates them.

4. How far controls should be separated depends on many factors:

a. Whether the controls are used sequentially or simultaneously.

b. Size of the control.

c. Range over which the control travels.

d. Cues available for judging the control's setting. (Location deserves special consideration when the operator's vision is restricted.)

e. How quickly operators must locate and activate the control.

f. How much vibration there is in the operator's compartment or area.

g. Kind of grasp required to operate the control (fingers versus hand grasp).

h. Operator encumbrances (gloves, harnesses, etc.).

i. Likelihood and consequences of operating controls accidentally.

j. Amount of force required to operate controls.

5. Individual control positions depend partly on how they are used, as well as on restrictive garments, harnesses, belts, gloves, etc.

6. For blind locating -- that is, finding and grasping the control without seeing it -- individual controls on a panel must be separated at least five inches if they are in the optimum reaching area directly in front of the operator.

7. When controls are at the man's farthest reach and he must locate them blindly, they should be as far apart as possible within a maximum of 12 inches.

8. When the man can use incidental or casual visual cues to find controls, and he uses them in random time sequence, with just one hand, the separations between them should be as follows:

a. Minimum separation = two inches.

b. Desired separation = four inches.

c. These separations are measured between the nearest edges of two controls.

d. When the man must operate a functional group of several levers at once, with one hand, the end levers must not be more than six inches apart.

9. The operator should be able to manipulate the following controls from his normal driving position without strain: steering controls, gear-selection levers, engine controls, brake controls, rear-view mirror adjustment, clutch, and communication controls.

10. The steering wheel should be positioned for easiest operation. There should be at least four inches between its outer edge and the nearest projection from vehicle or equipment.

11. Design foot pedals so an operator can rest his foot on them without operating them.

DESIGN CHARACTERISTICS

Design characteristics for controls are described in Figures 15 through 23 and Tables 14 through 22.

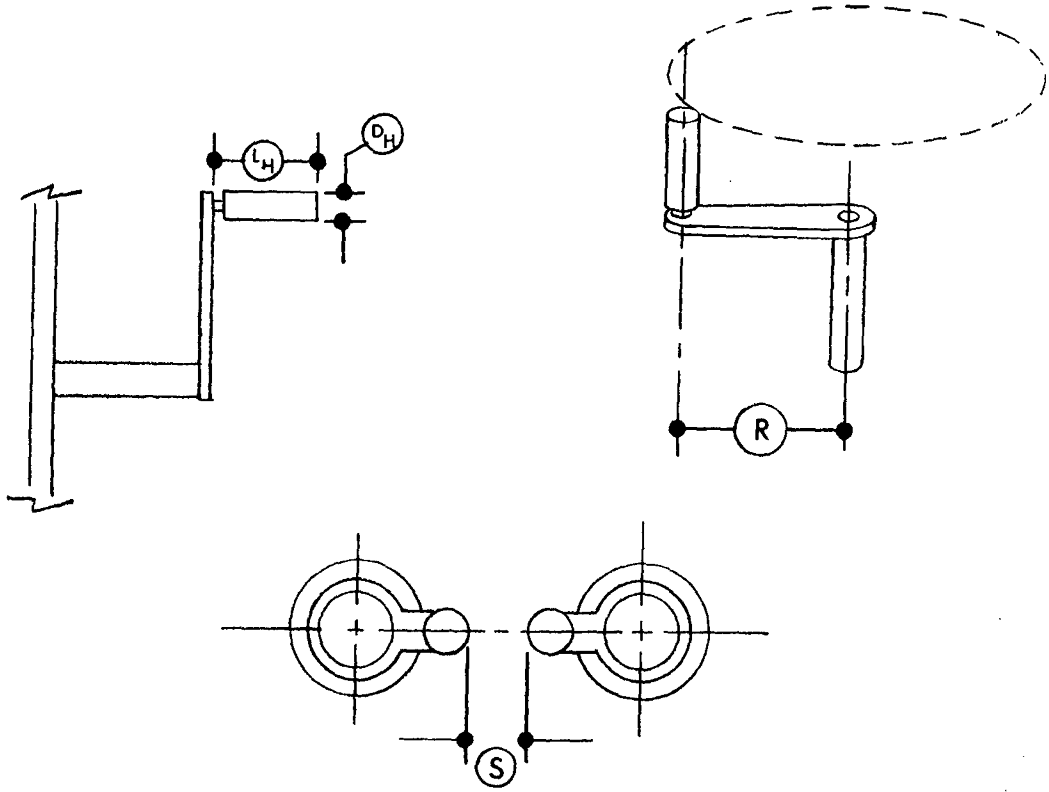


Fig. 15. CRANKS

TABLE 14

Cranks

Turning Rate Required (revolutions per minute)	Handle Dimensions: Diameter (D_H)	Handle Dimensions: Length (L_H)	Turning Radius (R): Min.	Turning Radius (R): Max.	Separation (S): Min.	Separation (S): Max.	Torque: Min.	Torque: Max.
None	1.0"	3.75"	9.0"	16"	3"	--	2 lb.	50 lb.
175	1.0"	3.75"	5.0"	8.0"	3"	--	6 lb.	15 lb.
275 (max.)	0.5"	1.5"	0.5"	4.5"	3"	--	2 lb.	5 lb.

HAND CRANKS

1. Cranks should be used primarily when the control must be rotated many times.

2. Handles should be shaped so the area of contact with the hand is as large as possible.

3. Handles should turn about their shafts freely.

4. For standing operators, handles should be between 36 and 48 inches above the floor.

5. If the fastest cranking speed is more than twice the slowest, the operator should have a choice of two gear ratios.

6. The outside edge of the crank handle should be at least three inches from any obstruction.

7. Cranks which must be turned rapidly should be mounted so their turning axes are between perpendicular to and 60 degrees from the body's frontal plane.

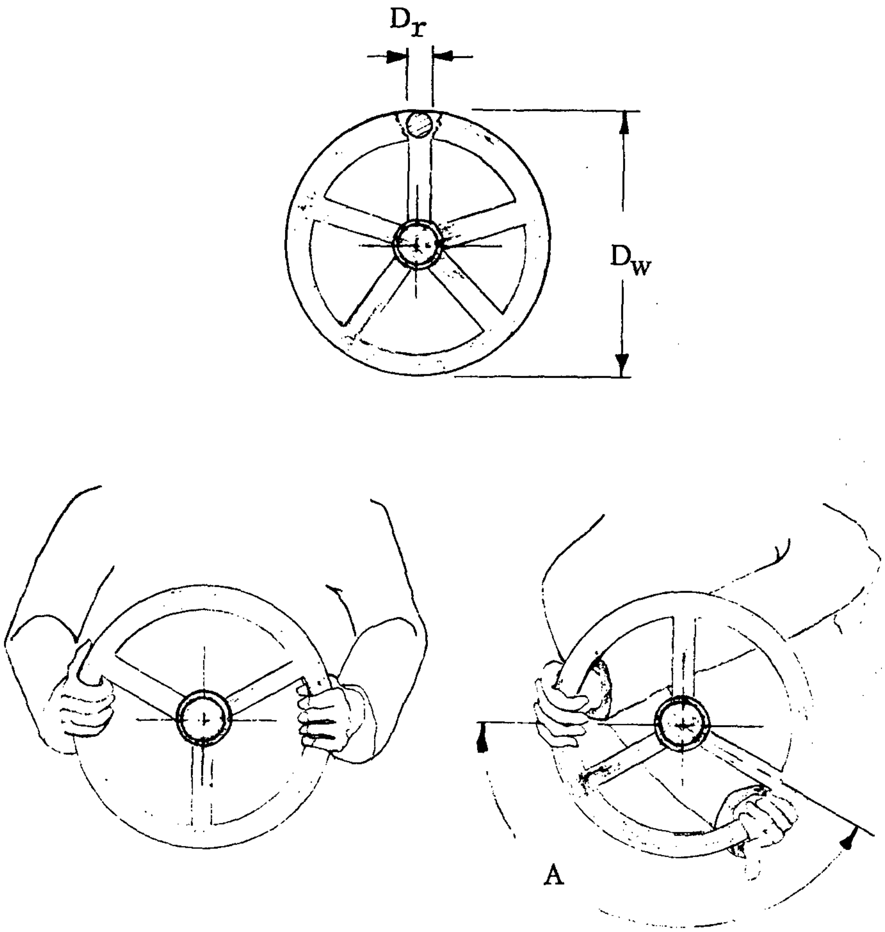


Fig. 16. HANDWHEELS

TABLE 15

Handwheel Dimensions

	Wheel Diameter (D_W)		Rim Diameter (D_r)		Displacement (A)		Resistance	
	a*	b	a	b	a	b	a	b
Minimum	2.0"	7.0"	0.75"	0.75"	--	--	5 lb.	5 lb.
Maximum	4.25"	21.0"	2.0"	2.0"	--	120^{o}	30 lb.	50 lb.

* a -- One-hand operation.
b -- Two-hand operation without releasing wheel.

HANDWHEELS

1. Use handwheels when the starting or rotational forces are too great for a one-hand control.

2. Handwheels that can be turned only with two hands should not turn more than 120 degrees.

3. Gripping surfaces should be indented or knurled for more positive grasping.

4. Handwheels should rotate clockwise for on, right, or increase; counter-clockwise for off, left, or decrease.

5. A valve is considered a handwheel.

6. Direction of motion should be indicated on handwheels, or next to them, with double-ended arrows and appropriate legends.

7. Handwheel-type valves should operate conventionally. Direction of movement should be shown by double-ended arrows, with the arrow tips marked "open" and "close."

8. All valve handles should have labels that clearly indicate their functions, as well as the direction of movement.

9. If a handwheel interferes with vision, and if it turns one full revolution or less, the part of it that is not needed for firm hand grasp may be cut away.

10. A spinner handle may be attached to the handwheel if many rotations are required.

11. Use multirotation controls for high precision over a wide range of adjustments.

12. Handwheel dimensions should be as shown in Table 15.

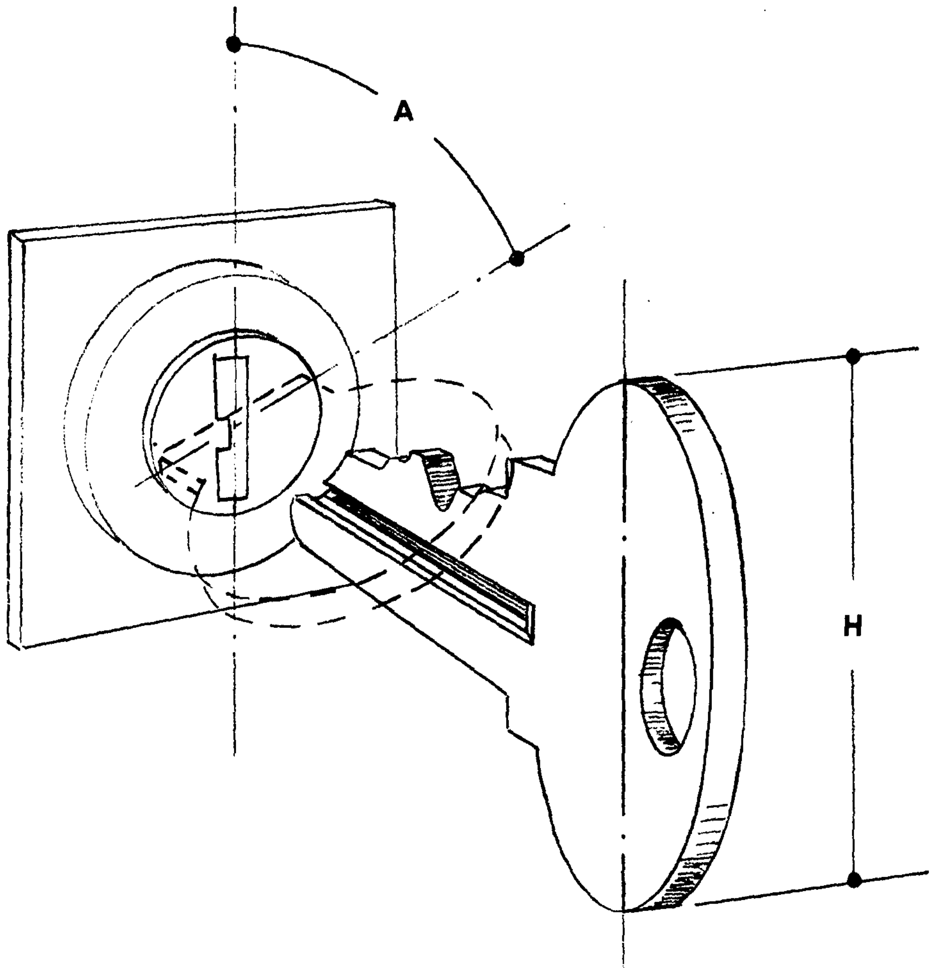


Fig. 17. Key-Operated Switch

TABLE 16

Key-Operated-Switch Dimensions

	Displacement (A)	Height (H)	Resistance
Minimum	30^{o}	0.5"	12 oz.
Maximum	90^{o}	3.0"	48 oz.

KEY-OPERATED SWITCH

1. Keys should be shaped so the proper way to insert them is obvious.

2. Keys with a single row of teeth should be inserted into the lock with the teeth pointing up or forward.

3. If keys have teeth on both edges, they should fit the lock with either side up.

4. Locks should be oriented so the key's vertical position is the off position.

5. Operators should not be able to remove the key from the lock unless the switch is turned off.

6. "On" and "off" positions should be labeled.

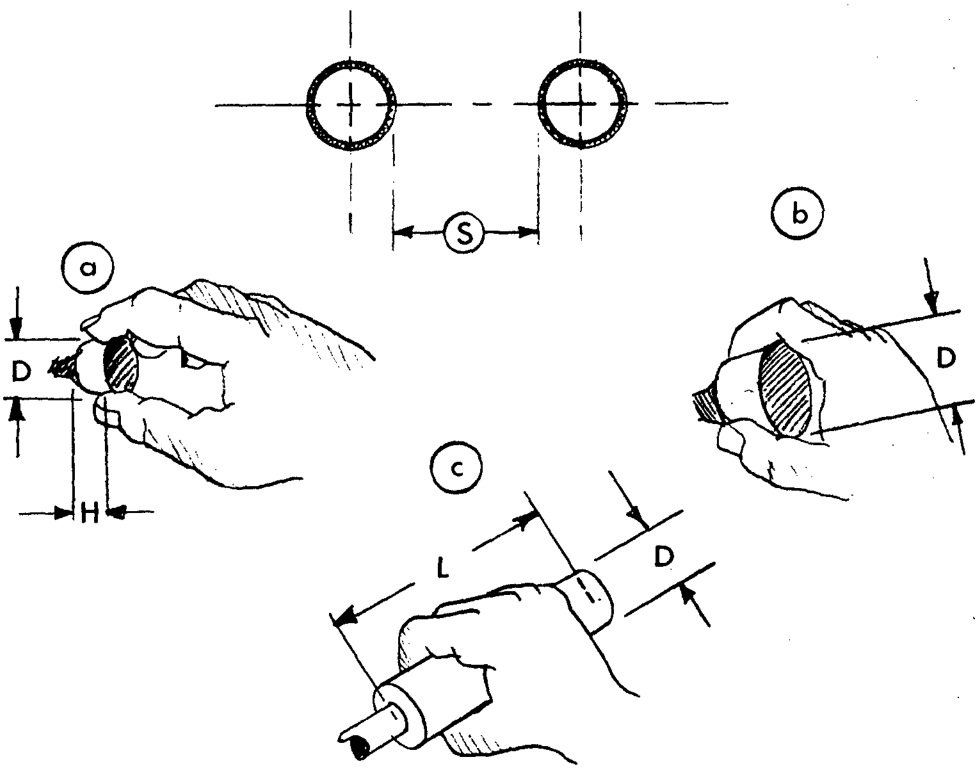


Fig. 18. KNOBS

TABLE 17

Knob Dimensions

	Fingertip Grasp (a)		Thumb & Finger Encircled (b)	Palm Grasp (c)		Separation (S)		Resistance	
	Height (H)	Diameter (D)	Diameter (D)	Diameter (D)	Length (L)	One Hand Individually	Two Hands Simultaneously	Small Knob[a]	Large Knob[b]
Minimum	0.5"	0.375"	1.0"	1.5"	3.0"	1"	3"	--	--
Optimum	--	--	--	--	--	2"	5"	--	--
Maximum	1.0"	4.0"	3.0"	3.0"	--	--	--	4.5 oz. in.	6.0 oz. in.

[a] Knobs one inch in diameter or smaller.

[b] Knobs larger than one inch in diameter.

KNOBS

1. Knobs or continuous rotary controls are used to make continuous changes or adjustments.

2. Use knobs where operators must make precise, accurate adjustments of a continuous variable with little force.

3. Knob diameters should be larger when it takes more force to operate the control. When two or more knobs are mounted concentrically on the same shaft, use the larger knob for fine adjustments and the smaller knobs for coarse adjustments.

4. Knobs should be serrated or knurled so the operator's fingers will not slip.

5. Knurled and serrated knobs should be designed so that, if the shaft sticks, the operator will not injure his hands.

6. Knobs which perform the same function should have the same shape.

7. Knobs should have enough resistance that inadvertent touching or accidental forces like vibration will not change settings.

8. On geared-down vernier knobs and indicators, like those for tuning radios, the pointer should move at least 1.5 inches for every complete revolution of the knob.

9. Choke and throttle controls should have diameters between 3/4 inch and 2 1/2 inches, with a resistance not to exceed two pounds.

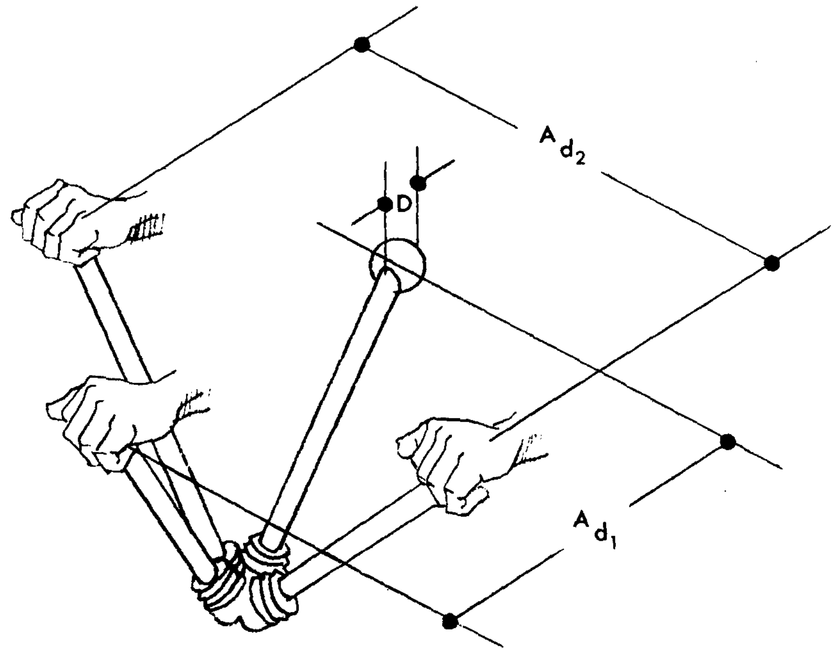


Fig. 19. LEVER/JOYSTICK

TABLE 18

Lever/Joystick

	Diameter (D)		Displacement (A)		Resistance (d1) (forward)		Resistance (d2) (lateral)	
	Finger Grasp	Hand Grasp	Forward (d1)	Lateral (d2)	Using one Hand	Using two Hands	Using one Hand	Using two Hands
Minimum	0.5"	1.5"	--	--	2 lb.	2 lb.	2 lb.	2 lb.
Maximum	3.0"	3.0"	14"	38"	30 lb.	50 lb.	20 lb.	30 lb.

LEVER/JOYSTICK

1. Use levers for large displacements or for applying large amounts of force.

2. When levers are close together and may be confused, the lever handles should be coded by shape.

3. When levers are mounted perpendicular to the floor, their handles should be between the operator's waist and shoulders.

4. When levers are mounted parallel to the floor, their handles should be 28 inches above the floor, where a standing operator can exert his greatest lifting force.

5. For greatest accuracy, the operator should push levers, rather than pull them.

6. When the man must operate a lever mounted in front of him quickly, it should move in a fore-aft direction.

7. When a lever must move from side to side, right-handed men can exert more force pushing leftward with their right hands.

8. When a group of levers in front of the operator pivots about in a common axis, or relatively close axes, all the levers should move in a fore-and-aft direction.

9. Discrete-position levers should have detents.

10. If men must make fine adjustments with small levers (e.g., joysticks), they should have support:

   a. Elbow support for gross hand movements.

   b. Forearm support for small hand movements.

   c. Wrist support for precise finger movements.

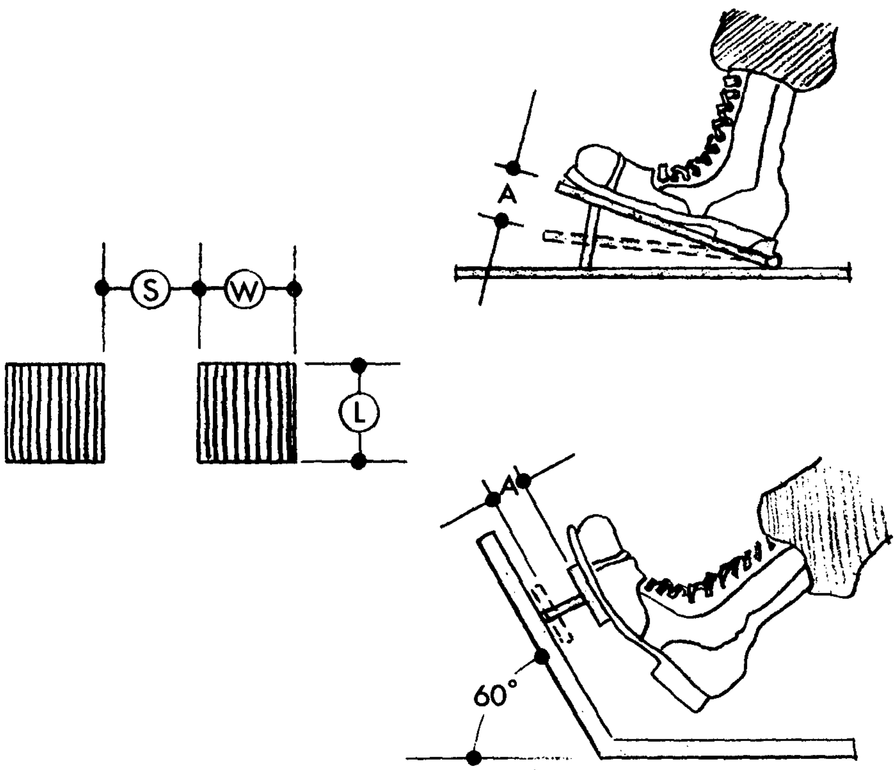


Fig. 20. PEDALS

TABLE 19

Pedals

				Displacement (A)				Resistance		
	Length (L)	Width (W)	Separation (S)	Normal Operation	With Heavy Boots	Ankle Flexion	Total Leg Movement	Foot Resting On Pedal	Ankle Flexion Only	Total Leg Movement
Minimum	1.0"	3.0"	4.5"	0.5"	1.0"	1.0"	1.0"	10 lbs.	10 lbs.	10 lbs.
Maximum	--	--	--	2.5"	2.5"	2.5"	7.0"	20 lbs.	20 lbs.	200 lbs.

PEDALS

1. Use foot-pedal controls for large displacements or applying a great deal of force.

2. There should be enough spring tension that an operator can rest the weight of his foot on the pedal without operating it.

3. The operator's leg motion should be simple and direct; it should not require delicate or complex movements.

4. There should be a non-skid surface on the face of the pedal and on the heel plate, or the pedal should be made of ribbed rubber, so the operator's foot will not slip.

5. The accelerator and brake pedal should be at least 4 1/2 inches apart.

6. When the brake pedal is depressed fully, it should project at least 1/4 inch above the accelerator.

7. For an operator to exert maximum force, his thigh should be 20 degrees from horizontal and his knee no more than 165 degrees from horizontal when the pedal is at the end of its travel.

8. Accelerators should not move more than 20 degrees between idling position and full depression; slightly more than 1 1/2 inches movement is most desirable.

9. The accelerator's pressure against the operator's foot should, ideally, be 8.8 pounds.

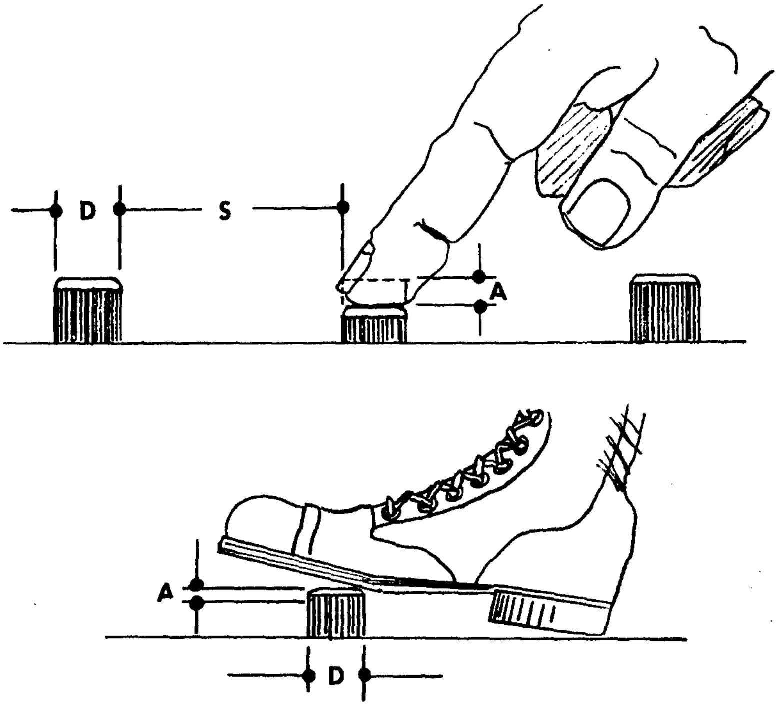


Fig. 21. PUSH BUTTONS

TABLE 20A

Hand Push Button

	Diameter (D)		Displacement (A)	Resistance		Push Button Separation (S)		
	Fingertip Operation	Thumb or Heel-of-Hand Operation	Thumb or Finger Operation	Fingertip Operation	Little-Finger Operation	Single-Finger Operation	Single-Finger Sequential Operation	Operation by Several Fingers
Minimum	0.375"	0.75"	0.125"	10.0 oz.	5.0 oz.	1.00"	1.00"	1.00"
Maximum	0.75"	--	1.500"	40.0 oz.	20.0 oz.	--	--	--

TABLE 20B

Foot Push Button

	Diameter (D)	Displacement (A)				Resistance	
		Normal Operation	Heavy-Boot Operation	Ankle Flexion Only	Total Leg Movement	Foot Will Not Rest on Control	Foot Will Rest on Control
Minimum	0.50"	0.50"	1.00"	1.00"	1.00"	4.0 lbs.	10.0 lbs.
Maximum	--	2.50"	2.50"	2.50"	4.00"	20.0 lbs.	20.0 lbs.

PUSH BUTTONS

1. Use finger or hand push buttons to make momentary contacts or to activate locking circuits which are used very frequently.

2. Push buttons should have feedback cues -- a definite feel and an audible click -- to tell the man that the push button is activated.

3. Push buttons should have an elastic resistance that increases gradually, then suddenly drops when the control is activated.

4. After the man operates a push button, he should get definite feedback (a visual or auditory indication) of the equipment response.

5. Push buttons should have a concave surface that fits the shape of the finger. Flat push buttons, if used at all, should at least have non-slip surfaces.

6. There are several ways to protect push buttons from accidental operation:

   a. Channel or cover guards.

   b. Flush mounting.

   c. Recessed mounting.

   d. Mechanical or electro-mechanical interlocks.

   e. Button guards.

7. Use foot push buttons if the operator will probably be using both hands when he needs to operate the push button.

8. Foot push buttons are apt to be operated accidentally; avoid using foot push buttons if inadvertent operation can have serious consequences.

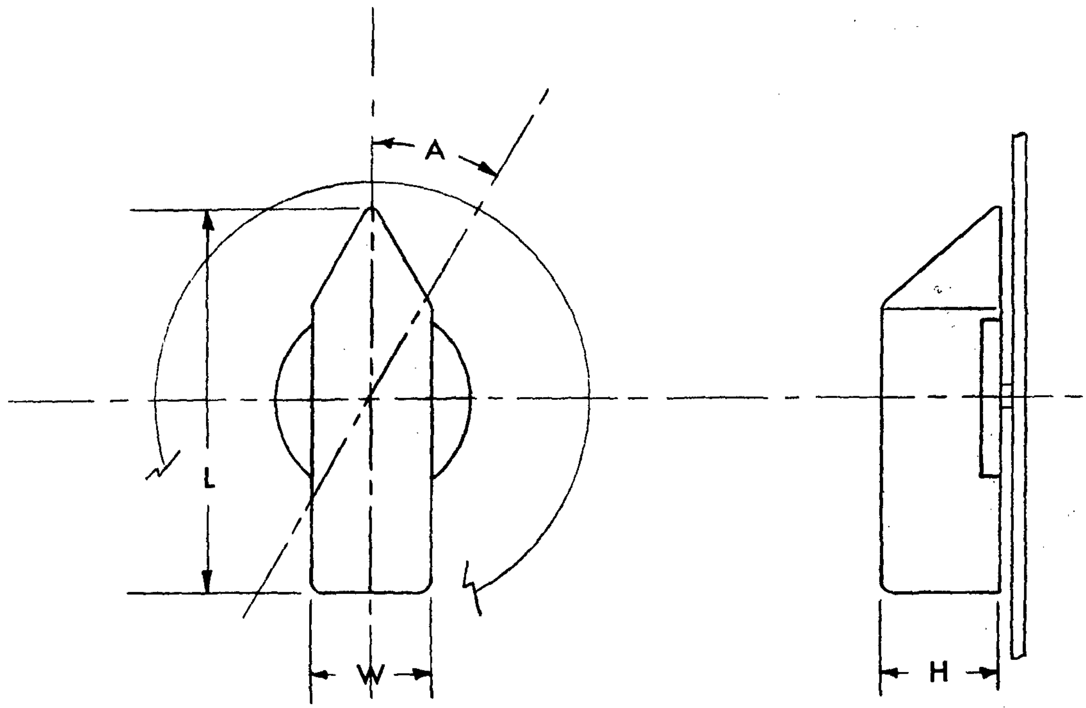


Fig. 22. ROTARY SELECTOR SWITCH

TABLE 21

Rotary Selector Switch

	Length (L)	Width (W)	Depth (H)	Displacement (A) Visual Positioning	Displacement (A) Non-visual Positioning	Resistance
Minimum	1.0"	--	0.5"	15^{o}	30^{o}	12 oz.
Maximum	4.0"	1.0"	3.0"	45^{o}	45^{o}	48 oz.

ROTARY SELECTOR SWITCH

1. Rotary selector switches should not have positions that are 180 degrees apart; such positions could be confused if the operator looked at the wrong side of the knob.

2. Switch positions should be between 15 degrees and 45 degrees from each other.

3. If operators must set rotary selectors without seeing them, the positions should not be closer than 30 degrees.

4. Switches should be designed so their detents offer enough resistance to movement that settings can be made by feel, without looking at them.

5. No rotary selector should have more than 24 positions.

6. There should be stops at both ends of the range of positions, unless the selector switch is continuously sequenced through 360 degrees.

7. Turning a selector switch clockwise should increase the numerical or alphabetical value associated with it.

8. Rotary selector switches should be designed so they cannot stop between positions.

9. Knobs on rotary selector switches should have pointers that move against a fixed scale.

10. Moving-pointer knobs should be bar-shaped, with parallel sides; the index end should taper to a point.

11. The pointer knob should be close to the scale, to minimize parallax.

12. The resistance of selector switches should be measured at the tip of the knob's pointer.

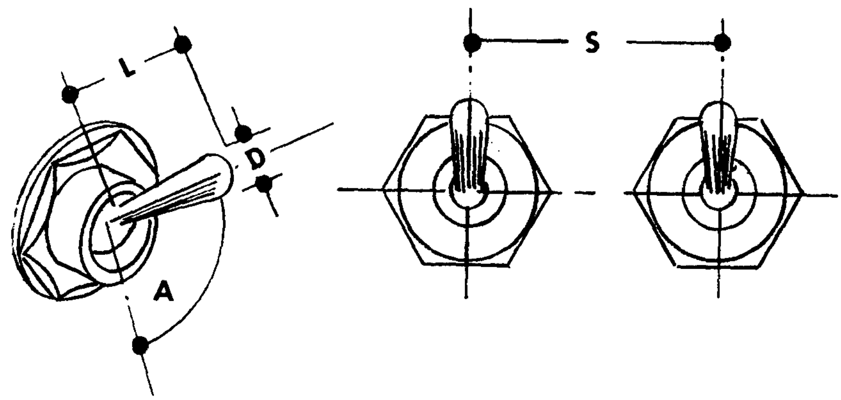


Fig. 23. TOGGLE SWITCHES

TABLE 22

Toggle Switches

	Displacement (A)	Arm Length (L) Bare Finger	Arm Length (L) Gloved Finger	Control-Tip Dimension (D)	Resistance Small Switch	Resistance Large Switch	Toggle-Switch Separation (S) Single-Finger Operation Lever-Lock Toggle Switch	Toggle-Switch Separation (S) Single-Finger Sequential Operation	Toggle-Switch Separation (S) Simultaneous Operation by Different Fingers
Minimum	30°	0.5"	1.5"	0.125"	10 oz.	10 oz.	0.75"	0.5"	0.625"
Maximum	120°	2.0"	2.0"	1.0"	16 oz.	40 oz.	--	--	--
Optimum	--	--	--	--	--	--	2.0"	1.0"	0.75"

TOGGLE SWITCHES

1. Toggle switches should have snap-action contacts and an audible click.

2. When toggle switches are used for momentary contacts, they should be spring-loaded to return to the off or neutral position.

3. If other displays do not give a positive indication of circuit status, toggle switches should be accompanied by pilot lights that do so.

4. If an indicator light accompanies a toggle switch, the light should be above the toggle switch if possible, or to the left of it.

5. Toggle switches should be oriented vertically, with "on" in the up position and "off" in the down position.

6. Toggle switches should be mounted horizontally only to make them consistent with the orientation of controlled functions or equipment.

7. If a toggle switch must be oriented horizontally, the "on" position should be at the right, and the "off" position at the left.

8. Critical toggle switches should have guards -- channel, recess, ring, or complete cover -- to protect them from accidental operation.

9. A toggle switch's resistance should increase slowly until it makes contact, then drop to zero as the switch snaps into position (except for momentary contact switches).

10. Toggle switches should be designed so they cannot stop between positions.

11. If space is severely limited, three-position toggle switches may be used instead of rotary selector switches.

12. Three-position toggle switches should not be used for critical system functions.

13. Three-position toggle switches can be used to make momentary contacts, snapping back to the off or neutral position when not manually controlled.

DISPLAYS

GENERAL REQUIREMENTS

1. In designing any equipment item that people must operate, giving them information about equipment status is always a prime consideration. Almost all of the operator's decisions and actions depend on the information which is presented to him.

2. Selecting or designing a display requires thorough knowledge of the kind, amount, and accuracy of information the operator will require.

3. All displays should conform to these general guidelines:

a. Display only the information that is essential for adequate job performance.

b. Display information only as accurately as the operator's decisions and control actions require.

c. Present information in such a way that any failure or malfunction in the display or its circuitry will be obvious immediately.

d. Present data in the most direct, simple, understandable and usable form possible.

e. Arrange displays so the operator can locate and identify them easily, without unnecessary searching.

f. Group displays functionally or sequentially so the operator can use them more easily.

g. Make sure that all displays are properly illuminated, coded, and labeled by their functions.

4. Follow the scale-marking and numbering practices below, to keep the system consistent and to maximize legibility:

a. Whenever appropriate, scales should start at zero.

b. Scale graduations should progress by 1 or 5 units, or decimal multiples thereof (e.g., 10 and 50, or .01 and .05). Graduations of 2 and 20 units may also be used.

c. Numbers should increase from left to right, from bottom to top, or clockwise.

d. Major scale graduations should represent whole numbers, unless measurements are normally expressed in decimals.

e. There should never be more than nine minor or intermediate marks, and fewer where possible.

f. There should be as much visual contrast as possible between the scale's face and its markings.

g. On stationary scales, numbers should be upright (never tilted).

h. On moving scales, numbers should be oriented so they will be upright when they are at the reading position.

i. Displays should be designed so pointers will just meet, but not overlap, the shortest graduation marks.

j. Space should be left to enter calibration data on instruments without reducing the dial's readability.

k. To minimize parallax, mount pointers as close to dial faces as possible.

l. All displays should be constructed, arranged, and mounted so ambient light will not reflect toward the operator from glass or plastic covers. It is especially important to consider reflections when panels slant away from the operator.

m. Use linear scales, rather than non-linear scales, wherever possible.

n. If operators have to interpolate, they must be able to interpolate accurately enough to meet system requirements.

5. Design displays so failures in the display or its circuitry will be obvious. If a display or its circuitry fails, it should not cause associated equipment to fail also.

6. Do not combine information used in different activities (e.g., operation and trouble-shooting) into a single display unless the activities are comparable and actually require the same information.

7. Arrange displays consistently throughout the system (except as required by other provisions in this section).

8. The displays that are used most often should be grouped together (unless other provisions in this section require separating them).

CRITERIA FOR CHOOSING TYPES OF DISPLAYS

1. Use dials, scales, gauges, or meters:

a. To indicate direction of movement or orientation in space.

b. To show increasing or decreasing trends of the values the instrument measures.

c. When only an approximate reading is needed.

d. For checking readings periodically, rather than continuous monitoring.

2. Use dichotomous (two-valued) indicators:

a. To indicate go-no-go situations qualitatively, on-off status, malfunctions, emergency warnings (use flashing signals), inoperative equipment, cautions, and the operability of separate components.

b. For especially critical information, illuminate the legends themselves (e.g., use legend lights -- words or numbers that are lighted from behind).

3. Use auditory displays (buzzers, bells, etc.):

a. As emergency or warning devices.

b. When it is important for the operator to react quickly.

4. Use auditory displays with, or instead of, lights:

a. When lights might not be noticed under unusual environmental lighting.

b. When the operator is already busy monitoring lights, dials, counters, and scopes.

c. When critical conditions justify multiple signals (warning, emergency, malfunction).

d. For extreme redundancy.

INDICATOR LIGHTS

1. At present, there are two general types of transilluminated indicators: simple indicator lights (e.g., pilot lights, bull's-eye lights, jewel lights, etc.), and single- and multiple-legend lights. Legend lights give information by lighting meaningful words, numbers, symbols, or abbreviations. Generally, the principles discussed under Simple Indicator Lights apply also to Legend Lights.

2. Use transilluminated indicators to display qualitative information, and primarily the information that either requires the operator to respond quickly or calls his attention to an important condition. Occasionally, they are also used to present maintenance and adjustment information.

3. If indicator lights are used solely for maintenance and adjustment, they should be covered during normal operation, yet readily accessible and visible when needed.

4. Master action, master warning and summation lights that indicate the condition of an entire subsystem should be separated from lights that show component status. Summation lights should also be larger.

5. Lights should indicate that the equipment has actually made the desired response, not merely that the control has been operated.

6. Indicators with flashers should be designed so that, if the flasher fails when the light should be flashing, it will light steadily.

7. Use lights and all other indicators sparingly -- display only the information that is necessary for effective system operation.

8. For easy maintenance, personnel should be able to replace pilot-light bulbs from the front of the display panel without using tools.

9. Panels that will be used outdoors should be designed so reflected sunlight cannot make indicators appear to be illuminated.

10. On displays that will be used at night, scale markings should be illuminated with red light (620 millimicrons and above) to maintain night vision.

Simple Indicator Lights

1. Use simple indicator lights whenever legend lights are not specifically required.

2. When using types of indicator lights that have only a single bulb, incorporate a master lamp-test control. However, panels with three lights or less may use press-to-test indicators instead.

3. Where a panel has some indicators with a single bulb and others with more than one bulb, the master light-test control should test both types.

4. Simple round indicator-light fixtures should be spaced far enough apart for unambiguous labeling and convenient bulb removal.

5. Indicate malfunctions positively, by having them turn on malfunction lights, rather than implying them deviously, by turning off the light that indicates satisfactory operation.

6. Do not use lights that merely indicate the position of a control unless the control position is not (or cannot) be shown by the control's design and labeling. Use lights to display the equipment's response, not merely a control's position.

7. When a control is associated with a transilluminated indicator, locate the indicator light so it is immediately and unambiguously associated with the control. In most instances, the light should be placed above the control.

8. Auxiliary lights should have brightnesses between 5 and 10 foot-Lamberts.

9. Indicators should not be so bright that they dazzle the operator.

10. When lights are used under varying ambient illumination, there should be a dimming control. Its range should be limited so that fully dimmed lights will still be visible under the brightest expected ambient illumination.

11. Critical indicators should be located within 30 degrees of the normal line of sight. Warning lights should be built into (or near) the control the operator uses to take action.

12. Indicate personnel or equipment danger with a flashing red light one inch in diameter.

13. Master summation indications for a system or subsystem should be steady red or green lights one inch in diameter.

14. Indicate all other conditions with steady lights 1/2 inch in diameter.

15. One-inch-diameter lights should be obviously brighter than 1/2-inch-diameter lights.

COLOR CODING

Red, green, yellow, blue, and white colors should be in accordance with Type I, Aviation Colors of MIL-C-25050.

a. Green

Green should indicate that equipment is operating satisfactorily: in tolerance, test OK, ready, etc.

b. White

White should show status -- conditions which are neither satisfactory nor unsatisfactory in themselves -- such as alternative functions and selection mode, test in progress, etc.

c. Yellow

Yellow should alert an operator to situations that call for caution, recheck, or delay.

d. Red

Red should alert an operator to conditions that make the system inoperative, e.g., error, no-go, failure, malfunction, danger.

e. Blue

Blue is used as a fifth color when necessary. It has no general meaning.

FLASH CODING

1. Flashing lights should flash three to five times a second, and their "on" and "off" times should be approximately equal.

2. Flashing Red -- Flashing red should indicate extreme dangers to equipment or personnel.

3. Flashing White -- Flashing white should be used as an alerting signal on communications equipment.

MOVING-POINTER FIXED-SCALE INDICATORS

Circular Scales

1. Clockwise pointer movement should give larger readings, as operators expect.

2. To display values ranging from positive through zero to negative, locate the zero point at the nine or twelve o'clock position. Positive values should increase when the pointer moves clockwise (to the right), and negative values should increase when the pointer moves counterclockwise (to the left).

3. It is generally better to place numerals inside the graduation marks, so the bezel will not hide them and so the scale can be relatively larger. If space is not limited, numbers may be placed outside the scale so the pointer will not cover them.

4. Except for multi-revolution, continuous-scale instruments, such as clocks, there should be an obvious gap -- not less than 1 1/2 divisions -- between the two ends of the scale.

Non-Linear Scales

Non-linear scales condense a large range into a relatively small space, yet permit sensitive readings in critical ranges. Where error tolerances are a constant percentage of the indication, a logarithmic scale is very suitable. However, logarithmic scales should have as many numbered graduation marks as possible, to minimize errors that might result because people are more used to reading linear scales.

Pointers

1. For best legibility, indicators with scales should have pointers that are relatively wide at the pivot, tapering gradually to a fine tip.

2. Pointer tips should be as wide as the smallest graduation mark.

3. In "edgewise" indicators -- such as rectangular meters with straight scales -- only the tip of the pointer may be visible. If so, it should be distinctive and obvious: a flag, spade, or target pointer.

4. Pointers should be pivoted at the right for vertical scales, and at the bottom for horizontal scales.

5. Pointer tips should never be more than 1/16 inch from the scale graduations.

6. The angle subtended between the pointer tip and the scale's plane should never be more than 20 degrees.

7. Pointers should meet, but not overlap, the shortest scale-graduation mark.

8. Pointers should not cover scale numbers completely.

9. Pointers should be the same color as the numbers and scale divisions (but see 3 above).

10. There should not be more than two pointers on a single shaft.

11. Reciprocal pointer ends should be easy to distinguish from each other.

EMERGENCY INDICATIONS

1. It is very important to find the most effective ways to tell the operator that an "emergency" condition exists and he must take corrective action. The following paragraph, outlining what is best from a human factors standpoint, should be applied wherever possible.

2. Signal emergencies with a combination of auditory warning signal and flashing light. The man operates a control to "acknowledge" the emergency, which silences the auditory warning and changes the flashing light to a steady light. When the operator has corrected the emergency condition, the steady light goes out ("normal" operating condition).

Auditory Warning Signals

1. Auditory warnings indicating hazardous conditions or conditions that require immediate corrective action should be as follows:

a. Used only with a warning light.

b. Easy to distinguish from background noises and easily recognizable.

c. The "master" warning sound's frequency should vary as indicated in Figure 24.

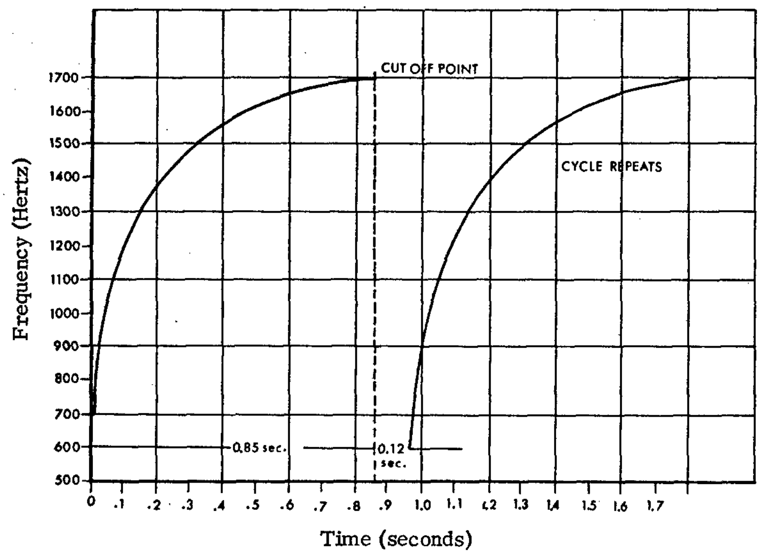


Fig. 24. FREQUENCY CHARACTERISTICS OF AUDITORY MASTER-WARNING SIGNAL

2. If additional warning sounds are needed, personnel can readily identify the following as different:

a. 1600 $\pm$ 50 Hz tone, interrupted at a rate of 1 to 10 Hz.

b. 900 $\pm$ 50 Hz steady tone, plus 1600 $\pm$ 50 Hz tone interrupted at a rate of 0 to 1 Hz.

c. 900 $\pm$ 50 Hz steady tone.

d. 900 $\pm$ 50 Hz steady tone, plus 400 $\pm$ 50 Hz tone interrupted at a rate of 0 to 1 Hz.

e. 400 $\pm$ 50 Hz tone, interrupted at a rate of 1 to 10 Hz.

3. Warning signals should be louder than the ambient noise so they can be detected and identified immediately. In noisy locations, the warning signal should be about 20 dB above the ambient noise level. (See Noise section, page 31.)

4. Warning-signal intensities must be kept as far below the human pain threshold, which is approximately 130 dB, as ambient noise conditions will permit.

5. An auditory signal may be used without an accompanying warning light when there is only one extreme emergency condition (e.g., vehicle on fire, "get out"), but in such cases there should not be any other auditory signals in the vehicle.

Visual Warning Signals

1. Designers should consider the following guidelines in weighing the physical characteristics and placement of "warning" indicators:

a. For optimum visibility, the master warning indicator should be within 30 degrees of the standard line of sight.

b. Emergency indicators should be obviously larger than general status indicators.

c. An emergency indicator's brightness contrast with the immediate background should be at least 2 to 1.

d. When illuminated, an emergency indicator should be at least as bright as the brightest light source on the same console.

e. Warning indicators should be colored red (see Indicator Lights, page 96) and located within 60 degrees of the standard line of sight.

f. When there is extreme danger to personnel or equipment, the warning indicator should be flashing red with these characteristics:

(1) Flash rate between three and five pulses per second.

(2) "On" time about equal to "off" time.

(3) If the "flashing" device fails, the light comes on steadily.

(4) Should provide "word" warning (such as DANGER - STOP) whenever possible -- and if it does, should be placed within 10 degrees of the standard line of sight.

(5) If it displays a symbol, instead of a word, the indicator should be within 30 degrees of the standard line of sight.

CODING

GENERAL

1. Coding helps distinguish controls, indicators, connectors, and other devices that perform the same function or are consistently used together. Coding is frequently used so various unrelated devices can be distinguished from each other readily.

2. There are many methods of coding; whichever method is selected, it should have a consistent meaning throughout the system.

3. When deciding which kind of coding to use in a particular situation, consider the following factors:

a. Types of coding already in use.

b. Kinds of information to be coded.

c. Nature of the tasks to be performed and the conditions under which they will be performed.

d. Number of coding categories each coding method offers (e.g., the number of different knob shapes available).

e. Space and illumination the various coding methods require.

f. Need for redundant or combination coding.

g. Standardizing coding methods.

CONTROLS

Color

1. Only a bare minimum of controls should be color coded (except for emergency controls).

2. Do not color code controls unless vision is unrestricted and ambient illumination is bright enough for reliable color discrimination.

3. Important, frequently used controls should be coded with colors that have high spectral visibility, so they attract the operator's attention and minimize search time.

4. The colors of critical controls should contrast sharply with those of non-critical controls.

5. Use colors that differ clearly from each other.

6. Where related controls and displays are color coded, they should be coded the same color.

7. Colors recommended for color coding are described in Table 23, which cross references several different color systems.

Shape

1. Use meaningful shapes which suggest the purpose of the control.

2. Within a given system, the shapes used for coding should differ enough to prevent confusion. Do not use combinations of shapes that look similar.

3. Controls with similar purposes or functions should have the same shape.

4. When operators must distinguish controls by touch alone, the shape on the control should be at least:

a. Side view (depth):	.25 inch or larger
b. Top view (width):	.50 inch or larger
c. Front view (length):	.50 inch or larger

5. A control's shape should not make it hard for personnel to use it.

6. Shapes used for coding should not have sharp edges or corners.

TABLE 23

Color Codes: Cross Reference[a]

Color	Munsell Notation (center point of area)	ISCC-NBS Color Designation (center point of area)	Ready Mixed Paints Fed. Std. No. 595	Pigmented Papers (Munsell Book of Color, Abr. Ed.)
Red	8.3 R 3.6/15	Vivid red	11105	5 R 4/14
Orange	2.1 YR 5.6/16	Vivid orange	12246	2.5 YR 6/14
Yellow	5.3 Y 8/12	Vivid yellow	13655	5 Y 8/12
Green	3.9 G 5.6/8.3	Brilliant green	14260	5 G 5/8
Blue	2 PB 4.1/10.0	Strong blue	15102	2.5 PB 4/10
Purple	1.3 RP 4.2/14.5	Vivid reddish-purple	17142	10 P 4/10 or 2.5 RP 4/10
White	N 9.0/ or higher	White	17875	N 9.0/ or N 9.4/
Black	N 2.0/ or lower	Black	17038	N 1.0/

[a] This material is reproduced from the American Standard: Marking Physical Hazards and the Identification of Certain Equipment, Safety Color Code for, Z53.1-1953. Copyright by ASA. Copies may be purchased from the American Standards Association, 10 East 40th Street, New York, N. Y.

Size

1. Use size coding when only two or three controls will be coded.

2. Size and shape coding may be combined, since the ability to discriminate shapes is independent of size discrimination.

3. Code consistently when controls have the same function on different items of equipment.

4. When coding knobs with diameters between 0.5 inch and 4.0 inches by size, each knob should be at least 20 percent larger than the next smaller one.

Location

1. When operators must make blind-positioning movements, the most effective way to code controls is by location.

2. Operators discriminate locations more accurately when controls are in front of them.

3. Location-coded controls should be lower than the operator's shoulder level.

4. Controls in the forward area should be separated about six to eight inches for optimum discrimination.

5. When controls are beside or behind the operator, they should be separated 12 to 16 inches for effective operation and accurate discrimination.

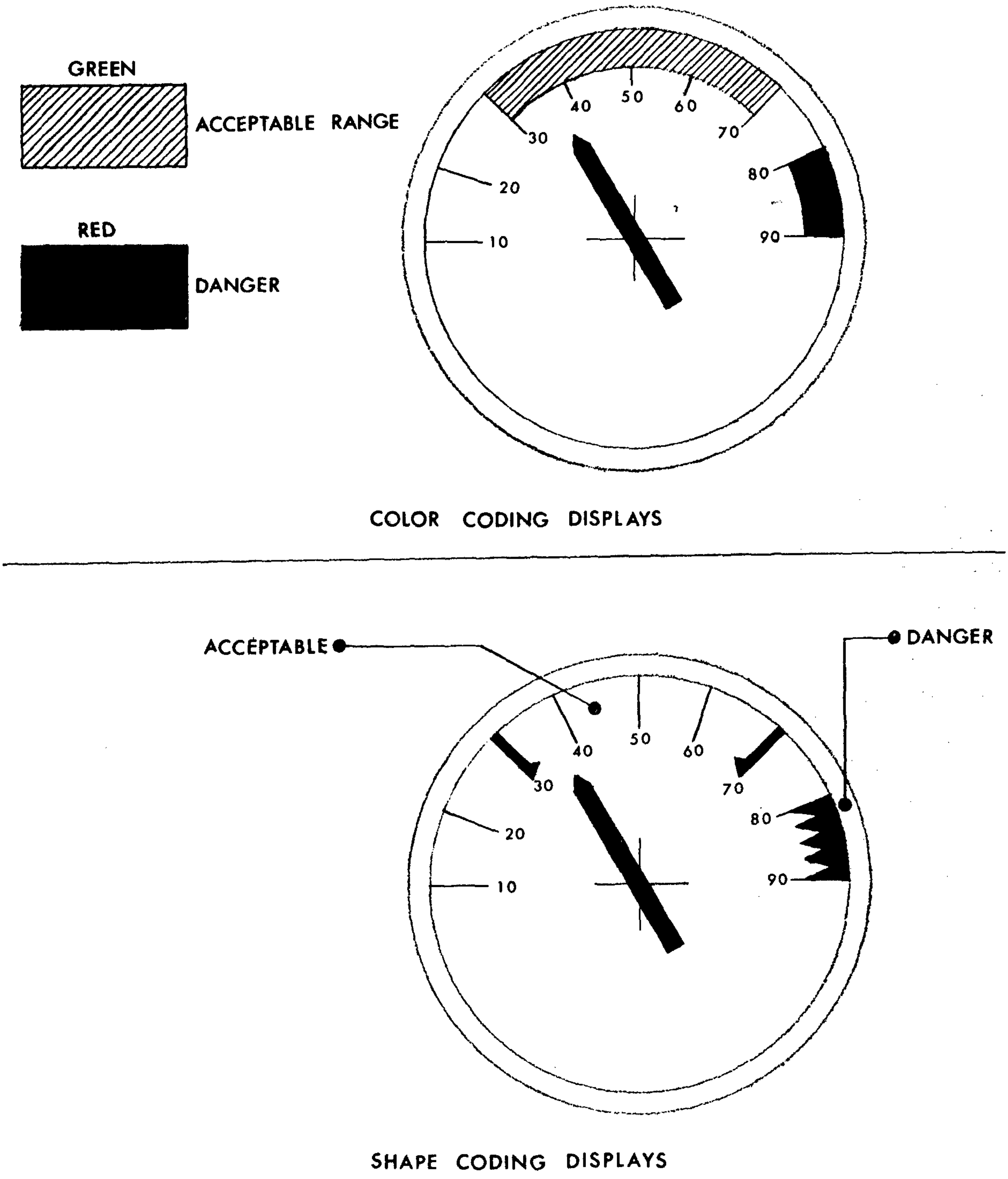


Fig. 25. CODING OF DISPLAYS

COLOR BANDING OF DISPLAY SCALE ZONES

1. Use color codes, markings, and bands (Fig. 25) so personnel can read displays more effectively:

a. To make it obvious at a glance whether the indication is within acceptable limits.

b. To make it equally obvious when the indication is a "danger" range requiring immediate corrective action.

c. To keep operators from misreading numbers or mistaking a desired numerical value.

2. Colors often appear different under different types of illumination; unless a display will always be used under white light, do not use color coding.

Shape

1. Although shape-coding displays may occasionally be useful, it is not generally recommended.

2. A display's scale zones may be coded with shapes (Fig. 25). The shapes used for coding purposes should be:

a. Easy to learn.

b. Distinguishable under dim illumination.

c. Distinguishable under any color of light.

Size

1. Transilluminated indicator lights that indicate emergency, failure, and master summation should be larger than other indicators.

2. All other types of displays may be coded with varying sizes.

Location

1. Location coding arranges displays into groups to make them distinguishable from each other.

2. Locations may be coded by:

a. Spacing between groups of displays; use horizontal separations where possible, rather than vertical separations.

b. Outlining or bordering display groups.

c. Placing display groups on different planes (with respect to the operator).

d. Symmetry.

CONDUCTORS

Electrical Conductors

1. The primary method of coding electrical conductors is by colored insulation. Every individual wire in a cable should be color coded over its entire length. There are 21 discriminably different patterns of solid colors and solids with striped tracers (Table 24). For coding more than 21 conductors, see MIL STD 686. Several ways of coloring wires are, in order of preference:

   a. Solid-colored insulation.

   b. Solid-colored insulation with colored-stripe tracer.

   c. Colored braid insulation with woven tracer.

2. Where conductors are coded with numerals, the numbers should be repeated at least every two inches over the conductor's entire length.

3. Numbered metal tags may also be used to code cables and conductors.

Hydraulic and Pneumatic Conductors

Hydraulic and pneumatic conductors should be coded with numbered metal tags.

TABLE 24

Electrical Cable Coding

Instructions	Number of Conductor	Basic Color	Tracer
1. Find the number of the conductor to be color coded.	1	Black	None
	2	White	None
	3	Red	None
2. The colors at the right of the number are the appropriate combination for that conductor.	4	Green	None
	5	Orange	None
	6	Blue	None
	7	White	Black
3. For example, if a cable consists of 12 conductors, the twelfth color combination would be black with white tracer. The eighth color combination would be red with black tracer. The fifth color combination would be orange without tracer, and so on.	8	Red	Black
	9	Green	Black
	10	Orange	Black
	11	Blue	Black
	12	Black	White
	13	Red	White
	14	Green	White
	15	Blue	White
	16	Black	Red
	17	White	Red
	18	Orange	Red
	19	Blue	Red
	20	Red	Green
	21	Orange	Green

Note: If a cable has concentrically laid conductors, the first combination or color applies to the center conductor. If a cable contains various sizes of conductors, the first color applies to the largest, continuing in order of conductor size.

LABELING

GENERAL

1. Identify things with labels for easy location, reading, or manipulation. The type of labeling depends on a number of factors, such as:

a. How accurately the item must be identified.

b. Time available for reading.

c. Distance between reader and label.

d. Brightness and color of illumination.

2. Labels should conform to these principles:

a. A label should give the user the information he needs to perform his task.

b. Labels should be located consistently throughout the equipment.

c. Labels should use familiar words; avoid overly technical or difficult words.

d. Make labels brief but unambiguous; omit punctuation.

e. Print words so they read horizontally, not vertically.

f. Supplement labeling where necessary with other coding procedures (such as color and shape).

g. Place labels where they can be seen easily, not where other units in the assembly will cover or obscure them.

h. Make labels large enough that the operator can read them easily at his normal distance.

i. Generally, use capital letters; however, if the label has several long lines, use upper- and lower-case letters.

j. Use bold-face letters only for short words or phrases that require emphasis.

k. Place labels on or very near to the item they identify; eliminate any confusion with other items and labels.

l. Labeling should be etched or embossed into the surface for durability, rather than stamped, stenciled, or printed. Decals are acceptable, but less desirable.

Style

1. The recommended typeface for labeling is Alternate Gothic #2 or an equivalent approved by the procuring activity. The same typeface should be used consistently throughout the system.

2. All numerals should be Arabic; avoid Roman numerals.

Height-to-Stroke Width Ratio

Where panel labels are illuminated by ambient or individual illumination, the height-to-stroke width ratio should be within the range 6:1 to 8:1.

Width

1. The average width of characters should be between 65 percent and 85 percent of their height.

2. The letters I, M, W, and the numerals 1 and 4, may vary substantially from the average width. The geometric proportions for these characters are determined by the typeface.

Spacing and Size*

1. Letters printed from foundry type.

a. Type founders cast their letters so they are automatically spaced properly when assembled in a composing stick -- so ordinarily printers do not use any spaces between letters. Thus the between-letter spacing is built in, and you have automatically specified it by your choice of typeface.

b. Spacing between words is not so standard, but it usually is roughly one-third the point body for material set in caps and lower case -- less for narrow or short letters, and more for wide or tall ones. It is usually about half the point body for material set in all caps. If copy is justified, the spacing between words can be considerably more or less than these averages, and apparently without affecting legibility very much.

c. Spacing between lines is almost purely a matter of judgment -- but it is limited by the fact that two pieces of type can be only so close together, depending on how much of the point body the letters occupy.

2. Lettering should read horizontally, from left to right, and there should be at least 1/8-inch space between lines.

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* Type sizes in points give only a rough indication of the heights of characters. For example, 18 points equals 1/4 inch; but 18-point letters, while cast on bodies 1/4 inch high, will seldom or never be that high. The actual size of 18-point characters varies widely from face to face and from foundry to foundry. Unless you have measured the letter heights corresponding to point sizes of a given face, do not specify lettering by point sizes; specify letter heights in fractions of an inch.

3. The following character heights should be used for a 28-inch viewing distance:

a. Console or panel title: 1/4-inch height

b. Subdivision title: 3/16-inch height

c. Component title: 1/8-inch height

4. If the operator must read labels when he is more than 28 inches from them, use the character heights in Table 25 to insure legibility.

TABLE 25

Character Height and Viewing Distance

Distance (inches)	Character Height (inches)
56 to 72	3/8
44 to 55	1/4
29 to 43	3/16
6 to 28	1/8

5. Component labels should be centered 1/8 inch above the component. If space is very limited, place the label 1/8 inch from the component's right edge, with the letters in a horizontal row.

6. The manufacturer's identification should not be displayed so it detracts the operator or interferes with his vision.

CONTENT

1. Labels should be brief, but not cryptic, ambiguous, or confusing.

2. Use common words or words the operator readily understands and ordinarily uses. Avoid technical words unless they are necessary to give exact information and the operator can reasonably be expected to have a working knowledge of them.

3. Avoid abbreviations and symbols if possible. Where space is limited, use MIL STD 12 abbreviations. Symbols, if used at all, should be meaningful and in common usage.

LABELING FOR IDENTIFICATION

Assemblies

Label assemblies with clearly visible, readable, and meaningful names or signs. Assembly labels should:

a. Specify the overall system the assembly is a part of.

b. Include the assembly's popular name and function.

c. Include a stock number for requisition purposes.

d. The gross identifying label on an assembly should be located:

(1) Where adjacent assemblies will not obscure it.

(2) On the flattest, most uncluttered surface available.

(3) On a main chassis of the assembly.

(4) Where it will not be removed accidentally, obstructed, or damaged in handling.

Connectors

Each permanently installed receptacle should have a label indicating type of output and the appropriate connector. This label should be next to the receptacle, aperture, or connector for clear identification.

Instruction Plates

1. Consult the latest issue of MIL-P-514 for instruction-plate specifications.

2. Instruction plates should be placed where the operator can see them easily.

3. Instruction plates should be as brief as clarity allows. Give only the information the operator needs -- preferably in diagrammatic form.

4. List instructions in a step-by-step format, rather than in a continuous paragraph.

5. Instructions should read from left to right.

6. Orient instructional diagrams so they relate logically to the objects they pertain to; locate them in conspicuous places on or near controls.

7. Indicate control movements with arrows parallel to the directions the controls actually move.

8. Instruction plates should be printed in white letters on a black background. The black color should be 37038, Federal Standard 595, or an approved equivalent.

9. Caution or warning plates should be printed in black letters on a yellow background. The black color should be 37038, Federal Standard 595, the yellow color should be 23538 or 23655, Federal Standard 595.

10. Information-plate lettering should be 12- to 14-point size, with titles in 24-point letters.

11. Avoid vertical lettering.

12. Instruction plates for transmissions should show maximum permissible rpm and/or road speed for each gear range.

13. Gearshift instruction plates should give operating positions of shift handles for transmission and transfer-case mechanisms.

14. Furnish instruction plates for all power take offs and winch controls.

Lift Points

1. Mark lift or hoist points clearly, indicating weight or stress limitations.

2. Label lift or hoist points at the point of lift, not on removable parts of the body member (e.g., protective cover, access covers, etc.) that may be separated from the lift point.

Safety and Hazards

Wherever possible, design equipment so it does not present hazards to personnel or equipment. If hazards are unavoidable, display warning signs prominently. These safety labels should be brief and uncluttered -- generally no more than two or three words.

GENERAL

1. Voice communication is the most common method of requesting and providing information. In military systems, communications may be transmitted in several ways:

   a. Electrically, using radio or telephone.

   b. Operator to operator.

   c. Visual (lights, flags).

   d. Buzzers and other auditory signals.

2. Communication equipment should be located to maximize its audibility in the area it serves. When two or more auditory displays (i.e., telephone, radio, intercom, etc.) are in the same area, their sounds should be distinctive.

3. Provide for communication between the vehicle operator and personnel in the cargo or passenger compartment (e.g., a momentary push button in cargo area connected to a light on the dashboard).

RADIO SET

1. The radio set should be located where the crew and the rest of the system are least likely to damage it.

2. Do not locate the radio set where it will interfere with the crew's normal movements or be a hazard to them.

3. The radio operator should be able to see the radio's control panel.

4. The radio operator should be able to reach the radio control panel to change frequencies.

5. When the radio has devices to protect it from damages like overloads and excessive heating, provide access points for checking these devices visually.

6. Maintenance personnel should be able to discharge capacitors before working on high-voltage circuits.

7. Protect all bare wires and terminals in medium-voltage or high-voltage circuits so they will not be short circuited or grounded, and so operating or maintenance personnel cannot touch them accidentally.

8. All exposed metal parts should be at ground potential.

RADIO ANTENNA

Locate radio antennas to minimize radio frequency (RF) hazards to personnel.

CONTROL BOX

1. Radio control boxes should be located so all controls are easily accessible.

2. Locate control boxes so they will not interfere with the crew's normal movements or be a hazard to them.

3. Do not locate control boxes where they can be used as steps or footrests.

4. Position control boxes so handset or microphone cables cannot be damaged by rotating or moving linkages.

5. Control boxes must be within the operating length of the standard audio accessories used with radio-interphone equipment. Control boxes should not be more than 30 inches from a crewman's normal working area.

6. Signal or warning lights on control units should be within the responsible crewman's field of vision.

AUDIO ACCESSORIES

1. Provide stowage hooks near each crew member so he can store audio accessories when he is not using them.

2. Locate hooks where they will not interfere with the crew's normal movements.

CABLE ROUTING

1. Route interconnecting communication cables so crew members will not use them as handholds or steps. If necessary, place protective guards over the cables.

2. Route all interconnecting cables neatly, without slack or loops. Space cable clamps about 12 inches apart.

STOWAGE

GENERAL

1. Secure stowed items in stowage boxes so they will not be damaged during cross-country operation. If stowage boxes cannot be provided, retain items with straps or brackets.

2. If items are inflammable or may be damaged by leaking lubricants, fuels, or water, stow them so they will have reasonable protection from engines, generators, exhaust components, etc.

3. All stowage locations should drain adequately when the vehicle is on level ground. Arrange drain holes so normal stowage will not block them.

4. Consider potential climatic effects in locating stowage space for items that crew members must wear.

5. There must be stowage space for life-support equipment (e.g., sleeping bags, arctic clothing, rations, etc.).

6. Consider climatic factors in locating items to make sure personnel will be able to operate them after they have been exposed to the environment.

7. Provide ways to safeguard all stowed equipment from pilferage.

8. Locate floor stowage boxes where they will not interfere with the crew's footing.

9. Stow items that are critical to the mission within easy reach of crew members.

10. Label stowage locations clearly and permanently to show where each item should be stored.

11. Wherever necessary, provide readily accessible stowage for fire extinguisher(s).

12. Where feasible, make stowage boxes part of the vehicle, rather than attachments.

INTERFERENCE

1. Stowed items should not interfere with the crew's entrance, exit, escape, movement, or operations.

2. Stowage should not interfere with system functions.

3. Design stowage so personnel can remove and replace a stowed item without having to remove or replace other stowed items or system components.

4. The 5th through 95th percentile men, wearing gloves, should be able to stow and unstow all stowed items without assuming unnatural positions.

USE OF STOWAGE SPACE

1. The accessibility and location of stowed equipment should reflect its function and use.

2. Items a particular crew member uses for his task requirement should be stowed conveniently and accessibly within his station's functional area.

3. Wherever possible, use dead space for stowing items.

4. There should be stowage for items like individual weapons, small-arms ammunition, etc.

RETAINING

1. Retaining devices should be simple, and they should be designed so they can be replaced quickly.

2. Design retainers so items can be stowed and unstowed by hand; no tools should be required.

3. Design retainers so items can be stowed and unstowed under all environmental conditions.

STOWAGE BOXES -- DOORS AND COVERS

1. Unless access covers or doors are completely removable, design them so they will stay open, once opened; unless gravity holds them open, use built-in braces or latches.

2. If instructions about a component in a box are on the door of the box, orient the lettering so it can be read when the door is open.

3. If personnel must have access to the rear of sliding, rotating, or hinged units, design them so they open or rotate their full distance freely and remain "open" by themselves.

4. It should be obvious how to open a cover or door; if it is not, attach a permanent instruction plate to the outside of the cover.

5. It should be obvious when a cover or door is in place but not secured.

6. Avoid using sharp edges and corners on doors, covers, and other exposed surfaces.

7. To simplify reinstalling removable inspection-access doors, either make them interchangeable or use sizes and shapes which will make their proper position obvious.

8. Obstructions (i.e., OEM or structural members) should never block covers or doors so they cannot be opened or removed.

9. If covers are hinged, allow space equal to the sweep volume of the cover so the body frame, brackets, etc., will not obstruct its opening.

MAINTENANCE

GENERAL

1. The Army program for materiel readiness emphasizes the complementary attributes of reliability and maintainability. Reliability is best expressed as the probability the materiel will perform its intended function, i.e., remain ready without requiring unplanned maintenance. Maintainability is the ease of keeping the materiel in (or restoring it to) readiness and availability. Maintainability depends on accessibility of parts, internal configuration, use, and repair environment, as well as the time, tools, and training skills required for maintenance.

2. The objectives of improving maintainability are:

a. Making materiel more available to perform its function and mission.

b. Reducing the cost of operational support during the materiel's service life.

3. Army materiel designers should contact the Maintenance Directorate of the Commodity Command responsible for procurement to get guidance and the latest available data about the Army Maintenance Program.

4. To avoid costly maintenance or redesign, maintainability must be designed into the materiel from its earliest development stage. Therefore it is imperative to program a design schedule for maintainability, including the following steps:

a. Planning for maintainability.

b. Designing for maintainability.

c. Testing and revising the design.

5. In planning for maintainability, designers should:

a. Determine the sizes of access openings, work surfaces, and access spaces maintenance personnel will have to go through to get to components.

b. Study operational vehicles or materiel resembling the one to be designed. List the maintenance features built into it and, from its maintenance history and experience, identify the maintenance features that should have been built into it, but were not.

c. Determine how components should be arranged and located to give greatest accessibility to the components that will probably fail most frequently, or whose failure would critically degrade the end item's performance.

d. Find out which tools and test equipment in the operational system may be adopted for the materiel being designed.

e. Determine what type, number, and organization of manuals the maintenance personnel will need to maintain the materiel properly, effectively, and safely.

6. In designing for maintainability the designer should consider:

a. Modular or unit packaging and, where feasible, throw-away units.

b. Replaceable modules or units that are independent and interchangeable. Replacing a module should not require adjusting or realigning other units extensively.

c. Easy access to check or service the materiel.

d. Equipment designs that can be serviced where they are finally installed.

e. Designing equipment so it can be tested with standard equipment already in the system. Where standard test equipment cannot be used, design and build special test equipment so it will be ready for issue when the materiel is ready for issue.

f. Because military vehicles must often be maintained on ground covered with deep mud or snow, in extreme temperatures, and in tactical blackouts at night, design so components can be maintained from above the vehicle rather than below, and from inside the vehicle rather than outside.

7. Test development and production models for maintainability with representative Army personnel under operational conditions. These tests should:

a. Use the procedures, tools, test equipment, and manuals that maintenance personnel will use.

b. Use maintenance personnel with realistic training -- no more than they would have if assigned to actual field maintenance.

8. Maintenance manuals should be ready for issue when the materiel is released for use.

TOOLS

1. Design so equipment can be maintained and adjusted with standard, commonly available hand tools and test equipment; minimize requirements for special tools. But if special tools are required, they should be designed for a variety of uses.

2. Organizational maintenance should use on-equipment materiel, General Mechanic's Tool Sets, Organization Sets, and organic recovery and handling equipment.

3. It should be possible to perform field maintenance with field-maintenance unit equipment.

4. Allow adequate clearances for the type of wrenches and the torques required. Allow clearance for box wrenches if common hand tools are used at torques of 50 ft-lb or more.

GENERAL WORK-SPACE REQUIREMENTS

1. The system work-spaces should be based on the following minimum requirements:

   a. The interrelationships of personnel and equipment in the work space.

   b. Points where operation and maintenance are (or may be) required.

   c. Space and clearance needed to accommodate personnel in anticipated body positions, using test equipment where needed to perform operation and maintenance.

   d. Requirements for access to the work point, including the size and weight of equipment carried and used at the work station.

   e. Requirements for wrenching or grasping items and working on them.

2. Consider protecting personnel against any hazards which might exist while they are performing their tasks.

3. Top surfaces of equipment should be reinforced (allow 250 pounds per man in calculating anticipated load) and have nonskid surfaces whenever personnel may use them as work platforms.

GENERAL ACCESS REQUIREMENTS

1. Where possible and feasible, design for accessibility by:

    a. Using modular design.

    b. Designing major units and assemblies, particularly engines, turbines, etc., with removable housings so they can be inspected completely.

2. Accesses should be designed, located, covered, and fastened so it will not be necessary to remove components, wires, etc., to reach an item requiring maintenance. These openings should be directly in line with the equipment to be serviced or maintained.

3. Design so any replaceable item can be removed after opening only one access (unless the accesses are latched or hinged doors).

4. Items requiring visual inspection (hydraulic reservoirs, gauges, etc.) should be located so personnel can see them without removing panels or other components.

5. Wherever accesses have sharp edges that could injure technicians, damage hoses, etc., line the accesses with internal fillets or other suitable protection.

6. Always provide visual access when the maintenance man needs to see what he is doing, particularly if he can encounter hazards inside the access. Do not require the technician to work blindly.

ACCESS

1. Provide access to all points, items, units, and components which require testing, servicing, adjusting, removal, replacement or repair.

2. The type, size, shape, and location of access (Table 26 and Figs. 26 through 28) should be based on a thorough understanding of the following:

a. Operational location, setting, and environment of the unit.

b. Frequency of using the access.

c. Maintenance tasks performed through the access.

d. Time required to perform these functions.

e. Types of tools and accessories required.

f. Work clearances required.

g. Type of clothing the technician is likely to wear.

h. How far into the access the technician must reach.

i. The task's visual requirements.

j. Packaging of items and elements, etc., behind the access.

k. Mounting of items, units, and elements behind the access.

l. Hazards in using the access.

m. Size, shape, weight, and clearance requirements for logical combinations of human appendages, tools, units, etc., that must enter the access.

3. For easy maintenance, some types of access are preferable to others (Fig. 28):

a. Uncovered or exposed equipment -- When structural, environmental, operational, and safety conditions permit, equipment should be left exposed for maintenance -- especially test and service points and maintenance displays and controls.

b. Semi-exposed equipment -- Items can be semi-exposed with:

(1) Quick-opening hoods or covers.

(2) Easily and quickly removable dust covers and cases.

c. Uncovered, limited-access openings -- Use uncovered openings only when no environment control is required and there is minimal danger to equipment or personnel. Work clearances around mounts, components, etc., should be considered as uncovered, limited-access openings.

d. Covered, limited-access openings -- Covered accesses should be evaluated by their covers and fasteners.

e. Riveted panels and doors -- Riveted panels are never acceptable access points. Overall layout and design of equipment should not require removing permanently attached structures, even for infrequent maintenance.

Shape of Accesses

1. Accesses should be whatever shape permits easiest passage of the required items, body appendages, implements, etc. The following should be considered:

a. Dimensions of the various items that must be replaced through the access.

b. Protuberances, attachments, handles, etc., on these items.

c. Methods of grasping items during removal, and the required clearances.

d. Requirements for clearance to do work within the compartment.

e. The operator's need to see what he is doing inside the compartment.

2. Accesses need not have regular geometric shapes; designers should consider irregular shapes when they will satisfy both structural and accessibility requirements best.

Size of Accesses

1. Access sizes depend on the same considerations as access shapes.

2. In general, one large access is better than two or more small ones; but visual and physical access may be provided separately when structural or other considerations require it.

3. When using stress doors or other access covers that are difficult to remove, provide a smaller access to frequently used test or service points.

TABLE 26

One-Hand Access Openings

A. Arm to Elbow			
	Light clothing:	4.0" x 4.5" or 4.5" dia.	
	Arctic clothing:	7.0" sq. or dia.	
	With object:	clearances as above	
B. Arm to Shoulder			
	Light clothing:	5.0" sq. or dia.	
	Arctic clothing:	8.5" sq. or dia.	
	With object:	clearances as above	
Minimal Finger-Access (First Joint)			
C. Operating push button		Bare hand:	1.25" dia.
		Gloved hand:	1.5" dia.
D. Twisting with two fingers		Bare hand:	2.0" dia.
		Gloved hand:	2.5" dia.

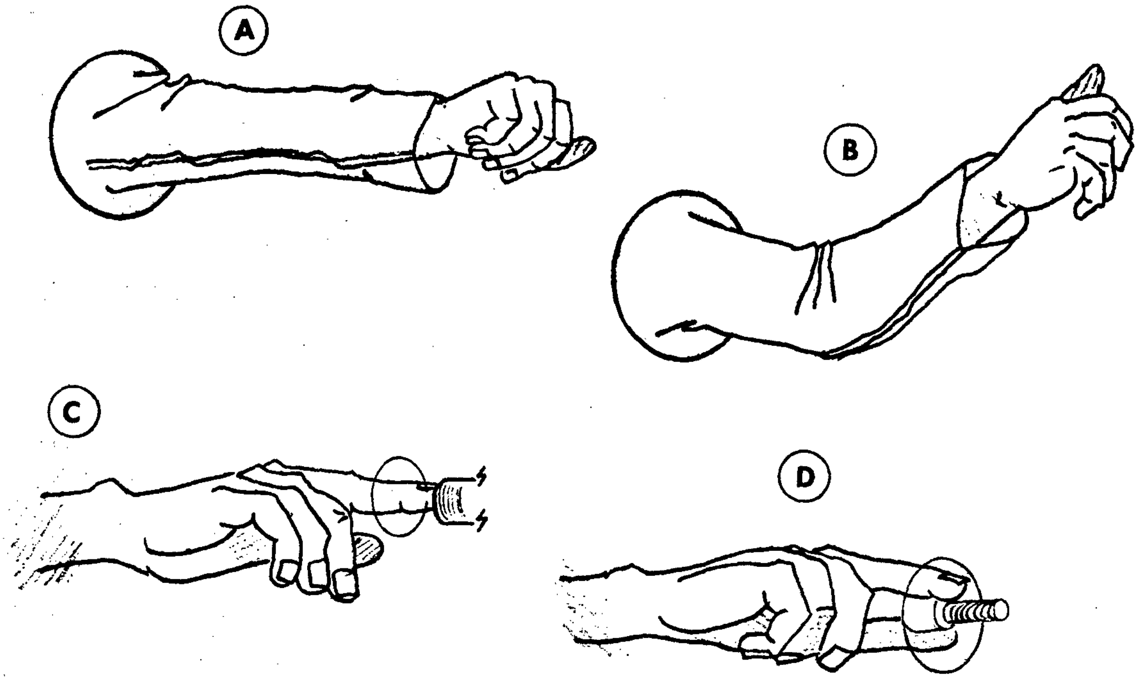


Fig. 26. ONE-HAND ACCESS OPENINGS

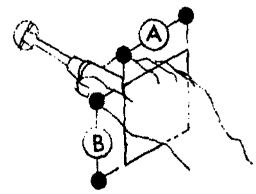
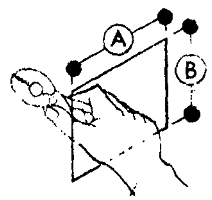
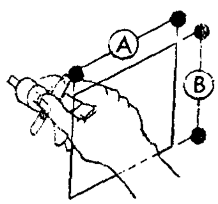
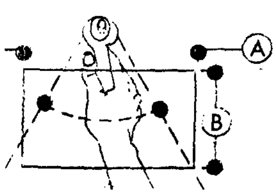
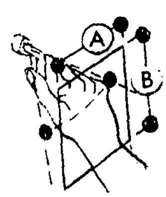
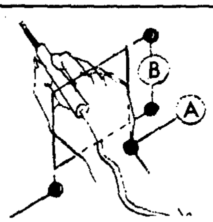
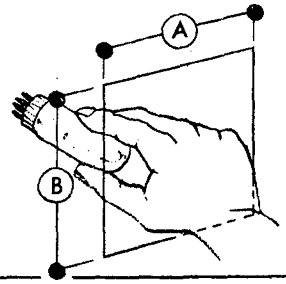
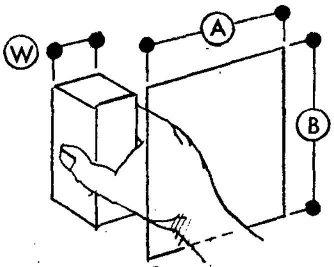
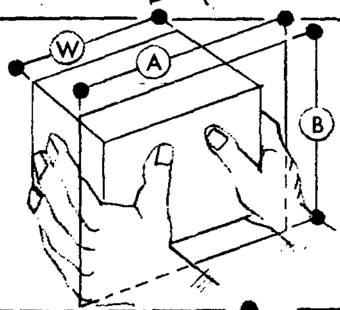
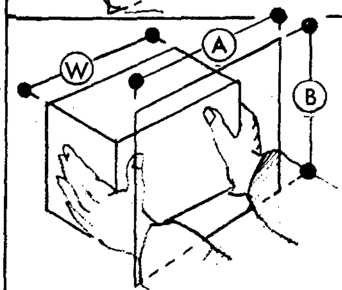
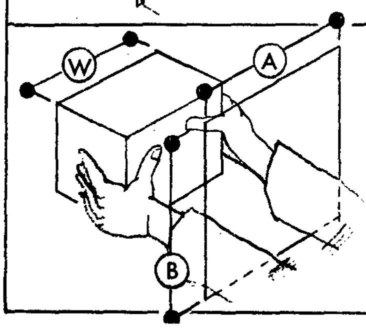
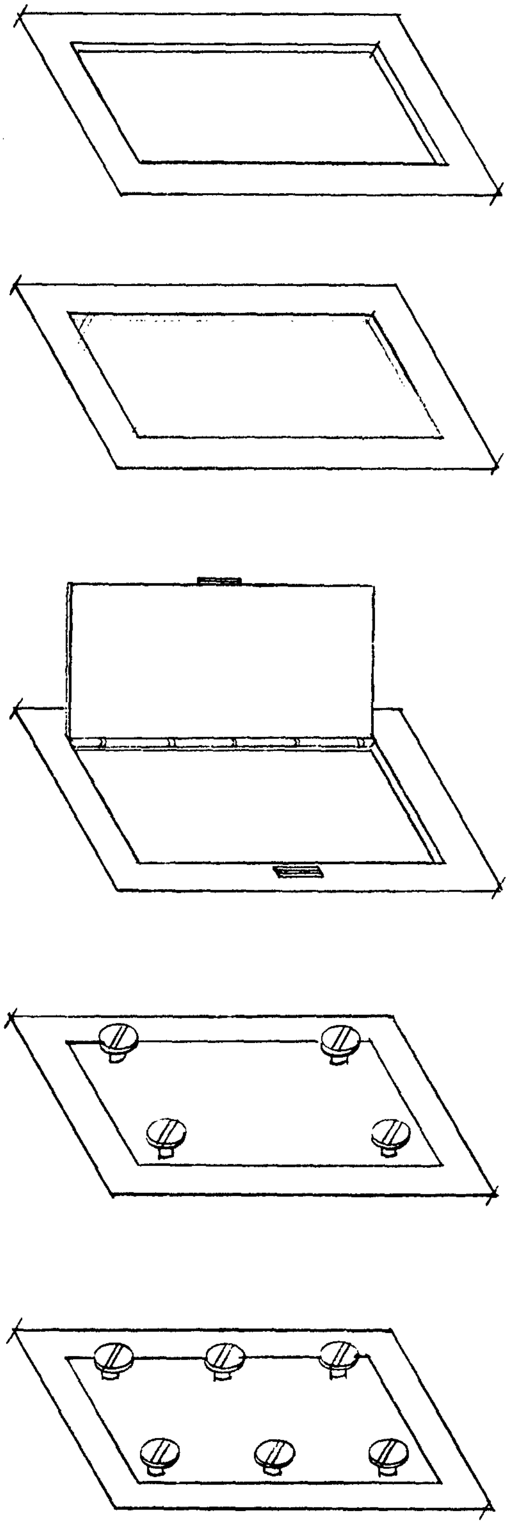
OPENING DIMENSIONS	DIMENSIONS (In Inches) A	B	TASK
	4.2	4.6	Using common screwdriver, with freedom to turn hand through 180°.
	5.2	4.5	Using pliers and similar tools.
	5.3	6.1	Using "T" handle wrench, with freedom to turn hand through 180°.
	10.6	8.0	Using open-end wrench, with freedom to turn wrench through 60°.
	4.8	6.1	Using Allen-type wrench, with freedom to turn wrench through 60°.
	3.5	3.5	Using test probe, etc.

Fig. 27. ACCESS-OPENING DIMENSIONS

OPENING DIMENSIONS	DIMENSIONS (In Inches) A	B	TASK
	4.2	4.7	Grasping small objects (up to 2-1/16" diameter) with one hand.
	W+ 1.75	5.0*	Grasping large objects (2 1/16" or more wide) with one hand.
	W+3.0	5.0*	Grasping large objects with two hands, with hands extended through openings up to fingers.
	W+6.0	5.0*	Grasping large objects with two hands, with arms extended through openings up to wrists.
	W+6.0	5.0*	Grasping large objects with two hands, with arms extended through openings up to elbows.

* Or sufficient to clear part if part is larger than 5.0".

Fig. 27. Continued



BEST -- NO COVER
(Use whenever possible.)

PERMANENT GLASS OR PLASTIC COVER
(Use where only visual inspection is required.)

HINGED OR SLIDING COVER
(Use where physical access is required and where dirt and moisture could be a problem.)

CAPTIVE QUICK-OPENING FASTENERS
(Use when space prevents use of hinged cover.)

SCREWED-DOWN COVER
(Use only when stress or pressurization requires. Minimize number of screws.)

Fig. 28. COVERS AND ACCESSES

Location of Accesses

Accesses should be located:

a. Only on equipment faces that are accessible as normally installed.

b. For direct access and maximum convenience for job procedures.

c. On the same face of the equipment as related displays, controls, test points, cables, etc.

d. Away from high voltages or dangerous moving parts (if not, provide adequate insulation, shielding, etc., around such parts so personnel will not be injured).

e. So that heavy items can be pulled out, rather than lifted out.

CONNECTORS

1. Connectors should be compatible with:

   a. Lines and Cables (page 161).

   b. Fasteners (page 151).

   c. Mounting (page 166).

   d. Environmental extremes they will be subjected to.

   e. Maintenance routines they are involved in.

2. Connectors should be selected, designed, and mounted for:

   a. Fast, easy maintenance operations.

   b. Easy removal and replacement of components and units.

   c. Fastest time to set up test and service equipment.

   d. Minimum danger to personnel and equipment from pressures, contents, or voltages of lines during the release of connectors.

   e. Hand operation where possible, or use with common hand tools.

3. Standardize connectors to minimize errors like mismating and cross connection during installation or maintenance.

4. Use connectors that are clearly different and physically incompatible when lines differ in content (i.e., different voltages, oils, gases, etc.).

5. Connectors should be accessible:

   a. With a minimum of disassembly or removal of other equipment or items.

   b. In proportion to how often they are operated; connectors used during pre-operating checks should be the most accessible.

6. Connectors should be located so that:

   a. Personnel can reach them easily to connect or disconnect them.

   b. They are visible enough that personnel can mate threads or pins without damaging them.

c. Fluids will not spill or leak -- but, even if they do, will not damage equipment.

d. There is enough space around each connector to grasp it firmly when connecting and disconnecting it.

7. In general, connectors should be separated at least:

a. 0.75" if used with bare fingers.

b. 1.25" if used with both bare and gloved fingers.

c. 3.00" if used with gloved or mittened hand.

d. As required for tool clearances.

8. Connectors should be designed and located so pressures, contents, or voltages of lines will not endanger personnel or equipment when connectors are released or handled.

9. Design and locate connectors so they will not be damaged by:

a. Movements of personnel, shifting objects, opening doors, etc.

b. Excessive tightening or man-handling during operation.

c. Shorts, or arcing from foreign objects, erroneous connection, or handling after disconnection.

10. Protect connectors by:

a. Recessing receptacles as necessary.

b. Recessing delicate parts (pins, keys, etc.) within the connector so they are not exposed to harmful contact.

c. Providing protective caps, inserts, covers, cases, and shields as necessary.

11. Connectors should be selected, designed, and installed so they cannot be mismated or cross-connected. The following means should be considered:

a. Use different sizes or types of connectors.

b. Arrange cables so their lengths correspond to the distances from the connector to the correct point of attachment.

c. Arrange wires, or provide separation blocks or other mounts, so the sequence of leads is obvious.

d. Polarize connectors or use different sizes of prongs and prong receptacles so lines with different voltages cannot be mismatched.

e. Use different -- and mutually incompatible and irreversible -- arrangements of guide pins, keys, or prongs.

f. Color-code or label connectors and receptacles so mismating is unlikely.

12. Connectors and associated parts and wiring should be coded and identified to:

a. Key them to references in the job instructions.

b. Identify replaceable items and parts for reordering.

c. Expedite and facilitate maintenance and trouble-shooting procedures.

d. Indicate the sequence routine or test procedures.

e. Provide adequate warnings or cautions about using connectors.

13. Label or code connectors and receptacles, as necessary, to ensure that:

a. Each plug is clearly identified with its receptacle.

b. Each wire is clearly identified with its terminal post or pin.

c. Test points are clearly identified by a unique mark or symbol.

d. Non-interchangeable connectors are clearly distinguishable.

e. The manner of connection or disconnection is obvious.

f. Plugs and receptacles have painted strips, arrows, or other indications to show how pins should be aligned for proper insertion.

g. Terminal strips and circuit boards are marked permanently to identify individual terminals and facilitate replacing them.

h. Power receptacles for primary, secondary, or utility systems are clearly labeled to prevent personnel injury or equipment damage.

14. Labels or codes on connectors and associated items should be located so that:

a. They are maximally visible during maintenance.

b. They are visible whether the connector is connected or disconnected. It should be possible to identify connectors without disconnecting them.

c. Their position is consistent in relation to associated pins, terminals, receptacles, etc.

15. The location for labels or codes are, in order of preference:

a. First -- Directly on the connector and receptacle.

b. Second -- On plates permanently attached to the connector and receptacle.

c. Third -- On tabs or tapes attached to the connector.

-- For receptacles, on the surface or panel immediately adjacent to the receptacle.

-- For recessed receptacles, on or near the access opening.

Classification of Connectors (in order of preference)

1. Plug-in connectors are the fastest and easiest to use, but they have low holding power; therefore:

a. Do not use plug-in connectors when accidental pulls on the cable may disconnect them.

b. Use plug-in connectors for cables that are connected and disconnected frequently.

2. Quick-disconnect devices have a variety of forms, including any type of connector that can be released by snap action, twisting up to a full turn, triggering a latch or spring device, or removing an external pin.

3. Use quick-disconnect devices to connect:

a. Items which must be disconnected or replaced frequently.

b. Items which must be replaced within critical readiness times.

4. Threaded connectors provide very secure connections, particularly when locked into place by set screws, retainers, or safety wires. They usually take longer to operate, depending on the number of turns and the types of tools they require.

5. Threaded connectors should:

a. Use the fewest turns that will satisfy holding requirements.

b. Operate by hand, if used for electrical connections.

c. Require only common hand tools.

d. Minimize the danger of accidentally loosening other connectors while working on one.

Electrical Connectors

1. Electrical connectors should have low insertion forces to minimize the possibility of damaging contact surfaces.

2. Electrical plugs should be designed, installed, and mounted so that:

a. It is impossible to insert the wrong plug into a receptacle.

b. It is impossible to insert a plug in its own receptacle the wrong way.

c. Wherever possible, plugs have multiple contacts, to reduce the number of plugs and, consequently, the number of maintenance operations.

d. Connectors "plug-in" or secure with no more than one complete turn, especially with auxiliary or test equipment.

e. Wiring is routed through the plugs and receptacles so disconnection does not expose "hot" leads.

f. All "hot" contacts are socket contacts or female connectors (i.e., receptacles are "hot" and plugs are "cold" when disconnected).

g. Plugs are self-locking or use safety catches, rather than requiring safety wiring.

3. Alignment keys or pins should be designed and located within the plug so that:

a. They extend beyond electrical pins to protect the pins from damage if the connector is misaligned.

b. They are arranged asymmetrically to prevent incorrect plug insertions.

c. All alignment pins for a given plug or series of plugs are oriented in the same direction. If this conflicts with precautions against mismating, pin orientations should differ consistently and systematically, for the technician's convenience.

4. Test points should be:

a. In plugs when test points are required but have not been provided elsewhere

b. In adapters to be inserted between the plug and receptacle, if test points cannot be incorporated into the plug and no other test points are available.

c. Accessible, with adequate working clearances, when the plug or adapter is in its normal position.

d. Coded and labeled so they can be seen clearly and identified easily in test procedures.

Fluid and Gas Connectors

1. Connectors for pipes, tubing, hoses, etc., should be located and installed so that:

a. It is not necessary to jack the equipment up to drain it, fill it, or perform other maintenance involving the connectors.

b. The technician can perform leakage tests easily and without danger. Tests should be planned so the technician does not have to hold his head in areas of extreme noise, vibration, or other danger while the equipment is running.

2. Gaskets and seals should be selected and installed so that they can be replaced easily without removing other connector parts or disassembling other equipment.

3. There should be job instructions giving the expected life of seals and gaskets and recommending when they should be changed.

4. Part of a gasket or seal should be visible after it is installed, as a check on failure to replace seals after disassembly.

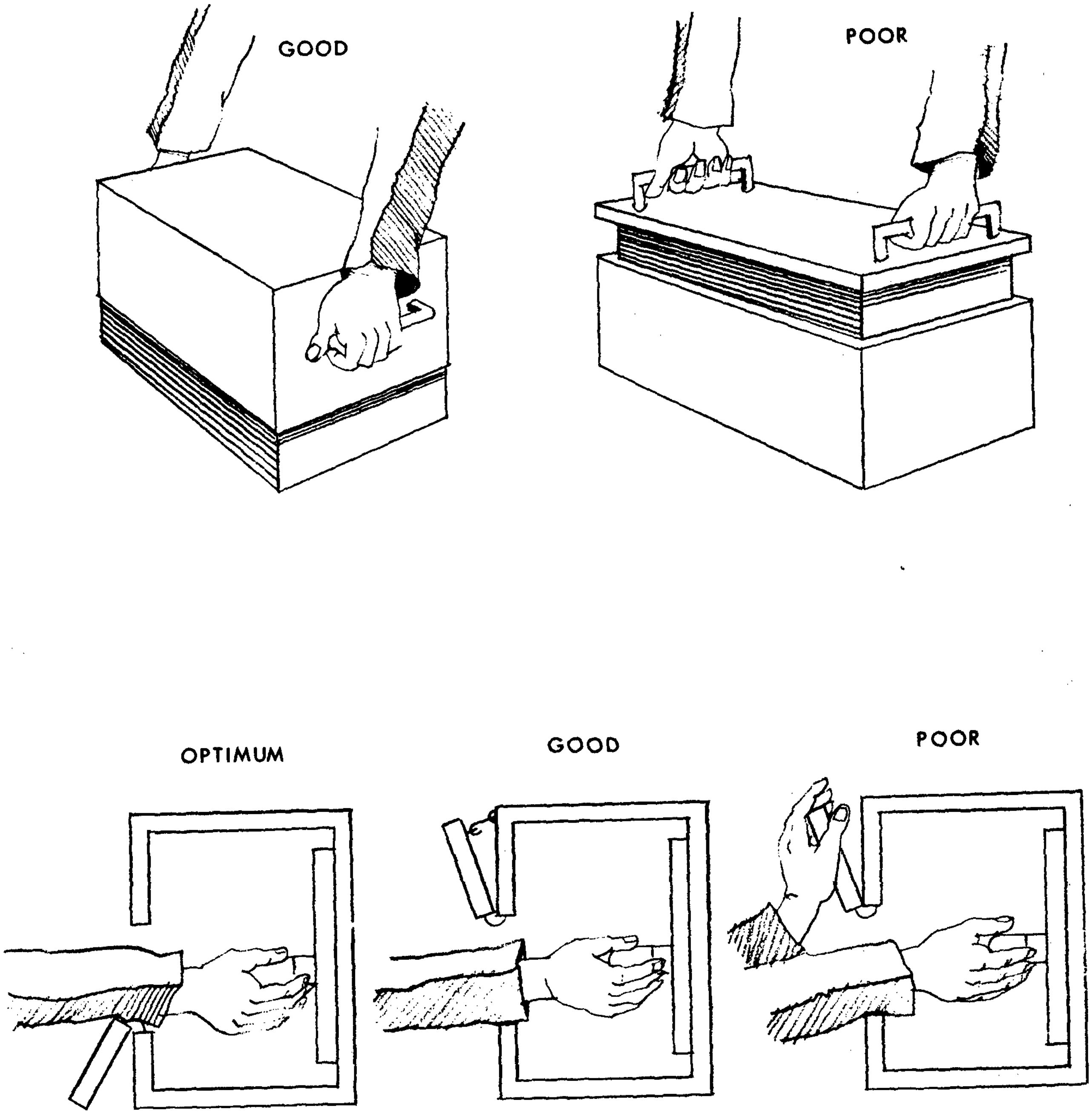


Fig. 29. COVERS AND CASES: DESIGN EXAMPLES

COVERS AND CASES

1. Covers, cases, and shields should be provided as necessary to:

a. Divide enclosures into sections which are cleaned by different methods.

b. Keep personnel from touching dangerous electrical or mechanical parts.

c. Protect delicate or sensitive equipment so it will not be damaged by movements of personnel, shifting cargo, loose objects, or installing and maintaining nearby assemblies.

2. Covers, cases, and shields should also be designed for fast, easy maintenance (Fig. 29). Their maintenance characteristics depend largely on:

a. How they are fastened.

b. Size, weight, and ease of handling.

c. Handles or provisions for tool grips.

d. Work space and clearance around them.

e. How often they must be opened or removed (i.e., the reliability and maintainability of the components they enclose).

3. A cover, case, or shield should have these characteristics:

a. Lightweight if possible, but whatever size is necessary for the degree of enclosure and the accessibility required.

b. Openable, removable, and transportable by one hand, by one man, or by two men (in that order of preference).

c. Handles or tool grips provided if it is heavy, difficult to open, or difficult to handle.

d. Enough clearance around enclosed components to prevent damage and avoid requiring extremely fine or careful positioning and handling.

e. Designed and located so bulkheads, brackets, or other units do not interfere with using it, and so it will not interfere with other maintenance operations when it is open.

4. The shape of the cover, case, or shield should be chosen as follows:

a. Use any shape appropriate for the degree of enclosure, accessibility, and the clearances required.

b. Make it obvious how the item must be positioned or mounted.

c. Make it obvious how enclosed delicate components are oriented, to prevent damage during removal.

d. Avoid indentations or settling areas on top surfaces, to prevent rust and corrosion, and keep dirt and grease from accumulating.

5. Covers, cases, and shields should be designed, located, and mounted so that:

a. They can be completely removed and replaced if they are damaged.

b. Irregular extensions and accessories can be removed readily.

c. They can be opened or removed as necessary, without taking the equipment apart or removing auxiliary equipment.

d. They have props, retainers, or other support where required so the equipment will not be unbalanced when opened.

e. When open, they do not obscure or interfere with controls, displays, test points, or connections used in working inside the access or enclosure.

f. They have adequate stops and retainers to keep them from swinging against or being dropped on fragile equipment or on personnel.

g. They have locking devices or retaining bars to hold them open if they might otherwise fall shut and cause damage, injury, or inconvenience. This is particularly necessary for doors, covers, and shields which may be used in high winds.

6. Fasteners for covers, cases, and shields should be selected, applied, and mounted so that:

a. They satisfy the preferences, requirements, and standardization aspects under "Fasteners" (page 151).

b. Hinges, latches, and catches are used wherever possible to reduce handling and stowing of covers and cases.

c. It is obvious when a cover or case is not in place or is not securely fastened. Where possible, spring-load fasteners so they stand out or the cover itself stays ajar when it is not secure.

7. Labels and markings on covers and cases should:

a. Tell how to open, remove, and position them, unless the design itself makes operation obvious.

b. Clearly indicate the functions of units behind the enclosure or the functions which are performed through the access (such as "Battery," "Fuel Pump," "Oil Here," etc.).

c. Warn about any dangers or hazards involved in removing the cover or case, or working within the enclosure.

d. Indicate how units, service equipment, etc., should be oriented or connected to go through the opening (unless this is already obvious).

e. Present instructions so they will be visible and properly oriented to a maintenance technician when the cover, door, or case is open.

8. Cases should be selected, designed, and mounted so that:

a. Cases lift off of units, rather than units lifting out of cases -- particularly when subassemblies are heavy (Fig. 29).

b. They are somewhat larger than the items they cover, so items inside can be removed and replaced easily without damaging wires or other components.

c. They have guidepins and tracks as necessary to help align the case, prevent it from cocking or binding, and to protect delicate or sensitive components from damage when the case is moved.

d. There is access to frequently used adjustment, test, or service points, so the case need not be removed for routine maintenance.

e. All aspects and portions of the equipment that are significant for maintenance are fully exposed when the case is removed.

f. Rubber stripping or other sealing material is selected and mounted so personnel will not damage it when the case is moved.

9. Covers are listed below in order of preference, and should have the following characteristics:

a. Hinged doors, hoods, and caps allow fastest and easiest access, with relatively few fasteners, and the cover is supported so the technician does not have to handle it. However, these covers do require "swinging space," which may interfere with other operations or components. When using hinged covers, consider the following:

(1) Where "swinging" or opening space is limited, use double-hinged or split doors.

(2) Place hinges at the bottom of the door, or provide a prop, catch, or latch to hold the door open -- particularly if the door must be opened in high winds (Fig. 29).

(3) When hinged doors are adjacent, they should open in opposite directions to maximize accessibility.

(4) Design hinged caps over service or test points so they will not interfere with inserting or attaching service or test equipment.

(5) Use stops, retainers, etc., as necessary to keep doors from swinging into adjacent controls or fragile components, and so they will not spring their hinges.

b. Sliding doors or caps are particularly useful where "swinging space" is limited. Small sliding caps are useful for small accesses that do not require a tight seal. When sliding covers are used, the following should be considered:

(1) Sliding doors and caps should lock positively.

(2) They should be designed so they will not jam or stick.

(3) They should be easy to use, and personnel should be able to use them without tools.

(4) Opening or closing them should not interfere with, damage, or make potentially harmful contact with wires or other equipment items.

c. Removable doors, plates, or caps require little space for opening and, once removed, do not interfere with work space. However, handling them takes time and effort, e.g., searching, bending, reaching, etc. When using removable covers, consider the following:

(1) Use tongue-and-slot or similar catches wherever possible for small plates, doors, and caps, to minimize the number of fasteners required.

(2) If small plates and caps are likely to be misplaced or damaged, secure them with retainer chains (see "Fasteners," page 151).

(3) If a removable plate must be attached in a certain way, design it so it cannot be attached improperly (i.e., use an asymmetric shape, locate mounting holes asymmetrically, or code both plate and structure with labels that will align when the plate is properly installed).

d. Removable panels or sections give access to whole sides of equipment. They discourage non-maintenance personnel from opening the access. They do not require "swinging space," but they are easily damaged and awkward to handle. They may also interfere with maintenance. When they are used, the following should be considered:

(1) Panels that must be removed for maintenance should be held with a minimum of combination-head, captive fasteners. Spring-loaded, quarter-turn fasteners are particularly recommended.

(2) It should be apparent when fasteners have been released.

(3) Panels and sections should be designed so one man can carry them and install or remove them with common hand tools.

(4) Panels and sections should have handles to facilitate removal, handling, and replacement.

(5) It should not be necessary to disconnect wires, components, etc., from a panel before removing it. If such items are attached to the panel, the panel should be hinged so they need not be removed.

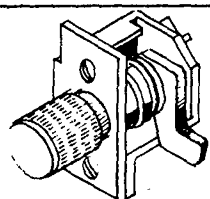
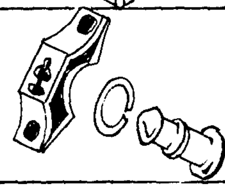
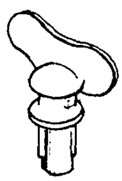
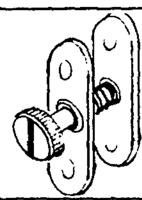
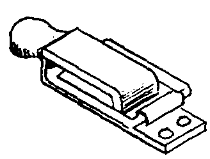
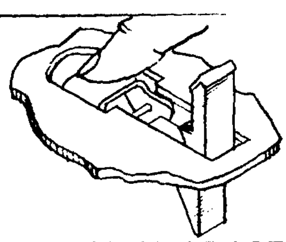
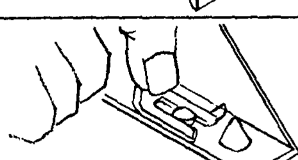
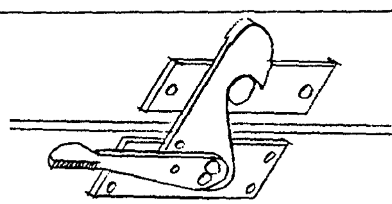
TYPE	DESCRIPTION
	Adjustable pawl fastener. As knob is tightened,the pawl moves along its shaft to pull back against the frame. 90^{o} rotation locks, unlocks fastener.
	"Dzus"-type fastener with screwdriver slot. Three-piece 1/4-turn fastener. Spring protects against vibration. 90^{o} rotation locks, unlocks fastener.
	Wing head. "Dzus" type. 90^{o} rotation locks, unlocks fastener.
	Captive fastener with knurled, slotted head. Retaining washer holds the threaded screw captive.
	Draw-hook latch. Two-piece, spring latch, base unit and striker. When engagement loop is hooked over striker, depressing lever closes unit against force of springs. Lever is raised to unhook.
	Trigger-action latch One-piece, bolt latch. Depressing trigger releases bolt, which swings 90^{o} under spring action and opens latch. To close, move bolt back into position.
	Snapslide latch. One-piece snapslide. Latch is opened by pulling lever back with finger to engage release lever.
	Hook latch Hook engages knob on striker plate. Handle is pulled up, locking in place. To release, reverse procedure.

Fig. 30. FASTENER EXAMPLES

FASTENERS

1. The design, selection, or application of fasteners should consider the following factors:

a. Work space, tool clearance, and wrenching space needed around the fastener.

b. Types of tools required to operate the fastener, depending on type of fastener, application, and location.

c. Frequency of use.

d. Time available for tasks involving operation of the fasteners.

2. Fasteners are available in a wide variety of types and sizes, and new types are always appearing. Before selecting fasteners, review the varieties available. Fasteners should be selected for durability, easy operation, speed, easy replacement, and other criteria in this section.

3. Standardize fasteners wherever possible to reduce spare parts and minimize the danger that personnel will damage them by using the wrong tool or fastener for a given application.

4. Minimize the number of types and sizes of fasteners within the system by:

a. Using only a few basic types and sizes which are readily distinguishable from each other (see Fig. 30 for representative examples).

b. Using the same type and size of fastener consistently for a given application (e.g., all mounting bolts should be the same for a given type of item).

c. Making certain that screws, bolts, and nuts with different threads also have clearly different physical sizes, so they will not be interchanged.

5. Minimize the types and sizes of tools required for fastener operation by:

a. Avoiding fasteners that require special tools.

b. Selecting fasteners that can be operated by hand or by common hand tools.

6. In designing, consider how stripped, worn, or damaged fasteners can be replaced. Avoid fasteners (studs) which are an integral part of the housing.

7. Fastener mounting holes or other tolerances should be large enough to allow "starting" fasteners without perfect alignment.

8. Attach hinges, catches, latches, locks, and other quick-disconnect devices with small bolts or screws, not with rivets.

9. Mount nuts and bolts, particularly those which are operated frequently or which are not very accessible, so they can be operated with one hand or one tool:

a. Provide recesses to hold either the nut or the bolt.

b. Attach either the nut or the bolt semi-permanently.

c. Use double nuts on terminal boards and similar applications.

d. Use nut plates, gang-channeling, or floating nuts.

10. Use a few large fasteners rather than many small ones (unless system requirements dictate otherwise).

11. Fasteners should be located so that they:

a. Can be operated without removing other parts or units first.

b. Can be operated with minimum interference from other structures.

c. Do not interfere with each other or with other components during release.

d. Are not hazards to personnel, wires, or hoses.

e. Have adequate hand or tool clearance for easy operation. Consider that it may take two hands or power tools to manipulate, breakaway, or remove stuck fasteners.

12. Fasteners that are normally operated by hand should be durable enough that they can be turned with a wrench.

Types of Fasteners (in order of preference)

1. Quick connect-disconnect devices -- Fast and easy to use, do not require tools, may be operated with one hand, and are very good for securing plug-in components, small components, and covers. However, their holding power is low, and they cannot be used where a smooth surface is required.

2. The following factors should be considered in selecting quick connect-disconnect fasteners:

a. Use these fasteners wherever possible when components must be dismantled or removed frequently.

b. These fasteners must fasten and release easily, without requiring tools.

c. They should fasten or unfasten with a single motion of the hand.

d. It should be obvious when they are not correctly engaged.

e. When there are many of these fasteners, prevent misconnections by giving the female section a color or shape code, location, shape, or size so it will be attached only to the correct male section.

3. Latches and catches -- Very fast and easy to use, do not require tools, have good holding power; especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required.

4. The following factors should be considered in selecting latches and catches:

a. Use long-latch catches to minimize inadvertent releasing of the latch.

b. Spring-load catches so they lock on contact, rather than requiring positive locking.

c. If the latch has a handle, locate the latch release on or near the handle so it can be operated with one hand.

5. Captive fasteners -- Slower and more difficult to use, depending upon type, and usually require using common hand tools; but they stay in place, saving time that would otherwise be wasted handling and looking for bolts and screws; can be operated with one hand.

6. The following factors should be considered in the selection of captive fasteners:

a. Use captive fasteners when "lost" screws, bolts, or nuts might cause a malfunction or excessive maintenance time.

b. Use fasteners which can be operated by hand or with a common hand tool.

c. Use fasteners which can be replaced easily if they are damaged.

d. Captive fasteners of the quarter-turn type should be self-locking and spring-loaded.

7. Regular screws -- Round, square, or flat-head screws take longer to use and are more subject to loss, damage, stripping, and misapplication.

8. Square-head screws are generally preferable to round or flat ones; they provide better tool contact, have sturdier slots, and can be removed with wrenches.

9. The following factors should be considered in the selection of screws:

a. Screw heads should have deep slots that will resist damage.

b. Use screws only when personnel can use screwdrivers in a "straight-in" fashion; do not require personnel to use offset screwdrivers.

10. If personnel must drive screws blindly, provide a guide in the assembly to help keep the screwdriver positioned properly.

11. Bolts and nuts -- Bolts are usually slow and difficult to use. Personnel must have access to both ends of the bolt, use both hands and, often, use two tools. Also, starting nuts requires precise movements. There are many loose parts to handle and lose (nuts, washers, etc.).

12. Keep bolts as short as possible, so they will not snag personnel or equipment.

13. Coarse threads are preferable to fine threads for low torques.

14. Avoid left-hand threads unless system requirements demand them; then identify both bolts and nuts clearly by marking, shape, or color.

15. Use wing nuts (preferably) or knurled nuts for low-torque applications, because they do not require tools.

16. Combination-head bolts and screws -- Preferable to other screws or bolts, because they can be operated with either a wrench or a screwdriver, whichever is more convenient, and there is less danger of damaged slots and stuck fasteners. In general, slotted hexagon heads are preferable to slotted knurled heads.

17. Internal-wrenching screws and bolts -- Allow higher torque, better tool grip, and less wrenching space. But they require special tools, are easily damaged, and are difficult to remove if damaged. They also become filled with ice and frozen mud.

18. The following factors should be considered in selecting internal-wrenching fasteners:

a. Minimize the number of different sizes to minimize the number of special tools; preferably, use only one size.

b. Select fasteners with deep slots, to reduce the danger of damaged fasteners.

c. Design so there will be a way to remove damaged internal-wrenching fasteners.

19. Rivets -- These permanent fasteners are very hard and time-consuming to remove. They should not be used on any part which may require removal.

20. Cotter key use should consider the following:

a. Keys and pins should fit snugly, but they should not have to be driven in or out.

b. Cotter keys should have large heads, for easy removal.

21. Safety wire use should consider the following:

a. Use safety wire only where self-locking fasteners or cotter pins cannot withstand the expected vibration or stress.

b. Attach safety wire so it is easy to remove and replace.

22. Retainer ring use should consider the following:

a. Avoid rings which become difficult to remove and replace when they are worn.

b. Use rings which hold with a positive snap action when possible.

23. Retainer chains should be used to:

a. Keep hatches or doors from opening too far and springing their hinges.

b. Turn doors or covers into useful shelves for the technician.

c. Prevent small covers, plates, or caps from being misplaced.

d. Secure small, special tools where they will be used.

e. Secure objects which might otherwise fall and injure personnel.

24. The selection of retainer chains for use in design should consider the following:

a. Use link, sash, or woven-mesh chains. Avoid bead-link chain, because it breaks more easily than other types.

b. Attach chains with screws or bolts; attach them strongly and positively, but so they can be disconnected easily when required.

c. Provide eyelets at both ends of the chain for attaching to the fasteners.

d. Chains should not be longer than their function requires.

HANDLES

1. The dimensions (Fig. 31), location, and position of a handle depend on:

    a. Weight of the item or unit.

    b. Number of men, or hands, required to lift or carry it.

    c. Type of clothing and gloves users wear.

    d. Item's operational position relative to other items and obstructions.

    e. How the item is handled or positioned.

    f. How far the item must be carried.

    g. How often the item must be handled or carried.

    h. Additional uses for the handle.

2. Handles should be designed and located to:

    a. Guard against operating controls accidentally.

    b. Protect delicate parts of instrument faces.

    c. Serve as locking devices to secure components in place.

    d. Serve as protective supports or stands (e.g., so they can be used as maintenance stands when items are inverted).

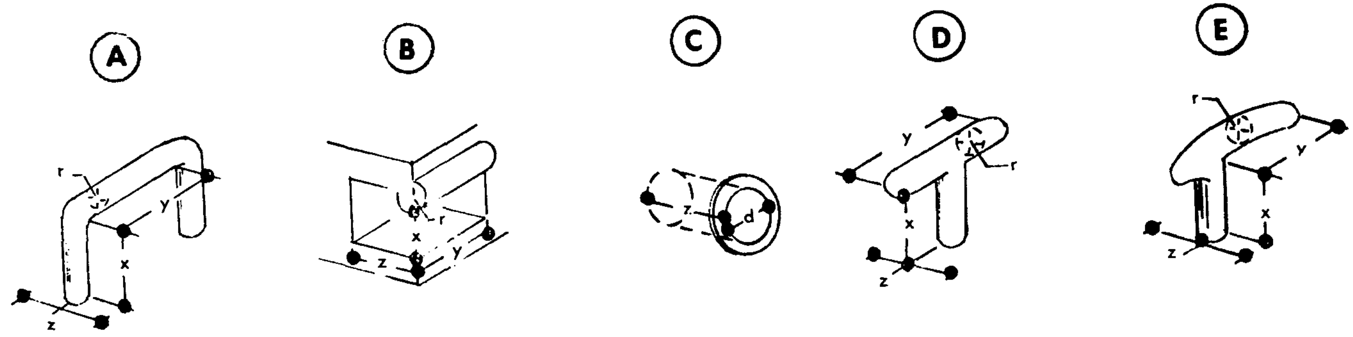
3. Use hand-shaped handles when items must be carried frequently or for long periods, to prevent undue side pressure on the fingers.

4. Recessed, concealed, or folding handles may be used to conserve space, but they must be accessible without tools and must remain securely folded when not in use.

5. Handles should be located so that:

    a. If there is only one handle, it is over the center of gravity.

    b. If there are two or four handles, they are equidistant from the center of gravity.



Type of Handle:	Bare Hand X	Bare Hand Y	Bare Hand Z	Gloved Hand X	Gloved Hand Y	Gloved Hand Z	Mittened Hand X	Mittened Hand Y	Mittened Hand Z
A. Two-Finger Bar	1.25"	2.5"	1.5"	1.5"	3.0"	1.5"	Not Applicable		
One-Hand Bar	2.0"	4.25"	2.0"	2.5"	4.75"	2.0"	3.0"	5.5"	3.0"
Two-Hand Bar	2.0"	8.5"	2.0"	2.5"	9.5"	2.0"	3.0"	11.0"	3.0"
B. Two-Finger Recess	1.25"-dia.		2.0"	1.5"-dia.		2.0"	Not Applicable		
One-Hand Recess	2.0"	4.25"	3.5"	2.5"	4.75"	4.0"	3.0"	5.5"	5.0"
C. Finger-Tip Recess	0.75"-dia.		0.5"	1.0"-dia.		0.75"	Not Applicable		
One-Finger Recess	1.25"-dia.		2.0"	1.5"-dia.		2.0"	Not Applicable		
D. T-Bar	1.5"	4.0"	1.5"	2.0"	4.5"	2.0"	Not Applicable		
E. J-Bar	2.0"	4.0"	2.0"	2.0"	4.5"	2.0"	3.0"	5.0"	3.0"

Curvature of Handle or Edge:

Weight of Item	Radius of Curvature (minimum)
up to 15 lbs:	R - 1/8 in.
15 to 20 lbs:	R - 1/4 in.
20 to 40 lbs:	R - 3/8 in.
Over 40 lbs:	R - 1/2 in.

Gripping efficiency is best if finger can curl around handle or edge to any angle of 120 degrees or more.

Fig. 31. MINIMUM HANDLE DIMENSIONS

c. Their locations do not interfere with operating or maintaining the equipment.

d. There is at least 2.5 inches of clearance between handles and obstructions.

e. They are on the front of a panel if it must be pulled from a rack.

f. They can be held comfortably.

g. The item which is carried will ride clear of the legs of personnel.

6. Handles, lugs, and other handling gear (casters, push bars, etc.) should be permanent parts of the equipment case.

7. Hoist lugs (lifting-eyes) should be provided on all equipment weighing more than 150 pounds. Mark "LIFT HERE" adjacent to each lug, and allow at least four inches space around the lifting eyes, for convenient use.

HANDLING EQUIPMENT

Jacks

1. Jacks should be designed so they can be transported, handled, and stored easily. Small jacks that one man must lift and carry should not weigh more than 40 pounds.

2. Jack handles should be designed so they can be removed or folded when the jack is not in use.

3. Jacks should be labeled to indicate:

a. The direction to turn the jack handle for raising and lowering.

b. The load they are designed to carry.

4. On hydraulic jacks, there should be mechanical safety-locking devices to keep the load from falling if the hydraulic system fails.

Cranes

1. Sections of crane booms should have hook eyes at their center of gravity for easier assembly and disassembly.

2. Where feasible, the boom length should be adjustable to make the equipment more versatile.

3. The crane operator's station should be located where he will have the best view of the load, the ground, and other equipment in the vicinity.

4. The main boom angle-indicator display should be easily visible to the operator and coded to alert the operator when there is danger of exceeding the maximum load angle.

5. Boom controls should have labels indicating their functions and direction of motion.

6. Boom controls should be spring loaded so they return to the stop position when released.

7. Crane hooks should have handles so operators can hold or guide hooks during lifting, without danger of injury.

8. The mouths of crane hooks should have safety-closure locking devices that are easy to open or close.

9. Retainers or locks used to keep booms in place during transport should be identified clearly and unambiguously.

LINES AND CABLES

1. Lines and cables should be selected, designed, bound, routed, and installed so the following operations can be performed quickly:

a. Troubleshooting, testing, checking, and isolating malfunctions.

b. Tracing, removal, repair, and replacement.

c. Removing and replacing other items and components.

d. Connecting and disconnecting.

2. Lines and cables should be compatible with:

a. Connectors (page 138).

b. Fasteners (page 151).

c. Accesses (page 130).

d. Environmental extremes they will be subjected to.

3. Lines and cables should be routed and mounted so that:

a. They are accessible without disassembling or removing other equipment.

b. Points of connection, mounting, splicing, or testing should be especially accessible.

c. They can be removed and replaced completely if they are damaged.

d. There are accesses and clearances for removing and replacing them.

4. Lines and cables should be routed so personnel will not use them for handholds or footrests.

5. Lines and cables should be routed and mounted so moving or rotating parts will not snag them, and so they do not interfere with normal operation.

6. Clamps or plates that mount lines and cables:

a. Should be spaced not more than 24 inches apart so personnel can remove one with each hand.

b. Should have heat-insulating liners so they do not become hot enough that personnel could be burned.

c. Should be designed so personnel can install or remove them with one hand, with or without common hand tools.

d. If cables are removed frequently, should be of a quick-release, hinged, or spring type. Hinged clamps are preferable, because they support the weight of the line during maintenance, freeing the technician's hands for other tasks. For overhead mounting, use a spring clamp with a hinged-locking latch over the clamp's open side to prevent accidents.

7. There should be adequate provision for handling and storing extension cables and cables used with ground power, service, and test equipment.

a. Provide adequate, covered space for storing lines and cables in support equipment.

b. Provide suitable racks, hooks, or cable winders in the storage space to hold lines and cables conveniently accessible.

c. Provide reels or reel carts for handling large, heavy, or very long lines and cables. Use automatic or power tensioning or rewinding reels where possible to make handling easier.

d. Use wheeled or mobile supports for extra-large lines and cables that must be moved frequently.

8. Install cables so foreign objects, flying stones, etc., will not damage them.

Fluid and Gas Lines

1. To avoid the possibility of mismating connectors during servicing or maintenance:

a. Standardize fittings so lines that differ in content cannot be interchanged.

b. Code lines by arrangement, size, shape, and color as necessary.

c. Use colored bands to identify all lines that carry fluids.

2. Keep lines from spraying or draining fluid on personnel or equipment when they are disconnected by:

a. Locating connections away from work areas and sensitive components.

b. Shielding sensitive components where required.

c. Providing drains and bleed fittings so lines can be drained or depressurized before they are disconnected.

d. Providing highly visible warning signs at connectors or wherever pressures or the contents of lines could injure personnel.

3. Prevent drainage problems by:

a. Designing lines so they can be emptied completely when necessary.

b. Making bends horizontal, rather than vertical, to avoid fluid traps.

c. Avoiding low points or dips in lines that make them difficult to drain.

d. Providing special drains at low points where necessary.

4. Mount and install lines so that:

a. Rigid lines with fittings do not have to be backed-off before they can be disconnected.

b. Use flexible tubing, rather than rigid lines, where feasible -- it allows easier handling, can be backed-off easily, and is easier to thread through equipment when it must be replaced.

c. Use flexible hose, rather than pipes or tubing, when there is only limited space for removing, replacing, or handling lines. It can be backed-off or pushed aside for access to other components.

5. Provide adequate supports for lines from external service or test equipment, or where extensions will be attached for other purposes. These supports must withstand not only the initial pressure through the line and the weight of its external extensions, but the rigors of handling and repeated connection and disconnection as well.

Electrical Wires and Cables

1. Make the layout and routing of wires as simple and logical as possible by:

a. Combining wires into cables (preferable) or into harnesses.

b. Minimizing the number of wires, harnesses, and cables.

c. Grouping conductors into cables -- and within cables or harnesses -- by their functions and relationships to replaceable items.

2. Conductors should be coded and labeled:

a. As provided under "Connector Requirements," (page 138).

b. So each conductor can be identified throughout the length of each cable or harness, wherever tracing is required.

c. So codes and labels correspond to connector designations, test point designations, and connector functions.

3. Mount electrical wires, harnesses, and cables so there is adequate accessibility through raceways, conduits, junction boxes, etc.

4. Route electrical wires and cables over, rather than under, pipes or fluid containers.

5. Wire and cable routes should be away from or suspended over areas where fluids may drip or accumulate (e.g., pans and trenches, under floorboards, etc.).

6. Leads should not be longer than necessary, but their lengths should allow:

a. Easy connection and disconnection, with enough slack to back wires away from attachment points so units can be removed easily.

b. Enough slack so terminal fittings can be replaced at least twice and preferably three times (if electrical considerations permit).

c. Moving units which are difficult to handle when mounted, to a more convenient position for connection or disconnection.

7. Mount leads so they are:

a. Separated far enough to clear the technician's hand or any tool required for checking or connecting them.

b. Oriented, where possible, so they will not be connected incorrectly or "crossed."

8. Use extension cables to:

a. Increase efficiency and make maintenance easier.

b. Test assemblies or components without removing them.

c. Check each functioning unit in a convenient place.

d. Allow parking support equipment or setting it in a convenient place.

e. Serve as many related functions as possible, but avoid the possiblity of misuse or misconnection.

MOUNTING AND ARRANGING

1. Most parts, items, and assemblies can be located in many places and arranged in many ways. For ease of maintenance and training, select arrangements by these criteria:

a. Accessibility.

b. Standardization.

c. Reliability figures and factors (as indicators of access requirements.)

d. Operating stress, vibration, temperature, etc.

e. Requirements for built-in test and malfunction circuits or indicators.

f. The peculiar characteristics of each item or module, and particularly:

(1) Size, weight, and clearance.

(2) Fragility or sensitivity, which impose needs to protect it.

(3) Needs and procedures for servicing, adjusting, or repairing it.

(4) Clearance for removing and replacing it.

(5) Access and clearance for tools around fasteners, connectors, test, or service points, etc.

(6) Specific factors such as critical lead length, weight balance, heat dissipation, etc., which may make it hard for personnel to carry out their tasks.

2. Arrange components, subassemblies and assemblies for easiest maintenance by:

a. Minimizing requirements for technicians to move from place to place during servicing, checkout, or troubleshooting.

b. Minimizing the need for the technician to retrace his movements or steps during servicing, checkout, or troubleshooting.

c. Minimizing the number of inputs and outputs to components and items.

d. Arranging the equipment so the technician can either replace an individual item of a group or replace the whole group, depending on the maintenance philosophy.

e. Equipping replacement components with new fasteners or brackets if the old ones are likely to be lost or damaged.

f. Avoiding making technicians follow long sequences of assembly steps before they can maintain the equipment.

g. Using sliding racks, or hinged assemblies, for maximum accessibility.

h. Organizing equipment by maintenance specialties, so one specialist can maintain his part of the system without removing or handling equipment that another specialist maintains -- particularly when the equipment is critical or maintaining it requires highly specialized skills.

3. Mount parts, subassemblies, assemblies, etc., so that:

a. They are accessible.

b. Fasteners are as recommended under "Fasteners," page 151.

4. Design mounting fixtures, brackets, etc., so:

a. Only interconnecting wires and structural members are permanently attached to units; make all other fixtures removable for easy maintenance.

b. Fixtures attached to the chassis are either strong enough to last for the life of the system or are replaceable.

c. Mounting is compatible with the part's size and weight, so leads will not fatigue and break, or the like, from the stress of normal handling.

5. Provide supports, guides, and guide pins as necessary to simplify handling, aligning, and positioning units.

6. Use shock mounts as necessary to:

a. Keep displays, markings, etc., from vibrating, not only to protect fragile or vibration-sensitive components and instruments, but also to prevent reading errors.

b. Isolate sources of high or dangerous noise and vibration, for more effective human performance.

7. Where personnel must mount parts without seeing them:

a. Secure the inaccessible side with mounts that allow exceptionally easy mating.

b. Do not use friction lugs, tongue and groove fittings, etc.

8. Mount components, modules, and parts so they will not inadvertently be reversed, mismated, or misaligned during installation or replacement.

9. Components with the same form, function, and value should be completely interchangeable throughout the system; however, components with the same or similar form, but different functional properties, should be:

a. Mounted with the same orientation throughout the unit.

b. Readily identifiable, distinguishable from each other, and not physically interchangeable.

10. Arrange and mount assemblies, components, parts, etc., so that:

a. There is adequate access around fasteners for tools and wrenches.

b. There is enough space to use test probes and other service or test equipment.

c. A given unit or component can be maintained:

(1) With the unit or component in place, if possible.

(2) Without having to disconnect, disassemble, or remove other items first.

d. All replaceable items, particularly disposable components, can be removed:

(1) Without removing or disassembling other items or units.

(2) By opening a minimum number of covers, cases, panels, etc.

(3) Without hindrance from structural members or other parts.

(4) Along a straight or slightly curved line, rather than through an angle or a more devious course.

e. All heavy, large, or awkward units are located so they:

(1) May be slid out or pulled out, rather than lifted out.

(2) Do not block access to other removable items.

f. When one unit must be placed behind or under another, the unit requiring more frequent maintenance should be more accessible.

g. Structural members of items, chassis, or enclosures do not block access to removable items, or to their connectors or fasteners.

h. Removing and replacing items require minimal tools and equipment, and, if practicable, only common hand tools.

i. Rapid, easy removal and replacement can be done by one man, by two men, or by handling equipment (in that order of preference).

j. Irregular, fragile, or awkward extensions -- such as cables, hoses, etc. -- are easy to remove before the unit is handled; such protrusions make handling difficult, because they are so easy to damage.

k. Handling and carrying can be done efficiently by one man.

(1) Removable items should weigh less than 45 pounds.

(2) Items that are difficult to reach should weigh less than 25 pounds.

(3) Items weighing more than 45 pounds should be designed for handling by two men.

(4) Provide hoist lugs for assemblies weighing more than 90 pounds.

11. The design, arrangement, and mounting of components, units, parts, etc., should give personnel maximum protection against injury.

12. Items should be located, arranged, mounted, and shielded so personnel can reach them, their fasteners, and adjacent items without danger from electrical potentials, heat, sharp edges or points, moving parts, chemical contamination, or other hazards. Specifically:

a. Do not locate parts, fasteners, service, or test points, etc., that require frequent servicing, near exposed terminals or moving parts.

b. Provide guards or shields to keep personnel from touching dangerous moving parts or electrical potentials.

c. Make ventilation holes small, and locate them where personnel cannot poke fingers, tools, etc., into hazardous areas (e.g., 1/4"-diameter holes will exclude fingers).

d. Capacitors, exhaust pipes, and other parts which retain heat or electrical potentials after the equipment is turned off should be located or shielded so personnel cannot touch them accidentally.

13. Mount adjustment and alignment devices where technicians cannot operate them unintentionally.

14. Hold small removable pins, caps, covers, etc., captive with chains or the like so they will not be lost or damaged.

15. Protect vital, fragile, sensitive, or easily damaged components by locating, arranging, and shielding them so they will not be:

a. Used for handholds, footholds, or rests.

b. Damaged by flying particles, loose objects, or movements of personnel or tools during maintenance.

TEST AND SERVICE POINTS

1. This section recommends ways to simplify testing and servicing.

2. Use distinctively different connectors or fittings for each type of test or service equipment, probe, grease, oil, etc., so they cannot be used incorrectly.

3. Avoid requiring separate funnels, strainers, adapters, and other accessories. Wherever practical, build such items into the equipment, or into service equipment, so they need not be handled separately.

4. Provide lubrication points so it will not be necessary to disassemble equipment to oil it; but if such points are not feasible, provide easy access for direct lubrication.

5. For operators to utilize the test and service points most efficiently, they should be provided, designed, and located:

a. By frequency of use and time required for use.

b. So they minimize disassembly or removal of other equipment or items.

c. On surfaces or behind accesses where they are easy to reach and operate when the equipment is fully assembled and installed.

d. So they are clearly distinguishable from each other; where necessary, use color coding and labeling to make them discriminable.

e. So there is adequate clearance between connectors, probes, controls, etc., for easy grasping and manipulation. The minimum clearances recommended are:

(1) 0.75 inch when only finger control is required.

(2) 3.0 inches when the gloved hand must be used.

f. So they offer positive indication -- by calibration, labeling or other features -- of the direction, degree, and effect of the adjustment.

g. With guards and shields to protect both personnel and test or service equipment, particularly if the equipment must be serviced while running.

h. So single test or service points are not in isolated positions, where they might be overlooked or neglected.

i. With lead tubes, wires, or extended fittings that bring hard-to-reach test and service points to accessible areas.

j. To avoid critical lead lengths and similar constraints that reduce accessibility.

k. To simplify using test or service points without seeing them.

l. Within easy functional reach or sight of related or corresponding controls, displays, fittings, switches, etc.

m. Away from electrical, mechanical and other hazards. The nearest hazard should be at least a hand's width (4.5 inches) away, with guards and shields provided as necessary to prevent injury.

n. So test points are not concealed or obstructed by the frame, brackets, other units, etc., to eliminate the need to disassemble, remove, or support other units, wires, etc., to test, service, or troubleshoot.

6. Avoid the following types of adjustment except where they will simplify the design or use of the equipment:

a. Extremely sensitive adjustments.

b. "System adjustments" (e.g., design systems so that components can be replaced without harmonizing or recalibrating the whole system).

c. Harmonizing or "mop-up" adjustments (e.g., those where "A" or "B" must be readjusted after A, B, and C have been adjusted in sequence).

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