U. S. ARMY

HEL Standard S-2-64A

HUMAN FACTORS ENGINEERING DESIGN STANDARD FOR VEHICLE FIGHTING COMPARTMENTS

Technical Specifications Office
Systems Research Laboratory

June 1968

HUMAN ENGINEERING LABORATORIES

ABERDEEN RESEARCH & DEVELOPMENT CENTER

ABERDEEN PROVING GROUND, MARYLAND

BLANK PAGE

Destroy this report when no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial products.

*HEL Standard S-2-64A

HUMAN FACTORS ENGINEERING DESIGN STANDARD

FOR VEHICLE FIGHTING COMPARTMENTS

Technical Specifications Office
Systems Research Laboratory

June 1968

APPROVED: JOHN D. WEISZ
Technical Director
Human Engineering Laboratories

* This standard supersedes HEL Standard S-2-64, May 1964.

U. S. ARMY HUMAN ENGINEERING LABORATORIES
Aberdeen Proving Ground, Maryland

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 HEL Standard S-2-64, May 1964.)

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.

CONTENTS

CONTROLS

DISPLAYS

CODING

LABELING

ARMAMENT

GUN-CONTROL SYSTEMS

OPTICAL INSTRUMENTS

AMMUNITION

STOWAGE

ENVIRONMENT

FIGURES

TABLES

HUMAN FACTORS ENGINEERING DESIGN STANDARD

FOR VEHICLE FIGHTING COMPARTMENTS

INTRODUCTION

1. To make sure equipment is properly utilized, it must be designed for a specific user population. This constraint upon design is an obvious, although perhaps unconscious, primary consideration of the designer.

2. Designers must design for men who will, in tactical situations, be under conditions of stress and fatigue from many causes. In the tactical situation, there may be a performance decrement that is not caused by any basic inability of the troops to perform but by the fact that the individual soldier is overloaded both physically and mentally.

3. Equipment must be designed to be as simple as possible to operate, and it should not require intellectual data transformation where personnel may be distracted. Equipment should also be kept simple to meet requirements for reliability and maintainability.

4. The designer must remember that training can improve crew proficiency but that training should not be used as a substitute for poor design.

5. As weapons systems become more complex, the Army must find better people to operate them or design equipment to be used by the people available. Designing the equipment for the people is the preferred choice.

6. It is important to understand the men who serve as crew members. Their capabilities and limitations are the base line for designing equipment.

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

8. Ideally, the needs of the Army, as well as the interests and background of the individual, are considered in the selection process. Thus, a man is placed in a job suited to his mental and physical capabilities and to his interests.

9. In peace time, in an Army that is comparatively small, the ideal can be and is followed closely. However, either in peace or in emergency, the primary consideration must be needs of the Army.

10. In time of emergency, standards are lowered and the needs of the Army assume paramount importance, with perhaps too little consideration for the individual's needs and interests. The Army requires, however, that even under these conditions the ideal selection and assignment processes be adhered to as closely as is feasible.

11. 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.

12. The characterization of typical personnel reported in the remainder of this section was obtained from USA HEL TN 2-62 and personal contacts with research personnel of Fort Knox, Ky. A vehicle fighting-compartment crew usually consists of four persons: a loader, a driver, a gunner, and a commander. Typically these personnel may be characterized as follows:

Loader

a. The typical loader is 20.8 years old with 20 months of service and has served 7.7 months as a member of a crew. He most probably holds the rank of Private (E-2). Contrary to the requirement that crew members score 100 or higher on the Army Classification Battery AE (Armor, Artillery, and Engineers Aptitude Area), the average loader has a score of 90 or lower in all aptitude areas.

b. His primary duties consist of:

(1) Loading and unloading the main gun.

(2) Operating and performing first-echelon maintenance on all vehicle radio communications equipment.

(3) Servicing and performing first-echelon maintenance on the calibre .30 machine gun, the calibre .45 submachine guns or other secondary weapon system on the vehicle.

(4) Stowing and maintaining all ammunition.

(5) Maintaining the turret and checking the stowage of his own personal equipment.

Driver

a. The typical driver is 21.3 years old with 22 months of service and has been a crew member for 14.7 months. He is most probably a Private First Class (E-3), and on the Army Classification Test Battery his score ranges from 91 to 105 in all aptitude areas. Again, these men do not necessarily meet the Army requirement of 100 or more in the AE aptitude area.

b. His primary duties consist of:

(1) Manipulating, reading and understanding, as applicable, the controls, instruments, parts, and assemblies of the vehicle.

(2) Conducting first-echelon maintenance.

(3) Driving during non-tactical and combat operations.

(4) Observing all safety precautions.

(5) Understanding arm and hand, light, and flag signals.

(6) Driving in formation.

(7) Reading and interpreting road and strip maps.

(8) Placing and securing the driver's stowage.

(9) Completing and maintaining certain vehicular forms, records, and publications.

Gunner

a. The typical gunner is an E-4, is about 22.6 years old, has been in the Army for about 37 months, and has been a member of the crew for about 12.5 months. His scores on the Army Classification Test Battery range from 91 to 105.

b. His duties consist of:

(1) Removing, installing, and maintaining all gunnery material.

(2) Checking and adjusting the fire-control equipment and the firing mechanism of the main gun and machine gun.

(3) Firing the main gun and the machine gun, utilizing direct-fire procedures.

(4) Firing the main gun in special and indirect-fire situations.

Commander

a. The typical commander is 27 years old, is an E-6 and has been in the Army about 89 months. For 47 months he has been a crew member.

b. The chances are one in five that he has had combat experience in armor, though not necessarily as a commander. His GCT score is usually 106 or higher on the Army Classification Battery.

c. As would be expected, the commander is the best trained of the four crewman. However, considering his position, generally he is still not as proficient as the Army says he should be.

d. Primary duties of the commander are:

(1) Commanding and controlling the vehicle and crew.

(2) Preparing, instructing, and disseminating training materials and information to crew members.

(3) Applying basic methods for collecting and reporting combat information, and applying and supervising troop counterintelligence measures.

(4) Establishing, maintaining, and taking responsibility for all communications within his vehicle and between his vehicle and all other vehicles in his platoon.

(5) Commanding and supervising firing of the weapons.

(6) Conducting all required inspections of the vehicle, crew, and armor materials in garrison and in the field.

ANTHROPOMETRICS

Body Dimensions

1. The anthropometric data shown in Tables 1, 2, and 3, and Figures 1, 2, and 3 provide a basis for design decisions not specifically covered in other sections. Use of these data must take the following into consideration:

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

b. The position of the body during performance of these tasks.

c. Mobility or flexibility requirements imposed by the tasks.

d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc.

e. Increments in the design-critical dimensions imposed by protective garments, packages, lines, padding, etc.

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

2. General rules for selecting the appropriate data:

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

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

c. Adjustable dimensions (seats, belts, controls, etc.) should be adjustable to accommodate the range of 5th through 95th percentile personnel.

3. The 5th percentile for a particular dimension is a value such that five percent of the personnel are smaller than the value expressed and 95 percent of the personnel are larger. Conversely, the 95th percentile for a particular dimension is a value such that 95 percent of the personnel are smaller than the value expressed and five percent of the personnel are larger.

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 measurement (Fig. 1, E-7) by as much as 2.5 inches. This slump factor must be considered in locating displays, in establishing a 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 and arctic clothed figure. This is to avoid confusions caused by the wide variations in other dress. It is necessary to make allowances for clothing and head gear. Table 2 shows increments added by the Combat Vehicle Crewman's Helmet, while Table 3 shows increments added by the basic uniform. (The data in Tables 1, 2, and 3 are for U. S. Army Armored Crewman.)

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, except where noted) 5th Percentile Nude	5th Percentile Arctic Clothed	95th Percentile Nude	95th Percentile Arctic Clothed
Weight (pounds)	128	154	215	245
Standing				
A. 1. Stature	64.3	67.3	73.0	75.3
2. Eye Height	60.8	62.3	68.6	69.7
3. Ear Height	59.8	--	67.4	--
4. Shoulder Height	52.8	54.5	60.8	62.3
5. Nipple Height	47.0	--	53.9	--
6. Kneecap Height	18.8	20.4	23.1	24.9
7. Calf Height	12.1	--	15.8	--
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	8.2	12.8	11.0	14.0
3. Waist Depth	6.7	10.0	9.4	14.0
4. Buttock Depth	7.6	--	10.2	--
5. Crotch Height	29.4	28.0	35.7	32.5
C. 1. Chest Breadth	11.0	--	13.8	--
2. Waist Breadth	9.4	--	12.3	--
3. Hip Breadth	12.0	15.7	14.7	18.5
4. Knuckle Height	27.7	--	32.4	--
5. Wrist Height	31.0	--	36.1	--
6. Waist Height	38.3	41.2	45.2	46.8
7. Elbow Height	40.6	-	46.4	--
8. Cervicale Height	54.9	57.6	63.1	65.0
Seated				
D. 1. Sitting Height	33.0	34.6	38.1	40.0
2. Mid-Shoulder Height	22.3	23.1	26.8	27.6
3. Shoulder Elbow Height	13.4	15.1	15.9	16.5
4. Waist Height	7.9	--	10.4	--
5. Thigh Clearance Height	4.8	6.3	6.5	7.5
6. Buttock-Knee Length	21.7	23.7	25.6	26.8
7. Back of Knee Height	15.7	15.8	18.8	17.9
8. Knee Height	19.5	22.1	23.2	25.3
9. Buttock-Leg Length	39.4	--	46.1	--
10. Forearm-Hand Length	17.4	21.4	20.6	22.6
E. 1. Shoulder Breadth	16.6	19.0	20.1	22.5
2. Forearm-to-Forearm Breadth	15.8	23.3	21.9	28.3
3. Hip Breadth, Sitting	12.2	16.5	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	7.4	6.7	10.8	10.7
7. Eye Height	28.3	29.1	33.2	33.5

* The values used in Table 1, 2, and 3 are those for U. S. Army Armored Crewmen (1966).

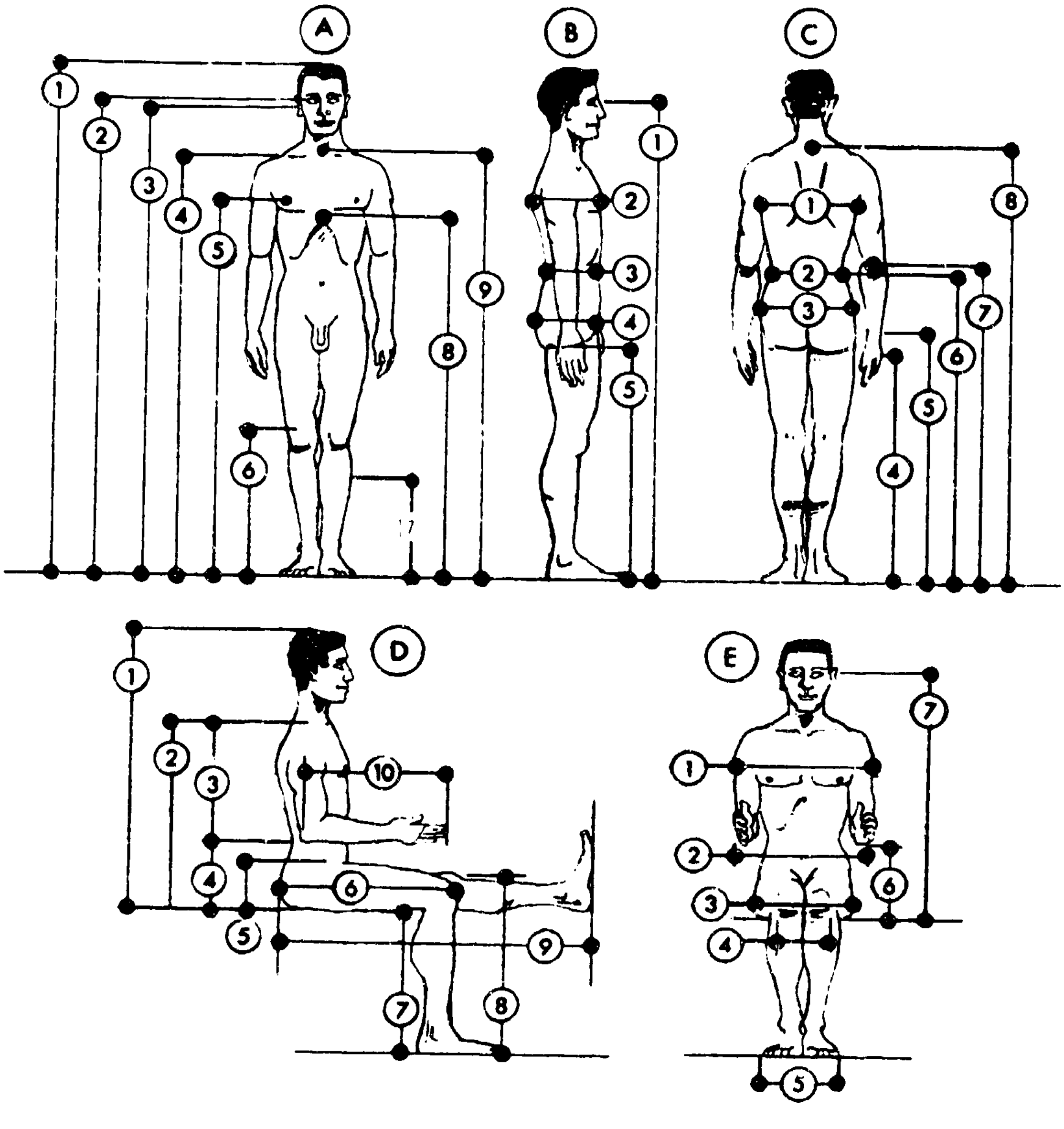


Fig. 1. BODY DIMENSIONS

TABLE 1 continued

Dimension	Design Values (inches)			
	5th Percentile		95th Percentile	
	Nude	Arctic Clothed	Nude	Arctic Clothed
F. Reach				
1. Functional Reach	29.6	30.7	36.1	37.8
2. Arm Reach From Wall	31.9	--	37.3	--
3. Maximum Reach From Wall	35.4	--	41.7	--
4. Span	65.9	68.9	75.6	77.0
G. Head				
1. Biocular Diameter	3.5	--	4.1	--
2. Interpupillary Distance	2.2	--	2.8	--
3. Interocular Diameter	1.1	--	1.4	--
4. Nasal Root Breadth	0.5	--	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	6.5	9.0
2. Edge of Right Ear to Left Ear	5.3	--	5.9	--
3. Minimum Frontal Diameter	4.0	--	4.7	--
4. Maximum Frontal Diameter	4.4	--	5.1	--
5. Breadth of the Face	5.2	--	6.0	--
6. Width of the Jaw	3.9	--	4.6	--
7. Ear Protrusion	0.6	--	1.1	--
I. Head				
1. Head Height (from ear)	4.7	6.5	5.7	7.9
2. Minimum Frontal Arc	4.8	--	6.1	--
3. Chin to Nose Length	2.2	--	3.1	--
4. Nose Length	1.8	--	2.2	--
5. Chin to Hairline Length	6.8	--	8.0	--
J. Head				
1. Head Length	7.1	10.9	8.2	10.9
2. Nasal Root to Wall	7.0	--	8.1	--
3. Ear Breadth	1.3	--	1.6	--
4. Ear Length	2.2	--	2.7	--

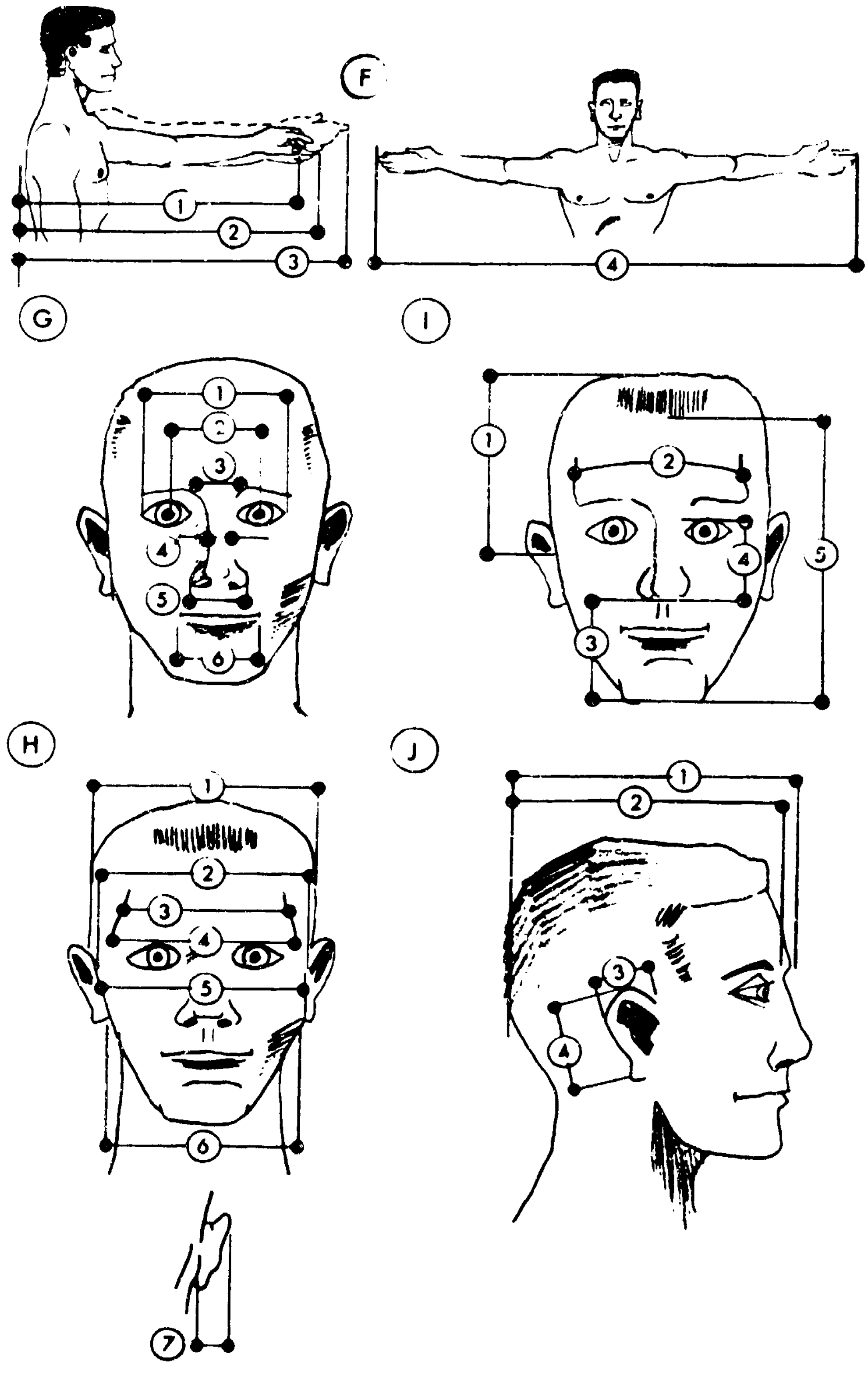


Fig. 1. Continued

TABLE I continued

Dimension	Design Values (inches) 5th Percentile Nude	5th Percentile Arctic Clothed	95th Percentile Nude	95th Percentile Arctic Clothed
K. Body Circumferences				
1. Neck	13.7	26.7	16.5	26.2
2. Shoulder	41.4	51.9	50.3	60.0
3. Chest	33.6	42.4	43.2	52.1
4. Waist	27.8	38.5	40.0	51.6
5. Hip	33.9	46.6	42.7	56.3
6. Upper Thigh	19.0	24.2	25.8	30.9
7. Lower Thigh	13.7	--	18.9	--
8. Calf	12.9	19.7	16.4	22.8
9. Ankle	8.1	15.3	10.0	18.2
10. Wrist	6.2	12.0	7.5	13.1
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. Ball of Foot Breadth	3.5	4.8	4.3	5.4
5. Ball of Foot Circumference	8.9	14.7	10.8	15.8
6. Foot Length	9.7	12.7	11.5	13.6
7. Ball of Foot Length	7.0	8.5	8.5	9.2
8. Heel Breadth	2.4	--	3.2	--
M. Hand				
1. Grip Diameter (Outside)	3.7		4.4	See
2. Grip Diameter (Inside)	1.6		2.1	Figure 3
3. First Phalanx III Length	2.5		2.9	for
4. Fist Circumference	10.7		12.4	95th
5. Thickness at Metacarp. III	1.0		1.3	Percen-
6. Finger Diameter (Third)	0.8		0.9	tile
7. Hand Length	6.8		8.2	
8. Hand Breadth at Metacarp	3.2		3.9	
9. Palm Length	3.7		4.6	
10. Hand Breadth at Thumb	3.7		4.6	
11. 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	
16. Thumb Crotch Length	1.6		2.3	

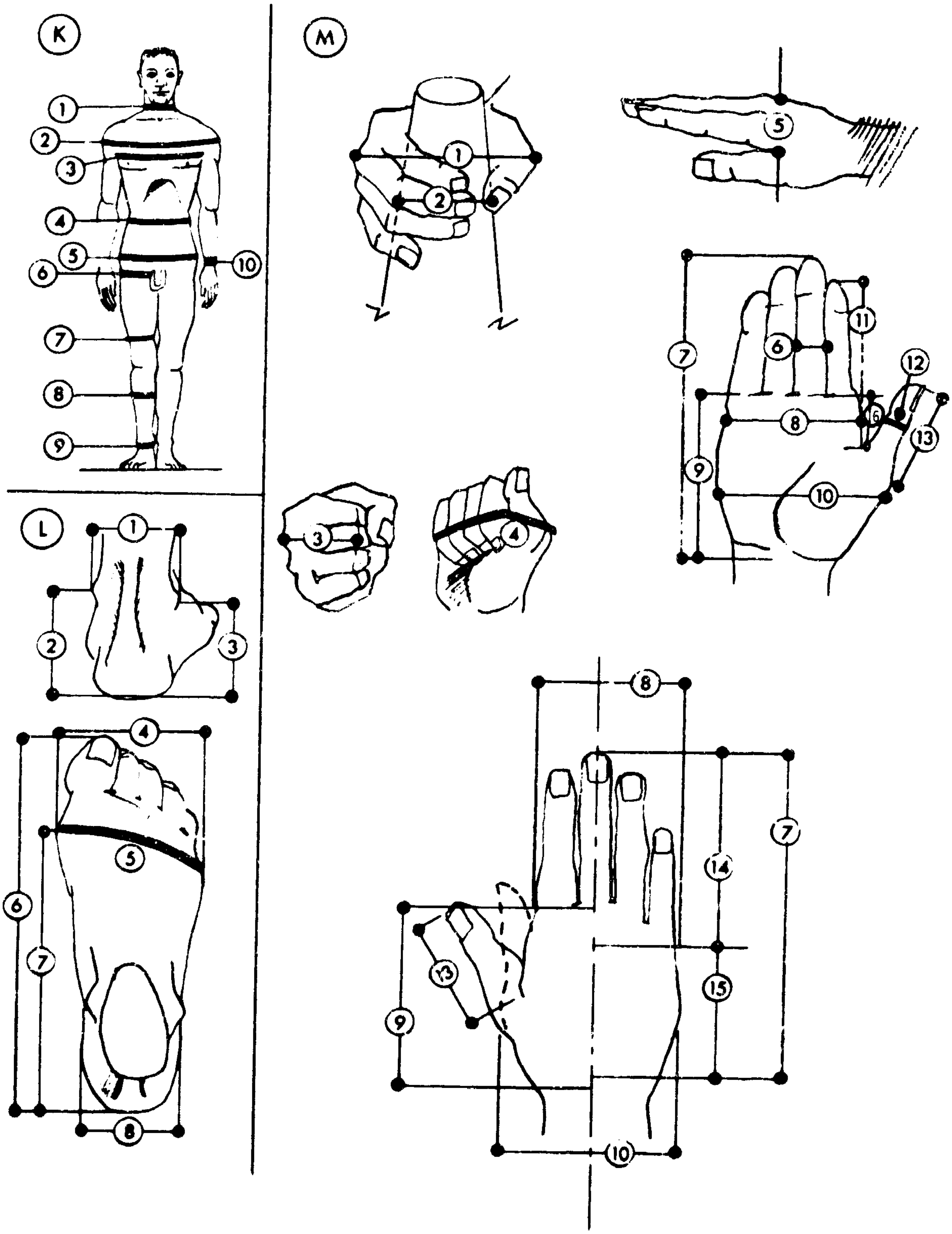


Fig. 1. Continued

TABLE 2

Dimensions of Combat Vehicle Crewman Helmet (T 56-6) Over Bare Head Dimensions

Dimension (inches)	Design Values (Percentile) Bare Headed 5th	Bare Headed 95th	With Helmet 5th	With Helmet 95th	Added by Helmet 5th	Added by Helmet 95th
A. 1. Length of Head	7.1	8.2	10.5	11.0		
2. Ear Hole to Back of Head	3.3	4.8	5.0	5.3		
3. Ear Hole to Front of Head	3.4	3.8	5.5	5.7		
4. Front Extension Beyond Head					2.1	1.9
5. Top Extension Beyond Head					2.1	2.1
6. Back Extension Beyond Head					1.7	0.5
7. Ear Hole to Top of Head	4.7	5.7	6.8	7.8		
B. 1. Right Eye Pupil to Right Side Head	1.7	1.9	3.5	3.7		
2. Right Eye Pupil to Left Side Head	3.9	4.6	6.9	7.6		
3. Left Eye Pupil to Right Side Head	3.9	4.6	5.7	6.4		
4. Left Eye Pupil to Left Side Head	1.7	1.9	4.7	4.9		
5. Midline to Right Side Head	2.8	3.3	4.6	5.1		
6. Midline to Left Side Head	2.8	3.3	5.8	6.3		
7. Eye Height to Top Head	4.7	4.9	6.8	7.0		
8. Right Extension Beyond Head					1.8	1.8
9. Left Extension Beyond Head					3.0	3.0
10. Standing Height (nude) to Top Head	64.3	73.0	66.4	75.1		
11. Sitting Height (nude) to Top Head	33.0	38.1	35.1	40.2		
12. Head Breadth	5.6	6.5	10.4	11.3		

Note: Measurements are for a properly adjusted helmet.

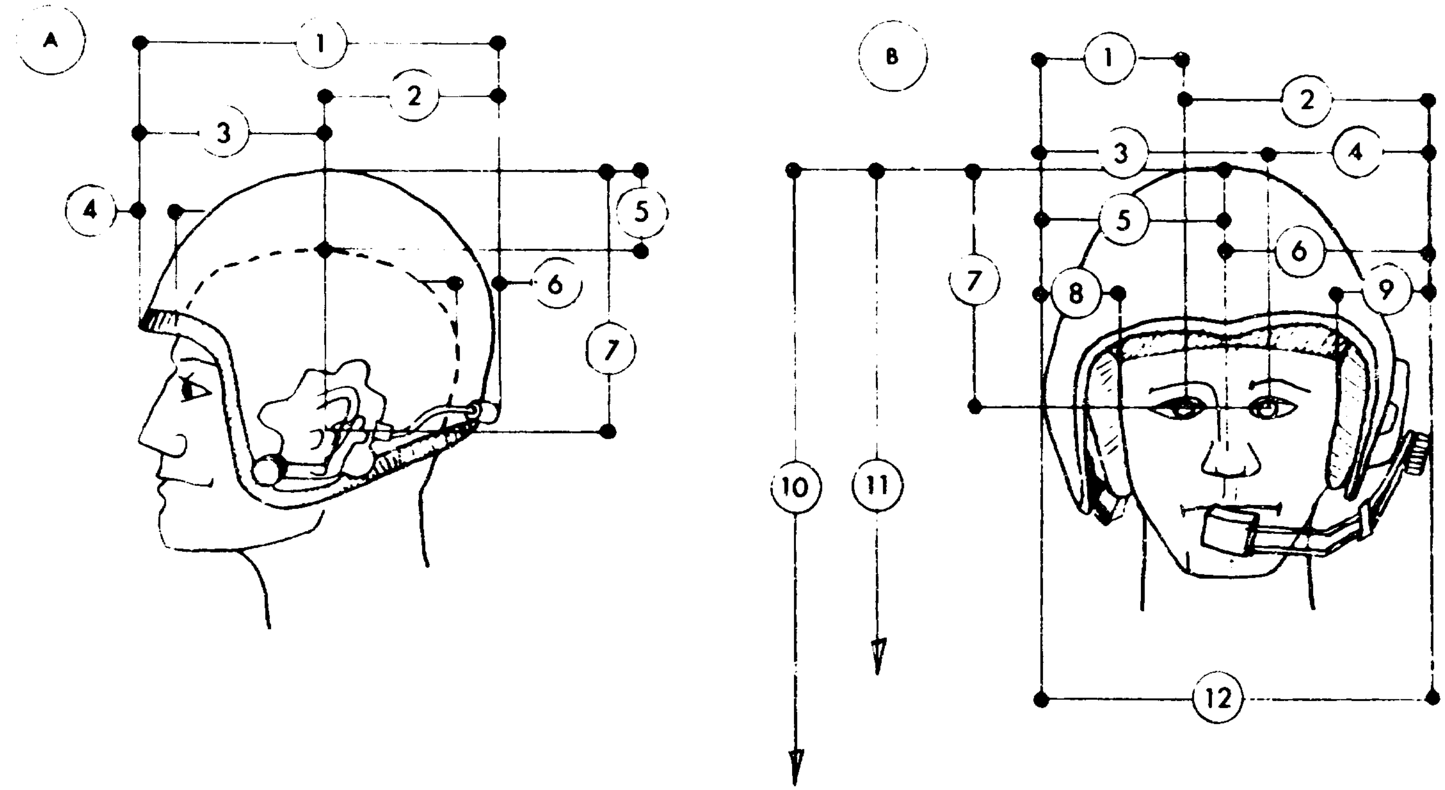


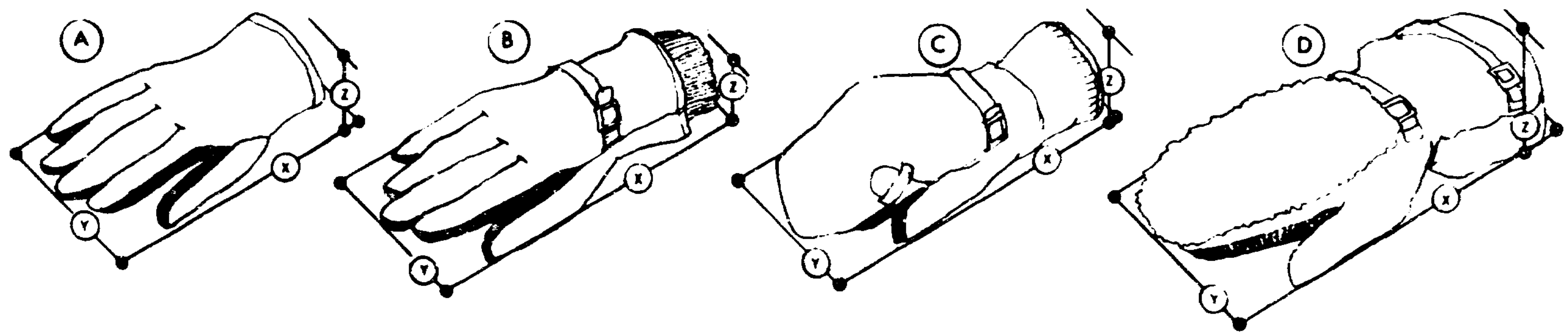
Fig. 2. DIMENSIONS OF THE CVC HELMET (T 56-6)

TABLE 3

Clothed Body Dimensions of the 5th and 95th Percentile Armored Crewman

	Basic Uniform: Underwear, Khakis, or O.D.'s or Fatigues, Socks, Shoes, Helmet and Liner		Additions to the Basic Uniform: Blouse or Field Jacket		Additions to the Basic Uniform: Blouse or Field Jacket Overcoat		Additions to the Basic Uniform: Combat Suit Overcoat Gloves, Woo. Cap, and Combat Boots	
	5th	95th	5th	95th	5th	95th	5th	95th
Weight (pounds)	137.4	224.4	139.8	226.8	146.6	233.6	152.0	239.0
Body Dimensions (inches)*								
A-1 Stature	66.9	75.7	66.9	75.7	66.9	75.7	67.0	75.8
D-1 Sitting Height	34.3	39.5	34.4	39.6	34.6	39.7	34.7	39.8
E-7 Eye Height, Sitting	28.3	33.2	28.4	33.3	28.5	33.4	28.6	33.5
D-2 Mid-Shoulder Height, Sitting	22.4	27.0	22.8	27.4	23.2	27.7	23.2	27.7
D-8 Knee Height, Sitting	20.8	24.5	20.8	24.5	20.9	24.5	20.9	24.5
D-6 Buttock-Knee Length	21.7	25.6	21.8	25.7	21.9	25.8	22.1	26.0
D-3 Shoulder-Elbow Length	13.5	16.0	13.9	16.4	14.3	16.8	14.3	16.8
E-1 Shoulder Breadth	16.8	20.3	17.5	21.0	18.1	21.6	18.1	21.6
C-1 Chest Breadth	11.2	14.0	11.3	14.1	11.5	14.3	11.7	14.5
E-2 Elbow Breadth	16.3	22.5	16.8	22.9	17.6	23.7	17.9	24.0
C-3 Hip Breadth	12.5	15.3	12.7	15.5	13.1	15.8	13.4	16.1
E-3 Hip Breadth, Sitting	12.7	16.1	12.9	16.3	13.3	16.6	13.6	16.9
E-4 Knee Breadth (both)	7.6	9.3	7.6	9.3	7.9	9.5	8.8	10.5
B-2 Chest Depth	8.6	11.4	9.1	12.0	10.0	12.8	10.0	12.8
L-6 Foot Length	10.9	12.9	10.9	12.9	10.9	12.9	12.7	13.6
L-4 Foot Breadth	4.0	4.7	4.0	4.7	4.0	4.7	4.8	5.4
M-7 Hand Length (See Fig. 3)								
M-10 Hand Breadth (See Fig. 3)								

* The letter and number associated with each body dimension refers to the drawings in Figure 1.



Hand Position	A Anticontact Glove			B Wet-Cold Glove			C Wet-Cold Mitten			D Arctic Mitten		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Extended Flat	10.5	4.7	2.5	10.7	5.7	3.0	14.2	6.0	3.2	16.6	5.4	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	5.0	3.5	7.3	5.5	3.5	11.0	5.7	4.2	14.0	5.5	4.5
1.0" diameter	7.0	5.0	3.5	7.3	5.3	4.0	11.0	5.2	4.5	14.0	5.2	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	5.4	5.0
Grasping Knob												
.25" diameter	8.0	3.8	4.3	9.0	4.6	4.0	11.5	5.0	4.2	15.5	4.8	4.5
1.0" diameter	9.0	3.5	4.0	9.0	4.5	4.0	12.0	5.0	4.2	15.8	4.8	4.8
2.0" diameter	9.5	3.7	3.7	9.2	4.5	4.2	12.5	4.6	4.4	16.0	4.7	4.8

Hand Dimensions (inches)

Fig. 3. GLOVED-HAND DIMENSIONS FOR 95th PERCENTILE MAN

Human Strength and Handling Capacity

1. The maximum amount of force or resistance that can be designed into a control should be determined by the greatest amount of force that can be exerted by the weakest person likely to operate the control. The maximum force that can be applied will depend on such factors as the type of control, the body member being used to operate the control, the position of this body member during control operation, the general position of the body, and whether or not support is provided by back rests, etc.

2. Equipment should be designed whenever possible to be lifted by one man. Two men may perform certain lifting tasks, but this is not normally desirable. Leg muscles -- not arm or back muscles -- should accomplish heavy lifting. The approximate safe lifting capacity of one man is shown in Figure 4; however, they should be reduced considerably under the following conditions:

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

b. If access and work space is less than optimum.

c. If the required force must be continuously exerted for more than one minute.

d. If the object must be finely positioned or delicately handled.

e. If the task must be repeated frequently (e.g., many times on a given day).

3. Listed in Figure 5 are the forces that can be exerted by 95 percent of the male personnel in terms of the direction of movement and the body member used.

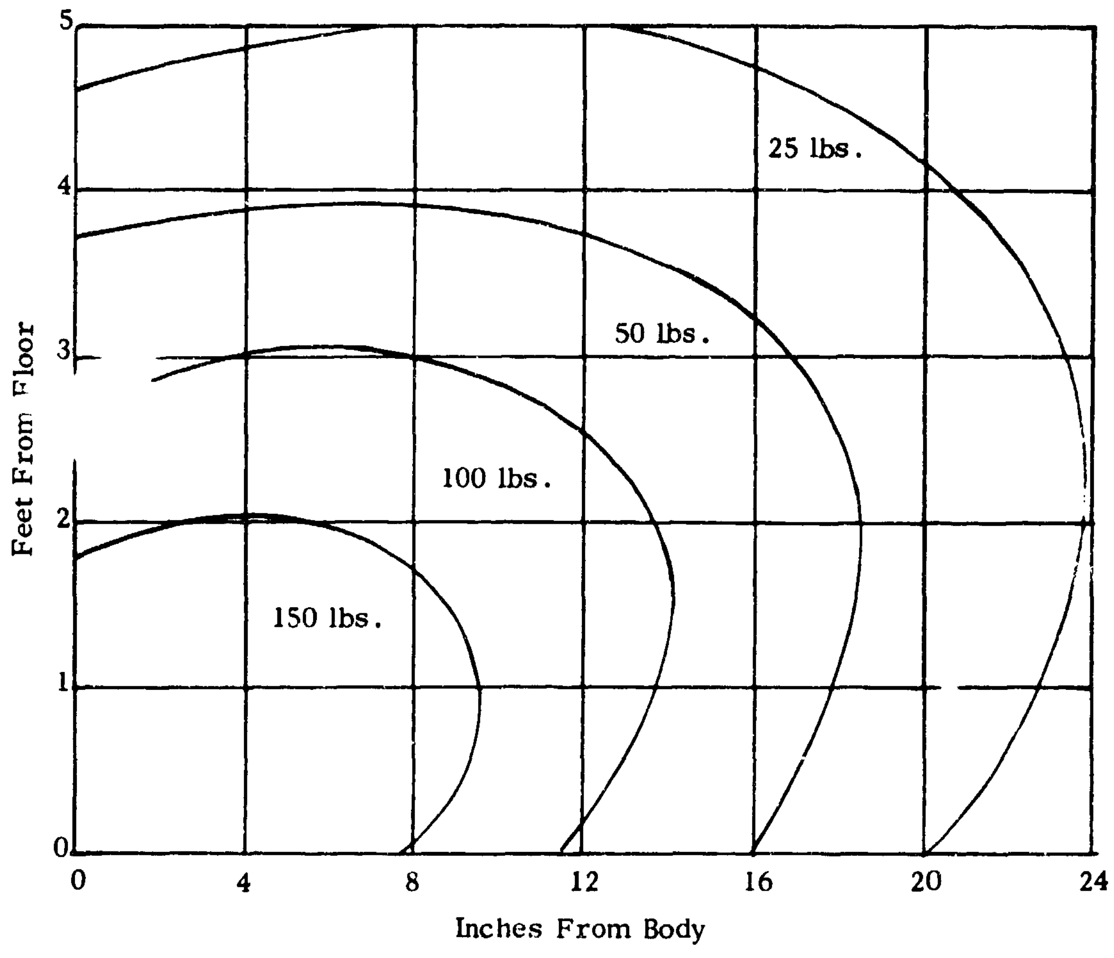
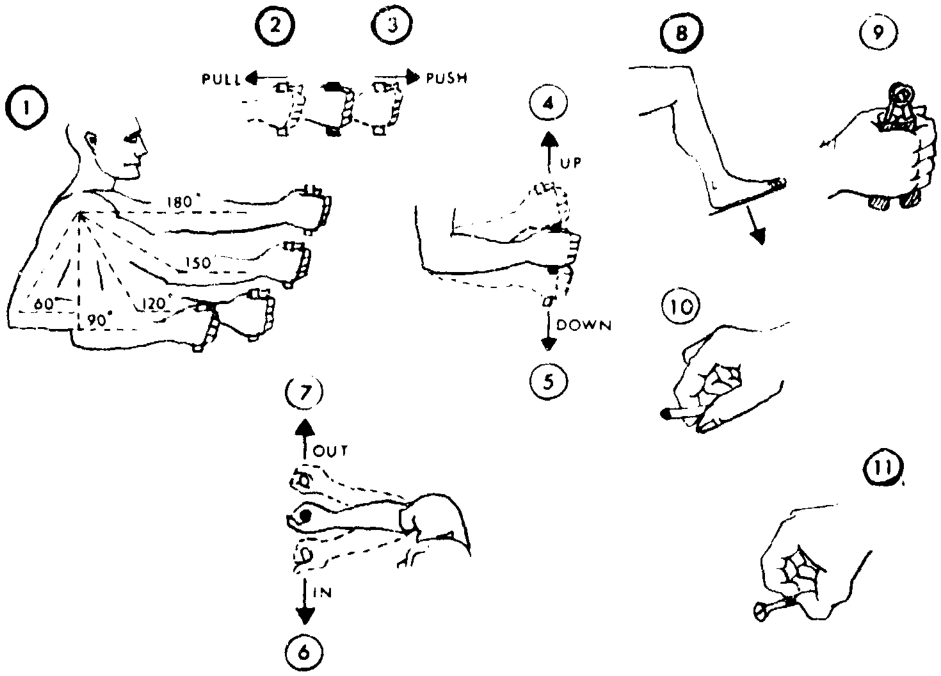


Fig. 4. MANUAL LIFTING CAPACITY
(using both hands)



ARM STRENGTH *

(1) Degree of Elbow Flexion	(2) Pull R**	(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*

	(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

*Design values, in pounds, for the given actions
**R = Right L = Left

Fig. 5. HUMAN STRENGTH

Range of Human Motion

1. All operating positions should allow freedom to move the trunk of the body. When large forces (in excess of 30 lbs.) or large control displacements (in excess of 15 inches in a fore-aft direction) are required, the operator should be provided with sufficient space to move his entire body.

2. Table 4 shows the ranges, in angular degrees, for each type of voluntary movement possible at the joints of the body illustrated in Figure 6. The designer must keep in mind that these ranges are high; since they are for nude personnel, they do not allow for the restrictions imposed by clothing.

a. Lower limit -- If the range of voluntary movement is used as a direct function in operating or maintaining the equipment, the maximum allowable angular value should be the Lower-Limit value. This would allow 90 percent of the population (i.e., 1.3 standard deviations below the mean value) to perform the voluntary movement.

b. Upper Limit -- If the range of voluntary movement is used in the design for body freedom of movement, then the Upper-Limit angle should be used.

TABLE 4

Range of Human Motion*

Body Member	Movement	Lower Limit (degrees)	Upper Limit (degrees)	Average (degrees)
A. Wrist	1. Flexion	74	102	90
	2. Extension	82	112	99
	3. Abduction	15	36	27
	4. Adduction	38	54	47
B. Forearm	1. Supination	84	135	113
	2. Pronation	46	101	77
C. Elbow	1. Flexion	129	152	142
D. Shoulder	1. Lateral Rotation	17	47	34
	2. Medial Rotation	68	119	97
	3. Flexion	172	200	188
	4. Extension	43	75	61
	5. Adduction	36	57	48
	6. Abduction	112	151	134
E. Hip	1. Flexion	96	126	113
	2. Adduction	15	43	31
	3. Abduction	37	65	53
	4. Medial Rotation (prone)	26	49	39
	5. Lateral Rotation (prone)	21	44	34
	6. Lateral Rotation (sitting)	18	39	30
	7. Medial Rotation (sitting)	19	40	31
F. Knee Flexion	1. Prone	112	135	125
	2. Standing	96	126	113
	3. Kneeling	147	168	159

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

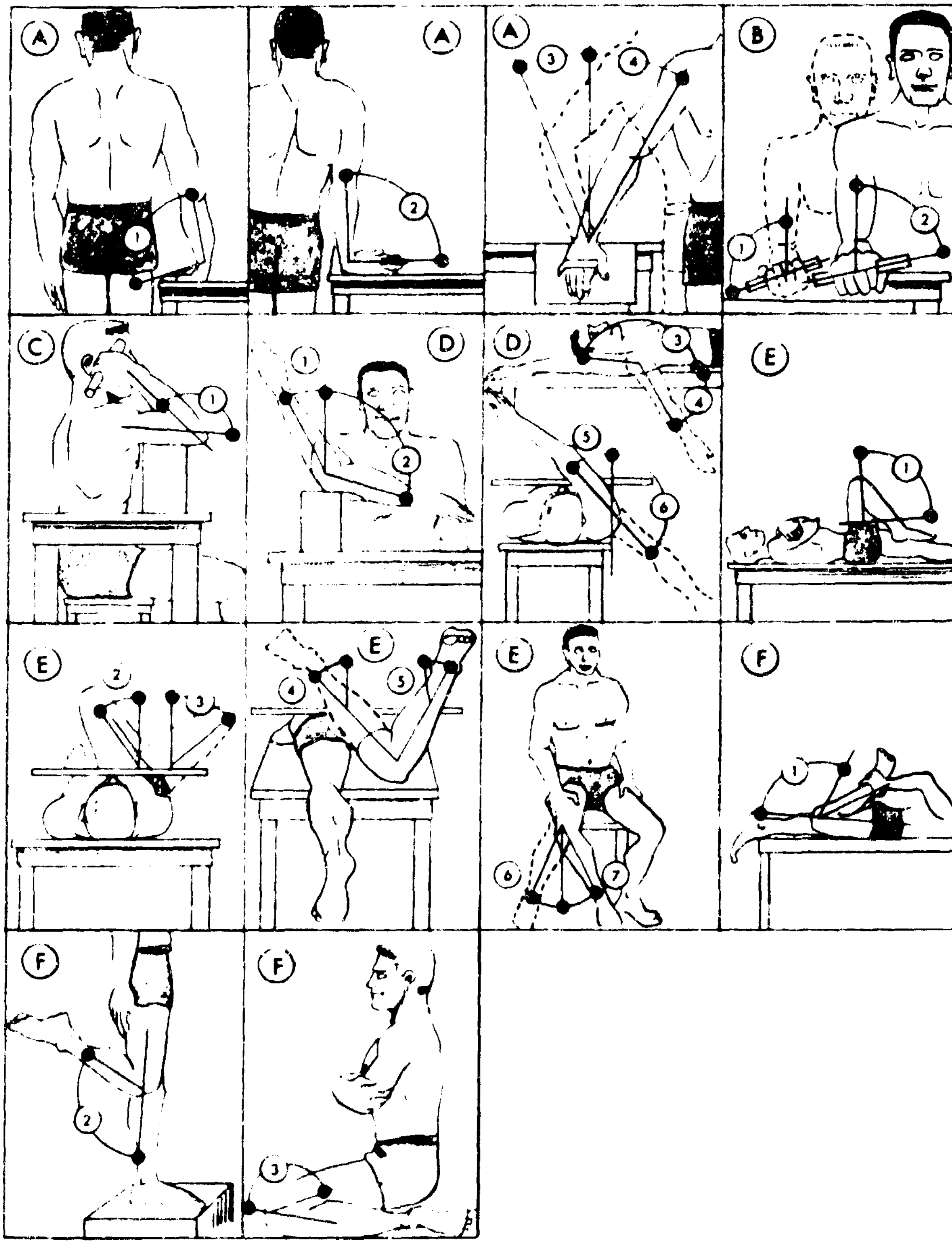


Fig. 6. RANGE OF HUMAN MOTION

TABLE 4 continued*

Body Member	Movement	Lower Limit (degrees)	Upper Limit (degrees)	Average (degrees)
G. Foot Rotation	1. Medial	19	47	35
	2. Lateral	27	55	43
H. Ankle	1. Extension	22	50	38
	2. Flexion	26	42	35
	3. Abduction	14	30	23
	4. Adduction	12	33	24
I. Grip Angle		93	109	102
J. Neck Flexion	1. Dorsal (back)	26	88	61
	2. Ventral (forward)	44	72	60
	3. Right	32	48	41
	4. Left	32	48	41
K. Neck Rotation	1. Right	61	93	79
	2. Left	61	93	79

* 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.

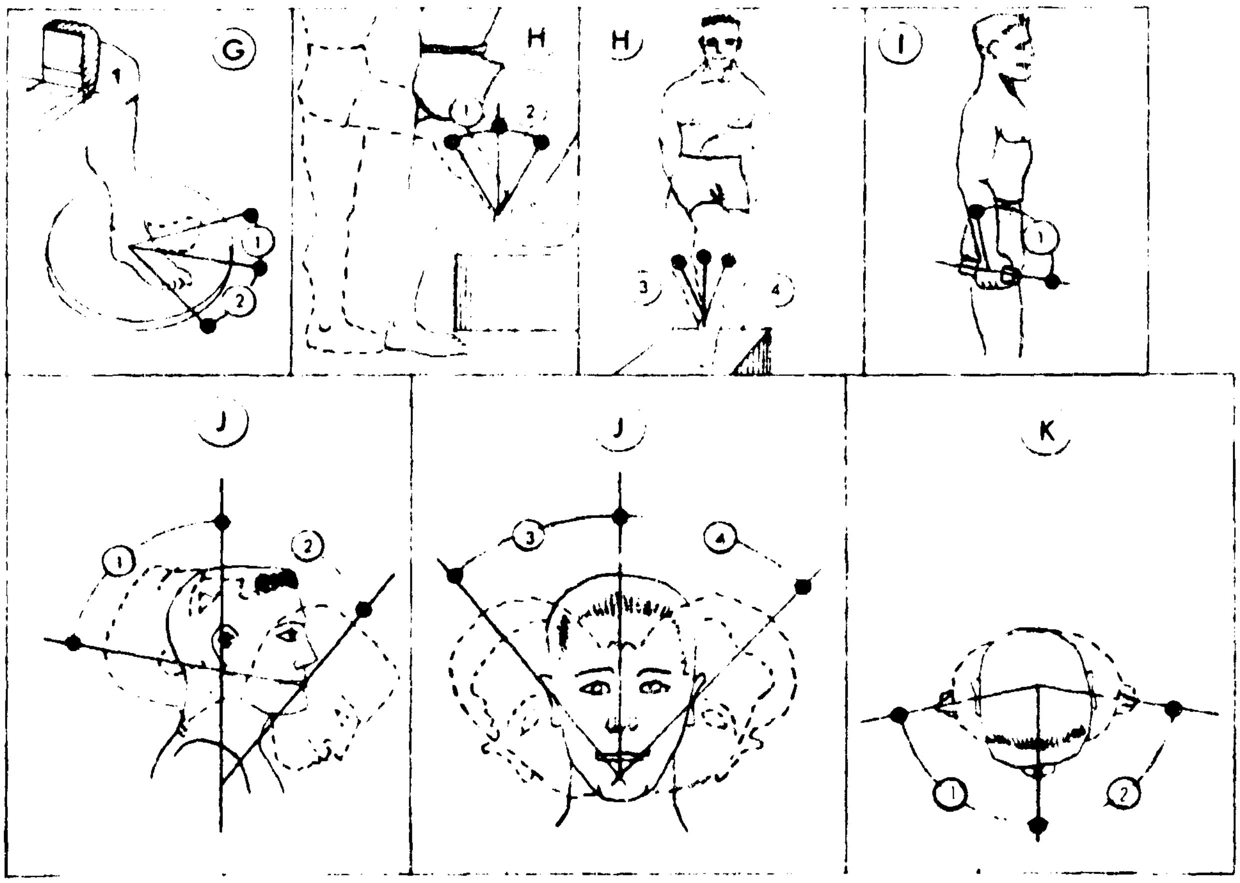


Fig. 6. Continued

Handles

1. The dimension, (Fig. 7) location, and positioning of handles are functions of the following conditions:

a. Weight of the item or unit.

b. Number of men, or hands, required to lift or carry the item.

c. Type of clothing and gloves worn by these men.

d. Operational position of the item relative to other items and obstructions.

e. Manner in which the item is to be handled or positioned.

f. Distance over which the item must be carried.

g. Frequency with which the item must be handled or carried.

h. Additional uses the handle could serve.

2. Handles should be designed and located to fulfill the following functions:

a. Guard against inadvertent actuation of controls.

b. Protect delicate parts of instrument faces.

c. Serve as locking devices to secure components in place.

d. Serve as protective supports or stands for components (e.g., can be used as maintenance stands when items are inverted).

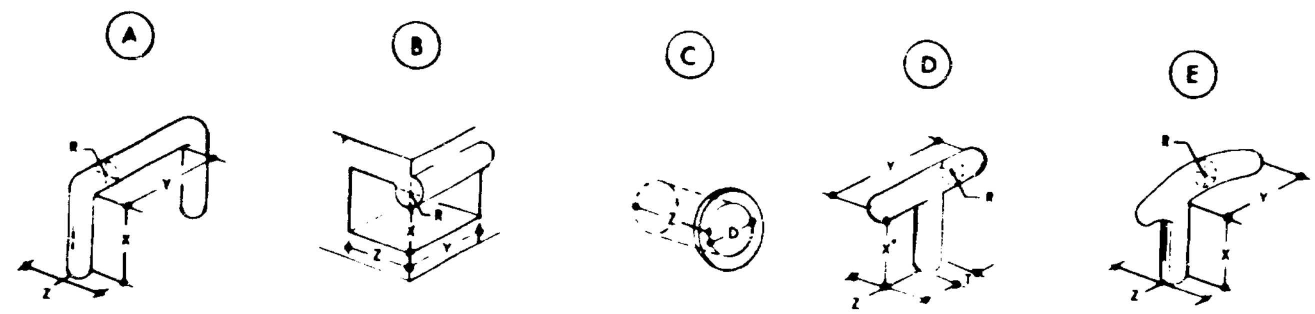
3. To prevent undue side pressure on the fingers, hand-shaped handles should be provided when items must be carried frequently or for long periods.

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. The location of handles should be such that:

a. Single handles are over the center of gravity.

b. Two or four handles are at equal intervals 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 (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.
T-Bar post:	R - 1/2 in.

Gripping efficiency is best if finger can curl around handle or edge to any angle of 120 degrees or better.

Fig. 7. MINIMUM HANDLE DIMENSIONS

c. Handles are placed where they do not interfere with equipment operation or maintenance.

d. At least a 2.5-inch clearance between handles and obstructions is provided.

e. They are placed on the front of a panel if an item must be pulled from the rack.

f. They can be held comfortably.

g. The carried item 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 lbs. Mark "LIFT HERE" near each lug, and provide a minimum of four inches above the lifting eyes, for convenient use.

CREW STATIONS

General

1. The ability of a soldier to enter and leave a vehicle fighting compartment easily and quickly is important tactically. Similarly the ease with which a wounded man can be evacuated, or the comfort and performance of a crew member whose station task requirements are performed in and below the hatch, is also important. Hatch size and configuration largely determines the ease and efficiency with which these operations can be accomplished.

2. Since the structural and ballistic strength of the vehicle fighting compartment must be maintained, size of an opening in the hull must be limited. Therefore, the size and shape of a hatch are of the greatest importance. The size and shape are determined by the cross-sectional size and shape of a soldier just below the shoulders, the clothing he is wearing, and his task requirements. However, protrusions around the hatch or obstructions above it may invalidate the advantages of an otherwise adequate opening.

3. Adequate handgrips and footsteps should be provided for the crew to reach the hatches easily and safely from the ground.

4. Hatches and doors should be capable of being opened readily with one hand.

5. All handgrips and latch handles should be operable with arctic mittens.

6. Latch handles should be designed so they will not freeze in extreme cold.

7. All handgrips and latch handles should be usable with the bare hands especially in warm climates when metal becomes extremely hot.

8. All hatches and doors should be adequate in size to admit fully equipped operational personnel.

9. All hatches and doors should be capable of being locked from the inside. Latching and locking the hatch should be done as one continuous motion.

10. A clear path should be provided from each hatch to the crew position or positions it serves. Men in a hurry should not have to squeeze around obstacles or avoid tripping over fire extinguishers, cables, and the like.

Overhead Hatches

1. Overhead hatches should be capable of operation by the 5th percentile man and should require no more than 50 pounds push or pull to open or close under all conditions of vehicle tilt.

2. When a handle is used for unlocking or locking the hatch, the force required to operate the handle should not exceed 30 pounds.

3. Spring-loaded hatch handles requiring two hands for operation of the hatch should not be used.

4. A positive-type latch should be provided to lock the hatch in the open position.

5. Padding should be provided on the inside of the hatch cover to prevent injury to personnel in the event the hatch cover should slam shut.

6. The hatch sizes recommended below are based on armor thickness of two inches or less. Where armor thickness is greater than two inches or where design configuration creates a tunnel effect for entrance or exit, the dimensions should be increased to approximate prone crawl space passage (see page 32).

Circular and Rectangular Hatches

1. Circular hatches should be a minimum of 22 inches in diameter; however, if the circular hatch is used for entry of personnel with bulky clothing or as an opening through which work is performed (such as the tank commander's hatch), then the hatch should be a minimum of 28 inches in diameter.

2. The minimum rectangular hatch size for one-man entry or exit should be 16 by 24 inches for light clothing or 20 by 28 inches for bulky clothing.

3. The minimum rectangular hatch size for two-man simultaneous entry or exit should be at least 48 inches wide by 60 inches high.

Contoured Hatches

1. The design depicted in Figure 8 represents the recommended size and configuration for a contoured hatch.

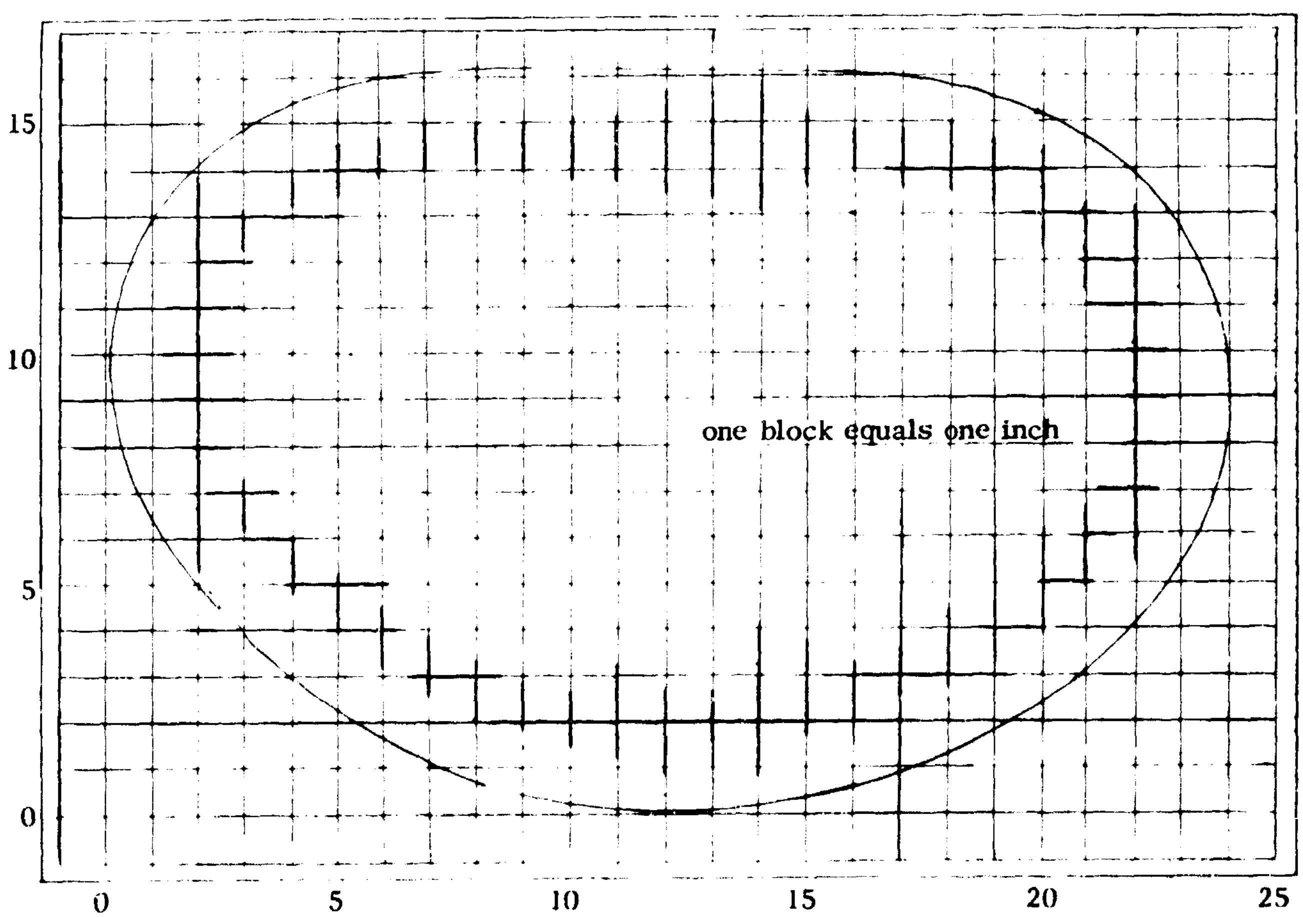


Fig. 8. CONTOURED HATCH DIMENSIONS
(For light clothed man)

Floor-Mounted Circular Escape Hatches

1. Floor-mounted escape hatches should not be restricted by seats or any obstructions.

2. Escape-hatch locking and unlocking mechanisms should not require more than 30 pounds of force to actuate.

3. Circular floor-mounted escape hatches should be a minimum of 22 inches in diameter.

4. Floor-mounted circular escape hatches should have a minimum clearance of 18 inches from the bottom of the hatch to the ground.

Crawlspace

1. Vehicle fighting compartments often require crawlspace to allow crew members to move from one part of the compartment to another. The size and configuration of crawlspaces will affect the ability of members to escape from the vehicle fighting compartment and to move from one station of the compartment to another station.

2. For a kneeling-crawl passage, the crawlspace should be 32 inches high by 25 inches wide.

3. For a prone-crawl passage, the crawlspace should be 22 inches high by 28 inches wide.

Cupolas

1. A cupola should be designed so its weapon can be serviced, loaded and unloaded either in the open or closed-hatch mode of operation.

2. The loading area should be designed for the 5th through 95th percentile hand envelope.

3. The cupola armament should be capable of being charged by the 5th and 95th percentile man in both the open and closed-hatch modes of operation.

4. The charging resistance of the cupola armament should not exceed 250 foot/pounds breakaway force or 60 foot/pounds sustained force. The charging handle should not travel more than 12 inches.

5. The traverse control should not strike or interfere with the operator when he is wearing full arctic gear.

6. The traverse and elevation control should be located within the functional reach of the operator. These controls should be capable of being operated in the opened and closed-hatch modes.

7. Manual cupolas, operated by the body, should not exceed 22 inch/pounds breakaway force or 15 inch/pounds sustained at the cupola rim.

8. A positive lock should be provided to lock the cupola in any position.

9. An identification mark should be provided on the cupola rim to correspond, in azimuth, with the main armament.

10. Cupola vision block should provide 360-degree vision in the unbuttoned or buttoned mode of operation.

11. Crash pads should be provided within the cupola in areas of probable impact.

12. The noise level in the cupola, when cupola armament is fired, should not exceed the values expressed in the environment section for impulse and continuous noise.

13. The cupola hatch should be provided with a positive lock.

14. The cupola hatch-lock mechanism should not require more than 30 pounds of force at the handle to activate.

15. The cupola hatch should not require the application of more than 50 pounds of force to open or close.

16. Minimum size for a round overhead cupola ring should be 26 inches.

17. An adjustable-intensity red and white light should be provided in the cupola to facilitate loading and servicing of the armament.

18. The cupola sight should be compatible with the CVC helmet when worn by the 5th through 95th percentile soldier.

19. Loose wires or other items should not be present to entangle or restrict personnel entering or leaving the cupola or going from the open to closed-hatch mode of operation.

20. Provisions should be made to prevent hot expended cartridge cases from coming in contact with the operator or causing problems with footing for other crew members within the vehicle fighting compartment. Expended cartridge cases and links should be caught in a bag or discharged to the outside of the compartment.

21. The cupola armament should be capable of having immediate remedial action applied to malfunctions while in the open or closed-hatch mode of operation.

22. Weapon adjustments should be capable of being made with the armament installed in the cupola and from inside the vehicle fighting compartment while in the open and closed-hatch mode of operation.

23. The armament up to 50 caliber should be capable of being installed and removed from the cupola by one man.

24. Sharp edges or other protrusions which will interfere or catch on clothing while operating or entering and leaving the cupola should be eliminated.

25. The ammunition ready box should be readily accessible and easily loaded.

26. The threading and loading of ammunition from the ready box should be easily accomplished by the 5th through 95th percentile soldier.

27. The ready box and loading area should be free of sharp edges.

28. Provision should be made for changing hot barrels where spare barrels are to be carried in the compartment (e.g., asbestos gloves).

Travel Locks

1. Provision should be made to unlock the external travel locks from inside the vehicle.

2. External travel locks should be capable of operation by personnel wearing arctic mittens.

3. Where a retaining pin is used, it should be capable of operation by personnel wearing arctic mittens.

4. The locking mechanism should be protected against freezing.

5. The parts of the locking mechanism that are to be handled should have low heat conductivity so that they may be handled in hot climates. The dark coloring of such metal parts causes them to become extremely hot in sunlight even in temperate climates. Also in these climates the heat of the engine or the engine exhaust will increase the temperature of the mechanism located above it.

Protective Padding

1. Protective padding should be provided in areas which come in contact with the body during vehicle motion with enough force to cause injury to crew members.

2. The placement of protective padding in vehicle fighting compartments should receive individual consideration for each vehicle design and development program.

3. Consideration must be given to the decrease in the dimensionally useable area caused by the application of protective padding to impact areas within the vehicle fighting compartment.

4. Padding should not restrict entry to, exit from, or required movement within the vehicle fighting compartment.

5. Materials such as ensolite or equivalent padding materials which have superior energy-dissipating properties should be considered for use as personnel protective padding in fighting compartments.

6. Padding materials should not be abrasive to the skin, contain toxic agents or have a tactile sensation of stickiness.

7. Current padding materials alone do not possess sufficient energy-dissipating qualities to adequately protect the head. Protective head gear should be worn by crew members at all times.

COMMANDER'S STATION

General

1. In the open hatch mode of operation for vehicle fighting compartments, the following design problems should receive consideration:

a. Blind spots in the visual field created by the vehicle configuration and appendages.

b. The commander's location and eye height within the fighting compartment configuration.

2. In the closed hatch mode of operation the following design problems should be considered:

a. Visual problems resulting from a reduced field of view and orientation.

b. The transfer of the eyes from one vision block to another requiring reorientation with the surroundings and relocation of visual cues.

c. Vibration seriously affecting visual acuity.

d. Psychological problems stemming from the reduction of visual contact with the surroundings. (Such loss of awareness by itself is enough to cause some anxiety in the crew members.)

3. Vision-block design should maximize field of view overlap to reduce the time required to re-establish visual cues.

Commander's Seat

1. The commander should be provided with a seat which has an adequate range of positions for comfortable operation in both the open and closed-hatch modes.

2. The commander's seat should provide an up-and-down adjustable range for both open and closed-hatch seating positions. The adjustable range of the buttock line should be at least six inches.

3. The commander's seat should be capable of being folded out of the way to allow the commander to operate in the open-hatch mode in a standing position.

4. A platform having an adjustable range of not less then ten inches in the closed-hatch mode should be provided to allow the 5th through 95th percentile vehicle commander to perform efficiently. Additional range will be required, in accordance with the compartment configuration, to allow the commander to adjust for open-hatch viewing.

5. The commander should not have to lift himself up from his seat to activate the seat-adjustment mechanism.

6. Adequate back support should be provided for the commander's seat. This provision should not interfere with the entry and exit of the commander or the gunner.

7. The commander's seat should be provided with a fore-and-aft adjustment of four inches.

8. The location and position of the commander's seat should not require him to assume an awkward body position in the open or closed-hatch mode of operation.

9. The commander should be able to operate all controls in the open and closed-hatch modes of operation while seated or standing.

GUNNER'S STATION

Gunner's Seat

1. The seat should be rectangular in shape, 15 to 18 inches deep and 15 to 20 inches wide.

2. The backrests should be 15 inches high and 12 inches wide with a slight curvature to support the back.

3. There should be adequate clearance for personnel wearing arctic clothing to enter and leave the seat. When one seat is placed immediately in front of another, this clearance must be determined when the front seat is in its rearmost horizontal adjustment and the rear seat is in its foremost horizontal position.

4. Foot rests and leg room should be provided for each seat.

5. Vertical seat-adjustment design should include the following considerations:

a. Fine adjustments or continuous adjustments should be provided to cover the entire range needed for the particular type of task performed from the seat. For example, where optics are used in relation to the seat, there should be an adjustment range of six inches in increments no larger than one inch.

b. The seat adjustments should provide a minimum overhead clearance of 40.2 inches to accommodate personnel wearing helmets.

c. When periscopes or other optical instruments are used, there should be clearance of at least eight inches above the center of the line of sight.

6. Both the vertical and horizontal adjustments should be made easily without interrupting operations.

7. For prolonged use, the seats and backrest should be padded for comfort.

8. Handgrips should be provided for support against shock and vibration.

9. Brow pads should be constructed to accommodate the head of the individual while he is wearing the CVC (Combat Vehicle Crewman's) helmet.

LOADER'S STATION

1. Every effort should be made to minimize the work rate required of the loader through improved ammunition stowage and handling capabilities. Higher work rates and slower loading speeds will also result from increased size and weight of rounds as well as from their stowage location.

2. The loader has the highest work rate of any crew member in the vehicle fighting compartment and is most likely to be affected by heat or inadequate ventilation.

3. Provision should exist for the loader to stand comfortably when riding in the open-hatch mode.

4. Provision should be made for the loader to sit comfortably when riding in the closed-hatch mode.

5. Space should be provided to allow the 5th to 95th percentile loader to sit or stand clear of the recoil of the main armament while holding a round of ammunition.

6. Where energy-absorbing devices are necessary because of case ejection velocity, they should be arranged to prevent rebounding of the case into the breech ring, preferably by deflecting the case downward.

7. The loader's seat should be capable of being removed from his workspace.

8. A safety feature should be provided to prevent the gunner from firing the main armament when the loader is in the path of recoil.

9. A vision device should be provided for the loader to observe outside activities while operating in the closed-hatch mode.

10. Noise levels at the loader's station should not exceed the values expressed in the environment section for impulse and continuous noise.

11. Adquate space should be provided for servicing of the secondary armament by the 5th to 95th percentile man.

12. The secondary armament gun barrel should be capable of being changed by one man from within the fighting compartment.

DRIVER'S STATION

Driver's Seat

1. The seat should be rectangular in shape, 15 to 18 inches deep and 15 to 20 inches wide.

2. The backrests should be 15 inches high and 12 inches wide with a slight curvature to support the back.

3. There should be adequate clearance for personnel wearing arctic clothing to enter and leave the seat. When one seat is placed immediately in front of another, this clearance must be determined when the front seat is in its rearmost horizontal adjustment and the rear seat is in its foremost horizontal position.

4. Foot rests and leg room should be provided for each seat.

5. Vertical seat-adjustment design should include the following considerations:

a. Fine adjustments or continuous adjustments should be provided to cover the entire range needed for the particular type of task performed from the seat. For example, where optics are used in relation to the seat, there should be an adjustment range of six inches in increments no larger than one inch.

b. The seat adjustments should provide a minimum overhead clearance of 40.2 inches to accommodate personnel wearing helmets.

c. When periscopes or other optical instruments are used, there should be a clearance of at least eight inches above the center of the line sight.

6. Both the vertical and horizontal adjustments should be made easily without interrupting operations.

7. For prolonged use, the seats and backrest should be padded for comfort.

8. Handgrips should be provided for support against shock and vibration.

9. Brow pads should be constructed to accommodate the head of the individual while he is wearing the CVC (Combat Vehicle Crewman's) helmet.

CONTROLS

General

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

2. Controls may be categorized on the basis of whether the action is discrete or continuous:

a. Discrete-action controls can be set at any one of a limited number of fixed positions.

b. Continuous-action controls can be set at any position within the limits of movement of the control.

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

4. There are certain stereotyped relationships between controls and displays that should be observed to take advantage of the man's previous learning, maximize transfer of training, and minimize error (Table 5).

5. The direction of movement of the control should be consistent with the movement of the controlled object.

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

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

8. Operating controls, instruments, and vision devices should be placed so their accessibility reflects their importance and frequency of use. The most important controls may not be the most frequently used; therefore, the criticality of the controls must also be considered.

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

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

TABLE 5

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

11. Controls should have the following information located on the panel or control:

a. The identification of the control function.

b. The method of operation, if it is not readily apparent.

12. Controls should be easily identifiable by the visual or tactile senses and should be clearly distinguishable from each other by color, size, shape or location.

13. The use of one control should not interfere with the use of another control unless they are purposely interlocked in sequence.

14. Controls should be designed so they will neither injure personnel nor entangle clothing or equipment.

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

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

Selection Considerations

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 force and range of settings are the primary consideration in control selection, apply the recommendations in Table 6.

3. In selecting the proper control, the designer should determine the following requirements:

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

b. The task requirements in terms of the precision, speed, range and force required using the control and the effect on the system of reducing one of these requirements in order to improve another.

c. The informational needs of the operator including his requirements for locating and identifying the control, determining the control position and sensing any change in control position.

d. The amount and location of available space in which to place the control.

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

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

TABLE 6

Recommended Manual Controls

Control Function	Control Type
Small Actuation Force Controls	
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
Continuous Setting (linear and less than 360^{0})	Continuous Rotary Knob Joystick or Lever
Continuous Slewing and Fine Adjustment	Crank Continuous Rotary Knob
Large Actuation Force Controls	
2 Discrete Positions	Foot Push Button Hand Push Button Detent Lever
3 to 24 Discrete Positions	Detent Lever Rotary Selector Switch
Continuous Setting (linear and less than 360^{0})	Handwheel Joystick or Lever Crank Two Axis Grip Handle
Continuous Setting (more than 360^{0})	Crank Handwheel Valve Two Axis Grip Handle
Elevation Setting	Crank Handwheel Joystick or Lever Two Axis Grip Handle

5. When precision settings are required over a wide range, multi-rotational controls should be used.

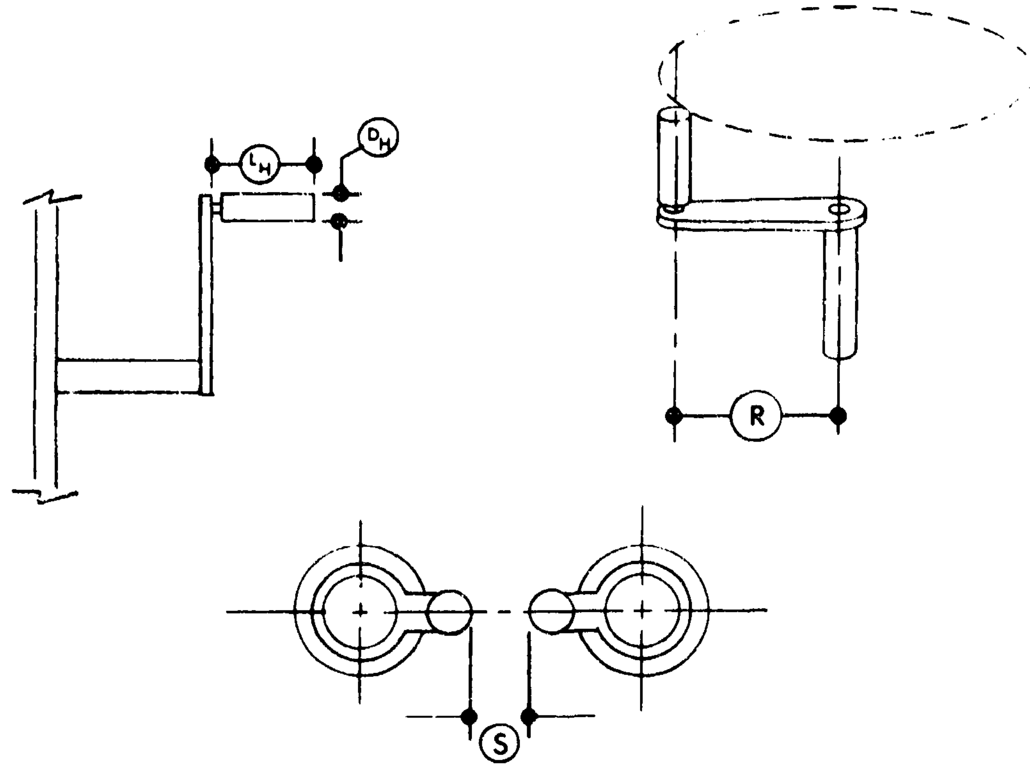
6. When performance requirements are such that the controlled object can be adjusted in a limited number of discrete steps, discrete-adjustment (detent) controls should be used rather than continuous-adjustment (non-detent) controls.

7. Controls may be combined to aid sequential or simultaneous operation, to reduce reaching movements, or to economize on panel space. However, the possibility of accidental activation should be minimized.

8. Controls requiring large or continuous forward application of force should be foot operated. Whenever possible, not more than two controls, of even the simplest type, should be assigned to each foot.

Design Characteristics

Control design characteristics are described in Figures 9 through 18.



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.	Resistance Min.	Resistance Max.
None	1.0"	3.75"	9.0"	16"	3"	--	2 lb.	10 lb.
175	1.0"	3.75"	5.0"	8.0"	3"	--	6 lb.	10 lb.
275 (max.)	0.5"	1.5"	0.5"	4.5"	3"	--	2 lb.	5 lb.

Fig. 9. CRANKS

Hand Cranks

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

2. Handle shape should allow the maximum amount of contact with the surface of the hand.

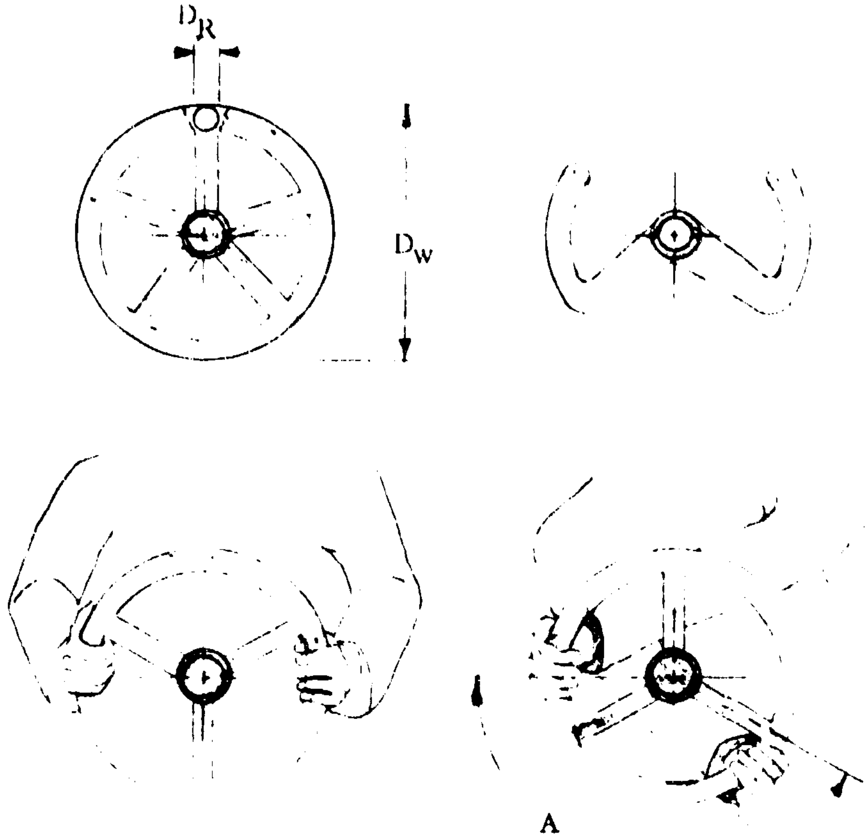
3. The handle should turn freely about its shaft.

4. Location should be between 36-48 inches above the floor for the standing operator.

5. If the ratio of fast-to-slow crank operating speed is greater than 2 to 1, the operator should have the choice of two gear ratios.

6. Spacing between the outside edge of the crank handle and any obstruction should be at least three inches.

7. Cranks which are to be turned rapidly should be mounted so the turning axis lie between perpendicular to and 60 degrees from the frontal plane of the body.



	D_W Wheel Diameter		D_R Rim Diameter		A Displacement		Resistance	
	*	**	*	**	*	**	*	**
Minimum	2.0"	7.0"	0.75"	0.75"	--	--	5 lb.	5 lb.
Maximum	4.25"	21.0"	2.0"	2.0"	--	120 deg.	30 lb.	50 lb.

*One-hand operation.
**Two-hand operation.

	Separation Two Hands Simultaneously
Minimum	3"
Preferred	5"

Fig. 10. HANDWHEELS

Handwheels

1. Handwheels, which are designed for two-hand operation, should be used when the breakout or rotational forces are too large to be overcome with a one-hand control.

2. Handwheels requiring constant two-hand operation should be restricted to a 120^{0} arc displacement.

3. The gripping surface should be indented or knurled to aid in grasping.

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

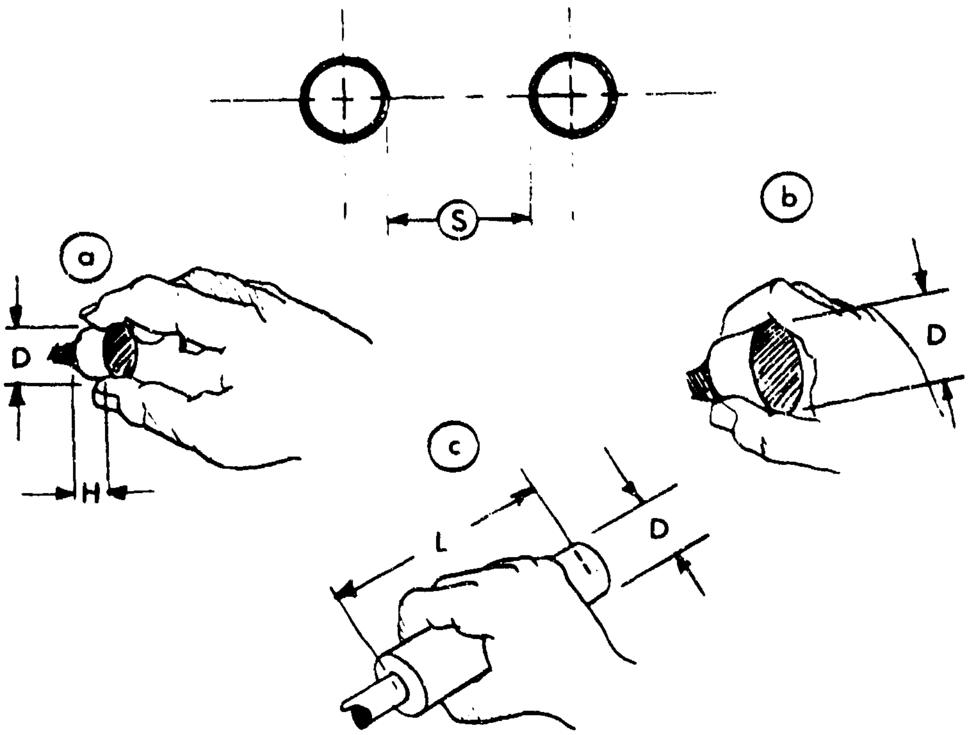
5. A valve handle is a special case of a knob or a handwheel.

6. All valve handles should be clearly labeled to indicate their function as well as the direction of movement.

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

8. Where multiple rotation is not required and the handwheel interferes with the visual field, that portion of the handwheel not needed for firm hand grasp may be cut away.

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



	Finger Grasp (a)		Palm Grasp (b)	Cylinder encircled by Thumb & Fingers (c)		Separation (S)		Resistance	
	Height (H)	Diameter (D)	Diameter (D)	Diameter (D)	Length (L)	One Hand Individually (Random)	Two Hands Simultaneously	Small Knob*	Large Knob**
Minimum	0.5"	0.375"	1.5"	1.0"	3.0"	1"	3"	--	--
Preferred	--	--	--	--	--	2"	5"	--	--
Maximum	1.0"	4.0"	3.0"	3.0"	--	--	--	4.5 oz. in.	6.0 oz. in.

* Knobs one inch in diameter or smaller.
** Knobs larger than one inch in diameter.

Fig. 11. KNOBS

Knobs

1. Knob diameter should increase with the force required to operate the control. When knobs are mounted concentrically on a shaft, the larger knob should be used for fine adjustments and the smaller knobs should be used for coarse adjustments.

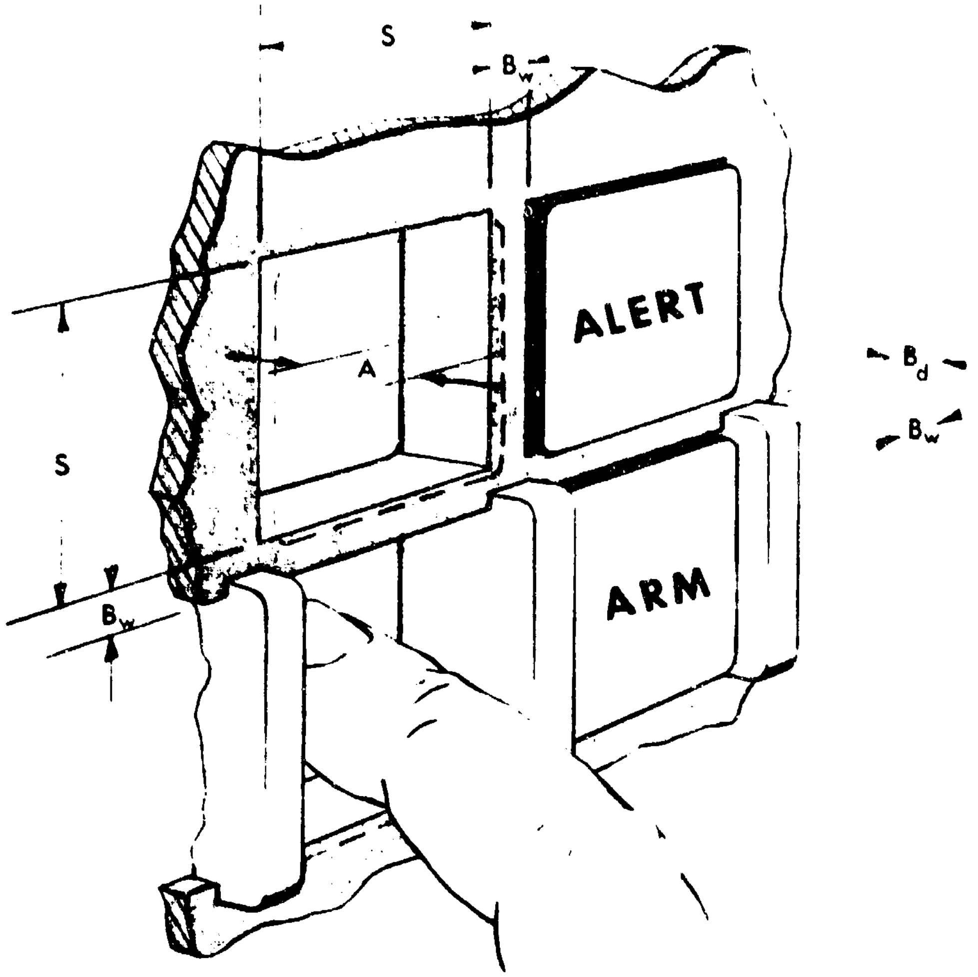
2. Knobs should be fluted or straight tooth knurled to prevent slipping.

3. The knurling and fluting of knobs should be such that if the shaft sticks, the operator is not likely to cause physical damage to his hands.

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

5. Resistance should be large enough so that inadvertent touching or outside forces will not change the setting.

6. Knobs should be secured to the shaft by two set-screws.



	S (Size)	A (Displacement)	Barriers* B_W	B_d	Resistance
Minimum	3/4"	1/8"	1/8"	3/16"	10 oz.
Maximum	1-1/2"	1/4"	1/4"	1/4"	40 oz.

*Barriers will have rounded edges.

Fig. 12. ILLUMINATED PUSHBUTTON SWITCH

Illuminated Pushbutton Switch

1. Illuminated pushbutton switches may be used for, but not necessarily limited to, the following conditions:

a. To display qualitative information which requires the operator's attention to an important system status.

b. Where minimal interpretation by the operator is required.

c. When functional grouping or a matrix of control switches and indicators is required and minimal space is available.

d. Illuminated pushbutton switches should be used instead of a pilot light and two-position toggle-switch combination.

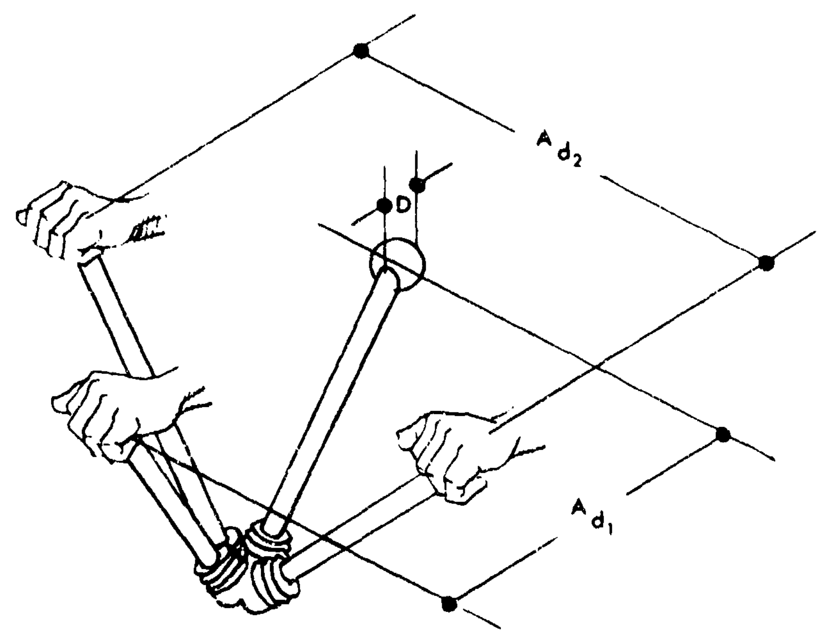
2. The location of illuminated pushbutton switches should be restricted to a 30^{o} cone along the normal line of sight from the operator's position.

3. For positive indication of switch activation, the switch should be provided with a detent or click.

4. Lamps within the illuminated pushbutton switch should be replaceable from the front by hand.

5. The legend should be legible when only one lamp is operating within the switch.

6. Where the illuminated pushbutton switch does not contain dual bulbs, the switch circuit should be provided with a lamp-test capability.



	Diameter (D)		Displacement (A)		Resistance			
					(d1) (forward)		(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.	60 lb.	20 lb.	30 lb.

	Separation*	
	One Hand Random	Two Hands Simultaneously
Minimum	2"	3"
Preferred	4"	5"

* The maximum separation for a group of levers operated simultaneously by one hand is six inches.

Fig. 13. LEVER/JOYSTICK

Lever/Joystick

1. Levers may be used when large amounts of force or displacement are involved or when multidimensional movements of the controls are required.

2. Levers mounted on and perpendicular to the floor should have their handles located between the waist and shoulder height of the operator.

3. Levers parallel to the floor should have the hand grips located 28 inches above the floor for the standing operator to be able to exert the greatest lifting force.

4. Lever should be pushed when accuracy is a requirement.

5. When rapid operation of a lever mounted in front of the operator is a requirement, a fore-and-aft direction should be used.

6. When large force is required and the lever must move in a lateral direction, the largest force can be obtained by the right hand pushing toward the left.

7. When grouped levers in front of the operator pivot about a common axis, or relatively close axes, they should move in a fore-and-aft direction.

8. For the seated operator the maximum push or pull of the lever is obtained with the elbow at 135°, hand grip at about elbow height and the lever moving in a vertical plane passing straight back through the shoulder joint.

9. Detents should be provided on discrete position levers.

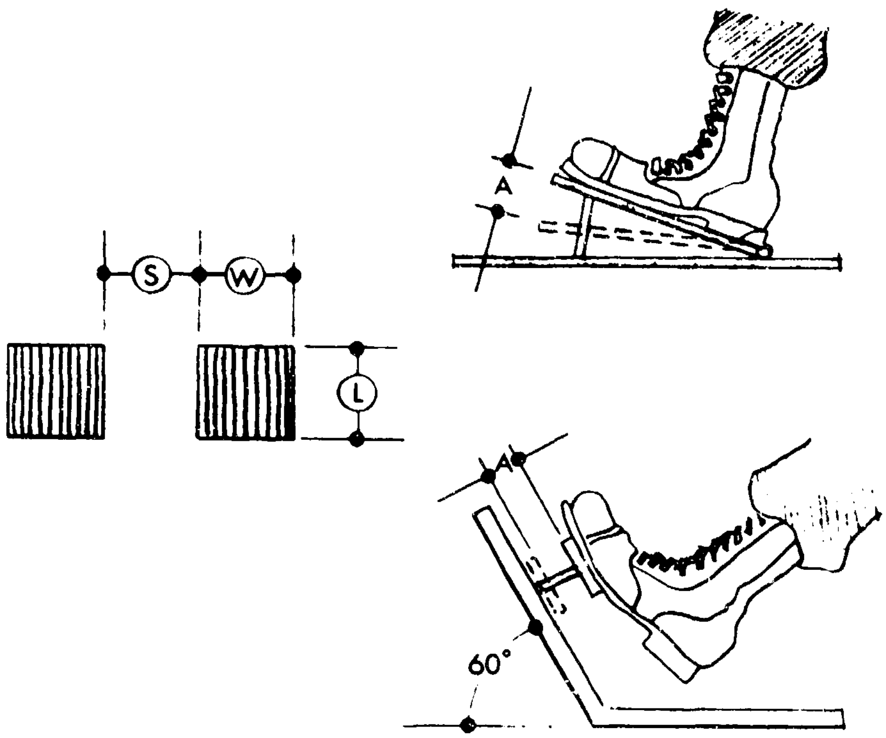
10. When fine adjustments are made with small levers (e.g., joysticks), the following should be provided:

a. Elbow support for large hand movements.

b. Forearm support for small hand movements.

c. Wrist support for precise finger movements.

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



	Length (L)	Width (W)	(A) Displacement: Normal Operation	(A) Displacement: With Heavy Boots	Operated by: Ankle Flexion	Operated by: Leg Movement
Minimum	3.0"	1.0"	0.5"	1.0"	--	--
Maximum	--	--	*	*	2.5"	7.0"

* Depends on how operated.

	Resistance: Foot not resting on pedal	Resistance: Foot resting on pedal	Operated by: Ankle flexion only	Operated by: Leg Movement
Minimum	4.0 lbs.	10 lbs.	--	--
Maximum	*	*	10 lbs.	180 lbs.

* Depends on how operated.

	Separation (S): One Foot Random Order	Separation (S): One Foot Sequential	Separation (S): Two Feet Simultaneously
Minimum	4"	2"	6"
Preferred	6"	4"	8"

Fig. 14. PEDALS

Pedals

1. If the application of a great deal of force and displacement is required, the foot pedal may be used as a control device.

2. Pedals should be designed so that they will return to the null position when the force is removed.

3. Pedals should be designed to utilize normal limb action, e.g., the foot and entire leg.

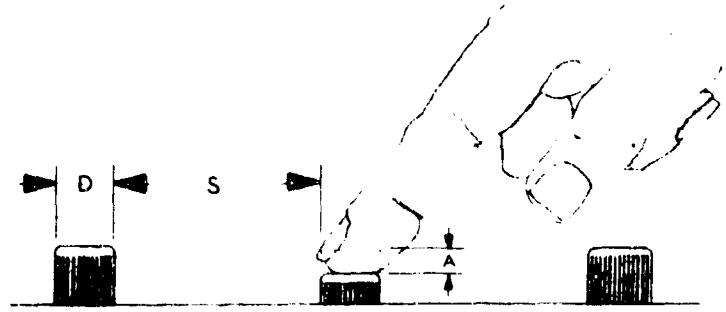
4. Spring tension should support the weight of the foot resting on the pedal before force is applied.

5. The motion of the operator's leg should not require delicate or complex movements but should, instead, be simple and direct.

6. A non-skid surface should be provided on the face of the pedal and on the heel plate where there is a heel plate.

7. Pedals should be designed in accordance with Figure 14.

(a)



(a) Hand Push Button

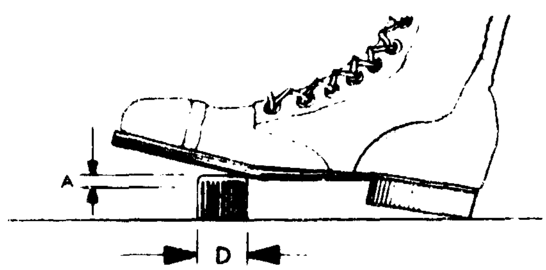
	D (Diameter)		A (Displacement)	Resistance	
	Fingertip Operation	Thumb or Heel* of Hand Operation	Thumb or Finger Operation	Fingertip Operation	Little Finger Operation
Minimum	0.50"	0.75"	0.125"	10.0 oz.	5.0 oz.
Maximum	--	--	1.500"	40.0 oz.	20.0 oz.

S (Push Button Separation)

	Random Order Single finger operation	Single finger sequential operation	Different fingers, randomly or sequentially
Minimum	0.50"	0.25"	0.50"
Preferred	2.00"	1.00"	0.50"

* This if for emergency controls.

(b)



(b) Foot Push Button

	D (Diameter)	Displacement (A)		Operated by		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"	--	--	4.0 lbs.	10.0 lbs.
Maximum	--	--	--	2.50"	4.00"	20.0 lbs.	20.0 lbs.

Fig. 15. PUSH BUTTOMS

Push Buttons

1. A definite click that is both felt and heard should indicate when the push button is activated.

2. Push buttons should have an elastic resistance that gradually increases and then suddenly drops to indicate that the control has been activated.

3. When push buttons are activated, there should be a definite feedback of the equipment response to the operator either by a visual indicator or an auditory response.

4. Push button surface should be concave to fit the shape of the finger. If this is impracticable, the surface should provide a high degree of frictional resistance to prevent slipping.

5. The following methods should be considered to safeguard against accidental activation of hand or finger-operated push buttons:

a. Channel or cover guards.

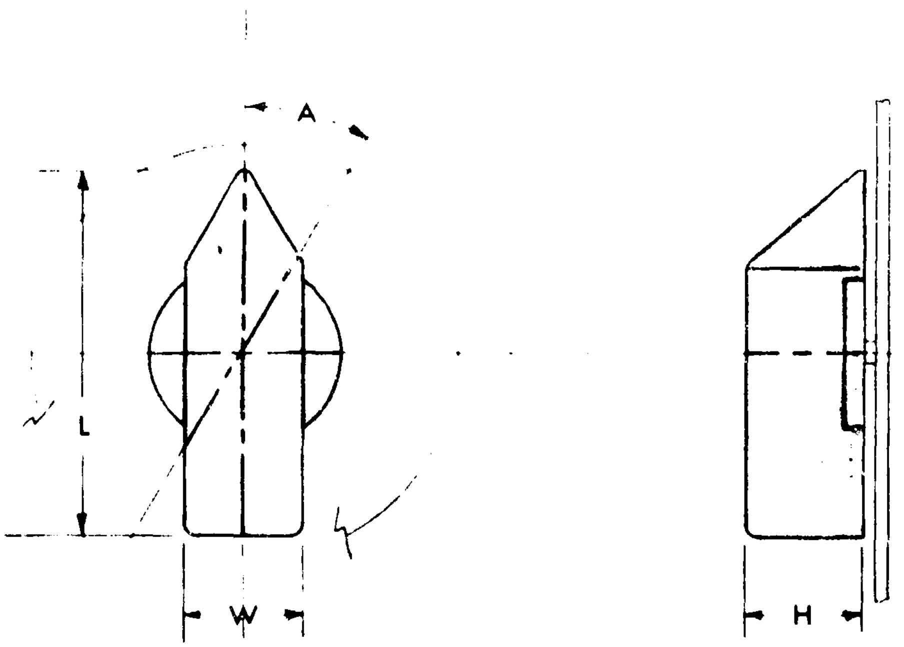
b. Flush mounting.

c. Recess mounting.

d. Mechanical or electro-mechanical interlocks.

e. Button guards.

6. Push buttons should be designed in accordance with Figure 15.



	Length (L)	Width (W)	Depth (H)	Displacement (A) Visual Positioning	Non-Visual Positioning	Resistance	Number of Positions
Minimum	1.0"	--	0.5"	15^o	30^o	12 oz.	3
Maximum	--	1.0"	3.0"	40^o*	40^o*	48 oz.	24

* When special requirements demand large separations, maximum should be 90^o.

Fig. 16. ROTARY SELECTOR SWITCH

Rotary Selector Switch

1. Rotary selector switches should be used for discrete functions when three or more detented positions are required.

2. Switches should be designed so that detent stops offer enough resistance to movement that settings can be made by touch alone.

3. Stops should be provided at the beginning and end of the range of control positions.

4. Clockwise rotation of a selector switch from the 12 o'clock position should result in a numerical or alphabetical increase of the scale associated with it.

5. It should not be possible for a rotary selector switch to remain fixed between positions.

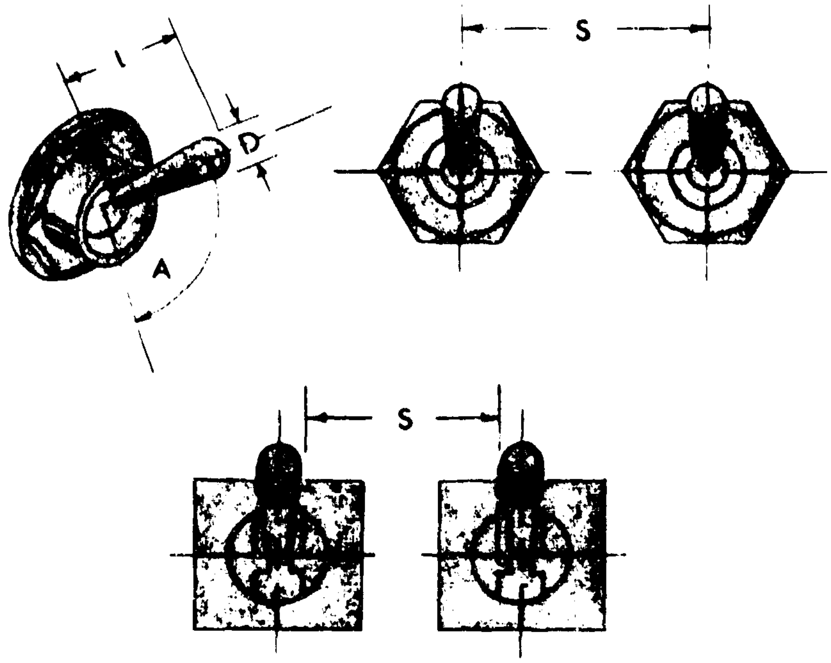
6. Rotary selector switches should use a moving pointer knob with a fixed scale.

7. Moving pointer should be bar-shaped with parallel sides and the index end should be tapered to a point.

8. Position of the pointer knob in relation to the scale should be such as to minimize parallax between pointer index and scale marking.

9. Rotary switch positions should not be located directly opposite each other.

10. Pointer knobs and switches should conform to Figure 16.



	Displacement* (A)	Arm Length (L) Bare Finger	Arm Length (L) Gloved Finger	Control-Tip Dimension (D)	Resistance	Number of Positions	Toggle-Switch Separation (S) Single Finger Operation (Random order) Lever-Lock Toggle Switch	Toggle-Switch Separation (S) Single Finger Sequential Operation	Toggle-Switch Separation (S) Different Fingers Random or Sequential
Minimum	30°	0.5"	.625"	0.125"	10 oz.	2	0.75"	0.5"	0.625"
Maximum	12[illegible]	.625"	.625"	1.0"	40 oz.	3	--	--	--
Optimum	--	--	--	-	--	--	2.0"	1.0"	0.75"

* Minimum refers to angle between adjacent positions. Maximum refers to total angular displacement.

Fig. 17. TOGGLE SWITCHES

Toggle Switches

1. Toggle switches should have flip-type operation and snap-action contact.

2. When toggle switches are used in momentary contact situations, they should be spring-loaded to the "off" or "neutral" position.

3. Where other displays do not provide a positive indication of circuit status, toggle switches should be accompanied by a pilot light.

4. Toggle switches should be vertically oriented. They should be "on" in the up position.

5. Where the toggle switch must be oriented horizontally, the "on" position should be to the right.

6. When an indicator light is used with the toggle switch, it should be located above or to the right of the toggle switch.

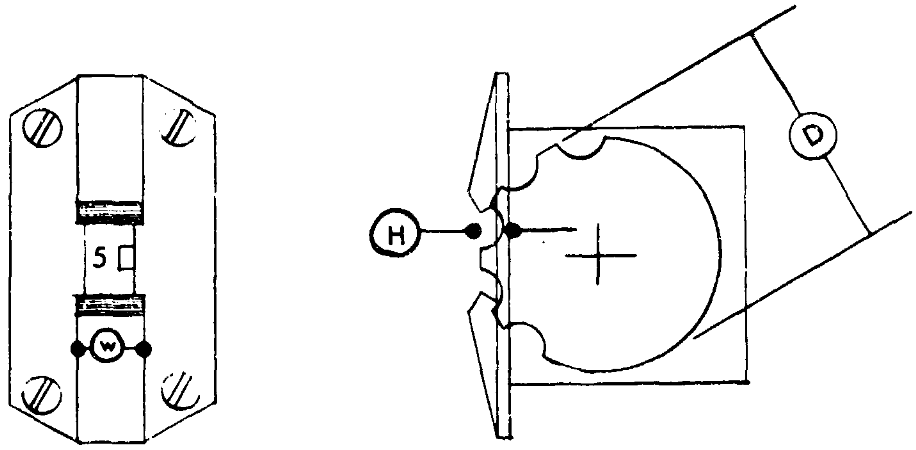
7. Critical toggle switches should be guarded against accidental activation.

8. Toggle-switch resistance should increase slowly until contact is made, and then drop to zero as the switch snaps into position, except for momentary contact switches.

9. It should not be possible for toggle switches to stop between positions.

10. Where there is a severe space limitation, a three-position toggle switch may be used in place of a rotary selector switch.

11. Toggle switches should conform to Figure 17.



	Diameter (D)	Width (W)	Depth (H)	Resistance
Minimum	1.5"	0.25"	0.125"	1 in.-lb.
Maximum	2.5"	0.5"	0.500"	3 in.-lb.

Fig. 18. THUMBWHEELS

Thumbwheels

1. Thumbwheel controls may be used where the function requires a compact digital control-output device and, in addition, a readout of these manual inputs for verification.

2. Each position should be separated by a fluted, or high-friction, area which may be raised no more than 1/16 inch from the periphery of the thumbwheel.

3. Thumbwheel controls may be coded by location, labeling, and color (e.g., use of reverse color for least significant digit wheel, similar to odometer coding).

4. Setting value should increase with downward stroke on the thumbwheel for system consistency.

5. For areas in which ambient illumination is low (below one foot lambert display brightness), the thumbwheel should be internally illuminated.

DISPLAYS

General Requirements

1. In the design of any item of equipment which involves a human component, one of the primary considerations involves the methods by which pertinent information regarding equipment functions should be presented to the human. Its importance stems from the fact that almost all of the operator's decisions and actions are based upon the information which is presented to him.

2. The selection or design of a display should be based on a thorough knowledge of the type, amount and accuracy of information required.

3. Methods of displaying information to operators should conform to the following criteria:

a. Displays should be restricted to only those types of information essential to perform the job adequately.

b. Display information should be limited to only that degree of accuracy actually required for the decisions and control actions necessary to accomplish assigned tasks.

c. Information should be presented in such a manner that any failure or malfunction in the display or display circuitry will become immediately apparent.

d. Data should be presented in the most direct, simple, understandable and usable form possible.

e. Displays should be easily located and identified without undue searching.

f. Displays should be functionally or sequentially grouped to simplify the operator's activities.

g. All displays should be properly illuminated, coded, and labeled as to function.

4. The following scale marking and numeral practices should be followed to standardize the system and make it as easy as possible for the operator to read the displays quickly and accurately:

a. Whenever appropriate, scales should start at zero.

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

c. The increase of numerical progression should read clockwise, from left to right, or from the bottom up.

d. Whole numbers should be used in numbering major graduation marks, except where measurements are normally expressed in decimals.

e. The number of minor or intermediate marks should not be greater than nine, fewer if possible.

f. Optimum visual contrast should be provided between scale face and markings.

g. On stationary scales, all numbers should be oriented upright.

h. On moving scales, all numbers should be oriented to be upright at the reading position.

i. The display should be designed so that the control or display pointer will just meet, but not overlap, the shortest graduation marks.

j. Provision should be made for placing calibration information on instruments without interfering with dial readability.

k. To minimize parallax, the pointer should be mounted as close as possible to the face of the dial.

l. All displays should be constructed, arranged, or mounted so as to minimize the reflection of ambient illumination from the glass or plastic display cover. This provision is especially important when panels are inclined from the vertical away from operator.

m. Wherever feasible, linear scales should be used in preference to non-linear scales.

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

5. Displays should be designed so that the failure of the display or display circuitry will be immediately or readily apparent to the operator.

6. Failure of display circuitry should not cause an erroneous reading or cause a failure in the equipment associated with the displays.

7. 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.

8. Arrange displays consistently throughout the system.

9. The displays that are used the most often should be grouped together.

Selection Considerations

1. For maximum efficiency in operation, dials, scales, gauges or meters should be selected for the following situations:

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

b. To distinguish increasing or decreasing trend of the values measured by the instrument.

c. When only an approximate reading is important.

d. For check reading rather than continuous monitoring.

2. Dichotomous (two-valued) indicators should be used for the following conditions:

a. For qualitative go-no-go situations, on-off status, malfunctions, emergency warnings (use flashing signals), inoperative equipment, caution, and the operability of separate components.

b. For critical information, when there is sufficient space on the panel, e.g., legend lights (words or numbers that are lighted from behind).

c. As warm-up indicators.

4. Auditory displays (buzzers, bells, etc.) should be used for the following situations:

a. As an emergency or warning device.

b. When the immediate reaction of the operator is important.

5. Auditory displays should be used with lights, or as alternatives to lights, in the following situations:

a. When environmental-lighting conditions are such that lights might not be easily detected.

b. When the operator will be occupied monitoring lights, dials, counters, and scopes.

c. When multiple signals (warning, emergency, malfunction) are needed.

d. When extreme redundancy is required.

Design Characteristics

Counters

1. Counters should be used for presenting large ranges of quantitative data where continuous-trend indication is not required but where quick precise reading is required.

2. The numbers should change by snap action in preference to continuous movement.

3. Counters should be mounted as close to the panel surface as possible to maximize viewing angle and minimize parallax and shadows.

4. Numbers should not follow each other faster than about two per second if the operator is expected to read the numbers consecutively.

5. Counters used to indicate sequencing of equipment should be designed to reset automatically upon completion of the sequence. Manual provision for resetting should also be provided.

6. The rotation of the counter reset knob should be clockwise to increase the counter indication or to reset the counter.

7. The counter character dimensions that should be used for labels and markings on panels for varying distances and conditions are discussed in the section on Labeling, pages 103-110.

Flags

1. Flags may be used to display dichotomous (two-valued) non-emergency conditions.

2. Flags should be in high contrast with background.

3. Flags should operate by snap action.

4. Flags should be as close to the surface of the panel as possible.

5. When flags are used to indicate the malfunction of a visual display, the "malfunction position" of the flag should at least partially obscure the operator's view of the malfunctioning display, and should be readily apparent to the operator under all expected levels of illumination.

6. Provisions should be made to test proper operation of the flags.

Gas Tube, Cold Cathode

1. This display technique should be used only to display quantified non-critical system information or status. The use of this display technique should be limited to non-critical information or status for the following reasons:

a. The viewing angle of the tube is restricted because the planes on which the characters appear are successively recessed from the face of the tube.

b. Legibility of the rearward characters is impaired by the presence of other characters in front.

Indicator Lights

1. There are two types of indicators: pilot lights and legend indicators. Pilot lights normally use colored lens and may or may not have a letter or number printed on the lens. The lens is normally recessed and contains only one lamp.

Legend indicators may or may not have a colored filter in the lens. They normally have a square flat lens and present information such as words, numbers, symbols or abbreviations. They contain from two to four lamps.

2. Use transilluminated indicators to display qualitative information, primarily information that either requires the operator to respond quickly or call 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 may be exposed to the rays of the sun 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.

1'. Legend indicators should be separated from lighted pushbutton switches using the same type lenses.

Pilot Lights

1. Use pilot 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. Pilot lights 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 a 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 a half inch in diameter.

15. One-inch-diameter lights should be obviously brighter than half-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.

Legend Lights

1. The number of legend lights should be kept to a practical minimum, while fulfilling information feedback requirements.

2. A legend light should illuminate immediately upon the occurrence of the event described by its legend; it should go out upon the termination of the event described by its legend.

3. A legend light should be used to provide qualitative information; normally, it should not give a command. If a command must be given, the legend should clearly and unambiguously indicate that this is the case.

4. Legend lights having excessively small frontal areas should be avoided. Ample frontal area should be available for lettering commensurate with the anticipated legend requirements.

5. The legend face should not be significantly recessed into its housing.

6. The possibility of legend loss or interchange should be minimized by such techniques as captive legends, coded keyways, etc.

7. Illumination of the mounted legend light should not result in light leakage.

8. Legend-light indications for malfunction-isolation purposes should be provided only down to the point of immediate concern to the operator in accordance with the system maintenance philosophy.

9. Lamps should be provided that incorporate filament redundancy or dual bulbs. That is, when one filament or bulb fails, the second remains illuminated. The decreased intensity of the light indicates the need for lamp replacement.

10. Trademarks, company names, or other similar markings not related to the information displayed to the operator should not appear on the face of the light.

Projection Displays

Projection displays use the principle of light projection in combination with artwork transparencies or sliding templates for the random presentation of words, numerals, symbols, etc., on a common display screen. These devices may consist of a number of miniature optical systems packaged in a single unit or of a single optical system using sliding templates for light interference. The image brightness of these displays, ranging from moderate to low may reduce legibility. Frequently, optical centering of lamp filaments may be required when items are installed or repaired. For character dimensions, see section on Counters.

Scalar Indicators

1. Before a designer selects a scale for a mechanical indicator he should decide on the appropriate scale range and analyze the operator's task to estimate the precision required of the instrument reading.

2. Scales should be designed so that interpolation between graduation marks is not necessary. However, when space is limited it is better to require interpolated readings than to clutter the dial with crowded graduation marks.

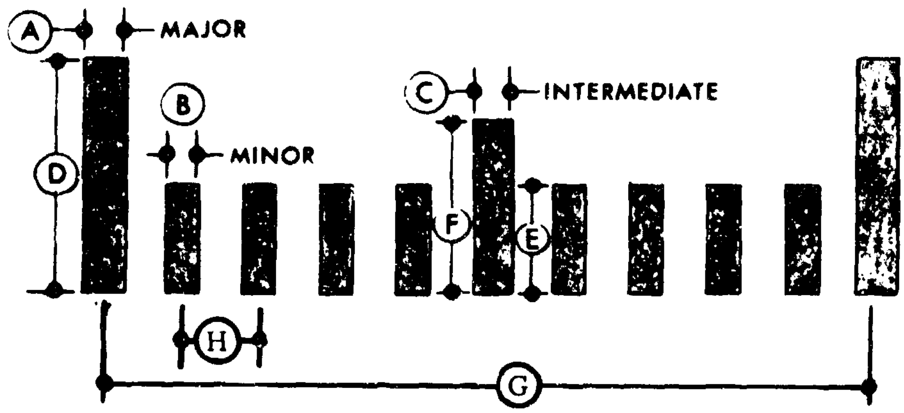
3. A scale that is to be read to the nearest 1, 10, or 100 pounds of pressure, etc., should be selected from those scales with graduation interval values of 1, 10, or 100. If accuracy to the nearest .5, 5, or 50 units or .2, 2, or 20 units is required, scales with the appropriate graduation interval values should be selected.

4. Scales numbered by intervals of 1, 10, 100, etc., and subdivided by ten graduation intervals are superior to other acceptable scales.

5. Some combinations of graduation interval values and scale numbering systems are more satisfactory than others. Table 7 will assist in the selection of the most readable scales.

6. For recommended scale dimensions, see Figure 19.

7. The pointer position of a scalar indicator should be at twelve o'clock for right-left directional information, and at nine o'clock for up-down information. For purely quantitative information either position may be used.



Dimension (in inches)	Viewing Distance 28 in.	36 in.	60 in.
A (Major index width)	0.035"	0.045"	0.075"
B (Minor index width)	0.025"	0.032"	0.054"
C (Intermediate index width)	0.030"	0.039"	0.064"
D (Major index height)	0.220"	0.283"	0.471"
E (Minor index height)	0.100"	0.129"	0.214"
F (Intermediate index height)	0.160"	0.206"	0.343"
G (Major index separation between midpoints)	0.700"	0.900"	1.500"
H (Minor index separation between midpoints)	0.070"	0.090"	0.150"

Fig. 19. SCALE MARKINGS

TABLE 7

Scale Numerical Progression

Good					Fair					Poor			
1	2	3	4	5	2	4	6	8	10	0	2.5	5	7.5
5	10	15	20	25	20	40	60	80	100	4	8	12	16
10	20	30	40	50	200	400	600	800	1000	0	15	30	45
50	100	150	200	250						30	60	90	120
100	200	300	400	500						0	60	120	180

8. If the display is used for setting, such as tuning in a desired wavelength, it is usually advisable to cover the unused portion of the dial face. The open window should be large enough to permit at least one numbered graduation to appear at each side of any setting.

9. If the display is used in tracking, as in the case of heading indicators, the whole dial face should be exposed.

Moving-Pointer Fixed-Scale Indicators

1. Circular scales should be designed as follows:

a. Clockwise movement of the pointer should increase the magnitude of the reading to be in keeping with the operator's expectations.

b. In cases where positive and negative values around a zero are being displayed, the zero should be located at the nine or twelve o'clock position. The positive values should increase with clockwise movement of the pointer and the negative values increase with counterclockwise movement.

c. In general it is better to place the numerals inside of the graduation marks to avoid constriction of the scale and hiding of numbers by the bezel. If space is not limited the numbers may be placed outside of the marks to avoid having the numbers covered by the pointer.

d. 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.

2. Vertical and horizontal straight scales should be designed as follows:

a. The pointer should move up or to the right to indicate an increase in magnitude.

b. The numbers should be located on the side of the graduation marks opposite the pointer. The graduation marks should be aligned evenly on the side of the scale toward the pointer but they should be stepped out on the other side whenever they are next to a number or when they mark off a standard interval on the scale.

c. The pointer should be to the right of vertical scales and at the bottom of horizontal scales.

Moving-Scale Fixed-Point Indicators

1. There are certain ambiguities with moving circular scales and the associated control movement, thus, moving-scale fixed-pointer indicators should not be used.

2. One of the following three principles of human engineering would have to be violated in the design of circular moving scales:

a. Principle 1 -- Scale numbers should increase in a clockwise direction around the dial. Values on moving circular scales, therefore, increase with counterclockwise rotation of the dial face.

b. Principle 2 -- The direction of movement of the associated control should be compatible with the direction of movement of the dial, e.g., clockwise movement of the control should result in clockwise movement of the dial.

c. Principle 3 -- Clockwise movement of a control should result in an increase in function.

3. If Principle 1 is compromised, i.e., clockwise movement of the control results in counterclockwise movement of the dial, operators err in the initial direction of turn. If Principle 3 is compromised, a standardized control movement-system relationship is violated.

4. The following recommended practices in the design and use of circular moving scales will minimize the effects of these incompatibilities:

a. The numbers should progress in magnitude in a clockwise direction around the dial face. Therefore, counterclockwise movement of the dial face increases the readings.

b. If the associated control has no direct effect on the behavior of the equipment, e.g., tuning in radio stations, etc., the scale should rotate counterclockwise (increase) with counterclockwise movement of the associated knob or crank.

c. If the associated control has a direct effect on the behavior of the equipment, e.g., speed, direction, etc., the scale should rotate counterclockwise (increase) with a clockwise, upward movement or movement to the right of the associated control.

5. The same direction-of-motion ambiguities exist for vertical and horizontal moving straight scales as for circular moving scales. The numbers should increase from bottom to top or from left to right. Also, the scale should move down or to the left (increase) when the associated knob or crank is moved clockwise, or when the associated lever is moved upward, or to the right.

Azimuth Indicators

A heading indicator with the numerical progression of 30, 60, 90, etc., is less satisfactory than some other numerical progression (Table 7). However, this may represent a compromise between the best numbering progression and a manageable size of dial. The heading indicator is a small dial and since the numbered cardinal points, e.g., north, east, south, and west, serve as anchoring points in interpreting this indication, a progression by 30's is an acceptable solution. When the dial can be made large enough however, the progression should be by 10's.

Non-Linear Scales

Non-linear scales condense a large range into a relatively small space and yet permit sensitive readings at certain critical ranges of the scale. In situations where error tolerances are a constant percentage of the indication, a logarthmic scale is suitable. However, logarithmic scales should contain as many numbered graduation marks as possible -- to minimize errors resulting from normal linear reading habits.

Pointers

1. Full visibility pointers on scalar indicators should be provided with a fine tip having a long taper that starts at the center of the dial.

2. The pointer tip should be the same width as the width of the smallest graduation mark.

3. For vertical and horizontal straight scalar indicators, where the exposed portion of the pointers is restricted by the rectangular configuration of the display, a flag, spade or target pointer should be used.

4. Pointers should be located to the right on vertical scales and at the bottom on horizontal scales.

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

6. The angle subtended between the tip of the pointer and the plane upon which the scale is located should be a maximum of 20 degrees.

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

8. Pointers should not completely cover the scale numbers.

9. Pointers should be the same color as the numbers and scale divisions.

10. There should be no more than two pointers on a single shaft.

11. Reciprocal pointer ends should be easily distinguishable from each other.

Control-Display Relationship

The placement of controls and displays on panels and consoles should be based on analysis of how often the operator uses them, how accurately he must use them, and the order in which they must be used, as well as how important the controls and displays are to monitoring or controlling system performance. Such an analysis provides a sound basis for the guidelines on arranging controls and displays which follow in this subsection. These guidelines are categorized three ways:

a. Priorities for Location of controls and displays.

b. Spacing between controls and displays.

c. Grouping of controls and displays by either Function or Sequence of operation.

Location of Controls and Displays

1. Priority of location refers to the placement of the most important controls and displays in the optimum visual and manual workspaces on the panel or consoles. To establish the importance of controls and displays the following factors should be determined:

a. Frequency and duration of use of the control or display.

b. Accuracy and speed with which the display must be read or the control activated.

c. Decrease in system performance and personnel or equipment safety resulting from an error or delay in using the control or display.

d. Ease of control manipulation in various locations in terms of force, precision, and speed requirements.

2. When the above factors have been determined, the designer should apply the following principles to the design:

a. Primary controls and displays should be placed within the optimum areas.

b. Emergency controls and displays should be placed in readily accessible positions, but they usually will not be located in the optimum areas in preference to primary controls and displays. In some systems, however, the emergency may be so critical that emergency controls and displays should be given top priority in location.

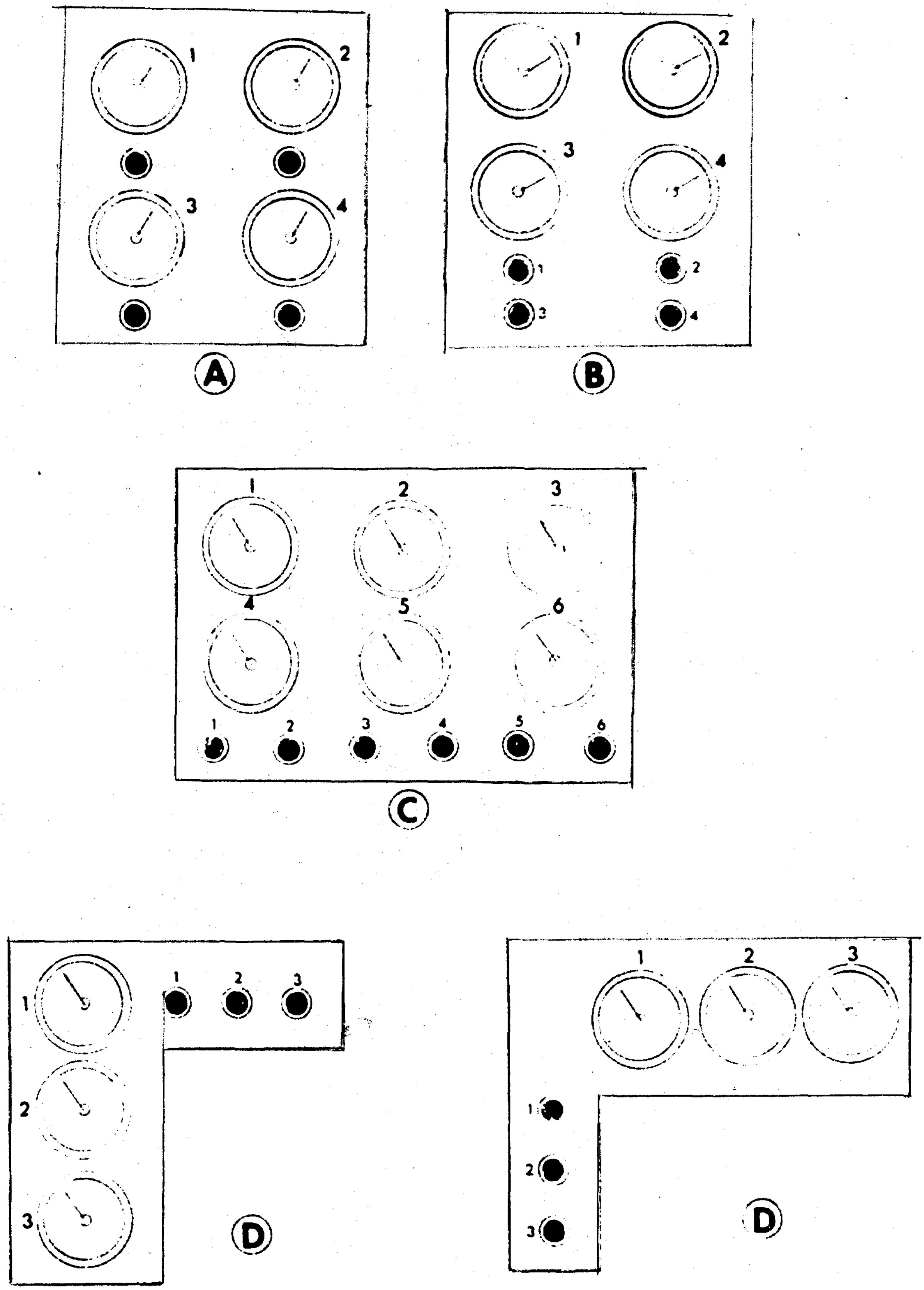


Fig. 20. CONTROL-DISPLAY RELATIONSHIP

c. Secondary controls and displays should be placed within the overall area.

d. Adjustment and calibration controls and displays that are used infrequently should be given lowest priority in assigning locations.

e. The sharing of control and/or displays by more than one operator requires special consideration.

(1) If primary controls and displays are involved, duplicate sets should be provided wherever there is adequate space. Otherwise, controls and displays should be centered between the operators.

(2) If secondary controls and displays are involved, they should be centered between the operators if equally important to each. If the controls or displays are more important to one operator than to the other, they should be placed nearer the operator having the principal requirement for their use.

(3) If direction-of-movement relationships are important, controls and displays should be located so that both operators face in the same direction.

Spacing of Controls and Displays

1. When many controls and displays are to be used by a single operator, their arrangement should aid in the identification of the control to be used with a particular display.

2. Where a control is associated with a specific display, the control should be located so that the operator's hand does not obscure the display.

a. Each control should be located directly beneath its associated display as illustrated in Figure 20A. Also, the displays should be arrayed in rows from left to right.

b. Another procedure is to locate all displays in the upper portion of the panel and all controls in the lower portion as illustrated in Figure 20B. Displays and controls should both be arranged in rows from left to right on the panel. If possible, the controls should occupy the same positions relative to one another as do the corresponding displays.

c. If the controls must be arranged in fewer rows than the displays, controls affecting the top row of displays should be positioned at the far left, controls affecting the second row of displays should be placed just to the right of these, and so on, as illustrated in Figure 20C.

d. If a horizontal row of displays must be associated with a vertical column of controls, or vice versa, the left-most display (control) should correspond to the top control (display) as illustrated in Figure 20D.

3. When more than one panel is mounted at approximately the same angle relative to the operator, the relative positions of controls and displays on their respective panels should be the same.

4. When one panel is at or near the vertical and the other is at or near the horizontal, the relative positions of controls and displays should be the same.

5. Separate control and display panels should never face each other.

6. The spacing of controls should be based on the following considerations:

a. Requirements for the simultaneous use of controls.

b. Requirements for the sequential use of controls.

c. Body part used to operate the controls.

d. Size of the control and the amount of movement required, e.g., displacement or rotation.

e. Need for blind reaching, i.e., the need to reach for and grasp the control without seeing it.

f. Effects on system performance of the inadvertent or premature use of a control.

7. For separation of controls under various conditions of use the designer should consider:

a. The minimum separation should be the smallest acceptable distance between adjacent controls when the operator is located in a stationary workspace having good environment conditions and when controls are placed within the optimum manual area.

b. The desirable separation is the preferred distance between adjacent controls which are operated intermittently.

Functional Grouping of Controls and Displays

1. Functional grouping should be used for controls and displays which are:

a. Identical in function.

b. Used together in a specific task.

c. Related to one equipment or system component.

2. When there is no definite sequence of operation, the controls or displays should be grouped by function.

3. Functional groups of displays and their associated controls should be spatially organized so that the relationship between their functions is apparent to the operator.

4. All displays that are to be used together should be placed at the same viewing distance.

5. Functionally related indicator lights, control devices, instruments and components should be located close to one another.

6. Displays should be grouped so as to facilitate check reading.

7. Chronological or sequencing arrays should be grouped for maximum simplicity in operator performance.

8. For purposes of ready identification, non-critical functional areas or groups, i.e., those not associated with emergency operation, should be outlined by black lines, 1/16 inch wide, using color number 37038 of Federal Standard 595. Emergency or extremely critical functional areas should be set apart by a 3/16 inch red border, using color number 31136 of Federal Standard 595. The colors are recommended to obtain system consistency. Federal Standard 595 is cited as a convenience to the designer in locating and matching the recommended colors.

Sequential Grouping of Controls and Displays

1. The following principles should be applied to displays which are observed in sequence:

a. When displays are arranged horizontally, they should be viewed from left to right (this is the preferred arrangement).

b. When displays are arranged vertically, they should be viewed from top to bottom.

c. Displays should be grouped, arranged, and located as close together as possible, providing this does not make each individual display difficult to interpret.

d. If there is a large number of displays, thev should be arranged in rows rather than columns.

2. The following principles should be applied to controls which are operated sequentially:

a. Controls used by the same hand should be arranged so that the operator moves his arm horizontally from one control to the next control (providing that control and display locations or direction-of-movement relationships are not violated).

b. Controls should be aligned horizontally on the panel; when they cannot be aligned horizontally, they should be arranged vertically from top to bottom.

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 a hazardous condition or conditions that require immediate corrective action should meet the following three requirements:

a. They should be used <u>only</u> with a warning light.

b. They should be easy to distinguish from background noises and easily recognizable.

c. The "master" warning sound's frequency should vary as indicated in Figure 21.

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

a. 1600 ± 50 Hz tone interrupted at a rate of 1 to 10 Hz.

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

c. 900 ± 50 Hz steady tone.

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

e. 400 ± 50 Hz tone interrupted at a rate of 1 to 10 Hz.

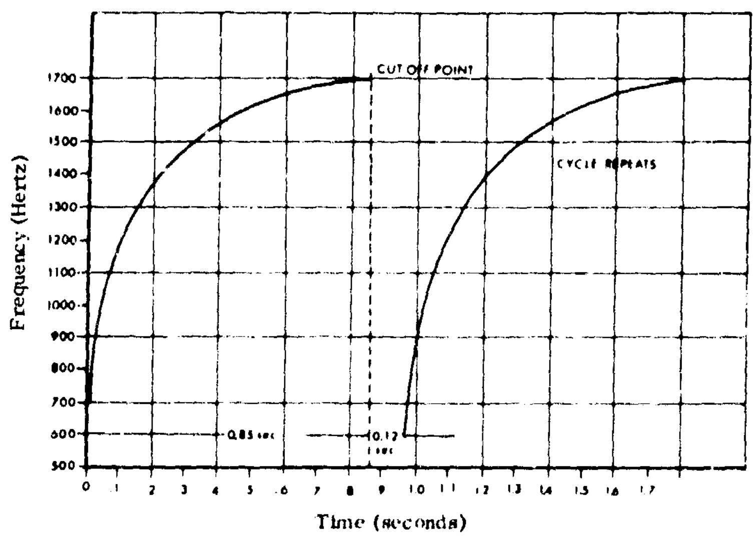


Fig. 21. FREQUENCY CHARACTERISTICS OF AUDITORY MASTER-WARNING SIGNAL

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 p.

4. Signals must be kept well below the human pain threshold, which is approximately 130 dB.

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," etc.), but in such cases there should not be any other auditory signals in the vehicle.

Visual Warning Indicators

1. The following criteria should be considered by the designer in determining the physical characteristics and location of "warning" indicators:

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

b. Indicators used to denote an emergency situation should be visually larger than general status indicators.

c. They should have a minimum brightness contrast to the immediate background of 2 to 1.

d. When illuminated they should be at least as bright as the brightest light source on the same console.

e. The warning indicator should be colored "red" (see p.) and located not more than 60° from the standard line of sight.

f. Where there is extreme danger to personnel or equipment, the warning indicator should have the following characteristics:

(1) It should be flashing red.

(2) It should flash at a rate of three to five pulses per second.

(3) It should have flashing "on" time approximately equal to "off" time.

(4) It should be such that when the "flashing" device fails, the light comes on steadily.

(5) Should provide "word" warning whenever possible, and "word" warning indicators should be placed within 10° of the standard line of sight.

(6) Where a symbol is used instead of a word, the indiactor should be placed within 30° of the standard line of sight.

CODING

General Requirements

1. Coding is used to identify controls, indicators, connectors and other devices that perform the same function or are consistently used together. Coding is also frequently employed to make various unrelated devices readily distinguishable from each other.

2. There are many methods of coding available to the designer; however, the method or methods selected should be consistent in meaning throughout the system.

3. When deciding upon the type of coding to use in a particular situation, the designer should consider the following factors:

a. The types of coding already in use.

b. The kinds of information to be coded.

c. The nature of the tasks to be performed and the conditions under which the tasks will be performed.

d. The number of coding categories available within each coding method, e.g., the number of different knob shapes available.

e. The space and illumination required for the various coding methods.

f. The need for redundant or combination coding.

g. The standardization of coding methods.

Controls

Color

With the exception of emergency controls, color coding of controls in vehicle fighting compartments is not recommended.

Shape

1. Functional shapes which suggest the purpose of the control should be used.

2. All shapes used in a particular application should be sufficiently different from each other to avoid confusion. Do not use combinations of shapes that look or feel similar.

3. Controls used for a similar purpose or function should be the same shape.

4. When the control must be distinguished by touch alone, the minimum dimensions of the shape selected for inclusion on the control should be:

a. Side view or depth of shape	.25 inch
b. Top view or width	.50 inch
c. Front view of length	.50 inch

5. The shape selected for a control should not hamper personnel's manipulation of the control.

6. The shape surface in contact with the hand should not have sharp edges or corners.

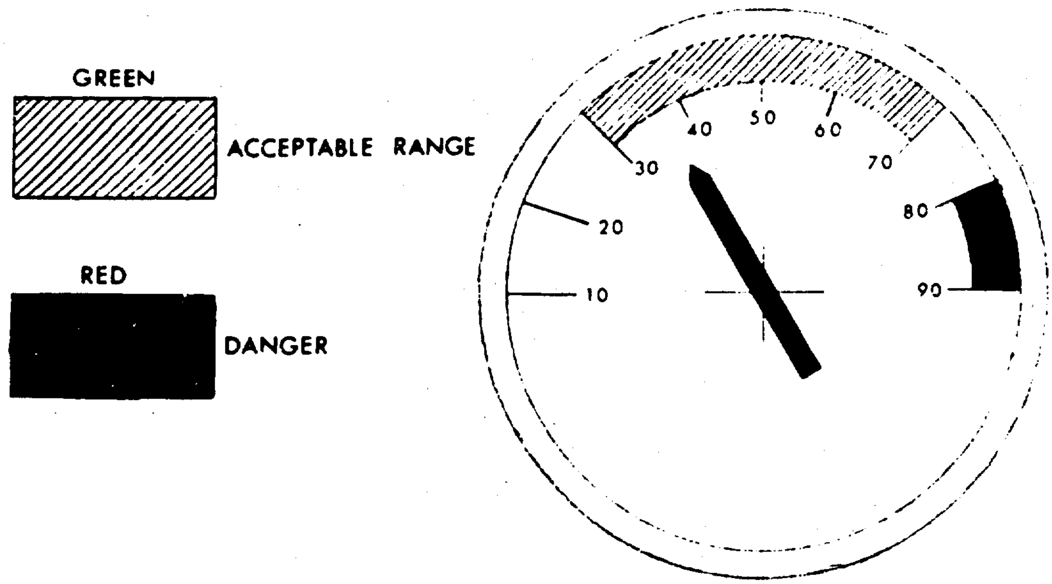
Size

1. Size coding should be used when only two or three controls are to be coded.

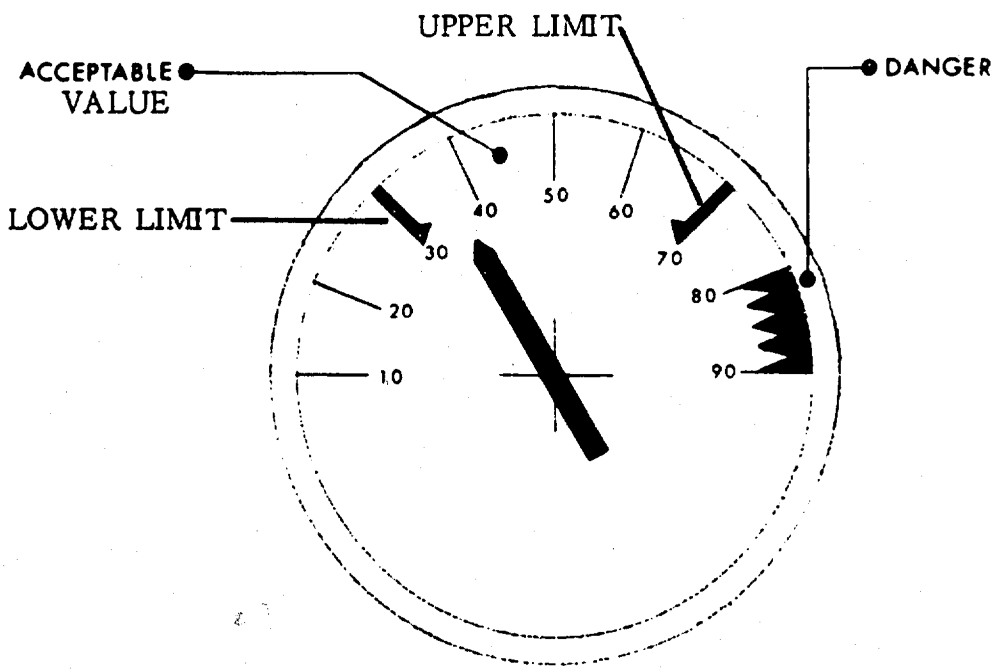
2. Size and shape coding may be used in combination, since the ability to discriminate shape is independent of the ability to discriminate size.

3. Controls performing the same function on different items of equipment should be coded consistently.

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



COLOR CODING DISPLAYS



SHAPE CODING DISPLAYS

Fig. 22. CODING OF DISPLAYS

Location

1. Coding controls by location is most effective where blind-positioning movements are required. For best location-coding for efficient use by the operator, the following criteria are recommended:

a. For more accurate location discriminations, coded controls should be located forward of the operator.

b. Coded controls should be located in areas lower than the level of the operator's shoulders.

c. When locating coded controls in the forward area, a separation of six to eight inches should be used for optimum discrimination.

d. When coded controls are located to the side or toward the back of the operator, a separation of 12 to 16 inches should be used for accurate discriminations and effective operation.

Displays

Color and Color-Banding of Display Scale Zones

1. For transilluminated indicators, color coding should indicate the type of action or response required as well as the status of equipment.

2. Color codes, markings and bands (Fig. 22) should be used to optimize display-reading performance:

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

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

c. To preclude the possibility of misreading numbers on the display or of mistaking a desired numerical value.

3. Since the appearance of colors often changes under different types of illumination, it is important that color-coded displays be used under white light only.

Shape

1. Shape-coded displays may prove useful in some instances but is not generally recommended.

2. Displays may be shape-coded by scale zones (Fig. 22). The shapes selected for coding purposes should be:

   a. Easily learned.

   b. Distinguishable under low illumination.

   c. Distinguishable under any color of light.

Size

1. Transilluminated indicator lights used to indicate emergency, failure and master summation should be larger than general status indicators, e.g., one inch in diameter as opposed to one-half inch.

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

Location

1. Location-coding provides for spacing or positioning displays in groups so that they may be distinguished from each other.

2. Locations may be coded in four ways:

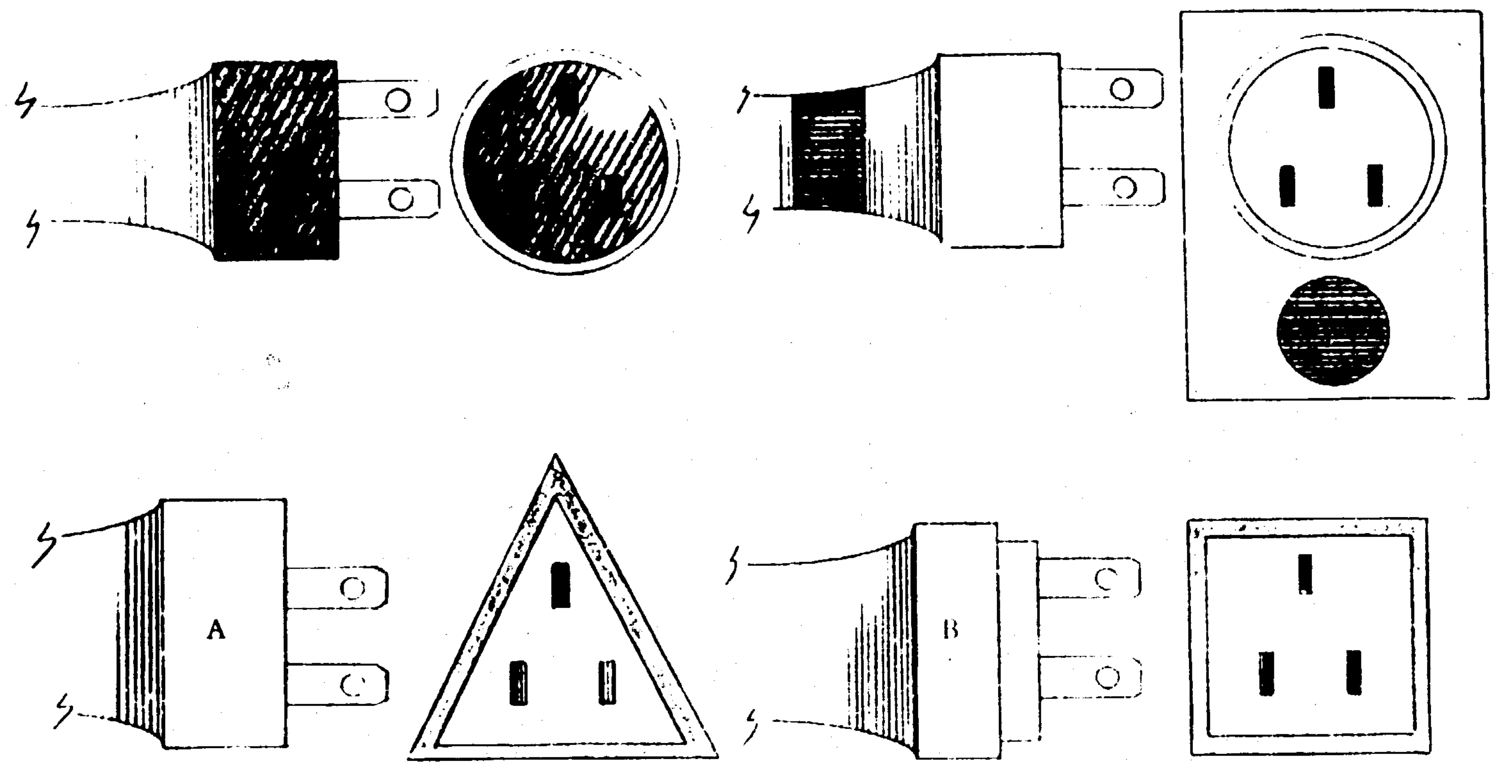
   a. By adequate spacing of display groups (horizontal separations are preferable to vertical separations).

   b. By outlines or borders around each display group.

   c. By placement on different planes with respect to the operator.

   d. By symmetry.

THIS PAGE LEFT
BLANK INTENTIONALLY



A. Male Plug -- triangular shape.

B. Male Plug -- square shape.

Fig. 23. CODING OF CONNECTORS

Connectors

1. The coding of connecting devices such as receptacles and plugs is an important aid in making proper associations between input and output lines connecting different items of equipment. All connectors should be coded to their mates.

2. The following general rules should be followed in color-coding connectors:

a. If possible, parts should be protected to prevent the wearing, fading, and disappearance of color.

b. Permanent color-coding methods are preferred rather than adhesive or bent-on tapes.

c. If the number of items to be coded is too great to be accommodated by the available colors, matching patterns of colors or striping may be used.

3. Two color-coding methods may be used for electrical connectors:

a. The face of the receptacle and the base of the plug may be coded the same color.

b. An area immediately adjacent to the receptacle may be coded the same color as a band on the plug.

4. Colors assigned for identification of connectors should be consistent in meaning with colors used elsewhere in the system.

5. Connectors may also be coded by matching plugs and receptacles of various shapes (Fig. 23). For example, the shape of the alignment pins may differentiate connectors and prevent mismatching of plugs and receptacles.

6. The requirement to match plugs with their proper receptacles may be met by size-coding. In many instances, receptacles appearing in proximity to each other will already be of different sizes because of other requirements. However, when this situation does not apply and size-coding is deemed necessary, receptacle sizes may be changed to aid in discrimination.

TABLE 8

Cable Coding

Instructions	Number of Conductors Desired	Basic Color	Tracer
1. Select the particular number	1	Black	None
of conductors to be color-coded.	2	White	None
	3	Red	None
2. The colors appearing to the	4	Green	None
right of the entry are the	5	Orange	None
appropriate combination for	6	Blue	None
the particular number of	7	White	Black
conductors.	8	Red	Black
	9	Green	Black
3. For example, if a cable consists	10	Orange	Black
of 12 conductors, the twelfth	11	Blue	Black
color combination would be	12	Black	White
black and white. The eighth	13	Red	White
color combination would be red	14	Green	White
and black. The fifth color	15	Blue	White
combination would be orange	16	Black	Red
and so on.	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 color or combination applies to the center conductor. If a cable contains various sizes of conductors, the first color applies to the largest and the sequence continues in order of conductor size.

Conductors

Electrical Conductor

1. Color is the primary method of coding electrical conductors. The individual wires of all cabling should be color-coded over their entire lengths.

2. There are 21 different patterns of solid colors and solids with striped tracers that are discriminable (Table 8). If more than 21 conductors are to be coded, the designer is referred to MIL-STD-686. The means of applying this coding system to conductors follow in order of preference:

   a. Solid-colored insulator.

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

   c. Colored braid with woven tracer.

Hydraulic and Pneumatic Conductors

Hydraulic and pneumatic conductors should be either color-coded (Tables 9 and 10) or coded by metal tags. The numbered tags should be used only in those cases where, because of adverse conditions (e.g., grease, mud, etc.), the color may become obscured.

NOTE

This material is reproduced from the American Standard:

Identification of Piping Systems, Scheme for the A13.1-1956.

Industrial Accident Prevention Signs, Specifications for Z35.1-1959.

Marking Physical Hazards and the Identification of Certain Equipment, Safety Color Code for Z53.1-1953.

TABLE 9

Hydraulic Coding

Function	Color	Definition of Function
Intensified pressure	Black	Pressure in excess of supply pressure induced by a booster or intensifier.
Supply pressure	Red	Pressure of the power-actuating fluid.
Charging pressure	Intermittent Red	Pump-inlet pressure, higher than atmospheric pressure.
Reduced pressure	Intermittent Red	Auxiliary pressure lower than supply pressure.
Metered flow	Yellow	Fluid at a controlled flow rate (other than pump delivery).
Exhaust	Blue	Return of the power-actuating fluid to reservoir.
Intake	Green	Sub-atmospheric pressure, usually on the intake side of the pump.
Drain	Green	Return of leakage of control-actuating fluid to reservoir.
Inactive	Blank	Fluid within the circuit but nor serving a functional purpose during the phase being represented.

(See Note p. 100)

TABLE 10

Pneumatic Coding

Function	Color	Definition of Function
Intensified pressure	Black	Pressure in excess of supply pressure induced by an intensifier or booster.
Supply pressure	Red	Pressure of the power actuating air.
Charging pressure	Intermittent Red	Compressor-inlet pressure, higher than atmospheric pressure.
Reduced pressure	Intermittent Red	Auxiliary pressure lower than supply pressure.
Metered flow	Yellow	Controlled flow rate.
Exhaust	Blue	Return of the power actuating medium to the atmosphere.
Intake	Green	Sub-atmospheric pressure, usually on the intake side of the compressor.
Inactive	Blank	Air pressure within the circuit but not serving a functional purpose during the phase being represented.

(See Note p. 100)

LABELING

General

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

   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; they should avoid overly technical or difficult words.

   d. Labels should be brief but unambiguous; omit punctuation.

   e. Labels should read horizontally, not vertically.

   f. Where necessary, labels should be supplemented with other coding procedures (such as color and shape).

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

   h. Labels should be large enough that the operator can read them easily at his normal distance.

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

j. Labels should use bold-face letters only for short words or phrases that require emphasis.

k. Labels should be placed on or very near the item they identify; there should be no 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.

Numeral and Letter Design

Style

1. Any one of the type fonts listed in Table 11 may be selected for labeling. However, when one type font has been selected it should be used consistently for labeling throughout the system.

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

TABLE 11

Recommended Type Fonts

Type Font	Type Font
Airport Bold Condensed	Futura Demi-Bold
Airport Demi-Bold	Futura Medium
Airport Medium Condensed	Futura Bold
Airport Semi-Bold	Groton Condensed
Alternate Gothic #2	Lining Gothic #66
Alternate Gothic #3	Spartan Heavy
Alternate Gothic #51	Spartan Medium
Alternate Gothic #77	Tempo Bold
Franklin Gothic Condensed	Vogue Medium

Height or Size*

1. The height of letters and numerals should be determined by the required reading distance and illumination. (When the appropriate height has been established in terms of distance and illumination, the width of the characters should be determined as a function of their height.)

2. With a 28-inch viewing distance, the height of numerals and letters should be within the range of values given below for "low" brightness and "high" brightness conditions:

	Height (inches)	
	(Brightness below 1 footlambert)	(Brightness above 1 footlambert)
For critical markings, with position variable (e.g., numerals on counters and settable or moving scales)	0.20-0.30	0.12-0.20
For critical markings, with position fixed (e.g. numerals on fixed scales, controls, and switch markings, or emergency instructions)	0.15-0.30	0.10-0.20
For noncritical markings (e.g., identification labels, routine instructions, or markings required only for familiarization)	0.05-0.20	0.05-0.20

* Type size in points does not describe the character size desired, i.e., 9 point is 1/8 inch but this is total block, not necessarily character size. The actual character size may vary from manufacturer to manufacturer for 9-point type.

3. For general dial and panel design, with the brightness normally above 1 footlambert, character height should approximate the values given below for various distances:

Viewing Distance	Height (inches)
20 inches or less	0.09
20-36 inches	0.17
36-72 inches	0.34
72-144 inches	0.68
144-240 inches	1.13

4. The following character heights should be used for the labeling indicated, based on 28-inch viewing distance:

a. Panel Title Character size: 1/4 inch.

b. Subdivision Title Character size: 3/16 inch.

c. Component Title Character size: 1/8 inch.

Width

1. The width of letters should preferably be three-fifths of the height, except for the "I", which should be one stroke in width, and the "M" and "W", which should be four-fifths of the height.

2. The width of numerals should preferably be three-fifths of the height, except for the "4", which should be one stroke width wider, and the "1", which should be one stroke in width.

3. Where conditions indicate the use of wider characters, as on a curved surface, the basic height-to-width ratio may be increased to 1:1 in accordance with MIL-M-18012.

Stroke Width

1. Black on White -- For black characters on a white (or light) background, the stroke width should be one-sixth of the height.

2. White on Black -- Where dark adaption is required or legibility at night is a critical factor, and white characters are specified on a black background, the stroke width of the characters should be from one-seventh to one-eighth of the height (i.e., narrower than specified for normal daytime vision).

3. For transilluminated markings or labels on panel surfaces, the stroke width should be within the range of one-eighth to one-tenth of the height. When dark adaptation is required, transilluminated markings or labels may appear excessively bright and thus the stroke width should be between one-twelfth to one-twentieth of the height.

Spacing

1. Letters and numerals should be so spaced that the area between adjacent characters is equal.

2. The spacing between words should be equal to the average character width of the type face used. However, the minimum spacing between characters (letters and numerals) should be one stroke width.

3. Spacing between lines of characters should be equal to the height of the capital characters. Where space constraints exist, the height of the lower case character should be used as the spacing between lines.

4. Component labeling should be centered one-eighth of an inch above the component. Where space is a constraint, the label should be placed to the right of the component one-eighth of an inch from the edge and read horizontally.

5. Manufacturer's identification should not be displayed on the front of a console or panel in a manner which may distract the operator or interfere with his visual task.

Content

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

2. Common words that are readily understood and ordinarily used by the operator should be used on labels. Technical words should be used only when they are necessary to impart exact information and it can be expected that the operator will have a working knowledge of them.

3. Abbreviations and symbols should be avoided if possible. Where space is constrainted, MIL-STD-12 abbreviations should be used. Where symbols are used, they should be meaningful and in common usage.

Labeling for Identification

Assemblies

Each assembly should be labeled with a clearly visible, readable and meaningful name or sign to increase the operator's efficiency. To accomplish this, the assembly label should meet the following requirements:

a. It should specify the overall system of which the assembly is a part.

b. It should include the assembly's popular name and function.

c. It should include a stock number for requisition.

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

(1) Where it is not obscured by adjacent assemblies.

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

(3) On a main chassis of the assembly.

(4) So as to prevent accidental removal, obstruction, or handling damage.

(5) So as to minimize wear or obscurement by grease, grime, or dirt.

Connectors

Each permanently installed receptacle should have a l[illegible] 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. Place instruction plates where the operator can see them easily.

3. Make instruction plates 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. Make instructions 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. Print instruction plates in white letters on a black background. The black color should be 37038, Federal Standard 595, or an approved equivalent.

9. Print caution or warning plates 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. Set information-plate lettering in 12- to 14-point size, with titles in 24-point letters.

11. Avoid vertical lettering.

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

13. Be sure gearshift instruction plates 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.

Test Points

1. Each test point should be labeled to aid ready recognition.

2. Nomenclature should be unique for every point in order to establish a cross-reference to pertinent manuals.

3. The manuals and, where possible, the test point labels should contain precise indications of the function and expected reading that can be tested at each 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.

ARMAMENT

Primary Armament

1. Stored mechanical energy should be protected, by interlock, from accidental actuation, e.g., a breech block has energy stored which, if inadvertently released, can injure the hand.

2. The electrical power potential of electrical power components should be capable of being disabled at the primary power source.

3. The main armament recoil mechanism should be capable of being exercised by crew personnel without damage to the system or danger of injury to personnel.

4. Main armament loading procedures should be reversible for efficient and safe round removal.

5. Provision should be made to minimize vibration of the gunner's sight from the shock of loading the main armament.

6. Main armament breech design should provide drains where necessary to preclude the trapping of cleaning fluids.

7. Maintenance of the main armament should not require special tools.

8. Main armament machined surfaces should be protected from the environment to minimize crew maintenance requirements.

9. Servicing of polished machine surfaces should not require removing the gun tube.

10. The controls for power operated breeches should be located away from the breech to protect personnel when the breech is in operation.

11. Main armament breech weight should not exceed 50 pounds where manual removal is required.

12. For manual breech operation, the operating force should not exceed 30 pounds for one-handed operation and 50 pounds for two-handed operation.

13. The main armament round chamber should be capable of being cleaned by 5th to 95th percentile soldiers.

14. Casing ejection should not endanger personnel or equipment.

15. Quadrants and other devices mounted on the main armament should be readable and accessible to the gunner throughout the maximum and minimum elevation and depression.

16. Space should be provided to store expended casings within the fighting compartment or a means should be incorporated into the design to allow disposal of these casings by some other method.

Secondary Armament

Boresighting

1. Boresighting should be capable of being accomplished by the naked eye and without the use of tools.

2. Extensive disassembly of the weapon for boresighting should not be required.

3. Boresighting should be capable of being performed from within the fighting compartment and without removing the weapon from its mount.

Removal and Replacement

1. The secondary armament should be capable of being removed and replaced without the use of tools. Thumb screws or similar fastening devices requiring less than five turns to be loosened or tightened should be used.

2. The secondary weapon should be capable of being mounted on the vehicle by crew members from a natural position with the weapon fully assembled.

3. All secondary armament retaining devices (i.e., pins, bolts) should be captive or attached to their mounts by a chain or similar captive device.

4. Clamps or similar weapon retaining devices should be hinged to swing away from the mount and should be the quick connect-disconnect type.

5. Retaining pins should be provided with L-shaped handles to expedite their removal under conditions of binding or corrosion.

Ground-Mount Operation

1. The pintles should be designed to position themselves by gravity and should not need to be held by hand when being positioned into a ground mount.

2. It is desirable that the pintle be capable of remaining attached to the weapon at all times to reduce the conversion time from secondary to ground-mount operation.

3. The weapon should be capable of being charged by the 5th to 95th percentile soldier in the prone position.

4. For ground-mount operation sights, the rear sight notch should be 3mm or wider and the front sight should be wide enough to fill the notch when taking a sight picture.

5. The secondary armament should be capable of being removed and put into the ground mount while hot.

Assembly and Disassembly

1. The barrel should be capable of being changed from the inside of the fighting compartment without affecting the boresight.

2. Quick-change barrels should not be capable of incorrect assembly.

3. The weapon should be capable of being dry-fired without damage to ancillary parts.

4. Spring-loaded retainers, releases and detents should be capable of being released by the use of the finger only.

5. The driving rod and spring, or similar kinetic-energy mechanical assemblies, should have a positive release or lock and not be hazardous if accidentally released during servicing.

Solenoids

1. Removing and replacing solenoids should not require extensive assembly or disassembly of the weapon.

2. Solenoids should be capable of activating the firing mechanism of the weapon by both manually and electrically.

3. Solenoid wiring should be protected against abrading through abuse or the striking of a surface when personnel are removing, replacing or servicing the weapon.

4. Solenoid wiring and connectors should be easily removable and mounted such that they will not be caught in turret rings, gun breeches, etc.

5. The solenoid, when checked electrically, should produce an audible click or visual signal to indicate that it is functioning.

6. Solenoids should be adjustable or an adjustment should be provided in the linkage, if any, limiting or compensating for tolerance build-up.

7. Solenoids should have an electrical connector designed to eliminate reverse polarity.

Operation

1. A blow-back weapon should be capable of being loaded without being cocked. Where this is not possible, a positive lock should be provided.

2. Where wires or chains are used to charge the weapon, the action of charging should be a non-directional reaction to an applied force, i.e., straight back pull to charge should not be required.

3. The trajectory and path of the ejected casing should be such that ejection will not injure a crew member.

4. Expended brass and links should be caught by a spent-brass container or be ejected outside the fighting compartment.

5. Charging resistance shall not exceed 250 foot/pounds breakaway or 60 foot/pounds sustained.

6. Rate selectors, safeties, triggers, etc., should be of sufficient size and resistance to accommodate the 5th and 95th percentile arctic-clothed hand.

7. Rate selectors, safeties, etc., should be clearly identified to indicate their position. It is desirable to have a detent for each position.

8. The design should permit removing jammed cases simply and quickly by the 5th and 95th percentile man without disassembling the weapon and without endangering the hand. If a tool is required, it is desirable to have it mounted to, be part of, or be captive to, the weapon on which it is to be used.

9. It is desirable to have a weapon that does not require headspace or timing, but where headspace and timing are required, a simple go-no-go system should be used to determine correct headspace and timing. It is desirable to have non-destructive feedback to indicate whether the headspace or timing is correct.

10. The weapon should be capable of being loaded by the 5th to 95th percentile hand in both the vehicle and the ground mount.

11. Flexible ammo-chute openings should be large enough to allow the ammo to be guided through the chute by the 5th to 95th percentile hand.

12. Flexible ammo chutes and ammo-chute openings should be free of sharp edges which could cut the hands of personnel during the loading operation.

GUN-CONTROL SYSTEMS

General

1. Controls should be conveniently located. They should be designed for easy operation by the crew members from natural positions, both standing and seated for the commander, with the vehicle moving or stationary.

2. The placement of elevation and traverse controls should be compatible with the location of sights. rangefinder, other essential fire-control instruments and secondary armament.

3. Use of power controls combining both elevation and traverse movements, is desirable. Controls should be operable without substantial loss of efficiency when wearing hand gear normally issued as part of the arctic uniform.

4. Design of the system should permit selective use of manual control, power control, or both.

a. Power and manual control of the gun system in elevation and traverse should be provided for the gunner.

b. The degree of control provided for the commander should be the same as that afforded the gunner.

5. The control should provide the aiblity to shift from one mode of operation to the other without excessive time for transfer of the gunner's hand.

6. Manual handwheel controls should be immobilized during power operation <u>without</u> engaging a lock or detent in a preselected position or rotation.

7. Separate controllers for azimuth and elevation increase body stabilization for the gunner when properly placed to aid his balance, but separate body supports, which provide body stabilization, permit the use of a single control handle.

8. In a gun-stabilized mode of operation, two-hand controllers for azimuth and elevation permit the gunner to make more rapid, precise correction to line of sight in either plane of response than would a one-hand controller; however, a one-hand controller will be more advantageous for a gunner who must operate a range-finder.

Manual Controls

Manual-Control Response Ratio

The optimum range of manual-control response is 10 to 20 mils of traverse per revolution and 10 to 15 mils of elevation per revolution. From the standpoint of training, uniform rates of response are desirable in all fighting compartments. To obtain moderate handcrank operating forces, the response ratio should approach minimum values, but should not be less than the lower limit specified (Fig. 9).

Manual Handcrank Force

1. An elevation cranking force of five pounds is considered a suitable limit for both starting and continuing motion.

2. Manual traverse should permit controlled manipulation of the turret through 360 degrees with the vehicle canted or pitched 15 degrees.

Handcrank Force

Direction	Maximum Resistance in foot pounds
Traverse	9
Elevation	8

3. When comparing system results with specified force or torque values, the variables are:

a. Ease of operation.

b. Operator fatigue.

c. Handcrank configuration.

d. Location in relation to the operator.

Physiological Factors

1. When a tank is tilted, it will normally become increasingly difficult to pull the turret up hill. Generally at a ten-degree and greater tilt the gunner will have to remove his eye from the periscope and assume a braced position using one hand or two hands or to change from one hand to the other in order to complete 360 degrees traverse at fast speed.

2. Where the effort to manually traverse remains under approximately five pounds and is reasonably uniform, a turret can be traversed for about 15 minutes at slow speeds, for approximately five minutes at moderate speed and generally less than three minutes at fast speed.

3. At fast manual-traverse speeds under level conditions, the gunner will have difficulty keeping his eye to the periscope. Tremor will set in after traversing about 180 degrees and it will generally be impossible to continue at a fast manual-traverse speed beyond 1.5 revolutions.

Manual Control Backlash

1. Backlash can influence the precision and speed of engaging stationary point targets and the retention of gun alignment on target during firing. Gun and turret control systems should be designed to minimize system backlash.

2. Maximum backlash movement should not exceed 1.0 mils in traverse and 1.4 mils in elevation.

Power Controls

Power-Controller Neutral-Zone Characteristics

1. Zero controller backlash should be provided.

2. The controller dead spot should not exceed $\pm 2^{\circ}$ and should be equal in each direction from center.

3. Positive centering of a released controller should be provided.

4. Positive response to small deflections of the controller should be provided to permit rapid, precise, point-target engagement.

Power Controller Operating Torque

1. Ease of handling and manipulation are the important factors in prolonged operation of the gun-control systems.

2. The recommended power-controller operating torque is five pounds.

Power-Response Rates

The graphic presentation of data in Figure 24 indicates desirable characteristics and an optimum traverse-response curve. Considerations in design should include:

a. Irregularities of response.

b. Difficulties of controlling turret and gun motion.

c. Limitations of performance caused by response slope characteristics and extreme response values.

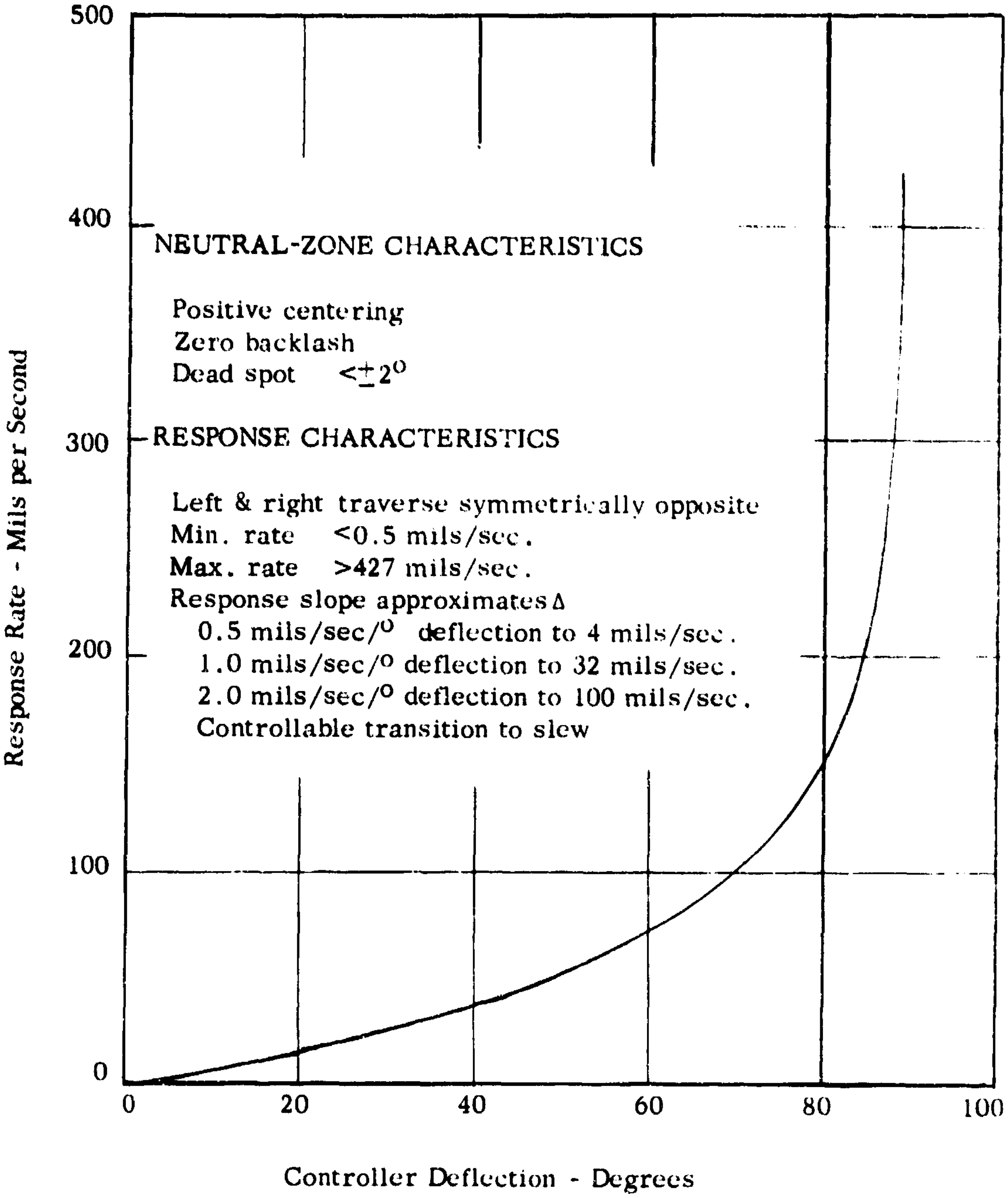


Fig. 24. OPTIMUM POWER-TRAVERSE RESPONSE RATES

Power Acceleration

A typical engagement of a combat target would require traversing the fighting compartment through 1600 mils or less; thus the ability to engage a target in minimum time depends on the angular acceleration and deceleration provided by the power gun-control system. An appropriate method to provide this acceleration and deceleration should therefore be incorporated into the system design.

Controller Shift Time

1. The commander's controls should be designed to override the gunner's control of the system.

2. The time required to shift control from the gunner to the commander or vice versa should be minimal.

3. The time required to shift the gunner's control from power to manual or vice versa should be minimized and the shift should be accomplished with as few operations as possible.

Utility and Compatibility of Operation

1. Slippage of the main gun, with the travel lock disengaged, should be negligible during all normal maneuvering. The gun elevating-system torque-overload relief device should permit main-gun slippage at a torque just below that which would cause damage to the system.

2. Strong magnets, where used, should be mounted so they will not deflect meters.

3. "Built-in" leveling, boresighting and synchronizing features should be provided on fire-control equipment whenever practical.

Fire-Control Maintenance

Mechanical Equipment

1. Split pins should not be used instead of the conventional taper pin.

2. Split clamp couplings should be used instead of sleeves to facilitate replacement of parts and adjustments.

3. The number of different types and sizes of bolts, nuts and screws used as fasteners should be kept to a minimum.

4. Where practicable, lock washers should be captive to their bolts and screws.

5. The method of pinning gears should be standardized throughout the system.

6. Set screws should be used where keyways or splines are used.

Hydraulic Equipment

1. Gauges should have an external pointer adjustment for ease of adjustment and calibration.

2. Adapters, couplings and hose assemblies that do not require special tools should be used wherever practical.

3. In case of an electrical failure, a means for manually operating the system should be provided.

4. Permanent metal labels should be provided to identify hydraulic equipment.

5. Safety fittings with built-in check-valve features should be used in hydraulic lines to limit the supply-fluid loss to a section if a line ruptures.

6. The system should be designed for automatic bleeding wherever possible.

7. Hydraulic systems should be coded (see Hydraulic and Pneumatic Connectors, p. 99).

8. Lines containing high-temperature fluids and high pressures should have provisions to protect personnel in case they rupture.

9. Hydraulic cylinders should be mounted in a readily accessible position.

10. Meters, gauges, and control valves should be placed in a centralized position.

11. Easily accessible, removable filters or strainers should be provided.

12. Relief valves should be utilized in hydraulic lines to prevent bursting and injuring of personnel.

13. Hydraulic lines having working temperatures of more than 120 degrees should be routed away from crew stations.

Accessibility of Components

1. Doors or hinged covers should be rounded at the corners and provided with slip hinges and stops to hold them open.

2. Rotating assemblies should be provided where feasible.

3. Access openings should be provided for instrument adjustment.

4. Lubrication points should be accessible and clearly marked.

5. Mounting bolts should be accessible to allow equipment to be installed without the removing of other parts and assemblies.

6. Fast-action, captive fastening devices which do not require special tools should be used for covers, cover plates, etc.

7. Where the operator must make adjustments, adjusting devices should be external to the operating mechanisms.

8. Access should be provided to both sides of equipment, with sufficient hand room for removing and replacing the equipment.

9. Fastening devices should be designed and located to facilitate the quick removal of components for repair.

10. High mortality items should be located near access openings.

Safety

1. Guards, safety covers and warning plates should protect personnel from moving mechanical parts.

2. When feasible, locking levers should be used instead of nuts, screws, etc.

3. Special warning and caution devices should be provided as near as possible to the parts of the system to which they apply. Indications should be given that are directly usable without further correction or interpretation.

4. Boots or covers should be provided for exposed couplings, universal joints, etc.

OPTICAL INSTRUMENTS

General

1. Blinking the eyes is an automatic process and personnel using optical instruments will blink occasionally because the eyes cannot focus steadily for very long without relaxing. Blinking is muscular rather than retinal and is least apparent when the eye is relaxed and accommodated for distant objects.

2. Eye muscles will be fatigued after comparatively short periods of continuous observation. Fatigue is usually greater under low illumination levels.

3. A particular type of fatigue results from the use of binocular instruments whose lenses cannot be adjusted to the span between the eyes (interpupillary distance). This fatigue occurs because both eyes involuntarily adjust themselves so that a single image is formed when the image is focused on the macula of each eye.

4. The more evenly diffused the light that can be brought from an object to the eye, the brighter and clearer will be the image that is formed. This characteristic is known as image brightness. There is always a considrable loss of light by absorption in the lenses and by reflection at the surfaces of the optical elements. This loss may be as great as 75 percent, and every effort should be made to reduce the loss to a minimum.

5. A factor contributing to image brightness is an objective lens aperture large enough to permit the eye lens to produce an emergent beam that will fill the pupil of the eye. During the day the pupil of the eye is from one-tenth to two-tenths of an inch in diameter. At night the pupil may dilate until the diameter is from one-quarter to three-tenths of an inch. An instrument for use at night should have an exit pupil aperture of this size to deliver as much light as the eye can use.

6. The true field of view of any optical instrument is the width and height of what can be seen at one time by looking through the instrument.

7. The maximum area of the field which might be imaged by the eyepiece is termed the apparent field of view. An apparent field of view of 45 degrees may be considered as a practical maximum for a highly corrected eyepiece. Thirty-five or 40 degrees is a more common value.

8. The full apparent field of view of an instrument can only be seen when the pupil of the eye of the observer is at the same position as the exit pupil. The distance from the eye lens to the exit pupil is termed the eye distance relief. The eye must be placed at this distance from a collective eyepiece in order to see most effectively through the instrument.

9. When the instrument imparts recoil to the observer, the eye distance becomes a very important design consideration. In the design of the instrument, the proper location of the exit pupil must be given careful consideration. If it is too far back, the eyepiece will become too bulky; if it is placed too close, the user of the instrument will suffer discomfort and will be unable to use the instrument to the best advantage.

Interpupillary Distance

1. In designing instruments for use by both eyes, provision must be made for adjusting the spacing between the eyepieces of the instrument to conform to the interpupillary distance of different observers.

2. The interpupillary distance of such instruments should be adjustable from 2.1 to 2.7 inches. Where this adjustment is not provided in the design of the instrument, several problems arise:

a. The lines of sight of both eyes will not traverse the most effective optical paths of the instrument.

b. The observer will not have full binocular vision nor view the most distinct images.

c. The observer will not be able to seal out unwanted light from the eyepieces.

Focusing

1. The eyepiece of instruments having magnification of more than four-power (4X) should be calibrated to accommodate the refracting qualities of the eyes of the individual observer. A single focus setting on instrument which have a magnifying power of 4X or less will have a sufficiently wide range of accommodation.

2. If personnel wear proper spectacles, a corrected eye will focus at the normal setting of the instrument. However, spectacles may prevent the eyes from properly addressing the eyeshield of the instrument, thereby permitting stray light to enter the eyes. In addition, the eyes may be placed so fai from the eyepiece as to restrict the field of view.

3. Focusing eyepieces should have a graduated scale calibrated in diopters; the range of adjustment should be at least plus 4 to minus 4 diopters.

Filters

Light filters should be provided where necessary.

a. Smoked (neutral) filters reduce the intensity of light and are effective when observing against or in the close vicinity of the sun or a bright light.

b. Yellow and amber filters protect the eyes from the reflection of sunlight on water and other general conditions of glare.

c. Amber and red filters are employed under various conditions of fog and ground haze. Red filters are also used in observing tracer fire.

d. Blue filters are helpful in detecting the outlines of camouflaged objects.

e. Greenish-yellow filters serve the same purposes as smoked and amber filters.

f. Polarizing filters do not change the color of objects but do decrease light intensity and glare.

Sights for Night Operation

1. Where continuous use of a sight will exceed one minute, the single optical-train sight should be equipped with two eye pieces.

2. It should be possible to gradually lower the brightness of a sight until it is extinguished.

3. Once an adjustment is made, the level of brightness should remain fixed under all conditions of vibration.

4. The sight should be evenly illuminated by means of an opal diffuser or some similar device.

5. Magnification of the image will increase the range of vision up to a limit under starlight brightness. However, the magnified image is proportionally affected by movement and vibration.

6. Blue is unsuitable for reticle color because of the difficulty in accommodating and because of chromatic aberration of the eye with an extended pupil.

7. A black reticle line decreases the visibility not only of targets covered or partly covered by the line, but also of those lying near the line. This characteristic is particularly true for indistinct, camouflaged or small targets, or for lazy conditions. These effects may have some influence as far as 2 1/3 mils from the edge of each line.

8. Aiming is not affected appreciably by considerable variation in reticle thickness; thin lines give personnel a feeling of precision when they are aiming. The lines should be .5 to 2 minutes in thickness.

9. The following factors should be considered in the design of reticles:

a. Line reticles should be used in preference to reticles containing one, two, or three central spots.

b. Using two vertical spots for any length of time fatigues the aimer and produces inaccurate results.

c. A ring should be used in preference to a single spot.

d. A small cross or very small circle should be used in preference to a dot.

e. The best pattern for a night sight is a simple circle with tabs added to the sides.

10. A complicated reticle pattern may cause aiming errors as large as 30 mils by interfering with a distinct view of the target. Therefore, it should be avoided.

Sight Elevation

The practice of making elevation correction for range by displacing the target image within the sight field imposes severe demands upon optical properties:

a. The greatest range position of the reticle occurs farthest from the center of the field; therefore, this region of the field should provide the best vision and the least parallax.

b. Curvature of field generally present in optical systems and most marked in the lens erecting types (straight tube) introduces parallax which, if eliminated at the center, increases beyond the center of the field.

c. Curvature of the field also presents focal difficulties. Thus, if the eyepiece is set to give a zero diopter setting in the center (as for infinity), a positive diopter condition develops away from the center for which the normal eye cannot accommodate. This condition makes the image of distant objects appear blurred just where vision should be the clearest.

Optical Material Maintenance

1. Instruments should be sealed with gaskets whenever possible.

2. Humidity indicators should be provided on sealed instruments to permit proper cycling of purging operations.

3. Where periodic purging and charging of optical instruments is required, an instruction plat indicating time interval and pressure requirements should be provided on the instrument.

4. Optical equipment should be designed according to the modular design concept, i.e., optical assemblies within an instrument or optical modules that have multiple application in equipment should be interchangeable.

5. Built-in aligning devices and other aids should be used wherever possible to ease the positioning optical elements.

6. Quick-release methods of removing optical instruments should be used wherever practical.

7. Whenever possible, optical instruments should be provided with built-in collimation features to allow field adjustment.

8. Windows should be provided for all exposed optical surfaces.

9. The use of slotted lens retainers should be avoided wherever possible.

10. The use of long, uninterrupted threads for lens retainers should be avoided.

11. Purging and charging fittings should be accessible for required maintenance.

12. Readily accessible openings should be provided to facilitate replacement, adjustment, and cleaning of reticles.

13. Light bulbs should be in accessible locations with sufficient hand clearance to allow the 5th to 95th percentile soldier to remove and replace them.

14. The operator should be able to remove and replace light bulbs without removing or disassembling other components.

15. The operator should be able to remove and replace light bulbs from the front (operator end) of the optical device.

16. Bulb retaining bases should be chain mounted to prevent their loss when the bulbs are removed and replaced.

17. Light-bulb receptacles should be clearly identified to indicate their relationship to the sights or sight reticles that they illuminate.

Boresight Knob Locks

1. Boresight knobs should be provided with a positive lock.

2. The application and release of the boresight adjustment-knob locks should not require more than 10 pounds of force to lock and unlock.

3. Boresight adjustment knobs should be capable of being unlocked, adjusted and locked by the 5th to 95th percentile soldier's hand.

Slip Scales

1. Where slip scales are used they should be capable of being slipped by the hand of the 5th to 95th percentile soldier.

2. Slip scales should operate by hand with no requirement for tools.

Sight Mounts

1. Key and keyway, eccentric and keyway, and single-dowel applications should be used for the final positioning of sight mounts.

2. The use of two or more dowel pins for final positioning of mounts on support surfaces provided on the weapon should be avoided.

3. Leveling vial supports should be strong enough to prevent displacement of the bubble under slight pressure.

Eyepieces and Eyecups

1. Any optical instrument that requires steady orientation of the eyes should be provided with a headrest and/or eyecups.

2. Eyecups should be made of soft rubber or an equivalent material.

3. Eyecups should be designed to prevent stray light and wind from entering the eyes. A proper fit is particularly important for observing at night or under conditions of poor illumination in order to dilate the pupil as much as possible.

4. Eyecups and eyepieces should be compatible with helmets, gas masks and other ancillary equipment.

5. When an optical instrument transmits energy to the observer, eye-relief distance and exit-pupil location should be consistent with the recoil characteristics of the weapon.

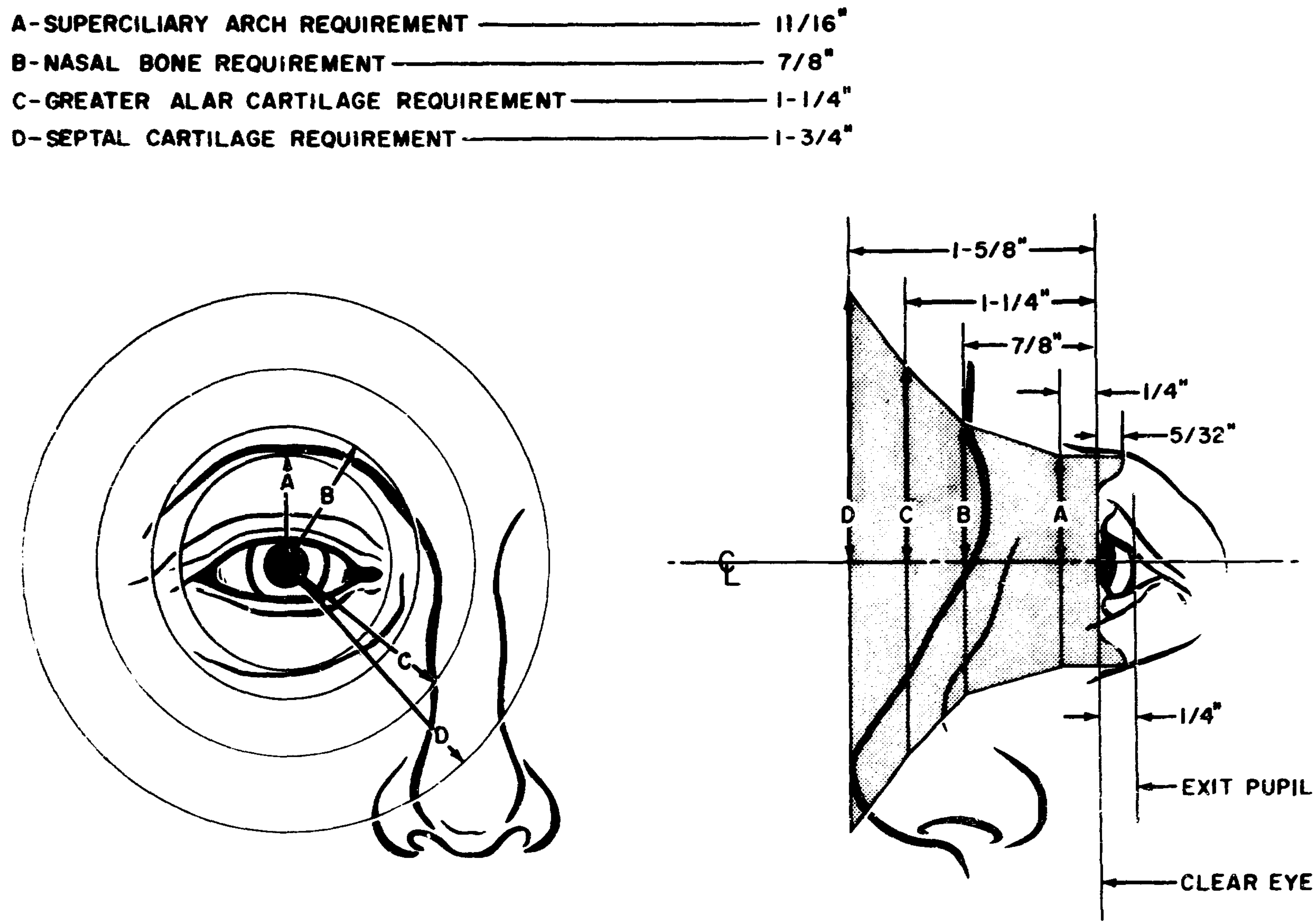


Fig. 25. ANATOMICAL LIMITS ON AXIALLY SYMMETRICAL OCULAR METAL PARTS

6. The radii of Figure 25 define a surface of revolution within which a satisfactory symmetrical eyepiece and eyecup must be designed if interferences with facial features are to be avoided. These should be applied to cushion forms when they are compressed to the maximum.

Brow Pad

1. The object of a cushioning device such as a headrest or brow pad is to absorb energy which would otherwise be absorbed by the human head, with resulting damage to its internal organs, bone structure or external tissues.

2. The cushion not only spreads the force over a greater time but also over a greater surface area, thus preventing a damaging amount of force from being exerted at any one point.

3. There are three general types of cushion material, as shown by the load-deflection curves in Figure 26. These curves are idealized and do not represent existing materials.

4. The curves have been drawn so that each one represents a cushion which has the normal characteristics required to provide the desired protection. For example, each curve reaches an assumed maximum tolerable force of 160 pounds at a compression of 0.9 inch. The 160 pounds is roughly the product of an assumed weight of 12 pounds for the head plus helmet and an assumed 13 g's maximum tolerable acceleration of human head. The 0.9-inch maximum allowable compression assumes an eye-relief distance of 1.25 inch and a safety clearance of 0.35 inch. In case the curve rises steeply after 0.9 inch to provide enough stopping force to prevent further travel, which might result in collision of the eye with the eyepiece of the telescope. However, in spite of the similarities, the three cushions depicted are not at all equal in effectiveness.

5. The energy in inch-pounds absorbed by the cushion is given by the area under the load-deflection curve. It can be seen from Figure 26 that the most energy absorption is provided by the cushion for which the force rises rapidly and then reaches a plateau for the rest of the compression distance. The higher energy-absorption capacity means that a greater velocity of the pad-supporting structure relative to the head can be tolerated.

6. So far, the shock has been considered as if it were a single event, resulting in only one compression cycle of the pad. Actually, the firing of the weapon results in a series of oscillations of the vehicle structure, against which the head must be protected to a greater or lesser degree, depending on amplitudes and frequencies of the oscillations.

7. The optimum protection of the head requires that the head-plus-headrest system have a natural resonance frequency differing as much as possible from the frequencies occurring in the weapon structure, and also different from the natural frequencies of the head itself.

8. A large damping coefficient is desirable only if the exciting frequency is less than three times that of any existing natural resonance frequency, otherwise damping actually increases the amount of force transmitted through the cushion by decreasing the mechanical impedance.

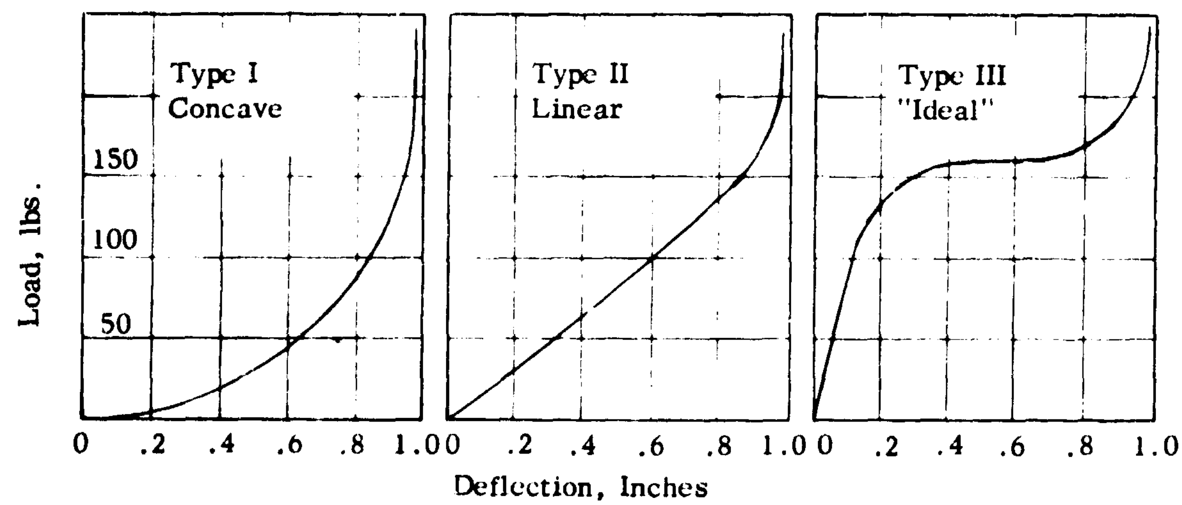


Fig. 26. TYPES OF CUSHION MATERIAL

AMMUNITION

Projectile* Stowage

1. Ready racks should be designed so projectiles can be stowed and removed easily with an ammunition hoist or manually. This should be an easy operation for the rear and side sections of the racks as well as for the front sections.

2. The projectiles should be protected from falling out of stowage or from banging against each other in stowage when the vehicle is moving or when the gun is fired.

3. The ready rack should be designed to minimize interference with the working area.

4. Whenever manhandling of ammunition is required, the projectiles should be stowed for efficient handling. For example, if the projectiles are stowed horizontally and parallel to the ramming trough, the man must make a 180 degree turn to get the projectiles into the trough. In this case, then, the nose of the projectile should be stowed away from the breech so that when the 180 degree turn is made the nose will be facing into the breech; otherwise the man will have to shift the projectile in his arms in order to position it properly in the ramming trough.

5. The ready rack should be designed so that the several different types of ammunition (HE, AP, Missile, etc.) can be stowed and removed without having to move other rounds.

Projectile Transfer

1. Where an ammunition hoist is used, the projectiles should be prevented from swinging about, thereby endangering personnel or damaging equipment.

2. The ammunition-hoist clamp should be designed to prevent accidental release of projectiles.

---

* The term projectile in this and the following section shall be taken to mean the fixed round as well as the projectile of a semi-fixed round.

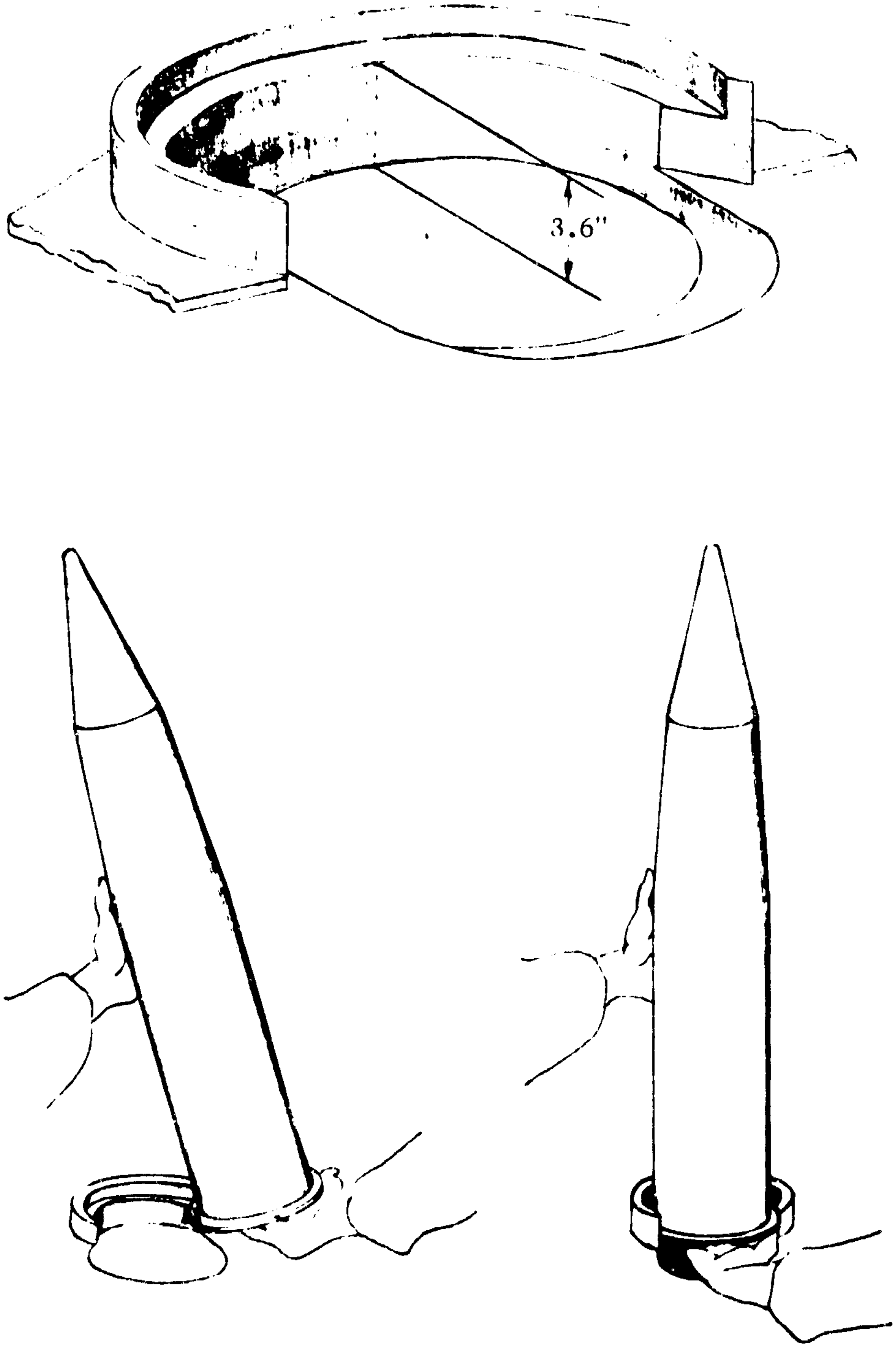


Fig. 27. RETAINERS FOR FLOOR-MOUNTED VERTICAL AMMUNITION READY RACKS

3. Provision should be made for manual operation of the ammunition hoist in case of power failure.

4. Unobstructed work space should be provided for transferring the projectiles from outside the vehicle to the ready rack and from the ready rack to the breech.

5. The hoist should be capable of being stowed out of the way of the ramming trough and breech-lock mechanism.

6. Provision should be made for disposing of empty shell cases in vehicles using fixed and semi-fixed ammunition.

Ammunition Stowage Racks

1. Personnel should be able to remove and replace ammunition from the stowage rack without striking any protrusions within the vehicle fighting compartment.

2. Ammunition-rack latching mechanisms should be of quick-release design and require no more than 12 pounds to operate.

3. It should be readily obvious to personnel when the ammunition-rack latching mechanisms are in the locked position but not secured.

4. Ammunition-rack locking mechanisms should be free of sharp edges or protrusions which can snag clothing or injure personnel during entrance, exit and movement within the vehicle fighting compartment.

5. Upright-mounted ammunition weighing over 40 pounds should have a floor retainer which has sufficient clearance to allow removal by the 95th percentile hand (Fig. 27).

6. Floor and hull stowage tube-type ammunition racks should be spring loaded so the stowed rounds will travel two inches out of the rack when the latching mechanism is released.

7. Where spring loading is not feasible the end of the tube should be recessed to maximize hand grip.

8. Floor-mounted ammunition racks should not interfere with the footing of crew members in the vehicle fighting compartment.

9. Stowed rounds and their stowage racks should not interfere with fighting-compartment controls or obscure displays.

10. Ammunition-rack retaining mechanisms, clamps, etc., should remain in the open position or fold out of the way by gravity when unlatched to allow the removal and replacement of ammunition in stowage racks.

11. Where ready racks are located to the rear of the gun breech, sufficient distance must be provided between the rack and the breech to accommodate the longest round anticipated for use plus the thickness of the 95th percentile gloved hand.

12. Ammunition stowage racks, whether loaded or empty, should not impede escape from the fighting compartment.

Fuzes

1. Fixed detents should be used for each position on a fuze so that the moving component of the control will snap into place in the selection of each fuze option.

2. Sufficient resistance should be built into the setting mechanism to prevent inadvertent change of setting.

3. The multi-position selectors should be so designed that the rotional forces to which the round is subjected in firing and in flight will not affect the setting made by the operator. Designing the selector mechanism so that linear acceleration will lock the selector in place will prevent such accidental changes in setting.

4. Markings and pointers should contrast maximally with their backgrounds.

5. Pointers should be designed so that they are the same color as markers when possible. The pointer tip should be as close to the index as possible, and they should never be separated more than a sixteenth of an inch.

6. The surface of hand-manipulated fuze controls should be of a material which will maximize the grip the operator can maintain on the fuze. However, the texture of the surface finish should not interfere with the aerodynamic characteristics of the round.

Missiles and Other Fragile Ammunition Rounds

The stowage of missiles and other fragile ammunition rounds (such as combustible-case ammunition) should conform to all the stowage and transfer principles applying to normal ammuntion. In addition, the following considerations should be satified:

a. The latching mechanism should have a cushioning material that will absorb all the forces (G-forces) that exist within a vehicle fighting compartment.

b. The latching mechanism/mechanisms, other cushioning material (e.g., base cushioning, etc.), and round orientation should not allow distortion, bursting or rupturing of the round or cartridge case and should prevent damage to the internal components of the missiles.

STOWAGE

General

1. Adequate means should be provided to dispose of used materials, including human waste, from within the fighting compartment.

2. Stowed items should be secured by straps, brackets or other restraining devices to allow cross-country operation without endangering personnel or displacing the stored item.

3. Items which are inflammable or subject to damge by leakage of lubricants, fuels or water should be stowed so as to receive reasonable protection from hot engines, exhaust components, etc.

4. All stowage locations should drain adequately with the vehicle on level ground. Drain holes should be arranged so that they will not be blocked by normal stowage.

5. Climatic factors should be considered in locating items that must be worn by crew members, and in locating items which exposure to the climatic environment would prevent from operating.

6. All stowed equipment should be capable of being safeguarded from pilferage.

7. Floor stowage boxes should not interfere with crew footing in the fighting compartment.

Interference

1. Stowed items should not interfere with entrance, exit, escape, movement or operations within the fighting compartment by crew personnel.

2. Stowage should not interfere with gun recoil, loading, maximum gun travel or other system functions.

3. Stowed items should be capable of being removed and replaced without the removal or replacement of other stowed items or components of the system.

4. Items to be stowed should be capable of being stowed and unstowed by the 5th through 95th percentile man, wearing gloves, without his having to assume an unnatural position.

Utilization of Stowage Space

1. The way an item is to be used should determine where and how it is stowed.

2. Items to be utilized by a particular crew member should be stowed conveniently and accessibly within the functional area of his station.

3. Dead space should be utilized to the maximum extent possible to stow items.

4. When necessary, stowed items can become part of the components of a fighting compartment, e.g., seats.

5. In the case of limited space within a fighting compartment, items can be tailored to the configuration of the compartment.

Identification

1. The location for stowed items should be clearly and permanently labeled with the identity of the item.

2. A stowage plan should be provided to clearly identify items and their locations.

Retaining Devices

1. Retaining devices should be simple and capable of quick removal and replacement.

2. Items should be capable of being stowed and unstowed by hand; no tools should be required.

3. Items should be capable of being stowed and unstowed under all environmental conditions.

Stowage Boxes: Doors and Covers

1. All access covers or doors not completely removable should be self-supporting in the open position, unless gravity normally holds them in that position.

2. Where instructions applying to a covered component are lettered on a hinged door, the lettering should be oriented for reading when the door is open.

3. Sliding, rotating, or hinged units should be free to open or rotate their full distance and remain in the "open" position without being supported by hand.

4. The method of opening a cover or door should be obvious; if it cannot be made obvious, an instruction plate should be attached permanently to the outside of the cover.

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

6. Sharp edges and corners should be avoided on doors, covers, and other exposed surfaces.

7. To expedite reinstallation, removable inspection-access doors should be interchangeable or have a size and shape which makes evident their proper position.

8. Covers or doors should not be prevented from opening or being removed by obstructions, i.e., turret, on-vehicle equipment, or structural members.

9. When a hinged cover is used, a space equal to the sweep volume of the cover should be provided, e.g., opening of the cover should not be obstructed by the body frame, brackets, etc.

ENVIRONMENT

General

1. The environmental factors affecting the design of fighting compartments can be separated into three major categories:

a. Environmental factors controllable through design, e.g., illumination, ventilation rate, etc.

b. Environmental factors not controllable through design, 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. To maximize the effectiveness of the man-machine weapon system, the designer should consider, throughout the design phase, the environmental extremes to which the system will be subjected and their effects on performance.

3. Ordnance should be capable of sustained fighting within any geographical area during any season of the year. In recognition of this need, Army Regulation 705-15, "Operation of Materiel Under Extreme Conditions of Environment," requires that materiel developed by Army Materiel Command be capable of acceptable performance throughout the ambient temperature range of $+115^{\circ}$ to -25° F with no aids or assistance other than standard accessories, and $+125^{\circ}$ to -65° F with specialized aids in kit form.

4. In a buttoned-up vehicle exposed to the sun, the air temperature within rises above the outside temperature. There are two sources of heat:

a. Solar radiation, which is distributed over the surfaces exposed to the sun.

b. Power-train components, which are heated to a high temperature when the vehicle is in operation.

5. The rate of solar radiation varies throughout the day, reaching a maximum of approximately 300 BTU per square foot per hour on a horizontal surface. Assuming complete absorption and equal transmission of the heat to the inside and outside, the total amount of solar heat transmitted to the inside of an armored fighting vehicle can amount to a maximum of approximately 12,000 BTU's per hour. With a ventilation

rate of 500 cubic feet per minute, inside air temperature would increase by 20° F. The same amount of solar heat ventilated at 2000 cubic feet per minute would increase temperature 5° F.

6. The total heat load to which the crew members are exposed in armored-vehicle fighting compartments is not measured by air temperature alone. The fighting-compartment wall temperatures, the moisture content of the air, and the rate of air movement within the fighting compartment are of equal importance. For example:

a. The air temperature inside an armored-vehicle fighting compartment (engine idling) on a moderately clear, midsummer day has been measured at 122° F with an outside air temperature of 85° F.

b. On a continuously clear day with a maximum air temperature of 98° F, the fighting-compartment wall temperatures reached 141° F.

c. In the California desert, interior wall temperatures in a buttoned-up, stationary vehicle fighting compartment rose to 150° F (outside air temperature was 104° F) and while the vehicle was driving cross country these temperatures ranged between 120° F and 130° F with an average outside air temperature of approximately 100° F.

d. The moisture content of the air within a vehicle fighting compartment is increased by the evaporation of sweat from crew members. Assuming an average rate of evaporation of one liter (2.2 pounds) per hour per man at temperatures up to 120° F, a five-man crew would contribute 11 pounds of water per hour.

7. In cold-weather operations experience has shown that crew heating is required for efficient tank operation. Owing to the great mass of steel involved in the design of most armored vehicle fighting compartments, it is doubtful whether a heater of sufficient capacity can be installed for general heating of an entire fighting compartment. Local space heating at the crew positions will normally be needed.

Temperature Requirements

1. The optimum temperature for personnel varies according to the nature of the tasks performed, the conditions under which the tasks are performed and the clothing personnel are wearing.

2. For maximum physical comfort while normally dressed, the optimum range of effective temperature for accomplishing light work is:

a. 70-80° F in a warm climate or during summer.

b. 65-75° F in a colder climate or during winter.

3. Effective temperature of the environment may be derived from Figure 28 or Figure 29.

4. The effective-temperature ranges are flexible because they vary according to the amount of work activity. A loader, for example, has a much higher work rate than a gunner. In general, the ranges should be extended upwards for tasks requiring minimal physical effort and downward for tasks requiring continuous muscular exertion. For example:

a. A prolonged exposure to an effective temperature of 85° F should be considered the maximum limit for reliable human performance.

b. Prolonged exposure of an ungloved man to effective temperatures below 55° F often results in a "stiffing" of fingers, thus degrading performance in tasks requiring manual dexterity.

c. A man wearing arctic clothing should not be exposed, while sitting quietly, to temperatures higher than 60° F; a temperature of 35-45° F is probably optimal.

5. In providing for heating and cooling of enclosed areas, it is important that the temperatures of the enclosed area be held relatively uniform. Air temperatures at foot level and at head level should not differ significantly.

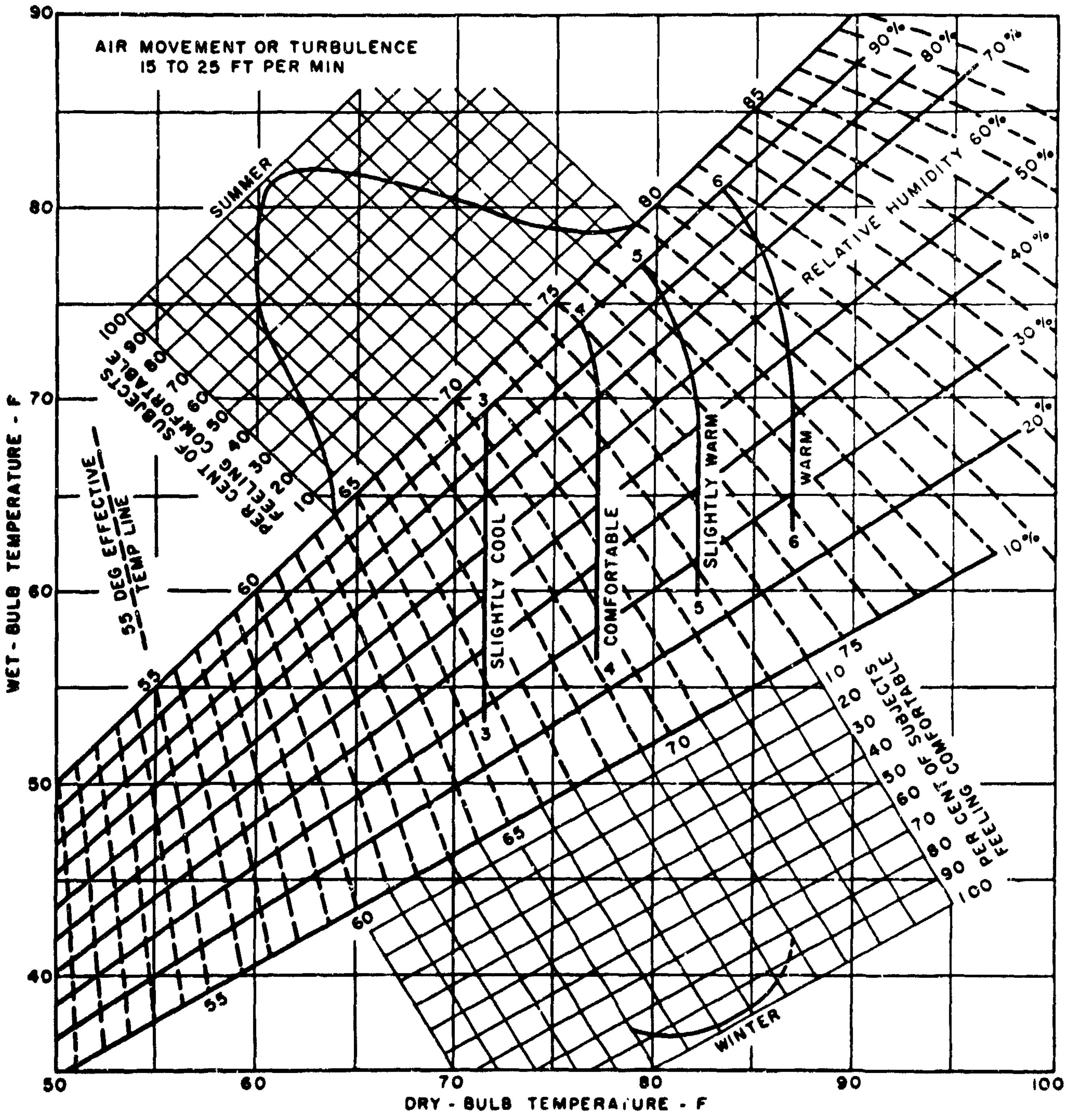
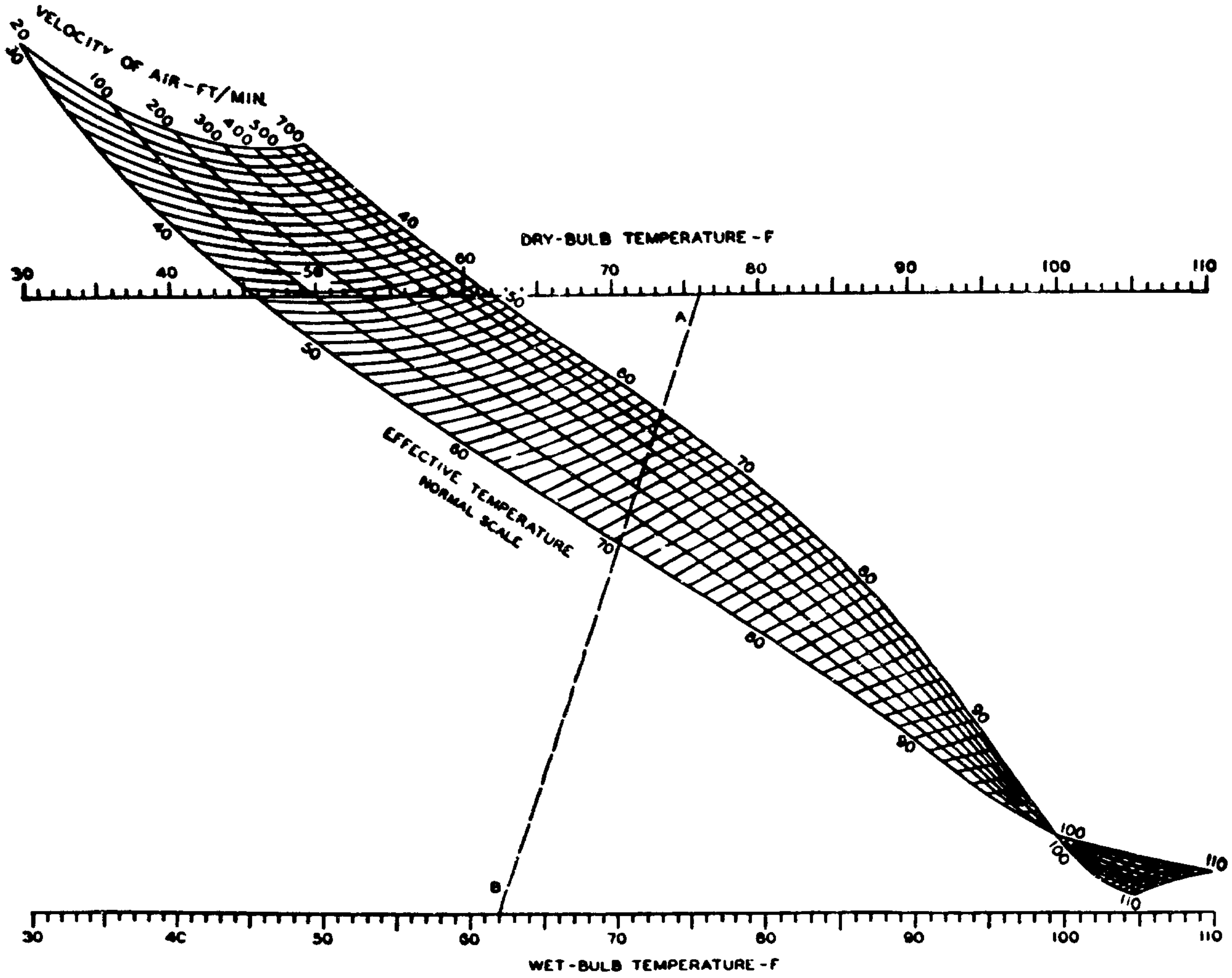


Fig. 28. EFFECTIVE TEMPERATURE CHART
(Reprinted by permission from A.S.H.R.A.E. Guide and Data Book, 1963.)



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. 29. DERIVING EFFECTIVE TEMPERATURE

Surface Temperatures

1. Table 12 provides the effects on the skin of personnel coming in contact with surfaces at different temperatures.

TABLE 12

Effects on Skin of Contact with Surfaces at Different Temperatures

Temperature (^{o}F)	Sensation or Effect
212	2nd-degree burn on 15-second contact
180	2nd-degree burn on 30-second contact
160	2nd-degree burn on 60-second contact
140	pain; tissue damage (burns)
120	pain; "burning heat"
91 ± 4	warm; "neutral" (physiological zero)
54	cool
37	"cool heat"
32	pain
Below 32	pain; tissue damage (freezing)

2. The highly localized heat from power-train components must be insulated from the fighting compartment to prevent imposing an excessive surface contact or ambient heat load upon the crew members.

Windchill

1. The windchill scale has been derived from the rate of freezing of water when influenced by ambient temperature and wind.

2. Figure 30 depicts the relationship of temperature and wind for various windchill values. A qualitative description of human reaction to windchill values to exposed skin includes:

Windchill Value	Human Reaction
100	Warm
400	Pleasant
800	Cold
1000	Very Cold
1200	Bitterly Cold
1400	Exposed Flesh Freezes

Ventilation

1. Crew-compartment ventilation must be independent of the main engine and be capable of operation for prolonged periods when the tank is stationary and the tank engine is off. A vehicle which is inadequately ventilated when stationary, even if it is ventilated at a higher engine speed, is not acceptable.

2. Compartment ventilation should provide a pattern of air flow sufficient to:

   a. Ventilate each crew member's position adequately.

   b. Mix and dilute contaminants present at crew members' positions.

   c. Divert the flow of contaminants from crew members' positions.

3. The comfort of a soldier at low temperatures depends upon the rate of air movement as well as the air temperature. The flow of cold air passing the man should be kept at a minimum.

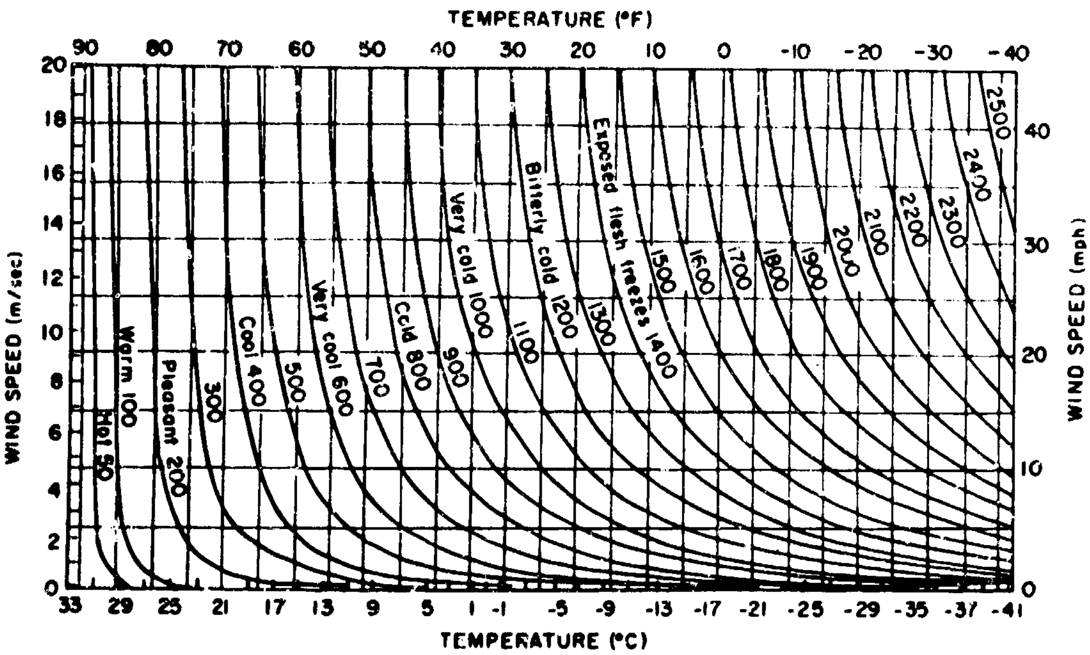


Fig. 30. WINDCHILL CHART
(Numbers on curves represent windchill in kg-cal/m^2/hr)

4. Positive-pressure ventilation should be provided to:

a. Protect against the entry of snow, dust, particles, etc.

b. Permit more adequate regulation of air temperature and air velocity.

c. Maximize CBR protection.

Noxious Substances

1. The gases produced when weapons are fired typically contain carbon monoxide (approximately one-third of the volume of fumes produced), oxides of nitrogen, and ammonia. These gases can result in the following hazards:

a. Carbon monoxide concentrations can cause loss of mental alertness and even disorientation and collapse.

b. Ammonia is highly irritating and, even in small concentrations, produces eye watering.

2. The presence of either carbon monoxide or ammonia in excessive concentration has been known to reduce the effectiveness of tank crews and has even caused collapse and unconsciousness in battle. It is obvious that concentrations of such toxic agents should not be permitted to build up beyond their tolerable limits in the crew compartment.

3. The Threshold Limit Value (TLV) for carbon monoxide (CO) is 50 parts per million (ppm); for ammonia (NH_3) is 50 ppm; and for nitrogen dioxide (NO_2) is 5.0 ppm. The NO_2 level is also a ceiling value which should not be exceeded at any time.

4. The TLV for the CO and NH_3 is a time weighted average limits for an eight hour period. Time weighted average concentrations permit excursions above the limit, provided they are compensated by equivalent excursions below the limit during the working day. It is not considered appropriate to interpret air concentration values as exceeding time-weighted average limits, if such values lie within the permissible excursions.

5. The principal toxic effect of carbon monoxide is the production of carboxylhemoglobin; ammonia is a pulmonary irritant and asphyxiant; nitrogen dioxide is a pulmonary irritant and edemagenic agent.

6. 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:

a. The loading condition of the engine.

b. The ambient temperature in which the engine is operating.

c. The type of fuel.

7. The exhaust products of CO (carbon monoxide) and CO_2 (carbon dioxide) occur no matter which fuel is used. In addition:

a. When multi-fuel engines are using gasoline, the exhaust products include nitrogen, oxygen, and hydrogen.

b. When these engines are operated on CITE, JP4, or kerosene, the exhaust products include aldehydes, H_2O, H_2 and free carbon.

c. When diesel fuel is used, the exhaust products include aldehydes, traces of nitrous oxides, sulphur compounds (SO_2, etc.), oxygen, nitrogen, and methane.

8. When multi-fuel engines are operated on CITE and diesel fuels, the exhaust products contain aldehydes which can cuase eye irritation and nausea among personnel. Conjunctivitis and nausea resulting in temporary disability have occurred among personnel exposed to these exhaust products. These temporary disabilities are common to conditions such as vehicles in convoy, the transportation of troops, and other situations where personnel are subjected to the exhaust stream of multi-fuel engines.

9. Careful consideration should be given in designing vehicle fighting compartments to provide sufficient ventilation to maintain these products below an irritating and nauseating level, and the direction and dispersion of these products (the exhaust of multi-fuel engines) should minimize exhaust concentrations.

10. For maximum allowable concentration of gases, vapors, fumes, dusts, etc., the latest issue of Threshold Limit Values of the American Conference of Government Industrial Hygienists should be consulted.

Protection Against Chemical Warfare Agents

1. Fighting compartments with negative ventilation are highly vulnerable to attack by chemical warfare agents since toxic gases released outside the fighting compartment are immediately drawn inside. There are numerous points of entrance, and there is no possibility, therefore, of removing the gases from the air before it enters.

2. So far as it is possible to protect fighting compartments from outside gas attack by proper ventilation, a positive-pressure system with a single inlet is recommended.

3. The rate of ventilation must be sufficiently high to insure rapid removal of the contamination and thus maintain the concentration-time exposure below the safe limit (consult Surgeon General for values).

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.

BLANK PAGE

Dust Concentrations

1. The dust concentrations to which armored personnel are exposed vary widely from imperceptible levels to dense clouds which may reduce visibility to almost zero.

2. Dust causes temporary eye and throat irritation and at times degrades performance and interferes with operations.

3. Filters should be capable of removing dust particles above five microns in diameter. Dust skirts are of great value in reducing the dust raised around a vehicle and should be provided.

4. The ventilation-system intake should be located in an area where the concentration of dust is minimum when the vehicle is moving.

5. Personnel protection by goggles and throw-away respirators should be provided for use where needed.

6. Table 13 provides a summary of dust concentrations to which armored personnel are exposed.

Mud and Water

Mud and water are analogous to dust in that the same aspects of design affect them. As with dust, it may be impractical to eliminate them as problems affecting comfort, but vehicle design should minimize the problem.

TABLE 13

Summary of Dust Concentrations to Which Armored Personnel are Exposed

Operations	Dust Concentrations Millions of particles per Cubic Foot
Minimum Activity	
Airborne dust from infantry camp; some from a road grader.	9.0
Motor pool of a medical battalion; slow traffic.	12.0
Bivouac area, Sunday afternoon, fresh breeze.	15.4
Div. Surg. tent, Hq., camp area.	21.0
Air base; planes taking off clean runway.	21.7
Motor pool; ambulance driving in loose sand.	22.5
Infantry training on regt. parade ground.	25.0
Ordnance unloading depot. Only three vehicles moving.	27.7
Army truck road. Dust raised by staff car.	27.7
Regimental area of cam; normal traffic.	29.0
Gas dump; no vehicular movement. Light to no breeze.	29.2
Repeated passage of 1/4-ton truck on tank trail.	29.2
Railhead with light traffic; no convoy movements.	31.0
Railhead with little traffic.	32.0
Hq., camp; light traffic, fresh breeze.	32.2
Ordnance unloading depot; heavy wind storm, no traffic.	34.5
Moderate Activity	
Infantry column; four companies ahead of sampler.	41.0
In convoy behind half-track.	41.2
Asst driver's seat; light tank midway of column of tanks (Co.)	42.7
Evacuation hospital area; sandy surface, fresh breeze.	44.2
Corner tank battalion motor pool; 16 tanks and 1 truck moved.	48.7
Entrance to railhead; almost continuous truck traffic.	51.0
Troops drilling -- no traffic.	51.7

TABLE 13 continued

Operations	Dust Concentrations Millions of particles per Cubic Foot
High Activity	
Maneuver road; dust raised by staff car.	75.0
Convoy of cargo trucks spaced 100 yards.	79.0
From 1/4-ton truck and wind-blown dust.	104.0
Deliberate dust disturbance by 1/4-ton truck.	113.0
Convoy of trucks and towed 75mm guns.	131.0
Repeated passage of 1/4-ton through pulverized silt bed.	160.0
Alongside moving tank column.	187.0
Inside tank following another 150 yards.	219.0
Convoy of trucks passing by.	250.0
Following 1/4-ton truck.	472.0
Thirty feet behind half-track; loose sand.	750.0
Extreme Activity (conditions deliberately fixed for maximum dustiness)	
Medium tank operating alone on dry driving range, 10 mph.	350.0
One tank trailing another, dry driving range, 10 mph.	700.0
End of column of five tanks, 10-15 mph.	250.0
Five tanks in wedge, sampled in a sixth center tank.	450.0
Midway of column of six light tanks, driving into wind.	1500.0

Summary	Average	Range
Minimum activity	25.0	9.0 to 35.0
Moderate activity	46.0	41.0 to 52.0
High activity	231.0	75.0 to 750.0
Extreme activity	620.0	350.0 to 1500.0

BLANK PAGE

ILLUMINATION

General

1. For efficient performance of the various tasks which vehicle fighting-compartment crews must perform, certain minimum amounts of light are required. Among the duties of the crew, map reading undoubtedly requires the highest level of illumination. The amount of light necessary for the location and identification of stowage items is the lowest.

2. For a given task the illumination required varies with conditions inside and outside the fighting compartment. In the daytime, for example, crew members are required to look out through the periscopes or other visual devices to drive the vehicle, spot the enemy, sight targets, etc. Alternately, they must manipulate controls, load weapons, clear machine guns, read maps and perform other tasks inside the fighting compartment. Thus, the crew members' eyes are exposed alternately to outside and inside light levels, which at times may differ as much as a thousandfold. When this difference in intensity is great, glare results from exposure to the outside illumination and time is required for the eyes to become adjusted to the lower light levels inside the fighting compartment. During this adjustment, visual efficiency is greatly reduced, with a corresponding reduction in ability to perform the task at hand.

3. The illumination of outside objects is not controllable -- the inside illumination of the vehicle fighting compartment is, and must be, sufficiently bright to permit performance of all of the necessary duties within the fighting compartment, but dim enough so as not to interfere with dark adaptation during night operations. A white light bright enough for map reading and other necessary duties will interfere with dark adaptation; and if dimmed down to where it will not interfere with dark adaptation, it is not sufficiently bright for the performance of these duties.

4. At night minimum illumination is required for efficient performance of the necessary tasks since there are no disturbing sources of outside light, and the eyes are adapted to low light levels. Furthermore, to preserve dark adaptation during night operations, illumination should be by red rather than white light. Red light and low levels of illumination at night have the added advantage of minimizing enemy detection of the vehicle by light leakage through periscopes and other apertures.

5. To provide a basis for designing the interior lighting system of a vehicle fighting compartment, the tasks of each member of the crew should be carefully appraised to determine how much illumination they require.

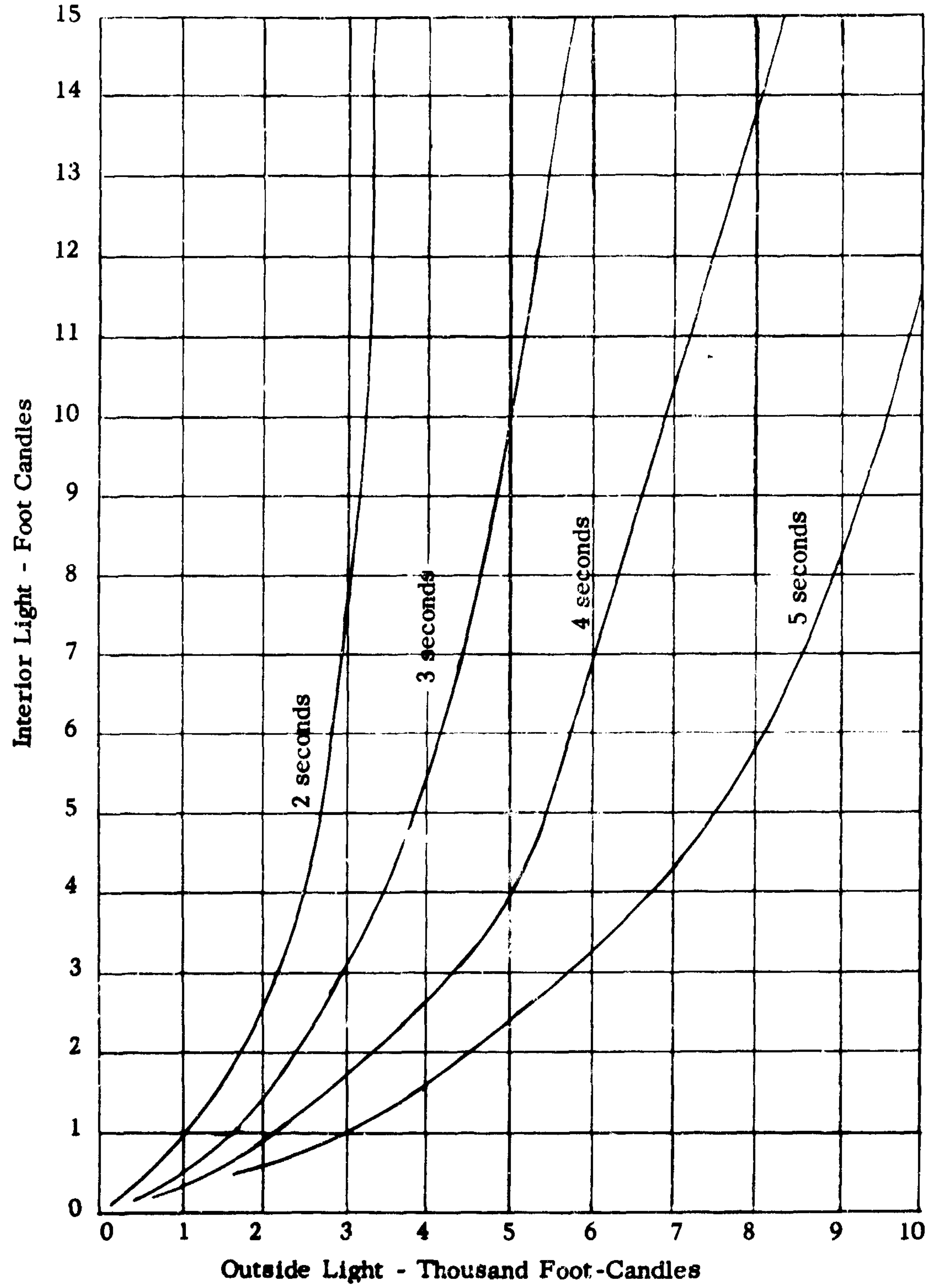


Fig. 31. GLARE RECOVERY TIME CURVES FOR MAP READING AFTER FIVE MINUTES EXPOSURE TO OUTSIDE LIGHT

6. Figure 31 shows various fixed levels of outside illumination in combination with different intensities of interior illumination representative of the practical ranges of lighting obtainable in vehicle fighting compartments. The outside illumination levels were selected to cover the range of daylight up to an extreme of 10,000 footcandles, which represents the illumination produced by bright sunshine on snow at high latitudes or white sand near the equator.

7. Following exposure to extreme glare (sunlight on sand or snow on a bright day), illumination of a higher order may be required for difficult tasks within the compartment. Where this requirement exists, auxiliary lighting should be provided for such difficult tasks as map and instrument-panel reading.

8. An empirical relationship between I_i, interior light level; I_o, outside illumination and t, recovery time, in seconds, may be expressed by the following equation:

$$I_i = 0.65e\left(\frac{2.9}{t^{1.41}} \times \frac{I_o - 600}{1000}\right)$$

9. Table 14 shows the levels of illumination required for efficient performance of various tasks in fighting compartments.

TABLE 14

Levels of Illumination for Efficient Performance of Various Tasks

	Night Operation (Red Light) Footcandles	Daylight Operation Footcandles
Map Reading	1	10
Clearing Machine Gun	.4	4
Operation of Controls	.3	4
Stowage	.002	.1

10. The illumination required for daylight operation (10 footcandles or less) in closed fighting compartments is considerably in excess of that necessary for night operation (1 footcandle or less), and red light offers no advantages under daylight conditions. The electrical energy required to produce red light of a given brightness is much more than that required for white light of equal brightness. Thus, a dual lighting system, supplying each crew position with white light for daylight operation and red light for night operation, with both controllable in intensity throughout the proper range, should be provided.

11. To perform their various tasks efficiently, personnel must have certain minimum amounts of light (Table 14).

Lighting Fixtures

Other factors which must be considered in selecting the number and location of fixtures are accessibility of the lights, convenient operation of switches and other controls, and the absence of glare from the fixture itself or indirectly in the form of reflection from periscope windows or other reflecting surfaces.

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 time required for 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 work by. Where both white light and dark adaptation are 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 red lighting). Colors often appear different under different types of illumination; so 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.

7. The following additional aids to night vision should be incorporated:

a. Lettering that must be read at low light intensities should be block-type white letters on a black background. (For height, width, and stroke-width dimensions see Labeling, pages 103 through 108.)

b. All knobs, controls, etc., should be painted white.

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

d. Maps designed for use under red illumination should be used.

8. When white light must be used for seeing, minimum interference with adaptation is produced by brief exposure of the lowest intensity possible.

BLANK PAGE

Brightness Ratios

The brightness ratios between lightest and darkest areas and/or between task and surroundings should be no greater than specified in Table 15.

TABLE 15

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 surroundings.
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 also 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 reflect it without diffusion.

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.

NOISE

General

1. Advancing technology has given Army equipment greater power and increase 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 communitions, 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 yound 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. 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 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 32.

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.

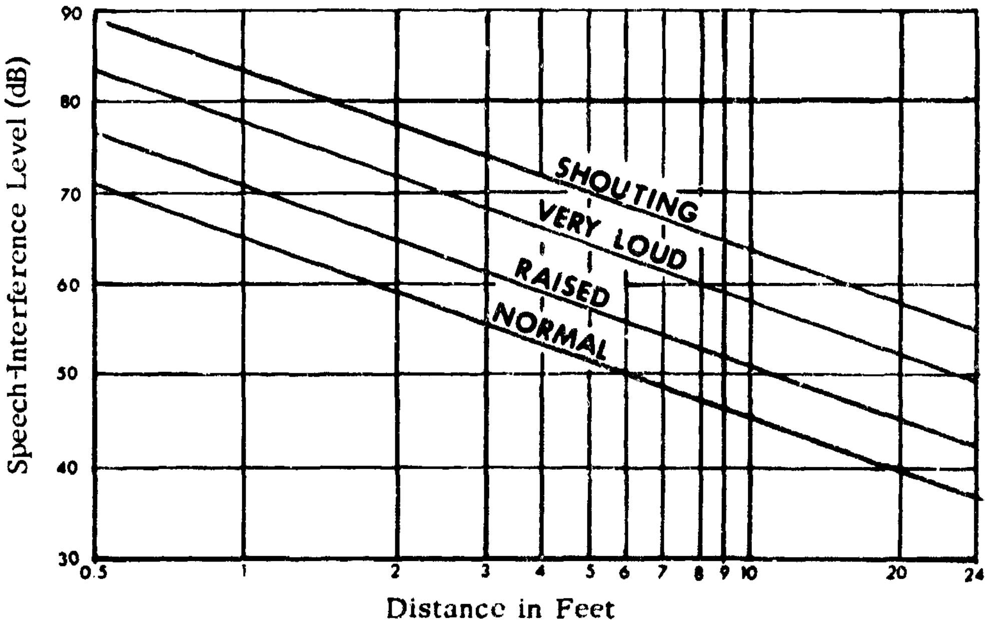


Fig. 32. PERSON-TO-PERSON COMMUNICATIONS

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 environments of both speaker and listener, which have 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 s sound is a high-frequency sound, whereas the vowel o is a low-frequency sound.

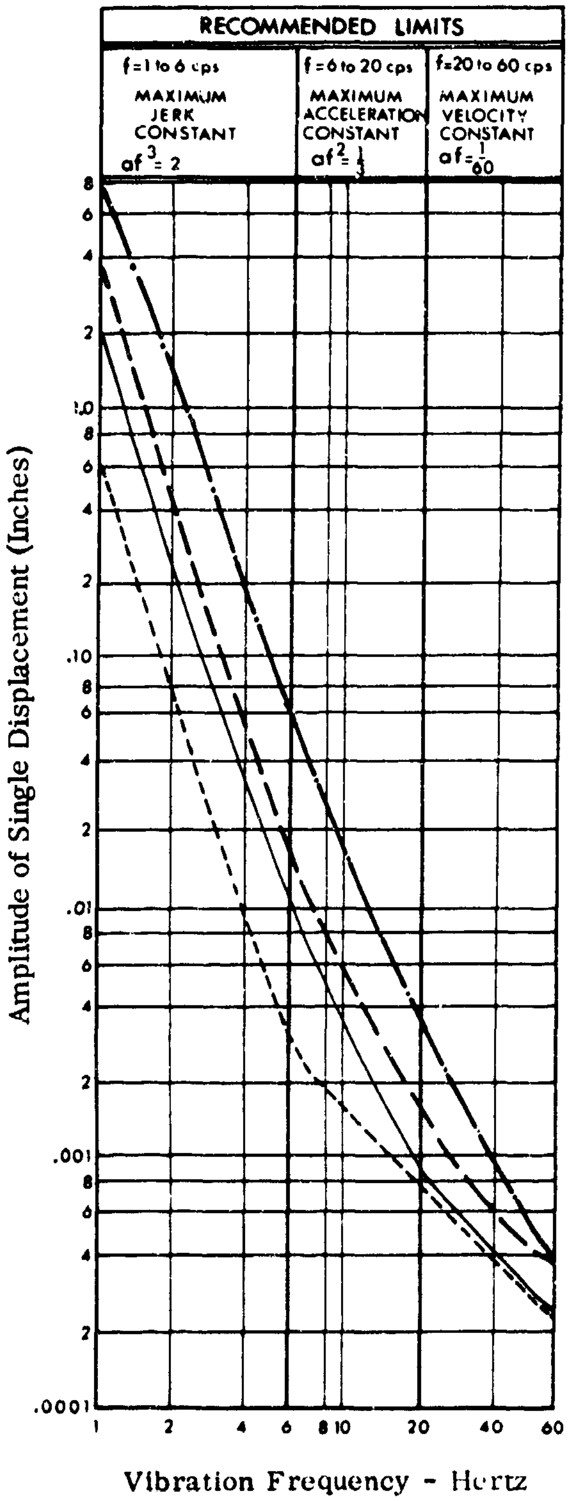
7. To measure how a noisy environment affects intelligibility, trained talkers and listeners should speak phonetically balanced word lists in accordance with the provisions and word lists established by the American Standards Association.*

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. Also, 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.

* 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, New York 10016.



DEFINITIONS

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

f = Frequency of vibration (Hertz)

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

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

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

LEGEND

Most Sensitive Reactions

- - - - - - - Strongly Noticeable

———————— Recommended Limit

— — — — Uncomfortable

——·——·—— Extremely Uncomfortable

Fig. 33. HUMAN REACTION TO VERTICAL VIBRATIONS

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 33 wherever possible.

c. Always kept below the "uncomfortable" to "extremely uncomfortable" range of Figure 33.

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.

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 consistently 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 system's performance.

d. Find out which tools and test equipment already 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. Using modular or unit packaging and, where feasible, throw-away units.

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

c. Providing easy access to check or service the materiel.

d. Designing equipment that can be serviced where it is 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 materiel must often be maintained on ground covered with deep mud or snow, in extreme temperatures, and in tactical blackouts at night, designing so components can be maintained 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, design them 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 types of wrenches and the torques required. Allow clearance for box wrenches if common hand tools are used at torques of 50 foot-pounds 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, 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. Protect 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.

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, design them 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 types of wrenches and the torques required. Allow clearance for box wrenches if common hand tools are used at torques of 50 foot-pounds 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, 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. Protect 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 units.

b. Using hinged or removable chassis.

c. Designing major units and assemblies, particularly engines, turbines, etc., with removable housings so they can be inspected completely.

d. Correlating the access design of units placed close to each other so that access to one does not interfere with access to another.

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.

7. Where accesses are unavoidably located over dangerous mechanical or electrical components, the access door should be designed so that when opened, it turns on an internal light and provides a highly visible warning label on the door.

8. Safety interlocks should be provided on accesses leading to equipment with high voltages. If the equipment circuit must be "on" during maintenance, a cheater switch should be provided that automatically resets when the access is closed.

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 (Tables 16 and 17; Figs. 34-36) 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. 35):

a. When structural, environmental, operational, and safety conditions permit, equipment should be left exposed for maintenance -- especially test and service points, maintenance displays and controls, and rack-mounted "black boxes."

b. Items can be semi-exposed with:

(1) Quick-opening hoods or covers.

(2) Easily and quickly removable dust covers and cases.

(3) Pull-out racks.

c. 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 accesses should be evaluated by their covers and fasteners.

e. 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.

TABLE 16

Minimal One-Hand Access Openings

	Width	Height	or	Diameter
(A) Empty hand to wrist:				
Bare hand, rolled:	3.75"	3.75"		3.75"
Bare hand, flat:	2.25"	4.0"		4.0"
Glove:	4.0"	6.0"		6.0"
Mitten:	5.0"	6.5"		6.5"
(B) Clenched hand to wrist:				
Bare hand:	3.5"	5.0"		5.0"
Glove:	4.5"	6.0"		6.0"
Mitten:	7.0"	8.5"		8.5"
(C) Hand plus 1" dia. object to wrist:				
Bare hand:	3.75"	3.75"		3.75"
Glove:	6.0"	6.0"		6.0"
Mitten:	7.0"	7.0"		7.0"
(D) Hand plus object over 1" in dia. to wrist:				
Bare hand:	1.75" clearance around object.			
Glove:	2.5" clearance around object.			
Mitten:	3.5" clearance around object.			
(E) 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.			
(F) 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 TO FIRST JOINT:				
(G) Push button access:	Bare hand:	1.25" dia.		
	Gloved hand:	1.5" dia.		
(H) Two finger twist access:	Bare hand:	2.0" dia.		
	Gloved hand:	2.5" dia.		
(I) Vacuum tube insert:	Miniature tube:	2.0" dia.		
	Large tube:	4.0" dia.		

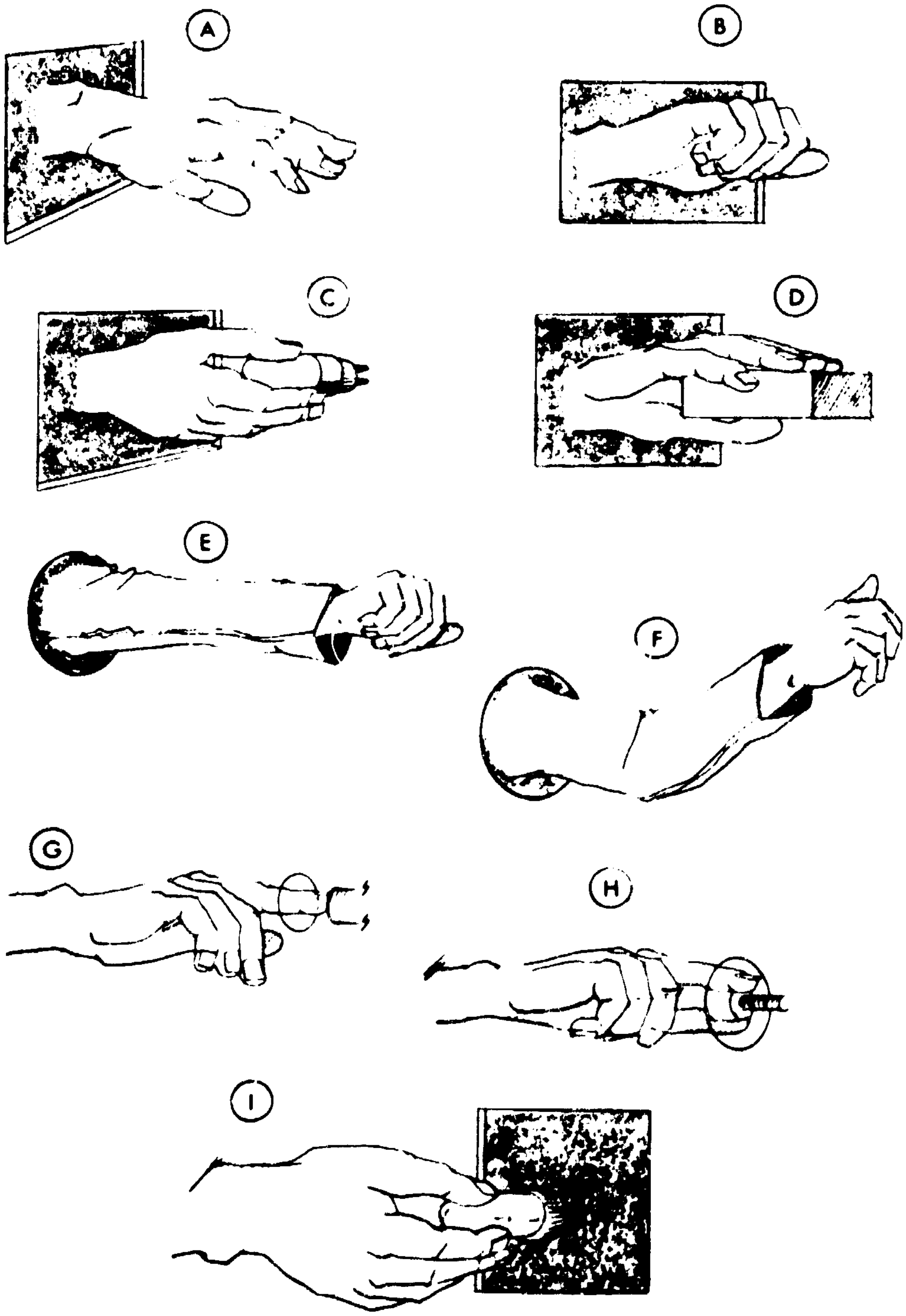


Fig. 34. ONE-HAND ACCESS OPENINGS

TABLE 17

Minimal Two-Hand Access Openings

	Width	Height
(A) Reaching with both hands to depth of 6 to 25 inches		
Light clothing	8" or 3/4 depth of reach[a]	5"
Arctic clothing	6" plus 3/4 depth of reach	7"
(B) Reaching full arm's length (to shoulders) with both arms	19 1/2"	4"
(C) Inserting box grasped by handles on the front	1/2" clearance around box, assuming adequate clearance around handles.	
(D) Inserting box with hands on the sides		
Light clothing	Box plus 4 1/2"	5" or 1/2" around box[a]
Arctic clothing	Box plus 7"	8.5" or 1/2" around box[a]

[a] Whichever is larger.

NOTE: If hands will curl around bottom of box allow an additional 1 1/2" in height for light clothing; 3" for arctic clothing.

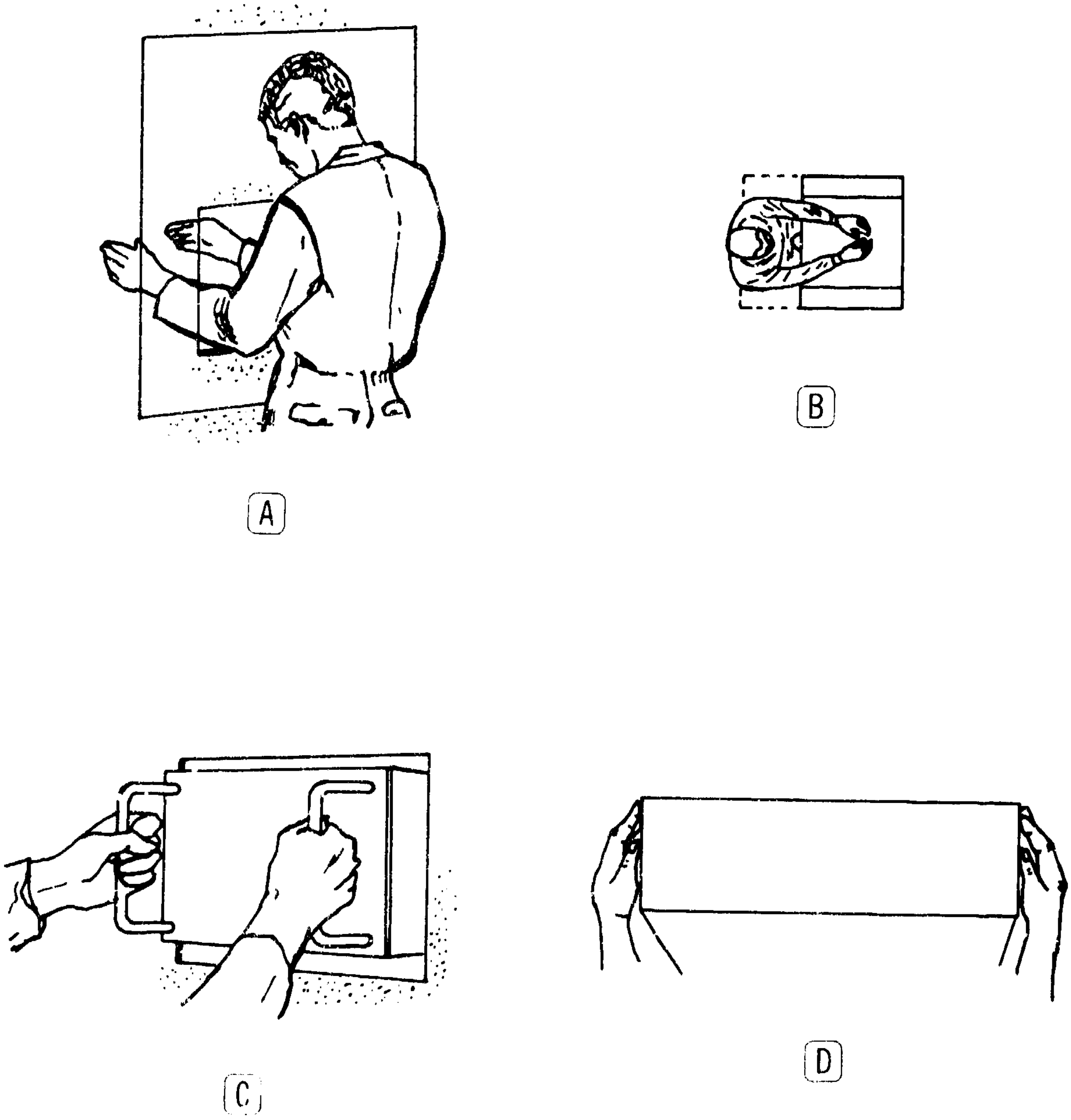
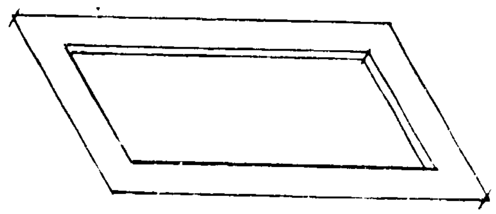
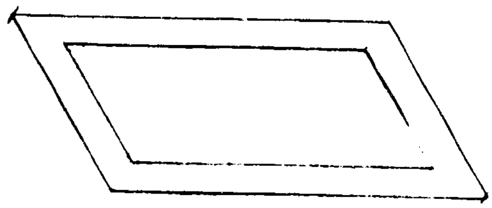


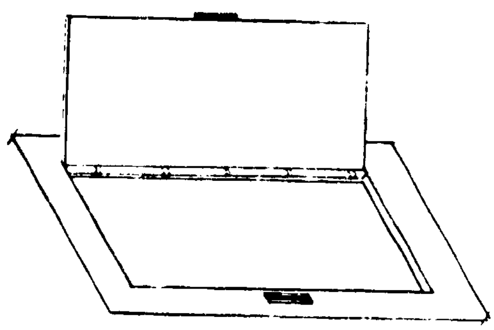
Fig. 35. TWO-HAND ACCESS OPENINGS



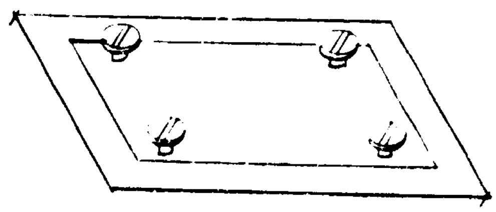
BEST -- NO COVER
(Use whenever possible.)



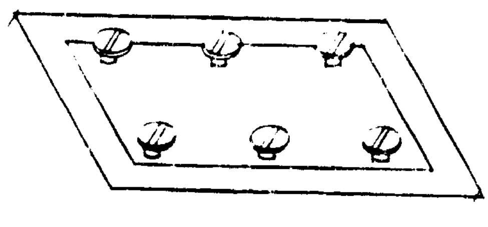
PERMANENT GLASS OR PLASTIC COVER
(Use where only visual inspection is required.)



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. 36. COVERS AND ACCESSES

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.

Location of Accesses

Accesses should be located:

a. Only on equipment faces that will be accessible in normal installation.

b. To permit direct access and maximum convenience for job procedures.

c. On the same face of the equipment as the related displays, controls, test points, cables, etc.

d. Away from high voltages or dangerous moving parts. (Provide adequate insulation, shielding, etc., around such parts to prevent injury to personnel when accesses must be located near hazards.)

e. So that heavy items can be pulled out rather than lifted out.

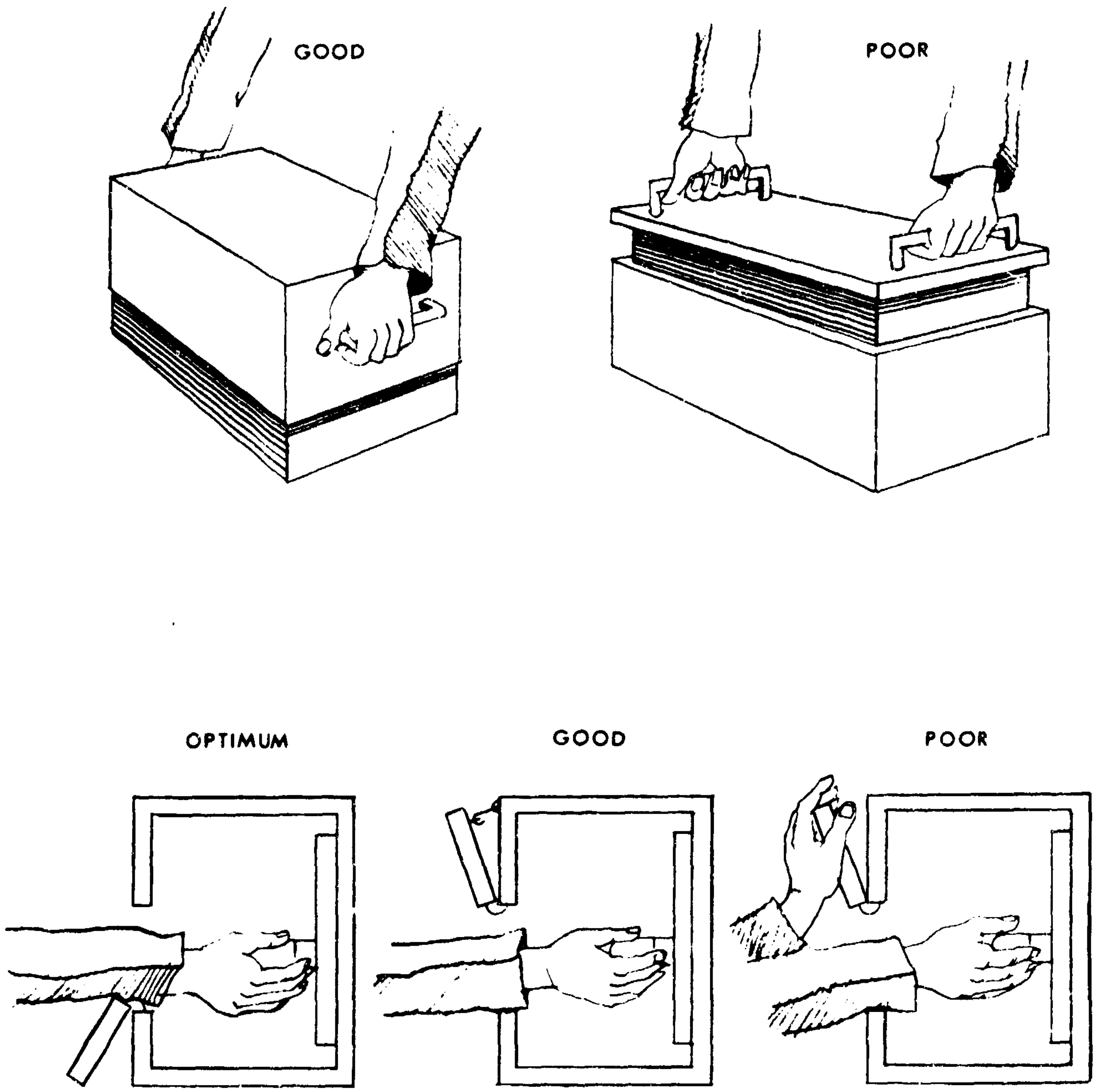


Fig. 37. COVERS AND CASES: DESIGN EXAMPLES

Covers and Cases

1. Covers, cases, and shields should be provided as necessary:

a. To divide enclosures into sections which are cleaned by different methods.

b. To keep personnel from touching dangerous electrical or mechanical parts.

c. To protect delicate or sensitive equipment so it will not be damged by movements of personnel, shifting cargo and loose objects, or by installing and maintaining nearby assemblies.

2. Covers, cases, and shields should also be designed for fast, easy maintenance (Figs. 36 and 37). 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:

a. Be as light in weight as possible, but whatever size is necessary for the degree of enclosure and the accessibility required.

b. Be openable, removable, and transportable by one hand, by one man, or by two men (in that order of preference).

c. Have handles or tool grips provided if it is heavy, difficult to open or difficult to handle.

d. Have lifting eyes, and plans for wrecker/crane handling if its weight is greater than 150 pounds.

e. Provide enough clearance around enclosed components to prevent damage and avoid requiring extremely fine or careful positioning and handling.

f. Be 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 and accessibility, and for 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 213).

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 in 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. 37).

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 protect delicate or sensitive components from damage when the case is moved.

d. There is access to frequently used adjustment, test, or service points without removing the case 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 (Figs. 36 and 37):

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. 36).

(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 so doors will not swing 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, door, 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

(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.

e. Removable stress panels or stress sections require a great many fasteners to meet operational requirements. Captive, quick-release fasteners should be used if they can satisfy the system requirements.

Mounting and Arranging

1. The majority of parts, items, and assemblies can be located and arranged in a variety of ways and places. The final arrangement should be based upon the following factors for ease of maintenance and training:

a. Accessibility preferences.

b. Standardization considerations.

c. Reliability figures and factors, as a basis for 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 with particular reference to:

(1) Item size, weight, and clearance requirements.

(2) Item fragility or sensitivity and resultant protection needs.

(3) Item servicing, adjusting or repair needs and procedures.

(4) Clearance requirements for removing and replacing each item.

(5) Tool access and clearance requirements for each item fastener, connector, test or service point, etc.

(6) Specific factors such as critical lead length, weight balance, heat dissipation, etc., which may hinder personnel in carrying out their tasks.

2. In laying out and arranging components, subassemblies or assemblies, the designer should maximally facilitate the required or expected maintenance operations by:

a. Minimizing the technician's place-to-place movement during servicing, checkout or troubleshooting.

b. Minimizing the technician's need to retrace his movements or steps during servicing, checkout or troubleshooting.

c. Minimizing the number of component or item inputs and outputs.

d. Arranging the equipment so the technician has the option of replacing either an individual item of a group or the whole group, in accordance with the maintenance philosophy.

e. Providing new fastener or bracket assemblies on spare components where the old ones are likely to be lost or damaged.

f. Avoiding undue assembly that disassembled sequentially for maintenance.

g. Using sliding racks, or hinged assemblies, to allow maximum accessibility. (Limit stops should be provided on rollout racks and drawers, but the design should permit convenient overriding of stops to remove a drawer.)

h. Organizing the layout according to maintenance specialties, so that maintenance performed by one specialist does not require removing or handling equipment maintained by another specialist -- particularly where such equipment is of a critical nature or its maintenance requires highly specialized skills.

3. Parts, subassemblies, assemblies, etc., should be mounted so that:

a. The manner of mounting satisfies accessibility.

b. Fasteners satisfy preferences and requirements under "Fasteners" (page 213).

4. Mounting fixtures, brackets, etc., should be designed so:

a. Only interconnecting wire and structural members are permanently attached to units (all other fixtures should be removable for ease of maintenance).

b. Fixtures which are built in to the chassis are either strong enough to withstand usage by personnel over the life of the system or are removable.

c. Mounting is compatible with the size and weight of the part, to prevent lead breakage or similar damage when personnel become fatigued.

d. They are thick and rounded enough to produce no sharp edges.

e. They are twist-to-lock or push-to-lock mounting type for small components; such brackets should be designed so:

(1) Locking studs are visible when the component is in place.

(2) Locking screws or dimples are provided as necessary to ensure security of the mount.

(NOTE: Hinged bars are useful for tieing down and permitting access to a number of small components at one time.)

5. Supports, guides, and guide pins should be provided as necessary to assist handling, aligning, and positioning units.

a. Bottom-mounted aligning pins should be used for components which are light enough to be lifted and positioned easily -- e.g., weigh less than 20 pounds for ease of operator handling.

b. Bottom-mounted aligning pins should not be used for heavy components.

c. Side-aligning devices or brackets should be used for heavy components, so that the component can be slid rather than lifted into and out of place.

6. Shock mounts should be used, as necessary, to:

a. Eliminate vibrational fluctuations in displays, markings, etc., to prevent operator errors in reading, as well as to protect fragile or vibration-sensitive components and instruments.

b. Control sources of high or dangerous noise and vibration that may degrade human performance.

7. Where blind mounting is required, the inaccessible side should be secured with mounts which:

a. Allow exceptionally easy mating.

b. Do not require access to friction lugs, tongue and groove fittings, etc.

8. Mounting of components, modules and parts should be designed to prevent their being inadvertently reversed, mismated or misaligned during installation or replacement.

9. While components of the same form, function and value should be completely interchangeable throughout the system, components of the same or similar form, but of different functional properties, should be:

a. Mounted in the same way throughout the unit.

b. Readily identifiable, distinguishable, and not physically interchangeable.

10. The rapidity, accuracy, and ease of maintenance, particularly trouble-shooting, are proportional to the amount of color coding, marking and labeling employed. These devices are the most direct links between the designer and repairman, and should be used as fully as possible to explain arrangement, functions, and relationships among items. There are no hard and fast rules for coding and labeling as a function of, or part of, arranging; how effective such efforts are depends largely upon the care and ingenuity of the designer. The following are useful guides and should be considered so that codes and labels used on and within equipment packages will be:

a. In accordance with the principles for coding and labeling.

b. In keeping with test-point and service-point coding and labeling.

c. Consistently and unambiguously used through the system.

d. Of such nature as to be easily read and interpreted.

e. Durable enough to withstand expected wear and environmental conditions.

f. Coordinated and compatible with:

(1) Codes and labels on related test and service equipment.

(2) Other coding and labeling within the system.

(3) Related job aids, instructions, handbooks and manuals.

11. For identification purposes, codes and labels should be provided on and within the arrangement as necessary to:

a. Outline and identify functional groups of equipment.

b. Identify each item or part by name or common symbol.

c. Identify each test or service point, and the sequence in which it is used.

d. Identify the value and tolerance of parts such as resistors (this identification should be direct rather than in color code where possible).

e. Indicate the direction of current or fluid flow to aid systematic elimination of possibilities when troubleshooting without continuous cross-reference to schematics.

f. Provide "maintenance highways" to guide the technician through routine processes.

g. Indicate the weight of units over 45 pounds.

h. Point out Warning and Caution areas.

i. Provide an outline procedure not made obvious by design, and to supply whatever information is necessary for troubleshooting and maintenance.

j. Provide for the presentation or recording of historical data where practical, particularly to:

(1) Display periodic readings at test points to reveal developing trends where these are fundamental to maintenance decisions.

(2) Record replacement dates or other data necessary for replenishment or preventive maintenance.

12. Assemblies, modules, parts, etc., should be arranged and mounted so that:

a. Adequate tool access and wrenching space is provided around fasteners.

b. Adequate space is provided for test probes and other service or test equipment.

c. Components to be serviced or repaired in position are at the most favorable working level, i.e., between hip and shoulder height.

d. Maintenance required on a given unit or component can be performed:

(1) With the unit or component in place, where possible.

(2) Without disconnecting, disassembling, or removing other items.

e. All replaceable items, particularly disposable modules, 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 more devious course.

f. 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 prevent access to other removable items.

(3) Are mounted on sliding drawers, racks, etc., wherever practicable. (Note: See item 2g, page 191.)

g. When it is necessary to place one unit behind or under another, the unit requiring more frequent maintenance is more accessible.

h. All chassis are completely removable from the enclosure with minimum effort and disassembly.

i. Structural members of items, chassis or enclosures do not prevent access to removable items, their connectors or fasteners.

j. Removal and replacement require as few tools and equipment as possible, and only common hand tools where practicable.

k. The unit can be removed and replaced by one man, two men, or handling equipment, in that order of preference.

l. Irregular, fragile or awkward extensions such as cables, hoses, etc., are easily removable before the unit is handled (such protrusions are easily damaged by personnel and make handling difficult).

m. Handling and carrying can be done efficiently by one man, meaning that:

(1) Removable items should weigh less than 45 pounds.

(2) Difficult to reach items should weigh less than 25 pounds.

n. Items over 45 pounds are designed for two-man handling.

o. Hoist lugs are provided for assemblies over 90 pounds.

13. The design, arrangement and mounting of components, units, parts, etc., should provide the maximum protection against injury to personnel or damage to the items.

14. Items should be located, arranged, mounted, and shielded so that technicians can reach them, adjacent items or associated fasteners without danger from electrical charge, heat, sharp edges or points, moving parts, chemical contamination or other hazards. Specifically, design, arranging and mounting should be such that:

a. Commonly worked on parts, fasteners, service or test points, etc., are not located near exposed terminals or moving parts that might injure personnel.

b. Guards or shields are provided to prevent personnel from coming into contact with dangerous moving parts or injury potentials.

c. Ventilation holes in equipment are located and made small enough to prevent insertion of fingers, tools, etc., into hazardous areas (e.g., 1/4" diameter holes will exclude fingers).

d. Tool guides are provided to allow safe manipulation of points adjacent to high voltages or other hazards.

e. Capacitors, exhaust pipes or other parts which retain heat or electrical potential after the equipment is turned off are located or shielded so personnel cannot contact them accidentally.

15. Adjustment and alignment devices should be mounted so they cannot be inadvertently actuated by the technician.

16. Small removable pins, caps, covers, etc., should be attached to prevent loss or damage.

17. Vital, fragile, sensitive, or easily damaged components should be located, arranged, and shielded 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. To make testing and servicing as simple as possible, the recommendations of this section should be considered by the designer.

2. Distinctively different connectors or fittings should be provided for each type of test or service equipment, probe, grease, oil, etc., to minimize the likelihood of error or misuse in their application.

3. Requirements for separate funnels, strainers, adaptors and other accessories should be avoided. Where practical, these should be built into the equipment or service equipment, so they need not be separately handled.

4. Test points should be combined, where feasible, into clusters for multipronged connectors, particularly where similar clusters occur frequently.

5. Templates or overlays should be provided where they would expedite different test procedures which utilize the same set of test points.

6. The maximum use of color codes, guidelines, symbols and labels should be made to facilitate the following logical test routines among the test points.

7. Test points should be arranged in a test panel or other surface according to the following criteria, listed in order of priority:

a. The type of test equipment used at each point.

b. The type of connector used and the clearance it requires.

c. The function to which each point is related.

d. The test routines in which each point will be used.

e. The order in which each point will be used.

8. When sequential testing is required, test points should be grouped in a line or matrix reflecting the sequence of tests to be made.

9. Lubrication points should be provided to avoid disassembly of equipment; but is such points are not feasible, easy access should be provided for direct lubrication.

10. For the operator to best utilize the test and service points on equipment, they should be provided, designed, and located as follows:

a. According to how often they are used and the time required to use them.

b. So that there will be a minimum of disassembly or removal of other equipments or items to reach them.

c. On surfaces or behind accesses which may be easily reached or readily operated when the equipment is fully assembled and installed.

d. To be clearly distinguishable from each other, where necessary by color coding and labeling.

e. So that test points and their associated labels and controls face the technician.

f. So that adequate clearance is provided between connectors, probes, controls, etc., for easy grasping and manipulation. The following minimum clearances are recommended:

(1) 0.75" when only finger control is required.

(2) 3.0" when the gloved hand must be used.

g. So they offer positive indication, by calibration, labeling or other features of the direction, degree and effect of the adjustment.

h. With guards and shields to protect personnel and test or service apparatus, particularly if the equipment must be serviced while running.

i. At a central panel or location, or at a series of functionally autonomous panels and locations.

j. To avoid locating a single test or service point in an isolated position where it is most likely to be overlooked or neglected.

k. With lead tubes, wires, or extended fittings to bring hard-to-reach test and service points to an accessible area.

l. To make units with critical lead lengths and similar constraints as accessible as possible.

m. With windows to internal items requiring frequent visual inspections, e.g., gauges, indicators, etc.

n. With tool guides and other design features to facilitate the use of test or service points which require blind operation.

o. Within easy functional reaching or seeing distance of related or corresponding controls, displays, fittings, switches, etc.

p. Away from dangerous electrical, mechanical or other hazards (a hand's width (4.5") separation should be provided from the nearest hazard, and guards and shields should be provided as necessary to prevent injury).

q. So they are not concealed or obstructed by the hull, turret, brackets, other units, etc., to eliminate the need to disassemble, remove, or support other units, wires, etc., for testing, servicing, or troubleshooting.

r. With signal and tolerance limits at the test points, provided no classified information is revealed that might compromise equipment performance.

11. Where adjustment controls are associated with test and service points, they should be designed and positioned so that:

a. They are located on a single panel or face of the equipment, or on a minimum number of functionally independent panels.

b. They are capable of being quickly returned to the original settings, to minimize realignment time if they are inadvertently moved.

c. Those that require sequential adjustment are loacted in the proper sequence and marked as necessary to designate the order of adjustment.

d. Adjustments are independent of each other whenever possible.

e. Adjustment procedures are clear and straightforward, and do not require conversion or transformation of related test values.

f. Knobs are used in preference to screwdriver adjustments, which require a tool and are generally unsatisfactory for easy manipulation.

g. Adjustability is avoided whenever the part values will not change during the life of the equipment or when an adjustment out of tolerance will not affect the system in any manner.

12. The following types of adjustment are to be avoided except where they will considerably simplify the design or use of the equipment:

a. Extremely sensitive adjustments.

b. "System adjustments" (e.g., a component or system should be designed to that components can be replaced without having to harmonize or recalibrate the whole system).

c. Harmonizing or "mop-up" adjustments (e.g., those that require A or B to be readjusted after A, B, and C have been adjusted in sequence).

Test Equipment

1. The purpose of the tester should be indicated on the outer surface of the equipment.

2. The instructions for using test equipment should be written in a step-by-step format.

3. Storage space for test equipment instructions should be provided on or within the test equipment (i.e., on the face of the test equipment, in a lid, or in a special compartment).

4. A signal should be provided on test equipment to indicate when it is warmed up.

5. A simple check should be provided to indicate when the equipment is out of calibration or is otherwise not functioning properly.

6. Exact values should be presented on test equipment displays, rather than indications which require multiplication or other transformation of display values.

7. Whenever more than one scale must be in the technician's view, they should be clearly differentiated by labeling and color coding to their respective control positions.

8. Selector switches should be used on test equipment instead of a number of plug-in connections.

9. Devices like circuit breakers and fuses should safeguard against damage if the wrong switch or jack position is used.

10. Written warnings should be provided on the tester to insure that the test equipment will be turned off when testing is completed.

11. A label should be provided on accessories associated with the test equipment that the technician must use.

12. Adequate stowage space should be provided in the lid or cover of test equipment for storage of all removable items such as leads and adaptors.

13. Fasteners or holders should be provided in storage compartments for test equipment accessories.

14. Portable test equipment should be shaped for convenient storage and handling.

15. Handles on the outside case of portable test equipment should be recessed or hinged to conserve storage space.

16. For ease of handling and utilization by the technician, test equipment should not be bulky or overweight. The following principles should be considered by the designer:

a. Stands or casters should be provided for devices over 30 pounds.

b. Wheels, casters or hoist-lifting should be provided for devices over 90 pounds.

c. Devices should be of rectangular shape, so they can be easily stored.

17. Handles should be provided which:

a. Are in accordance with "Handles" (page 26).

b. Allow the device to be easily handled and carried.

c. Are recessed or hinged for folding to reduce storage space.

d. Are shaped to fit the hand to ensure a secure grip.

e. Are plastic coated when equipment is normally exposed to the environment.

18. Hooks or other devices should be provided on the tester or on the prime equipment to attach the test equipment to it.

19. The weight and dimensions of portable test equipment should not exceed the following limits:

Dimensions	Hand-Held	One-man	Two-men
Weight (lbs)	5	45	90
Height	4"	18"	18"
Length	10"	18"	(Limited by work area)
Width	5"	10"	20"

20. Test probes should have tips designed to ensure proper contact with test points.

21. Test equipment should be designed and packaged to be fail-safe to preclude damage to the prime and tested equipment if the test equipment should malfunction.

Connectors

1. Connectors should be designed or selected, standardized and mounted with the following considerations of maintenance and safety in mind:

a. To make maintenance operations as quick and as easy as possible.

b. To facilitate removing and replacing components and parts.

c. To reduce "set-up time" of test and service equipment to a minimum.

d. To minimize the dangers to personnel and equipment from pressures, contents or voltages of lines when the connectors are released.

e. To provide for operation by hand wherever possible and, where it is not possible, by common hand tools.

f. To minimize the likelihood of mismating, cross connecting or similar errors in installation or maintenance. There are several ways of preventing such errors:

(1) Providing different sizes or types of connectors (Fig. 23, page 96).

(2) Arranging lines so the distances from the connectors to their correct attachment points prevents mismating.

(3) Arranging lines or providing separation blocks or other mounts so the sequence of leads is obvious.

(4) Polarizing or using different sizes of prongs and prong receptacles (a particularly useful way of preventing mismating between lines of differing voltages).

(5) Using different and mutually incompatible and irreversible arrangements of guide pins, keys, or prongs.

(6) Color coding or labeling connectors and their receptacles to minimize confusion and make mismating unlikely.

g. To provide visibly different and physically non-interchangeable connectors for lines that differ in content -- different voltages, different oils, etc.

2. Connectors should be located according to the following considerations:

a. To make them accessible with as little need as necessary to disassemble or remove other equipment or items.

b. To plan their accessibility according to how often they must be operated or checked.

c. To put them within easy reach for connection or disconnection.

d. To make them easily visible so the operator can start threads or pins without damaging the connectors.

e. To minimize spillage or leakage and, where it occurs, to make sure it will not damage equipment or endanger personnel.

f. To space connectors far enough apart from each other and from other obstructions so the operator can grasp them firmly for connecting and disconnecting. In general, the designer should apply these minimum separations:

(1) 0.75 inch -- for bare fingers.

(2) 1.25 inches -- for bare hand or gloved fingers.

(3) 3.00 inches -- for gloved or mittened hand.

(4) As required -- for tool clearances.

g. To minimize danger to personnel and equipment from pressures, contents, or voltages of lines when connectors are released or handled.

h. To prevent damage to connectors, connector parts and contacts:

(1) From movements of personnel, shifting objects, opening doors, etc.

(2) From excessive tightening or man-handling during operation.

(3) From short circuits, arcing to foreign objects, erroneous connection, or handling after disconnection.

3. Connectors should be protected:

a. By recessing receptacles.

b. By recessing delicate connector parts (pins, keys, etc.) within the connector.

c. By providing protective caps, inserts, covers, cases, or shields.

4. Connectors and associated parts and wiring should be coded and labeled as necessary:

a. To facilitate reference to them in job instructions.

b. To identify replaceable items and parts for reordering.

c. To expedite and facilitate maintenance and troubleshooting.

d. To reflect operating or test sequences.

e. To maintain continuity of reference throughout the system.

f. To provide adequate warnings or cautions relevant to connector operations.

g. To identify each plug clearly with its receptacle.

h. To identify each wire clearly with its terminal post or pin.

i. To identify each test point clearly by a unique mark or symbol.

j. To distinguish clearly among non-interchangeable connectors.

k. To make the manner of connection or disconnection clear.

l. To orient plugs and receptacles (by painted strips, arrows or other indicators) so pins are aligned for proper insertion.

m. To mark terminal strips and circuit boards permanently to identify individual terminals and to facilitate replacement of the connectors.

n. To prevent injury to personnel or damage to equipment by clearly labeling power receptacles for primary, secondary, or utility systems.

5. Connector codes and labels should be located as necessary:

a. To make them as visible as possible under operational maintenance conditions.

b. To make them visible in both the connected and disconnected conditions -- especially so connectors can be identified without having to be disconnected.

c. To keep their position consistent in relation to their associated pins, terminals, receptacles, etc.

d. Where space is not available for complete labels, to provide simple symbols and to explain those symbols on a nearby plate or in the job instructions.

e. To place codes and labels according to the following order of preference:

(1) Directly on the connector and receptacle.

(2) On plates permanently fixed to the connector and receptacle.

(3) On tabs or tapes attached to the connector.

(4) For receptacles -- on the immediately adjacent surface, panel, or chassis.

(5) For recessed receptacles -- on or near the access opening.

Classification of Connectors

1. Quick-Disconnect Devices:

a. Quick-disconnect devices exist in a variety of forms and include any type of connector that can be released by snap action, by twisting up to a full turn, by triggering a latch or spring device or by removing an external pin. Quick-disconnect devices should be used for two types of connections:

(1) Items which must be disconnected or replaced frequently.

(2) Items which must be replaced within critical readiness times.

2. Threaded Connectors:

a. Threaded connectors provide very secure connection, particularly when locked into place by set screws, retainers or safety wires. Usually they require more time to operate, depending on the number of turns required and the types of tools required. Threaded connectors should meet the following criteria:

(1) Require the minimum number of turns consistent with holding requirements.

(2) Be operable by hand when used for electrical connection, and otherwise require only common hand tools.

(3) Be designed and arranged to reduce the danger of accidental loosening of other connectors while working on one.

Electrical Connectors

1. Insertion forces of electrical connectors should be kept low to minimize the possibility of damaging contact surfaces on connector parts.

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 the wrong way in its own receptacle.

c. Multi-contact plugs are used wherever possible, to reduce the number of plugs and the number of maintenance operations required.

d. Plugs "plug-in" or require no more than one complete turn to effect secure connection, especially for connection of 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, e.g., receptacles are "hot" and plugs are "cold" when disconnected.

g. Plugs are self-locking or use safety catches rather than require safety wiring.

3. Alignment keys or pins should be designed and located with the plug so that:

a. They extend beyond electrical pins to protect the pins from damage due to misalignment.

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 mismating requirements, orientation of the pins should differ in a consistent and systematic manner, for the technician's convenience.

4. Test points should be:

a. In plugs when such testing is required and other special test points have not been provided.

b. In adapters to be inserted between the plug and receptacle, if it is not feasible to provide test points in the plug and other adequate test points are unavailable.

c. Accessible in terms of clearances and relationship to the normal setting of the plug or adapter.

d. Coded and labeled to be clearly visible and identifiable in test procedures.

Fluid Connectors

1. Connectors for pipes, tubing, hoses, etc., should be located and installed so that:

a. Draining, filling or other maintenance involving the connectors can be accomplished without jacking up the equipment.

b. Leakage tests can be performed easily and without endangering the technician. Test should be planned so the technician does not have to insert his head into areas of extreme noise, vibration or other danger while the equipment is running.

2. Gaskets and seals used in connecting fluid or gas lines should be selected and installed to:

a. Be easily replaceable without removal of other connector parts or disassembly of other equipment.

b. Be identifiable with part numbers so they can be easily ordered and handled logistically. The job instructions should state the expected life of seals and gaskets and recommend when they should be changed.

3. Gaskets and seals should be partly visible externally after they are installed, to reduce the common failure to replace seals during assembly or repair.

Lines and Cables

1. Lines and cables should be selected, designed, bound, routed, and installed so the following tasks can be easily and quickly performed:

a. Troubleshooting, testing, checking, and isolating malfunctions.

b. Tracking, removing, repairing, and replacing.

c. Removing and replacing other items and components.

d. Connecting and disconnecting.

2. Lines and cables should be compatible with:

a. Connectors (page 201).

b. Fasteners (page 213).

c. Accesses (page 175).

d. The environmental extremes to which they will be subjected.

e. Maintenance routines in which they will be used.

3. Lines and cables should be standardized to minimize the number of:

a. Types and varieties.

b. Different lengths.

c. Related connectors, fittings, fixtures, and features.

4. Lines and cables should be routed and mounted so they are accessible:

a. The operator should be able to reach them with a minimum of disassembly or removal of other equipment or items.

b. They should be accessible particularly at points of connection, mounting, splicing, or testing.

c. Accesses and clearances should be provided for removing and replacing damaged lines and cables.

5. Lines and cables should be routed so personnel will not use them for handholds or footrests.

6. 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.

7. 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 to burn personnel (see Table 12, page 148).

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. To prevent accidents with an overhead mounting, use a spring clamp with a hinged-locking latch over the clamp's open side.

8. 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 tension 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.

9. Cables should be installed so foreign objects, flying stones, etc., will not damage them.

Fluid and Gas Lines

1. The possibility of mismating connectors during servicing or maintenance should be avoided by:

a. Standardizing fittings so lines that differ in content cannot be interchanged.

b. Coding lines by arrangement, size, shape, and color as necessary.

c. Using colored bands to identify all lines that carry fluids.

2. Lines should not spray or drain fluid on personnel or equipment when they are disconnected. This may be accomplished 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. Drainage problems should be prevented 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. Lines should be mounted and installed so that:

a. Rigid lines with fittings do not have to be backed-off before they can be disconnected.

b. Us 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. Adequate supports should be provided for lines from external service or test equipment, or where extensions will be attached for other purposes. These supports should withstand not only the initial pressure through the line and the weight of its external extensions, but also the rigors of handling and repeated connection and disconnection.

Electrical Wires and Cables

1. The layout and routing of wires should be made 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 204).

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. Electrical wires, harnesses, and cables should be mounted so they are accessible through raceways, conduits, junction boxes, etc.

4. Electrical wires and cables should be routed over, rather than under, pipes or fluid containers.

5. Wires and cables should be routed 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. Leads should be mounted 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."

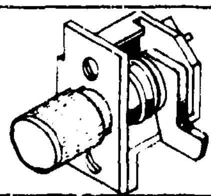
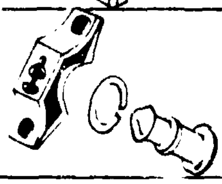
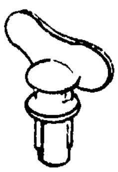
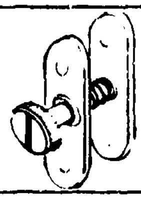
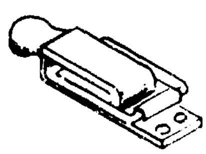
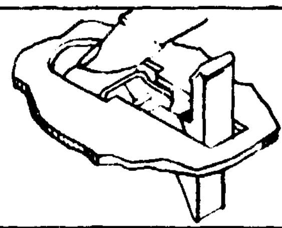
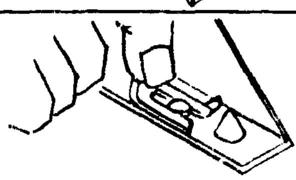
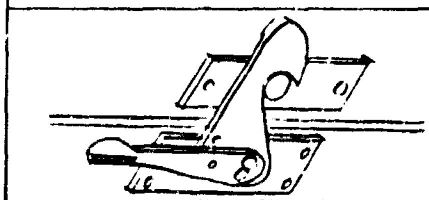
TYPE	DESCRIPTION
	Adjustable pawl fastener As knob is tightened the pawl moves along its shaft to pull back against the frame. 90° rotation locks, unlocks fastener.
	"Dzus"-type fastener with screwdriver slot Three-piece 1/4-turn fastener. Spring protects against vibration. 90° rotation locks, unlocks fastener.
	Wing head. "Dzus" type 90° rotation locks, unlocks fastener.
	Captive fastener with knurled, slotted head The threaded screw is made captive by a retaining washer.
	Draw hook latch Two-piece, spring latch, base unit and striker. Engagement loop is hooked over striker and lever is depressed, closing unit against force of springs. Lever is raised to unhook.
	Trigger action latch One-piece, bolt latch. Latch is opened by depressing a trigger to release bolt which swings 90° under spring action. 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. 38. FASTENER EXAMPLES

8. Extension cables should be used 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 without the possiblity of misuse or misconnection).

Fasteners

1. 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 according to durability, easy operation, speed, easy replacement, and other criteria following in this section.

2. Fasteners should be standardized 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.

3. The design, selection, or application of fasteners should take the following factors into consideration:

a. Work space, tool clearance, and wrenching space should be provided around the fastener.

b. The types of tools required for operating the fastener, as a function of fastener type, application and location.

c. How often the fasteners will be operated.

d. The time required for tasks involving operation of the fasteners.

4. The design should minimize the number of types and sizes of fasteners within the system by:

a. Using only a few basic types and sizes which can be readily distinguished from each other (Fig. 38).

b. Using the same type and size of fastener for all instances of a given application, e.g., all mounting bolts the same for a given type of item.

c. Making certain that screws, bolts, and nuts of different thread size are clearly different in physical size (otherwise they may be interchanged).

5. The design should minimize the number of tool types and sizes required to operate fasteners:

a. By avoiding requirements for special tools.

b. By selecting fasteners operated by hand or by common hand tools.

6. The replacement of stripped, worn or damaged fasteners should be considered in design. Fasteners (studs) which are part of the housing should be avoided.

7. Fastener mounting holes or other tolerances should be large enough to allow fasteners to be "started" without aligning them perfectly.

8. Hinges, catches, latches, and locks should be attached by bolts or screws, not by rivets.

9. Nuts and bolts, particularly those which are frequently operated or poorly accessible, should be mounted so they can be operated with one hand or one tool:

a. By providing recesses to hold either the nut or bolt.

b. By semi-permanently attaching either the nut or bolt.

c. By using double nuts on terminal boards and similar applications.

d. By using nut plates, gang-channeling or floating nuts.

10. A few fasteners should be used rather than many small ones, except where system requirements dictate otherwise.

11. Fasteners that are normally operated by hand should be durable enough that they can be turned with a wrench.

12. Fasteners should be located so that they:

a. Can be operated without prior removal of other parts or units.

b. Can be operated with minimum interference from other structures.

c. Do not interfere either with each other or with other components during release.

d. Do not constitute a hazard to personnel, wires or hoses.

e. Are surrounded by adequate hand or tool clearance for easy operation. The occasional need to use two hands or power tools to manipulate, breakway or remove stuck fasteners should be considered.

Types of Fasteners (in order of preference)

1. Quick Connect-Disconnect Devices are 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.

a. The following factors should be considered in selecting quick connect-disconnect fasteners:

(1) These fasteners should be used wherever possible when components must be dismantled or removed frequently.

(2) These fasteners must fasten and release easily without tools.

(3) They should fasten or unfasten with a single motion of the hand.

(4) It should be obvious when they are not correctly engaged.

(5) When there are many of these fasteners, misconnections should be prevented 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.

2. Latches and Catches are very fast and easy to use, do not require tools, have good holding power. They are especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required.

a. The following factors should be considered in selecting latches and catches:

(1) Use long-latch catches to minimize inadvertent releasing of the latch.

(2) Spring-load catches so they lock on contact, rather than require positive locking.

(3) If the latch has a handle, locate the latch release on or near the handle so it can be operated with one hand.

3. Captive Fasteners are slower and more difficult to use, depending upon type, and usually require common hand tools to release; but they stay in place, saving time that would otherwise be wasted handling and looking for bolts and screws and they can be operated with one hand.

a. The following factors should be considered in selecting captive fasteners:

(1) Use captive fasteners when "lost"screws, bolts, or nuts might cause a malfunction or excessive maintenance time.

(2) Use fasteners which can be operated by hand or with a common hand tool.

(3) Use fasteners which can be replaced easily if they are damaged.

(4) Make captive fasteners of the quarter-turn type self-locking and spring-loaded.

4. Regular Screws are round, square, or flat-head screws; take longer to use and are more likely to be lost, damaged, stripped or misapplied.

a. 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.

b. The following factors should be considered in selecting screws:

(1) Use screw heads with deep slots that will resist damage.

(2) Use screws only when personnel can use screwdrivers in a "straight-in" fashion; do not require personnel to use offset screwdrivers.

c. If personnel must drive screws blindly, provide a guide in the assembly to help keep the screwdriver positioned properly.

5. Bolts and Nuts 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.).

a. Keep bolts as short as possible, so they will not snag personnel or equipment.

b. Coarse threads are preferable to fine threads for low torques.

c. Avoid left-hand threads unless system requirements demand them; then identify both bolts and nuts clearly by marking, shape, or color.

d. Use wing nuts (preferably) or knurled nuts for low-torque applications, because they do not require tools.

6. Combination-Head Bolts and Screws are 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.

7. 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.

a. The following factors should be considered in selecting internal-wrenching fasteners:

(1) Minimize the number of different sizes to reduce the number of special tools needed; preferably, use only one size.

(2) Select fasteners with deep slots, to reduce the danger of damaged fasteners.

(3) Design so there will be a way to remove damaged internal-wrenching fasteners.

8. Rivets are permanent fasteners that are very hard and time-consuming to remove. They should not be used on any part which may require removal.

9. Cotter Keys should be used with the following considerations:

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.

10. Safety Wire should be used with the following considerations:

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.

11. Retainer Rings should be used with the following considerations:

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.

12. Retainer Chains should be used to keep hatches or doors from opening too far and springing their hinges; turn doors or covers into useful shelves for the technician; prevent small covers, plates or caps from being misplaced; secure small special tools where they will be used; or secure objects which might otherwise fall and injure personnel.

a. The selection of retainer chains should consider the following:

(1) Use link, sash or woven-mesh chains. Avoid bead-link chain, because it breaks more easily than other types.

(2) Attach chains with screws or bolts; attach them strongly and positively, but so they can be disconnected easily when required.

(3) Provide eyelets at both ends of the chain for attaching to the fasteners.

(4) Make sure chains are no longer then their function requires.

COMMUNICATIONS

General

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

   a. Electrically, using radio or telephone.

   b. Directly from operator to operator (face to face).

2. Electrically transmitted speech depends, to a great extent, on the characteristics of the microphone, transmission equipment and earphones; however, both direct and electrically transmitted voice communications have certain limitations in common. One of the limitations is the acoustical environment of both the speaker and listeners, and this factor is of great importance in determining communication effectiveness.

3. 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.

4. Most of the information carried in English speech is contained in consonants. Unfortunately consonants, which are in the high frequencies and contain little energy, are more readily masked than vowels. (For example, the s sound is a high-frequency sound whereas the vowel e is a low-frequency sound.)

5. Vowels produce more energy but transmit a very limited amount of intelligence.

6. Where the frequency band limits must be narrowed, the center of the frequency band should be retained near 1000 Hz.

Radio Set

1. The radio set should be located in an area of the vehicle that offers maximum protection from system operational damage or inadvertent crew damage.

2. The location of the set should not interfere with the normal range of movement of the crew or be a hazard to the crew.

3. The control panel of the radio set should be visible and readily accessible to the radio operator.

4. The operator should be able to reach the radio control panel to change frequency without dismantling any portion of the vehicle.

5. Where protective devices are provided within the equipment for primary and other circuits to protect the equipment from damge due to conditions such as overload and excessive heating, the operator should be able to check these devices visually.

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

7. Each component with exposed terminals in medium or high-voltage portions of a circuit should be protected from short circuit, grounding, or accidental contact by operating or maintenance personnel.

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

Radio Antenna

1. The location of radio antennas should minimize the possibility of RF burns to personnel.

2. On vehicle turrets with fully rotating machine-gun cupolas, antennas should be located so they will not be within the machine gun's field of fire.

3. Antennas and wave-guides should be at ground potential except for the energy to be radiated.

Control Box

1. All radio control boxes should be located to ease the operator's access to all controls.

2. Control boxes should be located where they will not interfere with the normal movements of personnel or present a hazard to them.

3. Control boxes should not be located where they could be used as a step or footrest.

4. Control boxes should be located in a position which routes the headset and microphone cables clear of any rotating or moving linkages.

5. Control-box location is limited by the effective operating length of the standard audio accessories used with radio-interphone equipment. The maximum distance that a control box should be installed from a crewman's normal working areas is 30 inches.

6. Where signal or warning lights are part of the control unit, the box should be located so that the signal warning is within the responsible crewman's narmal field of vision.

Audio Accessories

1. Stowage hooks should be provided in the general area of each crew member for storing audio accessories not in use.

2. Hooks should be located where they will be out of the normal path of movement of crew members.

Cable Routing

1. Interconnecting communication cables should be routed to minimize the possibility of their use as hand holds or steps. A protective guard should be placed over the cables where the possibility cannot be minimized.

2. All interconnecting cables should be routed neatly to eliminate droop and unnecessary loops in the cable. Cable clamps should be spaced approximately 12 inches apart.

SAFETY

General Principles of Human Behavior and Safety

1. Safety is of primary concern and should be reviewed and applied in terms of, but not limited to, the following:

a. Hazard classification.

b. Electrical and electronic safety factors.

c. Mechanical safety factors including hydraulics and pneumatics.

d. Toxicity.

e. Radiation.

2. There are a number of principles concerning human behavior that an equipment designer should consider. The principles listed below will supply at least a partial answer to why people make errors, misuse equipment or otherwise engage in unsafe practices. The principles are based on what actually does happen to equipment and how people actually use the equipment in the field. Armed with a knowledge of why people err, the designer can eliminate many not so obvious pitfalls in system design.

Principle 1. If insufficient or inadequate equipment is provided, equipment will be improvised or modified at the site in order to get the job done. Improvised equipment generally leads to improvised procedures. Improvised procedures ofter result in safety hazards.

Principle 2. People often feel that "it can't happen here." They feel that other people at other locations may get hurt (or damage equipment) by disregarding instructions, but "not us." Therefore, foolproof procedures are necessary where possible. Since procedures are based upon the design of equipment, it is the basic design which permits foolproof procedures to be developed.

Principle 3. Corrective action on a problem does not always mean the end of the problem. The action taken may not be sufficient or appropriate, or it may not affect the real cause of the problem. It might not completely prevent if from recurring elsewhere or in some other way.

Principle 4. No matter how simple and foolproof a procedure looks on paper, try it before finalizing the design.

Principle 5. If the implicit response of the equipment is wrong, it will eventually produce some wrong responses.

Principle 6. A warning note in the appropriate technical manual usually will not overcome a safety problem; it is only limited and supplementary value in reducing the probability of mishap. People may not have read, remembered, or even known where to find, such warning notes.

Principle 7. Do not rely upon special training for those who may use the equipment. Not all individuals will receive the "required" training. Some will have had outdated training, related training, or catch-as-catch-can training. Therefore, try to design for safety rather than hope for special safety training.

Principle 8. Tell some people "don't" and they do, notwithstanding the magnitude of personal risk. Instructions alone are not enough to guarantee proper care, operation, and safety.

Principle 9. Expect that the equipment will be used in the wrong way and study the consequences of doing the job incorrectly. Then design the equipment so that incorrect operation will do minimal damage.

Principle 10. Will the technician damage equipment or injure himself if he does not know what it is? Be sure that full, understandable and legible identification is provided.

Principle 11. Bad conditions which are condoned often seem to multiply and interact to produce serious safety problems.

Principle 12. People tend to avoid or eliminate continual sources of difficulty, but not always by sensible or logical approaches.

Principle 13. Just as development engineers work the "bugs" out of critical equipment, so must others work the "bugs" out of the task performances of each person assigned to critical tasks. Tasks may be de-bugged by tutoring operators as they practice on nonhazardous simulators or inerts. But a certain amount of on-the-job training takes place using operational equipment, and these partially trained personnel will make some mistakes. The original design of the equipment must anticipate such usage and mistakes.

Principle 14. If the designer does not know all of the requirements of the equipment, it is not likely that his design will meet all of them.

Principle 15. Abbreviated checklists are good only when the detailed procedures are known. If is difficult to get technicians to leave a checklist and consult the detailed job procedures when they encounter an unfamiliar area. When in doubt, people tend to experiment and fill in the gaps themselves.

Principle 16. Reputations of equipment are important. If there is even a rumor of hazard or difficulty, task performance and use of the equipment may be adversely affected.

Principle 17. An item of equipment which is difficult to maintain may not be kept in a condition to be used when needed. Equipment which is difficult to use will not be used if any substitute is available.

Principle 18. If the equipment is designed so as to be dependent upon communications between crew members, it is susceptible to human error. People are seldom able to recognize that they have not communicated sufficiently until mistakes have been made, and sometimes not even then.

Principle 19. In summary, the designer should remember that most of the reliability problems affecting operational equipment do not represent defects in the equipment itself, but defects in the way in which it is used. To count upon any significant differences in treatment of equipment on future program is wishful thinking. It is much better for the original designer to preclude the worst problems than for others to grapple with them after designs are relatively frozen.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Human Engineering Laboratories Aberdeen Proving Ground, Maryland 21005	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

HUMAN FACTORS ENGINEERING DESIGN STANDARD FOR VEHICLE FIGHTING COMPARTMENTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Technical Specifications Office

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1968	235	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	HEL Standard S-2-64A
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.
Released to Department of Commerce for sale to the public.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

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

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

Unclassified
Security Classification