METRIC

MIL-HDBK-759C
31 July 1995
SUPERSEDING
MIL-HDBK-759B
30 OCTOBER 1991

DEPARTMENT OF DEFENSE

HANDBOOK FOR

HUMAN ENGINEERING DESIGN GUIDELINES

This handbook is for guidance only. Do not cite this document as a requirement.

AMSC N/A AREA HFAC

FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. This document provides basic guidelines and data on human engineering design for military systems, equipment, and facilities. This handbook has been designed to supplement MIL-STD-1472D. To cue the MIL-STD-1472D user to such supplementary information, this handbook has been formatted to follow the same paragraph numbering, down to the third indenture level, as in MIL-STD-1472D, e.g., paragraph 5.4.5 of both MIL-STD-1472D and this handbook deal with miniature controls. Some paragraphs, necessarily, do not contain any information, but are reserved to accommodate new information that may become available. Additional paragraphs are added to accommodate information that does not appropriately fit elsewhere.

4. Beneficial comments (recommendations, additions, or deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, U.S. Army Missile Command, ATTN: AMSMI-RD-SE-TD-ST, Redstone Arsenal, Alabama 35898-5270, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

CONTENTS

PARAGRAPH PAGE

CONTENTS

PARAGRAPH PAGE

CONTENTS

PARAGRAPH PAGE

CONTENTS

PARAGRAPH PAGE

CONTENTS

CONTENTS

CONTENTS

This Page Intentionally Left Blank

1. SCOPE

1.1 Scope. This handbook provides human engineering design guidelines and reference data for design of military systems, equipment, and facilities. (Programmatic and technique-oriented guidelines may be found in DOD-HDBK-763 and MIL-HDBK-761.)

1.2 Applicability.

1.2.1 Application. The function- and commodity-oriented design guidelines and practices provided by this handbook apply to military systems, equipment, and facilities. They may be applied during any phase of acquisition, as appropriate, where design influence, design, or design evaluation is involved. (A comprehensive treatment of human engineering design of user-computer interaction is provided by MIL-HDBK-761.)

1.2.2 Selection of hardware, materials, or processes. Nothing in this handbook should be construed as limiting the selection of hardware, materials, or processes to items that may be described herein.

1.2.3 Gender considerations. Military systems, equipment, and facilities are designed for operation, maintenance, and control by both male and female personnel. Accordingly and unless stated otherwise, the design guidelines, preferred practices, and data herein apply to design of systems, equipment, and facilities for use by both men and women.

1.2.4 Force limits. If an item will be used by an already established military occupation that specifies physical qualification requirements, any discrepancy between the force guidelines in this handbook and the qualification requirements should be resolved in favor of the latter. In this event, the least stringent physical qualification requirement of all specialties which may operate, maintain, transport, supply, move, lift, or otherwise manipulate the item in the manner being considered should be selected as a maximum design force limit. If such physical qualification requirements do not cover the task addressed by the criteria herein, the criteria herein should be applied.

1.2.5 Manufacturing tolerances. When manufacturing tolerances are not perceptible to the user, the guidelines and preferred practices herein should not be interpreted in a manner preventing the use of components whose dimensions are within a normal manufacturing upper or lower limit tolerance of the dimensions specified herein.

This page intentionally left blank

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

SPECIFICATIONS

DEPARTMENT OF DEFENSE

MIL-P-514	Plate, Identification, Instruction and Marking, Blank
MIL-C-3702	Cable, Power, Electrical, Ignition, High-Tension
MIL-L-3976	Light, Marker, Clearance, Service and Blackout
MIL-B-8584	Brake Systems, Wheel, Aircraft, Design of
MIL-F-8785	Flying Qualities of Piloted Airplanes
MIL-C-13486	Cable, Special Purpose, Electrical. Low-Tension, Heavy-duty Multiple Conductors
MIL-F-15160	Fuses, Instrument, Power and Telephone
MIL-M-18012	Markings for Aircrew Station Displays, Design and Configuration of

STANDARDS

FEDERAL

FED-STD-376	Preferred Metric Units for General Use by the Federal Government
FED-STD-595	Colors (Requirements for Individual Color Chips)

DEPARTMENT OF DEFENSE

MIL-STD-188	Common Long Haul and Tactical Communication System Technical Standards
MIL-STD-195	Marking of Connections for Electrical Assemblies
MIL-STD-203	Aircrew Station Controls and Displays: Location, Arrangement and Actuation of, for Fixed Wing Aircraft
MIL-STD-250	Aircrew Station Controls and Displays for Rotary Wing Aircraft
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-681	Identification Coding and Application of Hookup and Lead Wire
MIL-STD-685	Identification of Cable Used for Transmission of Telephone, Telegraph and Teletype Signals
MIL-STD-686	Cable and Cord, Electrical, Identification Marking and Color Coding of
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1473	Standard General Requirements for Color and Marking of Army Materiel
MIL-STD-1474	Noise Limits for Military Materiel
MIL-STD-1908	Definitions of Human Factors Terms

HANDBOOKS

MIL-HDBK-761	Human Engineering Guidelines for Management Information Systems
DOD-HDBK-763	Human Engineering Procedures Guide

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.2.2 Other documents, drawings, and publications. The following other government documents, drawings and publications form a part of this document to the extent specified herein.

PUBLICATIONS

ARMY

FM 31-71	Northern Operations
NRDEC TR 84-034	Anthropometry of the Clothed U.S. Army Ground Troop and Combat Vehicle Crewmen; Natick Research, Development and Engineering Center

NAVY

NAEC TR 2100-07B	A Family of Manikins for Workstation Design; Naval Air Engineering Center
PMTC TP 75-49	Computerized Accommodated Percentage Evaluation (CAPE) Model for Cockpit Analysis and Other Exclusion Studies; Pacific Missile Test Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

NASA Ref. Pub. 1024	Anthropometric Source Book, Volume 1: Anthropometry for Designers

FEDERAL

29 CFR 1910	Occupational Safety and Health Standards
FMVSS-101	Federal Motor Vehicle Safety Standards

(Copies of other government documents, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the acquiring activity or as directed by the contracting officer.)

2.3 Non-government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the latest issue of the DoDISS and supplement thereto.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

ASTM E 380	Standard Practice for the Use of the International System of Units (SI)(The Modernized Metric System)

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187)

INTERNATIONAL STANDARDIZATION ORGANIZATION (ISO)

ISO 2631-1	Guide to the Evaluation of Human Exposure to Whole Body Vibration, Part 1: General Requirements

(Application for copies should be addressed to the American National Standards Institute, Inc., 11 West 42nd Street, New York, NY 10036.)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

SAE TP-810217	An Alternative to Percentile Model

(Application for copies should be addressed to the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001.)

(Non-government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.4 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

NOTE: Terms not appearing below are defined in accordance with MIL-STD-1908.

3.1 Battle-short switch. A switch used on high-priority equipment designed to bypass or short circuit interlock switches or devices during emergency conditions.

3.2 Inch-pound equivalents, abbreviations, and prefixes. Inch-pound units, metric units, and multipliers to convert from metric units to inch-pound units are presented in Table 1.

3.3 Primary controls. The most important and frequently used devices designed to control equipment and systems.

TABLE 1. Inch-pound equivalents, abbreviations, and prefixes

EQUIVALENTS		
TO CONVERT FROM	TO	MULTIPLY BY
candela per square meter (cd/m^2)	footlambert (fL)	0.291 864
kilogram (kg)	pound (lb) avoirdupois	2.204 623
kilopascals (KPa)	pound force/$inch^2$ (lbf/in^2)	0.145 038
lux (lx)	footcandle (fc)	0.092 903
meter (m)	foot (ft)	3.280 840
meter (m)	inch (in. or ")	39.370 079
$meter^2$ (m^2)	$foot^2$ (ft^2)	10.763 910
$meter^2$ (m^2)	$inch^2$ (in^2)	1550.003 120
$meter^3$ (m^3)	$foot^3$ (ft^3)	35.314 662
$meter^3$ (m^3)	$inch^3$ (in^3)	61203.745 303
millimeter (mm)	inch (in. or ")	0.039 370
$millimeter^2$ (mm^2)	$inch^2$ (in^2)	0.001 550
newton (N)	pound force (lbf)	0.224 809
newton (N)	ounce force (ozf)	3.596 942
newton meter (N·m)	pound-inch (lbf-in)	8.850 748
newton meter (N·m)	ounce-inch (ozf-in)	141.611 929
radian (rad)	degree (angle)(deg)	57.295 788
radian (rad)	minute (angle)(min)	3437.746 873

PREFIXES		TEMPERATURE CONVERSION
Nano n 10^{-9} Micro µ 10^{-6} Milli m 10^{-3} Centi c 10^{-2}	Kilo k 10^3 Mega M 10^6	$^oC = 5/9\ (^oF - 32)$ $^oF = 9/5\ ^oC + 32$

4. GENERAL GUIDELINES

The design of systems, equipment, and facilities should conform to the capabilities and limitations of the fully-equipped individual to operate, maintain, supply, and transport the materiel in its operational environment consistent with tactical criteria and logistic capabilities. Accordingly, design-induced workload, accuracy, time constraints, mental processing, and communications requirements should not exceed operator, maintainer, or controller capabilities. Design should also foster effective procedures, work patterns, and personnel safety and health, and minimize factors which degrade human performance. Design also should minimize personnel and training requirements within the limits of time, cost, and performance trade-offs.

This page intentionally left blank

5. DETAILED GUIDELINES

5.1 Control-display integration.

5.1.1 General criteria.

5.1.1.1 Relationship. Control-display relationships should be functionally effective and require a minimum of decoding or mental involvement on the part of the operator. This should include relationships between a control and specific display hardware (meters, instruments, and labeled control escutcheon plates), and/or external devices or visual elements that are used as visual references while operating particular controls. A control should not be used in any application in which its movement is likely to be ambiguously interpreted, such as when the manipulation required is opposite to that anticipated or expected by the typical operator.

5.1.1.2 Organization. Controls and displays should be organized in a manner that will minimize operator effort, confusion, and error, by means of functional grouping, sequential arrangement, accessibility to the nominal user's limb or hand, and/or nominal viewing axis of the operator.

5.1.1.3 Feedback. Control-display systems should be designed to provide feedback on control input and system state as rapidly as possible. Feedback should be considered at the three levels listed below:

a. Control Actuation.

   (1) Discrete state selectors. Controls of this type (toggle switches, push button switches, and rotary selectors) should provide positive indication of control actuation to the operator under all operational conditions. Control displacement sufficient to be unambiguously recognized may provide adequate feedback at this level for most functions.

   (2) Continuous adjustment controls. Controllers such as continuous adjustment knobs, cranks, and joysticks should provide feedback as to where the control is positioned with respect to its entire range of variability. Ordinarily, this is by means of visual indication via the control's moving pointer against a fixed scale.

b. Transient system response. Feedback at this level is used to provide an indication of system response to the control input between the time of control actuation and that of arriving at system steady-state condition in response to that input. When the transient response is short (less than two seconds duration), feedback at this level is sufficient (there is one clear visual or auditory indication that the system is in the process of responding). However, for especially critical functions, transient system response should be indicated by one of the feedback arrangements listed below.

(1) Direct positive feedback from the mechanism being driven via, for example, a strong auditory signal directly from a drive motor, or direct visual indication of the orientation of the driven unit.

(2) Redundant positive feedback from two different points in the system (a meter indication and a pilot light, which sense the system's transient state).

(3) Both positive and negative feedback, so that one or the other will always be activated, whether or not the system responds to the control input, such as when the positive feedback indicates the system is in the process of responding when it should; the negative feedback indicates that the system is not responding when it should; and/or one or the other of the indications would always be present during the transient period.

c. System steady-state. Feedback should be provided to indicate completion of the system's response to the control input and current system operating state. Usually a single positive feedback indication at this level is sufficient. (The onset of the indication signals completion of the response and the continuing indication constantly informs of system state.) Where the original control input is by some type of discrete state selector, a discrete state indicator for feedback is sufficient. Where the original control input was by a continuous adjustment control, an analog or digital indication of system state is usually required to indicate that the system has responded fully to the control input. Exceptions to this may be allowed where provision is made to automatically compare the completed system response with the magnitude of the control input and to indicate that the system has responded within satisfactory tolerance. For critical functions, a warning indication should be provided to signal at all times following the system transient response when the system state mismatches the ordered state as set by the input control(s).

5.1.2 Position relationships. Controls should normally be placed beneath or to the right of a related display except when:

a. the display would be obscured by the operator's hand,

b. panel space limitations require use of an array of displays that would be selectively operated by means of a "ganged" control device, wherein separate knobs would be associated with individual displays within the array, or

c. the control operation would be inefficient or awkward if the control were placed next to the display, or vice versa. Typical applications include such relationships as steering wheel, joystick or foot-operated controls relative to displays on an instrument panel.

5.1.2.1 General arrangement. Arrangement of controls and displays at workstations should be in accordance with those arrangement factors most likely to ensure effective operator performance. Care should be exercised to obtain the best balance of these factors when they may be in conflict or may vary in significance with the mode of operation at the workstation.

5.1.2.2 Operator orientation. Controls and displays associated with a given control or monitoring task(s) should be located and positioned with reference to a specified operator position(s), including criteria for visual monitoring beyond the immediate control-display interface, and should not impose difficult mobility problems for the operator (sitting or standing in an awkward position, frequent extreme reaching and body or head turning criteria, or constant changes in body position in order to accommodate to various control manipulation or visual monitoring tasks).

5.1.2.3 Simultaneous access. Where two operators must use the same control or display (when monitoring system status), the criteria listed below should be applied.

a. If the controls and displays have high priority, duplicate sets should be provided whenever there is adequate space. Otherwise, controls and displays should be centered between the operators.

b. If secondary controls and displays should be shared, 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 criteria for using them.

c. If the primary or secondary controls must be operated with the user's preferred hand (keyboards, keysenders), duplicate controls should be provided. Such controls should not be centered between the operators.

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

5.1.2.4 Functional grouping.

5.1.2.4.1 Functional group arrangement. Controls and displays should be grouped functionally when they are identical in function, used together in a specific task, and related to one equipment or system component. Once grouped, they should be spatially organized so that the relationship between them is apparent to the operator and all displays used together should be placed at the same viewing distance. In addition, controls and displays should be grouped by function when there is no definite sequence of function.

5.1.2.4.2 Sequence. The principles listed below should be applied to displays which are observed in sequence.

a. When displays are arranged horizontally, they should be viewed from left to right.

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, provided the layout does not make it difficult to interpret individual displays.

When the operator uses several controls in sequence with the same hand, the controls should be arranged in horizontal rows, from left to right, in order of operation. If horizontal rows are impractical, the controls should be arranged in vertical rows, from top to bottom, in order of operation.

5.1.2.4.3 Consistency. Similar control-display functions should be consistent from one operator workstation to another when it is likely that the same operator may be called upon to change workstations. Examples are listed below.

a. Left-right arrangements. When a group of control-display elements normally have a left-to-right and/or numbered relationship to other equipment components (aircraft engines numbered from left to right), the operator control-display arrangement should remain the same with respect to the operator's orientation within the workstation (facing forward, right, left, or aft).

b. Related but separated control-display arrays. When an array of controls on one panel corresponds to displays mounted on another panel because of special space limitations, the control and display arrays should be similarly arranged. That is, the leftmost control of a horizontal array should correspond to the leftmost display mounted on the other panel, or a topmost control of a vertical array should correspond to the topmost display on the other panel. Two horizontal panels should not be mounted so that they face each other and thus create the opportunity to confuse the left-to-right relationships.

c. Vertical vs horizontal control-display arrangements. When displays are arranged in a row or column the associated controls should be similarly arranged and spaced (see Figure 1), except as follows:

(1) Fewer rows of controls than displays. Controls affecting the top row of displays should be positioned at the far left; controls affecting a second row of displays should be placed immediately to the right of these, with an appropriate space between the two control arrays.

(2) Vertical vs horizontal association. If a horizontal row of displays should be related to a vertical row of controls or vice versa, the farthest left item in the horizontal array should correspond to the top item in the vertical array. Exceptions often lead to errors in spite of the recommended spatial associations; therefore, they should be avoided whenever possible.

(3) Multiple display vs single control. When the manipulation of one control requires reading of several displays, the control should be centered as near as possible below the display group.

(4) Multiple display vs ganged control. When up to three displays are to be individually affected by a three-layer, ganged rotary control switch, the switch should be centered below a horizontal display group, or to the right of a vertical display group. The knob-display associations should be as follows: top knob - right or upper display, middle knob - middle display, bottom knob - left or lower display.

5.1.3 Movement relationships. Reserved.

5.1.4 Control-display movement ratio.

5.1.4.1 Complexity and precision.

5.1.4.1.1 Coarse vs fine setting. The amount of control and/or display movement should be compatible with the operator's inherent capacity to discriminate visual and tactile inputs from displayed elements and/or control movement feedback. For coarse setting tasks, control movement should be less than display movement; for fine setting tasks, control movement should be greater than display movement. When a task may include criteria for both coarse and fine setting, the control-display movement ratio should be chosen to minimize the time to make control settings. At operator stations where some tasks require only coarse settings, but others require fine settings, the operator should be provided with two selectable ratios, normal and fine.

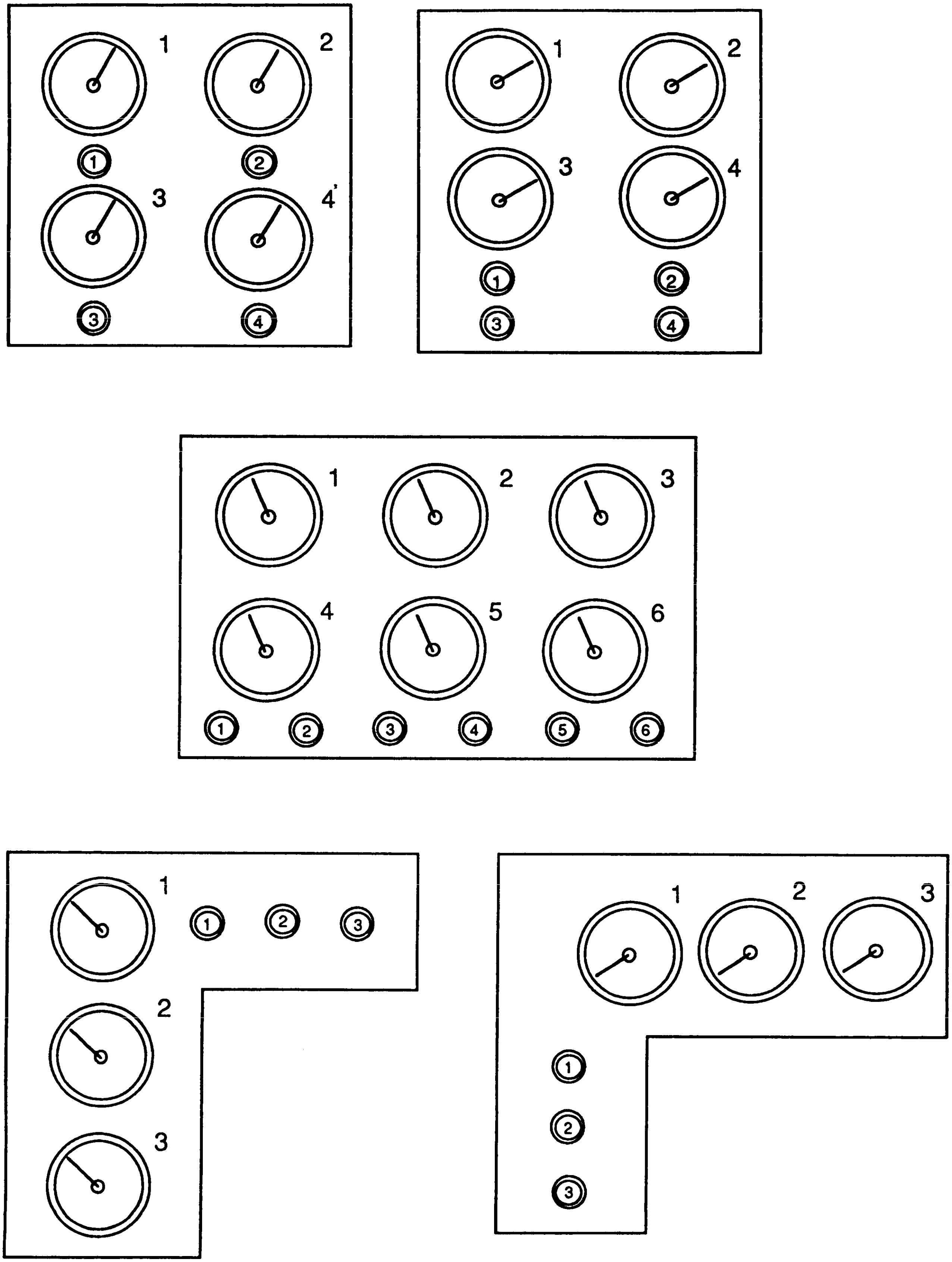


FIGURE 1. Control-display relationship.

5.1.4.1.2 Hand vs foot controls. Foot controls should be used only for coarse adjustments or settings. Hand- or arm-operated controls may be used for both coarse and fine adjustment. The more precision required, the less arm movement should be involved in control operation.

5.1.4.2 Counters. The counter-setting criteria listed below should apply:

a. Multi-digit, mechanical drum counters. One revolution of a knob should equal approximately 50 counts (right-hand drum rotates five times).

b. Multi-digit electronically-displayed counters. A momentary switch-type control should be used. Both slow and fast speed (slew) operation should be provided so the operator can either slew through the digits rapidly (about two digits per second for the cell being read) or step through, one digit at a time. In the latter case, the system should preclude the operator advancing more than one character in the event the control is not released. However, a system in which both forward and reverse display changes can be made is preferred so that the operator can back up one or two digits rather than having to cycle through the series to obtain the desired setting.

c. Single-digit electronically-displayed counters. A momentary-contact step advance may be sufficient unless frequent setting is required in which case a two-speed switch should be provided as for the multi-digit counter.

5.1.4.3 Foot-operated controls. Foot-operated controls should not be used to adjust a visual display directly (other than indirect display of vehicle changes in direction or acceleration). If a directly-coupled display adjustment is to be made by foot-operated control movements, it should be only for gross, relatively slow, settings. Foot-operated controls, when used to control the direction of vehicle movement (as in small submersibles) should be instrumented to indicate the direction and magnitude of control surface actuation as well as the heading of the vehicle.

This Page Intentionally Left Blank.

5.2 Visual displays.

5.2.1 General. Designing any equipment component that people operate to obtain information about equipment status always has priority and requires a thorough knowledge of the kind, amount, and accuracy of information the operator will require. Almost all of the operator's decisions and actions depend on the information which is presented. All visual displays should conform to these general guidelines:

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

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

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

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

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

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

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

h. The maximum viewing distance to displays located close to their associated controls should not exceed 635 mm. Otherwise, there is no maximum limit other than that imposed by legibility limitations, which should be compensated for by proper design.

i. With the exception of CRT and collimated displays, the minimum viewing distance should never be less than 330 mm and preferably not less than 510 mm.

j. The display should be illuminated with white light when dark adaptation is not essential. Red illumination should be used when dark adaptation is required. Other colors may be necessary when night vision goggle compatibility is required.

k. A failure in the display should not cause associated equipment to fail.

5.2.1.1 Alerting or warning displays. Reserved.

5.2.1.2 Display illumination and light distribution.

5.2.1.2.1 Display illumination. The full range of operational conditions should be taken into account in designing display illumination. A display which should be operable under conditions varying from night blackout conditions to full daylight should incorporate the necessary illumination features to allow proper use under all these widely varying conditions. A display which will always be used in a controlled lighting environment, such as a command and control center, may need to satisfy illumination criteria only for the ambient conditions of that task environment.

5.2.1.2.2 Light distribution. Reserved.

5.2.1.3 Information.

5.2.1.3.1 Redundancy. Redundancy of information appears in systems by presenting the same information in two or more different places, at two or more different times, or under two or more different encoding techniques. Redundancy may be constructively used to facilitate pattern recognition, enhance detectability, provide backup capability, speed up information retrieval, and increase reliability in information processing. Redundancy should be avoided, however, if it simply increases the volume of information which should be displayed and processed without obvious constructive purpose.

5.2.1.3.2 Display failure clarity. A suitable technique, such as one or more of the following, should be used to indicate to the operator that the display itself or the associated display circuitry has failed.

a. the display illumination is extinguished,

b. the display sweep stops scanning, or

c. a failure indicator is energized.

5.2.1.4 Location and arrangement. Reserved.

5.2.1.5 Coding. Reserved.

5.2.2 Transilluminated displays.

5.2.2.1 General.

5.2.2.1.1 Equipment response. Generally, equipment state rather than control position or condition should be displayed, considering the following:

a. equipment state should always be continually displayed,

b. control actuation should be transiently displayed, and

c. control setting should be continuously displayed if it can be at variance with equipment state. An in-transit condition should remain ON until the system state is consistent with the control state (except for in-transit durations shorter than the operator's response time).

5.2.2.1.2 Master warning, caution, and advisory lights. Master warning, caution, and/or advisory lights should be set apart from the lights which show the status of the subsystem components when used to indicate the condition of an entire subsystem, except as required for maintenance-only displays.

5.2.2.1.3 Display luminance and visibility.

5.2.2.1.3.1 Luminance. The luminance (brightness) of transilluminated displays should be compatible with the expected range of ambient illuminances associated with mission operation and/or servicing and maintenance of the system and equipment. The following factors should be considered in determining luminance levels:

a. Within-display contrast, such as contrast between light ON vs OFF modes; two-level contrast if display requires a dormant luminance to read an identifying label plus an active luminance increase to indicate functioning mode.

b. Display-surround contrast, such as contrast between the illuminated indicator and its immediate panel surface, in which case effects of ambient reflection on either the display or surround should be compensated for by such means as increased display luminance, surround surface modification, or use of filters or shields.

c. Operator visual-adaptation criteria, such as display luminance, should be compatible with the operator's criteria to detect low-level signals or targets in the external visual environment, and/or perceive faint signals on a CRT or read red-lighted instruments provided for night operation.

d. Conspicuity and attention-demand criteria, such as luminances, should provide the required alerting to ensure that the operator will not miss a critical warning, caution, or advisory message.

e. Distraction, such as luminance levels, should not dazzle or otherwise distract the operator in a manner that could be detrimental to safe, efficient system operation.

5.2.2.1.3.2 Luminance level. When a two-level indicator is used, the difference between the dormant and illuminated brightness should be approximately 1:2, considering always the factors noted above.

5.2.2.2 Legend lights.

5.2.2.2.1 Use. The number of legend lights should be kept to a minimum, as needed to provide required information feedback. A legend light should be used to provide qualitative information; it should not give a command. If a command should be given, the legend should clearly and unambiguously indicate that this is the case.

5.2.2.2.2 Design. The legend face should be essentially in the plane of the panel which houses it (not recessed) and should have large enough front areas to accommodate the anticipated legends without requiring unreasonable abbreviation. The possibility of losing or interchanging legends should be minimized by such techniques as captive legends. There should be a border around each legend not less than the width of the letter "H" of the selected font.

5.2.2.2.3 Visual contrast. Optimum visual contrast should be provided between the legend lettering and its background. The face of the light should not have trademarks, company names or other similar markings unrelated to the information displayed.

5.2.2.2.4 Illumination. A legend light should illuminate immediately upon the occurrence of the event described by its legend; it should go out when that event terminates. There should not be light leakage around the illuminated light.

5.2.2.2.5 Redundancy. Lamps should have redundant filaments 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.

5.2.2.2.6 Malfunctions. Legend-light indications for isolating malfunctions should be provided only down to the point dictated by the system maintenance philosophy. They should operate in a fail-safe fashion. Failure of a legend light or its indicator circuit should not influence or cause failure of its monitored circuits and equipment.

5.2.2.3 Simple indicator lights.

5.2.2.3.1 Use. Simple, non-legend light displays may be used when design considerations make legend light displays impractical, such as the following:

a. Small pilot lights preclude legend or symbol imprint on display surface.

b. Small equipment indicator, such as light to indicate radio is in AM vs FM mode.

c. Vehicular panel indicators, such as "high beam" headlight mode, or left or right "turn-signal indication."

d. External vehicle identification or mode lights, such as rear caution, stop, backup, or turn lights; vehicle perimeter warning and blackout lights; and aircraft position lights, navigation lights, and anti-collision lights.

e. Ground-based beacons, airport runway, taxiway, obstacle warning, and roadway signal lights.

f. Marinecraft position, navigation, and signaling lights.

5.2.2.3.2 International conventions and standards. International conventions and standards for aircraft, highway vehicles, and marinecraft should be followed in design, location, and luminance characteristics of all military systems utilizing public roadways; airways; or navigable streams, rivers, and sea-lanes.

5.2.2.3.3 Brightness. Simple light displays used on operator control panels should be sufficiently bright for the operator to easily differentiate between an ON and OFF condition. The indicator also should be designed and/or otherwise positioned or shielded so that bright ambient light will not cause the indicator to appear lighted when it is not, and/or so that the lighted indicator will not reflect on other critical viewing surfaces and thus diminish viewing effectiveness of a display or window. Light indicators should not be so bright as to create "dazzle" and/or destroy operator dark adaptation where required.

5.2.2.4 Transilluminated panel assemblies. Integrally-lighted subpanels should be designed so that all panel markings are equally visible throughout the range of panel light level adjustment, and brightness variation among separate subpanels on the same lighting circuit should not exceed 1:7.

5.2.3 Scale indicators.

5.2.3.1 General.

5.2.3.1.1 Applications. Scale indicators should be used in preference to digital readouts when the data displayed are of qualitative as well as quantitative value, or of qualitative value only. Scale indicators should not be used when the primary purpose is readout of precise quantitative information.

5.2.3.1.2 Preferred. The preferred type of scale indicator for most applications has a moving pointer and a fixed scale. With a moving-pointer, fixed-scale indicator, both the scale progression and control movement are compatible with operator expectancies. Therefore, this type of scale can be used effectively whenever a scale indicator is required. The other major type of scale indicator has a fixed pointer and a moving scale. Because there is always compromise to one or another human engineering principle in the use of this design, its use should be limited to:

a. where multiple scales can be lined up and read in a row or column, and/or

b. where speed and accuracy of setting is not critical.

5.2.3.1.3 Scale markings and numbering. No more than three sizes of marks should be used on any scale.

5.2.3.1.3.1 Graduations. The scales which require three sizes include those which have values in multiples of 10 but are graduated in five- and ten-degree intervals. The number of graduation marks between numbered marks (not to exceed nine) are presented in Table 2, and illustrations of various graduated scales are provided in Figure 2.

5.2.3.1.3.2 Intermediate marks. Intermediate marks ordinarily should not be numbered.

5.2.3.1.3.3 Numerals. On fixed scales, numerals should be vertically oriented; on rotating scales, numerals should be radially oriented and positioned so as to be upright when read against the pointer. Bearing dials should have numerals (and major graduation marks) at either 10 or 30 degrees, as shown in Figure 3.

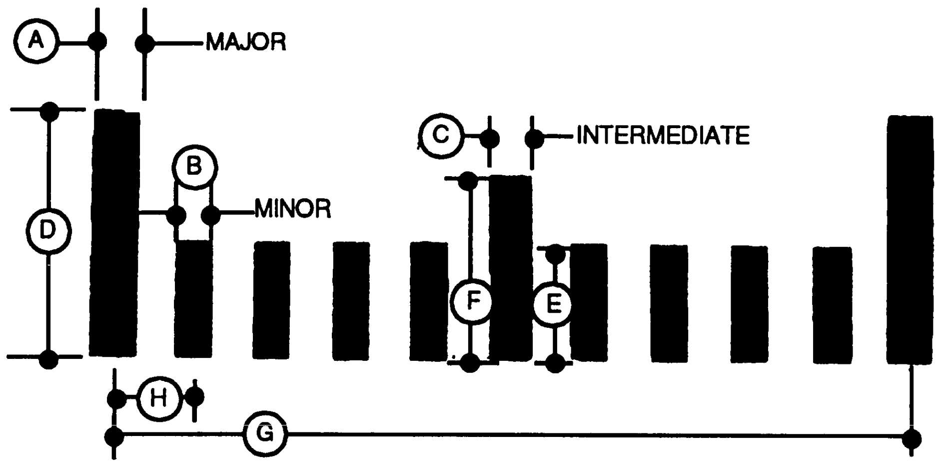
5.2.3.1.3.4 Major marks. Scales should start and end on a major graduation mark, even if this puts either or both ends beyond the usable range of the scale.

5.2.3.1.4 Pointers.

5.2.3.1.4.1 General. For best legibility, indicators with scales should have pointers that are relatively wide at the pivot, tapering gradually to a fine tip, arrowhead, or teardrop that is the same width as the smallest graduation mark.

5.2.3.1.4.2 Dial faces. If the display is used for making a 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 show at least one numbered graduation on each side of any setting. If the display is one used in tracking, such as a heading indicator, the whole dial face should be exposed.

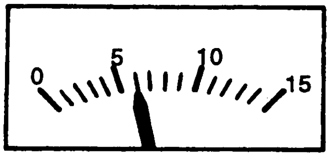
TABLE 2. Scale of markings.



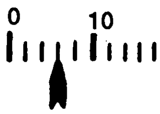
Dimension	Viewing Distance (mm)		
	710	910	1525
A (Major index width)	0.9	1.1	1.9
B (Minor index width)	0.6	0.8	1.4
C (Intermediate index width)	0.8	1.0	1.6
D (Major index height)	5.6	7.2	12.0
E (Minor index height)	2.5	3.3	5.4
F (Intermediate index height)	4.1	5.2	8.7
G (Major index separation between midpoints)	17.8	22.9	38.0
H (Minor index separation between midpoints)	1.8	2.3	3.8

Minimum scale dimensions for low illumination (1-3.4 cd/m^2)

Fixed-scale, moving-pointer preferred; three-level marking, numbered at each major mark. Pointer adjacent to graduation marks to preclude obscuration of either marks or numbers.

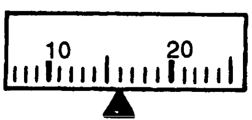


For short, finite scale, every 5th graduation is marked; using only two-level marking.

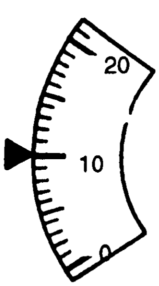


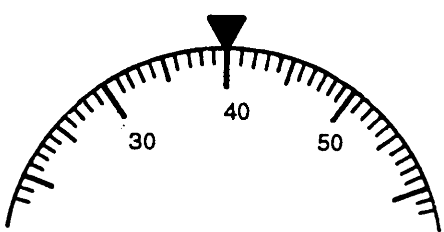
When scale crowding makes pointer-mark association difficult, scale may be graduated in units of two, with two-level scale marking and numbering at each major marking.

When dial face is deeply inset within instrument case and visibility of numbers is more important than scale pointer-mark association, pointer may be located inside the graduations along with numbers at major markings. Pointer width should be narrowed at point in which it passes numbers.



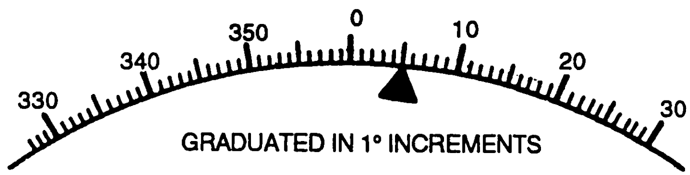
Moving scale against an index-mark or pointer may be used when scale length precludes the fixed-scale format (graduation marks would be too close together) . Open window configuration helps operator focus on significant scale area.



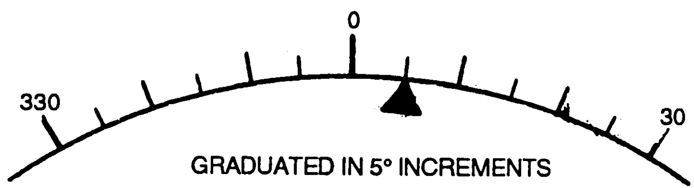


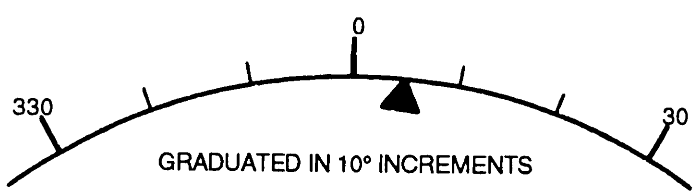
When open window configuration is oriented in vertical position, numbers should appear upright as each number passes the index mark or pointer. Total scale exposure is desirable when operator needs to refer to other portions of the scale.

FIGURE 2. Scale graduation, pointer position and scale numbering alternatives.



Smaller Scale Increments (where greater precision is required)





Larger Scale Increments (where less precision is required)

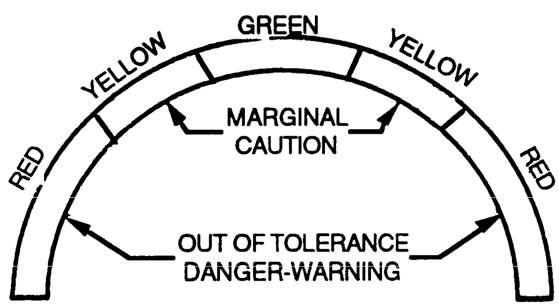
NOTE: The above general scale marking concepts also apply to displays in which measure is in roils.

FIGURE 3. Fixed-scale azimuth dials.

5.2.3.1.4.3 Tip configuration. With reciprocal (double-ended) pointers, it should be easy to distinguish the end that indicates the reading. In edgewise indicators, such as rectangular meters with straight scales, only the tip of the pointer may be visible. If so, it should be distinctive and obvious.

5.2.3.1.4.4 Pointers per shaft. There should not be more than two pointers on a single shaft.

5.2.3.1.5 Shape coding. Operating zones may be shape coded when the indicator must be viewed in very low-light-level work environments (0.07-0.7 cd/m^2) or where the illuminant color will cause difficulty in discrimination of colors (see Figure 4).



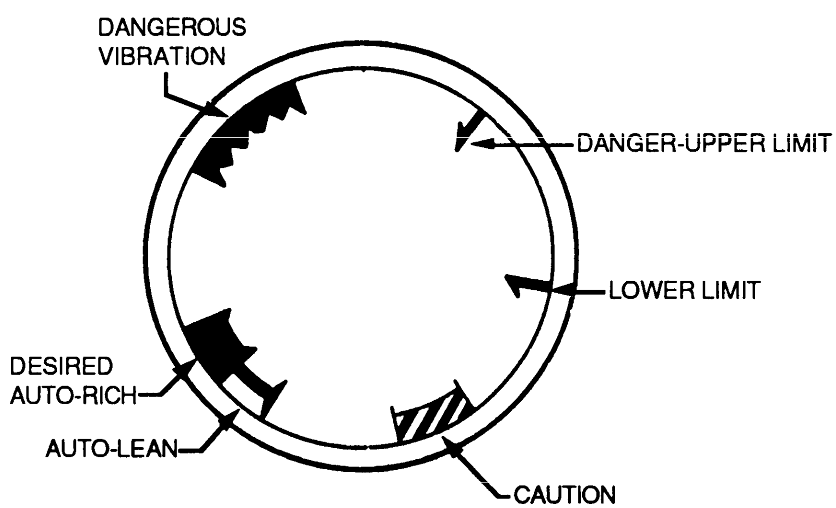


FIGURE 4. Examples of shape- and color-coding.

5.2.3.2 Moving-pointer, fixed-scale indicators.

5.2.3.2.1 Zero position and direction of movement. The position of the zero value on a numbered scale and the relative pointer movement should conform to criteria in Figure 5.

5.2.3.2.2 Aligned pointers for check-reading. When a stable value exists for given operating conditions in a group of circular-scale indicators, they should be arranged either in rows so that all pointers line up horizontally on the 9 o'clock position under normal operating conditions or in columns so that all pointers line up vertically in the 12 o'clock position under normal operating conditions. If a matrix of indicators is needed, preference should be given to the 9 o'clock position (see Figure 6).

5.2.3.2.3 Curved (arc), horizontal straight, and vertical straight scales.

5.2.3.2.3.1 Zero position and direction of movement. The position of the zero value on curved or straight scales should conform to criteria in Figure 7.

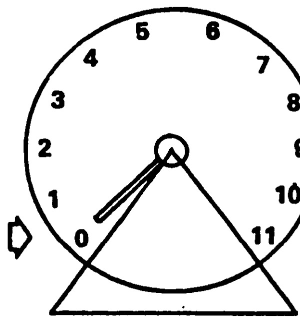
5.2.3.2.3.2 Relative position of scale marks and numbers. The numbers should be located on the side of the graduation marks opposite the pointer. The graduation marks should be aligned on the side of the pointer and stepped on the side of the numbers. The relative position of pointers, scales and numerals should conform to criteria in Figure 7.

5.2.3.3 Fixed-pointer, moving-scale indicators.

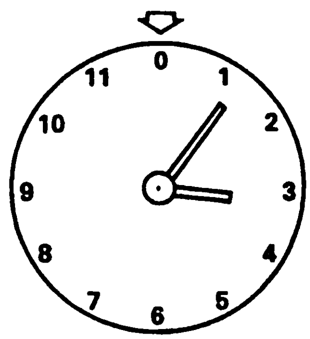
5.2.3.3.1 Setting. At least two number values should appear within the window at all times unless the scale is finite and the dial cannot be rotated continuously through successive rotations in the same direction. If the display will be used for tracking (as in the case of a directional indicator), the entire face of the dial should be exposed.

5.2.3.3.2 Circular scales. There are ambiguities in associating moving circular scales with control movements; thus fixed-pointer, moving-scale indicators are not recommended. Moving circular scales necessarily violate one of the following principles of human engineering:

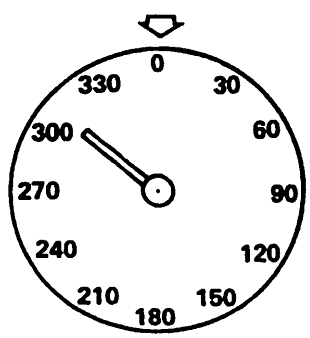
a. Scale numbers should increase in a clockwise direction. Values on moving circular scales should therefore increase with counterclockwise rotation of the dial face.



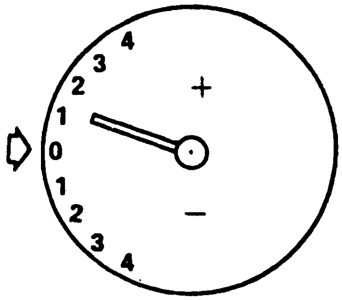
When a dial scale is of finite length, it should be numbered so that value increase is clockwise. The zero starting point should be approximately at the 7 o’clock position. There should be an obvious “break” between the two ends of the scale of at least 10° of arc.



When multirevolution pointer movement is involved, the zero reference should be at the top of the dial and there should be no break between scale ends. No more than two pointers should be used except for special cases, such as a clock (with second hand).



Azimuth dial scales should be laid out with the zero (or north) reference at the top of the dial, and scale values should increase clockwise. At least every 30° reference should be numbered.



Positive-negative dial formats should be laid out with the zero (or “null” position) located at the 9 or 12 o’clock positions. Scale values should increase right or left, or up or down as appropriate to provide positive-negative pointer movement relationships.

FIGURE 5. Zero position and pointer movement for circular dial displays.

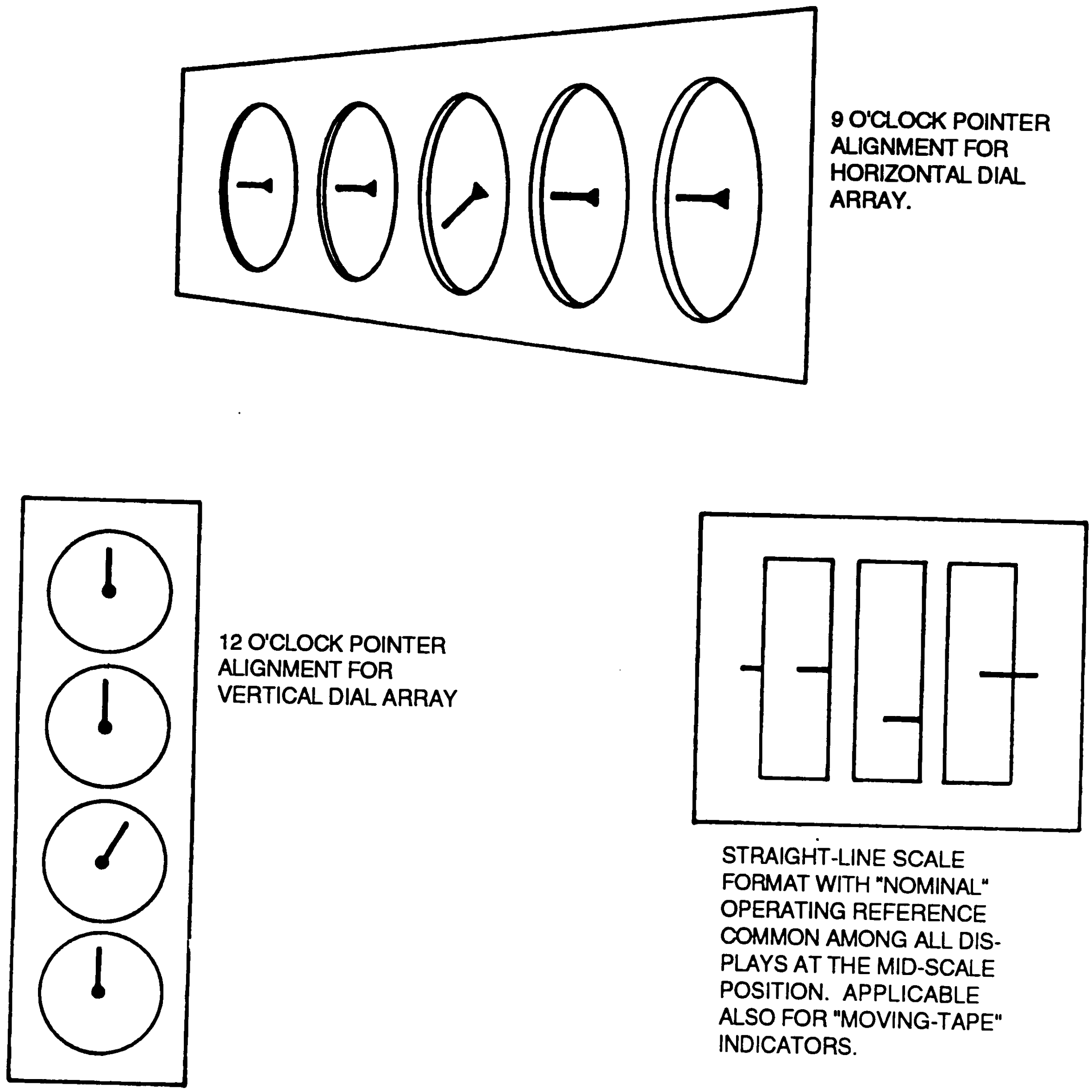
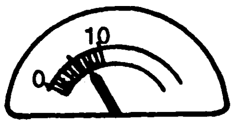
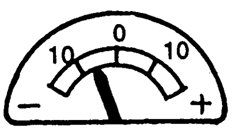
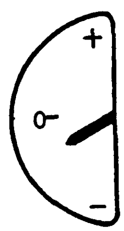


FIGURE 6. Aligned pointers for rapid check-reading.



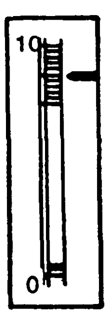
Numerals should be located outside scale marks, and pointers should ride against the inner scale annulus just short of the markings. The zero reference should be to the left so that increasing numbers and pointer motion is clockwise.





Zero reference (null) for arc scale formats should be centered on the scale, with Positive value increase to the right-or upward; negative increase to the left or downward. A "mirror image" of the vertical format is also acceptable.

Relative location of numerals, scale, and pointer on "straight-line" display formats should be as shown. Pointer should not cover either the scale marks or the numerals. The pointer should eminate from the right side of the vertical format and from the bottom of the horizontal format.



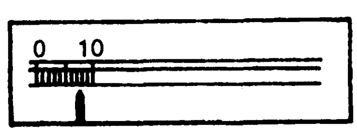


FIGURE 7. Relative position of scale marks, numerals and pointers on arc and straight-line scales.

b. The direction of movement of the associated control should be compatible with the direction of movement of the dial. (Clockwise movement of the control should result in clockwise movement of the dial.)

c. Clockwise movement of a control should result in an increase.

If Principle b is compromised, such as when counterclockwise movement of the dial occurs, operators err in the initial direction of turn. If Principle c is compromised, a standard control movement-system relationship is violated. The following practices are recommended for designing circular moving scales to minimize the effects of incompatibilities:

a. The numbers should increase clockwise around the face for controls without dial face masks. Therefore, the dial face moves counterclockwise to increase the readings.

b. If the associated control has no direct effect on the performance of the equipment (tuning in radio stations), the scale should rotate counterclockwise (increase) when the associated knob or crank is turned counterclockwise.

c. If the associated control has a direct effect on the performance of the equipment (speed or direction), the scale should rotate counterclockwise (increase) with a clockwise, upward or rightward movement of the associated control.

5.2.3.3.3 Straight scales moving vertically and horizontally. Straight scales that move vertically and horizontally exhibit the same direction-of-motion ambiguities as circular moving scales. The numbers should be printed so they increase from bottom to top, or from left or right on the scale plate itself. The scale should increase (move downward or to the left) when the associated knob or crank is moved clockwise, or when the associated lever is moved upward or to the right.

5.2.3.3.4 Accepted deviations. It is acceptable to deviate from the previously listed scale-design principles when other considerations have prime importance. Certain unique applications of scales may require other design features and compromises. For example, an azimuth indicator with the numerical progression of 30, 60, 90, is less satisfactory than those previously recommended. However, this arrangement represents a compromise between the best numbering progression and a manageable size of dial. Where the azimuth indicator is a small dial, the numbered cardinal points (north, east, south, west), serve as anchoring points in interpreting this indication and a progression by 30s is a good solution. Where the dial can be made large enough, the major intervals should be marked by 10s.

5.2.3.3.5 Non-linear scales. Non-linear scales condense a large range into a relatively smaller space, yet permit sensitive readings at certain critical ranges of the scale. When error tolerances are a constant percentage of the indication, a logarithmic scale is very suitable. However, logarithmic scales should show enough numbered graduation marks to prevent operators from reading the scale as if it were linear.

5.2.3.4 Composite scalar and pictorial displays. Color contrast should be used to aid the operator in differentiating among various elements of the combined or composite display, such as dark "land" vs light "sky."

5.2.3.5 Head-up display.

5.2.3.5.1 Use. The head-up display may be considered with the approval of the acquiring activity. The head-up display concept should not be used for ground-borne or sea-borne vehicles or other operator control-display installations without express approval of the acquiring activity.

5.2.3.5.2 Display and external viewing interference. Markings projected on the windshield should be designed and illuminated in a manner that will not create confusion with external visual details required by the pilot for safe flight. Brightness control should be provided the operator, with sufficient latitude to set the brightness appropriately for the expected visual environment variations.

5.2.4 Cathode ray tube (CRT) displays.

5.2.4.1 Use. Cathode ray tubes may be used for a wide variety of display purposes such as presentation of sensor data from radar and electronic-warfare systems, computer-generated data such as processed sensory data, target tracks, computer graphics, and status data. CRTs also may be used to show simulated exercises, aircraft system status, caution and warning indications, and presentation of television pictures. A CRT also may be employed for multiple uses in which case it should at least minimally satisfy the criteria for each use.

5.2.4.2 Screen luminance.

5.2.4.2.1 Operating range. The luminance used should be compatible with the CRTs operating characteristics and life expectancy. For example, the CRT should not be driven beyond its normal value in order to gain greater screen luminance since this could result in burning of the screen or in reduced life.

5.2.4.2.2 Operator visual capabilities and task criteria. Luminance of the faintest information displayed for operator response should be well above the operator's threshold considering target size and presentation rate, clutter, phosphor color, and ambient illumination conditions.

5.2.4.3 Ambient illuminance. CRTs which must be viewed under daylight conditions such as in an aircraft cockpit should utilize one or more appropriate means, such as the following, to bring viewing conditions within an acceptable range:

a. a deep shield or hood to reduce the amount of incident light,

b. scan conversion for continuous presentation at high luminance levels,

c. a high-output burn-resistant phosphor compatible with the higher ambient light levels,

d. a circularly-polarized filter for cancellation of light reflected off the face plate,

e. negative image polarity to present dark traces on a light background,

f. a filter and phosphor combination which will minimize screen fluorescence, and

g. a fiber-optic or mesh-type filter which tends to reject incident light and pass screen-emitted light.

5.2.4.4 Reflected glare. Reflection and glare off CRT face plates and cover plates should be minimized by one or more appropriate techniques such as:

a. shielding the CRT,

b. positioning light sources so they do not reflect off the CRT face plate into the operator's eyes,

c. use of a circularly-polarized filter for cancellation of light reflected in off the CRT face plate,

d. use of a cross-polarized lighting system (a polarizing filter over the CRT rotated 90° with respect to polarizing filters over the light sources),

e. use of a controlled ambient light system which delivers light only to the necessary work areas and baffles it from the CRT,

f. use of a selective spectrum lighting system wherein the spectral output of the CRT is substantially outside the spectrum of the ambient illumination, and

g. application of an anti-reflective coating on the CRT face plate and non-bonded filter surfaces to reduce the proportion of reflected light.

5.2.4.5 Color. Color is inherently a good coding dimension, but it should be utilized only when any loss of CRT resolution resulting from the use of color is acceptable; color codes are compatible with color stereotypes and conventional usage; and all users will be able to perceive the code. (Because there are some color vision deficient personnel (about 8% male population, rare in female population) in the armed forces, it cannot be assumed that any random operator will be able to differentiate the color codes reliably. Use of some other code redundantly along with the color code is the best way to ensure that the codes will be differentiable by all personnel. Thus, if friendly and hostile tracks are to be differentiated by color, they should also be differentiable by some other means such as shape coding.)

5.2.4.6 Persistence. Transient signals of very short duration such as those derived from radar and active sonar systems should be displayed with sufficient persistence for the operator to perform whatever operations are needed with respect to the signals. Persistence beyond signal duration on the display may be accomplished through use of persistent phosphors, periodic repainting (refreshing) of the image from processor memory, or utilization of scan converters or direct view storage tubes as appropriate to the application. With rotating sweep indicators, the persistence should be at least such as to display even faint signals above threshold for a period equal to one-quarter of a sweep rotation. Short to medium persistence is adequate for scan rates such as those used for television. Because some of the personnel in the armed forces may have flicker frequency induced seizures, operators of such devices should be screened carefully.

5.2.4.7 Dynamic range. A dynamic range of at least 7 dB should be provided for detection of targets on a plan-type indicator, and 20 dB or more is desirable for detection on an A-scan presentation or other deflection display. A dynamic range of at least 7 dB should be provided for TV images, and applications where fine-grain detail is important, such as high-resolution reconnaissance sensors, should provide the maximum attainable with the state-of-the-art.

5.2.4.8 Jitter. Erratic movement of sweep traces on CRT displays should be diminished to the point where it is not detectable by the operator.

5.2.4.9 Flicker. The refresh (repaint) rate of signals or data displayed on a CRT should not be between the rates of 7 Hz and 28 Hz except in applications requiring sensor scanning at these rates and as otherwise noted. Rates between 1 and 7 Hz should be utilized only when it is desired to capitalize on the conspicuity value of such rates, such as for warning signals or in the rare circumstances when flash rate coding might be utilized. Refresh rates for data which are to be perceived as continuously presented should be adjusted upward from 28 Hz as necessary to reduce flicker to a non-detectable level over entire range of display luminance.

5.2.4.10 Spot size and resolution. The spot size on a CRT should be compatible with the signal characteristics and type of scan to be utilized. For radar the spot size preferably should be smaller than the minimum size of a returned pulse as presented on the slowest sweep (longest range scale) in order to avoid loss of resolving power inherent in the radar system. For most CRT display applications spot diameter at all parts of the screen should subtend no more than one minute of arc from the normal viewing position. Alphanumeric characters should be scaled to subtend at least 15 minutes of arc; other complex shapes should subtend at least 20 minutes of arc.

5.2.4.11 Hand-capacitance effects. For applications where the operator's hand normally comes close to the screen, such as in plotting on the face plate or in using a light pencil for data pickoff, aluminized backing of the screen should be utilized so as to minimize the effect of hand capacitance which tends to add uncontrolled deflection to the CRT beam.

5.2.4.12 Burning of screen. The display design should minimize the likelihood of burning of long persistence phosphor screens, since it cannot be assumed that burn-damaged CRTs will always be properly replaced under operational conditions, and the presence of burned areas seriously degrades display legibility. Anti-burn techniques include use of aluminized backings and protective circuits for automatic intensity reduction whenever the beam remains stationary.

5.2.4.13 Distortion. Sweep non-linearity with raster on plan-type scans should be less than 2 percent. CRTs displaying only alphanumeric or graphics should show no obvious distortion in any column or row of characters, and the character aspect ratio should appear to be constant at all parts of the screen.

5.2.4.14 Screen shape. CRT display surfaces used exclusively for data presentation of computer graphics should be rectangular in shape. CRT displays used exclusively for TV image presentation should also be rectangular and should normally follow the standard practice of having a 3:4 aspect ratio (height to width). Those CRTs used exclusively for polar plots of sensor data should be round. The preferred display surface shape for A-scan presentations is rectangular. CRTs used simultaneously or sequentially for two or more different display functions may have round, square, or rectangular display surfaces as best fit the combined purposes.

5.2.4.15 Useful screen diameter. The diameter of direct-viewing console-mounted CRTs should normally be within the limits listed below:

a. For detection of signals from sensor systems: 215 mm ± 40 mm.

b. For both detection and tracking: 300 mm ± 50 mm.

c. Tactical or situation displays: at least 380 mm, maximum 760 mm.

d. Alphanumeric displays: size by considering the largest format which will be required and the recommended character size.

e. TV: minimum 120 mm, maximum 600 mm.

f. Single character display: 20 mm minimum.

g. Display of single pulse or short sweep segment for qualitative monitoring only: 20 mm minimum.

Smaller CRTs than those listed for detection, detection and tracking, and situation display may be used where there are severe space constraints such as in aircraft or submarines or hand-held units.

5.2.4.16 Viewer protection. A transparent safety screen which may be integral with the CRT face plate should be provided to prevent implosion injury. Protection as needed should also be provided against low-intensity X-radiation as prescribed by current regulations.

5.2.4.17 "Housekeeping" controls. The number of "housekeeping" controls (focus, intensity, and centering) to be used by the operator for adjustment of the CRT should be kept to a minimum. Such controls which are to be used by the operator (as opposed to a maintenance technician) should be finger-operated and available from the front panel but recessed and preferably covered when not in use. It should be noted that CRT displays used for different functions may require adjustments for the various parameters.

5.2.4.18 Display composition features. Convenient controls should be provided for structuring the display format and content in accordance with user criteria. Display capability should be provided to present both the current settings of all controls relating to display composition, and the total range of settings available.

5.2.4.19 Viewing angle. CRT screens should be perpendicular to the operator's line of sight (have a 90° viewing angle at screen center) whenever feasible and no part of any screen including secondary CRTs should offer a viewing angle of less than 45° from the operator's normal position.

5.2.4.20 Special criteria for TV displays.

5.2.4.20.1 Resolution. Resolution should be 400 lines or greater, both horizontally and vertically, except for low-resolution applications where line spacing need not be closer than needed to subtend one minute of arc from the normal viewing position.

5.2.4.20.2 Frame rate and interlacing. Except for slow-scan systems for reproduction of static images, the frame rate for sampling of video material should be a minimum of 30 Hz. There should be two display scans (fields) per frame period (or a minimum of 60 Hz) with the lines of the second scan in the frame period interlaced with the lines of the first scan.

5.2.4.20.3 Phosphors. The phosphors for TV screens should have short or medium persistence and high output.

5.2.4.20.4 Distortion. Spot diameter should not vary by more than a ratio of 3:2 at any two points on the screen. Distortion should not be sufficient to cause obvious non-linearity anywhere on the screen when viewing alphanumeric formats or picture images.

5.2.4.20.5 Gray scale. There should be a minimum of at least five distinguishable gray scale levels. When the criteria include interpretation of handwriting, resolution of fine detail, or complex image interpretation, up to eight gray scale levels should be provided.

5.2.4.21 Special criteria for sensor displays.

5.2.4.21.1 Types of scans. The type of scan selected should be appropriate to the operator's task in utilizing the sensor data. Commonly used scan types should be selected in preference to novel or experimental scan types except as approved by the acquiring activity.

5.2.4.21.2 Display scale sizes and range ring values. Display scale should be selected on the basis of the following criteria:

a. If rings are to be used, the display scales selected should be compatible with use of a constant number of range rings regardless of scale, as follows:

3 Range Rings	4 Range Rings	5 Range Rings
Any decimal multiples of:	Any decimal multiples of:	Any decimal multiples of:
15 unit scale	4 unit scale	5 unit scale
30 unit scale	8 unit scale	10 unit scale
60 unit scale	20 unit scale	25 unit scale

Display systems capable of presenting alphanumerics should present range ring values on the CRT.

b. Appropriate scale limits considering sensor characteristics such as maximum range, range resolution, bearing resolution, and maximum range of detection. For example, the display scales for use with a shipboard surface search radar having a minimum range of 200 m and a maximum range of 60 km might be as follows:

(1) Minimum: 2 km (not more than 10 times the minimum range value, to capitalize on range determination at close-in ranges as in station keeping).

(2) Maximum: 75 km (accommodates maximum range of the radar and is a good scale for estimation and interpolation).

c. Area and scaling limits suggested by representative operational situations including warfare operations, search patterns, maneuvers, and flight operations. For example, an air traffic control center which may have a number of missions involving close-in aircraft operations at ranges from 15 to 30 km should have a 30 km display scale for monitoring and control of aircraft on such missions.

5.2.4.21.3 Offset. Provision for offsetting display center should be made if it is expected that operators may find it advantageous to sometimes confine their attention to an expanded portion of the display which would not be centered on the sensory location. The preferred way of offsetting is through positioning a CRT marker that centers the new display with a two-coordinate controller and activates it with an entry switch. If the amount of offset is sufficient to displace the original display center off the scope, then a simple means of recapturing the original center should be provided.

5.2.4.21.4 Resolution, signal size, and viewing distance. In general, the display should present sensor signals with sufficient display resolution to match the resolution of the system. (A precision radar needs a high-resolution display but a mosaic of infrared detectors can suffice with a much lower display resolution.) The signal size should be sufficient to provide a subtended visual angle for the target of at least 12 minutes of arc for the normal position of the viewer. When the target is of complex shape and recognition is required, it should subtend no less than 20 minutes of visual angle and at least 10 lines or resolution elements (25 minutes in presence of heavy noise or clutter).

5.2.4.21.5 Reference and boundary marks. Provision may be made for range rings, grid marks, azimuth markings, map outlines, operational boundaries, and velocity vectors as appropriate for the intended operational situation. When such aids are provided, they should be selected as needed, parallax-free, and controllable in intensity. There should be no more than five range rings on a plan-type indicator.

5.2.4.21.6 Operator loading. In planning the number of detection and tracking displays which may be needed in a system, the following criteria should be considered:

a. Detection performance decreases as the amount of target activity increases. Detection displays should not require monitoring of more than four concurrent and independent detection situations by an unaided operator.

b. In a computer-based system relying upon operator updating of target positions, individual displays should not require tracking of more than six independent air targets or more than 15 independent surface targets. Systems which will be employed in situations where there may be groups of targets moving with common velocities should be capable of presenting computer-aided tracking aids such as raid-forming gates which treat the entire group as a single target for tracking purposes.

c. Systems performing automatic detection and tracking should provide sufficient display capability to accommodate an appropriate level of operator monitoring for manual backup in case of computer failure.

5.2.4.21.7 Automatic sequencing. Computer-aided display systems may provide priority-ordered automatic sequencing to facilitate manual track position updating or other recurrent manual operations. With automatic sequencing, each time a position update is entered by the operator, a marker on the display steps to the position of the next track needing updating.

5.2.4.21.8 Data readout. Computer-aided display systems should provide convenient operator-oriented facilities for readout of selected information on demand. In tactical data systems this may involve use of a two-coordinate controller to designate specific tracks on the CRT for readout, and an auxiliary display presenting formatted information held by the computer concerning the designated track.

5.2.4.21.9 Handover. Computer-aided display systems should provide convenient means for transferring responsibilities between operators (handover of targets on the basis of sector transit or operator overload).

5.2.4.21.10 Display gates. Computer-aided systems may provide display gates controllable in size and position by the operator to designate areas within which signal return is blanked out (censored) or identified as calling for special processing.

5.2.4.22 Special criteria for computer-generated displays.

5.2.4.22.1 Display of processed sensor data.

5.2.4.22.1.1 Quantized data. Systems which process and quantize sensor data before presenting it to an operator for detection should provide a minimum signal size on the display of 12 minutes of visual angle for the viewer's normal position; display coding to maximize the opportunity to discriminate signals from noise; and operator control to electronically mark points to be monitored, correlated, entered, or dropped.

5.2.4.22.1.2 Time-integrated data. Systems which accumulate processed data and present all or part of that history in integrated fashion on current scans should provide controls for adjusting the amount of data history to be displayed, means to differentiate the most recent data from the older data, and operator control to electronically mark points to be entered or dropped.

5.2.4.22.1.3 Time-compressed data. Systems which accumulate processed data and present all or part of that history in accelerated sequential playback should provide controls for adjusting the amount of data history to be displayed, adjusting playback rate between the limits of 12 and 30 frames per second, and electronically marking points to be entered or dropped. (For most applications, the minimum number of scans to be displayed in a sequence should be six.)

5.2.4.22.2 Alphanumeric characters.

5.2.4.22.2.1 Character generation. Provided they meet the legibility guidelines, characters may be generated by any of the commonly used techniques including the following:

a. Stroke generation, in which the character is drawn by deflecting the CRT beam through a series of connected line segments.

b. Lissajous generation, in which the beam is deflected through a sequence of segments of lissajous figures.

c. Facsimile generation, in which character shapes are stored in analog form as a mask within the CRT and are used to shape the electron beam.

d. Dot matrix generation in which an electronically stored dot matrix memory is used to intensity-modulate the beam as it scans the character space.

5.2.4.22.2.2 Legibility criteria. CRT-presented characters should be designed to avoid look-alike pairs which might be confused with one another (B and 8, 5 and S, 0 and D.) Characters should generally conform to the legibility criteria when:

a. Stroke width on CRTs for single-operator use may be determined by the normal width of a stroke on the CRT rather than by a fixed ratio of stroke width to height.

b. Minimum character height on raster scans should be seven raster lines.

5.2.4.22.3 Symbols and symbol modifiers. Symbols and their modifiers which are presented on CRTs should meet the following criteria.

a. Except for dots; small circles; and keyboard generated symbols such as the dash, quotation marks, and commas, minimum height of symbols should at least equal the minimum height for characters. Minimum symbol height on raster scans should be at least seven raster lines.

b. Color coding of symbols should be used only redundantly with some other coding technique. (For example, if shape coding is utilized to differentiate between hostile and friendly tracks, color coding may also be used to enhance the difference, but color coding should not be used as the sole means of differentiation.)

c. Selection of a symbol set and modifiers should be based on the following criteria:

   (1) Symbols and modifiers should reflect the interrelationships among the data in the set. For example, if a target represented by a circle, an engaged target should be presented as a modified circle (a circle with a bar across it) rather than as a completely different symbol (a triangle).

   (2) Clear differentiation should be maintained between basic symbol types, between modified symbol types, and between modified and unmodified symbols.

   (3) No more than five variations (three preferred) in a single dimension (hue for color coding) should be utilized in any set of symbols which must be discriminated from one another on an absolute basis (without side by side comparison).

5.2.4.22.4 Refresh rates. Except for time-compressed data and warning or alerting signals, all data on CRTs should be displayed at refresh rates of at least 28 Hz or greater as needed to prevent noticeable flicker.

5.2.4.22.5 Display-composition features. Convenient controls should be provided to allow the operator to select the categories of information which are needed for independent display and to determine how the selected information should be displayed (normal symbology, dots only, intensified, blinking, if this type of selective control over presentation mode is needed by the operator for task performance). Controls should be on an alternate action basis so that one switch action adds the category and the alternate action removes it (as opposed to two independent controls, one to add and the other to remove.) Positive indication should be provided at all times for the state of the display-composition switches. (The operator needs to be able to conveniently read out at any point in time precisely how the display has been structured.)

5.2.4.22.6 Operator-computer interaction. The opportunity for constructive use of operator-computer interaction should be considered for the following situations (as applicable):

a. Generation of trial solutions to tactical problems.

b. Generation of free-drawn graphics.

c. Solution of relative motion problems.

d. Construction of formatted messages.

e. Editing of messages.

5.2.4.22.7 Data readout. Computer-generated display systems should provide convenient operator-oriented means for readout of selected information on demand. In tactical data systems this may involve use of a two-coordinate controller to designate specific tracks for readout, a keyboard for entry of instructions to the computer, sophisticated computer algorithms for processing information per operator request, and displays for presenting formatted information in response to track oriented or other information requests.

5.2.4.22.8 Handover. Computer-generated display systems should provide convenient means for transferring responsibilities between operators (complete handover of responsibility as in shutting down a console, or handover of individual targets on the basis of sector transit, engagement status, or operator overload).

5.2.4.22.9 Interdisplay pointing. Incorporation of interdisplay pointing should be considered to allow each operator to position a display marker and drive one or more slaved markers on other displays as selected, to facilitate communication regarding areas of interest.

5.2.4.22.10 Composition and editing of messages. When the computer is used to assist the operator in composing and/or editing CRT-displayed messages the following features should be provided:

a. a cursor on the display (a line beneath a character) to identify where the operator is in the sequence,

b. controls as needed to allow rapid positioning of the cursor,

c. selection capability for standard message formats, and

d. automatic composition of those parts of standard formats for which the computer has the data.

5.2.4.22.11 Automation of functions.

5.2.4.22.11.1 Criteria for automation. Automated systems should be used to:

a. prevent operator saturation as in the detection and tracking of large numbers of targets in a surveillance system,

b. detect events (targets, signals) when the frequency of occurrence is very low and the unaided operator cannot maintain the required vigilance over the long period of time between events, and

c. replace manual functions wherever the capabilities of the automated system are clearly superior to those of a purely manual system.

5.2.4.22.11.2 Data filtering for monitoring automated functions. Displays used exclusively for monitoring automated functions should operate on a discrepancy or "management by exception" basis wherein only those data which deviate from expectation according to system mode and operational conditions are displayed. (This includes data on processor function as well as operational data.)

5.2.4.22.11.3 Data presentation for manual backup. In systems where manual backup may be required in case of computer failure, the backup display should not operate strictly on a discrepancy basis but rather should present sufficient data to keep the operator advised of the current state of processing and to provide all the baseline data which would be needed to initiate manual operation at any point in time.

5.2.4.22.11.4 Timely data processing and display. Automated systems should be designed to:

a. respond to operator information requests and control inputs in a timely manner,

b. impose minimal burden on the operator for routine aspects of data management, and

c. present routine information to the operator on a time-phased basis related to the task sequence but present urgent information on an interrupt basis using alerting techniques.

5.2.5 Large-screen displays.

5.2.5.1 Use. Large-screen displays may be used when:

a. groups of operators frequently refer to the same information and are required to interact as a team, based on the same information,

b. one or more members of a team of operators have to move about, yet require frequent referral to information required to make decisions, but which they cannot carry with them, or do not have displayed at their assigned position(s),

c. there are space or other constraints that preclude the use of individual displays for each team member to call up commonly-used information, or

d. it may be desirable to have general information available to persons who must not interrupt ongoing group operations by looking over the shoulder(s) of individual operator(s) to see their individual displays.

5.2.5.2 Angle of view. All critical display observers should be able to view the display as perpendicularly as possible, and in no case at an angle of less than 40° from the plane of the screen.

5.2.6 Other displays.

5.2.6.1 General.

5.2.6.1.1 Application. Where applicable, other display concepts, devices and/or techniques should be considered, including the following:

a. digit light arrays to monitor "countdown" operations,

b. drum-type, mechanical counters to display discrete numerical values, but non-trend information,

c. character readout devices (stacked edge-lit, back-projected, gas-discharge tube, CRT, plasma, liquid crystal display (LCD), light-emitting diode (LED)) that present alternate characters (numericals, letters, or numerals and letters) within the same viewing envelope, which may be used in conjunction with, or in lieu of a or b above,

d. mechanical flags incorporated within an instrument to indicate that the instrument is in a go vs no-go condition,

e. plotters and recorders to provide visual record of continuous graphic data,

f. printers for producing hard copy records from manual or computer input, and

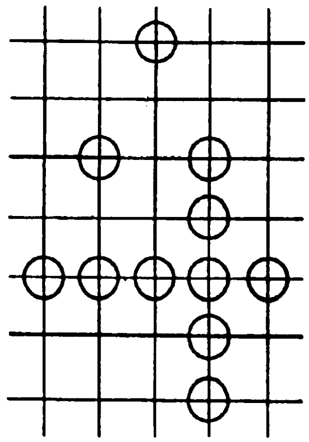
g. optical projection systems to present static and/or dynamic information for large screen, group viewing, projection of guidance information on a vehicle windscreen (head-up display), and for display of composite situation information.

5.2.6.1.2 Character-generating devices.

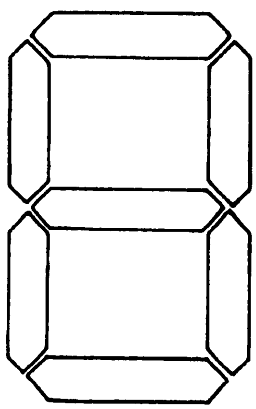
5.2.6.1.2.1 General. In making a selection from among the several types of readout devices, consideration should be given to the limitations of each device in terms of available brightness, colors, and reading speed and accuracy. For example, the character legibility of some indicators is better than others.

a. Devices that produce continuous-line characters provide the opportunity to maximize key legibility parameters, such as height-to-width ratio, stroke width, luminance contrast, and color.

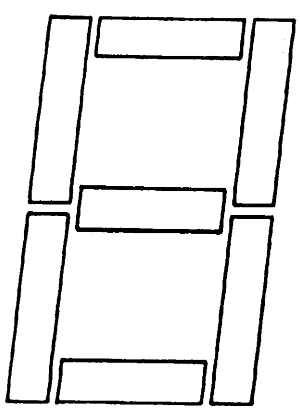
b. Devices that produce characters by means of dot or line segment patterns are limited in terms of the above legibility parameters. Dot patterns are more readable (see Figure 8).



5 x 7 DOT MATRIX MAYBE USED FOR BOTH LETTERS AND NUMERALS, AS WELL AS OTHER SYMBOLS. A 7 X 9 IS PREFERRED WHEN ACCURACY IS OF PARTICULAR IMPORTANCE FOR ALPHANUMERIC DATA SETS.



7-SEGMENT BAR-TYPE MATRIX IS ACCEPTABLE FOR NUMERALS, BUT CANNOT PROVIDE A FULL ALPHABET OF LETTERS.



ITALIC OR SLOPING MATRIX IS ACCEPTABLE AS LONG AS THE SLOPE DOES NOT EXCEED 11°.

FIGURE 8. Selection of dot and segmented matrix characters.

c. Depending on the state-of-the-art for a given device, some devices may be too large or too small for the particular application, such as panel space limits or viewing distance limits.

5.2.6.1.2.2 Alphanumeric character format. Characters and symbols should appear upright or slope slightly (up to 11°) to the right. Legibility and readability of unusual formats should be equivalent to that of standard Gothic capital letters and numerals.

5.2.6.1.2.3 Contrast direction. Character generation techniques should be chosen to best fit the operating environment.

a. Light symbols on a dark background should be used when work area illumination is low (less than about 3.4 cd/m^2)·

b. Either a light or dark background should be chosen for intermediate illumination levels.

c. Dark symbols on a light background is preferred when ambient light conditions are high (more than about 3400 cd/m^2).

5.2.6.1.2.4 Indicator spacing. Devices which are subject to glare problems (stacked edge-lit, gas-discharge tubes) should be designed to minimize intersurface reflections, halo effects around glow wires or engravings, and "hot spots" from lamp sources. When the particular display may be affected by external (ambient) light reflections, filters and/or anti-reflection coatings should be provided.

5.2.6.1.2.5 Lamp replacement. Devices which depend upon incandescent lamp sources should be packaged for ease of lamp replacement.

5.2.6.1.2.6 Intensity Control. Digital readout devices that may be used under dim-out or blackout operating conditions should be selected on the basis that operator-controlled dimming will be provided.

5.2.6.1.3 Digit light arrays.

5.2.6.1.3.1 Arrangement. Digit light arrays used for other than countdown purposes, should be arranged in normal single line format with increasing numbers from left to right or from top to bottom. The sequence for countdown operation should be reversed so that the numbers decrease from left to right or from top to bottom (see Figure 9).

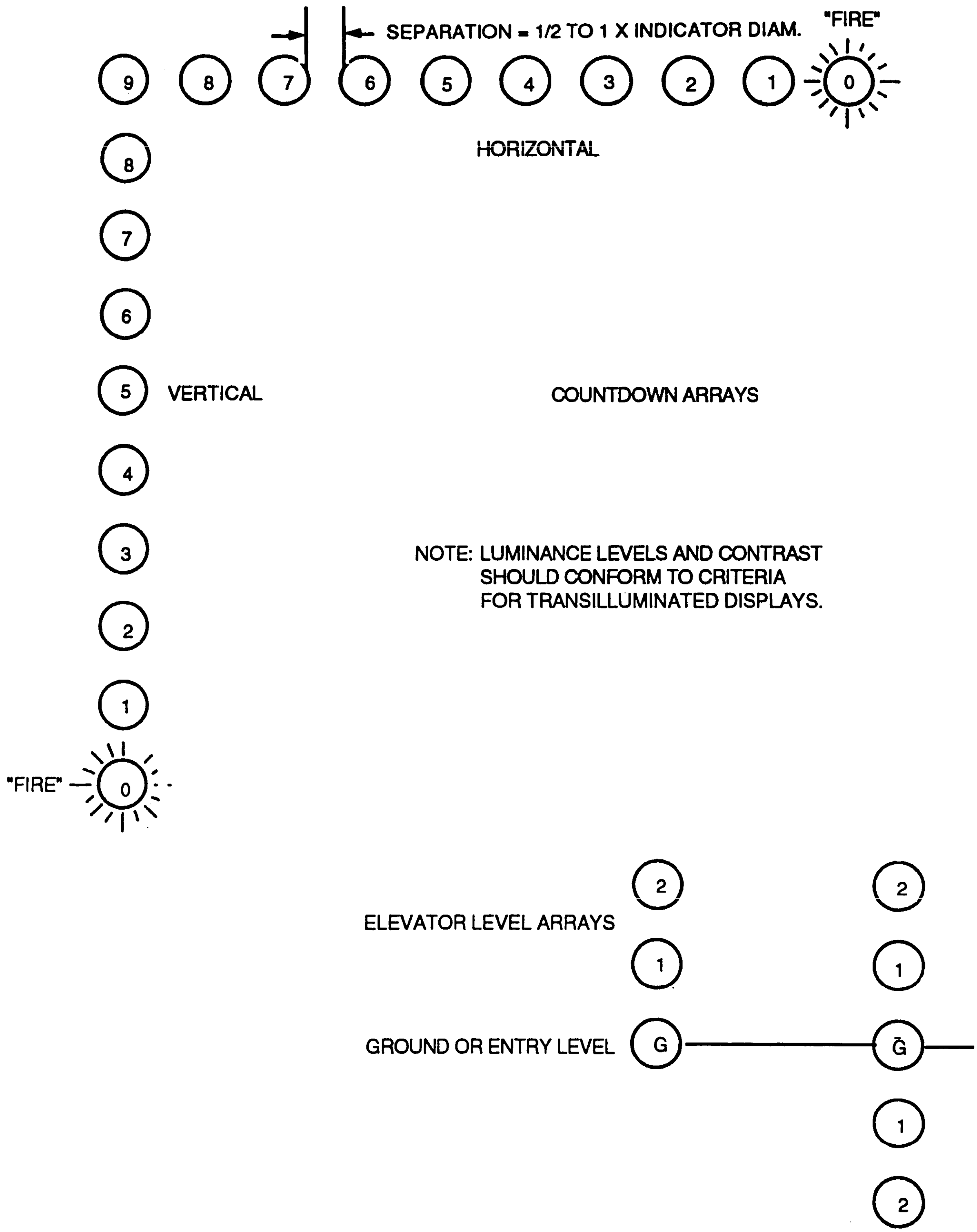


FIGURE 9. Digit light counter arrays.

5.2.6.1.3.2 Spacing. Lights should be spaced as follows:

a. Minimum = one half the diameter of the indicator light.

b. Maximum = equal to the diameter of the indicator light.

5.2.6.1.3.3 Color and contrast. Black numbers on a white background should be used (unless specific approval for a reversed contrast or colors is given by the acquiring activity). Adjacent panel surface should appear darker than the lighted indicator (a minimum contrast of 50 percent), and the surface should have a dull or matte finish.

5.2.6.2 Counters.

5.2.6.2.1 General.

5.2.6.2.1.1 Spacing. Large horizontal spacing between number drums should be avoided.

5.2.6.2.1.2 Snap action. If the operator must read numbers consecutively, numbers should not change faster than twice a second. Odometers and hour meters are exceptions to this rule.

5.2.6.2.1.3 Illumination. Table 3 shows the character sizes that should be used for counters viewed from various distances and under different illumination levels.

TABLE 3. Character sizes for mechanical counters (mm).

Viewing Distance	Height	Width	Stroke Width	Minimum Separation Between Numerals
Normal Illumination (above 3.4 cd/m^2)				
710	3.80	3.80	0.94	0.64
910	4.80	4.80	1.20	0.81
1525	7.90	7.90	1.30	1.30
Low Illumination (0.1 to 3.4 cd/m^2)				
710	5.60	5.60	0.94	0.94
910	7.10	7.10	1.20	1.20
1525	13.00	13.00	2.10	2.10

NOTE: For reading distances closer than 710 mm, characters should be at least 3 mm high.

5.2.6.2.1.4 Numbers. Numbers on counters should read horizontally, from left to right, rather than vertically.

5.2.6.2.1.5 Color. When only a small area of the counter drum is visible around each number, the counter frame should be the same color as the drum.

5.2.6.2.2 Drum-type mechanical counters. Mechanical, drum-type counters should conform to criteria in Figure 10.

5.2.6.3 Printers.

5.2.6.3.1 Application. Printers should not be excessively noisy if they will be located in an area normally occupied by personnel for more than a few minutes or where critical direct or telephone conversations are required.

5.2.6.3.2 Features. Printers should have the features shown below:

a. A paper advance control should be provided where necessary so the operator can read the most recently printed line.

b. A cutting edge should be provided to remove printed material rapidly and evenly.

c. There should be an indication of the paper supply remaining.

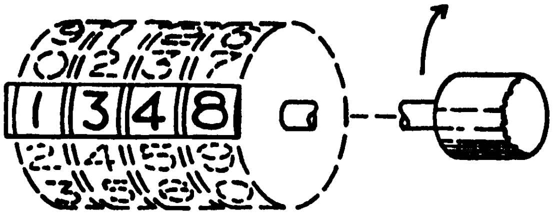
d. There should be some provision for taking up finished copy.

e. Paper retainers should be provided to reduce paper vibration.

5.2.6.3.3 Lettering. Lettering should be black on white paper to provide maximum contrast.

5.2.6.3.4 Paper. Hard-finish matte paper should be used to avoid smudged copy and glare. If record research is required, accordion-fold paper should be used.

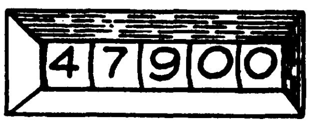
5.2.6.3.5 Control, replenishment, and service. Provision should be made for loading paper, ribbon, or ink without extensive disassembly or using special tools. Instructions for reloading should appear on an instruction plate attached to the printer. In addition, storage should be provided for supplies such as ribbons, spare paper, and ink.

a. 

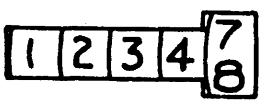
a. Counter drums should be numbered so that a clockwise rotation of drums and/or reset control produce increasing numerical values. Numerals should "snap" into position so that the entire numeral appears within the viewing window. Number height: width proportions should be within the range of 5:3 to 1:1, (1:1 is the preferred ratio) except for number '1'.

b. 

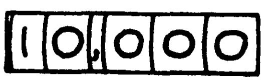
b. Spacing between adjacent numerals should not exceed 1/4 width of wide numerals; 1/2 width of narrow numerals when several numbers are to be read as a total value.

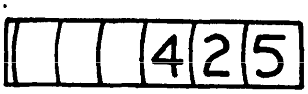
c. 

c. Counter drums should be mounted as close to the front panel surface as practical and the edges of the viewing window should be beveled to provide at least 45° off-angle view of the display.

d. 

d. When numbers on right drums need not be read accurately, these may move in a continuous motion--in which case at least two of the numbers should be visible.

e. 

f. 

e. Decimal points may be inserted within the viewing window or placed on the panel when the position remains constant. Commas should not be used unless more than four numbers appear in the window.

f. If left-hand numbers are seldom used, a blanking system should be provided rather than presenting several preceding zeros (the blanking device only exposes left-hand drums when numerical value is displayed.

FIGURE 10. Drum-type counter design.

5.2.6.4 Plotters and recorders. Reserved.

5.2.6.5 Flags.

5.2.6.5.1 Application. Flags should be used to display qualitative, non-emergency conditions.

5.2.6.5.2 Mounting. Where practicable the flag, when in the no-go position, should extend into the display area (and preferably obscure some displayed element) far enough to ensure that the operator will take note of the condition indicated by the flag (display or instrument inoperative).

5.2.6.6 Large-screen optical projection displays. Reserved.

5.2.6.7 Light-emitting diodes (LEDs).

5.2.6.7.1 Application. LEDs may be used in matrix displays in natural-emission colors, provided color-coding is not required. Red LEDs should be used in transilluminated displays in crew stations exposed to ambient illumination of direct sunlight. LEDs used in alphanumeric displays and green and yellow LEDs should not be used without approval of the acquiring activity.

5.2.6.7.2 Intensity control. The dimming of LEDs should be compatible with the dimming of incandescent lamps.

5.2.6.8 Dot matrix and segmented displays. Reserved.

5.2.6.9 Electroluminescent displays. Reserved.

5.3 Audio displays.

5.3.1 General. Speech input is received through microphones for processing and transmission through voice communication systems or for entry to speech recognition systems. Audio displays are used not only to present voice communication from another source but also to present sonically-derived sensor data, synthetic speech, alerting and cueing signals, and other acoustically-coded information. Unlike vision, which can be interrupted by eyelid closure, auditory input is constant. The perception of visual and auditory stimuli is influenced by the ability of the human brain to integrate this input. Vision integrates spatial contrast border, brightness, and color information while audition integrates sound pattern, dynamics, and frequency information. Visual and auditory integration times vary and depend upon several stimulus parameters but are normally short. These differences and others discussed in this section should be considered in planning and designing systems utilizing speech or other acoustic signals.

5.3.1.1 Use.

5.3.1.1.1 Voice Communication. Voice communication should be considered for systems in the situations listed below.

a. The message content or format cannot be predicted in advance.

b. Considerable and/or rapid interaction between operators will be required as where there must be joint solution of a war problem, or where it is necessary to "break into" concurrent information transmission.

c. The voice signal itself offers assurance of essential psychological support not otherwise available.

d. Users cannot conveniently look at a visual display to obtain information.

5.3.1.1.2 Individual speaker recognition. Automatic speaker recognition techniques may be employed in systems to positively identify an originator to an addressee or to restrict communication access to specific individuals (to limit access to a data bank). If individual speaker recognition is used for security purposes (to deny access to classified material by unauthorized personnel), it should be used in combination with some other control method in order to attain sufficient reliability.

5.3.1.1.3 Speech recognition for information retrieval and computer control. Automatic speech recognition systems which are used to recognize the spoken words but not the individual speaker provide an alternate to keysetting techniques for information retrieval and computer control. However, because of the possible misapplication of automatic speech recognition, such techniques should be considered for use only when:

a. the vocabulary needed at each phase of operation is comparatively small, (vocabulary criteria can be considerably reduced by using syntax control which limits the necessary vocabulary search to the words which are plausible at that particular point in the entry sequence),

b. error rates would be comparable to or more favorable than those with other types of control input such as keysets,

c. speed of entry would be equal to or faster than conventional entry techniques,

d. convenient means of error detection and correction are provided,

e. convenient means are provided to inhibit the system except when speech input is intended, and

f. performance will be satisfactory even under stress conditions.

5.3.1.1.4 Audio displays. Audio displays are necessary when amplified signals are used in voice communication. They should also be considered under the conditions listed below.

a. The information that is to be processed is short, simple, and transitory, requiring an immediate or time-based response.

b. The visual display is restricted by: overburdening; ambient light variability or limitation; operator mobility; degradation of vision by reason of vibration, high-g forces, or hypoxia; other environmental considerations; or anticipated operator inattention.

c. The critical nature of transmission response makes supplementary or redundant transmission desirable.

d. It is desirable to capture the operator's attention for advisory, cueing, alerting, or warning purposes.

e. Custom or usage has created anticipation of an audio display.

f. An auditory presentation is desirable to reinforce a visual presentation.

5.3.1.1.5 Sensor applications. Audio displays for sensor systems such as sonar and electronic countermeasures should be made compatible with the criteria stated herein. Deviations should require approval of acquiring activity.

5.3.2 Audio signals.

5.3.2.1 Warning signals. Warning signals should be used to alert personnel of immediate action required in hazardous or emergency situations. These signals should alert personnel and transmit identifying or action signals. These functions may be accommodated by either a two-element or single-element signal as appropriate to the situation in consideration of the total acoustic signal environment. Ordinarily, if a small set of warning signals is used, the single-element signal would be preferred since this would provide the shortest reaction time. Warning signals should consist of distinctive complex sounds of exceptional attention-getting value and be presented at a level of at least 20 dB (on the A-weighted scale) above the noise environment. Examples of warning signals include fire alarms, collision alarms, and transit bells on cranes.

5.3.2.2 Caution signals. Caution signals should be used to capture the attention of personnel so as to direct them to potentially destructive conditions requiring immediate awareness. (There is not immediate threat to life or major property damage, but there may be incipient threat to either, or there may be a possible threat to major system malfunction or abort.) They may provide either one or two functions. A single-function caution signal consists of an alert only and should be accompanied by a visually-presented message identifying the specific nature of the caution situation. Two-function caution signals which provide both the alerting and identification functions should be used where the total number of caution signals is small. Caution signals should consist of distinctive complex sounds at least 20 dB on the A-weighted scale above the noise environment. They should persist intermittently until restoration of normal conditions or manual shut off. Upon termination, they should be automatically reset to respond to the next initiating condition. A volume control may be incorporated provided full volume is automatically restored upon initiation of the next caution signal.

5.3.2.3 Alerting signals.

5.3.2.3.1 General. Alerting signals should be provided whenever there is a requirement for immediate response to a situation outside of the operator's normal task sequence, such as when there is incoming traffic on an unattended circuit, or some system function needs attention on an irregular basis, or there may be a minor component failure. Alerting signals should be of a spectral composition and character more demanding of attention than either advisory or cueing signals. They may be momentary or continuous in nature as appropriate, but if momentary they should be repeated periodically until either proper action is taken or the signal is turned off. Similarly, continuously-presented alerting signals should persist until initiation of proper action or signal turn-off. After the signal is terminated, it should be automatically reset to respond to the next initiating condition. As a general rule, alerting signals should exceed the noise level in the critical band for all major signal components by at least 20 dB.

5.3.2.3.2 Differentiation from routine signals. Alerting signals intended to bring the operator's attention to a malfunction or failure should be differentiated from routine signals such as bells, buzzers, and normal operation noises.

5.3.2.4 Advisory signals. Audio signals may be provided to transmit information of an advisory nature which does not require specific operator response or acknowledgment. In quiet areas, advisory signals should be presented at a level of 50 to 70 dB on the A-weighted scale. Where there is a noise background, they should be at least 20 dB above the noise level in the critical band centered on each major component frequency of the advisory signal.

5.3.2.5 Cueing signals. Audio cueing signals should be provided for pacing operator actions in situations requiring timely execution of task elements but where: (1) operator attention may be diverted from the task at hand, or (2) the operator depends on the cueing signal to know when to perform the task. Cueing signals may be used in combination with visually-presented messages providing specific task element instructions. Cueing signals should be short, tonal, and non-annoying but distinctive in character, and, as a general rule, should exceed the noise level in the critical band by at least 20 dB. Consideration should be given to instrumenting the cueing signal system so as to generate a repetition of the signal if the operator fails to perform the desired action.

5.3.2.6 Prioritization. When there could be a possibility of simultaneous presentation of automatically initiated messages, a message priority system should be provided, such that the most critical message overrides for initial presentation any messages occurring lower on the priority list. Following initial presentation of the top priority message, other messages should be presented in the priority order, except that no caution messages should be presented until all warning messages are terminated.

5.3.3 Characteristics of audio warning signals.

5.3.3.1 Warning recognition time. Warning signals should be sufficiently distinctive so that they can be unambiguously recognized as warning signals within 0.5 seconds of initiation. Single-element signals should, in addition, convey full meaning of the signal within that initial 0.5 second period. In the worst case, two-element signals should convey full meaning of the signal within 2.5 seconds of initiation.

5.3.3.2 Control of warning signals. Warning signals may be either manually or automatically initiated, whichever is more appropriate to the circumstances. Manually initiated signals should also be manually terminated. Automatically initiated signals should persist until either automatically or manually terminated. Automatic termination should not be on a time basis but rather on either initiation of action to restore normal conditions or upon restoration of normal conditions. Provision for manual termination should always be provided. Automatic reset for the next initiating condition should be provided for all signals which can be automatically initiated. Local area volume control (with volume reduction limited to ensure signal audibility) may be incorporated provided full volume is automatically restored upon initiation of the next warning signal.

5.3.3.3 Compatibility with existing signal codes. Warning signal characteristics and meanings selected for a system or facility should be compatible with signals already established for the particular warning situation.

5.3.3.4 Compatibility with other critical signals. No warning signal should be of such a character as to preclude hearing any other warning signal or reception of vital voice communication.

5.3.4 Signal characteristics in relation to operational conditions and objectives. Reserved.

5.3.5 Verbal warning signals. Reserved.

5.3.6 Controls for audio warning devices. Reserved.

5.3.7 Speech transmission equipment. Reserved.

5.3.8 Speech reception equipment. Reserved.

5.3.9 Operator comfort and convenience. Materials selected should be impervious to biological organisms such as molds and fungi and should not deteriorate from humidity or perspiration.

5.3.10 Operating controls for voice communication equipment. For situations in which operators using microphones and/or headsets also have both hands occupied most of the time, consideration should be given to providing hands-free operation of microphone and headset switching through use of foot switches, voice-actuated switches, or remotely controlled switches as appropriate to the circuits in use. If there may be any requirement to operate the microphone and/or headset switching from a standing position, then hand-operated switches should also be provided.

5.3.11 Speaker side tone. If headsets are used, feedback of the speaker's own voice (side tone) should be provided via the earphones.

5.3.12 Speech intelligibility. Reserved.

5.3.13 Communications.

5.3.13.1 General. Voice communication is the most common method of requesting and providing information. In military systems, information may be transmitted by using radio or telephone or from operator to operator. Electrically transmitted speech depends, to a great extent, on the characteristics of the microphone, transmission equipment, and the reception equipment; however, both direct and electrically transmitted communications have certain limitations in common. One of the limitations is the acoustical environment of both the speaker and listener, and this factor is of great importance in determining communication effectiveness. Communication equipment should be located to ensure the maximum intelligibility in the area served. In most cases, this will require a receiver and headset, i.e., earphones housed in earcups. The earphones will provide the audio signal close to the ear and the earcups will provide a passive attenuation of environmental noise. The combination of earphones and earcups increase the signal-to-noise ratio of the audio signal.

5.3.13.1.1 Masking of speech by noise. Most of the energy required for near-perfect speech intelligibility is contained in the range of 200-6,100 Hz. This range may be narrowed to 250-4,000 Hz without significant loss in intelligibility. Consonants contain energy mainly at frequencies above 1,500 Hz, whereas vowels contain lower-frequency energy. Unfortunately, the consonants, which convey most of the information in English speech, contain very little energy. Thus, they are more subject to interference (masking) from noise than are vowels. Vowels contain more energy but transmit less information. Since masking of the audio signal is mainly the result of low frequency noise, the use of active noise reduction (ANR) should be used to phase cancel low frequency noise. This is especially important in extremely noisy background environments when passive attenuation is normally used to reduce background noise.

5.3.13.1.2 Power. The communication system should be capable of power output at least 15 dB louder than the anticipated ambient noise. The user should have a gain control for adjusting the output level. Output sound pressure level should not exceed 105 dB peak voice level at the ear, but where appropriate, average level may be increased by using compression or automatic volume control.

5.3.13.1.3 Audible signals. When two or more items of communication equipment with audible signals (telephone, radio, and intercom) are in the same area, each should have a distinct signal or 3D audio technology should be used.

5.3.13.2 Telephones. A telephone should be used when messages are from one person to another person, ambient noise is too high (more than 75 dBA, or exceeding NC-55) for a loudspeaker system, and security of communication is a requirement. If the operator is in a fixed position with hands free, a handset should be used; if the operator's task requires using both hands, a headset should be used; and if the operator must be mobile within a limited area, a headset and extension cord should be used.

5.3.13.3 Loudspeakers (announcing system or intercom). An announcing system or intercom may be used when:

a. the ambient noise level is low,

b. it is desirable to transmit to several stations simultaneously,

c. it is desirable for several persons within a space to receive simultaneously, and

d. the listener must move about within a space, and a headset would be an impediment.

5.3.13.4 Receiver and headset. The receiver and headset should have a frequency response of ± 3 dB between 250 and 6,000 Hz to maximize intelligibility.

5.3.13.4.1 Warning signals. Auditory warning signals should be presented through the operator's headset as well as to the work area when ambient noise level will exceed 85 dBA or when the operator will ordinarily wear earphones covering both ears during normal equipment operation.

5.3.13.4.2 Headset jacks. Headset jacks or connectors should be placed so the headset cord will not obstruct the work area or interfere with the operator's normal functions. If listeners wear headsets while working in high ambient noise (85 dBA or above), headsets should cover both ears, and their attenuation qualities should be capable of reducing the ambient noise level to less than 85 dBA.

5.3.13.5 Talkers. Supervisory personnel may sometimes be required to maintain communications on (or monitor) more than one circuit at a time. These personnel should be assisted by the use of 3D audio technology to help clarify multiple source audio input signals or a talker who can monitor and repeat messages on the major or the more important circuit, as assigned. The talker's duties are passing on outgoing messages and repeating incoming ones. The supervisor or equipment operator should have a talker if they receive messages simultaneously on different channels, receive so many messages on a single channel that they distract from another task(s), or move often enough, or far enough, that it becomes impractical to use extension cords. The use of multi-channel wireless FM receivers should be considered as a replacement to hard wire extension cords.

5.3.13.6 Radio sets.

5.3.13.6.1 Location. The radio set should be located where normal system operations and crew activities are not likely to damage it. Such locations should also minimize interference with the crew's normal range of movement and eliminate hazards to them. However, radio control panels should be readily visible and accessible to operators. The operator should also be able to reach control panel(s) to change frequency without having to open doors or remove covers. When protective devices such as fuses and circuit breakers are located inside the equipment, there should be a visible status indicator where the operator can see it.

5.3.13.6.2 Safety. All external metal parts which operators ordinarily touch should be at ground potential. There should be a provision for discharging high-voltage circuits and capacitors to 30 volts within two seconds before maintenance personnel work on them. In addition, if components in a high-voltage circuit have exposed terminals, they should be protected so that operating and maintenance personnel cannot short circuit, ground, or contact them accidentally.

5.3.13.7 Radio antenna. Locations for radio antennas should be selected to minimize the possibility of radio frequency hazards to personnel. Antennas and waveguides should be at ground potential, except for the radio frequency energy meant to be radiated.

5.3.13.8 Control box. Control box locations should be chosen so that operators have easy access to controls. The boxes themselves should not interfere with the operator's normal movements or present any hazard to them. It is important that the boxes not be placed where they are likely to be used as footrests or steps. Any cables connected to headsets or microphones should be clear of rotating or moving linkages. Boxes should be within easy reach of standard connecting cables (760 mm) from the crewman's nominal working area. If warning lights are mounted on the control box, they should be located within the responsible crewman's field of vision.

5.3.13.9 Audio accessories. Stowage hooks should be provided in each crew member's normal working area for storing audio accessories such as microphones, headsets, handsets, and cords when not in use. However, these hooks should be located where they will neither obstruct the operator's normal movements nor be likely to cause injury when equipment is removed from stowed positions.

5.3.13.10 Cable routing. All interconnecting cables should be routed neatly (clamped at approximately 300 mm intervals) to eliminate droop and unnecessary loops so that personnel are not apt to use them as handholds or steps. If this is not feasible, cables should be covered by protective guards.

5.3.13.11 Telephone or radio communications. Design of military integrated telephone or radio communication systems, either of a switched or point-to-point nature, should be in accordance with the applicable requirements of MIL-STD-188.

This Page Intentionally Left Blank.

5.4 Controls.

5.4.1 General criteria.

5.4.1.1 Selection. Criteria in Table 4 should be used in determining the type of control to be used on operator control panels. In addition, the following paragraphs should be consulted before deciding on specific control application. Table 5 shows recommended controls.

5.4.1.1.1 Basic factors in selection. Basic factors in selection include:

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

b. the task's criteria (precision, speed, range, and force required to use the control) and how the system is affected by sacrificing one to improve another,

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

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

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

5.4.1.1.2 Compatibility with users. The type of control selected and the location of the motion envelopes should assure that suitably-clothed and suitably-equipped user personnel with applicable 5th through 95th percentile body dimensions and 5th percentile strength can operate them.

5.4.1.1.3 Functional efficiency. Since more operators are right-handed than left-handed, a higher portion of operators will be more accurate, faster, and be able to apply more force with the right hand or foot than with the left. Accordingly, equipment should generally be designed for right-handed operation.

a. Hand manipulation is more precise than foot manipulation.

b. More force usually can be applied by the foot and leg than by the hand and arm.

TABLE 4. Control selection criteria.

FUNCTION	CONTROL									
	Selector Switch	Round Knob	Discrete Thumb Wheel	Cont. Thumb Wheel	Crank	Push Button	Toggle Switch	Rocker Switch	Lever	Joystick, Ball, Mouse
Select power state ON-OFF	3					1	2	2	1[a]	
3-State (OFF-STBY-ON)	1						2	3		
Select between OFF/Prime Mode/Secondary Mode(s)	1					2	3	3	1[a]	
Select one or more of N related functions						1	2	2		
Select one of N mutually exclusive functions of any order						1				
Select one of 3-24 discrete alternatives - sequential order	1									
Select digit - discrete	2[b]		2[b]			1[c]				
Set value on - continuous scale		1		2	3				3	
Select value in - discrete steps	1		1			1				
Select operating condition	2					1	1	1	2	
Enter alphanumeric data						1[c]				
Initiate test subfunction (momentary)	3					1	1	2		
Initiate directional function	3			3		2[d]	1	1[d]	1	
Generate stepping impulse (momentary hold)						1	1	2		
Slew counters or other numeric readout		1[e]			1[f]	1	1			
Reset mechanical counter, manual		1	3	1						
Interrupt sequence, "hold"						1	2	2		
Engage - disengage mechanical function									1	
Adjust light level, continuous		1	3	1					3	
Adjust sound level, continuous		1	3	1					3	
Coarse adjustment		1[g]		2[h]	2[i]				2[j]	
Fine adjustment		1[k]		2[l]	2[m]				3[n]	
Adjust to null position		1		2	3				3	
Single-coordinate tracking		3			2				1	
Two-coordinate tracking					3					1

1 = most preferred; 3 = least preferred

NOTES:
- a - Lever for heavy duty power circuits
- b - Only if sequential selection is acceptable
- c - Keyboard
- d - Multiple controls
- e - Rate control
- f - Manual only
- g - Small diameter
- h - Small motion
- i - Few turns
- j - Short throw
- k - Large diameter
- l - Large motion
- m - Many turns
- n - Long throw

TABLE 5. Recommended manual controls.

CONTROL FUNCTION	CONTROL TYPE
Small actuation force required:	
2 Discrete positions	Keylock Push button Toggle switch Legend switch Slide switch
3 Discrete positions	Rotary selector switch Toggle switch Push button
4 to 24 Discrete positions	Rotary selector switch
Continuous setting (linear and less than 360°)	Continuous rotary knob Joystick or lever
Continuous slewing and fine adjustment	Crank Continuous rotary knob
Large actuation force required:	
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°)	Handwheel Joystick or lever Crank Two-axis grip handle
Continuous setting (more than 360°)	Crank Handwheel Valve Two-axis grip handle

c. Where right-hand manipulations could create difficulties for a left-handed operator, the control should be selected and located to minimize degradation for both left- and right-handed operators.

d. Manipulatory characteristics of candidate control devices should be compatible with operator biomechanical characteristics and limitations. For example, natural musculoskeletal motions, excursions, precision, and strength factors should be considered in choosing the particular control device and locating it with respect to the operator.

5.4.1.1.4 Environmental and physical constraints. The considerations listed below should be considered in the selection, design, and placement of controls.

a. Mobility constraints of special clothing (gloves or mittens), connections, electrical leads, and/or special restraint systems (seat belts).

b. Degrading effects of expected environments such as acceleration or deceleration, vibration, ambient light, extreme cold, or extreme heat.

c. Operator support and/or anchoring, for example, in order to apply required force to maintain a given control contact for the required duration and/or to have sufficient stability to perform a precise manipulation.

5.4.1.1.5 Standard practice. Unless demonstrable improvement in operator performance is shown by alternate concepts, standard practice relative to certain control-function utilization should be followed. Examples include the following:

a. primary vehicle steering by a steering wheel,

b. three-dimensional vehicle steering or attitude control by a joystick or a combination joystick wheel and rudder pedals,

c. primary vehicular braking by foot pedal(s),

d. primary automotive acceleration by foot pedal,

e. aircraft throttle control by manually-operated levers,

f. automotive transmission gear position selection by a ever,

g. continuous adjustment, panel control functions by rotary controls,

h. discrete multi-position selection panel control functions by rotary selector switches, push buttons, or mechanically detented levers,

i. multi-axis, console-type tracking function control by joystick, track ball and/or hand cranks,

j. manual valve control by rotary knobs or T-handles (valves should have the word VALVE in their labels), and

k. simple two-position, panel control functions by push button, toggle, rocker, or slide switches.

5.4.1.2 Direction of movement.

5.4.1.2.1 Stereotypes. Where most users expect to find standard stereotyped relationships between controls and displays, these expectancies should be followed to take advantage of previous learning, maximize transfer of training, and minimize error (see Table 6).

TABLE 6. Conventional control movement stereotypes.

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

5.4.1.2.3 Control-display motion. The following combination motion relationships should be observed:

a. In general, a right, clockwise, forward or upward control motion should result in clockwise, right, or upward motion of the moving element of an associated display (instrument pointer), except for certain aircraft control-display combinations ("fly-to" principle for joystick and aircraft direction and attitude displays) and valve-display combinations (counterclockwise valve rotation results in a clockwise or upper pointer motion on a pressure gauge).

b. Although not preferred, when a numerical scale used on a rotary control skirt is to be set against a fixed-index marker, the clockwise rotation of the knob should result in increasing scale values (the scale should be designed so that values increase in a counterclockwise direction around the knob skirt).

5.4.1.2.4 Control-device motion. When a control affects the movement of some appended device which is directly observable by the operator (window, windshield wiper, remotely-controlled object such as a crane boom and tackle or hook), the motion of the control and the controlled object should be similar.

5.4.1.2.5 Control-vehicle motion relationships. The control-vehicle motion relationships listed below should be observed:

a. Ground vehicles. Standard vehicle control convention should be observed with respect to automotive and similar vehicles:

(1) Clockwise motion of the steering wheel results in a right turn;

(2) Forward movement of the accelerator results in increase in speed;

(3) Forward movement of service or parking brake pedals results in slowing and/or stopping of vehicle;

(4) Rearward (pull) motions of a hand brake result in slowing or stopping of vehicle; and

(5) Upward motion of column-mounted turn-signal lever results in activation of right turn-signal light.

When a rotary knob is used on the end of column-mounted levers, forward rotation of the knob as viewed from above should produce an increasing function for either side of the steering wheel. However, the concept of clockwise for increase does not hold for the left-hand knob.

b. Aircraft, spacecraft, and submersibles. A forward movement of any lever control normally should result in an increase in aircraft performance (addition of engine power or trimming for increased speed). Exceptions include the joystick (which moves aft to raise the nose of the aircraft; to the right for a right turn or right roll). For all aircraft control conventions refer to MIL-STD-203 and MIL-STD-250.

c. Tracked vehicle steering. Because of independent drive systems typically used in tracked vehicles, steering control (lever) movements should follow the convention of forward lever movements to drive the associated track. A combination of right control lever forward with left control lever aft should produce a left turn and vice versa.

d. Marinecraft steering. Clockwise movement of a wheel should result in a right turn of the vessel. A right movement of a tiller control should result in a left turn of a small boat.

5.4.1.2.6 Proportional controls. It is permissible to make control action disproportionately rapid where settings are not critical or disproportionately slow where personnel should make fine adjustments. With proportional controls, including engine throttles, the action of the device that is controlled should parallel the force and movement applied to the control.

5.4.1.3 Arrangement and grouping. Reserved.

5.4.1.4 Coding.

5.4.1.4.1 Methods and requirements. Many methods of coding are available. The choice of coding should be based on factors such as:

a. types of coding already being used,

b. kinds of information to be used,

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

d. number of coding steps or categories available (the number of different knob shapes available, and how many of those shapes users can discriminate easily),

e. need for redundant or combination coding, and

f. standardizing coding methods.

Any coding method that is selected should be used consistently and with consistent meaning throughout the system. Consideration should be given to consistency of coding used within a system compared to coding used in other systems which the operator may be employing (either separately from, or in conjunction with, the system being designed). The method should allow controls to be identified easily by sight or touch and discriminated from each other by color, size, shape, and location.

5.4.1.4.2 Location coding. When operators cannot see controls, but should operate them by blind positioning, the most effective coding method is by location. Operators discriminate locations more accurately when controls are in front of them. Controls in the forward area should be spaced about 150 to 200 mm apart. When controls are beside (or behind) the operator, they should be 300 to 400 mm apart, for easy recognition without confusion.

5.4.1.4.3 Size coding.

5.4.1.4.3.1 Discrimination of sizes. When size coding knobs with diameters between 13 mm and 100 mm, each knob's diameter should be at least 20% larger than the next smaller one.

5.4.1.4.3.2 Similar functions. Code sizes should be consistent when controls have similar functions on different items of equipment.

5.4.1.4.3.3 Sub-coding. Size-coded knobs may also be sub-coded by shapes. Within the acceptable size range, users can recognize shapes regardless of size.

5.4.1.4.4 Shape coding.

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

5.4.1.4.4.2 Dimensions. When operators must distinguish controls by touch alone, the shape of the control should be free of sharp edges or corners and at least:

a. Height: 13.0 mm or larger.

b. Width: 13.0 mm or larger.

c. Depth: 6.5 mm or larger.

5.4.1.4.5 Color coding.

5.4.1.4.5.1 Emergency controls. All emergency controls should be coded red. To give these emergency controls the visual emphasis they demand, only a bare minimum of other, less important controls should be color coded. Colors used to code critical controls should contrast sharply with those used for non-critical controls.

5.4.1.4.5.2 Ambient lighting and color-coding exclusion. Color coding requires unrestricted vision, as well as reasonably bright, whitish ambient light for colors to be easily discriminable from each other. This type of coding should not be used when visibility is restricted or obstructed, the illumination is dim, or under colored light.

5.4.1.5 Labeling of controls. Controls should have labels (on panel or control) that identify what they control and show how to operate the control. Some equipment manufacturers are developing uniform symbols for use with controls. Uniform symbols, which have been standardized and accepted, may be used in lieu of labels.

5.4.2 Rotary controls.

5.4.2.1. Discrete rotary controls.

5.4.2.1.1 Rotary selector switches.

5.4.2.1.1.1 Shape. Bar or bar and pointer-shaped knobs should be used with rotary selector switches so that an operator can tell which way the knob is pointing, and can quickly identify a selector function from a continuously-adjustable control function. A white reference line should be inscribed on the face of the knob, running from approximately the midpoint of the knob to the pointing edge. The pointing end of the knob should also be tapered so that the pointing end is easily differentiated from the non-pointing end, and also so that the reference mark can be "followed" (visually) to a point adjacent to a reference mark or numeral on the interfacing panel. Contrast between the reference mark and its knob background should be at least 50%. When an application requires the operator to judge pointer position without benefit of visual reference, the sides of the knob (except for the tapered end) should be parallel. If additional shape coding is required, the code should be applied as an extra cap. The shape code should not interfere with the general shape objectives noted above.

5.4.2.1.1.2 Positive detents. Rotary selector switches should have mechanical detents so that the switch knob cannot be positioned between nominal switch positions. Table 7 shows knob detent placement parameters.

5.4.2.1.1.3 Number of switch positions. Stops should be provided at the beginning and end of the range of control positions if the switch is not required to be operated beyond the end positions or specified limits.

5.4.2.1.1.4 Dimensions, resistance, displacement, and separation. Knob dimensions, switch displacement, and control separation should conform to criteria in Table 8 and Figure 11.

TABLE 7. Knob detent placement.

Total No. of Settings	Recommended Starting Position (Degrees)			Recommended Angular Displacement (Degrees)	Recommended Radius for 13 mm Separation (mm)
	Left-Hand Operation	Right-Hand Operation	Either Hand		
3	15	265	320	40	20
4	350	255	300	40	20
5	325	245	285	35	20
6	305	235	205	35	20
7	285	225	255	35	20
8	265	215	240	35	20
9	250	210	230	30	20
10	230	200	215	30	25
11	215	195	205	30	25
12	0, 90 or 180	180, 270 or 360	0 or 180	30	25

TABLE 8. Rotary selector controls.

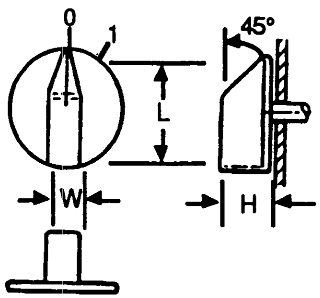
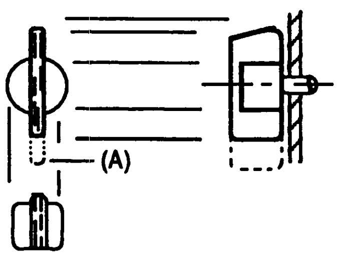
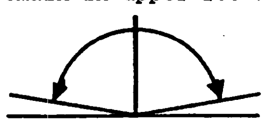
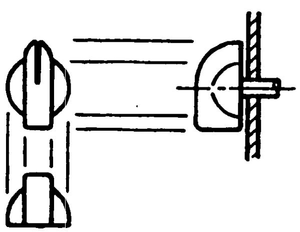
	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Preferred for accurate identification of knob position by feel. For use on electronic, aircraft, and automotive control panels where high force switches are not required. Skirt optional. Switch resistance (approximate) max: L = 38 mm: 0.11 N•m L = 50 mm: 0.34 N•m L = 100 mm: 0.68 N•m	L = 38 mm to 100 mm; if gloves are worn, add 13 mm	W = 13 mm to 25 mm	H = 16 mm to 75 mm	Min = 15°; minimum for blind position identification = 30°	See figure 16. For simultaneous operation of adjacent knobs (two hands), add 25 mm (38 mm for gloves).
	Above guidelines acceptable as long as knob positions remain in upper 160°.  (A) Extended tail helpful for higher torque. Use only when pointer marking clearly visible.	See above	See above	See above	See above	See above
	Preferred alternative to (A) above where high torque is not required.	See above	See above	See above	See above	See above

TABLE 8. Rotary selector controls - continued.

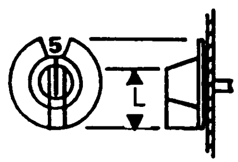
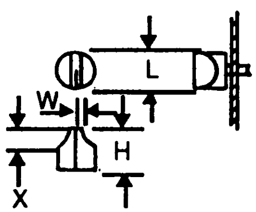
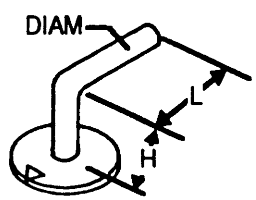
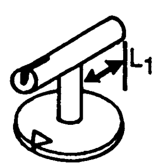
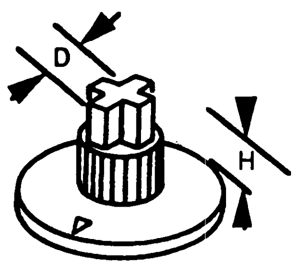
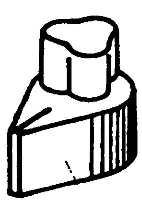
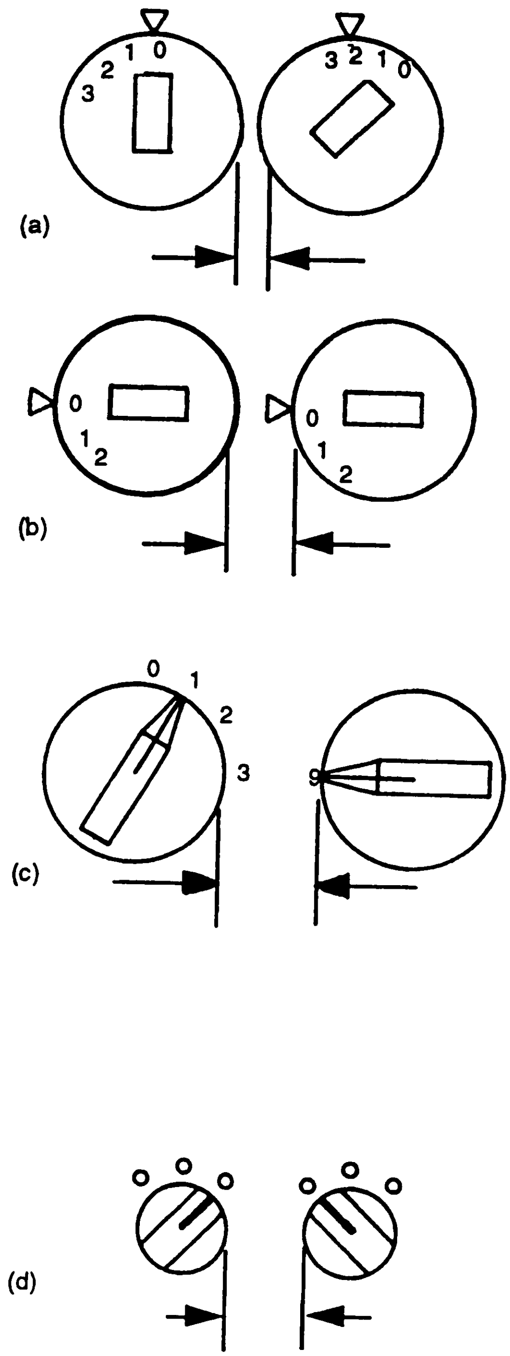
	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Preferred alternative to (A) above when only gross setting is required (major numbered positions) and where high torque is not required.	L - Min = 25 mm; other dimensions same as (A)	See above	See above	See above	See above
	Acceptable only for applications where panel space is limited and gloves not worn; switch resistance less than .042 N•m	L - Min = 19 mm	W - Min = 6.5 mm	X - Min = 13 mm	See above	25 mm
	For heavy duty, high torque switches:					
	Preferred	D = 16 mm to 25 mm	L - Min = 100 mm	H - Min = 32 mm	Min = 10°	End to end handle separation = 75 mm
	Acceptable alternative	D = See above	L_1 - Min = 50 mm	H = See above	See above	See above

TABLE 8. Rotary selector controls - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Tactile control identification, preferred method for rotary controls	D - Min = 16 mm	H - Min = 3.2 mm, max = 19 mm			
	Tactile cap for rotary selector knob	Same as above	Same as above			



Nominal separation between moving-pointer knobs requires only that there is adequate physical separation between the knob skirts to prevent knob movement interference when the zero or referencing index is at the 12 o'clock position.

Separation between moving-pointer knobs that have the referencing index at the 3 or 9 o'clock position should be sufficient to ensure that there is not visual confusion regarding knob to which the index mark refers. Minimum should be about twice the nominal character width.

Separation between moving-pointer, fixed-scale configurations should be based on clear visual separation of adjacent scale characters. The minimum should be at least four character widths. However, if the knob length extends the full width of the skirt and the handle is not tapered at the pointing end, there should be at least a 25 mm separation between knobs when they are end-to-end.

Separation between small, detented knob configurations should be at least 25 mm unless there are adjacent panel referencing marks or characters, in which case separation minimums should be established on the basis of(c) above, or the 25 mm criteria whichever is greater.

FIGURE 11. Rotating knob separation.

5.4.2.1.2 Key-operated switches (KOS).

5.4.2.1.2.1 Keylocks. Keylocks used solely to lock and unlock doors, cabinets, covers or drawers should conform to the conditions listed below.

a. Key position and motion relative to locking and urdocking should conform to the criteria in Figure 12.

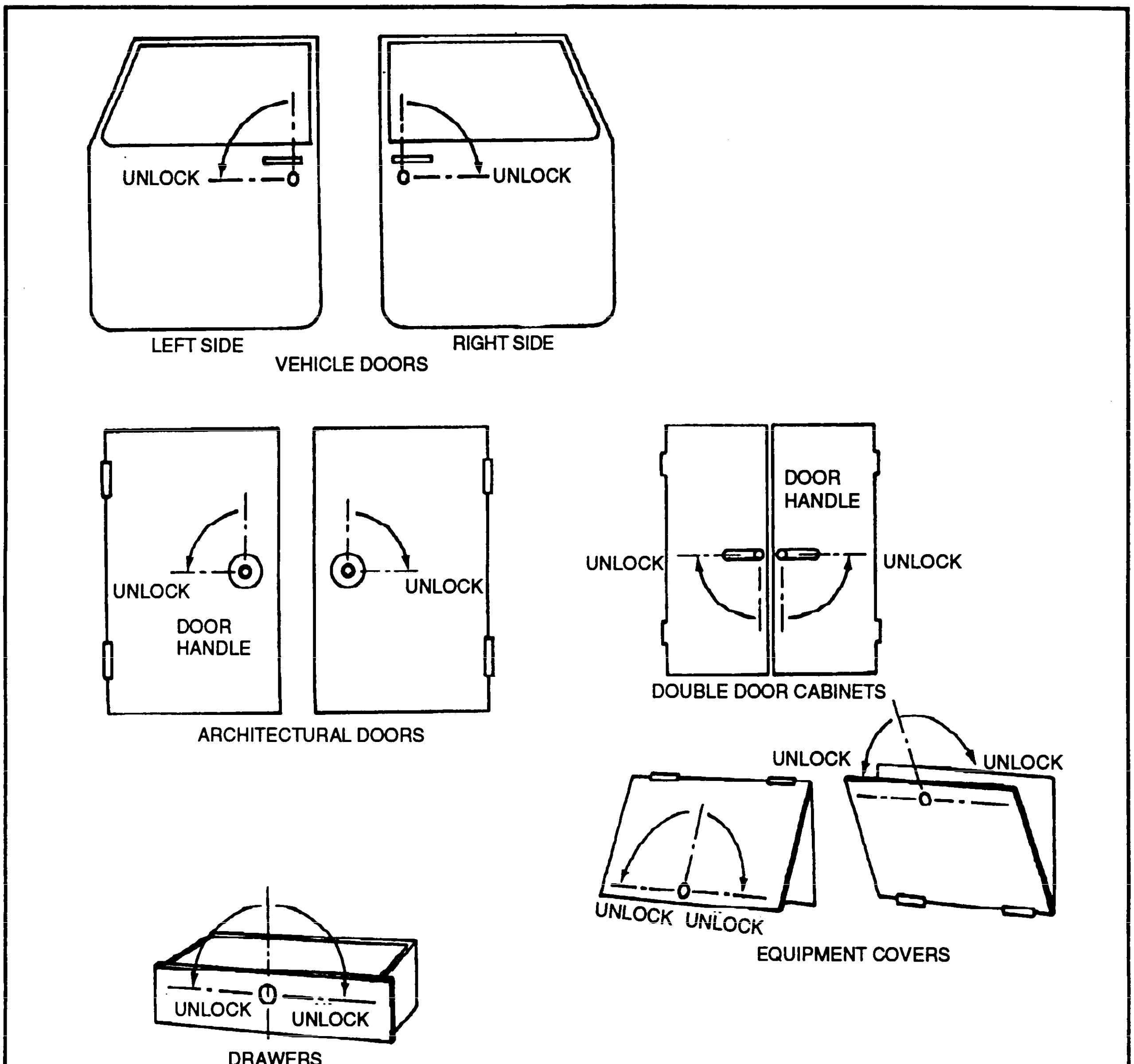


FIGURE 12. Keylock mounting criteria.

b. Reversible key designs should be used. It is preferable to have keys that will operate the lock with either side "up." If key designs are used that have teeth only on one side, the lock should be oriented so that the "flat" edge of the key will be on the bottom to enter a vertical (lock) slot, and to the right to enter a horizontal (lock) slot.

c. Lock systems used for vehicle exterior doors should be designed so that the operator cannot inadvertently lock himself out of the vehicle.

d. Keylocks exposed to external weather conditions should be weatherproof. They should not become inoperable because of dirt accumulation nor freeze because of moisture collection and freezing temperatures.

e. When several keylock systems are required on the same vehicle or equipment, and all locks must be accessible to the operator, a single key and identical locks should be used. On the other hand, when access to certain closures must be limited to people other than the operator, different keylock assemblies should be used so that the operator's key will not unlock these special locks.

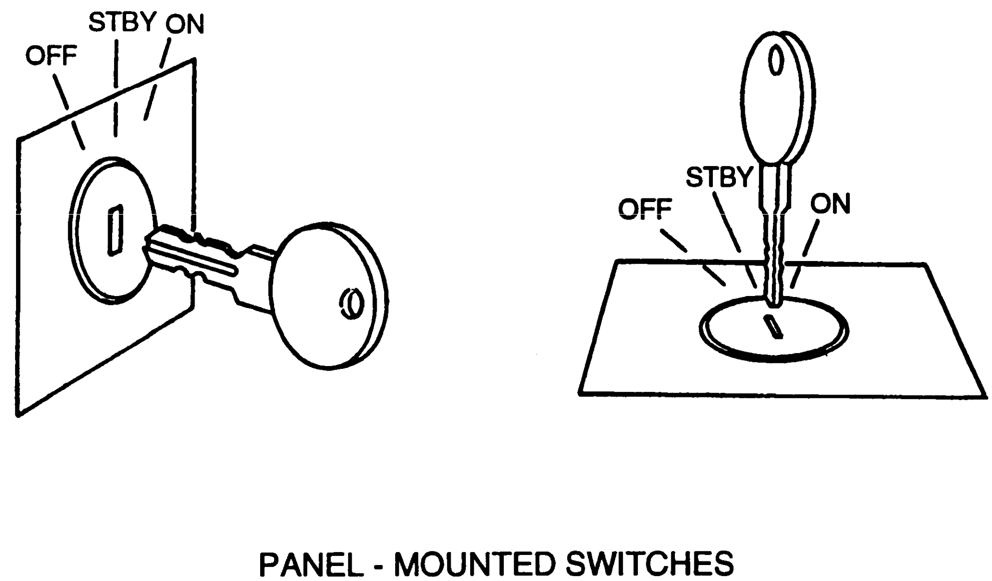
5.4.2.1.2.2 Keylock switches. Keylock switches which are used not only to provide security (by removing the key), but also to provide ON-OFF functions, should conform to the conditions listed below.

a. Key should be removable only in the security position.

b. Key position and motion relative to locking, unlocking, and ignition should conform to criteria in Figure 13.

c. Keylock switches that will be used externally should be weatherproofed to prevent failures resulting from dirt and freezing.

d. An auditory signal should be provided for vehicle ignition keylock systems to advise the operator that the key has been left in the ignition lock after the engine has been shut off.



NOTES: 1. Switchlocks should generally be oriented so that the pivotal off key position is vertical and/or forward (horizontal panel).

2. Key displacement between functional positions should beat least 30°. Mechanical detents should preclude positioning the key in between designated positions.

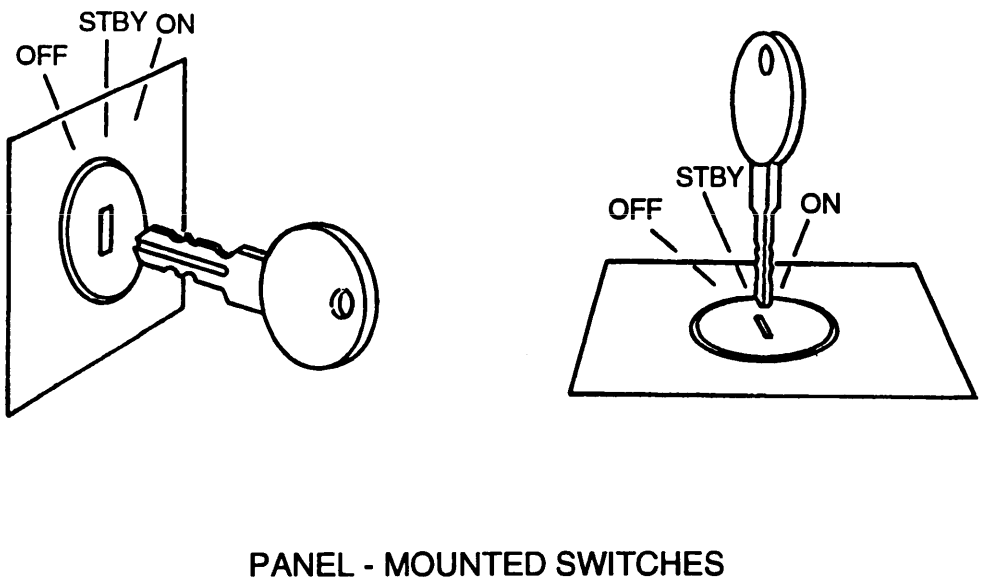
3. When only two functional positions occur (on-off), displacement between the two positions should be 90°.

4. Total displacement of multi-position keylock switches should not exceed 120°.

FIGURE 13. Keylock switch criteria.

5.4.2.1.3 Discrete thumbwheel controls.

5.4.2.1.3.1 Application. Mechanically-demented thumbwheel controls may be used as an alternative rotary selector device when the application will benefit from the compactness of such devices, and appropriate visual and/or audio feedback is provided. Numeric thumbwheels should be oriented and move as indicated in Figure 14.



NOTES: 1. Switchlocks should generally be oriented so that the pivotal off key position is vertical and/or forward (horizontal panel).

2. Key displacement between functional positions should beat least 30°. Mechanical detents should preclude positioning the key in between designated positions.

3. When only two functional positions occur (on-off), displacement between the two positions should be 90°.

4. Total displacement of multi-position keylock switches should not exceed 120°.

FIGURE 13. Keylock switch criteria.

5.4.2.1.3 Discrete thumbwheel controls.

5.4.2.1.3.1 Application. Mechanically-demented thumbwheel controls may be used as an alternative rotary selector device when the application will benefit from the compactness of such devices, and appropriate visual and/or audio feedback is provided. Numeric thumbwheels should be oriented and move as indicated in Figure 14.

5.4.2.1.3.2 Dimensions, separation, and resistance. Control resistance should be elastic, building up and then decreasing as each detent is approached so that the control snaps into position without stopping between adjacent detents.

5.4.2.1.3.3 Labeling and visibility. Marking and labeling of thumbwheel controls should conform to criteria herein with respect to visibility of markings and design of numerals.

5.4.2.1.3.4 Color Coding. Thumbwheel controls may be coded by means of color and/or contrast (dark vs light surfaces). Examples are reversing the colors of the least significant digit wheel as on a typical odometer, and where used as an input device, the thumbwheel switch OFF or NORMAL positions may be color coded to permit a visual check that the digits have been reset to their normal value.

5.4.2.1.4 Continuous Adjustment Thumbwheel Controls.

5.4.2.1.4.1 Use. Continuously-adjustable thumbwheel controls may be used as an alternate to rotary knobs when the application will benefit from the compactness of the thumbwheel device.

5.4.2.1.4.2 Orientation and movement. Thumbwheels should be oriented and move in the directions specified in Figure 14.

5.4.2.1.4.3 Thumbwheel serrations. The rim of the thumbwheel should be serrated to aid the operator in manipulating the control.

5.4.2.1.4.4 Labeling and visibility. Marking and labeling of continuously-adjustable thumbwheel controls should conform to criteria herein with respect to visibility of markings and legibility of label alphanumerics.

5.4.2.2 Continuous-adjustment rotary controls.

5.4.2.2.1 Knobs.

5.4.2.2.1.1 Use. If the adjustment requires reference to a scale, the scale should be placed on a panel and an index line should be inscribed on the pointer (moving-pointer fixed-scale format). If the range of knob movement involves more than 360° rotation, scales should not be used, except for directional input devices (azimuth setting).

5.4.2.2.1.2 Direction of movement. Turning a knob clockwise should produce an increase.

5.4.2.2.1.3 Knobs mounted with set screws. Control knobs should be mounted with large set screws which are accessible enough to be tightened or loosened with a standard-size screwdriver. Selection of a switch, with regard to location of the set screw (Figure 15), is a function of access to the set screw in the installed position. If control resistance is substantial (selector switches with several contact discs), minimize the possibility of knobs slipping on their shafts by using knobs with two set screws, spaced about 90° apart.

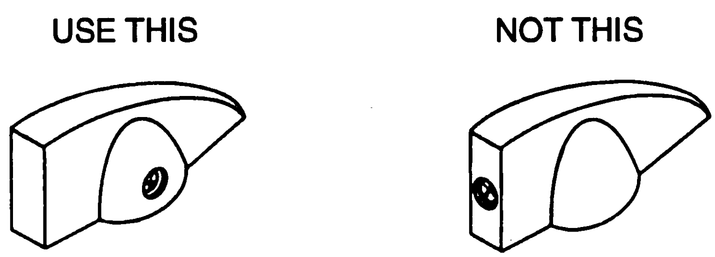


FIGURE 15. Set screws for control knobs.

5.4.2.2.1.4 Knob style.

5.4.2.2.1.4.1 Shapes. Knobs which perform the same function should have the same shape. The shape should be determined by the knob's function and use. Representative knob shapes are shown in Figure 16.

5.4.2.2.1.4.2 Open-window, skirted knobs. Special knob designs consisting of a bar-type knob and open-window skirt may be used for applications in which visual confusion maybe reduced by exposing only one number of a scale at a time (see Table 8).

5.4.2.2.1.5 Tactile (touch) recognition. For knobs that must be recognized by touch alone, use easily recognizable knob shapes (see Figure 17). Some sets of knobs have been specially developed and validated experimentally for tactile recognition.

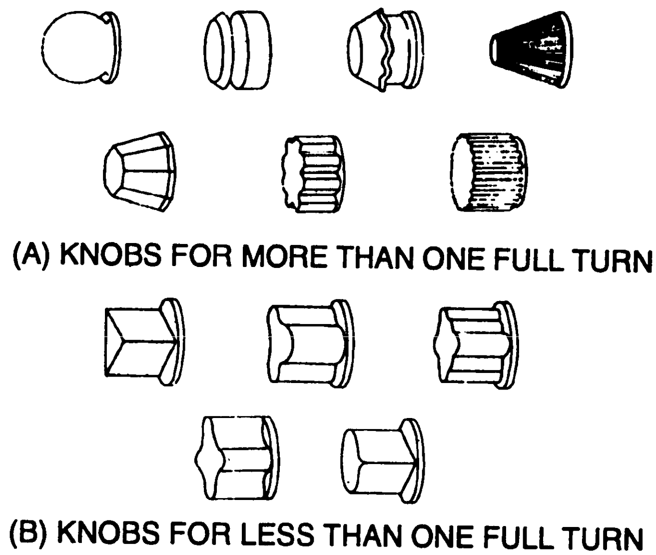


FIGURE 16. Recommended knob shapes.

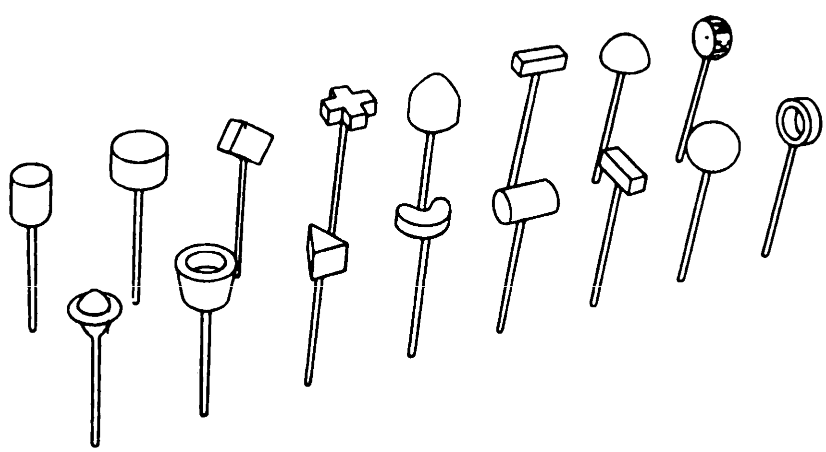


FIGURE 17. Easily recognizable knob shapes.

5.4.2.2.1.4.6 Knob rims. All rotary adjustment knobs should have rims with suitable surfaces for secure grasp. Very small knobs should have knurled surfaces to provide maximum torquing capability. Intermediate and larger sizes of knobs should have serrated rims, except that knobs used where high torque is required should have rim indentation rather than serration for firmer grasp. Larger knobs should utilize rim indentation to aid gripping for application of higher torques. The design should ensure that the operator will not injure a hand if the shaft sticks.

5.4.2.2.1.4.7 Twist grip controls. Handle-like rotary controls may be used for special applications (motorcycle accelerator control).

5.4.2.2.1.4.8 Knob mounting. Rotary selector knob attachment should preclude the possibility of the knob slipping on the shaft, and/or the knob being replaced with the pointing end opposite from its correct position.

5.4.2.2.1.4.9 Contact hazard. When knobs are used in vehicles and are located where they could be contacted during the sudden deceleration of a crash, frontal surface area should be large, and all edges should be rounded in order to minimize the potential injuries associated with small, sharp, knob designs.

5.4.2.2.2 Ganged control knobs. Reserved.

5.4.2.2.3 Continuous-adjustment thumbwheel controls. Reserved.

5.4.2.2.4 Cranks.

5.4.2.2.4.1 Positioning. Cranks which must be turned rapidly should be mounted so their turning axes are between 60° and 90° from the body's frontal plane (Figure 18). For standing operators, they should be between 900 and 1200 mm above the floor.

5.4.2.2.4.2 Handles. Handles should be used to maximize the area of contact with the hand. They should turn about their shafts freely. The outside edge of the crank handles should clear any obstruction by at least 75 mm.

5.4.2.2.4.3 Simultaneously-operated hand cranks.

5.4.2.2.4.3.1 Application. Simultaneously-operated hand cranks should be used in preference to other two-axis controllers where extreme precision is required in setting cross hairs or reticules as in map readouts or optical sighting mechanisms. This type of control may also be used in other applications requiring X and Y control provided there is no criteria for rapid or frequent operation.

5.4.2.2.4.3.2 Dynamic characteristics. The dynamic characteristics of simultaneously-operated hand cranks should be the same as those for single cranks. The gear ratio and dynamic characteristics of the cranks should be such as to allow precise placement of the follower (cross hairs) without overshooting or undershooting and successive corrective movements.

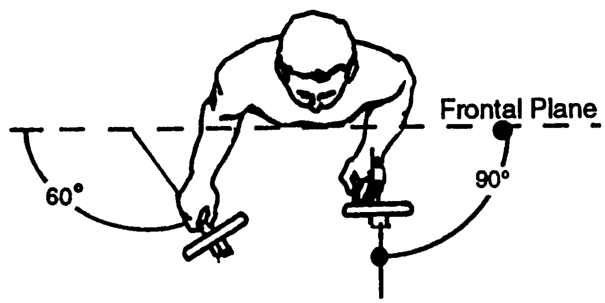


FIGURE 18. Proper mounting of rapidly operated crank.

5.4.2.2.5 Handwheels, two-hand operated.

5.4.2.2.5.1 Position. Handwheels (including steering wheels) should be selected in terms of size and expected usage to provide operator use convenience based upon whether the operator is seated or standing to operate the wheel. For seated operation, the wheel should normally be centered on the operator's centerline and sloped so that both of the operator's arms and hands have approximately equal access to the wheel. In addition, wheels operated from the seated position should be sized and positioned for convenient ingress or egress as well as over-the-wheel viewing, where applicable.

5.4.2.2.5.2 Wheel hub delethalization. Steering wheel hubs should be recessed and provided with a broad pad to minimize the possibility of driver impalement during a crash. Consideration should also be given to use of a collapsible steering column for rapidly-moving vehicles. Such steering wheels should be structurally resistant to major rim or spoke distortion considering the loads that could be created by the driver's body being thrust into the wheel during a crash.

5.4.3 Linear controls.

5.4.3.1 Discrete linear controls.

5.4.3.1.1 Push button, finger- or hand-operated.

5.4.3.1.1.1 Use. Push button controls should be used primarily for simple switching between two conditions, selection of alternate ON-OFF functions from an array of related conditions or subsystem functions, release of a locking system such as on a parking brake, or entry of a discrete control order. Push buttons should not be used indiscriminately merely to make all panel controls look alike, or where another type of switch could be used to save panel space (toggle switch). Push button-type controls may be used for any of the following kinds of operations singly or in combination (see Table 9).

5.4.3.1.1.2 Shape. Push button cap surfaces should, in general, be flat, but with rounded edges. However, for proper finger-centering, which should be ensured, the cap surface may be concave. General cap shapes may be round, square, or rectangular as long as they provide adequate finger, thumb or hand contact area, and are compatible with identification or legend criteria.

5.4.3.1.1.3 Channel or cover guard. Primary methods for minimizing inadvertent switch actuation should conform to criteria in Table 10.

5.4.3.1.1.4 Momentary contact. Momentary contact controls should be used for single "push-HOLD and release-OFF" functions. The push button should be one of the following types: (1) non-illuminated, (2) continuously ON switchcap light or legend, or (3) momentary ON switchcap light.

5.4.3.1.1.5 Alternate action. Alternate action for a single function may be implemented either in a two-button format or as a single button. With the single-button type, a first press sets the switch to the ON state and a second press sets it to OFF. Feedback to indicate the ON state should be provided either by switchcap lamp or legend or by a closely associated lamp or legend. With the two-button type, the buttons are mechanically interlocked so that one button is always depressed and the other button is in the up position. Although the depressed button provides feedback on switch state, additional feedback by means of switchcap lamp or closely associated lamp or legend should normally be provided.

5.4.3.1.1.6 Stepping action. Successive presses of the switch cycle it through three or more states. Switch state feedback may be provided by selective illumination of integral or associated legends.

TABLE 9. Representative push button switch applications.

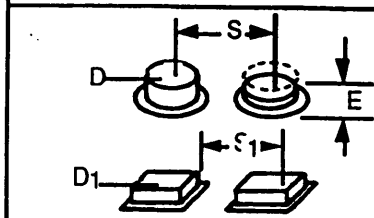
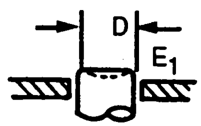
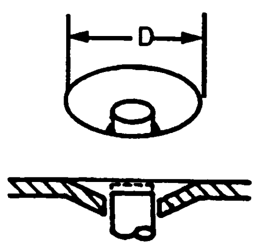
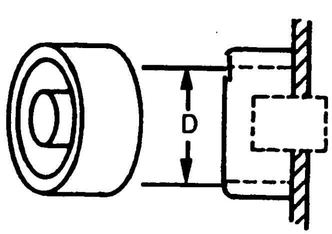
TABLE 9. Representative push button switch applications.

Function	Switch Action	Switch Configuration	Switch State Feedback Options					
			Depressed Switchcap	Integral Lamp(s)	Integral Legend(s)	Adjacent Lamp(s)	Adjacent Legend(s)	Other Display Reflecting Switch Action
Send short discrete signal to initiate or terminate some other function.	Momentary contact	Single button	Momentary only	Momentary only	Momentary only	Momentary only	Momentary only	Sufficient
Send short signal of controllable duration.	Momentary contact	Single button	Momentary only	Momentary only	Momentary only	Momentary only	Momentary only	Sufficient
Choose between two mutually exclusive states	Alternate action, latching	Two-button interlocked	If mechanically latched	C	Sufficient	C	Sufficient	C
		or Single-button	If mechanically latched	C	Sufficient	C	Sufficient	C
Step through three or more switch states.	Stepping, latching	Single button with legend matrix	(No)	(No)	Sufficient (if multiple legend)	C	Sufficient	C
Independently choose one out of three or more mutually exclusive states.	Latching and interlocked	Array of buttons	If mechanically latched	C	Sufficient	C	Sufficient	C
Independently choose two or more out of a set of control functions each having two states.	Alternate action, latching	Array of buttons	If mechanically latched	C	Sufficient	C	Sufficient	C

NOTES:

1. The feedback referred to pertains only to knowledge of switch state, not system state (which may impose additional feedback requirements).
2. A feedback option designated "sufficient" means that, properly instrumented it can provide all the information the operator needs concerning switch state; other methods showing annotation or C (contributing) need to be used in combination to provide adequate feedback.

TABLE 10. Push button switches.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Panel-mounted push buttons: Single-finger, one button at a time. Non-legend or buttons that require only a single number on the front surface may be round, square, or rectangular.	D - Min diameter or dimension (D_1) - 10 mm*			E - Excursion, preferred min = 3.2 mm; preferred max = 6.5 mm. Add 13 mm for gloves**	S - Min = 19 mm (25 mm with gloves) S_1 - Min = 13 mm
	A concave surface may be used to aid finger-centering (non-glove operation only).	D - Max = 19 mm; Min = 13 mm				
	Recessed button to minimize inadvertent operation. Tapered "well" guides finger.		D - Min well opening = 19 mm; 32 mm with gloves			
	Prevent inadvertent operation of critical switch, either with guard ring or panel well.		D - Same as above			

*For miniaturized applications, diameters as small as 3.2 mm may be used providing they accommodate all other relevant requirements, e.g., use of handwear, need for ruggedness.

**Depressed buttons should remain exposed by at least 2.5 mm. Switches with no motion, e.g., thermal, may be used providing they accommodate all other relevant requirements.

TABLE 10. Push button switches - continued.

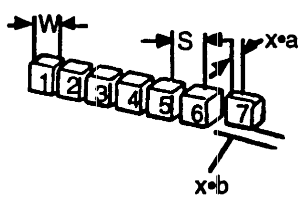
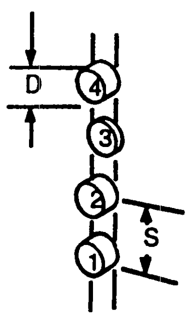
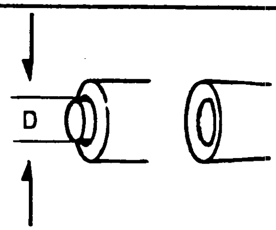
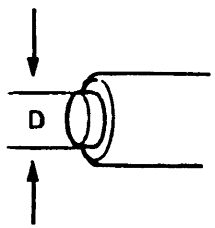
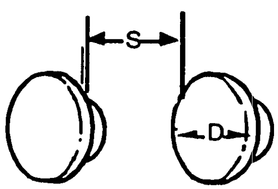
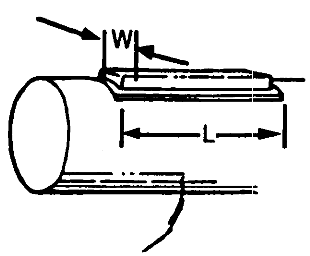
	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Ganged push button assembly: Square, rectangular, or round shapes are acceptable. Depression of any button should cause any previously depressed button to return to deactivated position.	W or D - Min = 10 mm (13 mm for gloves)			x·a - Min exposure when depressed = 3.2 mm x·b - Min depression to actuate = 3.2 mm (preferred = 5 mm) Max displacement should not exceed 13 mm	S - Center-to-center spacing, Min = 19 mm (25 mm for gloves)
	Numbered butons should progress as illustrated.					

TABLE 10. Push button switches - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Handle, end-mounted, push button switch: Index finger-operated. Recess to preclude inadvertent operation.	D - Min = 10 mm			Same as above	
	Thumb-operated	D - Min = 13 mm			Same as above	
	Alternate finger or heel of the hand operation. Convex surface desirable	D - Min = 25 mm			Same as above	S - Min for palm operation = 75 mm
	Grip handle switch Alternate multi-finger or palm operation	W - Min = 6.5 mm	L - Preferred min = 25 mm		Same as above	

5.4.3.1.1.7 Combination. Sets of related switching functions of the above types may be combined as an assembly. These may be independent, interlocked or a combination of both, may be momentary or latching or a combination of both; and may be non-illuminated, or have switchcap lights or legends. Feedback as to active switch states should always be provided. Interlocking and latching functions may be either mechanical or electrical.

5.4.3.1.1.8 Push button identification and legends. Although push buttons may be identifiable by means of panel labels and/or symbols, labels placed on the push button face (where size and other use factors are compatible) are preferred. Criteria for labels, symbols and legends should be followed. Legends normally should be legible with or without internal illumination, but legends may be invisible during any distinct modes in which the button is never used. A lamp test capability and/or dual lamp reliability should be provided, except for switches using light-emitting diodes (LEDs) in place of incandescent lamps. No more than three lines of lettering should normally be used on a legend plate. Lamps within incandescent legend switches should be replaceable from the front of the panel, by hand, and the legend or cover should be keyed to prevent possibility of interchanging legend covers.

5.4.3.1.2 Foot-operated switches. Foot-operated switches should be located so the operator has some normal heel resting position on the floor or a floor board. Avoid placing a foot switch beneath or behind other pedals wherein it might be possible for the operator's foot to become momentarily entangled or trapped during the transfer between the switch and a pedal.

5.4.3.1.3 Keyboards, keypads, keysets, and menu selectors.

5.4.3.1.3.1 Use.

a. Alphanumeric keyboards with standard typewriter key configurations should be used for applications where a general-purpose entry criteria cannot be satisfied by numeric entries alone, by smaller keysets with either dedicated or programmable keys, or by menu selection techniques.

b. Keypads (decimal entry keysets) should be used for applications requiring frequent entry of decimal digits, whether data or numeric codes.

c. Keysets with each key dedicated to a specific switching function should be used whenever the number of switching functions is manageable and need not change with time or operational condition.

d. Multi-function (programmable) keysets offering means of changing the switching function of individual keys should be utilized whenever switching criteria vary substantially for different phases or modes of operation and the total number of functions to be switched cannot be conveniently handled by dedicated keys.

e. Menu selection techniques which provide for display and selection of switchable states on a CRT may be used as an alternate to the multi-function keyset.

5.4.3.1.3.2 Keyboards.

5.4.3.1.3.2.1 Mounting. The keyboard should be mounted so that it is directly in front of the operator when it is in use. The first row of keys should be between 230 mm and 300 mm above the seat level and the tiers of keys should slope upward toward the back at an angle between 10° and 30° from the horizontal with 17° preferred (see Table 11).

5.4.3.1.3.2.2 Function control. Convenient means of switching keyboard function and indicating keyboard state should be provided to enable composing and posting message text prior to its release, editing posted data or text material, and directly entering data or instructions to a computer.

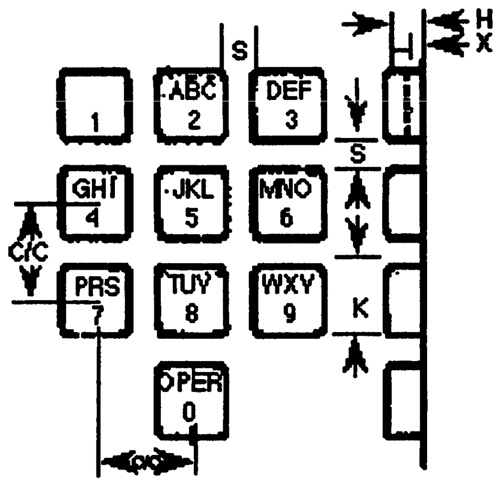
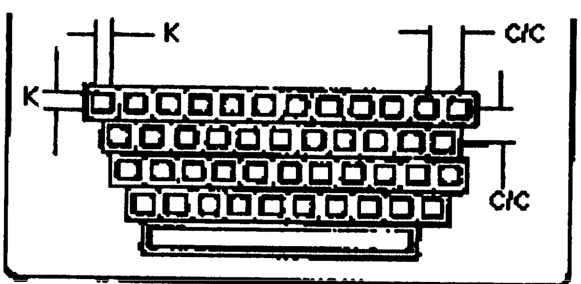
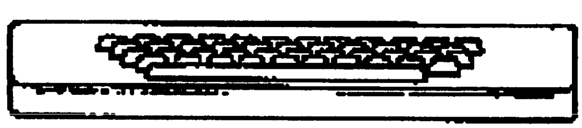
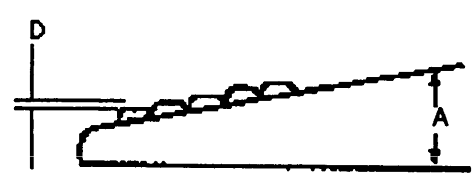
5.4.3.1.3.3 Keypads.

5.4.3.1.3.3.1 Mounting. Keypads may be mounted wherever they are conveniently available for use. Keypads requiring frequent use should be mounted in a preferred location for controls such as a desk top and should be sloped as indicated for keyboards.

5.4.3.1.3.3.2 Actuating force. The actuating force required for keypads should fall in the range of 0.25 N to 3.9 N. (This actuating force range does not apply to touch-activated keypads.) The larger actuating forces should be used where the user wears gloves or mittens, or is subjected to substantial vibration or acceleration.

5.4.3.1.3.3.3 Function control. Switches for control functions should be provided to allow clearing either the last posted digit only or all posted digits.

TABLE 11. Nominal keyboard characteristics.

Telephone	
	K - Key Size = 9 mm S - Separation = 6 mm H - Height = 6 mm X - Depressed Extension = 2 mm C/C - Center to Center Spacing = 17 mm NOTE: For other dimensions refer to Table 10 for single finger push buttons.
Typewriter	
	K - Key Size = 13 mm C/C - Center to Center Spacing = 19 mm D - Displacement = 5 mm for electric; 2 mm for typical manual machine A - Varies widely; preferred slope is between 16-17°
 	

5.4.3.1.3.4 Dedicated keysets.

5.4.3.1.3.4.1 Configuration. A dedicated keyset consists in essence of two or more push button sets which are grouped together because of some commonality of purpose and which utilize some common control and/or display functions. As best fits the purpose, key action may be momentary contact or latching, and key tops may (1) be opaque, (2) contain an indicating lamp, (3) provide a continuously illuminated label, (4) provide an illuminated label when activated, or (5) provide both (3) and (4). The functions and physical configuration of the push buttons in the keyset should be appropriate to the switching functions it must handle and to the operator's task.

5.4.3.1.3.4.2 Mounting. Dedicated keysets may be mounted wherever they are conveniently available for use.

5.4.3.1.3.4.3 Actuating force. The actuating force required for dedicated keysets should fall in the range of 0.25 N to 11.3 N. The larger actuating forces should be used only with large-size illuminated switchcaps which are 25 mm wide or larger as may be needed to accommodate switchcap labeling. The preferred actuating force for push buttons which can be mounted on 20 mm centers is about 2.8 N.

5.4.3.1.3.4.4 Feedback. Feedback should be provided to inform the operator whether or not the pressed key was, in fact, actuated; the intended key selection was the one which was made; the system is in the process of responding to the actuated key; and the system has completed its response to the actuated key.

5.4.3.1.3.4.5 Function control. Switches for control functions governing operation of the keyset should be provided as needed for the particular application.

5.4.3.1.3.5 Multi-function (programmable) keysets.

5.4.3.1.3.5.1 Special criteria. Multi-function keysets require instrumentation for accommodating switching at two levels: a gross function, or mode level and a detailed, or item level within each mode.

5.4.3.1.3.5.2 Function (or mode) selection. The amount of selection capability should be dependent upon the number of different sets of switching functions to be used alternatively. The mechanization of the function selectors should ordinarily be by rotary selector or by interlocked push buttons with latching actuation. The complete range of choices as well as the current mode indication should be visible to the operator at all times, except in those instances where function selectors are implemented by entry of coded switching instructions using a general-purpose keyboard. (Mode switching also may be implemented for initiation by the computer, in which case manual switching capability can be correspondingly reduced.)

5.4.3.1.3.5.3 Switching for item selection. The amount of selection capability should be dependent upon the number of switching actions which must be independently controllable. Item selection should be provided by push buttons of the appropriate types (latching or momentary; interlocked or independent) for the specific switching functions.

5.4.3.1.3.5.4 Item labeling and feedback. Item labels applicable to each mode should be displayed on or adjacent to the item selector switches, and labels which are inapplicable to the selected mode should not be visible. Appropriate feedback should be provided to indicate the current state of each item selector switch. When switching to a new mode, feedback should be provided as to the current state of each switchable function. In addition, feedback may be needed to indicate which switches can or cannot be utilized in the current mode (by extinguishing labels for switching functions which are inapplicable).

5.4.3.1.3.5.5 Configuration. The physical configuration of the keyset should be appropriate to the switching functions it should handle and to the operator's task. A sample configuration is shown in Figure 19.

5.4.3.1.3.5.6 Mounting. Multi-function keysets may be mounted wherever they are conveniently available for use.

5.4.3.1.3.5.7 Actuating force. The actuating force for the push buttons in multi-function keysets should fall in the range of 0.25 N to 11.3 N. The larger actuating forces should be used only with large-size illuminated switchcaps 25 mm wide or larger which may be needed to accommodate switchcap labeling. The preferred actuating force is about 2.8 N.

5.4.3.1.3.6 Menu selectors.

5.4.3.1.3.6.1 Special criteria. Menu selectors require control at three levels: (1) function-level switching to select which one out of the set of menu listings is presented on the display, (2) a control for selection of a particular item from the menu, and (3) a control for entry or activation of the selected menu item. Menu-item selection may implemented by means of a cursor controlled by push buttons, a light pencil, or a grid and stylus-type device. The entry instruction itself should be implemented as a separate momentary-contact switch.

5.4.3.1.3.6.2 Configuration. The physical configuration of menu selector controls and displays should be appropriate to the switching functions it should handle and to the operator's task. Two sample configurations are shown in Figure 20.

5.4.3.1.3.6.3 Dimensions, displacement, and separation. The push button switches should conform to dimensional criteria for legend switches.

5.4.3.1.3.6.4 Mounting. The cursor control (thumbwheel, keypad) should be mounted beneath the menu listing. The ENTER button should be close to and preferably to the right of the cursor control. The function (mode) selectors should be mounted conveniently near the cursor control.

5.4.3.1.4 Toggle switch controls.

5.4.3.1.4.1 Use. The application and design criteria for toggle switches is given in Table 12.

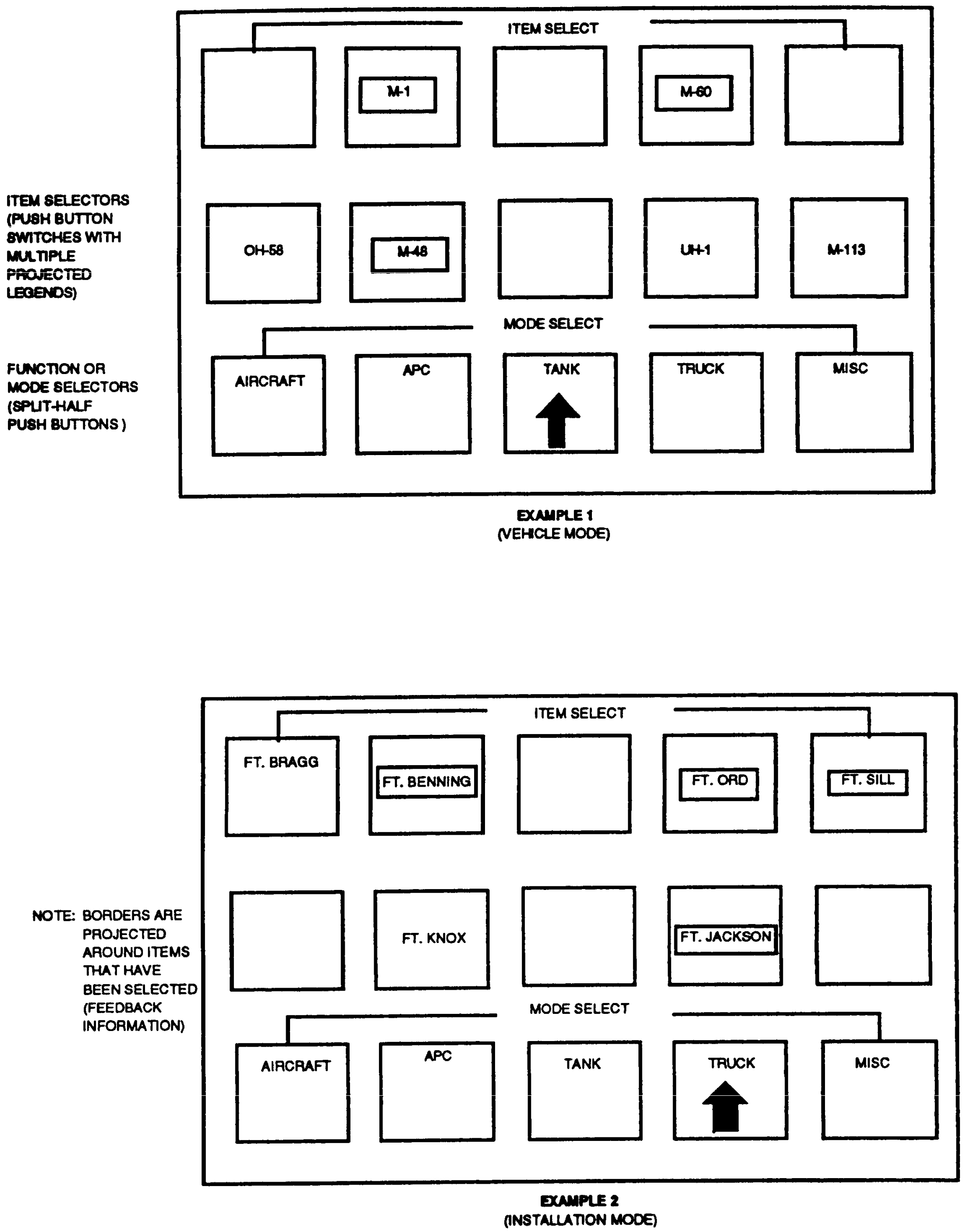


FIGURE 19. Multi-function keyset format examples.

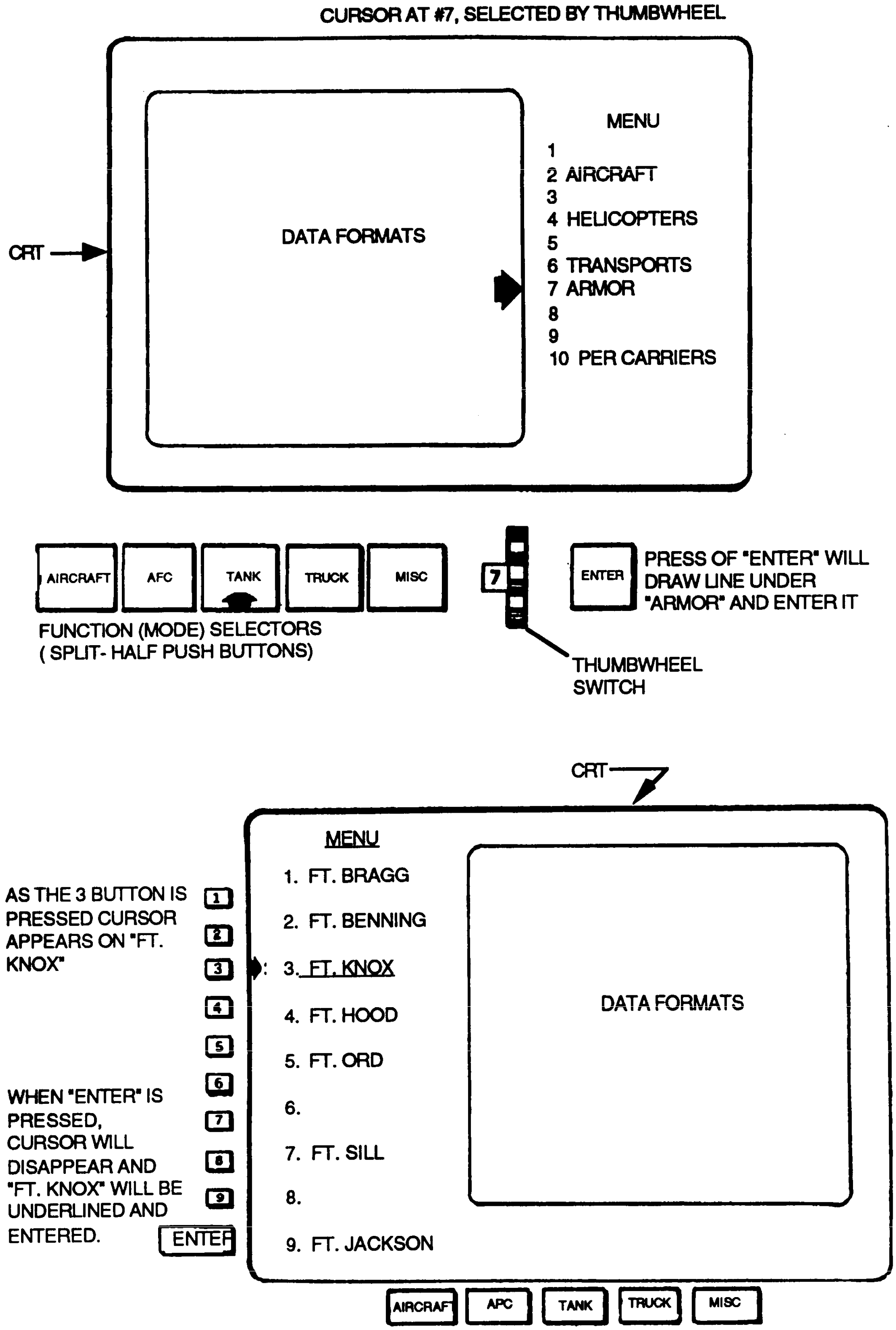
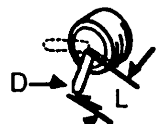
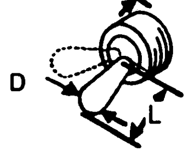
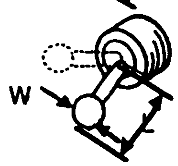
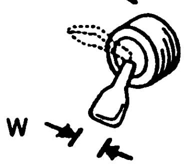
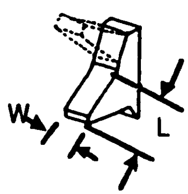


FIGURE 20. Menu selector types and format examples.

TABLE 12. Toggle switches.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Miniature toggle switch: Limit use to indooor applications where limited panel space precludes standard size components.	D - Diameter min = 3.3 mm	L - Length min = 13 mm			
	Standard configuration: Use larger sizes for applications where gloved operation is likely.	D - Diameter min = 4.5 mm max = 7.8 mm	L - Length min = 13 mm max = 50 mm			
	Ball cap design applicable where firm grasp of toggle is needed because of vehicle or operator oscillation.	D - Diameter min = 4.5 mm max = 7.8 mm (add 13 mm for gloves)	Same as above			
	Flat or applied tab handles provide improved visual position reference when operationally important.			W - Handle width min = 4.5 mm		
	Applied tab handle provides means for color coding.		L - Length preferred = 10 mm max = 25 mm	W - Width preferred = 10 mm min = 4.8 mm max = 19 mm		
	Alternate to any standard size configuration above.		Same as above	Same as above		

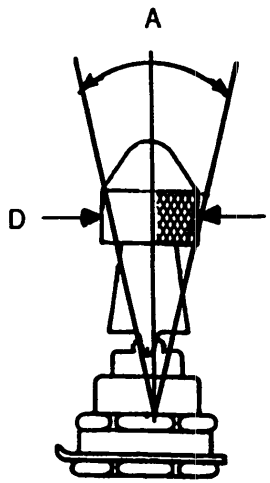
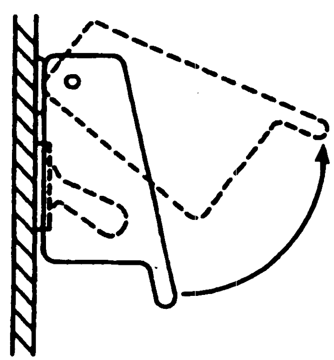
		DESIGN GUIDELINES				
	APPLICATION GUIDELINES	DIMENSIONS			DISPLACEMENT	SEPARATION
	Typical two-step interlocking safety switch.	D - Diameter min = 10 mm			A - Angular displacement: Two positions min = 30°, max = 80°; three positions - min = 17°, max = 40°	Should not be closer than 50 mm to other control or structure.
	Alternate cover guard switch. Cover easily color-coded. Not applicable for miniaturized toggles.					May be horizontally spaced as close as 13 mm (25 mm for gloves).

TABLE 12. Toggle switches - continued.

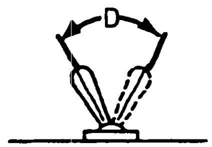
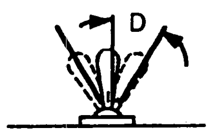
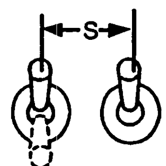
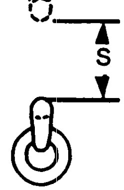
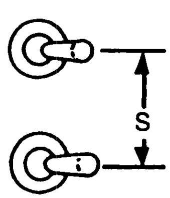
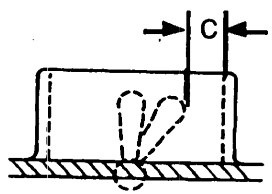
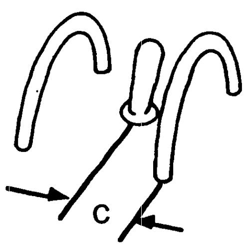
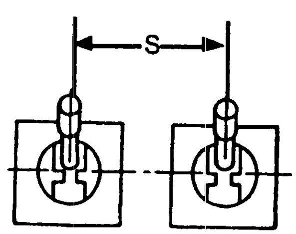
	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Two-position switches only when visual recognition of switch position mandatory.				D - Displacement angle Min = 30°	
	Three-position switches.				D - Displacement angle Min = 17°; 25° preferred	
	Side-by-side arrangement vertical displacement.					S - Center-to-center spacing Min = 19 mm Max for simultaneous multi-finger = 28 mm
	Tip-to-tip separation					S - Min = 25 mm
	Vertical arrays					S - Min = 25 mm NOTE: Add 13 mm for gloves

TABLE 12. Toggle switches - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Guard switches where accidental displacement of a switch may be undesirable (not necessarily dangerous).	C - Tip - guard finger clearance Min = 13 mm				
		C - Min = 25 mm; 32 mm for gloves				
	Use two-motion safety switch when switch-use error could lead to dangerous consequence (pull to operate).					S - Min = 25 mm (50 mm preferred); add 13 mm for gloves

5.4.3.1.4.2 Orientation. When toggle switches are located on panels that slope as in wrap-around or stacked workplace arrangements, switch orientation and movement should conform to criteria in Figure 21.

5.4.3.1.5 Legend switches.

5.4.3.1.5.1 Use. Legend switches are particularly well-suited to the conditions listed below:

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

b. To reduce demands for the operator to interpret information.

c. When functional grouping or a matrix of control switches and indicators is required but space is very limited.

5.4.3.1.5.2 Characteristics. The following characteristics apply to legend switches:

a. Legend switches should be located within a 30° cone (total included angle) along the operator's normal line of sight.

b. For positive feedback that the switch has operated, legend switches should have a detent or a click.

c. Legend switch lamps should be replaceable from the front of the panel.

d. Legends should be legible with or without internal illumination.

e. If legend switches do not have duplicate bulbs, dual filament, or equivalent reliability, the legend switch circuit should permit a positive test of the lamp.

5.4.3.1.6 Rocker switches. Reserved.

5.4.3.1.7 Slide switch controls. Reserved.

5.4.3.1.8 Discrete push-pull controls. Rotate to the right for activation or increasing function in the case of combination pull-rotary switches. An exception should be permitted in the case of certain contemporary automotive switches (combination headlight, parking light, and panel-dome light switch).

5.4.3.1.9 Printed circuit (PC) switch controls. Reserved.

5.4.3.2 Continuous-adjustment linear controls.

5.4.3.2.1 Levers.

5.4.3.2.1.1 Use. Lever-type controls may be used, when large forces or displacements are involved, as an alternate control for electrical switching when it may be more cost-effective to provide direct mechanical linkage between the control and controlled element, or when multi-dimensional, mechanical or electro-mechanical, multi-stage control modes (gear shift) are required. Lever-type controls should not be used where very precise electrical outputs are required (in lieu of a precision electrical adjustment, where a rotary controller is more appropriate). Levers should be considered for the general classes of control listed below:

a. braking (mechanical);

b. mode selection (environmental system);

c. gear selection (vehicle or machine transmission);

d. gross, continuous adjustment (temperature, audio volume, throttle); or

e. steering (joystick, track vehicle)

5.4.3.2.1.2 Coding. Color and/or shape coding may be used when it is important for the operator to quickly identify and/or differentiate among critical controls or several controls that may be grouped in proximity to each other. Special control coding criteria already established should be followed. When shape-codes are used, they should be designed so that they do not interfere with the basic criteria for ease of manipulation, and should be free of sharp corners that could result in operator injury in the event of violent contact by the operator.

5.4.3.2.1.3 Labeling Where appropriate, lever handles should be marked and/or labeled for ease of positioning and identification.

5.4.3.2.1.4 Resistance. The resistance incorporated in levers should be within the limits indicated in Table 13 (measured as linear force applied to a point on the lever handle). For joystick controls, elastic resistance which increases with displacement may be used to improve "stick feel".

5.4.3.2.1.5 Location, position, direction, and range of movement. The location, position relative to the operator, and direction and range of lever movement should be compatible with operator reach, mobility, natural movements, and strength capabilities. In addition, direction of motion criteria should be preserved. When high forces are required of the operator, the

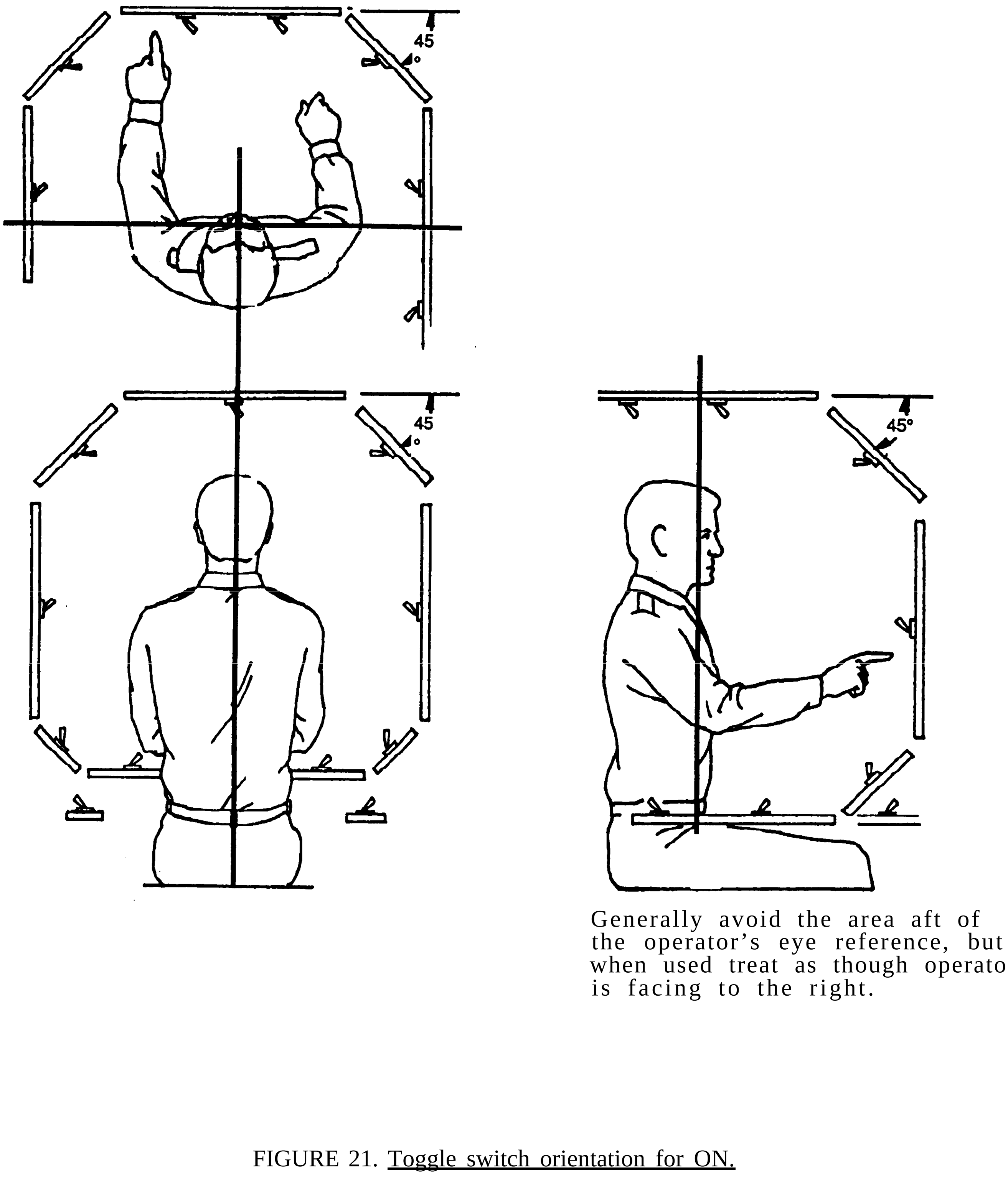


FIGURE 21. Toggle switch orientation for ON.

TABLE 13. Levers.

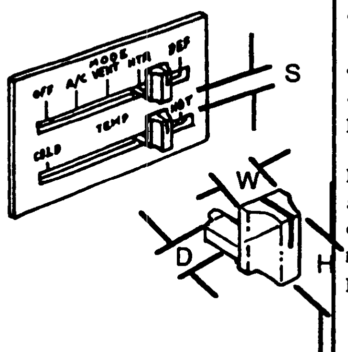
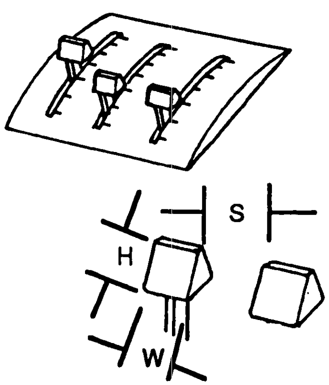
CONFIGURATION EXAMPLE	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Slide-levers may be used for low-force, continuous-adjustment or gross-mode selection (do not use for precise setting). Handles should be "tab-shaped", with long dimension perpendicular to motion axis (to serve as a pointer).	D - Min = 13 mm (19 mm with gloves)	W - Min = 6.5 mm	H - Min = 16 mm		S - Min = 19 mm (25 mm with gloves)
	Movement axis may be up-down, lateral or fore-aft. Functional increase should be: • Up • Right • Forward					
	Banked, slide-lever assemblies may be used for electrically- and/or mechanically-connected selector or adjustment functions to provide rapid visual check of related settings. Note: Resistance for above control types should be: Min - 2.8N Max - 110N	Same as above	Same as above	Same as above		Same as above

TABLE 13. Levers - continued.

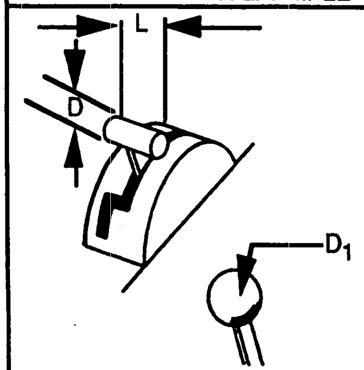
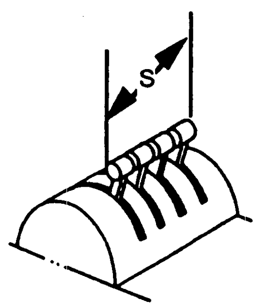
CONFIGURATION EXAMPLE	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Throttle levers: Handgrip may be either cylindrical or spherical.	D - Min = 19 mm; Max = 28 mm D_1 - 38 ± 6 mm	L - Min = 65 mm			Finger clearance all sides, min = 50 mm
	Multi-engine throttle assembly: Note: When thrust reverse is incorporated, the design should include a separate manipulative motion (lift + **aft lever movement**).					S - Typical 100 mm, not to exceed 125 mm

TABLE 13. Levers - continued.

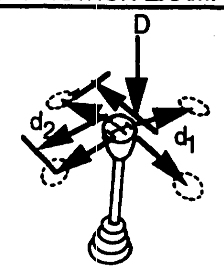
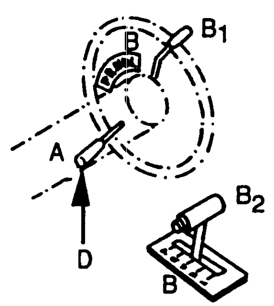
CONFIGURATION EXAMPLE	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Gear-shift lever: Manual transmission: Locate for right-hand operation. Resistance: approximately 9 - 13 N	D - Knob diameter = 32 mm			d_1 and d_2 between discrete positions = Min = 125 mm, Max total = 200 mm	
	Automatic transmission: (B_1 preferred; B_2 acceptable). Detented positions required* A. Other functions: 1. Turn signal - rotate about column; CW = right turn, CCW = left turn. 2. Headlight dimming; lever moves toward bottom of column for "dim". B. Letters should illuminate to indicate position of lever. Resistance: Approximately 4.5 - 45 N * It should be impossible to leave gear lever between positions. Separate motion required to position lever in reverse (lift or press thumb button).	D - Handle diameter 19 - 32 mm if cylindrical, 25 - 32 mm if spherical		Finger clearance between levers and wheel rim - Min = 50 mm	Gear shift - Min between positions = 25 mm for B_1; 38 mm for B_2 25 - 50 mm between detents recommended	

TABLE 13. Levers - continued.

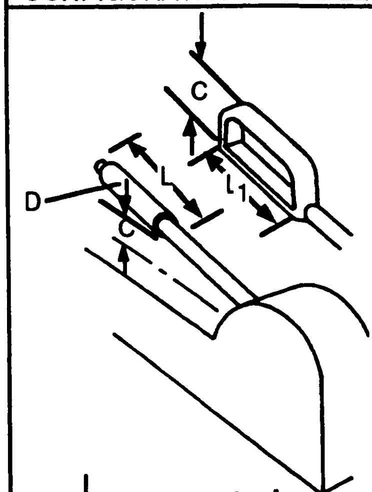
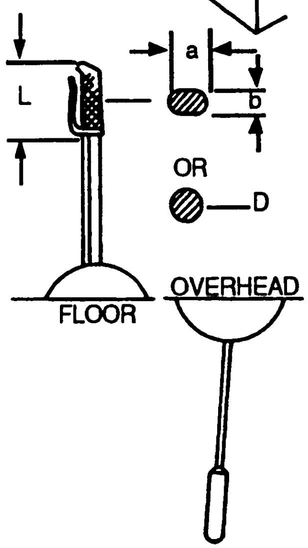
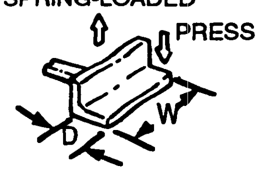
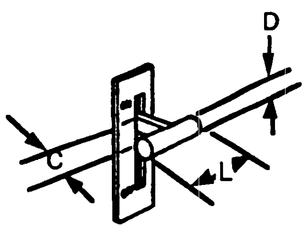
CONFIGURATION EXAMPLE	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Hand brake, with thumb-button release L_1 - Loop handle acceptable	D - Diameter = 25 - 32 mm	L - Length Min = 100 mm L - Length Min = 115 mm	 C - Clearance Min = 50 mm	Nominal = 100 - 125 mm	Min = 65 mm All sides of handle
	High-force levers: Center of handle should be approximately 230 - 255 mm laterally from operator centerline, at elbow level. Provide clip-type release where applicable. Round or oval-shaped handle should be used. Max resistance approximately 187 N	Max a x b = 38 x 25 mm D = 38 - 45 mm with clip lever. Max fore-aft span should not exceed 75 mm.	L - Length Min = 100 mm		Max for seated operator = 355 mm	Min clearance should be 50 mm in front, 75 mm either side

TABLE 13. Levers - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
SPRING-LOADED 	Two-position, spring-return to "off" tab-lever. Use only in up-down orientation. Resistance: approximately 4.5 - 27 N	D - Min = 19 mm	W - Min = 25 mm		Displacement = 25 - 75 mm	
	Heavy-duty lever device. Handles should permit use of at least three fingers. Use only in up-down orientation. Resistance: approximately 4.5 - 45 N	D - Min = 16 mm	L - Min = 65 mm	C - Min clearance = 32 mm, 38 mm with gloves	Min = 50 mm	Min separation between ends of handles = 19 mm (25 mm with gloves); min of 50 mm clearance behind handle

lever handle should be located between waist and shoulder levels, and the force should normally be applied in a pulling direction.

5.4.3.2.1.6 Detents. When levers are used as "selector" controllers, mechanical detents should be provided (in addition to panel labels or markings) to provide tactile feedback indicating that the lever is positively positioned at designated settings. Detents and panel markings should coincide precisely.

5.4.3.2.1.7 Non-slip handles. Surfaces of lever handles should provide sufficient friction (by means of the specific material used, and/or addition of serrations or knurling) to reduce the probability of the operator's hand or fingers slipping while operating the lever.

5.4.3.2.2 Displacement (isotonic) joysticks.

5.4.3.2.2.1 Hand-operated displacement joysticks.

5.4.3.2.2.1.1 Dynamic characteristics. Recessed mounting or pencil attachments may be used to provide greater precision of control. One or more switches actuated by either thumb or finger pressure may be integrally mounted.

5.4.3.2.2.1.2 Refresh rate. When used for generation of free-drawn graphics, the refresh rate for the follower on the CRT should be sufficiently high to ensure the appearance of a continuous track. Delay between contact movement and the confirming display response should be minimized and should not exceed 0.1 second.

5.4.3.2.2.2 Finger-operated displacement joysticks. Reserved.

5.4.3.2.2.3 Thumbtip- or fingertip-operated displacement joysticks. Reserved.

5.4.3.2.3 Isometric joysticks (two-axis controllers). Display systems requiring a single operator to make control movements along two orthogonal coordinate axes simultaneously should utilize one of the following types of controllers: simultaneously-operated hand cranks, ball control, joystick, grid and stylus devices, pantographs, or free-moving XY controller (mouse). Selection should be made on the basis of matching controller characteristics with system criteria (see Table 14).

5.4.3.2.4 Ball controls. (Also known as track balls, ball trackers, joyballs, or rolling balls). Reserved.

5.4.3.2.5 Gird-and-stylus devices. Reserved.

TABLE 14. Two-axis controllers for display system applications.

Type of Controller	Control Order Utilized	Acceptable Display Applications			
		XY Data Pickoff	Continuous Tracking	Free-Drawn Graphics	Setting Cross Hairs
Simultaneously-operated hand cranks	Position	Not Recommended	Not Recommended	Not Recommended	Good
Ball control	Position	Good	Fair	Poor	Good
Isometric joystick (Shift stick)	Position, Rate-Aided	Good	Good	Fair	Fair
Isotonic joystick (displacement stick)	Position, Rate-Aided	Good	Good	Good	Fair
Grid and stylus devices	Position	Good	Fair	Good	Good
Free-moving XY controller (mouse)	Position	Good	Not Recommended	Not Recommended	Fair
Light pen (augmented)	Position	Good	Fair	Good	Fair

5.4.3.2.6 Free-moving XY controllers (mouses). Reserved.

5.4.3.2.7 Light pen. Reserved.

5.4.3.2.8 Pedals.

5.4.3.2.8.1 Play. Pedal control systems should be designed to minimize excess play' (movement that does not activate the control system).

5.4.3.2.8.2 Adjustment. Sufficient control and/or seat adjustment capabilities should be provided to accommodate the leg reach capabilities of the total range of expected operators (5th percentile female to 95th percentile male). Consideration should also be given to combined vertical and horizontal adjustment effect on reach. For seated operator configurations where external vision is critical and corresponding control panel constraints may be present, the pedal-seat-vision interactions should be considered to provide the best-fit among eye reference, seat and pedal adjustment position, and adjustment range.

5.4.3.2.8.3 Automotive-related foot controls.

5.4.3.2.8.3.1 Arrangement. Assemblies of foot-operated controls should conform to industry practice with respect to arrangement.

a. Manual transmission: The clutch should be positioned for left-foot operation; service brake and accelerator for right-foot operation. Headlight dimmer function may be provided as a left or right hand- or foot-operated floor switch or column-mounted stalk (lever).

b. Automatic transmission: The above arrangement should be followed except that the service brake should be accessible for either right- or left-foot operation (in which case the brake pedal should be laterally elongated sufficiently to make it convenient for operation by either foot).

5.4.3.2.8.3.2 Pedal, geometric relationships. Clutch, service brake, and accelerator pedals should be arranged so that the primary contact point of each pedal (height and distance from the floor, heel-reference point) is approximately the same, to make it convenient for the operator to shift his foot from the accelerator to the service brake pedal without having to lift the foot an excessive amount. The pedal contact point should be based on a point on the accelerator pedal that matches an "all-of-the-foot" position when the operator's heel rests normally on the floor, and the accelerator pedal is in the "un-depressed" position. Lateral pedal positions should be arranged and spaced so that the total array is approximately centered on the operator's centerline (so the operator is not required to sit in a skewed position in order to operate certain pedals). For maximum, long-duration comfort, the accelerator pedal should be not more than about 300 mm right of the operator's centerline.

5.4.3.2.8.3.3 Lateral pedal array limits. Lateral spacing of individual pedals should conform to criteria in Table 15. However, the overall array should not exceed 760 mm as measured between the outermost pedal centerlines.

5.4.4 High-force controls. Reserved.

5.4.5 Miniature controls. Reserved.

5.4.6 Touch-screen controls for displays. Reserved.

5.4.7 Quickened and predictor controllers. Complex tracking functions may require use of quickened or predictor approaches to control-display implementation. These approaches should be utilized only with the approval of the acquiring activity.

5.4.8 Integral, handle-mounted controls.

5.4.8.1 Use. Handle-mounted, auxiliary controls may be integrated into the handles of primary controllers such as joysticks, or equipment such as cameras and power tools, when such integration enhances the simplicity and/or efficiency and safety of system operation.

5.4.8.2 Number of controls. The number of controls integrated into a handle should not exceed three (a trigger, plus two thumb-operated switches in a joystick handle) unless specified by the procurement specification or upon specific approval by the acquiring activity.

5.4.8.3 Inadvertent input. The type of auxiliary switch, its motion characteristics and location should be such that movement of the auxiliary switch will cause minimal probability that the primary control or equipment operation and/or positioning is inadvertently disturbed.

5.4.8.4 Thumb switches.

5.4.8.4.1 Types. Push buttons, slide, or rotary thumb switches may be used as appropriate for any of the following switch modes:

a. Push button: ON-OFF (communication).

b. Two-dimensional toggle: two-axis, spring-centering (aircraft trim).

TABLE 15. Foot-operated controls.

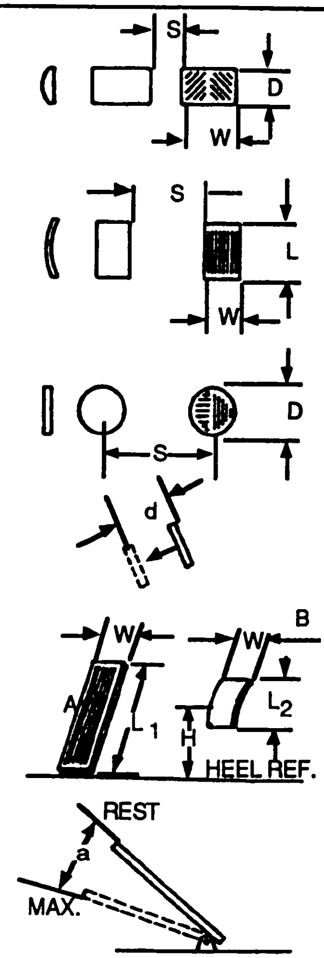
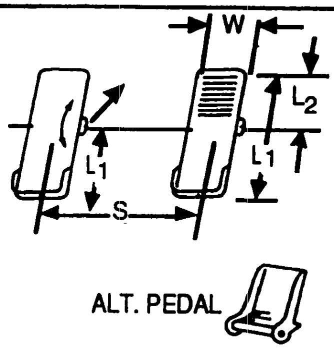
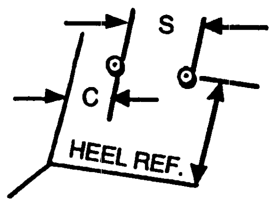
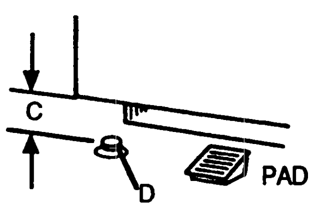
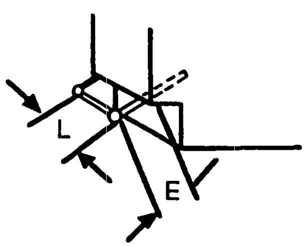
	APPLICATION GUIDELINES	DESIGN GUIDELINES: DIMENSIONS			DESIGN GUIDELINES: DISPLACEMENT	DESIGN GUIDELINES: SEPARATION
	Pedal applications: Clutch or brake. Convex tread surface. Force requirements: Clutch = 450 N max Brake = 70 N min; 450 N max	W x D - Min = 75 x 50 mm				S - Min to prevent foot slipping between pedals = 50 mm
	Alternative pedal shape & spacing. Convex tread surface.	W x L - Min = 50 x 75 mm				S - Min separation to allow foot to pass between pedals = 125 mm; 180 mm for heavy boots
	Round pedal shape acceptable. Flat tread surface.	D - Min = 57 mm	S - Comfort separation = 305 ± 50 mm Max = 405 mm Min = 200 mm		d - Rest to activate Max = 180 mm Min = 25 mm Preferred = 65 - 100 mm	(Note: Edge to edge pedal separations of between 50 mm and 115 mm should generally be avoided because of possibility of getting foot caught.)
	Accelerator pedal applications: a. Floor-hinged, full pedal b. Suspended pedal (pedal should be free-swivel) Action displacement envelope. Nominal cruise angle should cause lower leg and foot included angle to be between 90°-105°. Force requirements: max = 90 N; min = 4.5 N	W - Min = 50 mm L_1 = 255 ± 50 mm L_2 - Min = 90 mm	H = 150 mm optimum		a - Displacement max = 30° (20° with heavy boots)	

TABLE 15. Foot-operated controls - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Aircraft rudder and brake assembly. Should have min fore-aft adjustment of 230 mm. Toe pressure operates brake; fore-aft movement of pedal fulcrum operates rudder. Force requirments: See MIL-F-8785.	W - Min = 150 mm	L_1 - Min = 255 mm L_2 - Min = 125 mm			S - Min = 380 mm; max = 530 mm
	Foot switches. Normally use only one per foot (max two). Force requirments: max 4.5 N (See MIL-B-8584 for specific dimensions.)	D - Diameter min = 25 mm	H - Distance from heel reference = 180-255 mm	C - Clearance to obstructon min = 75 mm	Min = 13 mm Max = 65 mm For boots, increase min to 25 mm	S - Min = 75 mm
	Foot switches, stand options: Normal, frequent activation; speed not critical. Force requirements: Preferred max = 90 N	D - Button diameter min = 25 mm; larger preferred		C - Clearance beneath undepressed bar for toe min = 65 mm; 75 mm with boots		
	Emergency operation, speed important	E - Extension min = 100 mm	L - Accessible to either foot; full width of the expected work envelope			

c. Slide switch: single-axis ON-OFF, momentary ON plus ON-HOLD (safety switch for hand-held power tool).

d. Rotary thumbwheel: rotary selector (maximum of three positions), continuous adjustment (audio volume).

Other auxiliary thumb-operated control applications should be subject to the approval of the acquiring activity.

5.4.8.4.2 Location and operation. Thumb switches should be positioned and operate in a fashion that is compatible with comfortable and natural thumb articulation limits, considering the total range of hand sizes for the expected user population, and constraints imposed by wearing of gloves.

5.4.8.4.3 Resistance. Resistance should not exceed limits for push buttons, slides, or thumbwheels as specified in other sections of this handbook.

5.4.8.4.4 Dimensions and displacement. Dimensions and displacement of handle-mounted, auxiliary thumb switches should conform to criteria in Table 16.

5.4.8.5 Index finger-operated switches and triggers.

5.4.8.5.1 Use. Index finger-operated, auxiliary, handle-mounted controls should be used for typical "trigger" operations (weapon firing, camera film operation, and power tool motor activation). Since the operator typically expects to use the index finger for these types of functions, other index finger operations should not be implemented without express approval of the acquiring activity. Similarly, "trigger" functions should not be implemented in the form of non-index finger operation (thumb or palm).

5.4.8.5.2 Location and operation. Trigger controls should be located and operate in a manner that is compatible with the inherent limitations for using the basic control handle. (The operator should not be required to shift his hand from the normal hand-grip position in order to actuate the trigger.) If the trigger should be operated simultaneously while holding another auxiliary switch (safety), location and operation of both controls should be such that the operator can comfortably and naturally activate both controls without inadvertently disturbing the primary handle positioning or aiming. Special consideration should be given to restrictions which may be imposed by wearing of gloves (reach and mobility).

5.4.8.5.3 Resistance. Trigger-pull characteristics, including resistance level and profile, should be as specified by the acquiring activity. Unless otherwise directed by the acquiring activity, trigger response should be "even" throughout the trigger pull, i.e., breakout vs steady-state should be approximately equal with no apparent "build-up" prior to final contact with the mechanical stop.

TABLE 16. Grip switches.

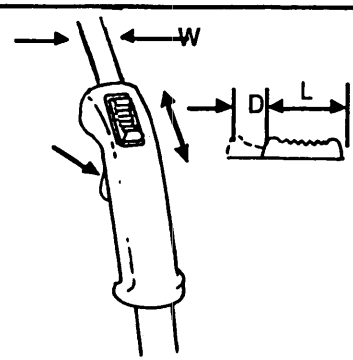
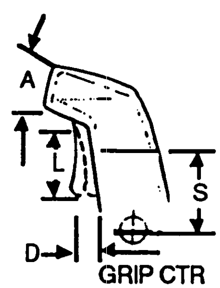
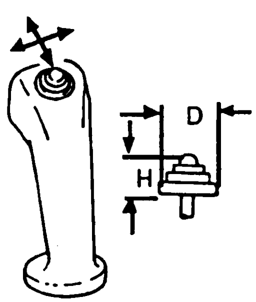
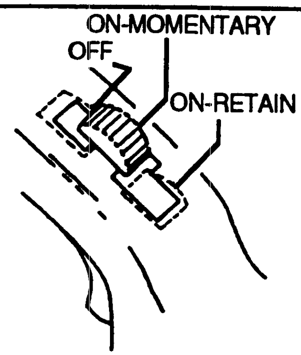
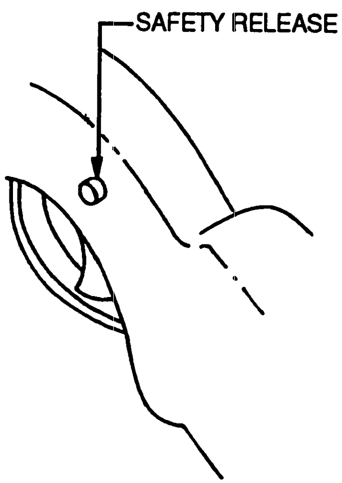
	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Thumb-actuated switch, two or three position, single axis. Typical application is supplemental on-off function coupled to primary control grip. Concave contact surface with serration desirable.	L - Switch length: Min = 16 mm	W - Width: Min = 6.5 mm		D - Min = 6.5 mm; Max = 19 mm	N/A
	Index finger operated trigger. Applications include hand weapons and joystick weapon firing control. Slight concave surface desirable	L - Min = 25 mm	Same as above	A - Preferred angle between 30° and 45°	D - Min = 3.2 mm; Max = 16 mm	S - Grip to trigger center spacing = 50 ± 6 mm
	Thumb-operated, two-dimensional switch, spring-centering. Typical application is trim control. Switch cap shown is typical.	D - Diameter = 19 ± 6 mm	H = 19 ± 6 mm		D - Min = 6.5 mm; Max = 19 mm	N/A

TABLE 16. Grip switches - continued.

	APPLICATION GUIDELINES	DESIGN GUIDELINES				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	Active thumb-operated safety and trigger controls. Mechanical thumb switch guide (spring-loaded, momentary-to-off). Must have thumb switch in momentary or retain to actuate trigger.					
	Momentary safety button. Must be held to actuate trigger.					

5.4.8.5.4 Safety. Inadvertent trigger operation should be minimized through proper use of trigger guards, safety latches, or other means to prevent inadvertent operation during non-operating modes (storing or carrying) and inadvertent operation during primary firing or operating modes (trigger activation before the operator is prepared).

5.4.8.5.5 Dimensions, displacement, and clearance. Trigger dimensions, displacement, and clearance limits should conform to criteria in Table 16.

5.4.8.6 Grip-actuated switches.

5.4.8.6.1 Use. Handle-mounted grip switches should be used only for discrete ON-OFF enabling functions with respect to a trigger mechanism, or control outputs from a joystick.

5.4.8.6.2 Dimensions, displacement, and resistance. The grip-actuated switch should be compatible with the natural placement and contour of the operator's palm, as it conforms to the handle during use of the primary handle manipulation (for moving a joystick and positioning a tool or camera). The switch tab should be approximately 7.5 mm long by 9.5 mm wide and have rounded edges. Switch displacement should be between 3 mm and 6 mm. Resistance should not exceed 22.5 N nor be less than 3 N.

This Page Intentionally Left Blank.

5.5 Labeling.

5.5.1 General. Labels should conform to these principles:

a. A label should give the user the information needed to perform the task.

b. Labels should be located consistently on all equipment.

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

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

e. Words should be printed so they read horizontally, not vertically.

f. Labeling should be supplemented where necessary 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 made large enough that the operators can read them easily at normal distance.

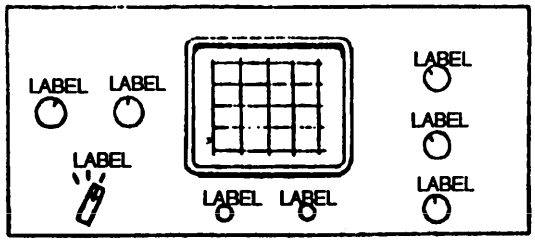
i. Generally, capital letters should be used; however, if the label has several long lines, upper- and lower-case letters should be used.

j. Bold-faced letters should be used only for short words or phrases that require emphasis.

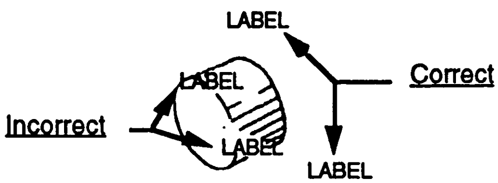
k. Labels should be placed on, or very near, the item they identify; any confusion with other items and labels should be eliminated.

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

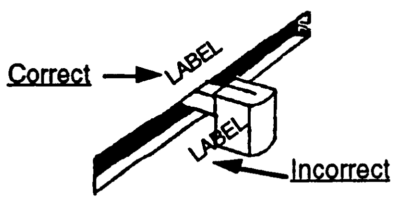
5.5.2 Orientation and location. Labels should be located so as not to obscure other information needed by the operator, and should be placed where a control or operator's normal hand or arm position will not obscure the label (see Figure 22).



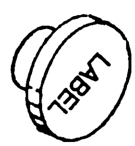
Locate labels consistently above or below a control or display on a given panel (Above is preferred except when the panel is located above the observer's eye level).

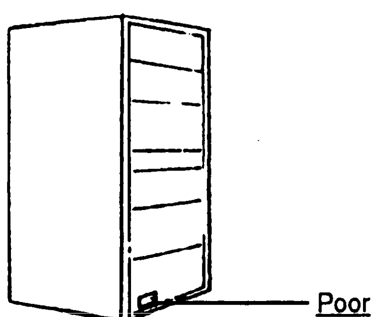


Locate label so that a control handle will not obscure the label.



Do not place label on a control that could rotate the label to an upside-down position.





Do not place placards near the floor or other positions that preclude the observer from getting his or her eyes in a position adequate for reading the placard.

FIGURE 22. Location and position of labels.

5.5.3 Contents. Reserved.

5.5.4 Qualities.

5.5.4.1 Brevity. Special markings and symbols (pictorials and arrows) should be considered when they unambiguously convey meaning in a more direct manner than words.

5.5.4.2 Understandability. Extended instructional or procedural information for placards and signs should be concise but understandable to the intended user.

a. Omit words that are unnecessary to convey the meaning of the message.

b. Place each procedural step on a separate line and include numbers, dots, or other techniques to emphasize the beginning of each step.

c. Use acronyms sparingly and only when they are familiar to the intended user.

d. Avoid use of instructions that require reference to another, perhaps unavailable resource. However, such reference may be used for placards that pertain only to a depot maintenance situation and where resource materials are typically available.

5.5.4.3 Visibility and legibility. The following factors should be taken into consideration:

a. contrast between the lettering and its immediate background;

b. height, width, stroke width, spacing and style of letters and numerals, and/or size of detail for other abstract or pictorial symbols;

c. method of application (etching, engraving, decal, silk screen);

d. relative legibility of alternate words; and

e. specular reflection.

5.5.4.4 Consistency. When function and application are identical, words or abbreviations used should be identical. Conversely, the same words should not be used to identify two or more controls or displays when these are not functionally identical.

5.5.4.5 Label background. Placards or signs that include their own independent background should provide maximum contrast between lettering and immediate background. Shiny metallic backgrounds should not be used for operational labels, placards, signs, or markings.

5.5.4.6 Access. Labels should be placed on the outside of equipment covers to identify control, display, or other functions located within a covered compartment. Labels attached to lines or cables for the purpose of identification should be positioned so the label is visible and properly oriented with respect to the nominal viewing position of the field technician rather than the factory assembler. Both ends of a cable or line should be labeled, and the connector elements also should contain appropriate, matching labels.

5.5.4.7 Label surface. Whenever practicable, labels, legends, placards or signs should be placed on a flat surface. If a label must be placed on a curved surface, lettering or symbols should be completely visible to an observer from the nominal vantage point. When the curvature of the surface is such that the lettering becomes too small to be read, another mode of labeling, such as an attached tag, should be used.

5.5.5 Label characteristics.

5.5.5.1 Style. Letters and numerals should be of a simple style without serifs except as may be necessary to distinguish between characters which would otherwise be confused.

5.5.5.2 Character stroke width. When characters are used on a light background, the stroke width should be approximately 1/6 the height of the character. When light characters are used on a dark background, the stroke width should be 1/7 to 1/8 the height of the character. These ratios should apply regardless of how high characters are made for distance viewing. However, for certain applications, characters with different stroke widths may be used on the same sign for emphasis. In this case, the thinnest character stroke should be no less than 1/8 nor the thickest character stroke greater than 1/5 of the respective character heights.

5.5.5.3 Stroke continuity. Continuous stroke characters should be used where applicable and practical for all equipment labels, legends, placards, and signs. Stencil characters may be used for shipping containers. Stencil characters should not have stroke breaks greater than 1/2 the character stroke width.

5.5.5.4 Character spacing. The minimum space between characters within a word should be one stroke width. However, character spacing should be adjusted to provide an appearance of open area balance within single words. An example is adjacent vertical strokes between adjoining characters compared to adjacent characters in which vertical components are far apart. In such cases, it is recommended that the space between adjacent vertical strokes be slightly wider than between vertical-horizontal or horizontal-horizontal strokes.

5.5.5.5 Word spacing. The preferred space between words is the width of one character (except for "I" or "1"). Minimum spacing between words should be 1/2 the width of one character.

5.5.5.6 Character height. Character height for labels, legends, and signs should be determined on the basis of criteria in Figures 23 and 24. For marking of aircrew station displays, refer to MIL-M-18012.

5.5.5.7 <u>Confusion between "I", "1" and "L" and between "0" and "O"</u>. When a label, legend, placard, or sign contains characters which might be confused, they should be made distinguishably different.

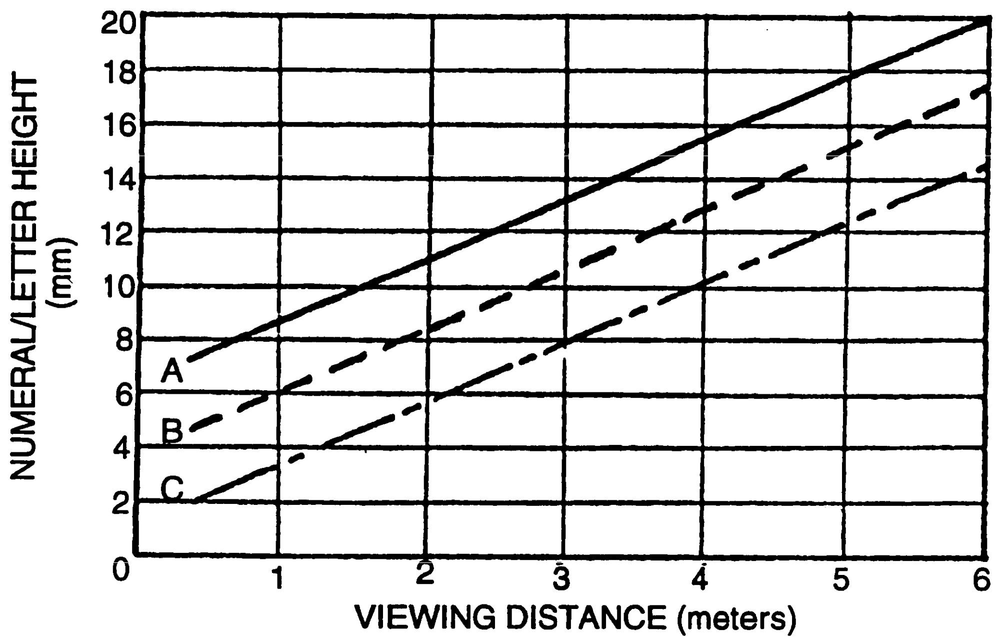
a. The lower case letter "L" should have a tab at the lower end extending to the right.

b. The numeral "1" should have a tab at the upper end extending to the left.

c. The numeral "0" should appear narrower than the letter "O" of a given font.

5.5.5.8 <u>Pictorials</u>. Pictorial symbols may be used in place of word labels and/or in addition to a word label when the pictorial provides quicker operator response. They should be completely unambiguous in the expected visual operating environments and should not be used on a control that may rotate and thus position the symbol so that it may be confusing. Pictorials for automotive equipment should conform to criteria in Federal Motor Vehicle Safety Standard (FMVSS) 101. Other pictorials should be subject to approval by the acquiring activity.

5.5.5.9 <u>Borders</u>. There should be sufficient clear space between characters and words used for labeling or signing to prevent the label from appearing crowded or difficult to read. The minimum clearance around a character or word should be 1/2 character height or more. Clearance around a character, or word, or set of words should not make the label appear "lost" within a large expanse of background. No performance limits have been established for maximum clearance around a label.



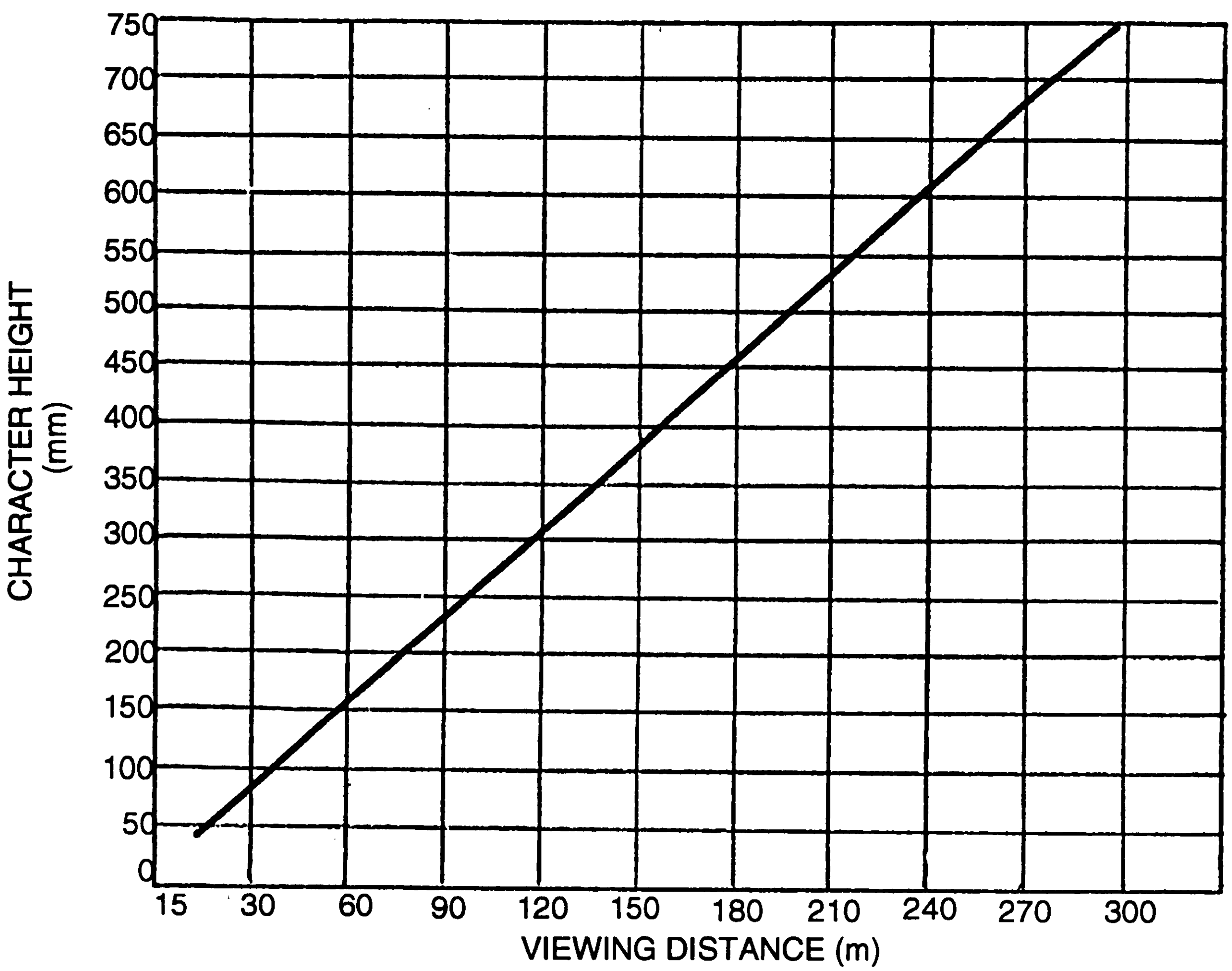
A. For displays where the position of the numerals may vary and the illumination is between 1.0 and 3.4 cd/m^2.

B. For displays where the position of the numerals is fixed and the illumination is 1.0-3.4 cd/m^2, or where position of the numerals may vary and the illumination exceeds 3.4 cd/m^2.

c. For displays where the position of the numerals is fixed and the illumination is above 3.4 cd/m^2

NOTE: Minimum space between characters, 1 stroke width; between words, 6 stroke widths.

FIGURE 23. Close proximity character height criteria.



Minimum letter height for 3 meter viewing distance= 7.6 mm. Letter height for longer viewing distances may be computed as follows:

$$\text{Desired character height (mm)} = \frac{\text{Viewing distance (m) x (7.6) mm}}{\text{3 m}}$$

FIGURE 24. Extended distance character height criteria.

5.5.6 Equipment labeling.

5.5.6.1 Cabinets. When several equipment cabinets are located in a single work area, each cabinet should be labeled to aid the operators and other personnel in quickly identifying what is located in each equipment cabinet. Such identification labels should be located in a conspicuous position considering the typical observation points from which each piece of equipment must be identifiable. Primary cabinet labels should be located in as consistent a manner as practicable so that observers do not have to hunt for the label. The size of the material on each label should be consistent with viewing distance criteria.

5.5.6.2 Panels. Where applicable, each panel within a given equipment or console should be labeled if the panel must be identified from others. When a given panel integrates a specific operating function as distinct from another panel, a general system or subsystem identification label should be provided.

5.5.6.3 Subfunctions. When subfunction areas on a single panel must be easily and quickly differentiated from other areas on the panel, the subfunction area should have a label approximately centered above the subfunction area. When the shape of the components within the subfunction area is not uniform, consideration should be given to surrounding the area with a suitable border to define the limits of the subfunction area.

5.5.6.4 Cabinet, panel, subfunction, and component label differentiation. Labels for identifying a prime equipment cabinet vs panels, subfunctions on a panel, and individual panel components should be capable of being differentiated in terms of the label size (letter height). The size encoding should progress according to the priority listing indicated below:

a. Largest label size for the prime equipment.

b. Next largest label for individual panels.

c. Next largest label for subfunction areas within a panel.

d. Smallest label for individual components, such as displays or controls.

Label sizes should be compatible with expected viewing distances; however, to provide discriminable differences among label sizes, each label character height should be at least 25% less than, or greater than, the next function label (see Figure 25).

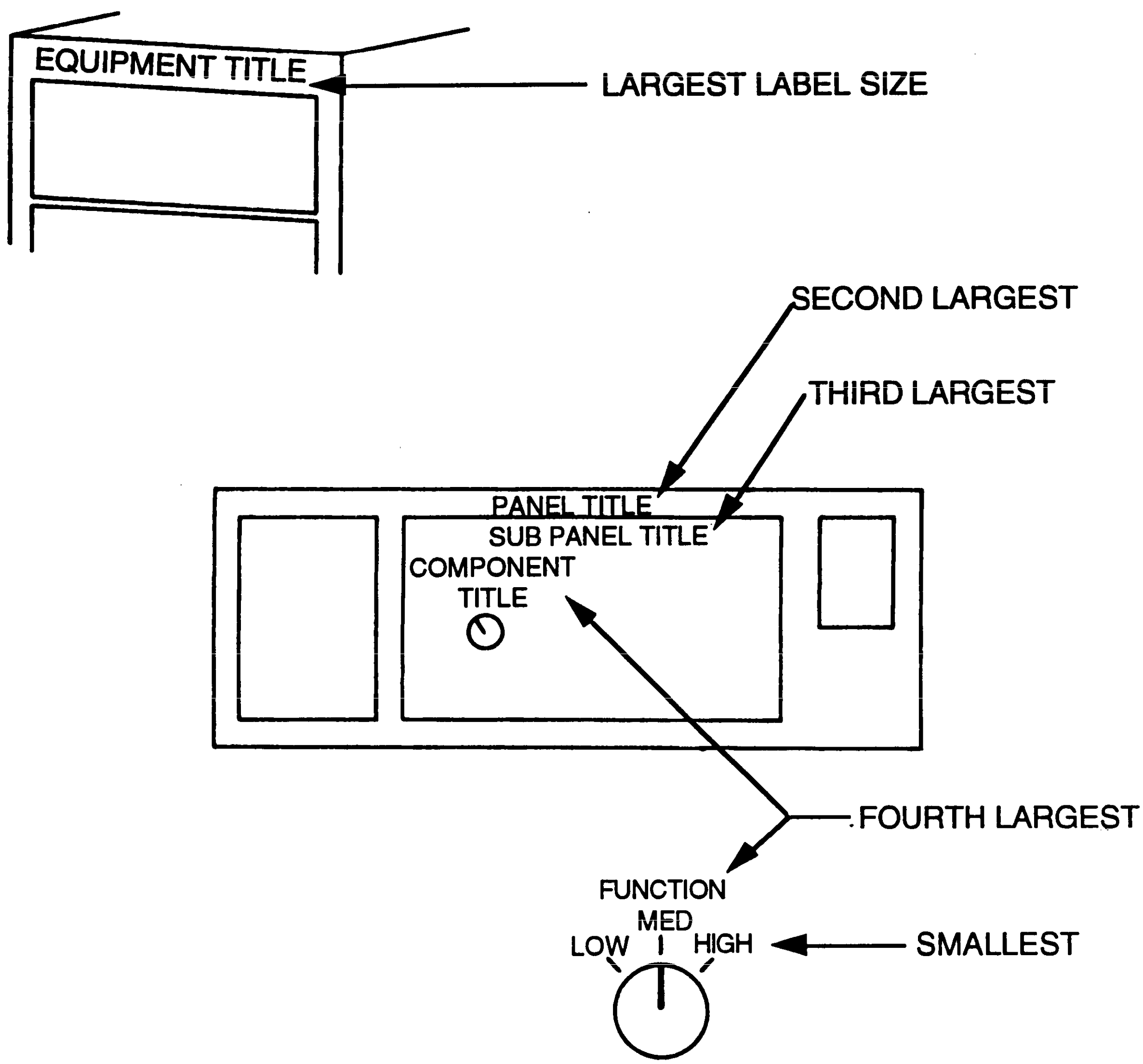


FIGURE 25. Label-size hierarchy.

5.5.7 Labeling for identification.

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

a. specify the overall system of which the assembly is a part,

b. include the assembly's popular name and function, and

c. include a stock number for requisition purposes.

The gross identifying label on an assembly should be located:

a. where adjacent assemblies will not obscure it,

b. on the flattest, most uncluttered surface available,

c. on a main chassis of the assembly, and

d. where it will not be removed accidentally, obstructed, or damaged in handling.

5.5.7.2 Instruction plate. Instruction-plate decal specifications can be found in MIL-P-514. Instructions should be as brief as clarity allows and placed where the operator can see them easily. They should read from left to right and listed in a step-by-step format rather than in a continuous paragraph.

5.5.7.2.1 Diagrams. Diagrams containing only the information the operator needs should be used where possible. Orient such diagrams so they relate logically to the objects to which they pertain. Locate them in conspicuous places on or near controls.

5.5.7.2.2 Color. Instructions should be printed in white letters on a black background. The black color should be 37038, FED-STD-595, or an approved equivalent.

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

5.5.7.2.4 Caution plate and decals. Caution plates or decals should be printed in yellow letters on a black background. The black color should be 37038, FED-STD-595; the yellow color should be 23538 or 23655, FED-STD-595.

5.5.7.3 Lift points. Mark lift and hoist points clearly indicating weight and stress limitations. Label lift or hoist joints at the point of lift, not on removeable parts of the body member that may be separated from the lift point.

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

5.5.7.5 Hazard signing and marking. Appropriate signing and marking of all potential hazards to personnel should be provided. The following signing and marking should be considered.

a. Fixed physical obstructions (low overheads, open hatches or manholes, posts, and guardrails).

b. Moving hazards (conveyor belts, chains, gears, loaders, cranes, and booms).

c. Equipment contact hazards (high-voltage and high-temperature).

d. Radiation hazards (electromagnetic and nuclear).

e. Laser beams.

f. Toxic contaminants (substances and gases).

g. Flash or high intensity light.

h. Requirement for safety glasses.

i. High noise or blast.

j. Criteria for hard hats.

k. Explosives.

l. High-pressure containers and hoses.

m. Slipping and falling hazards.

n. Other (fire, first aid and rescue).

This Page Intentionally Left Blank.

5.6 Anthropometry.

5.6.1 General. In design work, human engineering, or any other application of anthropometric data, measurements of a single body dimension are seldom used alone. Usually, two or more measurements should be considered together. Stature and chest circumference, as well as waist circumference, are utilized in the sizing of many items of clothing, while neck circumference and sleeve length are needed for shirts, and waist circumference and crotch height are required for trousers. Similarly, in human engineering applications, sitting height and functional reach, for example, are used in the design of vehicles and aircraft, while hip breadth, sitting and popliteal height are required for the design of seating.

5.6.2 Anthropometric data.

5.6.2.1 Highly-correlated measurements. In general, height measurements (waist height, crotch height, sitting height) and the lengths of the arms or legs are highly correlated with stature. Circumference measurements or body girths are more likely correlated with weight. Breadth measurements tend to be more highly correlated with weight than with stature.

5.6.2.2 Relationship between measurements. The degree of relationship may be expressed by a correlation coefficient or "r" value. The "r" value describes the degree to which two variables vary together (positive correlation) or vary inversely (negative correlation). The correlation coefficient, "r", has a range of values from +1.0 (perfect positive correlation) through -1.0 (perfect negative correlation).

5.6.2.3 Bivariate tables. The variability of two body measurements and their interrelationship with each other may be shown graphically in a bivariate table. The bivariate table shows the ranges of two measurements and the numbers or frequencies of individuals who have the various possible combinations of values of the two measurements. The values indicating the ranges of the two measurements represent the midpoints of the intervals in those ranges. The frequencies or numbers of individuals may be given as actual numbers or may be expressed as percentages of the sample. While the relationship between two measurements is summarized by the coefficient of correlation, or "r" value, the extent or degree of correlation may also be estimated from the appearance or general shape of the bivariate distribution. A bivariate table, which shows a fairly well-defined band sloping from the lower left to upper right indicates a high degree of correlation that would normally be confirmed by a comparatively high coefficient of correlation (0.7 and higher). If this slope is absent, and the distribution is oval in shape, that means the correlation coefficient is low, and that the two variables are not changing in a similar fashion. See Table 17 for a bivariate frequency table for waist circumference and crotch height.

TABLE 17. Abivariate frequency table.

	CROTCH HEIGHT (cm)																									
		65 .50	67 .00	68 .50	70 .00	71 .50	73 .00	74 .50	76 .00	77 .50	79 .00	80 .50	82 .00	83 .50	85 .00	86 .50	88 .00	89 .50	91 .00	92 .50	94 .00	95 .50	97 .00	98 .50	100 .00	101 .50	TOT ALS
	127.50						1																				1
	125.00																										0
	122.50																										0
	120.00						1			1																	2
	117.50												1		1					1							3
W	115.00											1	1				1	1									4
A	112.50										1	1	1	2		2	1	1									9
I	110.00	1					1		1	1	2			2	4		3	2		1							18
S	107.50							1	1	4	2		3	1	2	1		1	1								17
T	105.00			1	1		1		3	3	3	3	4	3	4	1	2	4	1				2				36
	102.50							2	4	2	3	5	7	7	11	3	3	2	1	4	2						56
C	100.00					1		2	4	5	5	4	11	8	7	4	10	4	4	1	2			1			73
I	97.50						1	2	4	6	8	11	14	7	13	7	8	3	5		4						93
R	95.00			1		2	3	3	3	7	13	9	21	19	19	19	11	14	5	4	2	1	1				158
C	92.50				1	3	4	3	11	11	12	12	32	24	23	23	25	5	8	2	5	1	1				206
U	90.00		1				6	5	4	11	20	29	44	33	33	28	27	15	11	7	5	1	2	1	1		284
M	87.50		1		2		1	9	12	27	21	37	45	55	40	39	42	27	19	11	7		1	1			397
F	85.00				2	2	5	9	13	20	39	49	65	63	60	55	41	32	29	14	4	2		1			503
E	82.50					3	6	16	10	32	37	73	70	97	74	84	49	41	24	16	7	4	1	2		1	647
R	80.00			2	1	2	5	13	20	38	62	90	119	107	110	94	86	72	36	27	10	8	4		2		908
E	77.50				2	1	6	6	19	43	50	122	100	119	141	91	87	57	43	23	15	9	1	1	1		937
N	75.00				1	2	2	13	22	40	82	72	131	139	114	102	89	57	43	23	19	8	4	1			964
C	72.50			1	2	2	6	5	18	38	50	62	84	96	104	80	54	48	18	12	12	4	3				699
E	70.00			1		1	6	12	12	36	40	41	56	58	63	45	33	17	19	3	1	2	1		1		448
	67.50				1		3	7	9	5	10	18	17	27	15	20	13	6	5	4							160
c	65.00					2	6	2	3	3	.7	5	6	1	4	2	2	2	5	1							46
m	62.50						1				1		1	3		2											8
	60.00											1	1	1													3
	Totals	1	2	6	13	21	64	110	174	333	468	645	834	872	842	702	587	411	272	154	95	40	21	8	5	1	6682

SUMMARY STATISTICS

	MEAN	STD DEV	REGRESSION EQUATIONS	SE-EST	R
WAIST CIRCUMFERENCE	80.30	8.18	.005*X + 79.877	8.18	.003
CROTCH HEIGHT	83.94	4.67	.002*Y + 83.782	4.67	

5.6.2.4 Regression analysis. The coefficient of correlation is a measure of the relationship between variables. Given values of one variable, it is possible to predict the value of another variable. The predictive relationship between two variables can be shown in terms of a "line of best fit," or in terms of the mathematical definition of this line, called a "regression line." The application of regression analysis is useful for predicting measurements and relationships between measurements when an actual sample is not available.

5.6.3 Use of data.

5.6.3.1 Interrelationships. The anthropometric data represent values for individual body measurements. These are values for each independent measurement and, as such, give no indication of the interrelationships or correlations among the various body measurements.

5.6.3.2 Multiple dimensions. Extreme caution should be used when two or more dimensions are simultaneously used as criteria for design. Percentile values are not additive between different dimensions (see "An Alternative to Percentile Model," Society of Automotive Engineers (SAE) Technical Paper No. 810217). For example, it is incorrect to assume that the combination of the 5th percentile values will describe the dimensions of a "5th percentile man." In practice, the 5th to 95th percentile values of some dimensions will have to be exceeded in order to accommodate the same range in another key dimension. Therefore, percentile values are inadequate for designs where two or more dimensions are used simultaneously as design parameters. Instead, appropriate multivariate data and techniques should be used (see: "Computerized Accommodated Percentage Evaluation (CAPE) Model for Cockpit Analysis and Other Exclusion Studies," Pacific Missile Test Center (PMTC), TP 75-49; and "A Family of Manikins for Workstation Design," Naval Air Engineering Center (NAEC) TR 2100-07B).

5.6.3.3 Variability of relationships. The relationships or correlations between body measurements are highly variable. Certain dimensions may not always have the same influence on other dimensions.

5.6.3.4 Clothing. Examples of the changes in anthropometric values imposed by different clothing ensembles and more specific may be found in "Anthropometry of the Clothed U.S. Army Ground Troop and Combat Vehicle Crewmen," Natick Research, Development and Engineering Center (NRDEC) TR 84-034.

5.6.3.5 Posture. Different cockpits and crewstations often require their operators to assume different postures, which may change as the operator fatigues. Because anthropometric data are derived from measurements taken in standard anthropometric postures, suitable allowances should be made for postural variation. Further information may be obtained from the appropriate service agency responsible for anthropometry.

5.6.3.6 Slump factor. Seated eye-height measurements may be reduced as much as 65 mm when personnel sit in a relaxed or slumped position. This slump factor should be considered when selecting the range of movement for adjustable seats, as well as in locating displays, optics, and vision ports. The slump factor is not a valid reason for lowering ceilings to save space.

5.6.3.7 Human subjects. Once the equipment or workspace design has progressed from the drawing board to a full scale mockup, the use of persons closely resembling various percentiles in conjunction with the mockup is a valuable design practice.

5.6.3.8 Information sources. Data on arm and leg reach, center-of-mass and joint centers for body segments and the inertial properties of the human body are sometimes of interest to equipment and workspace designers. Data are available in various publications. An example of a convenient and informative source of data is NASA-STD-3000, "Man-Systems Integration Standards."

5.6.4 Special populations. Reserved.

5.6.5 Body movement.

5.6.5.1 Range of motion. Table 18 gives the ranges, in angular degrees, for all voluntary movements the joints of the body can make, as illustrated in Figure 26. The designer should remember that these are maximum values; since they were measured with nude personnel, they do not reflect the restrictions clothing would impose. The lower limit should be used when personnel must operate or maintain a component; the upper limit should be used in designing for freedom of movement.

5.6.5.2 Whole body. All operating positions should allow enough space to move the trunk of the body. When large forces (more than 13.6 kg) or large control displacements (more than 380 mm in a fore-aft direction) are required, the operator should have enough space to move his entire body.

5.6.6 Human strength and handling capacity.

5.6.6.1 Exerted forces. The maximum amount of force or resistance 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 used to operate it, the position of this body member during control operations, the general position of the body, and whether or not support is provided by backrests.

TABLE 18. Range of human motion.[1]

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

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

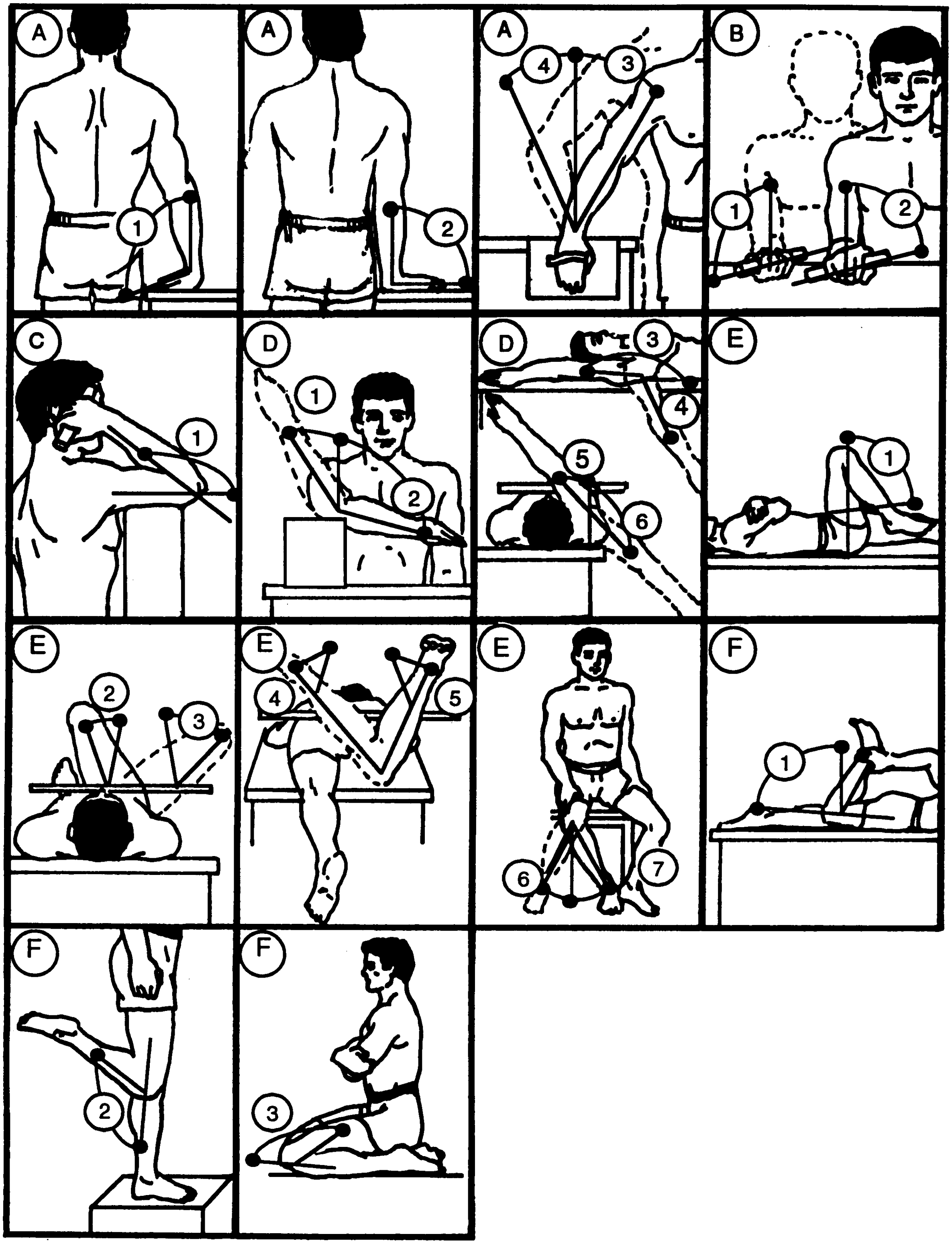


FIGURE 26. Range of human motion.

TABLE 18. Range of human motion - continued.[1]

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

[1]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: Rotation of the palm of the hand downward.
Supination: Rotation of the palm of the hand upward.

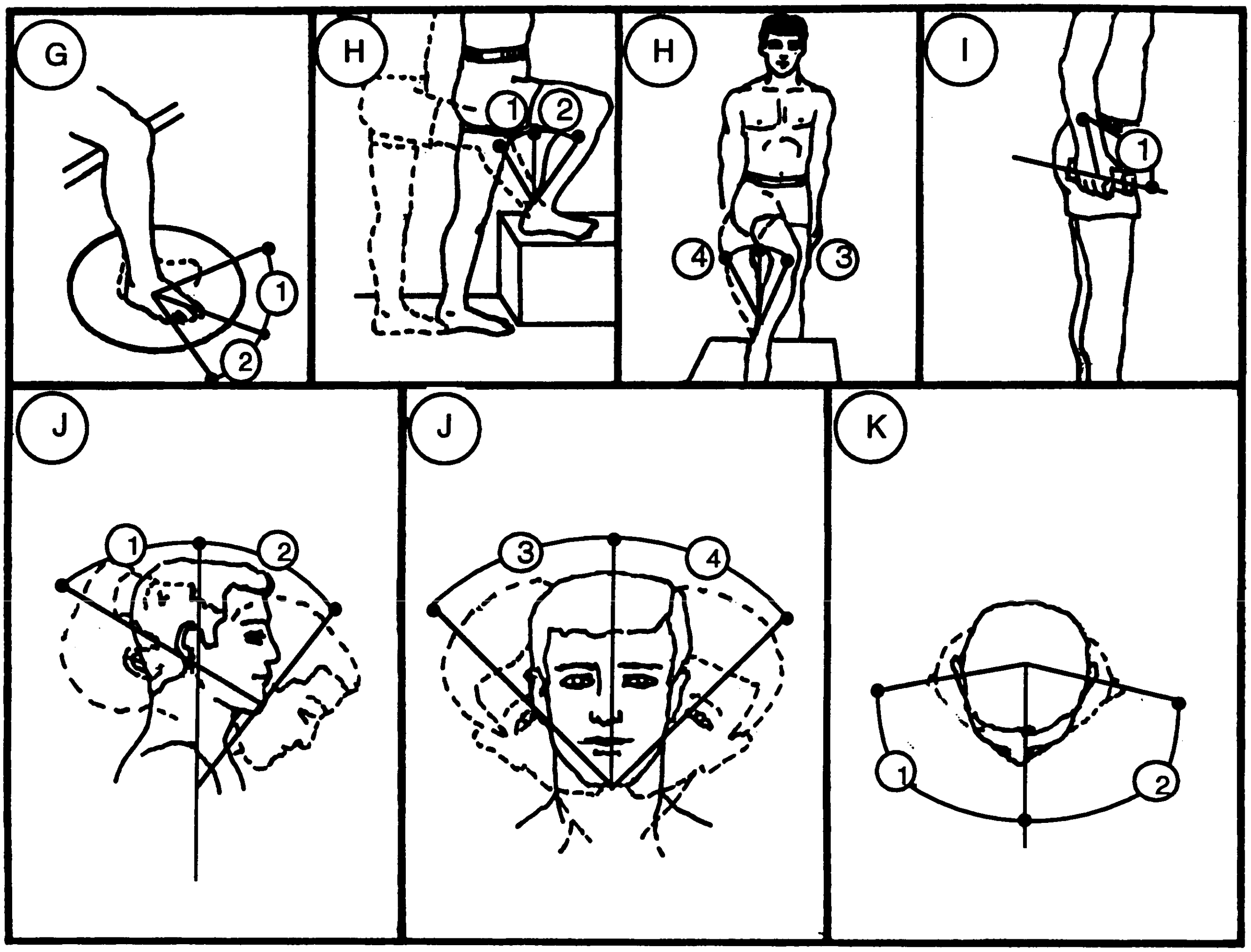


FIGURE 26. Range of human motion - continued.

5.6.6.2 Lifting.

5.6.6.2.1 Comparative strength. Much research, currently investigating the maximum lifting characteristics of males and females, has produced little insight into the relative strength of women to men. The U.S. Army Research Institute of Environmental Medicine (ARIEM) has been collecting data in this area. ARIEM suggests the following strength relationship:

a. For upper extremities, women's strength is 56.5% of men.

b. For lower extremities, women's strength is 64.2% of men.

c. For trunk extremities, women's strength is 66.0% of men.

These numbers (based on sample size N = 1500) may serve as a preliminary design guideline until more up-to-date information may be available.

5.6.6.2.2 One person lift. Whenever possible, equipment should be designed so one person can lift it. Some lifting tasks may require two persons, but this is not normally desirable.

5.6.6.2.3 Other application limits. Design should also take into consideration conditions when the object might be very difficult to handle (slippery), workspace might be less than optimal, or the object must be positioned or handled delicately.

This Page Intentionally Left Blank

5.7 Workspace design.

5.7.1 General. This section of the handbook has been prepared to consolidate information about the dimensional aspects of workspaces. Anthropometric data necessary for the planning and design of functional workspaces are presented. This information addresses design concerns pertaining to general types of seating access, and to standing, stationary and mobile workspaces, including the crewstations of combat vehicles. The key to proper workspace layout is to first give consideration to the accommodation of the operator(s) and his tasks, and then to the dimensioning of the overall workspace. Thus, insofar as it is consistent with the operational mission, the workspace should be laid out with the person as the primary consideration. The reverse, designing the workspace and then adding the person, is usually ineflicient and most often not cost effective.

5.7.2 Standing operations.

5.7.2.1 General. Whenever possible, workspace should be designed so operators can do routine, frequent, or short-term jobs while standing. A standing operator's workstation is not as limited to strict dimensional constraints as a seated operator's workstation because the standing operator can face in any direction and move from one position to another. If they are not free to do so and must remain in one position, the workspace should be designed so the operator can sit or take a sit-stand position.

5.7.2.2. Advantages. Some of the advantages of the standing position include those listed below:

a. Operator's arms can apply more muscular force and make larger movements such as when operating a large lever.

b. Operators can move to see and use components in areas that would be inaccessible to seated users.

c. Operators can change positions, to reduce fatigue and boredom; many standing tasks can be done in either a sitting or a standing position.

d. Standing saves space; the operators can use flat working surfaces, without knee room.

5.7.2.3 Work surface. A horizontal, or nearly horizontal, work surface which serves primarily as a work or writing surface, or as a support for the operator's convenience items, should be 915 ± 15 mm above the floor, unless the surface is being used for locating certain types of controls (joystick, track ball, and keyboards) which should be 1.02 to 1.07 m above the floor. Care should be taken, when combining a horizontal workspace and a control panel, to ensure that the operators will have adequate workspace (minimum of 250 mm deep) and that they will be able to reach the control panel (maximum of 400 mm deep).

5.7.2.4 Equipment placement. Any equipment that standing operators view or adjust only occasionally may be placed anywhere around them as long as it is at the proper height. This principle does not apply if the operator's attention must be concentrated in one particular direction most of the time.

5.7.2.5 Dimensions. Recommended dimensions for standing workspace are given in Table 19 and Figure 27.

5.7.3 Seated operations.

5.7.3.1 Advantages. Some advantages of having operators work while seated include those listed below:

a. The operator can use more than one pedal control simultaneously.

b. The operator can exert greater force on foot controls.

c. Sitting reduces fatigue.

d. Operators have greater stability and better equilibrium when the equipment is vibrating or moving.

TABLE 19. Standing workspace dimensions,

Work Benches				
Standard Type: A.1 Height:	0.91 m above floor			
B.1 Width:	0.99 m			
Podium Type: A.2 Height:	1.04 m above floor			
B.2 Width:	0.91 m			
Work Clearances (mm)		**Minimum**	**Preferred**	**Arctic**
c.	Passing body depth	330	380	380
D.	Standing space	760	910	
E.	Foot space	100Xl00		
F.	Overhead clearance	1855	2030	1930
G.	Maximum overhead reach		685	635
H.	Maximum depth of reach		585	585
I.	Walking space width	305	380	380
J.	Passing body width	510	810	810

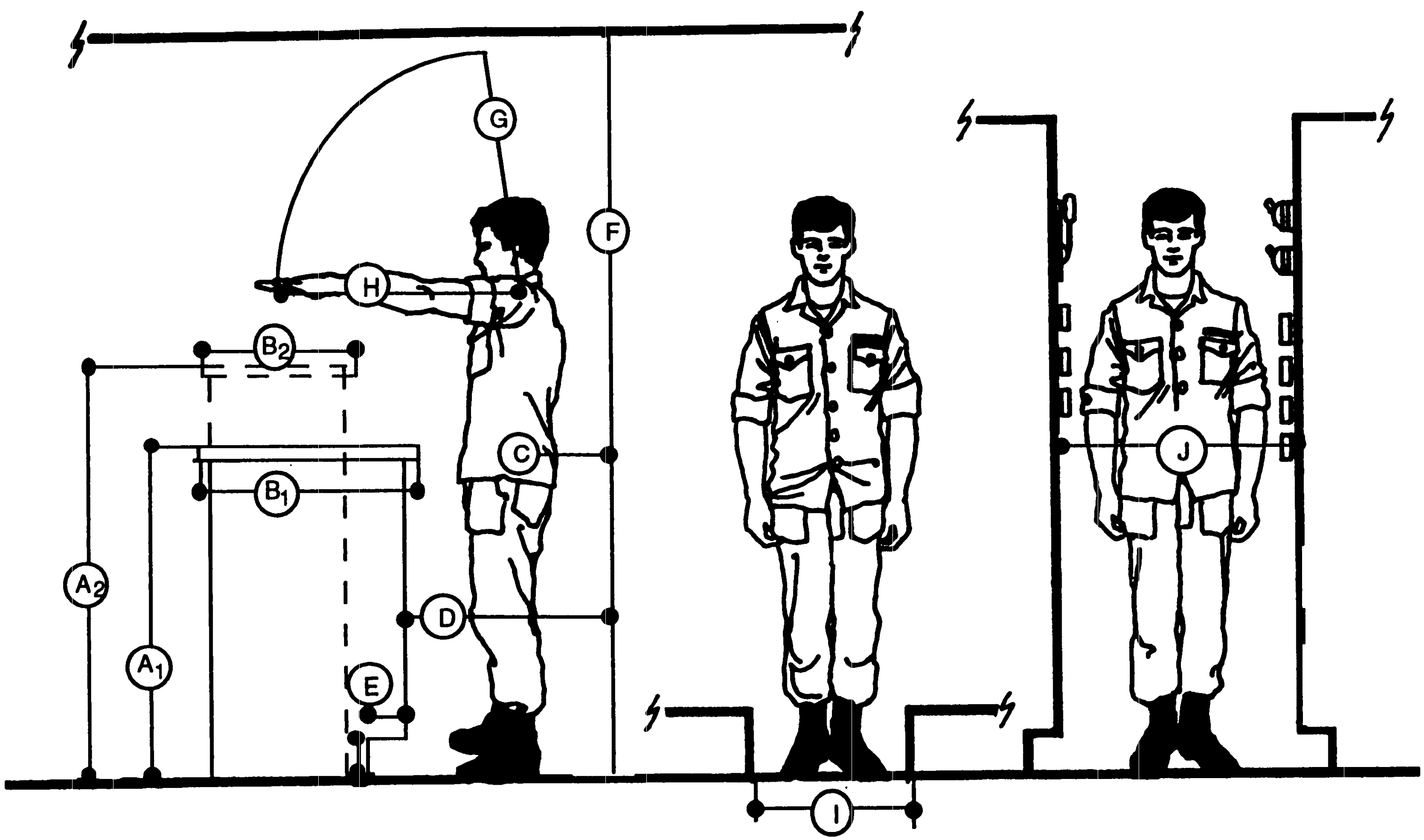


FIGURE 27. Standing workspace dimensions.

5.7.3.2 Seating. The main objective of seat design is stabilizing the operator's body so that the operator can work efficiently (see Figure 28 and Table 20).

5.7.3.3 Cushioning. Chairs should be cushioned whenever operators must remain seated for more than an hour or more than 20% of the time. Uncushioned stools or benches are adequate for intermittent sitting, but they should conform to applicable criteria for seats. Good seat cushions should:

a. have flat, firm shape, but with enough softness to deform,

b. have resilient material under the cushion to absorb shocks,

c. support body weight, primarily around the two bony points of the pelvis,

d. tilt backward 5° to 7°, so the seat (rather than the user's muscles) supports the back,

e. be shaped to follow the inward curve of the lower back, and provide adequate support for it, to relieve strain on the back muscles,

f. avoid applying pressure under the thighs,

g. use perforated or ventilated material, to prevent "hotness" or "sweatiness," and

h. allow the sitter to shift positions. (Larger backrests are better, because more support area gives greater opportunity for changing positions.)

5.7.3.4 Armrests. Seats usually should have armrests so the elbows can help support some of the upper-body weight. These rests should be undercut to allow space for the hips and thighs. Where a console or panel has a tracking control, the armrest should support the operator's arm so he is in the same plane as the control. These rests should be removable, since they sometimes interfere with tasks the operator must perform.

5.7.3.5 Footrests. Whenever the operators must work for extended periods in seats higher than 460 mm or with work surfaces higher than 760 mm, footrests should be provided.

5.7.3.6 Temporary seats. If there is not enough space to include a permanent seat, consider a temporary "swing-away" seat (see Figure 29).

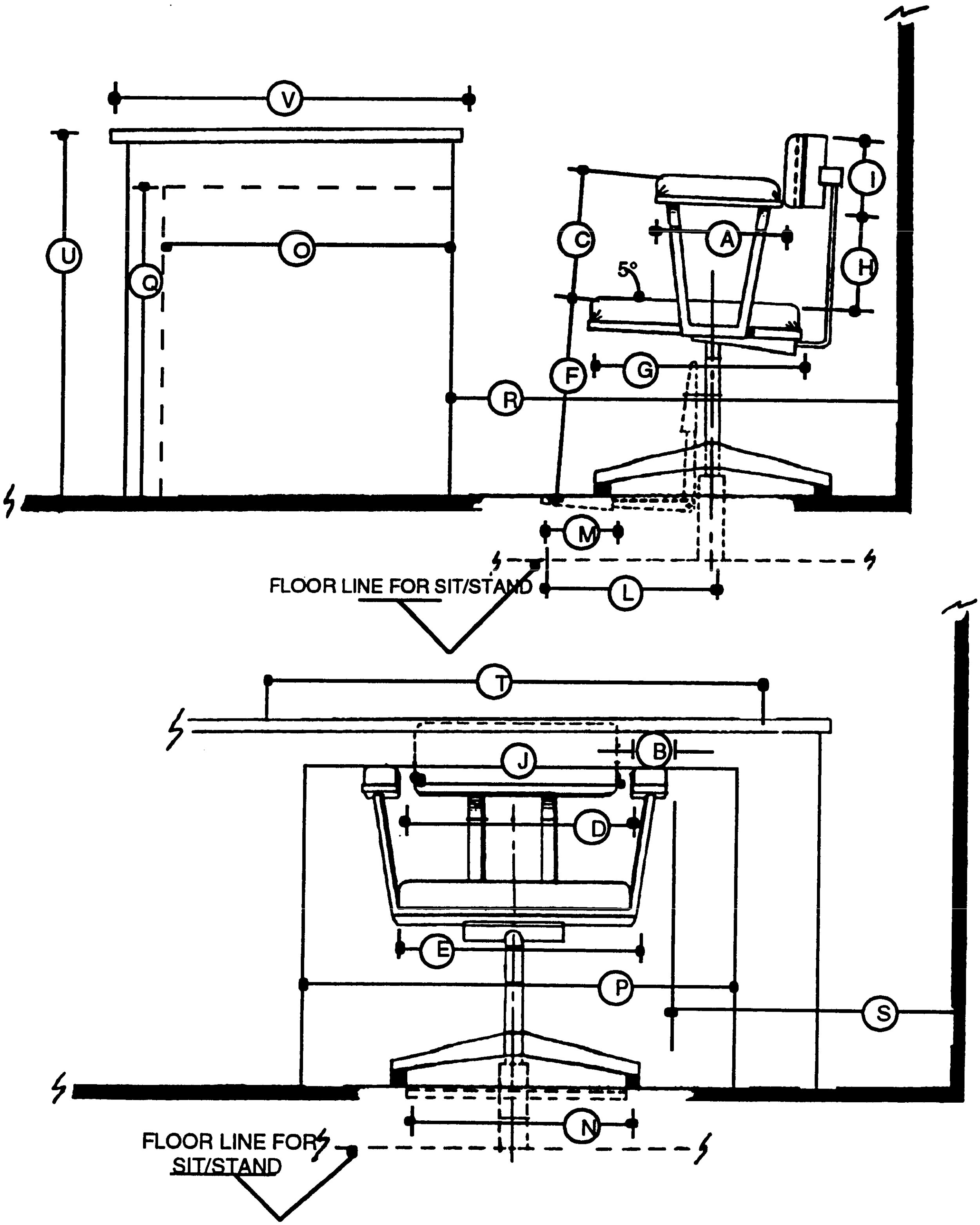


FIGURE 28. Seated workspace dimensions.

TABLE 20. Seated workspace dimensions.

			Fixed (mm)	Adjustment[1] (mm)
Chair				
Armrests:	A.	Length	255	
	B.	Width	50	
	C.	Height	215	
	D.	Separation	460	
Seat:	E.	Width	405	
	F.	Height	460	±5O
	G.	Depth	405	
Backrest:	H.	Space	150	±50
	I.	Height	380	
	J.	Width	405	
Footrests:	L.	From center	180	
	M.	Width	150	
	N.	Length	255	
Workspace			Minimum	Preferred
	O.	Kneehole depth	460	
	P.	Kneehold width	510	
	Q.	Kneehole height (standard office)	635	
	R.	Desk to wall	810	
	S.	Armrest to wall	610	
	T.	Lateral work clearance		
		(1) Shoulders	585	
		(2) Elbows	635	
		(3) Best overall	l m	
	U.	Height of work surface	735	760
	V.	Width of work surface		
		(1) Elbow rest alone	100	200
		(2) Writing surface	305	405
		(3) Desk work area		910

[1]Adjustment range. Adjustability is preferred for these dimensions.

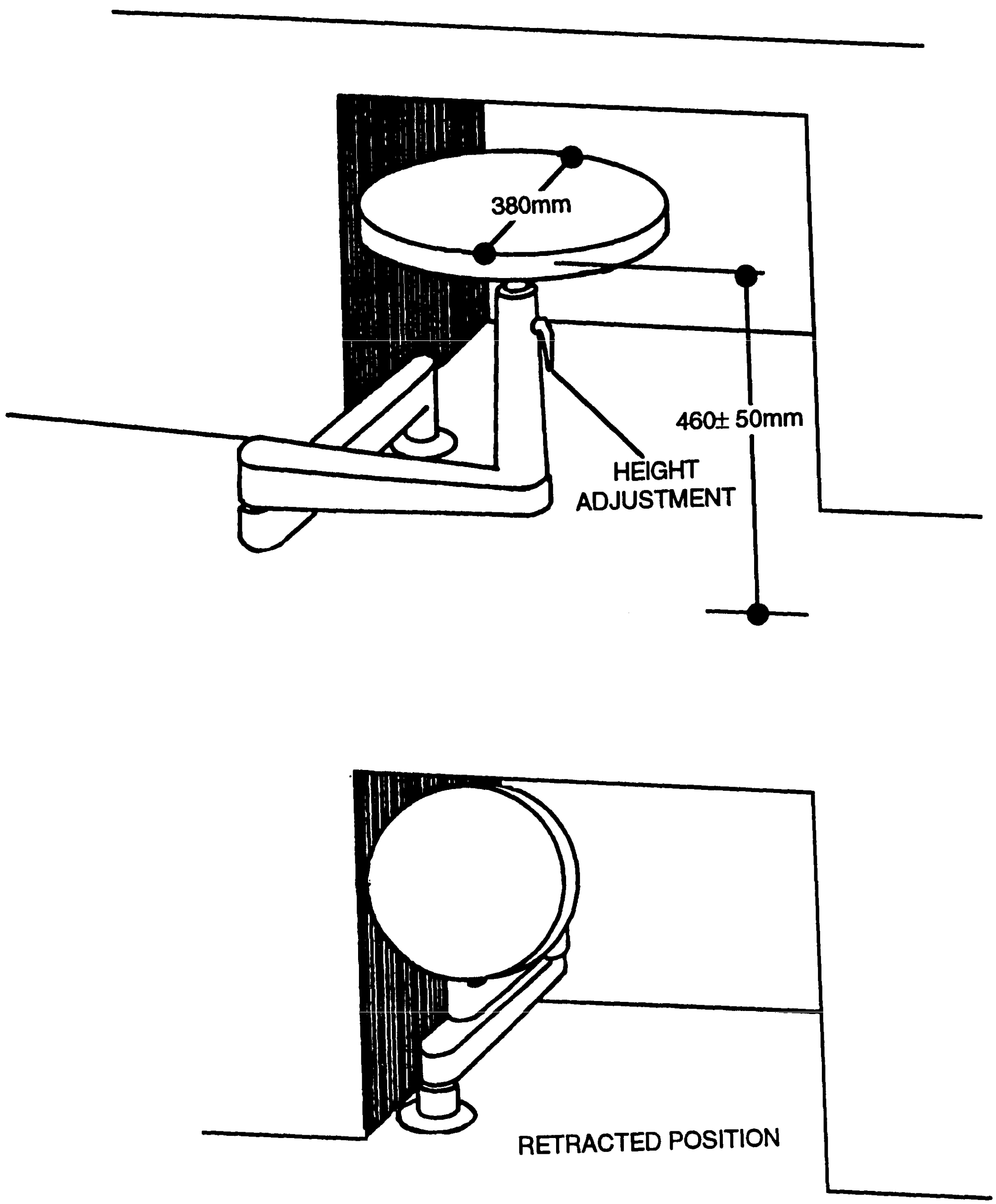


FIGURE 29. Swing-away seat for short-term operations.

5.7.3.7 Mobile workspace. Because of space limitations, personnel sometimes have to perform tasks where they can neither sit nor stand. These cases should be minimized as much as possible. If personnel must work in or pass through such limited spaces, minimum necessary clearances are given in Figure 30 and Table 21.

5.7.4 Common working positions. Reserved.

5.7.5 Standard console design. The effectiveness with which the operator performs tasks will depend upon: designing the contours and slopes of the console or instrument panel to minimize parallax in viewing displays, locating controls so they can be easily manipulated, and providing adequate space and supports for the operator.

5.7.5.1 Display surfaces. The various surfaces on consoles or instrument panels can be classified in terms of primary and secondary display and control areas. Each of these has its own guidelines.

5.7.5.1.1 Primary display surface. The primary visual surface on consoles or instrument panels should be reserved for displays which are used frequently or are critical to successful operation. Special cases, where controls and displays are combined, or control and display compatibility is important (even though the displays are of secondary importance), may warrant placing them on this surface.

5.7.5.1.2 Secondart display surface. The secondary display surfaces are located above or to the side of the primary display surfaces. These surfaces should be used for displays which are used infrequently during operations (set-up, adjustment, or operationally non-critical functions).

5.7.5.1.3 Design principles. The designer should use the principles listed below in laying out displays on the console or instrument panel.

a. Frequently monitored displays should be within the operator's preferred viewing area.

b. Indicators that are used for long, uninterrupted periods should be in the preferred position.

c. The preferred distance to displays is 635 mm.

d. The viewing distance to displays should not be less than 250-300 mm for short viewing periods, and preferably not less than 400 mm.

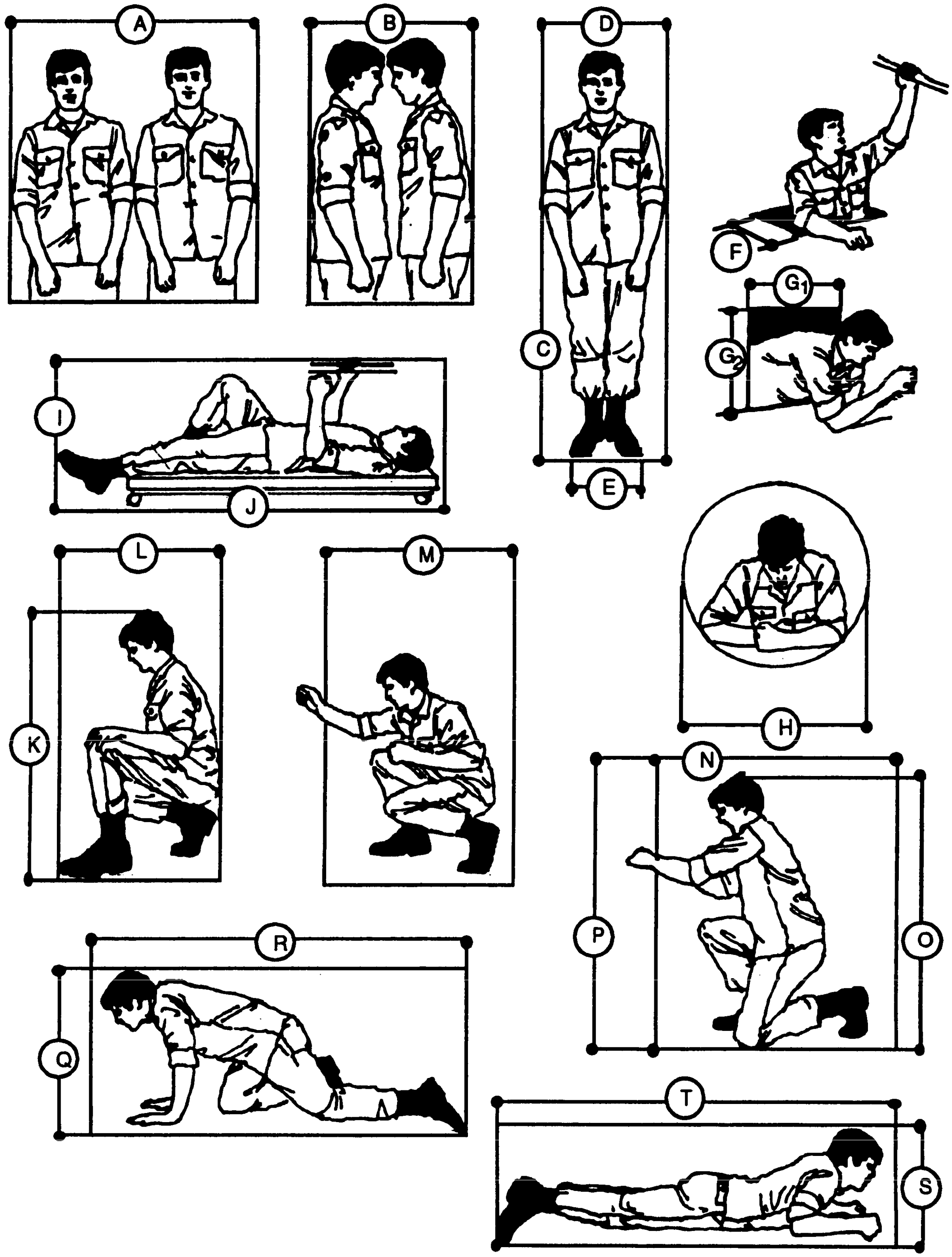


FIGURE 30. Mobile workspace dimensions.

TABLE 21. Mobile workspace dimensions.

	Dimensions (mm) Minimum	Preferred	Arctic Clothed
A. Two men passing abreast	1.06 m	1.37 m	1.53 m
B. Two men passing facing	760	910	910
Catwalk Dimensions			
C. Height	1.60 m	1.86 m	1.91 m
D. Shoulder width	560	610	810
E. Walking width	305	380	380
F. Vertical entry hatch			
Square	450	560	810
Round	560	610	
G. Horizontal entry hatch			
Shoulder width	535	610	810
Height	380	510	610
H. Crawl through pipe			
Round or square	635	760	810
Supine workspace			
I. Height	510	610	660
J. Length	1.86 m	1.91 m	1.98 m
Squatting workspace			
K. Height	1.22 m		1.29 m
L. Width	685	910	
Optimum display area	685	1.09 m	
optimum control area	485	865	
Stooping workspace			
M. Width	660	1.02 m	1.12 m
Optimum display area	810	1.22 m	
Optimum control area	610	990	
Kneeling workspace			
N. Width	1.06 m	1.22 m	1.27 m
O. Height	1.42 m		1.50 m
P. Optimum work point		685	
Optimum display area	510	890	
Optimum control area	510	890	
Kneeling crawl space			
Q. Height	785	910	965
R. Length	1.50 m		1.76 m
Prone work or crawl space			
S. Height	430	510	610
T. Length	2.86 m		

e. Displays requiring accurate readout should be located closer to the operator's line of sight than displays requiring only gross monitoring.

f. Displays should be mounted perpendicular to the line of sight. Angular deviation from the line of sight up to 45° may be acceptable, provided accurate instrument reading is not essential and parallax is not too great.

g. All instruments and legends should be readable from the operator's normal head position, allowing for normal head rotation and for restrictions imposed by helmets or other head gear.

h. All displays necessary to support an operator activity or sequence of activities should be grouped together.

i. Infrequently used displays can be in the periphery (maximum viewing angle) of the visual field.

5.7.5.2 Control surfaces.

5.7.5.2.1 General. In general, the control area is below the area where displays are mounted; displays which are closely associated with controls can be mounted on these surfaces. The optimum manual space is that in which hand-operated controls can be manipulated with the greatest speed and accuracy (Figure 3 1). This space is reserved for controls which must be operated frequently or are critical to operations placing controls in the optimum space permitting rapid and accurate identification, reaching and operation, and location of visual displays near the controls.

5.7.5.2.2 Design guides. The designer should use the principles listed below in arranging controls on the console.

a. Primary controls should be located between shoulder level and waist height.

b. Controls should be located so that simultaneous operation of two controls will not necessitate crossing or interchanging hands.

c. When controls are operated frequently, they should be located to the left front or right front of the operator.

d. Frequently used controls should be grouped together, unless there are overriding reasons for separating them.

e. Frequently used controls should be located for right-hand operation.

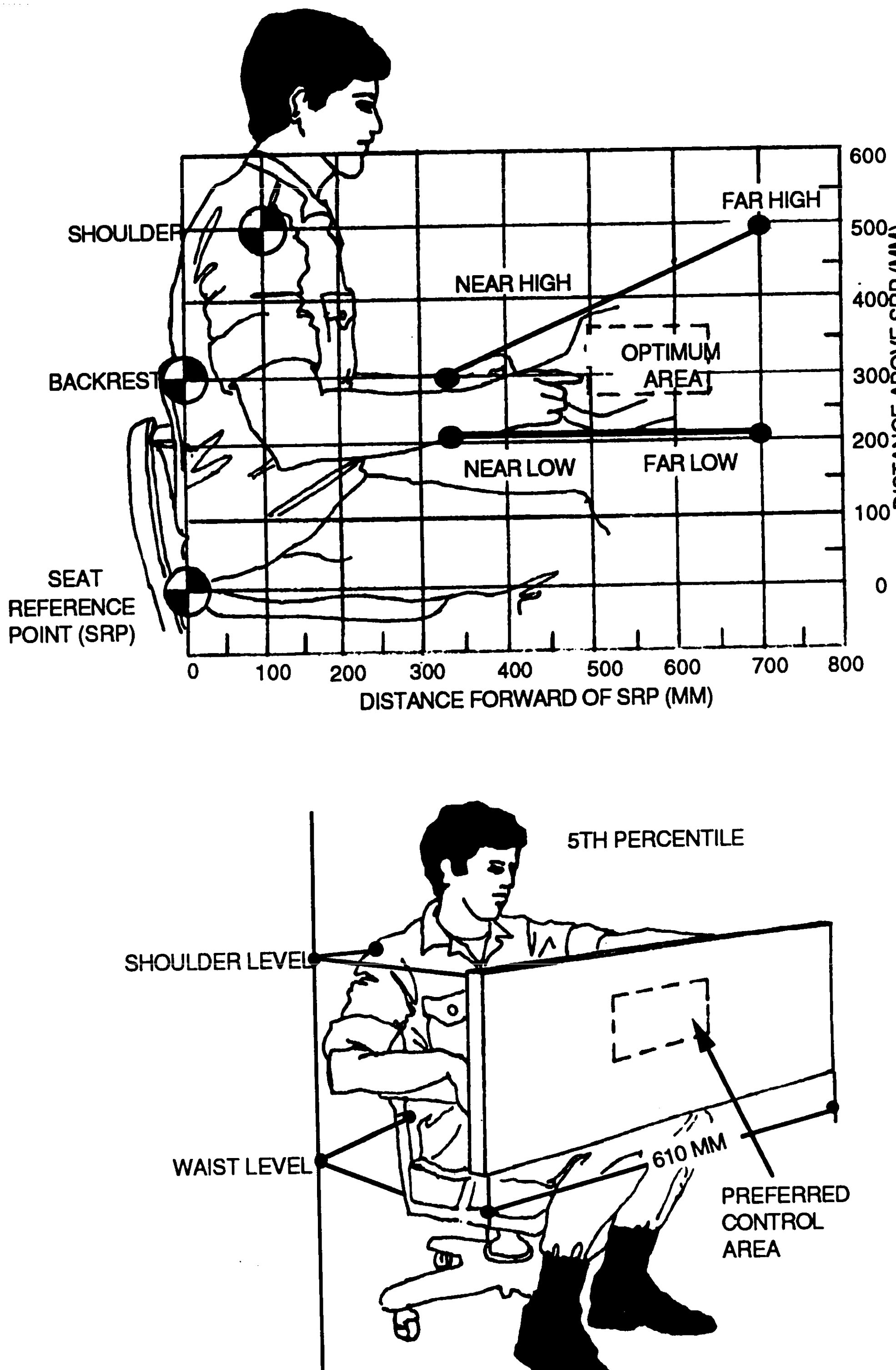


FIGURE 31. Seated optimum manual control space.

f. Frequently used controls should be within a radius of 400 mm from the normal working position.

g. Occasionally used controls should be within a radius of 500 mm.

h. Infrequently used controls should be within a radius of 700 mm.

i. Controls should be located where the user can see them to check their positions, regardless of the viewing angle.

j. All controls should be within the maximum reach of the seated operator (see Figure 31).

k. Controls requiring fine adjustments should be located closer to the operator's line of sight than controls requiring gross positioning.

l. When the operator must manipulate controls while monitoring a display, the controls should be placed close to, and directly below, that display.

m. Controls that are used infrequently should be placed to one side to prevent inadvertent activation.

n. Occasionally used controls may be mounted behind hinged doors or recessed into the panel to reduce distraction and prevent inadvertent operation. If, because of space constraints, controls must be placed where operators locate them without seeing them, designers should consider these error tendencies:

   (1) When controls are above shoulder level, operators tend to reach too low.

   (2) When controls are on either side of the operator, the operator tends to reach too far to the rear.

   (3) When controls are placed below shoulder level, operators tend to reach too high.

   Groups of controls should be arranged so these error tendencies will not cause injury, damage equipment, or allow incorrect operation.

o. When controls need to be placed where operators cannot see them, shape coding should be considered in their design to aid the operator in detecting the correct control by touch.

5.7.6 Special-purpose console design. Reserved.

5.7.7 Stairs, ladders, and ramps.

5.7.7.1 General criteria. Stairs, ladders and ramps should be:

a. provided wherever operators or maintenance personnel must change elevation abruptly by more than 305 mm,

b. selected to give the fastest, most efficient access to (and between) workplaces and areas,

c. constructed of materials which are lightweight, nonconductive, splinterproof, waterproof, humidity resistant, and resistant to chemical action,

d. strengthened to withstand the combined weight of the heaviest combination of personnel and equipment that is apt to be on them at any one time,

e. provided with non-skid material on surfaces where personnel may step, walk, or stand,

f. unencumbered by obstructions, edges, notches, or burrs that might injure personnel or damage hoses and cables,

g. adequately lighted (see Table 22),

h. adequately marked to warn users against any dangers involved in using them (unavoidable low overhead and possible shock hazard),

i. designed to be carried, handled, and positioned by one person wherever possible (but never more than two persons), and

j. used for safe, easy passage over low objects (pipes, lines, and ridges).

5.7.7.1.1 Layout and design. The layout and design of stairs, ladders, and ramps should make use of the considerations listed below:

a. Limited amounts of space and clearance available.

b. Expected environmental conditions, and especially whether the structure may get wet or be covered with ice or snow.

c. The type, direction, and frequency of traffic over the structure.

d. The relative efficiency of alternate traffic plans and patterns.

TABLE 22. Illumination criteria for representative tasks.

Task	Illumination Level (lux) Recommended	Illumination Level (lux) Minimum	Light Source
Perceiving small details with low contrast for prolonged times or where speed and accuracy are essential (examples: repairing small components, inspecting dark materials, layout drafting).	1615	1075	General services plus supplementary
Perceiving small details with fair contrast where speed and accuracy are not so essential (examples: handwriting, electronic assembly).	1075	540	General services and/or supplementary
Prolonged reading, desk or bench work, general office and laboratory work (examples: assembly work, filing records).	755	540	General services and/or supplementary
Occasional reading, recreation, reading signs where visual tasks are not prolonged (example: reading a bulletin board).	540	325	General services and/or supplementary
Perceiving large objects with good contrast (example: locating objects in bulk supply warehouse).	215	110	General services
Passing through walkways, handling large objects (example: loading from a platform).	215	110	General services

e. Loads or other equipment users must carry.

f. The configuration and weight of other equipment that may have to move over the structure.

5.7.7.1.2 Guardrails and handrails.

5.7.7.1.2.1 General. Guardrails and handrails should meet the criteria of Figure 32.

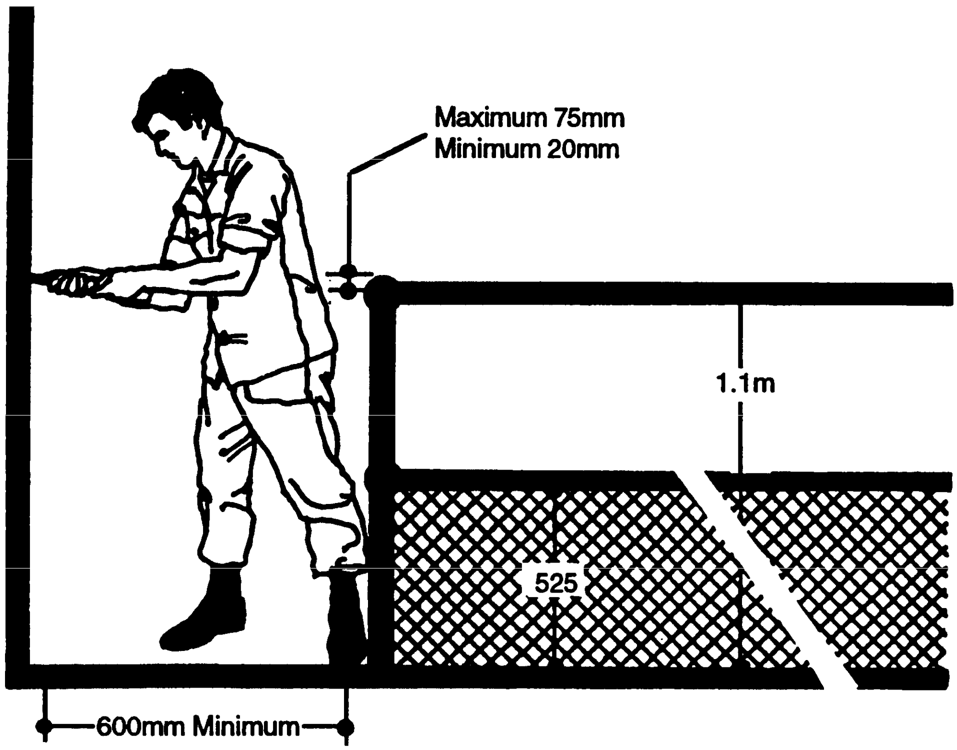


FIGURE 32. Guardrail and handrail dimensions.

5.7.7.1.2.2 Uses. Guardrails and handrails should be used to:

a. keep personnel from falling off raised work places,

b. keep personnel from falling through floor openings or manholes,

c. keep personnel within safe bounds when passing through hazardous areas,

d. help personnel climb inclines and stairs, and

e. help personnel stabilize themselves when working in moving vehicles or around high winds, fog, ice, or other hazards.

5.7.7.2 Stairs.

5.7.7.2.1 General. Long flights of stairs should be avoided. there should be at least one landing for each story (2.44 to 3.66 m of elevation), and landings, are recommended every 10 to 12 treads. Where practical, treads should be open, without the vertical risers to connect them. However, metal screens or kick plates should be fastened to the underside where needed to prevent injuries or avoid damaging equipment.

5.7.7.2.2 Risers. Riser height, or the distance between steps or stairs, should be uniform (between 125 and 200 mm). The distance between steps and landings, if different from the uniform riser height, should also be between 125 and 200m.

5.7.7.2.3 Load carrying. When people carry loads weighing more than 9 kg, or where stairs are more than two stories high, use deep treads (300 mm) and low risers (125 mm).

5.7.7.3 Ladders.

5.7.7.3.1 Rung ladders. Rung ladders are acceptable for occasional traffic, but they should not be used for frequent passage. They are comparatively unsafe, difficult to climb, and difficult from which to accomplish work. Loads cannot be carried up rung ladders safely unless they are strapped to personnel. As fixed ladders are preferable because they are more stable, pose fewer clearance problems, and can be protected with guardrails, safety belt rigging, and other safety features. Portable ladders should be avoided; when used at all, they should be restricted to emergency functions, infrequent maintenance tasks, or tactical situations where fixed ladders are impractical. For rung ladder dimensions, see Figure 34.

5.7.7.3.2 Handrails. When ladder steps (rungs) also serve as handrails, they should have round rungs. However, level steps, 75-100 mm deep, are also acceptable if there are handrails on both sides of the ladder.

5.7.7.3.3 Moving parts. Two-section extension ladders should assemble with permanently captive hardware such as hinges and locks rather than blots and nuts. Folding ladders should have catches and locking mechanisms that are simple, easy to release, and easy to maintain by the suitably-clothed and suitably-equipped users with applicable 5th to 95th percentile body dimensions.

5.7.7.3.4 Safety devices. Both fixed and portable ladders should have safety devices appropriate for their length, use, and operating conditions. For example, long ladders used in adverse weather or under emergency conditions should have carrier rails and safety belts; ladders erected against poles should have pole-lashing devices. In addition, moveable ladders should have secure feet which are not apt to slip. Secure ladder feet include rubber-cleated, pivoted feet for temperatures above freezing and steel cleats for use in ice and snow.

A. Spread: 290 mm per meter length of front section plus 160 mm per length of back section
B. Tread depth: Min. 75 mm; best 75 - 100 mm
C. Step spacing: min. 230 mm; best 280 - 300 mm
D. Min. width between top of siderails:
   Metal ladders: 300 mm
   Wood ladders: 290 mm
E. Width at bottom: Add 90 mm per meter of length
F. Length of ladder: Maximum of 6 m

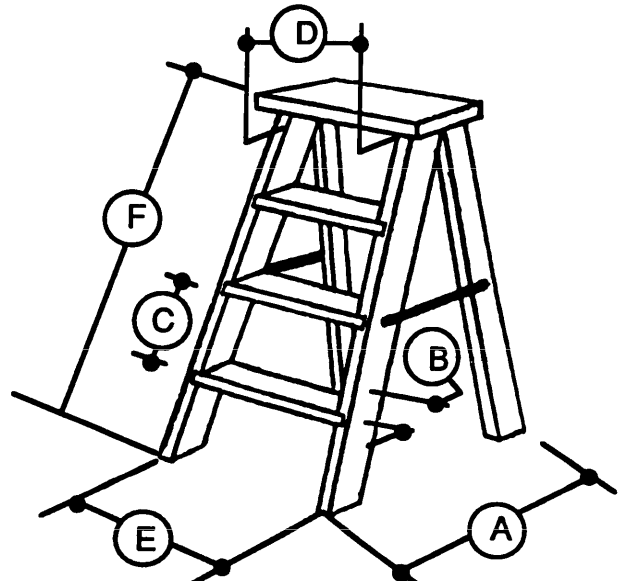


FIGURE 33. Stepladder dimensions.

A. Height of cage from base of ladder: 2.1 m
B. Flare at bottom of cage: 810 mm
c. Depth of cage from center of ladder: 710 mm
D. Max. distance between cage ribs : 460 mm
E. Width of cage: 680 mm
F. Rung diameter: See fixed ladders
G. Rung spacing: See fixed ladders
H. Maximum ladder length:
   Single ladders: 9.1 m
   Two-section metal ladders: 14.6 m
   Two-section wood ladders: 18.3 m
I. Min. width between siderails:
   Metal ladders: 300 mm
   Wood ladders up to 3 m long: 290 mm

(Add 6 mm for each additional 610 mm in length.)

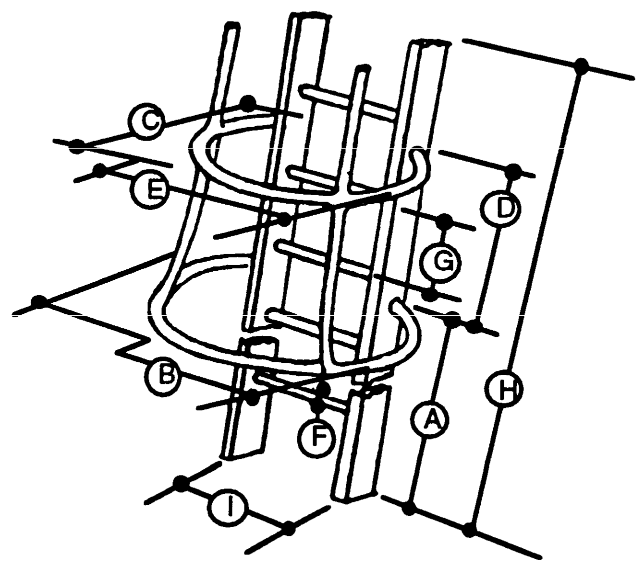


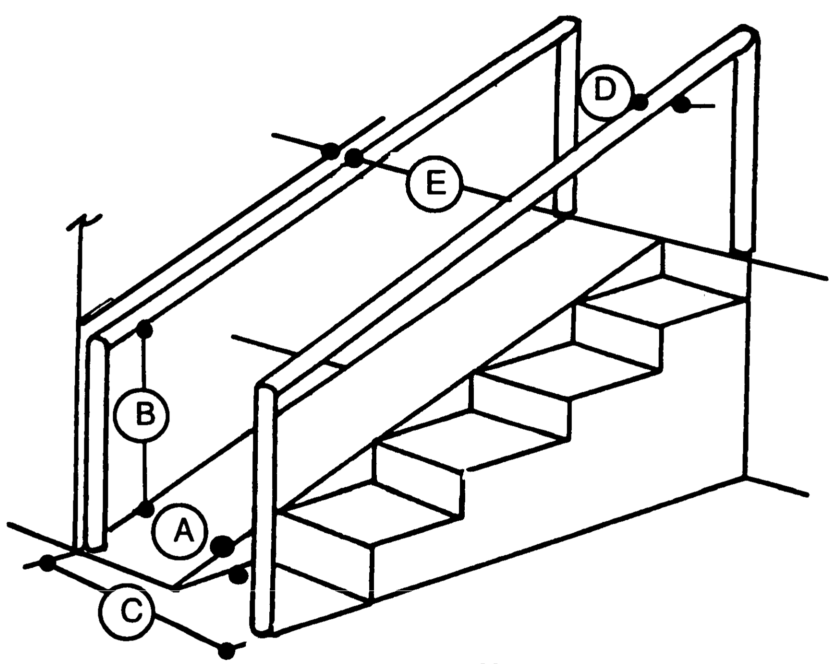
FIGURE 34. Rung-ladder and ladder-cage dimensions.

5.7.7.3.5 Weights. Where one person must lift ladders and store them by hand, ladder weights should be limited as shown below, depending on how high above ground level the ladder must be lifted:

Lift Distance (Meters)	Weight (Kilograms)
1.52	11.3
1.83	9.0

5.7.7.4 Ramps.

5.7.7.4.1 General. Ramps make it possible for personnel to roll stock from one level to another. However, in situations where personnel must push or pull stock up ramps, the ramps should be elevated carefully to the into consideration human strength and safety. Ramps or inclines should be used for slopes under 20°. For slopes between 7° and 20°, consider using combination ramps and stairways. (See Figure 35.)



		Minimum	Maximum
A.	Angle of rise:	-----	20°
B.	Height of handrails:	960 mm	1.1 m
C.	Width: Determined by function and usage; particularly size of rolling stock and loads .		
D.	Diameter of handrail:	25 mm	75mm
E.	Clearance around handrail:	50 mm	------

FIGURE 35. Ramp dimensions.

5.7.7.4.2 Pedestrian traffic. When pedestrian traffic uses ramps, handrails should be provided. There also should be traverse strips of non-skid material, at least 50 mm wide and 150 mm apart, over the entire length of the ramp. From the standpoints of space and speed, stairways carry pedestrian traffic more efficiently than ramps do.

5.7.7.5 Personnel platforms and work areas. Reserved.

5.7.7.6 Elevators, inclinators, and hydraulic-operated work platforms.

5.7.7.6.1 General. Platforms should be used where personnel must be raised to within optimal (or at least tolerable) working distance of equipment. Platforms should be designed with the considerations listed below.

a. Measure at least 610 mm wide and 910 mm long.

b. Leave both of the user's hands free for work.

c. Provide continuous work surface around the work area or between related parts of it.

d. Hold one or two persons (but no more).

e. Have sufficient strength to hold the heaviest combination of personnel and equipment that it will ever be required to support, plus a safety allowance. (In calculating this load, assume each person weighs 113.4 kg.)

f. Conform closely to the equipment surface it adjoins:

(1) Average conformation should be within 50 mm.

(2) Gaps greater than 150 mm should be avoided.

(3) Contact plates, cushions, bumpers, or pads should be used as necessary to protect equipment surfaces.

5.7.7.6.2 Portable platforms. Portable platforms should be constructed of lightweight material and be fully collapsible. Any platform on wheels should have brakes and wheel locks.

5,7.7.6.3 Equipment on Platforms. When users must carry equipment onto a platform, access stairs should not be steeper than 35°. Provisions should be incorporated in the platform to support test equipment at convenient working levels.

5.7.7.6.4 Handrails and toeboards. Platforms should have handrails and toeboards around the outer edges. Screening and latticework may also be used (see Figure 32).

5.7.8 Ingress and egress,

5.7.8.1 Routine. Enclosed work areas should have conventional entrances and exits for routine access to permit unrestricted flow for all anticipated traffic. They should be located so personnel who are entering or leaving will not operate controls accidentally or block access to controls.

5.7.8.2 Non-routine. Designers should consider providing auxiliary entrances as well as any needed emergency exits. Emergency exits should allow enough space for rapid exit of all occupants, including any who must carry essential equipment or wear bulky protective clothing, without danger of injuring personnel or damaging the equipment they carry.

5.7.8.3 Walkways and Passageways.

5.7.8.3.1 General. Corridor widths should be designed with consideration for peak traffic load expected, direction of traffic flow, and number and size of entrances and exits in the area. To allow people to move without restriction, the minimum widths given in Figure 36 should be observed.

5.7.8.3.2 Clearance. Adequate clearance for personnel wearing bulky protective clothing and carrying equipment should be allowed. A person can move through a corridor 510 mm wide with some difficulty; however, a one-person or one-direction corridor should be a least 760 mm wide.

5.7.8.3.3 Floors. Corridors should have non-side floors.

5.7.8.4 Doors.

5.7.8.4.1 General. Door dimensions should be as shown in Figure 37. Sills should usually be omitted, unless they are necessary for weather protection or ventilation control.

5.7.8.4.2 Sliding doors. Sliding doors are recommended when large vehicles or large pieces of equipment must be moved into (or out of) compartments. Separate hinged doors should be inserted into sliding doors for personnel use.

5.7.8.5 Escape hatches.

5.7.8.5.1 General. Escape hatches should be designed so they can be opened with one motion of the hand or foot. If personnel must use a handle or push button to open the hatch, its operating force should be less than 220 N. If emergency hatches must be placed overhead, they should weigh 22.6 kg or less and they should open by force of gravity. All personnel, except the weakest 5% of the population, should be able to release and open these hatches.

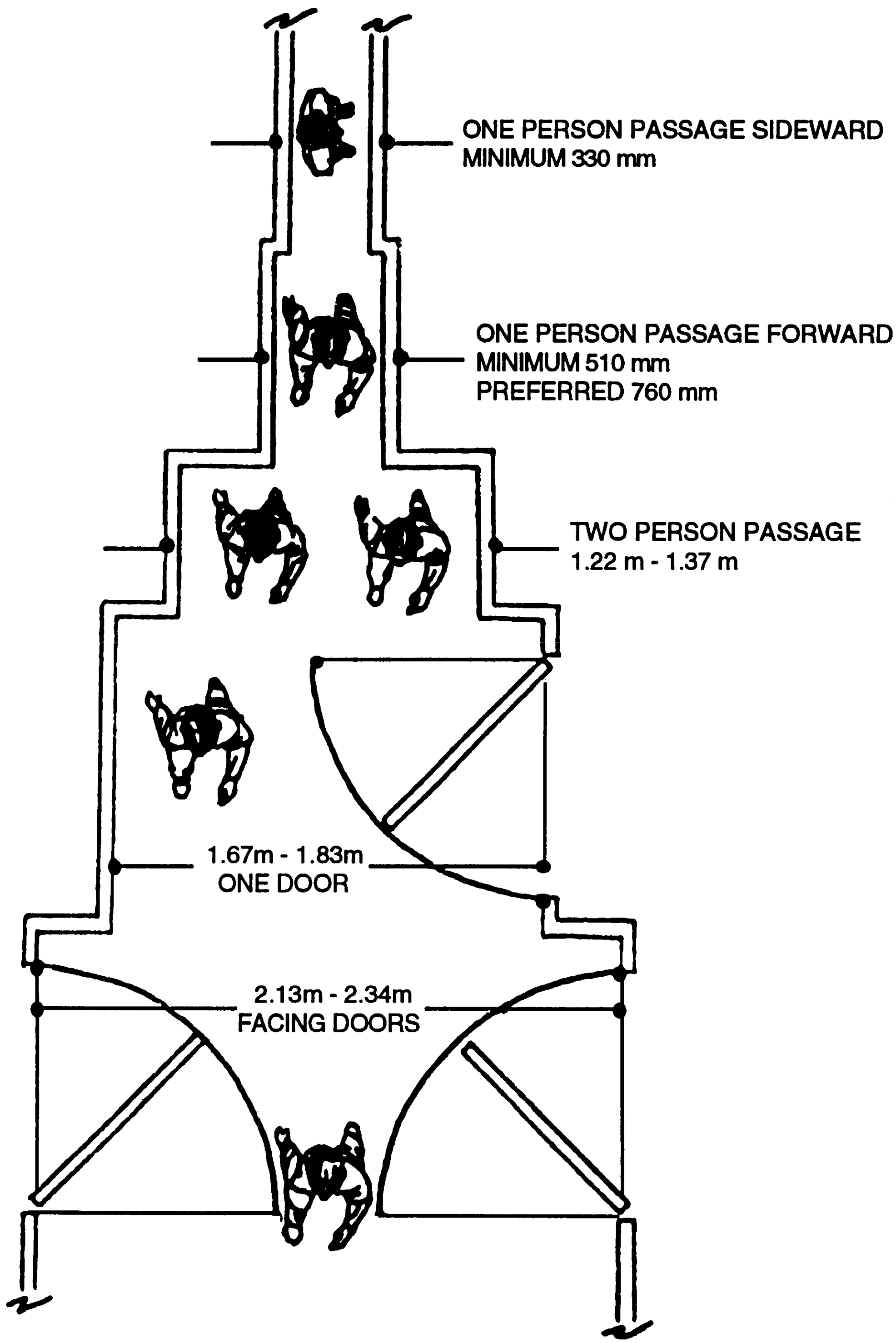


FIGURE 36. Walkway and passageway dimensions.

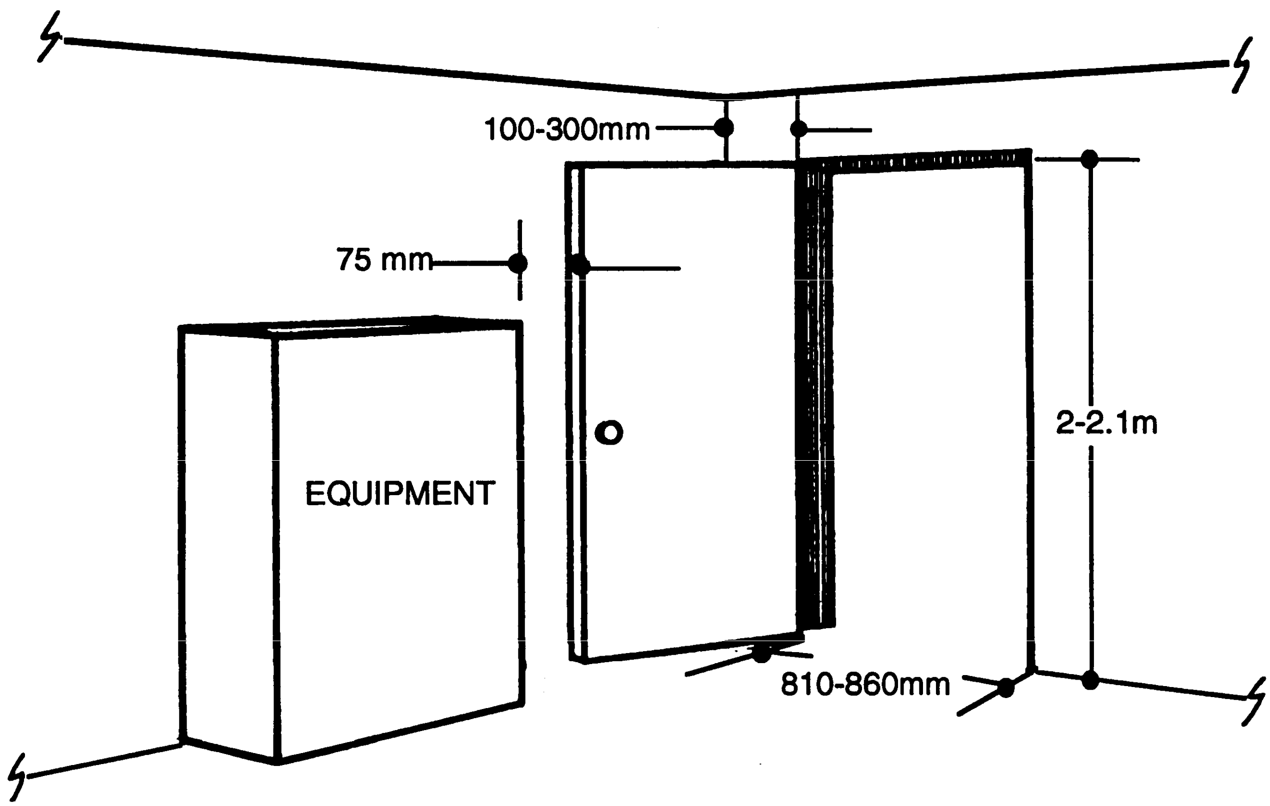


FIGURE 37. Door dimensions.

5.7.8.5.2 Wall hatches. Wall escape hatches in vehicle-mounted shelters should be clear of all obstructions (side panels or raised tailgate).

5.7.8.5.3 Dimensions. Escape hatch dimensions should be based on the work area from which personnel must escape, the equipment and clothing they will be wearing, and the environment they will enter. Minimum and preferred dimensions for emergency hatches are:

	Minimum (mm)	Preferred (mm)
a. Rectangular hatch opening	405x610	510X710
b. Square hatch opening	460	560
c. Circular hatch opening	560	710

5.7.9 Surface colors. Reserved

This Page Intentionally Left Blank.

5.8 Environment.

5.8.1 Heating, ventilating, and air conditioning.

5.8.1.1 Heating.

5.8.1.1.1 Mobile personnel enclosures (shop vans, shelters). Heating should be provided within mobile personnel enclosures utilized for detail work or occupied during prolonged periods of time to maintain interior dry bulb temperature above 10° C.

5.8.1.1.2 Permanent and semi-permanent Personnel enclosures (shops, offices]. Heating should be provided within permanent and semi-permanent personnel enclosures utilized for detail work or occupied for prolonged periods of time to maintain interior dry bulb temperature of 18° C. The heating system should have provisions for regulating (shutters, louvers, fan-speed controls, fuel-proof carburetor) the amount of heat it delivers and be designed such that hot-air discharge is not directed on personnel.

5.8.1.1.3 Vehicle design thermal considerations. Power-train and subsystem components, which are heated to a high temperature when the vehicle is in operation, is one source of heat. Solar radiation, which is distributed over the surfaces exposed to the sun, is another source of heat. The rate of solar radiation varies throughout the day, reaching a maximum of approximately 945 watts/m^2 per hour on a horizontal surface.

5.8.1.2 Ventilating. Reserved.

5.8.1.3 Air conditioning. Reserved.

5.8.1.4 Environmental factors. There are three major categories of environmental factors which affect equipment design.

a. Environmental factors that design can control (illumination, ventilation rate, and temperature).

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

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

5.8.1.4.1 Environmental extremes. To maximize the effectiveness of the weapons system, the designer should consider the environmental extremes to which the system will be subjected and the effect on performance. Military materiel should be capable of sustained operations within the climatic extremes specified in the materiel requirements documents. When deviations from the stated tolerable conditions are necessary, consequences should be considered in design to prevent adverse effects such as:

a. criteria for protective clothing or devices which affect the mobility, reach workspace, or access size, for efficient and effective operation and maintenance;

b. reduced human performance;

c. borderline conditions which, though they have little or no direct effect on equipment, may seriously impair the ability of the operator or technician to perform effectively; and

d. conditions which contribute to longer maintenance time or increased maintenance errors, oversights, and erroneous decisions, and which are detrimental to system availability and performance.

The above adverse effects can sometimes be minimized through the use of alternatives such as:

a. rotation of personnel at their workstations,

b. decreased workloads,

c. increased workspace allotments,

d. individual protective measures or supplemental equipment,

e. personnel selection and training, and

f. acclimation of operating personnel.

5.8.1.4.2 Hot environment.

5.8.1.4.2.1 Heat stress factors. Five basic factors that determine the degree of heat stress exerted by the environment are air temperature, humidity, air movement, heat radiation and direct conduction from objects.

5.8.1.4.2.2 Effective-temperature ranges. The effective-temperature ranges are flexible because they vary according to the amount of work activity. Dry bulb temperature should be decreased by 1.7° C for each 29 watts per hour increase in metabolic rate above the resting 117 watts per hour level, with relative humidity kept at or below 60% to allow sufficient evaporation to avoid perspiring. In general, the ranges should be extended upwards for tasks requiring minimal physical effort and downward for tasks requiring continuous muscular exertion.

a. An effective temperature of 29.5° C should be considered the maximum limit for reliable human performance.

b. Minimum temperature requirements are dependent upon the tasks to be performed in specific applications. Heating should be provided within personnel enclosures used for detailed work or occupied during extended periods of time if the dry bulb temperature drops below 10° C.

c. Prolonged exposure of an ungloved person to effective temperatures below 13.00 C often results in “stiffening” of fingers, which degrades performance in tasks requiring manual dexterity.

d. A person wearing arctic clothing should not be exposed, while sitting quietly, to temperatures higher than 15.5° C; a temperature of 1.5-7.0° C is optimal.

e. In providing for heating and cooling of enclosed areas, it is important that the temperature of the enclosed area be held relatively uniform. The temperature of the air at floor level and at head level should not differ significantly (by more than 5.5.0 C).

f. Relative humidity above 30% and below 70% is considered adequate if the optimum temperature range for physical comfort is maintained.

g. Side walls of the compartment should be kept at equal temperatures in so far as possible; however, temperature differences of 11° C or less do not significantly degrade comfort.

5.8.1.4.2.3 Measurement methods. Conventional methods for measuring environmental stress include the ordinary dry bulb thermometer, wet bulb thermometer, and black globe thermometer. However, dry bulb temperature does not include the effects of humidity, air movement, or radiation. Wet bulb is a better index since it includes humidity as well as air temperature but is not a good index of heat stress imposed by radiation. Radiant heat can most easily be determined by the black globe thermometer.

5.8.1.4.2.4 Wet bulb globe temperature. The Wet Bulb Globe Temperature (WBGT) index is more applicable than the effective-temperature index in the range beyond the comfort and discomfort zones of heat stress. WBGT incorporates, as a major element, the evaporative cooling available to a natural wet bulb thermometer (one with a wettable wick, exposed to ambient air motion and extending into a water reservoir) under whatever air motion exists in the environment; this contrasts with the conventional, psychometric wet bulb thermometer, where air is moved across the wetted bulb either by a fan or by “slinging” the thermometer at the end of a handle. Because of this difference, the natural (non-psychometric) wet bulb temperature is a better representation of the actual evaporative cooling available to a sweating person. The WBGT index is calculated as:

$$WBGT = 0.7T_{WBnp} + 0.2Tg + 0.1T_A$$

where Tg, representing the radiant heat, is the temperature at the interior center of a 15.2 cm, black globe and T_A is a non-psychometric, but shaded, dry bulb (air) temperature. In the absence of a radiant heat source (solar, engine, furnace), a modified Wet-Dry (WD_{85}) index should be used where:

$$WD_{85} = 0.85\ T_{WBnp} + 0.15T_A$$

Use of a psychometric rather than shaded dry bulb for T_A makes little difference in either WBGT or WD; however, use of the psychometric wet bulb for T_{WBnp} can result in serious discrepancy, unless wind velocity approaches or exceeds 3 m/s or ambient relative humidity approaches 100%. Note that regulations for control of heat illness reference WBGT, while provisions for comfort and performance decrements typically reference effective temperature.

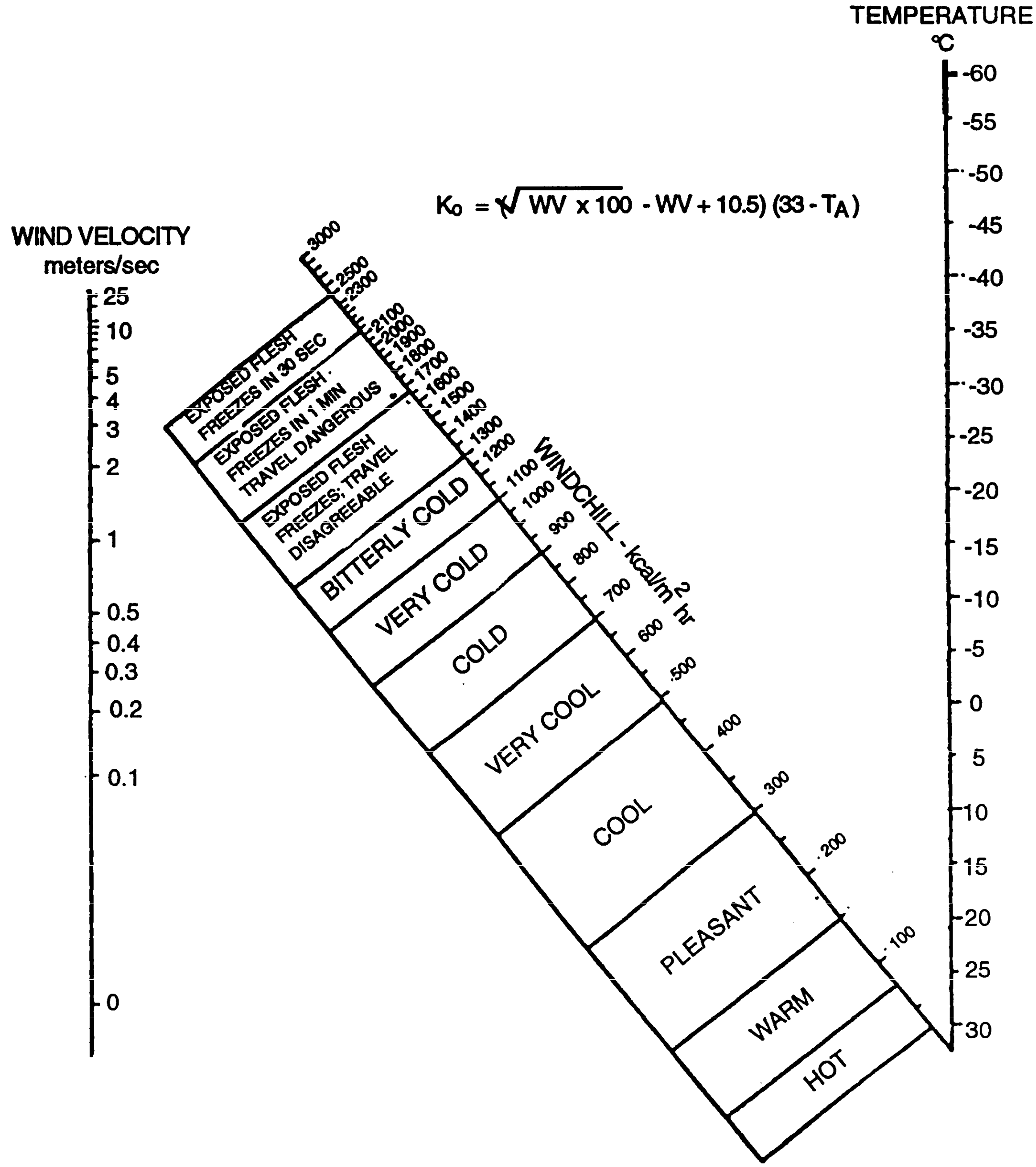
5.8.1.4.3 Cold environment.

5.8.1.4.3.1 Windchill. The windchill scale has been derived from the rate of freezing water influenced by ambient temperature and wind. Figure 38 depicts the relationship between temperature and wind for various windchill values.

5.8.1.4.3.2 Human reaction to windchill. A qualitative description of human reaction to windchill values top exposed skin includes:

Windchill Value	Human Reaction
100	warm
200	Pleasant
800	Cold
1000	Very Cold
1200	Bitterly Cold
1400	Exposed Flesh Freezes

The above reaction should not be taken to indicate that freezing of exposed flesh does not occur below a windchill value of 1400. In fact, during the Korean campaigns, significant numbers of cold injury occurred at windchill values between 900 and 1000. The discrepancy presumably occurs because the freezing of flesh at dry condition temperatures (about the 1400 windchill level) differs from the freezing of flesh at wet condition temperatures (possibly as low a windchill value as 800). As a rule of thumb, if personnel are exposed to a windchill index (WI) of 1200 or above while operating equipment, they should be protected. Windchill indices this large are common even in temperate climates.



In outdoor cold weather, the wind velocity has a profound, sometimes decisive, effect on the hazard to men who are exposed. The windchill concept dramatizes this by providing a means of quantitative comparison of various combinations of temperature and wind speed. Note for example that -45° C with an air movement of 0.045 m/s has the same windchill value, and therefore is predicated to produce same sensation on exposed skin as -8° C with a wind of only 0.45 m/s or -10° C with a wind of 2.2 m/s. The windchill index does not account for physiological adaptation or adjustments. It is based on field measurements of the rate of cooling of a container of water by Paul Siple during World War II.

FIGURE 38. Windchill chart.

5.8.1.4.3.3 Wind and windchill. The WI relates the amount of heat actually lost by a person to the wind velocity and temperature. In evaluating a windchill hazard, designers should consider air movement at personnel positions. Table 23 gives the cooling power of wind expressed as “Equivalent Chill Temperature.” Frostbite can occur even in relatively warm temperatures if wind penetrates the layer of insulating air around the body to expose body tissue.

5.8.1.5 Thermal tolerance and comfort zones.

5.8.1.5.1 Optimum temperatures. The optimum temperatures for personnel varies according to the nature of the tasks, the conditions under which the tasks are performed, and the clothing personnel are wearing. The optimum range of effective temperature for accomplishing light work while dressed appropriately for the season or climate is 21 -27° C in a warm climate, or during summer, and 18-24° C in a colder climate, or during winter.

5.8.1.5.2 Limited thermal tolerance zones. Physically fit troops acclimate to work in the heat most rapidly (3 to 4 days of 100 minutes of physical work in the heat each day) and stay acclimated (for 3 or more weeks after cessation of work in the heat). Less fit, unacclimated individuals may not initially be able to complete a full 100 minutes of work in the heat and will have to be brought to this level over a period of 6 to 8 days. Unacclimated troops should not be required to perform hard physical work for more than two hours at WBGTs above 25° C while fully-acclimated troops can workup to 8 to 12 hours a day at WBGTs in the 27° C range. In these cases, water intake should be maximized by command, if necessary. At these levels of WBGT, troops will lose one quart of sweat per hours. This represents a dehydration (loss of body fluids) amounting to about 1.5% per hour and a 5 to 6% level of dehydration is incompatible with sustained, unimpaired performance of hard physical work. While a 10 C lower threshold WBGT maybe appropriate for women in general, a very fit acclimated female may experience no more difficulty with heat exposure than a male of average military fitness. Emphasis on physical fitness and acclimatization to heat will be a more effective approach than emphasis on intrinsic differences in heat tolerance between men and women.

5.8.2 Illuminance.

5.8.2.1 General. Criteria for appropriate illumination cannot be satisfied merely b y providing a sufficient amount of light to perform tasks or providing emergency lighting (approximately 32 lux) to enable personnel to operate important controls or to find the exit from the system. The following should be considered.

TABLE 23. Equivalent chill temperature.

WIND SPEED	COOLING POWER OF WIND EXPRESSED AS "EQUIVALENT CHILL TEMPERATURE"																				
M/SEC	TEMPERATURE (°C)																				
CALM	4	2	-1	-4	-7	-9	-12	-15	-18	-21	-23	-26	-29	-32	-34	-37	-40	-43	-46	-48	-51
2.2	2	-1	-4	-7	-9	-12	-15	-18	-20	-23	-26	-29	-32	-34	-37	-40	-43	-46	-48	-51	-57
4.5	-1	-7	-9	-12	-15	-18	-23	-26	-29	-32	-37	-40	-43	-46	-51	-54	-57	-59	-62	-68	-71
6.7	-4	-9	-12	-18	-21	-23	-29	-32	-34	-40	-43	-46	-51	-54	-57	-62	-65	-68	-73	-76	-79
8.9	-7	-12	-15	-18	-23	-26	-32	-34	-37	-43	-45	-51	-54	-59	-62	-65	-71	-73	-79	-82	-84
11.2	-9	-12	-18	-21	-26	-29	-34	-37	-43	-46	-51	-54	-59	-62	-68	-71	-76	-79	-84	-87	-93
13.4	-12	-15	-18	-23	-29	-32	-34	-40	-46	-48	-54	-57	-62	-65	-71	-73	-79	-87	-87	-90	-96
15.6	-12	-15	-21	-23	-29	-34	-37	-40	-46	-51	-54	-59	-62	-68	-73	-76	-82	-90	-90	-93	-98
17.9	-12	-18	-21	-26	-29	-34	-37	-43	-48	-51	-56	-59	-65	-71	-73	-79	-82	-90	-90	-96	-101
WINDS ABOVE 18 M/SEC HAVE LITTLE ADDITIONAL EFFECT	DANGER					INCREASING DANGER (FLESH MAY FREEZE WITHIN 1 MINUTE)						GREAT DANGER (FLESH MAY FREEZE WITHIN 30 SECS)									

a. The brightness contrast between each visual task object and its background.

b. Glare from work surfaces and light sources.

c. The level of illumination required for the most difficult tasks.

d. The color composition of the illumination source and the equipment surfaces.

e. Time and accuracy required in task performance.

f. Possible variations in operating conditions (such as outdoor panel blackout operation or outdoor panel visibility under bright sunlight) which may affect the lighting system, the task criteria, or the personnel.

5.8.2.2 Illumination levels and distribution. The examples of illumination levels are expressed in Table 22.

5.8.2.3 Lighting fixtures. Factors which should be considered in selecting the number and location of fixtures are accessibility of 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 windows or other reflecting surfaces.

5.8.2.4 Brightness ratios. The brightness ratios between lightest and darkest areas and/or between task and surroundings should meet the criteria presented in Table 24.

5.8.2.5 Glare.

5.8.2.5.1 General. One of the most serious illumination problems is glare or dazzle from surfaces. Relatively bright light shining into the observer’s eyes as the observer tries to observe a relatively dim visual field or reflected glare from work surfaces is common cause of reduced performance in visual tasks. Glare not only reduces visibility for objects in the field of view, but causes visual discomfort.

5.8.2.5.2 Direct glare. Direct glare arises from a light source within the visual work field. Direct glare should be controlled by avoiding placing bright light sources within 60° of the center of the visual field. Since most visual work is at or below the eye’s horizontal position, placing luminaries high above the work area minimizes direct glare. Using indirect lighting and more relatively dim light sources, rather than a few very bright ones as well as using polarized light, shields, hoods, or visors to block the glare in confined areas will also reduce glare.

TABLE 24, Brightness ratios.

Comparison	Environmental Classification* A	B	c
Between tasks and adjacent darker surroundings	3:1	3:1	5:1
Between tasks and adjacent lighter surroundings	1:3	1:3	1:5
Between tasks and more remote darker surfaces	10:1	20:1	***
Between tasks and more remote lighter surfaces	1:10	1:20	***
Between luminaries and adjacent surfaces	20:1	***	***
Between the immediate work area and the rest of the environment	40:1	***	***

*A Interior areas where reflection off entire space can be controlled for optimum visual conditions.

B Areas where reflection off immediate work area can be controlled, but there is only limited control over remote surroundings.

C Areas (indoor and outdoor) where it is impractical to control reflection and difficult to alter environmental conditions.

*** Brightness ratio control not practical

5.8.2.5.3 Reflected glare. Reflected glare refers to reflections from shiny surfaces in the visual field. Reflected glare should be controlled by using surfaces that diffuse incident light, rather than reflecting it specularly and arranging direct-light sources so their angle of incidence to the visual work area is not the same as the operator's viewing angle.

5.8.2.5.4 Eyeglasses. 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° above and 45° below the line of sight, or if it is within 20° left or right of the line of sight.

5.8.2.6 Reflectance.

5.8.2.6.1 General. Large surface areas should be covered with non-saturated colors such as tints, pastels, and warm grays that are non-glossy. Some non-critical small areas such as door frames and molding may be glossy if ease of cleaning is essential.

5.8.2.6.2 Surface reflectance values. Generally recommended surface reflectance values for work places such as power stations, control rooms, offices and maintenance areas are indicated in Figure 39.

5.8.2.7 Dark adaptation.

5.8.2.7.1 General. 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, duration of exposure and intensity of the previous light.

5.8.2.7.2 Ambient light. Ambient light is generally incompatible with dark adaptation. If it is dimmed enough so that it does not interfere with dark adaptation, it will not be bright enough by which to work. Where both ambient light and dark adaptation are required, the conflict should be resolved by evaluating the priorities of the operator's tasks. (If night vision is more important than reading maps, use red lighting.) Minimum interference with dark adaptation is produced by brief exposure of the lowest intensity possible. Colors often appear different under different types of illumination, so unless a display will always be used under ambient light, do not use color coding.

5.8.2.7.3 Red light. Low-brightness and red light is used to do visual work and for instrument and display marking (between 0.07 cd/m^2) where maintaining maximum dark adaptation is required. 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 cutoff would maintain dark adaptation more effectively, but would waste too much of the available light energy.

5.8.2.7.4 Additional aids. The additional aids to night vision listed below should be incorporated.

a. Lettering that must be read at low light intensities should be block-type white letters on a black background.

b. All controls (knobs, switches) 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.

5.8.3 Acoustical noise. Reserved.

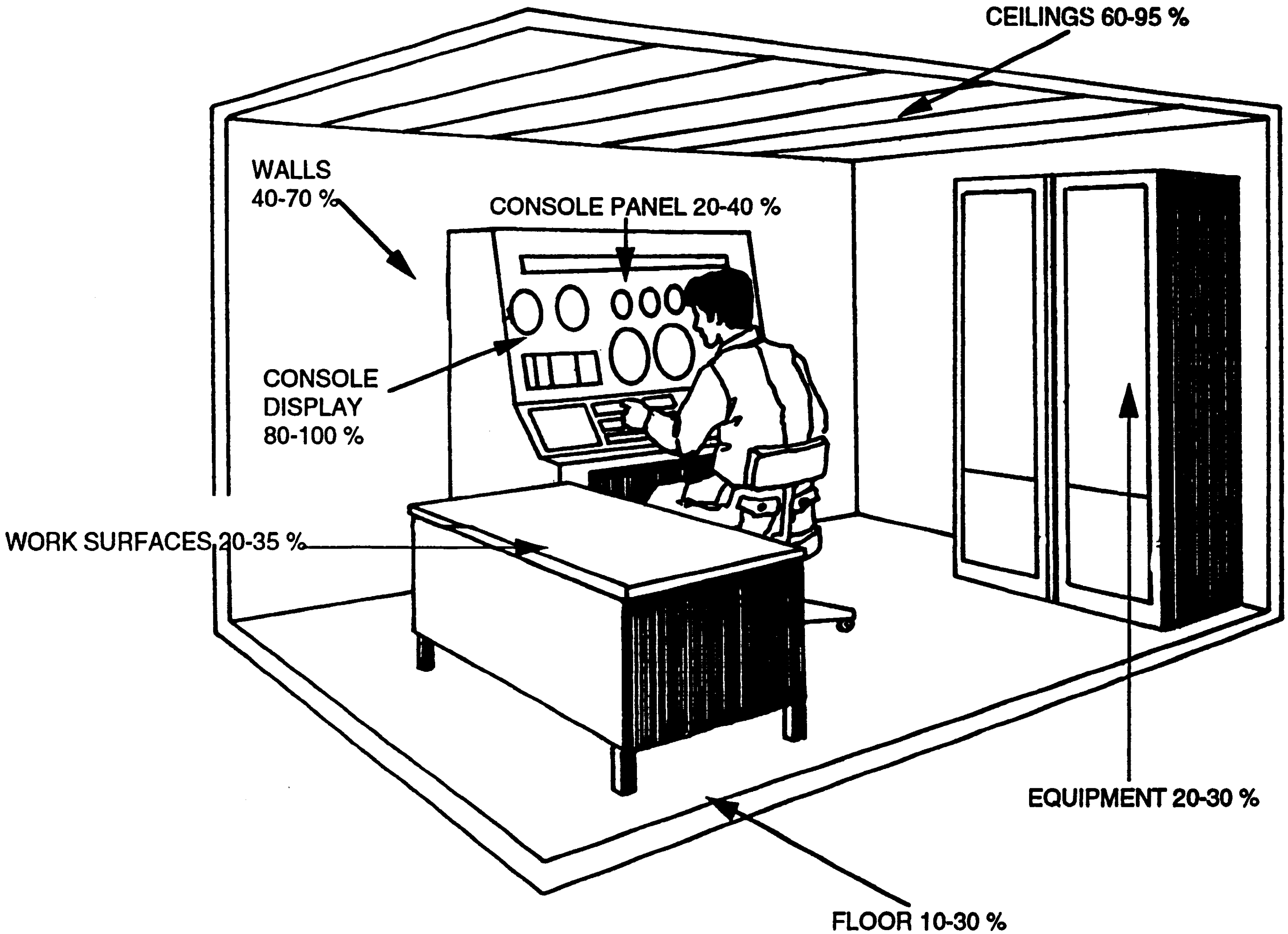


FIGURE 39. Workspace reflectance values.

5.8.4 Vibration.

5.8.4.1 Whole-body vibration. Facilities and facility equipment should be designed to control the transmission of whole body vibration to levels which will prevent safe operation and maintenance (see ISO 2631-1). In the case of multi-directional vibration, each direction is to be evaluated independently with respect to the limits presented. Performance is adversely affected to the degree that vibration can, at high levels, cause critical body damage. Vibration can also make dials, letters, and sight retitles difficult to read and makes controls, tools, or other objects difficult to manipulate. The human physical condition is affect by vibration because it contributes to increased fatigue, nervousness, and irritability that can lead to oversights and errors in judgment.

5.8.4.2 Equipment vibration. Vibration can be reduced and controlled by isolating equipment from vibration sources by shock mountings and fluid couplings, providing proper balance of rotating elements of equipment and providing damping materials or cushioned seats for standing or seated personnel.

5.9 Design for maintainer.

5.9.1 General.

5.9.1.1 Standardization. The following standardization practices should be followed in design of equipment.

a. Standardize types and sizes of bearings where practical.

b. Standardize knob set screws so that a standard diameter and thread are used for a given shaft diameter.

c. Standardize tolerances on similar parts for interchangeability.

d. Standardize the method of pinning gears; set screws should be used where keyways or splines are used.

5.9.1.2 Special tools.

5.9.1.2.1 General. Determining tool design is dependent upon maintenance operations and characteristics of the equipment. Neglecting tool design until equipment design and procedures are final may result in the need for special tools or an unnecessarily wide variety of standard tools. Definition of tool requirements early in equipment design and development, before procedures and designs are final, will result in tools compatible with the equipment on which they will be used and with the job to be performed. Tools should be designed for simplicity, practicality, and universality and should be evaluated for adequacy during developmental testing of the system. The requirement for special tools should be minimized or eliminated. This requirement should be considered mandatory on the part of the design engineer. Consideration of tool design early in equipment development will result in fewer special tools and devices. Special tools should be used only when standard tools cannot be used or when necessary to facilitate maintenance tasks, reduce time, or improve accuracy. Special tools already in the supply system should be investigated for adequacy in unique situations. Necessary special tools should be made available when the equipment requiring their use is completed.

5.9.1.2.2 Considerations. These areas should be considered in design and distribution of tools.

a. If possible, require only those tools normally found in the maintenance technician's tool kit.

b. Minimize the variety and number of sizes of tools required.

C. A comprehensive list of tools needed for all maintenance tasks should accompany each equipment system. This should include all special tools necessary to perform the authorized work, together with the equipment items requiring their use.

d. Equipment should be designed to minimize the need for torque wrenches. The design activity should review each special requirement in an attempt to make design changes to eliminate the need for torque wrenches.

e. If torque wrenches or guns are used for factory assembly and are necessary equipment, provide maintenance personnel with similar tools.

f. Specify tools which are compatible with the design of the equipment on which they will be used as well as with the job to be performed.

g. Provide for the use of speed or power tools such as ratchets, speed screwdrivers, or power wrenches when demanded by torque requirements or space limitations.

h. Enable the technician to assemble a tool for many different uses by providing maintenance personnel with socket wrenches and accessories (breaker bars, extensions, and joints).

i. Positive snap-locking action should be used for connecting sockets to the various components of a socket set. They should be designed so they can be easily connected and disconnected.

j. Tool handles should have adequate gripping surfaces. Tools used where dropping could result in maintenance delay or possible tool loss should be provided with thongs sufficiently long to enable the user to place a loop over his wrist.

k. The use of heat- or cold-resistant handles on tools which are to be used in extreme climates should be specified. Metal handles are undesirable for use in cold climates.

l. In evaluating the finish to be applied to tools, the designer should consider that tools with a dull finish prevent reflected glare in areas of high illumination. However, dull-finished tools are often overlooked when closing assemblies, causing loss of tools and possible damage to the equipment. The designer should therefore consider the advantages and disadvantages of the type of finish in relation to the potential application of the tool.

5.9.1.2.3 Mechanical equipment. The design of mechanical equipment should consider the ideas listed below.

a. Interchangeable fastening devices should be used, and the number of types and sizes of bolts, nuts, and screws should be kept to a minimum. Where practicable, lock washers should be attached to the bolts and screws.

b. Fast-acting fastening devices should be used for covers and cover plates that are of the captive type and do not require special tools.

c. Corrosion-resistant, sealed bearings should be used in all fire control materiel, except where the sleeve type has a logical application.

d. Wherever possible, self-aligning bearings should be used instead of ball caps and sockets in worm gear mechanisms.

e. Securing bearings by staking should be avoided; stakes have a tendency to break when in use for prolonged periods of time.

f. Dual doweling should be eliminated. Instead, eccentric dowels, dowels with stopscrews, with slots, with edge-locating shoulders, and with keys should be used.

g. Where possible, the use of split pins should be avoided; taper pins are more desirable.

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

i. Ferrous parts that are susceptible to corrosion and are used internally in instruments should be appropriately plated. Phosphate finishes (especially where not oiled) do not provide sufficient protection.

j. Oil-impregnated bearings should be used where practical.

k. Related subassemblies should be grouped together as much as possible.

l. A manual means for the engagement, disengagement and locking of elevating and traversing mechanisms should be provided to facilitate maintenance.

m. In high-speed applications, it should be specified that mating gears be of materials having dissimilar wear characteristics.

n. Backlash and torque lash should be minimized. The effects of backlash and lost motion should be taken into consideration in the selection or design of movable parts.

o. The same type socket should be used on all socket set screws.

p. Screws, studs, and nuts made of non-ferrous material should be used where practicable.

q. Using dowel pins for the final positioning of mounts on support surfaces provided on the weapon should be avoided; fixed locating points present a problem when mounts are interchanged. Consider key and keyway, eccentric and keyway, or single dowel pins for the final positioning of mounts.

5.9.1.2.4 Safety.

a. Adequate insulation should be provided on tool handles or other parts of the tools which the technician is likely to touch while performing maintenance on electrical or electronic equipment near voltages in excess of 30 volts.

b. Spark resistant tools should be provided if they are to be used in areas where fire or explosion hazards exist.

c. Storage for tools should be provided so they cannot fall and cause personnel injury or equipment damage.

d. Sharp corners and edges should be eliminated on tool chests.

e. Casters or a sufficient number of properly sized and located handles should be provided to facilitate lifting if tool chests are too large to be handled easily by one person. Handle location should ensure that the chest will remain balanced when lifted.

5.9.1.2.4.1 Safety features. The safety features listed below should be considered.

a. Doors or hinged covers should be designed so they are rounded at the corners and provide slip hinges and stops to hold them open.

b. In mounting fire control components, access to both sides of the equipment should be provided, and sufficient hand room should be provided for the technicians to remove and replace parts.

c. Personnel should be protected from moving mechanical parts by the use of guards, safety covers, and warning plates.

d. Covers or boots for exposed couplings and universal joints should be provided.

5.9.1.3 Maintainability.

5.9.1.3.1 General. Materiel readiness emphasizes the complementary attributes of reliability and maintainability. Reliability is best expressed as the probability the materiel will perform its intended function, for example, 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 and external configuration, use, and repair environment, as well as the time, tools, and training skills required for maintenance. The objectives of improving maintainability are to make materiel more available to perform its function and mission and to reduce the cost of operational support during the materiel's service life.

5.9.1.3.2 Maintainability in the design schedule. To avoid costly maintenance, or redesign, maintainability should be designed into the materiel during the initial development stage. Therefore, it is imperative to schedule for maintainability. First plan, then design, and finally, test the design to ensure maintainability.

5.9.1.3.2.1 Planning for maintainability. In planning for maintainability, designers should consider the points listed below.

a. Determine the size of required access openings, work surfaces, and workspace so that components are accessible to maintenance personnel.

b. Study operational materiel similar to that to be designed. List the maintenance features built into it and, from its maintenance history and experience, identify additional maintenance features that should have been incorporated to improve maintainability.

c. Determine how components should be arranged and located to provide rapid access to those components with the lower reliability that will probably require maintenance most frequently, or whose failure would critically degrade the end item's performance.

d. Identify tools and test equipment already in the operational system that can be made available for maintenance of 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.

5.9.1.3.2.2 Designing for maintainability. Wherever practical, the designers should consider and incorporate the following features into design and development projects.

a. Simplification of operator and maintenance functions.

b. Use of modular or unit packaging or throw-away components and techniques.

c. Use of self-lubricating principles.

d. Use of sealed and lubricated components and assemblies.

e. Use of built-in testing and calibration features for major components.

f. Use of self-adjusting mechanisms.

g. Use of gear-driven accessories to eliminate belts and pulleys.

h. Minimize number and complexity of maintenance tasks.

i. Maximize design simplicity.

j. Design for quick recognition of malfunctions or marginal performance.

k. Design for quick identification of the replaceable defective components, assemblies, and parts.

l. Design to eliminate torque specifications at organizational or aviation unit maintenance level and minimize need for all other torque specifications.

m. Design to minimize skills and training requirements of maintenance personnel.

n. Design to minimize the types and number of tools and test equipment (both standard and special) required to perform maintenance.

o. Design for accessibility to all systems, equipment, and components requiring maintenance, inspection, removal, and replacement.

p. Design for maximum safety and protection for personnel and equipment.

q. Design equipment to permit maintenance from above and outside in contrast to requiring access for maintenance from underneath.

r. Design of items should facilitate manual handling required during maintenance and comply with established manual force criteria.

s. Design equipment to facilitate assembly and disassembly.

5.9.1.3.2.3 Testing the design. Development and production models should be tested for maintainability under operational conditions. These tests should use maintenance personnel with the same amount of training as those assigned to actual maintenance, and use the procedures, tools, test equipment, and manuals that maintenance personnel will use.

5.9.1.3.3 Manuals. Complete and current maintenance manuals should be issued with the materiel as it is released for use.

5.9.1.4 Stowage.

5.9.1.4.1 General. The following statements are applicable to stowing equipment.

a. Stowed items should be secured by straps, brackets or other restraining devices to provide for cross-country operation.

b. All stowage locations should be designed to drain adequately when the vehicle is on level ground. Drain holes should be arranged so that they will not be blocked by normal stowage.

c. Items which are flammable or subject to damage by leakage of lubricants, fuels, or water should be stowed in a manner to protect them from engines, generators, and exhaust components.

d. To prevent its loss, peculiar equipment should be designed to be properly secured when installed or stowed.

e. Items of mission-critical nature should be stowed in a manner to permit rapid access by crew members.

f. Consider all environments in which the crew will operate when locating and designing stowage space for items worn by crew members.

5.9.1.4.2 Identification. A stowage plan should be provided identifying the stowed items and their locations. Also, stowed items should be permanently labeled for ease of identification.

5.9.1.4.3 Interference. Stowed items should not interfere with system functions, operations, or established personnel movement (entrance, exit, or escape) routes.

5.9.1.4.4 Removal and replacement. Stowed items should be capable of being removed and replaced without having to remove or replace other stowed items or components of the system.

5.9.1.4.5 Retaining devices. Items should be capable of being stowed and removed under all environmental conditions. The retaining devices should be simple, capable of quick removal and replacement, and need no tools. Retaining devices should be attached to either the stowage space or the stowed item to prevent loss.

5.9.1.4.6 Utilization of stowage space. The accessibility and locations of stowed equipment should be determined by the functional utilization of each item. Items used by a particular crew member should be stowed in a convenient, accessible location within the functional area of the crew member's station.

5.9.1.4.6.1 Unused space. Unused space should be utilized to provide suitable stowage for items.

5.9.1.4.6.2 Individual items. When operating equipment, stowage should be available for doffed personal items such as individual weapons, small arms ammunition, rations, and helmets if donning of other special gear is required.

5.9.1.5 Stowage areas and boxes: doors and covers.

a. Unless access covers or doors are intended to be removable, they should be designed so they can be retained open.

b. Instructions about contents in a box should be located so they can be read when the door is open.

c. Required access should be provided to the rear of sliding, rotating or hinged units so they open or rotate their full distance freely and remain "open" by themselves.

d. Openings of covers or doors should be designed to be obvious or have opening instructions affixed to the outside.

e. When a cover or door is in place, but not secured, it should be visually obvious.

f. Sharp edges and corners on doors, covers, and other exposed surfaces should be rounded.

g. To simplify reinstalling removable inspection access doors, they should be interchangeable or of the size and shape which will make their proper position obvious.

h. Obstructions (material or structural members) should never block covers or doors so they cannot be opened or removed, or restrict the required access through the cover or door opening.

i. If covers are hinged, space equal to the sweep volume of the cover should be allowed so the body frame and brackets will not obstruct its opening.

j. Items should be capable of being stowed and unstowed by the 5th through 95th percentile user while wearing cold-weather gear and gloves without having to assume a strenuous or difficult position.

5.9.2 Mounting of items within units.

5.9.2.1 General. Units should be located so no other equipment has to be removed to gain access to them. All components should be laid out so they are accessible with the emphasis for easy access placed on items that require frequent inspection and maintenance. Components maintained by the same technician should be grouped together so that only a minimum of moving from position to position is necessary during system checking. Components that require frequent visual inspection, check points, adjustment points, cable-end connectors, and labels should be located in positions that can be seen easily. All components should be located to minimize the possibility of equipment damage or personnel injury.

5.9.2.2 Stacking avoidance. Units should not be stacked. If stacking is necessary because of space limitations, place the unit requiring the least frequent access in the back or on the bottom.

5.9.2.3 Hinge-mounted units. Small hinge-mounted units, which require access to the back, should be free to open their full distance and remain open without being held (see Figure 40).

5.9.2.4 Frames and structural members. Frames and structural members should not interfere with maintenance and operational personnel reaching components they have to maintain, inspect, or operate (see Figure 41).

5.9.2.5 Tubes. Tubes should be replaceable without interference from resistors, capacitors, or wiring and without removing assemblies or subassemblies. Miniature tube sockets should be oriented with gaps facing in one direction to facilitate replacing tubes (see Figure 42). When tubes are replaced through narrow openings, an external indication of the position for pin insertion should be provided.

5.9.2.6 Fuses. Fuses should be located so they can be seen and replaced without tools or removing other parts or subassemblies.

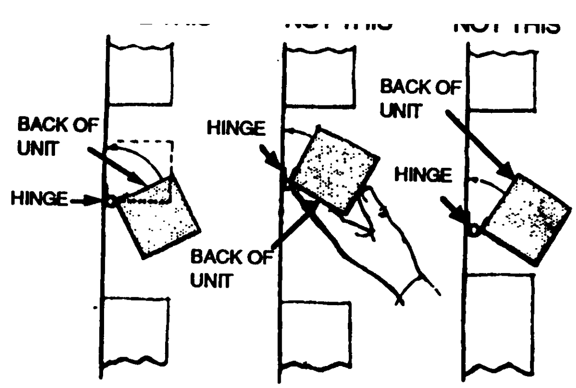


FIGURE 40. Hinged units.

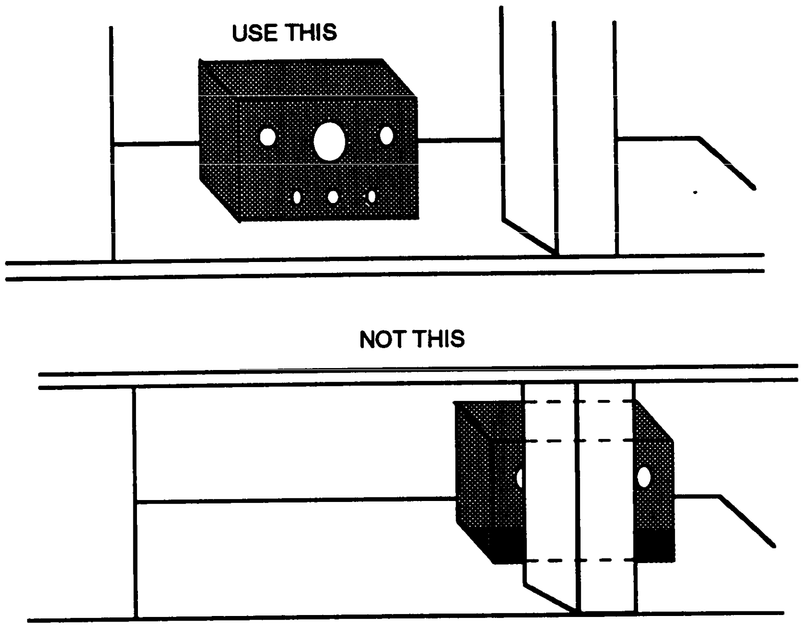


FIGURE 41. Component placement.

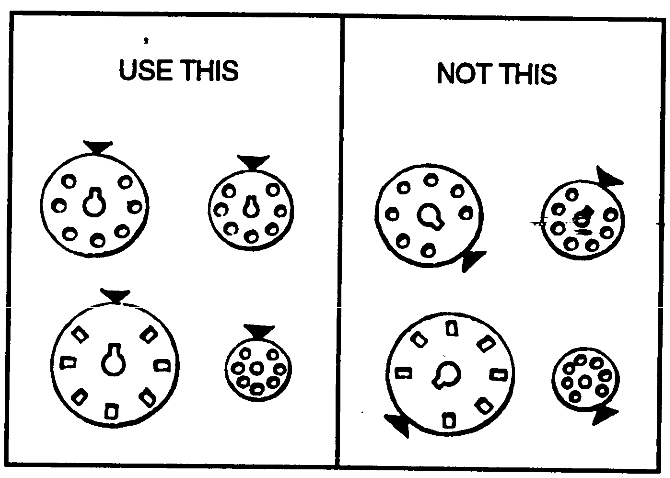


FIGURE 42. Tube socket orientation.

5.9.2.7 Equipment units design checklist. The following checklist (Table 25) summarizes some of the important features to be considered in the design of equipment units. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is NO, the design should be restudied to ascertain the need for correction.

TABLE 25. Equipment units design checklist.

1. Are plug-in components used where feasible?
2. Is wrong installation of unit prevented by virtue of size, shape or configuration?
3. Are modules and mounting plates labeled?
4. Are guides used for module installation?
5. Are means provided for pulling out drawers and slide-out racks without breaking electrical connections when internal in-service adjustments are required?
6. Are units and assemblies mounted so that replacing one does not require removal of others?
7. Are parts mounted on a single plane, not stacked one on another?
8. Are parts mounted on one side of a surface with associated wiring on the other side?
9. Are easily damaged components mounted or guarded so they will be protected?
10. Are all replaceable parts accessible by fold-out construction or other special techniques when necessary?
11. When fold-out construction is employed, are parts and wiring positioned to prevent damage by opening and closing?
12. Are braces provided to hold hinged assemblies in the "out" position while being worked on?
13. Are parts which retain heat or electrical potential after the equipment is turned off located so that the technician is not likely to touch them while replacing commonly malfunctioning parts?
14. When screwdriver adjustments must be made by touch, are screws mounted vertically so that the screwdriver will not fall out of the slot?
15. When necessary, are internal displays illuminated?
16. Are internal controls (switches, adjustment screws) located away from

TABLE 25. Equipment units design checklist - continued.

dangerous voltages?

17. Are screwdriver guides provided on adjustments which are located near high voltages?

18. Are parts located so that other large parts (such as indicators and magnetron tubes), that are difficult to remove, do not block access to them?

19. Are parts, assemblies, and components placed so there is sufficient space to use test probes, soldering irons, and other tools without difficulty?

20. Are parts, assemblies, and components placed so that structural members of units do not prevent access to them?

21. Are all throwaway items made accessible without removal of other items?

22. Are units designed so that it is unnecessary to remove an assembly from a major component to troubleshoot that assembly?

23. Is equipment laid out so the technician will not have to retrace movements during checking routines?

24. Are all miniature tube sockets oriented with the gaps facing one direction?

25. When tubes must be replaced through small access openings, is there an external indication of the position for pin insertion?

26. Are all fuses located so they can be seen and replaced without removal of any other items?

27. Are fuse assemblies designed and placed so that tools are not required to replace fuses?

28. Are removable units removable along a straight or moderately curved line?

5.9.3 Adjustment controls.

5.9.3.1 Protection from fluids. Components should be placed in positions where oil and other fluids are not likely to fall on them.

5.9.3.2 High-temperature guards. High-temperature parts should be guarded or located so personnel will not contact them during operation or maintenance. Heat-producing equipment should be arranged and shielded so discomfort to personnel is avoided.

5.9.3.3 Enclosure of high-current devices. High-current switching devices should be enclosed to protect personnel. Components that retain electrical potential after the equipment is turned off should be equipped with bleeder networks. Internal controls should not be located close to dangerous voltages.

5.9.4 Accessibility.

5.9.4.1 General. Accessibility is defined as the relative ease with which an assembly component can be reached for inspection, service, repair, or replacement. It is a fundamental requirement for maintainability and should be designed into the equipment because adding access provisions for maintenance purposes after the equipment is built is inefficient, costly, and often inadequate. If it can be reached quickly, requiring the use of only a few simple steps, an item is accessible; if it requires many tools, special tools, many or difficult operations, it is inaccessible, even though it is possible to eventually reach it. The disassembly or removal of parts that are in the way of easy access to a part needing maintenance is highly undesirable, especially in field conditions. Adequate space is usually not available for laying out parts as they are removed. This increases the possibility that they will be lost, damaged, or contaminated, and further malfunctions will be introduced into the system.

5.9.4.2 Psychological aspects. The more difficult or involved a maintenance task is, the more readily an operator or mechanic will put it off in preference to less demanding tasks. Periodic maintenance activities, such as checks, adjustments, or general troubleshooting may be unduly postponed or neglected entirely. Thus, inaccessibility is a human engineering problem as well as a problem for the design engineer.

5.9.4.3 Environment. The environment in which maintenance tasks will be performed should also be considered by the designer when determining the size of access openings. Access for a gloved or mittened hand is considerably larger than for a bare hand. Wearing gloves or mittens seriously limits the dexterity and skill with which technicians can perform their duties. Certain simple tasks may be impossible to perform while wearing arctic mittens. Wearing cold-weather clothing creates problems such as persons becoming less agile. Their bodies may become wedged in narrow hatches, or their feet may stumble on steps, ladders, and small, closely-spaced pedals. Their hands may be unable to operate intricate hand controls with deftness and precision.

5.9.4.4 Equipment. Equipment design for accessibility should include the following considerations.

a. Provide access openings for instrument adjustment.

b. Provide external access to internal adjusting devices.

c. Locate high-mortality parts near access openings.

d. Make lubrication points easily accessible and clearly marked.

e. Make mounting bolts easily accessible.

f. Avoid through bolts having nuts that are inaccessible except through extensive disassembly of adjacent parts.

g. Socket-head screws should not be used where relative inaccessibility would require special or modified hexagonal wrenches.

5.9.4.5 Workspace.

5.9.4.5.1 General. The system criteria should be based on the following minimum considerations for the 5th to 95th percentile maintenance population wearing cold-weather clothing.

a. Points where operation and maintenance may be required.

b. Space, clearance, access and movement criteria needed for personnel using equipment to perform the functions of operation and maintenance.

c. Criteria for access or passage to the workstation, as well as the size and weight of equipment carried and used at the workstation.

5.9.4.5.2 Other features. The workspace should allow personnel to change their body positions if the task requires kneeling, crawling, or crouching for a prolonged period of time. Consideration should also be given to providing protection against any potential hazards which might exist while personnel are performing their tasks. Auxiliary hooks, holders, lights, outlets, non-skid treads, expanded metal flooring, or abrasive coating on surfaces used for walking, climbing, or footholds should be provided at the workstation to assist personnel in performing their jobs, as appropriate. Top surfaces of equipment should be reinforced and provided with non-skid surfaces whenever they are used as work platforms. (Use 113.6 kg per person to calculate anticipated load.)

5.9.4.6 General-access criteria.

5.9.4.6.1 Design. Where possible and feasible, design for accessibility by using modular design, and equipping major units and assemblies (particularly engines and turbines) with removable housings so they can be inspected completely. Any replaceable item should be designed so that it can be removed after opening only one access (unless the accesses are latched or hinged doors). Accesses should be designed so that they are located, covered, and fastened so it will not be necessary to remove components or wires to reach an item requiring maintenance. These openings should be directly in line with the equipment to be serviced or maintained.

5.9.4.6.2 Visual inspection. Items requiring visual inspection (hydraulic reservoirs, gauges) should be located so personnel can see them without removing panels or other components, particularly if hazards can be encountered inside the equipment.

5.9.4.6.3 Sharp edges. Accesses having sharp edges or protrusions that could injure personnel or damage hoses should be lined with internal fillets or other suitable protection prior to access for maintenance.

5.9.4.7 Access. Access should be provided to all points, items, units, and components which require testing, servicing, adjusting, removing, replacing, and repairing. The type, size, shape, and location of accesses (see Figures 43-44) should be based on a thorough understanding of the considerations listed below.

a. Operational location, setting, and environment of the unit.

b. Frequency of use.

c. Maintenance tasks performed through the access and the intricacy of the tasks.

d. Time required to perform maintenance functions.

e. Types of tools and accessories required.

f. Workspace required.

g. Type of clothing likely to be worn by personnel.

h. Necessary access reach.

i. Visual requirements and the intricacy of the tasks.

j. Packaging of items and elements 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, and units that will enter the access.

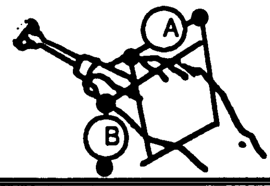
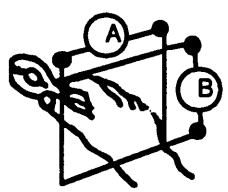
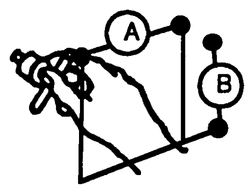
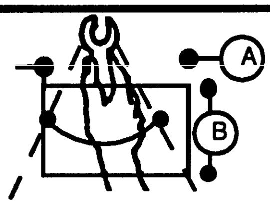
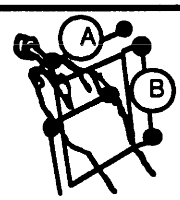
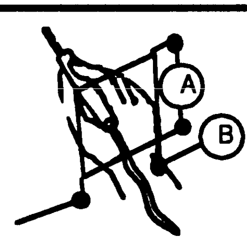
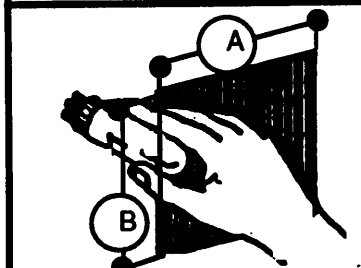
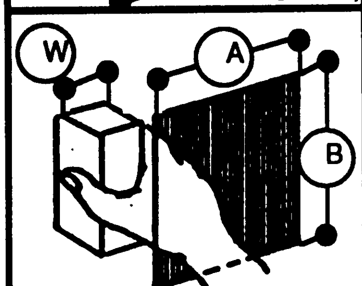
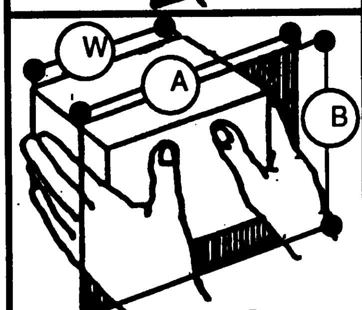
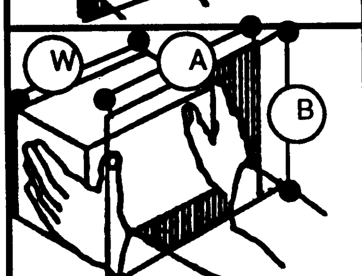
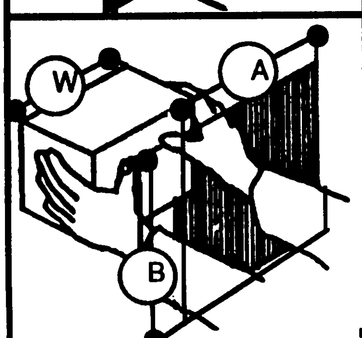
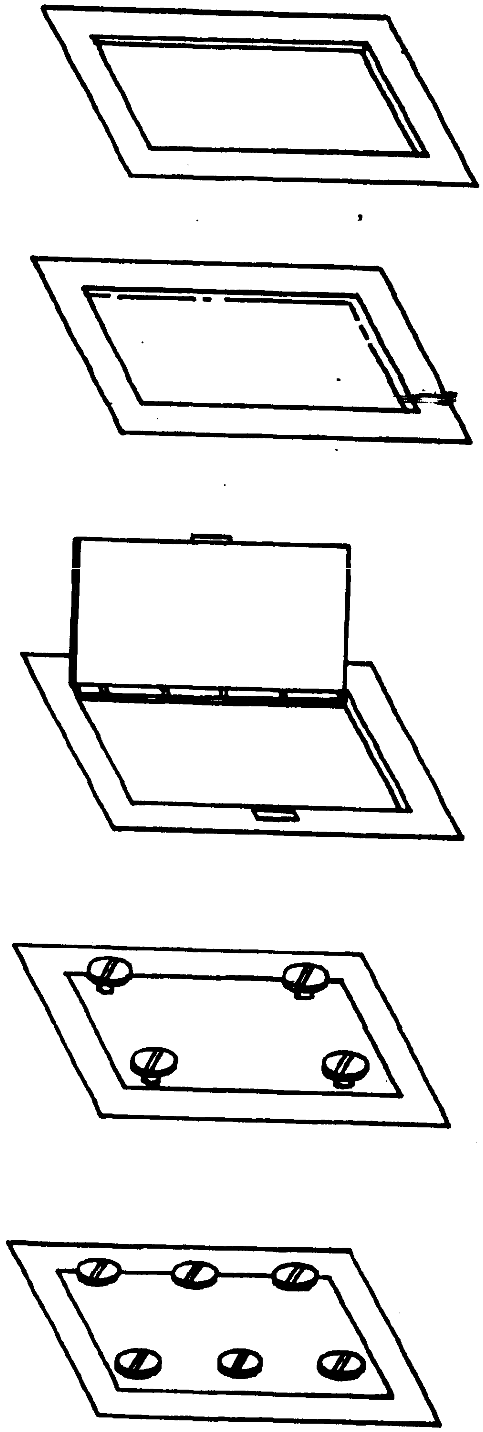
OPENING DIMENSIONS	DIMENSIONS (IN MM) A	DIMENSIONS (IN MM) B	TASK
	110	120	USING COMMON SCREWDRIVER, WITH FREEDOM TO TURN HAND THROUGH 180°.
	130	115	USING PLIERS AND SIMILAR TOOLS.
	135	155	USING "T" HANDLE WRENCH, WITH FREEDOM TO TURN HAND THROUGH 180°
	270	200	USING OPEN-END WRENCH, WITH FREEDOM TO TURN WRENCH THROUGH 60°.
	120	155	USING ALLEN-TYPE WRENCH WITH FREEDOM TO TURN WRENCH THROUGH 60°.
	90	90	USING TEST PROBE.

FIGURE 43. Access opening dimensions.

OPENING DIMENSIONS	DIMENSIONS (IN MM) A	B	TASK
	110	120	GRASPING SMALL OBJECTS (UP TO 50mm WIDE) WITH ONE HAND.
	W+45	125*	GRASPING LARGE OBJECTS (50mm OR MORE WIDE) WITH ONE HAND.
	W+75	125*	GRASPING LARGE OBJECTS WITH TWO HANDS, WITH HANDS EXTENDED THROUGH OPENINGS UP TO FINGERS.
	W+150	125*	GRASPING LARGE OBJECTS WITH TWO HANDS, WITH ARMS EXTENDED THROUGH OPENINGS UP TO WRISTS.
	W+150	125*	GRASPING LARGE OBJECTS WITH TWO HANDS, WITH ARMS EXTENDED THROUGH OPENINGS UP TO ELBOWS.

* Or sufficient to clear part if part is larger than 125 mm.

FIGURE 43. Access opening dimensions - continued.



BEST-NO COVER
(USE WHENEVER POSSIBLE)

PERMANENT GLASS OR PLASTIC
COVER (USE WHERE ONLY VISUAL
INSPECTION IS REQUIRED).

HINGED OR SLIDING COVER
(USE WHERE PHYSICAL ACCESS
IS REQUIRED AND WHERE DIRT
AND MOISTURE COULD BE A
PROBLEM).

CAPTIVE QUICK-OPENING FASTENERS
(USE WHEN SPACE PREVENTS USE OF
HINGED COVER).

SCREWED-DOWN COVER
(USE ONLY WHEN STRESS OR
PRESSURIZATION REQUIRES
MINIMUM NUMBER OF SCREWS).

FIGURE 44. Covers and accesses.

5.9.5 Lubrication. Reserved.

5.9.6 Case and cover mounting.

5.9.6.1 Covers, cases, and shields.

5.9.6.1.1 General. Covers, cases, and shields should be provided as necessary to divide enclosures into sections which are cleaned by different methods and to keep personnel from touching dangerous electrical or mechanical parts. They also protect delicate or sensitive equipment so it will not be damaged by movements of personnel, shifting cargo, loose objects, or installing and maintaining nearby assemblies.

5.9.6.1.2 Design for maintenance. Covers, cases, and shields should also be designed for fast, easy maintenance (Figure 45). Their maintenance characteristics depend largely on how they are fastened; the size, weight, and ease of handling; and whether handles or provisions for tool grips are provided. Other characteristics include the workspace and clearance around them and how often they must be opened or removed.

5.9.6.2 Characteristics.

a. They should be lightweight if possible, but whatever size is necessary for the degree of enclosure and the accessibility required.

b. They should be openable, removable, and transportable by one hand, by one person, or by two persons, in that order of preference.

c. Handles or tool grips should be provided if it is heavy, difficult to open, or difficult to handle.

d. Enough clearance should be provided around enclosed components to prevent damage and to avoid requiring extremely fine or careful positioning and handling.

e. They should be designed and located so bulkheads, brackets, or other units do not interfere with using them, and so they will not interfere with other maintenance operations when they are open.

5.9.6.3 Shape. Any appropriate shape for the degree of enclosure, accessibility, and clearances required may be used. It should be made obvious how the item must be positioned or mounted, and how enclosed delicate components are oriented in order to prevent damage during removal. Indentations or settling areas on top surfaces should be avoided to prevent rust and corrosion and keep dirt and grease from accumulating.

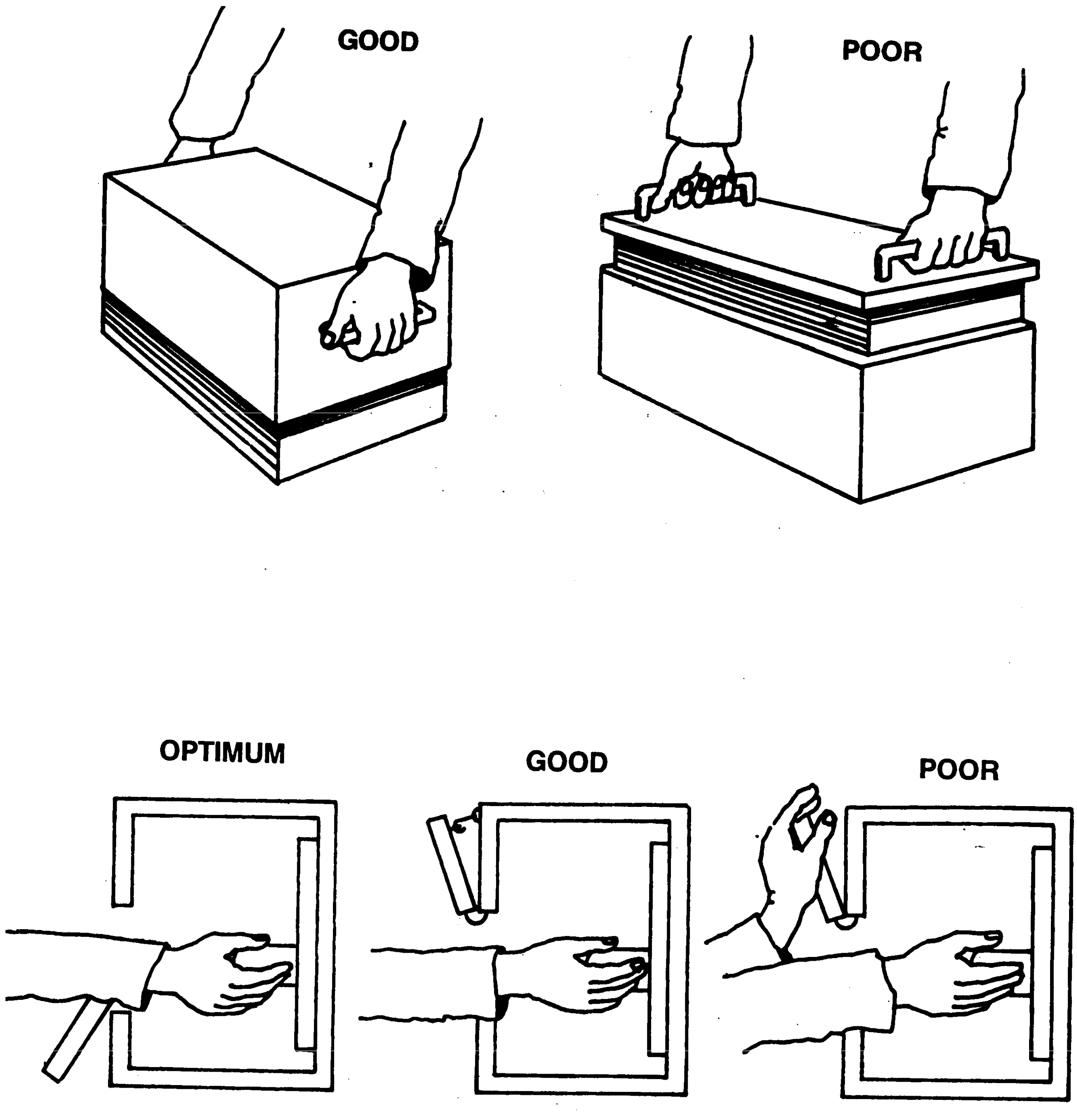


FIGURE 45. Cover and case design examples.

5.9.6.4 Location and mounts. Covers, cases, and shields should be designed, located, and mounted so that they can be removed and replaced if they are damaged and irregular extensions and accessories can be removed readily. They should be capable of being opened or removed as necessary without taking the equipment apart or removing auxiliary equipment. Props, retainers, or other supports should be located or mounted where required so the equipment will not be unbalanced when opened. When open, they should not obscure or interfere with controls, displays, test points, or connections used in working inside the access or enclosure. They also should have adequate stops and retainers to keep them from swinging against, or being dropped on, fragile equipment or on personnel, and 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 when used in high winds.) If feasible, stowage provisions should be provided if the covers, cases, or shields are removable.

5.9.6.5 Fasteners. Fasteners for covers, cases, and shields should be selected, applied, and mounted so that they satisfy the preferences, criteria, and standardization aspects. Hinges, latches, and catches should be used wherever possible to reduce handling and stowing of covers and cases. It should be obvious when a cover is not in place or is not securely fastened. Where possible, spring-loaded fasteners should be used so they can stand out or the cover itself stays ajar when it is not secure.

5.9.6.6 Labels and markings. Labels and markings on covers and cases should:

a. present instructions on 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," or "Oil Here");

c. warn about any dangers or hazards involved in removing the cover or case, or working within the enclosure;

d. indicate how units or service equipment should be oriented or connected to go through the opening (unless this is already obvious); and

e. present instructions so they will be visible and properly oriented to a maintenance technician when the cover, door, or case is open.

5.9.7 Cases. Cases should be selected, designed, and mounted so that cases lift off of units, rather than units lifting out of cases, particularly when subassemblies are heavy (see Figure 45). They should be somewhat larger than the items they cover, so items inside can be removed and replaced easily without damaging wires or other components. They should have guidepins and tracks, as necessary, to help align the case, prevent it from cocking or binding, and to protect delicate or sensitive components from damage when the case is moved. Access to frequently used adjustment, test, and service points should be available so the case need not be removed for routine maintenance. All aspects and portions of the equipment that are significant for maintenance should be fully exposed when the case is removed. Rubber stripping or other sealing material should be selected and mounted so personnel will not damage it when the case is moved.

5.9.8 Covers. Covers are listed here in order of preference.

5.9.8.1 Hinged doors, hoods and caps. 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. Where swinging or opening space is limited, double-hinged split doors should be used. Hinges should be placed at the bottom of the door, or a prop, catch, or latch should be provided to hold the door open, particularly if the door must be opened in high winds. When hinged doors are adjacent, they should open in the opposite directions to maximize accessibility. Hinged caps should be used over service or test points so they will not interfere with inserting or attaching service or test equipment. Stops or retainers should be used as necessary to keep doors from swinging into adjacent controls or fragile components, and so they will not spring their hinges.

5.9.8.2 Sliding doors and caps. 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 using sliding doors and caps, they should lock positively, be designed so they will not jam or stick, and be easy to use. Personnel should be able to use them without tools. Opening or closing them should not interfere with, damage, or make potentially harmful contact with wires or other equipment items.

5.9.8.3 Removable doors, plates, and caps. Removable doors, plates, or caps require little space for opening and, once removed, do not interfere with workspace. However, handling them takes time and effort. When using removable covers, tongue-and-slot or similar catches should be used wherever possible for small plates, doors, and caps, to minimize the number of fasteners required. If small plates and caps are likely to be misplaced or damaged, secure them with retainer chains (see 5.9.10.6.12). If a removable plate must be attached in a certain way, it should be designed so it cannot be attached improperly. For example, 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.

5.9.8.4 Removable panels or sections. 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 used, 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, and it should be apparent when fasteners have been released. Panels and sections should be designed so one person can carry them and install or remove them with common hand tools, and should have handles to facilitate removal, handling, and replacement. It should not be necessary to disconnect wires or components from a panel before removing it. If such items are attached to the panel, it should be hinged so they need not be removed.

5.9.9 Access openings and covers. The following checklist (Table 26) summarizes some of the important features to be considered in the design of equipment units. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is NO, the design should be restudied to ascertain the need for correction.

5.9.10 Fasteners.

5.9.10.1 General. The design, selection, or application of fasteners should consider the workspace, tool clearance, and wrenching space needed around the fastener, and the types of tools required to operate the fastener, depending on the type of fastener, application, and location. How often the tool will be used and the time available for tasks involving operation of the fasteners are other considerations. The fasteners also will have to be used by personnel who may be wearing arctic gloves or mittens.

5.9.10.2 Selection. Fasteners are available in a wide variety of types and sizes, and new types are always appearing on the market. Before selecting fasteners, review the varieties available. They 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. Fasteners should be selected for durability, easy operation, speed, and easy replacement.

5.9.10.3 Minimize fasteners and required tools. Minimize the number of types and sizes of fasteners within the system by using only a few basic types and sizes which are readily distinguishable from each other (see Figure 46) and using the same type and size of fastener consistently for a given application. For example, all mounting bolts should be the same for a given type of item. Another way to minimize the number and types of sizes is by making certain that screws, bolts, and nuts with different threads also have clearly different physical sizes so they will not be interchanged, by avoiding fasteners that require special tools, and by selecting fasteners that can be operated by hand or by common hand tools.

TABLE 26. Equipment units access checklist.

1. Are clearance holes for mounting screws in cover plates and shields oversize to obviate need for perfect alignment?

2. Are cases designed to be lifted off units rather than units lifted out of cases?

3. Are cases made larger than units they cover to preclude damage to wires and components?

4. Are guides or tracks provided to prevent cases cocking to one side?

5. If the method of opening a cover is not obvious, is an instruction plate attached to the outside of the cover?

6. When covers are not in place and secure, are means provided to make it obvious?

7. Are no more than six fasteners used to secure the case?

8. Are the same type fasteners used for all covers and cases on a given piece of equipment?

9. Is ventilation-hole screening of small enough mesh provided to prevent entry of probes or conductors that could inadvertently contact high voltages?

10. When the sealing edges of a case must be slid over sealing material (such as rubber stripping), does the sealing material adhere tightly enough to prevent it from buckling or tearing?

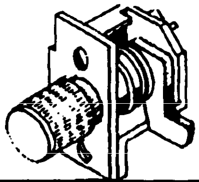
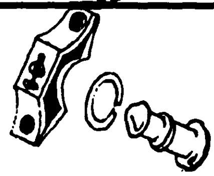
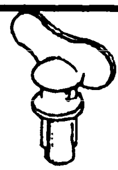
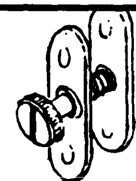
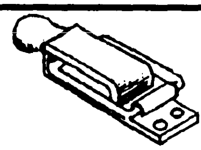
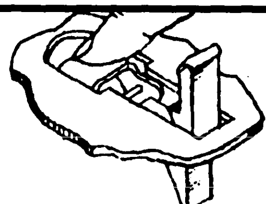
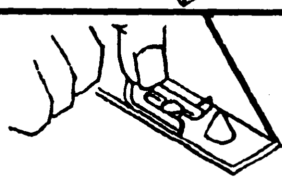
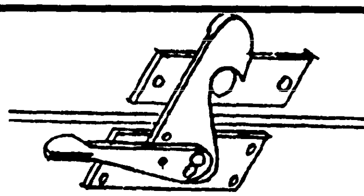
TYPE	DESCRIPTION
	Adjustable pawl fastener. As knob is tightened, the pawl moves along its shaft to pull back against the frame. 90° rotation locks, unlocks fastener.
	"Dzus" type fastener with screwdriver slot. Three-piece 1/4-turn fastener. Spring protects against vibration. 90° rotation locks, unlocks fastener.
	Wing head. "Dzus" type. 90° rotation locks, unlocks fastener.
	Captive fastener with knurled, slotted head. Retaining washer holds the threaded screw captive.
	Draw-hook latch. Two-piece, spring latch, base unit and striker. When engagement loop is hooked over striker, depressing lever closes unit against force of springs. Lever is raised to unhook.
	Trigger-action latch. One-piece, bolt latch. Depressing trigger releases bolt, which swings 90° under spring action and opens latch. To close, move bolt back into position.
	Snapslide latch. One-piece snapslide. Latch is opened by pulling lever back with finger to engage release lever.
	Hook latch. Hook engages knob on striker plate. Handle is pulled up locking in place. To release, reverse procedure.

FIGURE 46. Fastener examples.

5.9.10.4 <u>One-hand or one-tool operation</u>. Nuts and bolts, particularly those which are operated frequently or which are not very accessible, should be mounted so they can be operated with one hand or one tool and recesses should be provided to hold either the nut or the bolt. Either the nut or the bolt should be attached semi-permanently, and they should not interfere with each other or with other components during release. Nuts and bolts should not be hazards to personnel, wires, or hoses and should have adequate hand or tool clearance for easy operation. It should be considered that it may take two hands or power tools to manipulate, breakaway, or remove stuck fasteners. Fasteners that are normally operated by hand should be durable enough that they can be turned with a wrench.

5.9.10.5 <u>Other considerations</u>. Consider how stripped, worn, or damaged fasteners can be replaced. Fasteners (studs) which are an integral part of the housing should be avoided. Fastener mounting holes or other tolerances should be large enough to allow "starting" fasteners without perfect alignment. Attach hinges, catches, latches, locks, and other quick-disconnect devices with small bolts or screws, not with rivets.

5.9.10.6 <u>Types of fasteners (in order of preference)</u>.

5.9.10.6.1 <u>Quick-connect and quick-disconnect devices</u>. These 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. The factors listed below should be considered in selecting quick-connect and quick-disconnect fasteners.

a. These fasteners should be used wherever possible when components must be dismantled or removed frequently.

b. These fasteners should fasten and release easily, without requiring tools.

c. They should fasten or unfasten with a single motion of the hand.

d. It should be obvious when they are not correctly engaged.

e. When there are many of these fasteners, prevent misconnections by giving the female section a color or shape code, location, or size so it will be attached only to the correct male section.

5.9.10.6.2 <u>Latches and catches</u>. These items are very fast and easy to use, do not require tools, and 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. The factors listed below should be considered in selecting latches and catches.

a. Long-latch catches should be used to minimize inadvertent releasing of the latch.

b. Catches should be spring-loaded so they lock on contact rather than requiring positive locking.

c. If the latch has a handle, the latch release should be located on, or near, the handle so it can be operated with one hand.

d. Latches and catches should be evaluated for snap down and release forces that could be hazardous to handle during operation.

5.9.10.6.3 Captive fasteners. Captive fasteners are slower and more difficult to use, depending upon type, and usually require using common hand tools, but they stay in place, saving time that would otherwise be wasted handling and looking for bolts and screws, and can be operated with one hand. The factors listed below should be considered in selecting captive fasteners.

a. Captive fasteners should be used when "lost" screws, bolts, or nuts might cause a malfunction or excessive maintenance time.

b. Fasteners should be used which can be operated by hand or with a common hand tool and which can be replaced easily if they are damaged.

c. Captive fasteners of the quarter-turn type should be self-locking and spring-loaded.

5.9.10.6.4 Regular screws. Round, square, or flat-head screws take longer to use and are subject to loss, damage, stripping, and misapplication. 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. If personnel must drive screws blindly, provide a guide in the assembly to help keep the screwdriver positioned properly. Screw heads should have deep slots that will resist damage, and should be used only when personnel can use screwdrivers in a "straight-in" fashion. Personnel should not be required to use offset screwdrivers.

5.9.10.6.5 Bolts and nuts. Bolts are usually slow and difficult to use. Personnel must have access to both ends of the bolt, use both hands, and often use two tools. Also, starting nuts require precise movements. There are many loose parts to handle and lose such as nuts and washers. Design considerations should include keeping bolts as short as possible, so they will not snag personnel or equipment. Coarse threads are preferable to fine threads for low torques and reduce the possibility of cross-threading. Left-hand threads should be avoided unless system requirements demand them. If used, both bolts and nuts should be identified by clearly marking, or shape or color coding. Wing nuts (preferably) or knurled nuts should be used for low-torque applications, because they do not require tools.

5.9.10.6.6 Combination-head bolts and screws. Combination-head bolts and screws are preferable to other screws or bolts because they can be operated with either a wrench or a screwdriver, and there is less danger of damaged slots and stuck fasteners. In general, slotted hexagon heads are preferable to slotted knurled heads.

5.9.10.6.7 Internal-wrenching screws and bolts. Internal-wrenching screws and bolts (socket heads) allow higher torque, better tool grip, and less wrenching space, but require special tools, are easily damaged, and are difficult to remove if damaged. They also become filled with ice and frozen mud. The number of different sizes should be limited to minimize the number of special tools; one size is preferred. Fasteners with deep slots should be selected to reduce the danger of damaged fasteners.

5.9.10.6.8 Rivets. Rivets are very hard and time-consuming to remove. They should not be used on any part which may require removal.

5.9.10.6.9 Cotter key. Keys and pins should fit snugly, but they should not have to be driven in or out. Cotter keys should have large heads for easy removal.

5.9.10.6.10 Safety wire. Use safety wire only where self-locking fasteners cannot withstand the expected vibration or stress. Attach safety wire so it is easy to remove and replace.

5.9.10.6.11 Retainer ring. Rings which become difficult to remove and replace when they are worn should be avoided. Rings which hold with a positive snap action should be used when possible.

5.9.10.6.12 Retainer chains. Retainer chains should be used to:

a. keep hatches or doors from opening too far and springing their hinges,

b. turn doors or covers into useful shelves for the technician,

c. prevent small covers, plates, or caps from being misplaced,

d. secure small, special tools where they will be used,

e. secure objects which might otherwise fall and injure personnel, and

f. secure removable pins to prevent loss.

The selection of retainer chains for use in design should consider link, sash, or woven-mesh chains. Bead-link chain should be avoided because it breaks more easily than other types. Chains should be attached with screws or bolts; attach them strongly and positively, but so they can be disconnected easily when required. Eyelets should be provided at both ends of the chain for attaching to the fasteners and chains should not be longer than their function requires.

5.9.11 Unit design for efficient handling.

5.9.11.1 General. Handling equipment includes ground support equipment used for handling, lifting, and positioning tasks required during system maintenance.

5.9.11.2 Handling equipment.

5.9.11.2.1 Jacks.

5.9.11.2.1.1 General. Jacks should be designed so they can be transported, handled, and stored easily. Small jacks, that one person must lift and carry, should not weigh more than 18 kg.

5.9.11.2.1.2 Handles. Jack handles should be designed so they can be removed or folded when the jack is not in use.

5.9.11.2.1.3 Labels. Jacks should be labeled to indicate the direction to turn the jack handle for raising and lowering, and the load they are designed to carry.

5.9.11.2.1.4 Hydraulic jacks. On hydraulic jacks, there should be mechanical safety-locking devices to keep the load from falling if the hydraulic system fails. Only non-flammable hydraulic fluid should be used in jacks.

5.9.11.2.1.5 Jacking points. Jacking points should be conspicuously labeled on equipment.

5.9.11.2.2 Cranes.

5.9.11.2.2.1 Crane booms. Sections of crane booms should have hook eyes at their center of gravity for easier assembly and disassembly. Where feasible, the boom length should be adjustable to make the equipment more versatile.

5.9.11.2.2.2 Boom indicators and controls. The main boom angle-indicator display should be easily visible to the operator and coded to alert the operator when there is danger of exceeding the maximum load angle. Load capacity, in kg, should be indicated on the equipment and audible warning devices should be provided when load is exceeded. Boom controls should have labels indicating their functions and direction of motion and be placed in the most accessible area for the 5th through 95th percentile operator when wearing cold weather clothing. These controls should be spring-loaded so they return to the stop position when released. Latches on control levers should not cause delay in operation.

5.9.11.2.2.3 Hooks. Crane hooks should have handles so operators can hold or guide hooks during lifting, without danger or injury. The hook mouths should have safety-closure locking devices that are easy to open or close.

5.9.11.2.2.4 Other considerations.

a. The crane operator's station should be located where the operator will have the best view of the load, the ground, and other equipment in the vicinity.

b. Retainers or locks used to keep booms in place during transport should be identified clearly and unambiguously.

c. Fail-safe load holding devices should be provided to reduce dropping objects.

d. Cranes that rotate on a turntable should be provided with a mechanical safe.

e. Foot-operated controls and brake pedals that require locking should lock by foot action only. Pedals should rise from a depressed position in a backward as well as vertical movement.

5.9.11.2.3 Hoists.

5.9.11.2.3.1 General. Hoists should have an automatic cutoff of power to stop lifting when a bind occurs. Moving parts, such as belts, chains, and gears should be covered to prevent personnel from accidently coming in contact with them.

5.9.11.2.3.2 Control box. The hoist control box should be lightweight and designed to be hand-held so the operator may reach the "up" and "down" control while holding the box securely and comfortably. Where a push button control is used, it should be spring-loaded to the "off" position and recessed. The "up" and "down" hoist controls should be clearly labeled, preferably on the control.

5.9.11.3 Handles and grasp areas.

5.9.11.3.1 General. Hand-shaped handles should be used when items must be carried frequently or for long periods, to prevent undue side pressure on the fingers. Recessed, concealed, or folding handles may be used to conserve space, but they should be accessible without tools and remain securely folded when not in use. Handles, lugs, and other handling gear (casters, push bars) should be permanent parts of the equipment case, and hoist lugs (lifting-eyes) should be provided on all equipment weighing more than 68 kg. "LIFT HERE" should be marked adjacent to each lug, and a minimum of 100 mm space should be allowed around the lifting eyes for convenient use.

5.9.11.3.2 Location. The primary consideration in the design and location of handles should be to allow the device to be easily handled and carried. Some secondary considerations are to guard against accidental operation of controls to protect delicate parts of instrument faces, to serve as locking devices to secure components in place, to serve as protective supports or stands so they can be used as maintenance stands when items are inverted, and to allow the device to be easily handled and carried.

5.9.12 Mounting and packaging.

5.9.12.1 General. Assemblies, modules, and parts should be packaged and mounted in accordance with the principles listed below.

a. Adequate tool access and wrenching space is provided around fasteners.

b. Adequate space is provided for use of test probes and other service or test equipment.

c. Components to be serviced or repaired in position are at the most favorable working level (between hip and shoulder level).

d. Maintenance required on a given unit or component can be performed with the unit or component in place, where possible, and without disconnection, disassembly, or removal of other items.

e. All replaceable items, particularly disposable modules, are removable without removal or disassembly of other items or units; by opening a minimum number of covers, cases, and panels, without hindrance from structural members or other parts; and 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 may be slid out or pulled out rather than lifted out, do not prevent access to other removable items, and are mounted on sliding drawers and racks wherever practicable.

g. When it is necessary to place one unit behind or under another, the unit requiring the most frequent maintenance is most 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 minimum tools and equipment, and only common hand tools where practicable.

k. Rapid and easy removal and replacement can be accomplished by one person, two persons, or handling equipment, in that order of preference.

l. Irregular, fragile, or awkward extensions, such as cables and hoses 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 person:

(1) Removable items should weigh less than 16.8 kg.

(2) Difficult to reach items should weigh less than 11.3 kg.

n. Items over 16.8 kg are designed for two-person handling.

o. Hoist lugs are provided for assemblies over 40.8 kg.

5.9.12.1.1 Arrangement. The majority of parts, items, and assemblies can be located and packaged in a variety of ways and places. The final arrangement should be based on 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, and temperature.

e. Criteria for built-in test and malfunction circuits or indicators. The peculiar characteristics of each item or module should be chosen with particular reference to:

(1) item size, weight, and clearance requirements;

(2) item fragility or sensitivity and resultant protection needs;

(3) item servicing, adjustment, or repair needs and procedures; and

(4) tool access and clearance criteria for each item fastener, connector, test, or service point.

f. Specific factors such as critical lead length, weight balance, and heat dissipation, which may hinder personnel in carrying out their tasks.

5.9.12.1.2 Safety. Items should be located, packaged, mounted, and shielded so that access to them, adjacent items, or associated fasteners can be achieved without danger to personnel from electrical charge, heat, sharp edges, points, moving parts, chemical contamination, or other hazards. Design, packaging, and mounting should be according to the considerations listed below.

a. For personnel protection, commonly worked on parts, fasteners, service, or test points should not be located near exposed terminals or moving parts.

b. Guards or shields should be provided to prevent personnel from coming into contact with dangerous moving parts or potential injury.

c. Ventilation holes in equipment should be located and made small enough to prevent insertion of fingers and tools into hazardous areas.

d. Tool guides should be 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, should be located or shielded so personnel cannot contact them accidentally.

5.9.12.1.3 Facilitation of maintenance operations. The layout and packaging of components, subassemblies, or assemblies should maximally facilitate the required or expected maintenance operations.

a. Place-to-place movement of the technician during servicing, checkout, or troubleshooting should be minimized.

b. The need for the technician to retrace movements or steps during servicing, checkout, or troubleshooting should be minimized.

c. The number of component or item inputs and outputs should be kept to a minimum.

d. The equipment should be packaged so the technician has the option of replacing an individual item of a group, or the whole group, in accordance with the maintenance philosophy.

e. New fastener or bracket assemblies should be provided on spare components where the old ones are likely to be lost or damaged.

f. Undue sequential assembly that requires sequential disassembly to accomplish maintenance should be avoided.

g. Sliding racks, or hinged assemblies, should be used to allow maximum accessibility.

h. Organization should be according to maintenance specialties so that maintenance performed by one specialist does not require removal or handling of equipment maintained by another specialist, particularly where such equipment is of a critical nature or its maintenance requires highly specialized skills.

5.9.12.1.4 Other considerations.

a. Adjustment and alignment devices should be mounted so they cannot be inadvertently actuated by the technician.

b. Mountings of components, modules, and parts should be designed to prevent their being inadvertently reversed, mismated, or misaligned during installation or replacement.

c. 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 readily identifiable, distinguishable, and not physically interchangeable.

d. Hinged bars are useful for tying down and permitting access to a number of small components at one time.

5.9.12.2 Removal.

5.9.12.2.1 Mounting. Parts, subassemblies, and assemblies should be mounted so that only interconnecting wire and structural members are permanently attached to units; all other fixtures should be removable for ease of maintenance. Fixtures which are built into the chassis should be either strong enough to withstand usage by personnel over the life of the system or are removable. Mounting should be compatible with the size and weight of the part to prevent lead breakage or similar damage from fatigue under personnel handling stress.

5.9.12.2.2 Pins, caps, and covers. Small removable pins, caps, and covers should be attached to prevent loss or damage. Vital, fragile, sensitive, or easily damaged components should be located, arranged, and shielded so they will not be used for handholds, footholds or rests, or damaged by flying particles, loose objects, or movement of personnel or tools during maintenance.

5.9.12.2.3 Spring clamps. Use spring clamps to mount tubing, pipes, or wiring which may require frequent removal and replacement (see Figure 47). For overhead mounting, use a spring clamp similar to that used for floor mounting, but provide a hinged locking latch over the open side of the clamp to prevent accidents.

5.9.12.2.4 Straps and brackets. Straps and brackets should be thick or rounded enough so that they have no sharp edges. They also should be twist or push-to-lock mounting type for small components; such brackets should be designed so locking studs are visible when the component is in place and locking screws or dimples are provided, as necessary, to ensure security of the mount. Straps and brackets should be used as necessary for tying down large components and supporting items mounted on the underside of assemblies. They also should be used instead of cantilever brackets for mounting parts and as necessary to prevent the mounted item from sliding or jumping out of position. "U" straps should be used to "tie down" components, not to secure or support them.

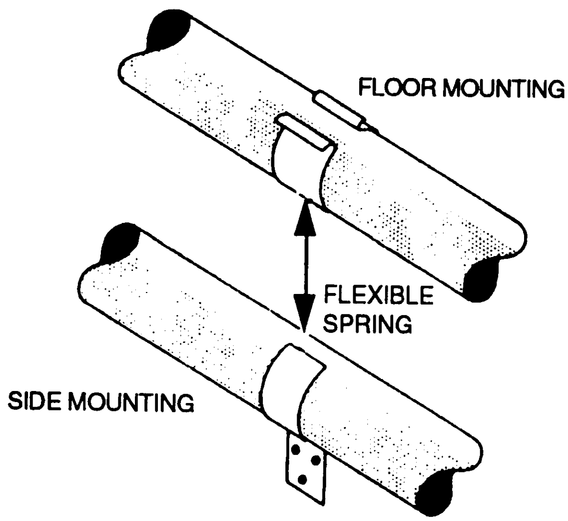


FIGURE 47. Use of spring clamps.

5.9.12.3 Alignment.

5.9.12.3.1 Guides and guide pins.

5.9.12.3.1.1 General. Supports, guides, and guide pins should be provided as necessary to assist handling, aligning, and positioning units. Their design should prevent mismating or misalignment during installation or replacement.

5.9.12.3.1.2 Bottom-mounted aligning pins. Bottom-mounted aligning pins should be used for components which are light enough to be lifted and positioned easily such as those weighing less than 9 kg.

5.9.12.3.1.3 Side-aligning devices. Side-aligning devices or brackets should be used for heavy components so the components can be slid rather than lifted into and out of place.

5.9.12.3.2 Shock mounts. Shock mounts should be used, as necessary, to eliminate vibrational fluctuations in displays and markings which will cause error in operator reading as well as to protect fragile or vibration-sensitive components and instruments. Shock mounts also control sources of high or dangerous noise and vibration for effective human performance.

5.9.12.4 Coding.

5.9.12.4.1 Coding, marking, and labeling. The rapidity, accuracy, and ease of maintenance, particularly troubleshooting, are proportional to the amount of color coding, marking, and labeling employed. These are the most direct links between the designer and the technician and should be used as fully as possible to explain the arrangement, function of, and relationship among items. There are no hard and fast rules for coding and labeling as a function or part of packaging; the effectiveness of such efforts depends largely on the care and ingenuity of the designer. Codes and labels used on and within equipment packages should be:

a. in accordance with the principles for coding and labeling,

b. in keeping with test and service-point coding and labeling,

c. consistently and unambiguously used throughout the system,

d. of such a nature as to be easily read and interpreted,

e. durable enough to withstand expected wear and environmental conditions, and

f. coordinated and compatible with codes and labels on related test and service equipment, other coding and labeling within the system, and related job aids, instructions, handbooks and manuals.

5.9.12.4.2 Identification. For identification purposes, codes and labels should be provided on, and within, the packaging 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 (directly 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 cross-reference to schematics,

f. indicate "maintenance highways" to guide the technician through routine processes,

g. indicate the weight of units over 16.8 kg,

h. point out warning and caution areas,

i. present an outline procedure not made obvious by design and to supply whatever information is necessary for troubleshooting and maintenance, and

j. allow the presentation or recording of historic data where practical, particularly to display periodic readings at test points, to allow development of trends where these are fundamental to maintenance decisions, and permit recording of replacement dates, or other data necessary to replenishment criteria or preventive maintenance.

5.9.12.5 Rollout racks, slides, or hinges.

5.9.12.5.1 General. Pull-out, roll-out, or slide-out drawers, shelves, racks or other hinged or sliding assemblies (see Figure 48) should be provided as necessary and wherever practicable to optimize workspace, tool clearance, and accessibility, and reduce the need for the technician to handle fragile or sensitive items. This would also facilitate the handling and/or positioning of heavy or awkward items as well as maintenance of items which are frequently moved from the installed position for checking, servicing, or repair. Pull-out or slide-out racks and drawers should be designed in the manner listed below.

a. A minimum number of operations are required to open or release them.

b. They operate with a force less than 178 N.

c. A smooth-operating bearing assembly facilitates operations, as needed.

d. They lock automatically in both servicing and operating positions.

e. Handles are provided, as necessary, to facilitate operation and handling.

f. Assemblies may be opened without breaking internal connections which are necessary for required maintenance.

g. Extension cables or hoses are provided, as necessary, to allow completely removable assemblies to be checked in a convenient location.

h. Guards and shields are provided, as necessary, to prevent damage to fragile or sensitive parts when the assembly is moved.

5.9.12.5.2 Retaining devices. Rests, limit stops, guards, and/or retaining devices should be provided as part of the basic chassis. These devices should prevent the assembly from being dropped, prevent heavy assemblies from tipping the equipment, and allow complete and convenient removal of the assembly. These devices also should allow the assembly to open its full distance and remain open without being held.

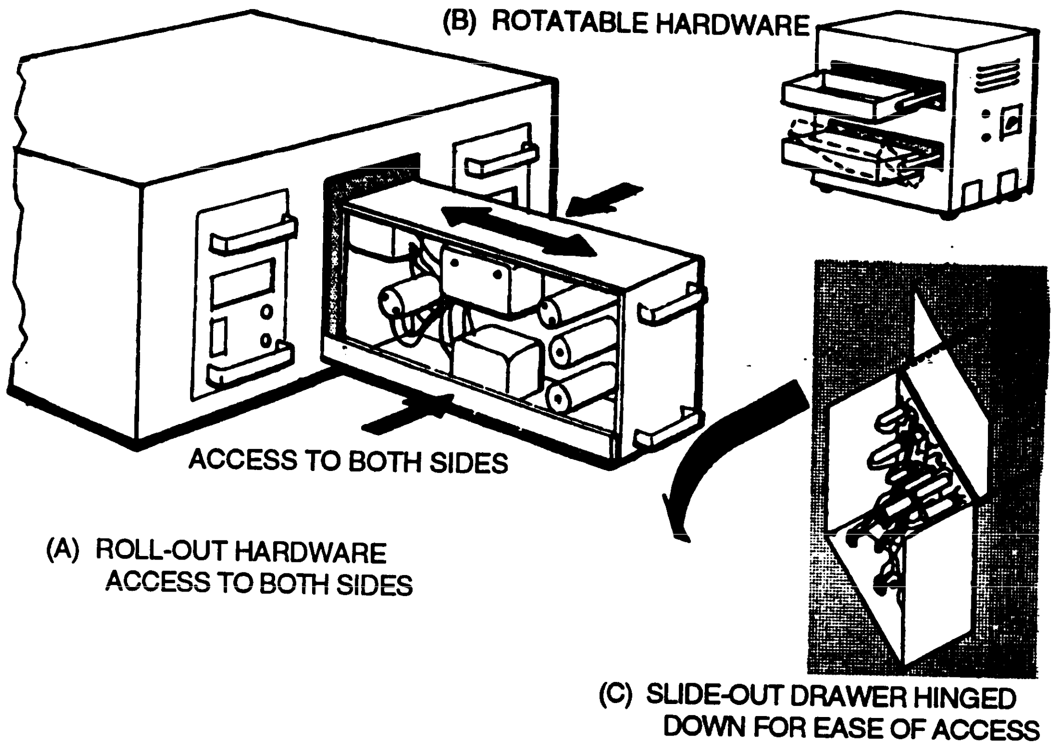


FIGURE 48. Pull-out, roll-out, and slide-out drawers.

5.9.12.5.3 Internal connectors. Where internal connection is not required during maintenance, connectors to a drawer or shelf may be attached to the assembly itself, so that closing the assembly effects connection. This requires that the connector parts be mounted on the assembly and rear wall and locks be provided to ensure that connectors remain engaged. Guides should be provided to ensure proper orientation of the assembly prior to pin engagement. If necessary, insulation should be provided to ensure safety.

5.9.12.6 Fold-out construction. Fold-out construction should be used for subassemblies whenever feasible (see Figure 49); the parts and wiring should be positioned to prevent damage to them when the assembly is opened or closed.

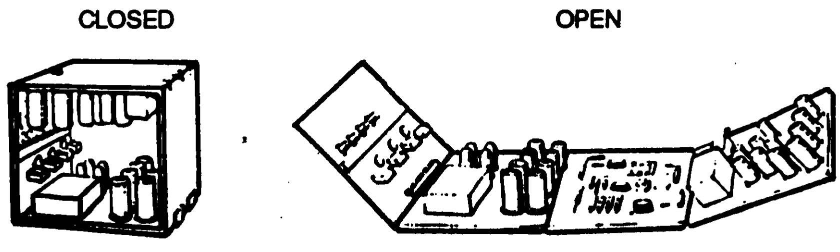


FIGURE 49. Fold-out construction for electronic chassis.

5.9.12.7 Braces. Braces, or similar items, should be provided to hold hinged assemblies in the "out" position while they are being repaired (see Figure 50). Rests or stands should be provided to prevent damage to delicate parts. If feasible, the rests or stands should be a part of the basic chassis as shown on Figure 51.

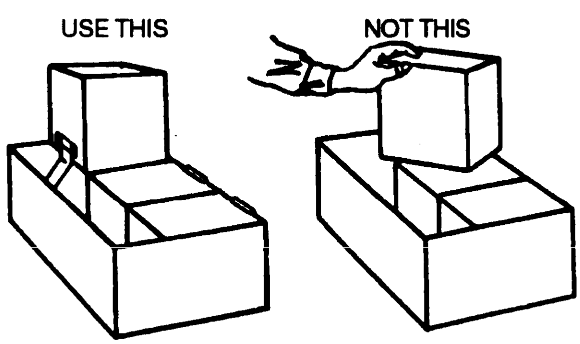


FIGURE 50. Hinged assemblies.

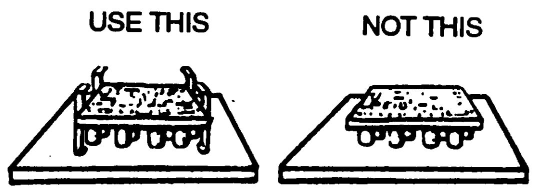


FIGURE 51. Use of maintenance stands.

5.9.12.8 Blind mounting. Where blind mounting is required, the inaccessible side should be secured with mounts which allow exceptionally easy mating and do not require access to friction lugs or tongue-and-groove fittings.

5.9.13 Conductors.

5.9.13.1 General. Lines and cables should be selected, designed, marked, bound, routed, and installed so the following operations can be performed quickly.

a. Troubleshooting, testing, checking, and isolating malfunctions.

b. Tracing, removing, repairing, and replacing cables.

c. Removing and replacing other items and components.

d. Connecting and disconnecting.

5.9.13.1.1 Design recommendations.

a. Route cables so that they are not pinched by doors, lids and slides, are not walked on or used for handholds (see Figure 52), and are accessible to the technician, by not being under floorboards, behind panels or components that are difficult to remove, or routed through congested areas, and need not be bent or unbent sharply when connected or disconnected (see Figures 53 and 54).

b. Design cables or lines which must be routed through walls or bulkheads for easy installation and removal without the necessity for cutting or compromising the integrity of the system.

c. Cable routing should avoid close contact with tubes, transformers, or rectifiers so that they will not be damaged by overheating.

d. Provide guards or other protection for easily damaged conductors such as waveguides, high-frequency cables, or insulated high-voltage cables.

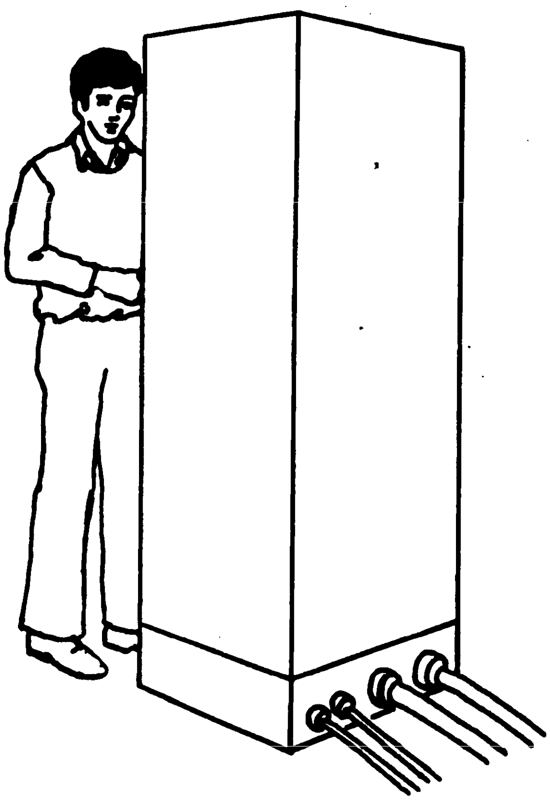


FIGURE 52. Routing cables.

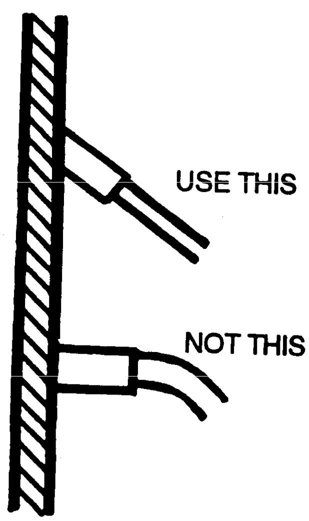


FIGURE 53. Cable connections.

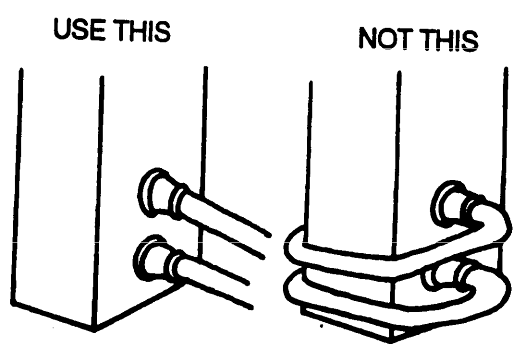


FIGURE 54. Cable bends.

e. Protect electrical wiring from contact with fluids such as grease, oil, fuel, hydraulic fluid, water, or cleaning solvents. These may damage insulation and result in injury to personnel.

f. Provide a means for keeping cables and lines off the ground. While permanent lines should never be on the ground, keeping them clear is especially important in areas where ice and snow may cover the lines for long periods, making them inaccessible for maintenance.

g. Where cable connections are maintained between stationary equipment and sliding chassis or hinged doors, provide service loops to permit movement, such as pulling out a drawer for maintenance without breaking the electrical connection. The service loop should have a return feature to prevent interference when removable chassis are replaced in the cabinet. Figure 55 shows two methods of recoiling the cable.

h. Provide storage space for long electrical cables which are a part of ground power, service, and test equipment. Often a storage compartment is present, but no easy means is provided for coiling the wire into a shape and size which will permit storage. A simple means is a cable winder, a device around which the cable may be wrapped (see Figure 56). Use a circular spool as a cable winder to prevent bending radii of less than six times the diameter of the cable.

i. Precautions should be taken to protect the insulation at the ends of cables from moisture. Moisture-proof jacketing, which will withstand the required temperature range and mechanical abuse, should be used.

j. Provide protective covers for the cable to prevent damage to connectors during periods of non-use. Provisions should be made to secure the protective cover to the cable to avoid misplacement.

5.9.13.1.2 Compatibility. Lines and cables should be compatible with interfacing connectors, fasteners, accesses, and environmental extremes to which they will be subjected.

5.9.13.2 Coding. Conductors should be coded and labeled so each conductor can be identified throughout the length of each cable or harness, wherever tracing is required, and so codes and labels correspond to connector designations, test point designations, and connector functions.

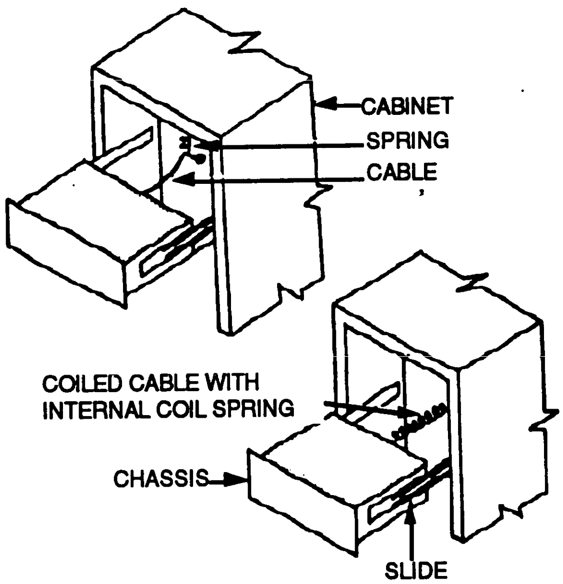


FIGURE 55. Methods for recoiling service loops.

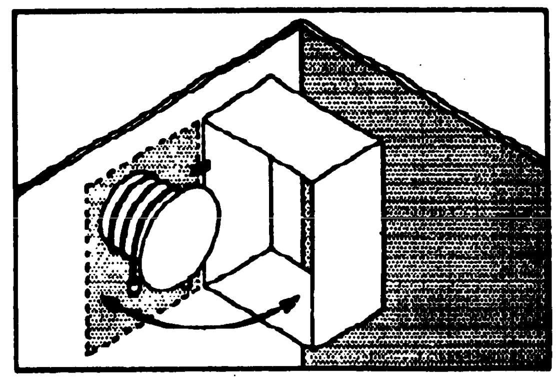


FIGURE 56. Cable winder.

5.9.13.2.1 Wires. Wires may be color coded by (in order of preference) solid-color insulation, solid-color insulation with colored-stripe tracer, or colored braid insulation with woven tracer. Every wire in a cable should be color coded over its entire length. There are 21 discriminably different patterns of solid colors and solids with striped tracers (see Table 27).
For more than 21 wires, see MIL-STD-686. If a wire's color may become obscured, wires may be coded with numbered metal tags.

5.9.13.2.1.1 Number coding. Where wires are coded with numbers, the numbers should be repeated at least every 50 mm over the wire's entire length.

5.9.13.2.1.2 Specific wire coding information.

5.9.13.2.1.2.1 Hook-up wire. Coding for hook-up wire is prescribed by MIL-STD-681.

5.9.13.2.1.2.2 Telephone, teletype, and telegraph wires. Coding for telephone, teletype, and telegraph wire is prescribed by MIL-STD-685.

5.9.13.2.1.2.3 High- and low-tension power cables. Coding for high-tension power cables is prescribed by MIL-C-3702; coding for low-tension power cables is prescribed by MIL-C-13486.

TABLE 27. Electrical cable coding.

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

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

5.9.13.2.2 Hydraulic and pneumatic conductors. Hydraulic and pneumatic conductors should either be color coded (see Table 28) or coded by metal tags. Metal tags should be used where adverse conditions (such as grease or mud) could obscure colors; otherwise, color coding should be used.

5.9.13.3 Cable clamps. Clamps or plates that mount lines and cables should be spaced not more than 610 mm apart so personnel can install or remove one with each hand with or without common hand tools, and have heat-insulating liners so they do not become hot enough that personnel could be burned. They should be the quick-release hinged or spring type if cables are removed frequently. Hinged clamps are preferable, because they support the weight of the line during maintenance, freeing the technician's hands for other tasks. For overhead mounting, a spring clamp should be used with a hinged-locking latch over the clamp's open side to prevent accidents.

5.9.13.4 Length. The length of cables should be the same for each installation of a given type of electronic equipment if the circuit might be affected by differences in the length of the cable.

(Even if a unit can be adjusted to compensate for differences in the length of the cable, using different lengths of cable means that an adjustment made on the bench might be out of tolerance when the unit is installed.)

TABLE 28. Hydraulic and pneumatic 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	Subatmospheric 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 not serving a functional purpose during the phase being represented.

5.9.13.4.1 Extension cables. Use extension cables to:

a. increase efficiency and make maintenance easier,

b. test assemblies or components without removing them,

c. check each functioning unit in a convenient place,

d. allow parking support equipment or setting it in a convenient place, and

e. serve as many related functions as possible, avoiding the possibility of misuse or misconnection.

5.9.13.4.2 Handling and storage. There should be adequate provision for handling and storing extension cables and cables used with ground power, service, and test equipment. Adequate, covered space should be provided for storing lines and cables in support equipment. Suitable racks, hooks, or cable winders should be available and conveniently accessible in the storage space to hold lines and cables. Reels or reel carts should be used for handling large, heavy, or very long lines and cables. Automatic or power tensioning or rewinding reels should be used where possible to make handling easier. Wheeled or mobile supports also should be used for extra-large lines and cables that must be moved frequently.

5.9.13.5 Cable routing.

5.9.13.5.1 General. Interconnecting communication cables should be routed to minimize the possibility of their use as handholds or steps. A protective guard should be placed over the cables where the possibility of such use exists.

5.9.13.5.2 Maintenance. Cable routing should facilitate ease of maintenance by ensuring that each unit can be checked in a convenient place (extension cables should be provided when necessary). Units in drawers and slide-out racks should be able to be pulled out to be worked on without breaking electrical connections. Connectors should be reached easily for replacement or repair, and units that are difficult to connect where they are mounted should be capable of being moved to a more convenient position for connecting and disconnecting.

5.9.13.5.3 Mounting. Lines and cables should be routed and mounted so that they fulfill the conditions listed below.

a. They should be accessible without disassembling or removing other equipment.

b. Points of connection, mounting, splicing, or testing should be especially accessible.

c. They can be removed and replaced completely if they are damaged.

d. There are accesses and clearances for removing and replacing them.

e. Personnel will not use them for handholds or footsteps and will not step or walk on them.

f. Moving and rotating parts will not snag them, and so they do not interfere with normal operations.

g. Cables routed through metal partitions should be protected by use of insulating grommets.

h. Foreign objects, such as flying stones, will not damage them.

i. Cables routed in areas where potential risks for degradation are high (passageways; across walkways; or exposure to adverse conditions such as oil, blasts, and heat) should be protected by conduit.

5.9.13.5.4 Layout and routing. The layout and routing of wires should be made as simple and logical as possible by combining wires into cables (preferable) or into harnesses, minimizing the number of wires, harnesses, and cables, and grouping conductors into cables, and within cables or harnesses, by their functions and relationships to replaceable items. Electrical wires, harnesses, and cables should be mounted so there is adequate accessibility through raceways, conduits, and junction boxes. Electrical wires and cables should be mounted over, rather than under, pipes or fluid containers.

5.9.13.5.5 Leads.

5.9.13.5.5.1 Length. Leads should not be longer than necessary, but their lengths should allow easy connection and disconnection with enough slack to back wires away from attachment points so units can be removed easily. They should be long enough to allow slack so terminal fittings can be replaced at least twice, and preferably three times (if electrical considerations permit). Leads also should be long enough to permit units which are difficult to handle when mounted to be moved to a more convenient position for connection or disconnection.

5.9.13.5.5.2 Mounting. Leads should be mounted so they are separated far enough to clear the technician's hand or any tool required for checking or connecting them, and oriented, where possible, so they will not be connected incorrectly or crossed.

5.9.13.5.6 Junction boxes. Cables should fan out in junction boxes for easy inspection, especially if there are no other test points in the circuits (Figure 57). Each terminal in the junction box should be clearly labeled and easy to reach with test probes.

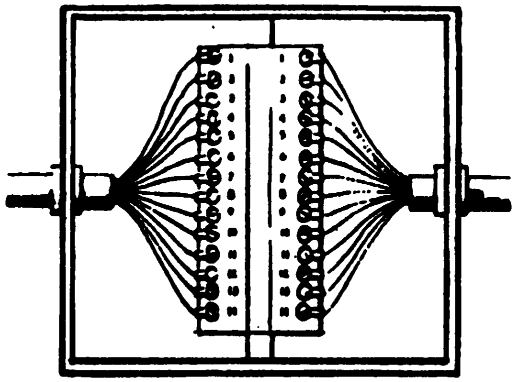


FIGURE 57. Cable inspection.

5.9.13.5.7 Harnesses. Cable harnesses should be designed so they can be built in a shop or factory and installed as a package.

5.9.13.5.8 Preformed cables. Use preformed cables when possible (see Figure 58). They permit flexible, more efficient assembly methods and minimize the chances of making wiring errors. They also permit testing and coding of the entire cable before installation. Once the cable is placed in position on the chassis, the leads can be connected without the usual interference and confusion caused by stray wires.

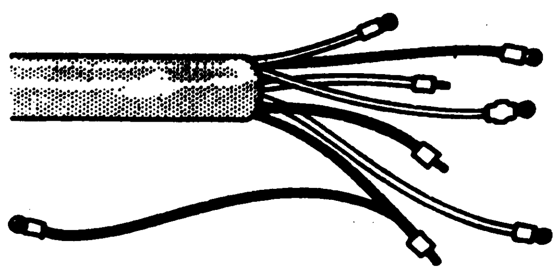


FIGURE 58. Preformed cables.

5.9.13.6 Cable Protection.

5.9.13.6.1 Plastic covering. Consider using clear plastic covering to insulate leads on cables so that breaks in internal wiring can readily be seen. Neoprene-covered, rather than aluminum-sheathed cable, should be used in areas where intense vibration or corrosive substances may cause failures. These coverings should remain flexible at low temperatures.

5.9.13.6.2 Wires. When polyvinyl wire is used, care should be taken so there will be no cold flow of the insulation resulting from tightness of the lacing or mounting. High-temperature wire should be used when wires are routed near ducts carrying pressures over 3.5×10^5 Pascals and/or temperatures above 200° C. Wires and coverings also should remain flexible at the low temperatures encountered in cold regions. Color code or number code insulated wire and cable in accordance with MIL-STD-195 and MIL-STD-681.

5.9.13.6.3 Metallic shielding. Metallic shielding, unprotected by outer insulation, should be secured to prevent the shielding from contacting exposed terminals or conductors.

5.9.13.7 Fluid and gas lines.

5.9.13.7.1 Personnel and equipment protection. Lines should be kept from spraying or draining fluid on personnel or equipment when they are disconnected by locating connections away from work areas and sensitive components, shielding sensitive components where required, and providing drains and bleed fittings so lines can be drained, or depressurized, before they are disconnected. Cutoff valves should be provided at appropriate locations in the system to permit isolation or drainage of the system for maintenance or emergency purposes.

5.9.13.7.2 Mounting and installation. Lines should be mounted and installed so that rigid lines with fittings do not have to be backed-off before they can be disconnected. Flexible tubing, rather than rigid lines, should be used where feasible because it allows easier handling, can be backed-off easily, and is easier to thread through equipment when it must be replaced. Flexible hose, rather than pipes or tubing, should be used 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. Fuel lines should not be routed above electrical cables or above hot pipes or areas.

5.9.13.7.3 Prevention of mismating. To avoid the possibility of mismating connectors during service or maintenance, standardize fittings so lines which differ in content cannot be interchanged. Lines should be coded by arrangement, size, shape, and color as necessary, and colored bands should be used to identify all lines that carry fluids.

5.9.13.7.4 Fluid and gas connectors. Connectors for pipes, tubing, hoses, and similar connectors should be located and installed so that it is unnecessary to jack the equipment up to drain it, fill it, or perform other maintenance involving the connectors, and so that the technician can perform leakage tests easily and without danger. Tests should be planned so the technician's head is not in areas of extreme noise, vibration, or other danger while the equipment is running.

5.9.13.7.5 Gaskets and seals. Gaskets and seals should be selected and installed so that they can be replaced easily without removing other connector parts or disassembling other equipment. Part of a gasket or seal should be visible after it is installed as a check on failure to replace seals after disassembly. There should be job instructions giving the expected life of seals and gaskets and recommending when they should be changed.

5.9.13.7.6 Drainage problems. Prevent drainage problems by:

a. designing lines so they can be emptied completely when necessary,

b. making bends horizontal, rather than vertical, to avoid fluid traps,

c. avoiding low points or dips in lines that make them difficult to drain,

d. providing special drains at low points where necessary, and

e. providing cutoff valves at appropriate points in the system to permit isolation or drainage of particular lines for maintenance or emergency purposes.

5.9.13.7.7 Supports. 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 the rigors of handling and repeated connection and disconnection as well.

5.9.13.8 Wiring and cables.

5.9.13.8.1 General. Standardized connectors should be provided. Bonding points should be accessible and their securing screws should have vibration-proof washers.

5.9.13.8.2 Safety precautions. The following general safety precautions should be adhered to during selection, routing, and maintenance of wires and cables.

a. Test points should be provided for checking components when their terminals are not accessible.

b. Electrical shielding should be easy to remove.

c. All ground return connections should be brought to a common, grounded, bus bar.

d. All wiring should be positioned away from sharp corners.

e. Wiring passing through unprotected holes in metal parts should be protected by grommets.

f. All electrical cables should be oil-proof, unless their location provides adequate protection against contact with oil.

g. Exposed cables should be protected from mechanical damage. (Consider the use of armored cables in such installations.)

h. Long unsupported lengths of cable or wire should be avoided.

i. Cables may be run inside frame members, providing they are accessible and not exposed to heat or oil.

j. Electrical cables should be color-coded or tagged for ease of identification.

k. Electrical cables should be of the quick-disconnect type wherever possible (see Figure 59).

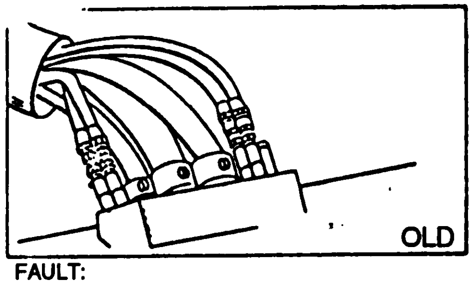
l. Wires and coverings should remain flexible at the low temperatures encountered in cold regions.

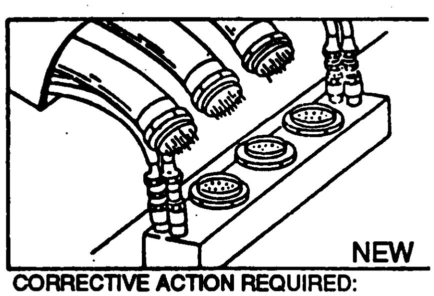
5.9.14 Connectors.

5.9.14.1 General.

5.9.14.1.1 Compatibility. Connectors should be compatible with lines and cables, fasteners, mounting, environmental extremes and maintenance routines to which they will be subjected.

5.9.14.1.2 Selection and design. Connectors should be selected, designed, and mounted for fast, easy maintenance operations, and easy removal and replacement of components and units. Connector design should also allow the most rapid set-up test and service of equipment and minimize danger to personnel and equipment contents, from pressures, contents, voltages, or lines during the release of connectors. Use of tools to perform connect or disconnect operations is not desirable from a human factors viewpoint; therefore, connectors should be easily connected and disconnected by hand where possible.





Time required for removal of cables was approximately 2 hours. Removal of 10 or 15 individual bolt-on connections and drawing harnesses out of boxes and through conduit will result in higher mortality rate on wiring and unnecessary downtime.

Recommend that wiring harnesses be equipped with quick-disconnect fittings. Pin and socket type quick-disconnect fittings can be separated in no more than 3 minutes for all three cables.

FIGURE 59. Quick-disconnect cable connections.

5.9.14.1.3 Accessibility. Connectors should be accessible without disassembly or removal of other equipment or items. In proportion to how often they are operated, connectors used during preoperating checks should be the most accessible.

5.9.14.1.4 Location. Connectors should be located so that personnel can see and reach them easily to connect or disconnect them safely. Access to perform the function should be made available. Fluid connector leakage or accidental spillage should be controlled as necessary to prevent damage to equipment.

5.9.14.1.5 Protection from damage. Connectors should be designed and located so they will not be damaged by moving personnel, shifting objects, opening doors, excessive tightening or manhandling during operation, shorts, arcing from foreign objects, erroneous connection, or handling after disconnection. Protect connectors by recessing receptacles; by recessing delicate parts such as pins and keys within the connector so they are not exposed to harmful contact; and by providing protective caps, inserts, covers, cases, and shields as necessary.

5.9.14.1.6 Mismating and cross-connections. Connectors should be selected, designed, and installed so they cannot be mismated or cross-connected. The following means should be considered.

a. Different sizes or types of connectors should be used.

b. Cables should be arranged so their lengths correspond to the distances from the connector to the correct point of attachment.

c. Wires should be arranged or separation blocks or other mounts should be provided, so the sequence of leads is obvious.

d. Connectors should be polarized or different sizes of prongs and prong receptacles should be used so lines with different voltages cannot be mismatched. If different size prongs on prong receptacles are used, the difference should be obvious enough to preclude attempts to mate and potentially damage connectors.

e. Different, mutually incompatible and irreversible arrangement of guide pins, keys, or prongs should be used.

f. Connectors and receptacles should be color-coded or labeled so mismating is unlikely.

5.9.14.2 Classification (in order of preference).

5.9.14.2.1 Plug-in connectors. Plug-in connectors are the fastest and easiest to use, but they have low holding power; therefore plug-in connectors should not be used when accidental pulls on the cable may disconnect them. Plug-in connectors should be used for cables that are connected and disconnected frequently.

5.9.14.2.2 Quick-disconnect devices. Quick-disconnect devices have a variety of forms, including any type of connector that can be released by snap action, twisting up to a full turn, triggering a latch or spring device, or removing an external pin. Use quick-disconnect devices to connect items which must be disconnected or replaced frequently and items which must be replaced within critical readiness times.

5.9.14.2.3 Threaded connectors. Threaded connectors provide very secure connections, particularly when locked into place by set screws, retainers, or safety wires. They usually take longer to operate, depending on the number of turns and the types of tools they require. Threaded connectors should use the fewest turns that will satisfy holding requirements, be operable by hand if used for electrical connections, require only common hand tools, and minimize the danger of accidentally loosening other connectors while working on one.

5.9.14.3 Identification. Connectors and associated parts and wiring should be coded and identified to key them to references in the job instructions and identify replaceable items and parts for reordering. Coding will expedite and facilitate maintenance and troubleshooting procedures, indicate the sequence routine or test procedures, and provide adequate warnings or cautions about using connectors.

5.9.14.3.1 Labeling. Label or code connectors and receptacles to ensure that:

a. each plug is clearly identified with its receptacle,

b. each wire is clearly identified with its terminal post or pin,

c. test points are clearly identified by a unique mark or symbol,

d. non-interchangeable connectors are clearly distinguishable, and

e. the manner of connection or disconnection is obvious.

Plugs and receptacles should have painted strips, arrows, or other indications to show how connector interfaces should be aligned for proper connection. Terminal strips and circuit boards should be permanently marked to identify individual terminals and facilitate their replacement, and power receptacles for primary, secondary, or utility systems should be clearly labeled to prevent personnel injury or equipment damage.

5.9.14.3.2 Location. Labels or codes on connectors and associated items should be located so that they are optimally visible during maintenance and are visible whether the connector is connected or disconnected. It should be possible to identify connectors without disconnecting them, and their positions should be consistent in relation to associated pins, terminals, and receptacles.

5.9.14.3.3 Order of preference. The location of labels or codes is, in order of preference, first, directly on the connector and receptacle; second, on plates permanently attached to the connector and receptacle; and third, on tabs or tapes attached to the connector. On receptacles, labels and codes should be placed on the surface or panel immediately adjacent to the receptacle and on recessed receptacles, on or near the access opening.

5.9.14.4 Aligning pins and keyways. Alignment keys or pins should be designed and located within the plug so that they extend beyond electrical pins to protect the pins from damage if the connector is misaligned and should be arranged asymmetrically to prevent incorrect plug insertions. All alignment pins for a given plug or series of plugs should be oriented in the same direction. If this conflicts with precautions against mismating, pin orientations should differ consistently and systematically for the technician's convenience.

5.9.14.5 Coding. Coding connector receptacles and plugs is an important aid that helps operators associate input and output lines connecting different items of equipment. Some coding should be provided to associate each connector with its mate.

5.9.14.5.1 Color coding.

5.9.14.5.1.1 General.

a. All colors used for coding should be readily discriminable from each other under operational lighting.

b. Colored areas should be protected, in so far as possible, to keep the color from wearing off, fading, or disappearing.

c. Permanently applied colors are preferable to adhesive tapes or bent-on tapes.

d. If many connectors must be coded and there are not enough easily discriminable colors, matching patterns of colors and/or stripes should be used.

e. Colors used to code connectors should be consistent and have the same meaning throughout the system.

5.9.14.5.1.2 Two color-coding methods. Either of two color-coding methods may be used for electrical connectors. Apply the same coding color to the face of the receptacle and the base of the plug or apply the same coding color to an area around the receptacle, and a band around the plug.

5.9.14.5.2 Shape codes. Connectors may be coded by using various shapes of matching plugs and receptacles (see Figure 60). Different shapes of alignment pins also may be used to differentiate connectors and to prevent mismating.

5.9.14.5.3 Pin configurations. Still another coding method is using connectors with different numbers and configurations of pins (see Figure 61) or unique keyway slots so that it is physically impossible to mismate connectors without breaking them. However, to prevent such damage, designers should select and code connectors so it is obvious which pairs do, or do not, match. Users should not be tempted nor encouraged to make mistakes. When a plug and a receptacle look generally similar but do not mate, use additional coding to differentiate them.

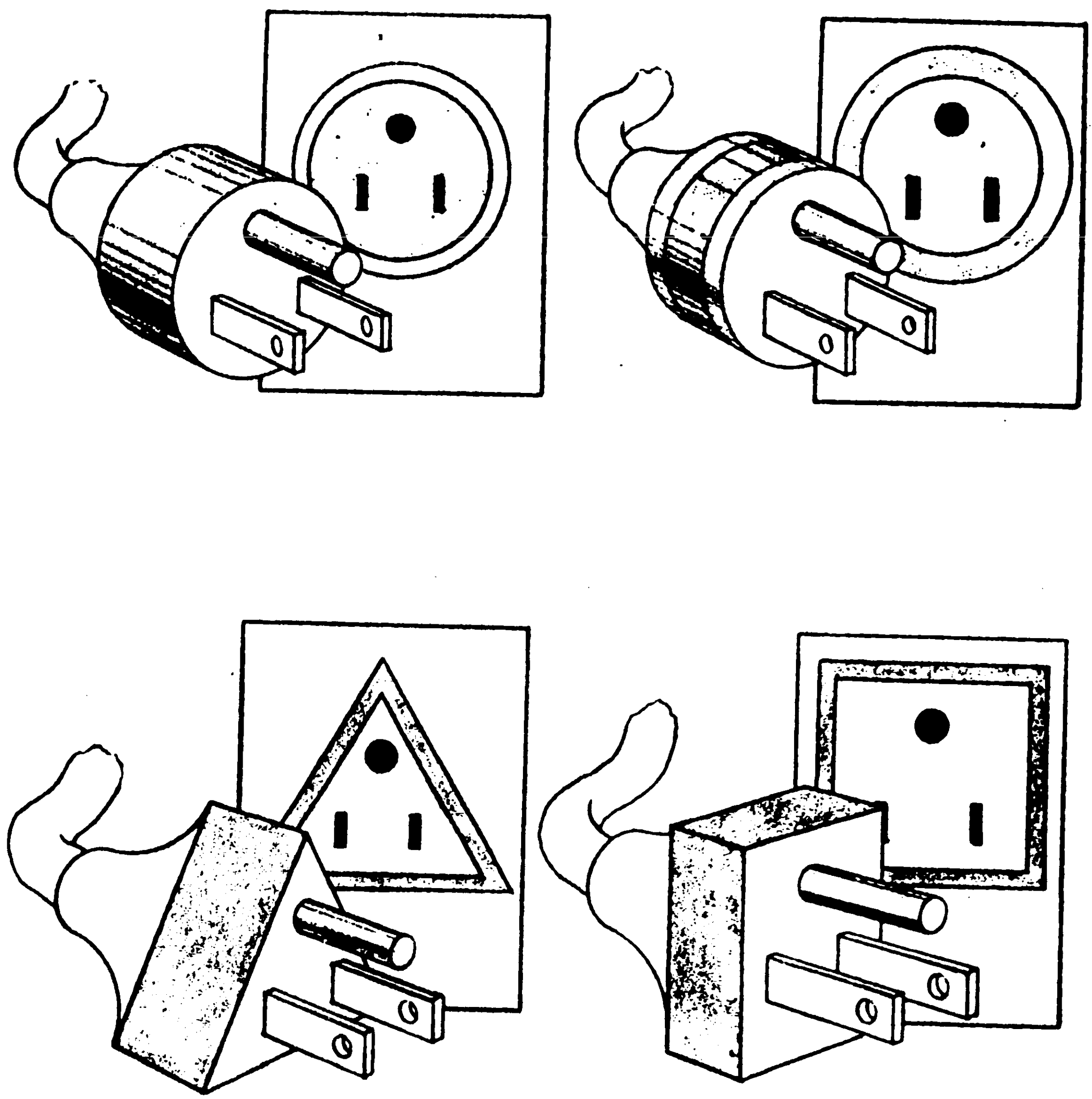


FIGURE 60. Coding of connectors.

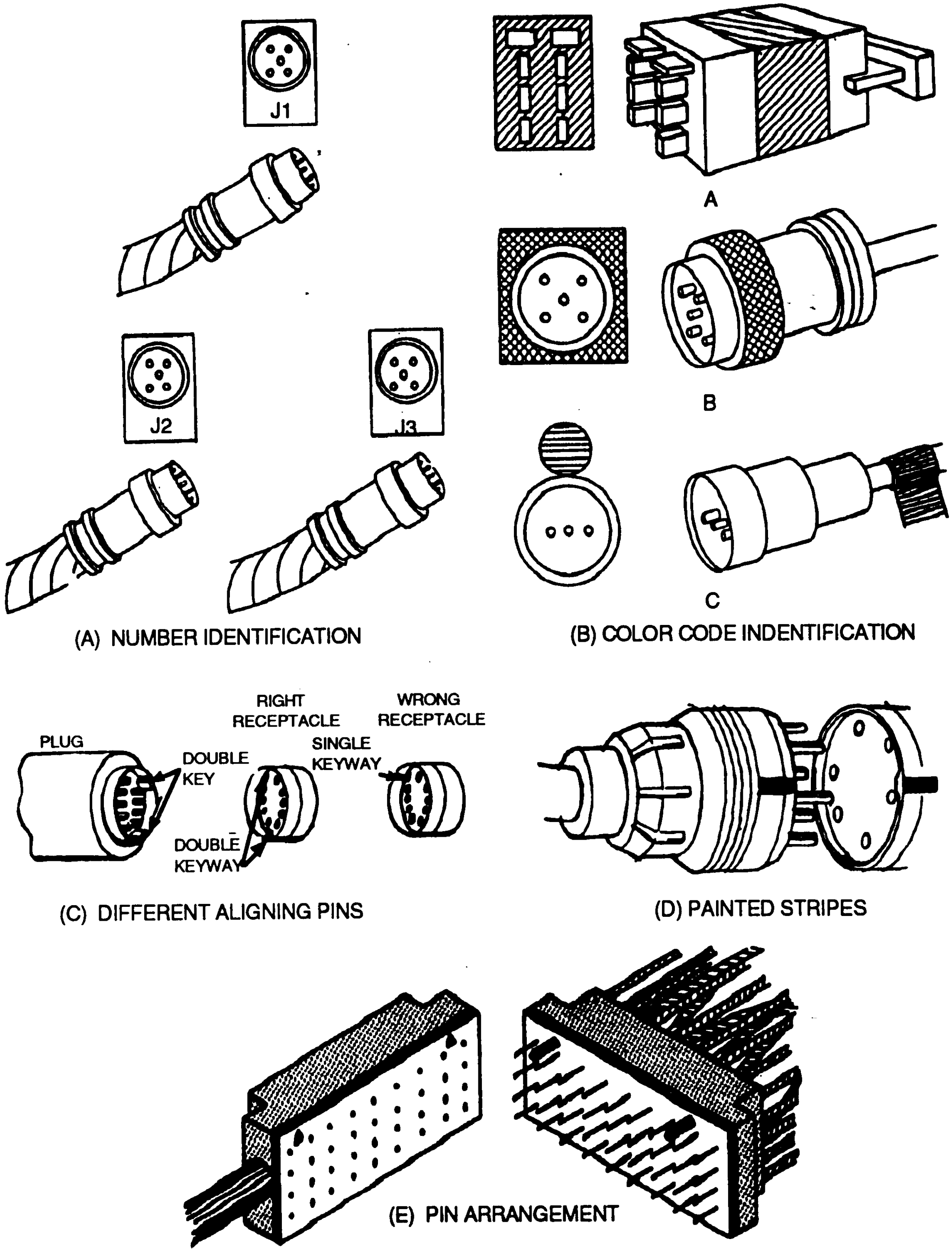


FIGURE 61. Identifying plugs and receptacles to prevent mismatching.

5.9.14.6 Electrical connectors. Electrical plugs should be designed, installed, and mounted so that it is impossible to insert a plug into a wrong receptacle or into the correct receptacle the wrong way. Wherever possible, plugs should have multiple contacts to reduce the number of plugs and, consequently, the number of maintenance operations. Connectors should "plug-in" or secure with no more than one complete turn, especially with auxiliary or test equipment. Wiring should be routed through the plugs and receptacles so disconnection does not expose "hot" leads. Examples of "hot" contacts are socket contacts and female connectors. Receptacles should be "hot" and plugs should be "cold" when disconnected. Plugs should be self-locking or use safety catches rather than requiring safety wiring; plugs should have low insertion forces to minimize the possibility of damaging contact surfaces.

5.9.14.7 Electronic modules.

5.9.14.7.1 General. There are two primary reasons for designing electronic equipment with relatively small, removable or replaceable units. Constructing electronic equipment with easily removable assemblies, subassemblies, and components permits the division of maintenance responsibility. This design permits rapid corrective maintenance at the user level. When equipment is built with removable units, it is easier to work on malfunctioning parts.

5.9.14.7.2 Design recommendations.

a. Replaceable components should be designed so they cannot be installed in the wrong way. Also, if two parts are physically interchangeable, they should be functionally interchangeable. Designs, mockups, and manufacturing processes should be continually reviewed to identify and correct, or compensate for, all potential sources of such errors.

b. Tapered alignment pins, quick-disconnect fasteners, and other similar devices should be able to facilitate removal and replacement of components.

c. Mounting brackets and surfaces should be designed so that mounting bolts and fasteners can be placed on a surface adjacent to the technician's workspace. Guides and guide pins should be provided for alignment of units on mountings (see Figure 62).

d. Where possible, units should be designed so they are removable along a straight, or slightly curved line, rather than through an angle (see Figure 63).

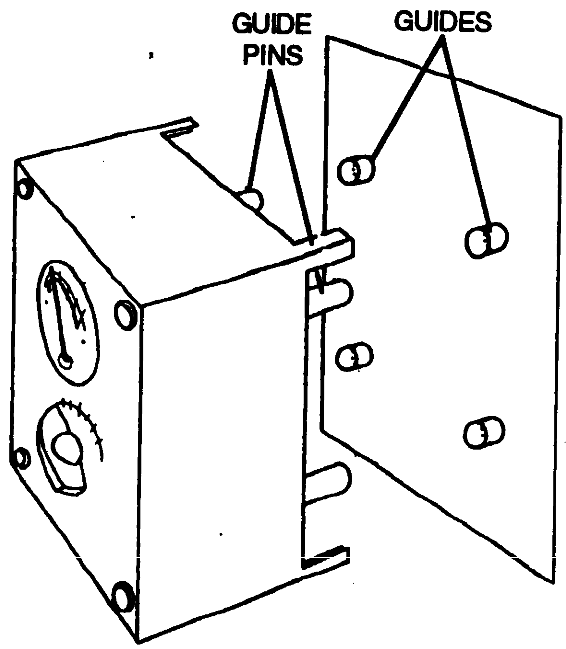


FIGURE 62. Alignment guides and guide pins.

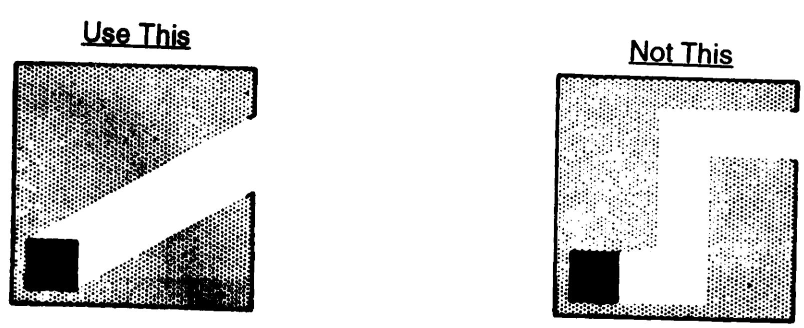


FIGURE 63. Equipment removal.

e. Mounting brackets should be designed so that the component can be installed only in the correct position. Where space permits, side-alignment brackets which permit installation in only one position should be provided (see Figure 64).

FIGURE 64. Use of side-alignment brackets.

f. Bottom-mounted aligning pins should be used for components which are light enough to be lifted easily. Such aligning pins are not desirable for heavy components because they require a lifting process for aligning the component. Side-aligning devices, similar to the one shown in Figure 64, are more desirable for heavy components because the component can be slid into place.

g. Symmetrical components should be coded, labeled, or keyed to indicate the proper orientation for mounting or installation.

h. Opening more than one access panel to remove any single unit should not be required.

i. Components should be positioned so that the technician does not have to reach too far for heavy units.

j. For components that are heavy or relatively inaccessible, slide-out racks should be provided. When using roll-out mounting racks, limit stops should be provided to prevent dropping the components.

k. Units should be designed for easy connection to each other and to the housing in which they are installed.

l. Electronic and electrical units should be designed with plug-in rather than solder connections.

m. When using AN connectors, the quick-disconnect type (see Figure 65) should be specified.

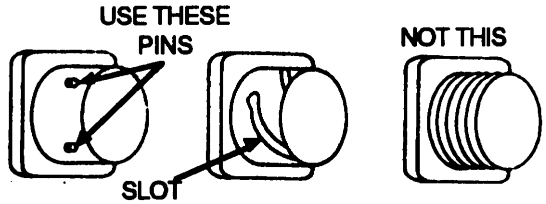


FIGURE 65. Types of AN connectors.

n. Incorrect assembly should be made difficult by using different sizes, or completely different types of connectors. Where incorrect assembly is possible, use coding techniques such as different color, size, and shape.

o. Connectors requiring no tools (or only common hand tools) and with only a fraction of a turn or quick-snap action should be used.

p. Mounting bolts, screws, and fasteners that can be easily removed and replaced with minimum chance for error should be provided. Use captive bolts and nuts to prevent dropping small items into the equipment.

q. Small removable parts such as pins, caps, and covers should be attached to the main body of the equipment by small chains or other suitable means to prevent their loss. Because some retainers tend to break apart, especially when kinked, care should be exercised in the selection of suitable retainers to ensure that they meet performance requirements.

r. Lock washers or other restraining measures should be used to prevent bolts and nuts from vibrating loose. Safety wire is not generally recommended, but if it must be used, a simple means of attaching it should be provided.

s. The weight of components should be kept under 13.6 kg where possible.

t. Adequate handles on all units weighing more than 4.5 kg should be provided. Handles should be provided for units weighing less than 4.5 kg if they might otherwise be difficult to grasp, remove, or hold.

5.9.14.8 Cabling and connectors checklist. Checklists summarizing the important maintainability design features relating to cables (Table 29) and connectors (Table 30) are presented below. These checklists contain items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is NO, the design should be restudied to ascertain the need for correction.

TABLE 29. Cable checklist.

1. Are cables long enough that each functioning unit can be checked in a convenient place?

2. Can units which are difficult to connect when installed, be moved to convenient positions for connecting and disconnecting?

3. Are cable harnesses designed for fabrication in a shop as a unit?

4. Are all cables color coded and are both ends tagged? Can the selected colors be distinguished?

5. Are cables and lines directly accessible to the technician wherever possible (not under floorboards or behind panels which are difficult to remove)?

6. Are cables routed so they need not be bent or unbent sharply when being connected or disconnected?

7. Are cables routed so they cannot be pinched by closing doors or lids or so they will not be stepped on or used as handholds by maintenance personnel?

8. Are cables or lines attached to units which can be partially removed (chassis on slide racks) and attached so units can be replaced conveniently without damaging the cable or interfering with securing the unit?

9. Is a 75 mm minimum clearance provided wherever possible between control cables and wiring? Has the designer anticipated potential chafing hazards and provided physical means to prevent chafing?

10. Is electrical wiring routed away from all lines that carry flammable fluids or oxygen?

11. Is care taken in design of cable conduits to prevent collection of water or debris which could interfere with operation of a control system (freezing or short circuiting)?

12. Is the necessity for removing connectors or splicing lines avoided?

13. Is direct routing through congested areas avoided wherever possible?

14. Are cable entrances on the fronts of cabinets avoided where it is apparent they could be "bumped" by passing equipment or personnel?

15. Are cables flexible in severe cold temperatures?

TABLE 30. Connector checklist.

1. Are adjacent solder connections far enough apart so work on one connection does not compromise the integrity of adjacent connections?

2. Are connector plugs designed so that pins cannot be damaged (aligning pins extended beyond electrical pins)?

3. Are self-locking safety catches rather than safety wire provided on connector plugs?

4. Are connectors designed so that it is physically impossible to reverse connections or terminals in the same or adjacent circuits?

5. Is the use of special adapters avoided since these are often lost?

6. Are electrical connectors protected from possible shorting through contact with external objects? Are adequate covers provided on electrical connectors to prevent foreign matter from shorting out the connector or causing damage to the connector threads and pins? Are provisions made to secure the cover to the connector to avoid misplacement during periods of non-use?

7. Are separate ground connections provided for each voltage regulator so that a single grounding failure does not cause failure of several other systems?

8. Are quick-disconnect devices used wherever possible to save time and minimize human error (fractional-turn, quick-snap action, and press fit)?

9. Are unkeyed symmetrical arrangements of aligning pins on connectors avoided?

10. Are electrical terminals plainly marked +(plus) or -(minus), since the marked caps may be lost?

11. Do markings on plugs, connectors, and receptacles show proper position of keys for aligning pins for proper insertion position?

12. Is the use of identical fittings avoided by staggering location, varying lengths, size or shape, or by shape, symbol, or color coding?

13. On cable-connected removable units, will plug and receptacle disconnect before cable breaks?

14. Are connectors located for easy accessibility for replacement or repair?

15. Are U-lugs (spade) used in lieu of O-lugs (ring) where frequent removals are anticipated?

16. Are auxiliary-equipment connectors used that do not require tools for their operation?

TABLE 30. Connector checklist - continued.

17. If tools must be used to operate connectors, are only standard tools required?
18. Do connectors used to connect test equipment to a test point require not more than one full turn?
19. Can wires be unsoldered and removed without damaging plugs?

5.9.15 Test points.

5.9.15.1 General. In order to make testing and servicing as simple as possible, the recommendations of this section should be considered by the designer.

5.9.15.1.1 Arrangement of test points. Test points should be arranged on a panel or other surfaces according to the criteria listed, in order of priority.

a. The type of test equipment used at each point.

b. The type of connector used and the clearances 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 will be used.

5.9.15.1.2 Design considerations. In order for the operator to best use the test and service points on equipment, the following criteria are recommended for consideration by the designer. These test and service points should be provided, designed, and located:

a. According to the frequency and time requirements of use.

b. So that there will be a minimum of disassembly or removal of other equipment or items.

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 use 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, and controls for easy grasping and manipulation. Minimum clearances recommended are 19 mm when only finger control is required, and 75 mm 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 equipment, particularly if the equipment must be serviced while operating.

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; such points are 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 overcome accessibility deficiencies resulting from critical lead lengths and similar constraints.

m. With windows to internal items requiring frequent visual inspections, such as gauges and indicators.

n. With tool guides and other design features to facilitate operation of test or service points which require blind operation.

o. Within easy functional reach or seeing distance of related or corresponding controls, displays, fittings, and switches.

p. Away from dangerous electrical, mechanical, or other hazards. A hand's width (115 mm) separation should be provided from the nearest hazard along with guards and shields, as necessary to prevent injury.

q. So they are not concealed or obstructed by the hull, turret, brackets, or other items.

5.9.15.1.3 Other considerations. The following topics represent areas not covered in the above paragraphs but are still important design considerations.

a. Templates or overlays should be provided where they will expedite the use of different test procedures which use the same set of test points.

b. The maximum use of color codes, guidelines, symbols, and labels should be made to facilitate following logical test routines among the test points.

c. Distinctively different connectors or fittings should be provided for each type of test or service equipment, probe, grease, or oil to minimize the likelihood of error or misuse.

d. 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 handled separately.

e. Test points should be combined, where feasible, into clusters for multi-pronged connectors, particularly where similar clusters occur frequently.

f. Lubrication points should be provided to avoid disassembly of equipment; but if such points are not feasible, easy access should be provided for direct lubrication.

5.9.15.2 Adjustment.

5.9.15.2.1 General. Where adjustment controls are associated with test and service points, they should be designed and positioned as listed below.

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. Adjustments are independent of each other whenever possible.

d. Those that require sequential adjustment are located in the proper sequence and marked as necessary to designate the order of adjustment.

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; the latter are generally unsatisfactory from the standpoint of easy manipulation and the requirement for tools.

5.9.15.2.2 Adjustments to avoid. The following types of adjustment are to be avoided, except where their use will considerably simplify the design or use of the equipment.

a. Extremely sensitive adjustments.

b. "System adjustments," such as where components cannot be replaced without recalibrating the whole system.

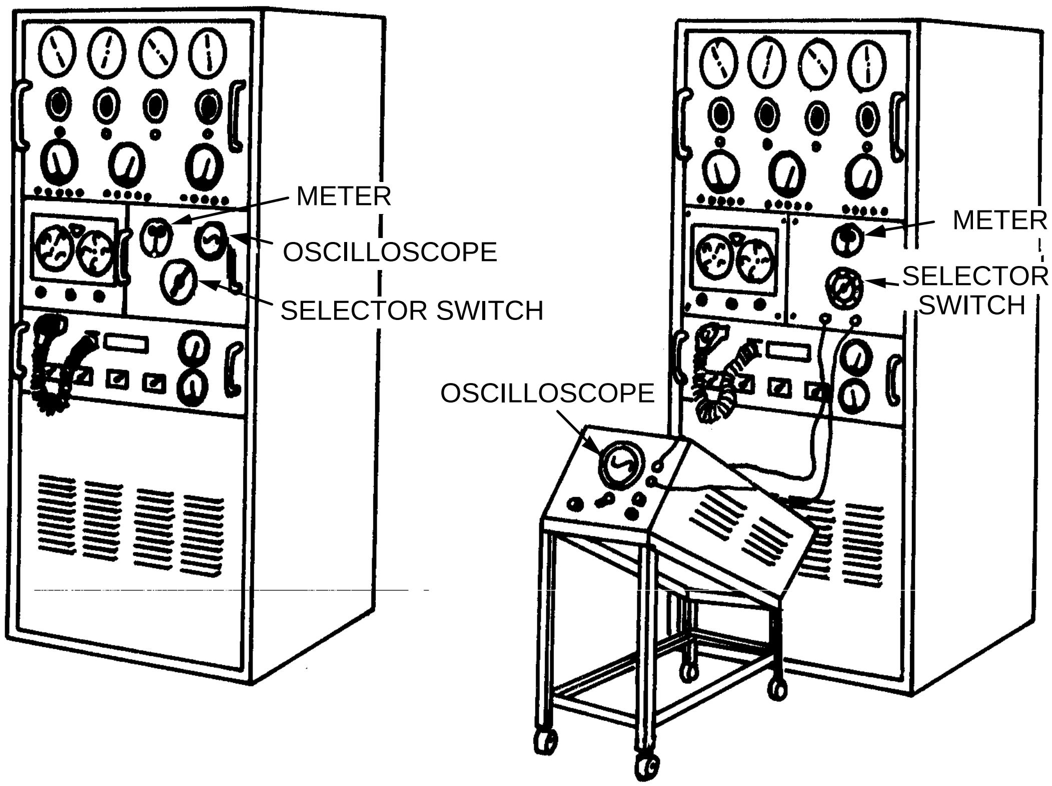
c. Harmonizing or "mop-up" adjustments, such as those that require "A" or "B" to be readjusted after A, B, and C have been adjusted in sequence.

5.9.15.3 Troubleshooting. The following arrangements are intended to help the designer evaluate the adequacy of the test point arrangement.

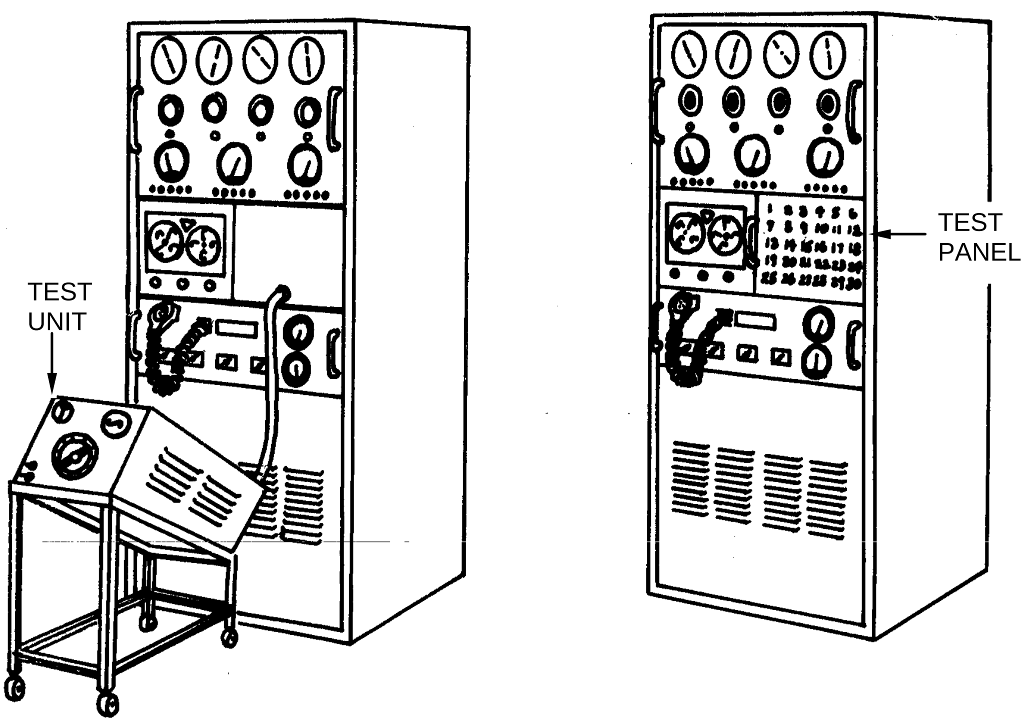
a. A built-in test unit, built in as part of the installation, is most desirable for efficient maintenance and troubleshooting. For example, if voltages and wave shapes must be checked, the test unit might consist of a meter, an oscilloscope, and a rotary switch for selecting circuits, as shown in Figure 66A. The meter and oscilloscope should have fixed, preset circuits so that the meter always reads center scale and the oscilloscope needs no adjustment. Either an in-tolerance meter reading or an in-tolerance waveform on the oscilloscope should be coded for each position of the rotary switch. If more test points are needed than can be handled by a single switch, multiple switches could be used.

b. A partially built-in test unit is sometimes preferred because some oscilloscopes are large, heavy, and expensive. It might not be practical to design a test unit such as that recommended in above for each major component of a system. An acceptable compromise is to mount a center-reading meter on each major component that can be checked by meter and then provide a set of test jacks as an outlet for signals requiring an oscilloscope, as shown in Figure 66B. The selector switch and circuits for this arrangement should be designed as before.

c. A portable test unit may be required if neither of the two previous arrangements is practicable because of space or weight limitations. An integrated portable test unit resembling the built-in unit can be designed, as shown in Figure 66C. A single multi-prong contact, on the end of a cable, can be used to attach the test unit.



A. Built-In Test Unit B. Partially Built-In Test Unit



C. Portable Test Unit D. Built-In Test Panel

FIGURE 66. Alternate methods for grouping test points.

d. If, for some reason, none of the alternatives described above is practicable, a built-in test panel should be provided on the equipment, as shown in Figure 66D. With this arrangement, the outputs of each test point should be designed for checking with standard test equipment, and the points should be planned to provide a miniature block diagram of the system, with each block representing a line replaceable unit. Overlays for the test panel should direct the technician to test points to check and the order in which to check them. In-tolerance signals should be shown on the overlays, and test points should be coded on the panel, with full instructions provided in the maintenance manual, in the event the overlay is lost.

e. Test points for the input and output on each replaceable unit may be provided if none of these arrangements is practicable. If possible, mount components on one side of the board or chassis and wiring on the other side (see Figure 67). Even if the wiring is mounted on the same side as the parts, test leads should be brought through to the back. An advantage in having test points on the back is that full identifying information for each test point can be marked on the back without being obscured by parts.

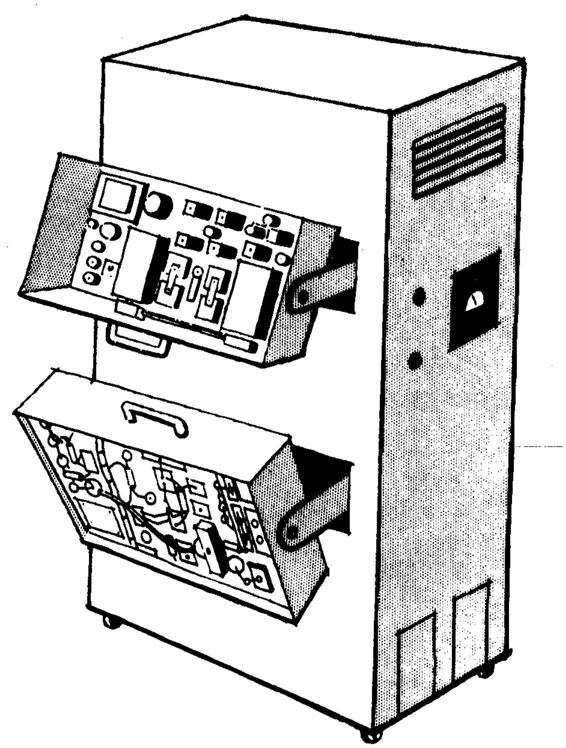


FIGURE 67. Test points on replaceable units.

5.9.15.4 Marking and coloring. Label each test point with a number, letter or other symbol that identifies it in the maintenance instructions. If possible, label each test point with the in-tolerance signal and the tolerance limits of the signal that should be measured. If possible include the name of the unit in the label. Consider color coding test points so they can be located easily. Use phosphorescent or chemoluminescent markings on test points, selector switches and meters that might have to be read in very low ambient illumination.

5.9.15.5 Test points checklist. The following checklist (Table 31) summarizes some of the important features pertaining to the design of test points. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is NO, the design should be restudied to ascertain the need for correction.

TABLE 31. Test points checklist.

1. Are test points located on the front panel wherever possible?
2. Is accessibility of external test points assured under conditions of use?
3. Are test points grouped for accessibility and convenient sequential arrangement of testing?
4. Is each test point labeled with name or symbol appropriate to that point?
5. Is each test point labeled with the in-tolerance signal or limits which should be measured?
6. Are test points labeled with the designation of what output is available?
7. Are all test points color coded with distinctive colors?
8. Are test points provided in accordance with the system test plan?
9. Do test-lead connectors require no more than a fraction of a turn to connect?
10. Are test points located close to controls and displays with which they are associated?
11. Is the test point used in an adjustment procedure associated with only one adjustment control?
12. Are means provided for an unambiguous signal indication at a test point when the associated control has been moved?

TABLE 31. Test points checklist - continued.

13. Are test points located so the technician operating the associated controls can read the signals on the display?
14. Are test points provided for a direct check of all replaceable parts?
15. Are fan-out cables in junction boxes used for checking if standard test points are not provided?
16. Are test points planned for compatibility with the maintenance skill levels and not randomly located?
17. Are test points coded or cross-referenced with the associated units to indicate the location of faulty circuits?
18. Are test points provided to reduce the number of steps required (split-half isolation of trouble, automatic self-check sequencing, minimizing of step retracing or multiple concurrent tests)?
19. Are test points located so as to reduce hunting time (near main access openings, in groups, properly labeled, near primary surface to be observed from working position)?
20. Are test points which requiring test-probe retention designed so that the technician will not have to hold the probe?
21. Are built-in test features provided wherever standard portable test equipment cannot be used?
22. Can the technician gain access to routine check points without removing the unit or module or removing a cover from the cabinet?
23. Are test points adequately protected, illuminated, and accessible?
24. Are routine test points available to the technician without removing the chassis from the cabinet?

5.9.16 Test equipment.

5.9.16.1 General. Regardless of the engineering sophistication of the testing device, unless the technician recognizes it as being useful, reliable, and operable, the technician will avoid using it, and the design will be, for all practicable purposes, wasted. To design for usability, the designer should consider the statements listed below.

a. Technicians are trained to use complex devices, but they occasionally forget what they learn.

b. Technicians avoid using devices they do not understand or find difficult to operate.

c. Supervisors hesitate to let technicians use expensive, complex equipment when the operation of the equipment is not simple or self-evident.

d. When test equipment is overly complex and difficult to operate, the technician:

   (1) must spend considerable time and effort learning to operate it,

   (2) tends to make errors in usage,

   (3) can learn to operate only a small number of devices well, and

   (4) finds that habits developed with one device interfere with learning to use or operate another device.

e. Military testers, which are drab, unattractive and apparently rugged, actually get rougher treatment than those which look fragile or have eye appeal. Therefore, testers should be designed to look no tougher than they are, and to compensate for the rough treatment they are likely to receive.

5.9.16.1.1 Common complaints about available test devices. The following list provides common complaints about available test devices or reasons for not using them. Each of these reasons is a result of inadequate consideration of the user during design and should be avoided in the design of new devices.

a. The device was too clumsy, heavy, or awkward to carry to the job.

b. There were an unnecessarily large number of different test devices.

c. Procedures and displays were inconsistent from device to device.

d. There was confusion as to the accuracy, operation, or purpose of the device.

e. The device was inaccurate, unreliable, or too often out-of-tolerance.

f. Calibration was too difficult and kept the device out of use too often.

g. The device was not compatible with the tested equipment. For example, connectors were too loose or too hard to reach, leads were not long enough, or workspace was too small to use the device.

5.9.16.1.2 Operation and maintenance.

a. Equipment should be made simple to operate and provide self-checking calibration features.

b. Test equipment should be designed for one-person operation.

c. A simple method to calibrate test equipment should be provided. Equipment should be equipped with a go/no-go indicator or simple check to determine whether the tester is malfunctioning or needs calibration.

d. A warm-up indicator should be provided if applicable. Required warm-up time should be indicated clearly near the warm-up switch if no visual signal is provided. Warm-up procedures should be explicit.

e. A simple check should be incorporated into the tester for testing the accuracy of the results.

f. Conversion tables should be provided when needed.

g. Attached instructions that clearly indicate the purpose of the tester and special caution for its use should be provided.

h. Set-up procedures should be provided on an instruction card attached to the equipment.

i. Tests necessitating quantitative readings and adjustments by operating personnel should be avoided. Information should be furnished by qualitative, positive signaling devices, such as color-coded signals and zero-center meters, or similar means of indication.

j. Equipment should be designed either to prevent the operator from making errors or to warn the operator of errors.

k. Components or equipment should be clearly labeled as to whether it is to be used with alternating or direct current.

l. Circuit breakers should be provided on all testers to safeguard against damage if the wrong switch or jack position is used.

m. Fail-safe features should be incorporated into the equipment to minimize the danger to operator and/or equipment should failure occur.

n. Regularly stocked standard components and units should be specified.

o. If components are physically interchangeable, they also should be functionally interchangeable.

p. Test equipment should be designed to be as rugged as the conditions of its use; that is, equipment to be used in the field should be more rugged than that built for laboratory use.

q. Controls, dials, and adjustments should be designed to prevent misalignment caused by vibration, service use, or accidental contact.

r. Safeguards against equipment damage from inadvertent human error should be provided.

s. Equipment should be provided with devices to ensure that it is turned off when testing is completed.

t. Power switches should be provided to shut off automatically when the tester lid is closed.

u. A device to indicate that power is on should be included on the tester panel.

v. Controls should be designed to prevent equipment damage if it is operated at the wrong time or in the wrong manner.

w. Delicate components should be located where they will not be damaged while the unit is being operated.

5.9.16.1.3 Maintenance environment. To best utilize an individual with respect to test equipment, the maintenance environment in which testing is to be done should be considered, particularly with regard to:

a. the environmental extremes to be withstood by the human operating the device,

b. maintenance procedures and policies the users will have to follow,

c. symbols and codes commonly employed by, or familiar to, the user,

d. methods of information presentation, data collection, or maintenance feedback by, or familiar to, the user,

e. purposes for which the tester will be employed, in terms of what the technician should do with the information obtained from the tester,

f. tasks involved in using the tester, from maintenance task assignment to return of the tester to storage, and

g. the manner of transporting the tester from storage to place of application, including how far it must be transported, and by what means as well as the clothing or other encumbrances the technician will be wearing.

5.9.16.2 Instructions. To facilitate understanding and increase operator efficiency, instructions should be provided in the manner described below.

a. On the face of the tester, in the lid, or in a special compartment.

b. In a step-by-step fashion, numbered, or lettered in serial order.

c. In easy view while the device is being operated.

d. As complete and detailed as required, but strictly job oriented.

e. In simple language, avoiding uncommon terms or symbols.

f. Large enough to be clearly and easily read in poor light.

g. Emphasize critical material by larger type or color coding.

h. Have a distinguishable title where more than one instruction list is required (color coding should be considered also).

i. As a reminder that the device must be calibrated, especially if calibration is required before each use or change in use.

j. As a reminder to ensure that the test equipment will be turned off when testing is completed.

5.9.16.3 Displays. Whenever more than one scale must be in the technician's view, each should be clearly differentiated from the other by labeling and color coding to their respective control positions. Exact values should be presented on test equipment displays rather than indications which require multiplication or other transformation of display values.

5.9.16.4 Switches. Selector switches should be used on test equipment instead of a number of plug-in connections. Devices, such as circuit breakers and fuses, should be employed to safeguard against damage if the wrong switch or jack position is used.

5.9.16.5 Portable test equipment.

a. Portable test equipment may be necessary when the number, or complexity, of functions to be tested would make hand-held testers too heavy or bulky.

b. Portable test equipment may be necessary when a number of pieces of equipment must be tested and are physically separated.

c. Portable test equipment may be necessary when the equipment to be tested will not be located at a permanent testing installation.

d. Portable test equipment should be of medium size and weight and be approximately cubic in shape.

e. Rectangular or square shapes are recommended for easy storage. If possible, their dimensions should fit relay racks for transportation in shop vans in the field.

f. Storage space for test equipment instructions should be provided on, or within, the test equipment.

g. Stands or casters should be provided for devices weighing more than 13.6 kg.

h. Wheels, casters, or hoist-lifting should be provided for devices weighing more than 40.8 kg.

i. Hooks or other devices should be provided on the tester, or on the prime equipment, to attach the tester to the equipment during the test.

j. An adjustable harness or sling should be provided to facilitate carrying test equipment.

k. If the test equipment has a removable cover, handles or grips should be provided on the sides of the test equipment for carrying it when the cover is not attached.

l. Portable test equipment should have rounded corners and edges for safety.

m. Hinged, permanently attached covers are recommended. If the test equipment must have a removable cover, it should be labeled with the same identification as the test equipment.

n. Tester connectors should be clearly labeled with the type of electrical source that should be used.

o. Panel lighting should be provided so the tester can be used under conditions of low or high illumination.

p. Stands should be provided, on which the test equipment can be placed, while being used.

q. The weight and dimensions of portable test equipment should not exceed those listed in Table 32.

TABLE 32. Weight and dimension limits of portable test equipment.

	Operability Hand-Held		Portability One Person	Portability Two Persons
Dimensions	Optimum	Maximum	Maximum	Maximum
Weight (kg)	1.4	2.3	11.3	40.8
Height (mm)	50	100	460	485
Length (mm)	200	255	460	
Width (mm)	100	125	255	

5.9.16.6 Hand-held testers.

a. Hand-held testers should be used for making measurements at fairly inaccessible locations.

b. Hand-held testers should be small, lightweight, and conveniently shaped.

c. Hand-held testers should not weigh more than 2.3 kg and should be capable of being held and operated with the same hand (Figure 68).

d. The hand-held tester should have a grip on the underside through which the hand can be inserted (see Figure 68). This grip will reduce the probability of dropping the tester and will eliminate the necessity of holding the tester with both hands.

e. The underside of the tester should be serrated or ridged to prevent it from slipping out of the operator's hand.

f. The tester should be equipped with a string or strap so the operator can place it around his neck when it is not in use; the tester can then stand free and leave both hands free for other tasks. A means should also be provided to clip or attach the tester to the operator's body or clothing to prevent the tester from swinging into other equipment or interfering with accomplishment of other tasks when not in use.

g. Hand-held testers should be as functionally simple as possible.

h. The tester should be self-powered and not require attachment to an electrical outlet.

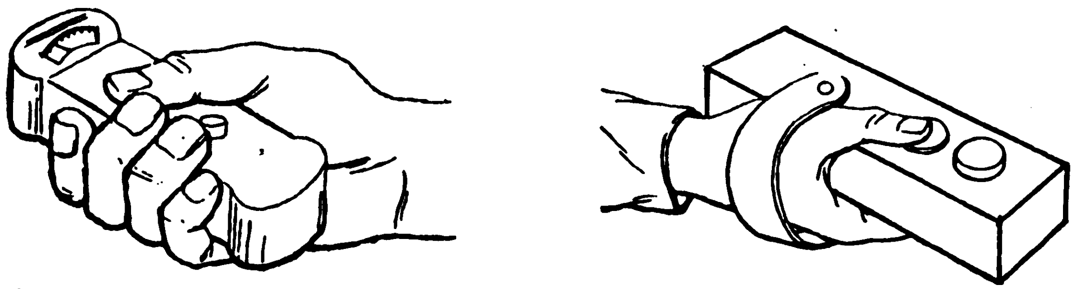


FIGURE 68. Hand-held testers.

i. The indicator on the tester should be of the simple go/no-go type with a light to indicate out-of-tolerance conditions. If a meter is necessary, tolerance zones should be color coded.

5.9.16.7 Console-type testers.

a. Modular design should be used to the greatest extent possible; and off-the-shelf units should be specified whenever they are available.

b. Equipment should be designed so that consoles can be converted from one function to another by replacing modules.

5.9.16.8 Test equipment checklist. A summary of some of the important test equipment design recommendations is presented below (Table 33). The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is NO, the design should be restudied to ascertain the need for correction.

TABLE 33. Test equipment checklist.

1. Are the instructions for using the test equipment in a step-by-step format?

2. Is there a signal which shows when the test equipment is warmed up?

3. If it is not feasible to present such a signal, is the warm-up time required clearly indicated near the power switch?

4. Is a simple check provided to indicate when the test equipment is out of calibration or is otherwise not functioning?

5. Is an appropriate indication of test equipment performance provided so the technician does not attempt to measure with a faulty standard or instrument out of calibration?

6. Do test equipment displays, which require transformation of values, have conversion tables attached to the equipment with the transform factor by each individual switch position or display scale?

7. Is adequate support provided for test equipment which must be taken into the work area?

8. Are built-in test features provided wherever standard portable test equipment cannot be used?

9. Does portable test equipment weigh under 11.3 kg if it is to be carried by one person?

10. Do plugs, jacks, and binding posts used for testing test equipment appear on the outer casing of equipment, so it is unnecessary to remove the case? If internal repair requires removal of the case, are duplicate jacks and plugs provided on the chassis so "jury-rig" connections to the case are unnecessary?

11. Are a display light, automatic power switches, or printed warnings provided to ensure that test equipment is turned off when testing is completed?

12. Is storage for cables and test leads (within test instrument case lid) designed so the loose cables cannot interfere with closure of the case?

13. Are the purposes of the test equipment and special cautions displayed in a conspicuous place on the outer surface of the test equipment?

14. Are units which are not self-checking designed to be checked in the operating condition, without the aid of special rigs and harnesses, wherever possible?

15. Are selector switches provided in lieu of a number of plug-in connectors?

5.9.17 Failure indications and fuse requirements.

5.9.17.1 Fuses and circuit breakers.

a. Fuses or circuit breakers should be provided so that each unit of a system is separately fused and adequately protected from harmful variations or transient voltages.

b. When fuses are used, they should conform to MIL-F-15160.

c. Fuses should be located on the front panel of the unit where they can be seen and replaced without removing other parts. Fuses should not be located inside the equipment.

d. Fuses should be grouped in a minimum number of central, readily accessible locations, and should be replaceable by the equipment operator whenever possible, without the use of tools.

e. Fuses should be provided which safeguard the circuit if the wrong switch or jack position is used and overload indicators should be provided on each major component.

f. Spare fuses should be provided and located near the fuse holder, and labels adjacent to the fuse holder should provide both fuse value and function. (If space is limited, provide fuse value rather than fuse function.)

g. Fuse holder cups or caps should be the quick-disconnect rather than the screw-in type; they should be knurled and large enough to be removed easily by hand.

h. To protect the fuse and fuse holder against corrosion, whenever practicable, the fuse (including the contact surfaces) and the interior of the fuse holder should be coated with a silicone electrical lubricating compound. The exterior of the fuse holder, except contact surfaces, should be coated with fungicidal varnish. If possible, sealed fuses should be used.

i. Fuse installations should be designed so that only the "cold" terminal of the fuse can be touched by personnel.

j. When selecting fuses or circuit breakers, consider the suitability of each to perform a particular function (see Table 34). There are two types of circuit breakers, thermal air and magnetic air. Thermal-air circuit breakers are used primarily for overcurrent circuit protection. They are best adapted to DC circuits up to 250 volts, and to AC circuits up to 600 volts in capacities up to 600 amperes. Magnetic-air circuit breakers may be used to provide protection in event of overcurrent, undercurrent, reverse current, low voltage, and reverse phase.

k. Fuse ratings should be indicated adjacent to the fuse in whole numbers, common fractions such as 1/2, or whole numbers and common fractions such as 2 1/2.

TABLE 34. General comparison of fuses and circuit breakers.

Function	Fuse	Circuit Breaker Thermal Air	Magnetic Air
Instantaneous action	X		X
Time delay features	X	X	X
Resetting		X	X
Adjustable tripping range for other than maximum setting			X
Automatic resetting			X
Remote control resetting and tripping			X
Overcurrent protection	X	X	X
Low current, reverse current, reverse phase, and low voltage protection			X

5.9.17.2 Relays.

5.9.17.2.1 General. If possible, circuits should be designed to avoid the use of relays. When relays are required, they should be the largest size practical and be made of the highest grade of arc-resistant material. The circuits should include a positive feedback loop through a set of relay contacts to ensure proper operation of the relay. The feedback loop may be part of the circuit function or a separate circuit used for troubleshooting.

5.9.17.2.2 Mercury-type. Mercury-type relays should be used whenever possible, but the angle of tilt should be kept in mind. Since liquid automatically seeks the lowest level, contact will be broken should the relay tilt more than 30° from the vertical. This limitation rules out many airborne applications.

5.9.17.2.3 Vacuum- and gas-filled. To avoid oxidation of relay contacts, glass enclosed vacuum- or gas-filled relays should be used. If the circuit is extremely critical, consider "out-gassing" of materials after periods of storage even though a vacuum initially prevailed.

5.9.17.3 Moist environments. Hermetically-sealed relays should be used for applications in moist or salty environments because natural organic insulators, such as paper or cotton, can contribute to the corrosion of windings in the presence of moisture or high direct current potentials. Synthetic insulating materials should be used to reduce these effects.

5.9.17.4 Power transients. Relay operation can cause transients in the power supply if large currents are applied, or interrupted by the relay. If operation at minimum current is not possible, decoupling networks and filters may be necessary.

5.9.17.5 Time delays increase relay lifespan. The time delay between the application of coil current and the closing of contacts will increase with the life of the relay as spring members fatigue. If close timing is important, external circuits, copper slugs in the relay core, or air dashpots should be used to control the delay.

5.9.17.6 Shock and vibration. The effects of shock and vibration can be decreased by using relays with contacts that are mounted on short, thick supports. Wiping, or follow-through contacts, such as those used in a stepping relay, should be used when the relay will be subjected to shock and vibration. Relays should be used in the energized position, if possible, as the holding force is greater, and there is less danger of inadvertent opening. Adequate current should be supplied to the coil to obtain the strongest armature attraction.

5.9.18 Printed circuit boards. Reserved.

5.9.19 Ignition equipment. Ignition equipment for internal combustion engines should be designed to have the following maintainability characteristics:

a. Spark plugs should be of the highest quality and reflect the most advanced technology in the state-of-the-art. Materials selected should provide maximum life, ease of adjustment, and maintenance. Self-cleaning types should be used wherever possible.

b. Distributors should be located to permit rapid and easy access to all maintenance points, close line of sight inspection, and rapid total removal and assembly. Flywheels used for timing should be clearly and adequately marked by engraving or deep stamping, and be provided with an accurate rigid pointer.

c. Ignition points should be designed and located for rapid removal, adjustment, and assembly.

d. Ignition timing advance mechanisms should be rapidly and easily replaceable and capable of inspection.

5.9.19.1 Dynamotors. Dynamotors should be designed to allow for the use of commutator dressing and burnishing stones and should be mounted so they do not have to be removed to dress and burnish the commutator.

5.9.19.2 Slip rings. Slip rings should be protected from the entrance of dust and moisture and should be self-cleaning and accessible for servicing. These assemblies should be provided with extra slip rings, where practicable, for emergency repairs.

5.9.20 Batteries.

5.9.20.1 General.

a. Batteries should be installed in locations away from sources of heat and be protected in such a manner as to ensure satisfactory functioning within the maximum and minimum operating ambient-air temperature limits.

b. Battery holders should be rugged and have easily operated clamping devices, not requiring the use of tools, to hold the battery firmly in position against all vibrations, motions, and shocks (such as from gunfire).

c. One person should be capable of rapidly and easily removing batteries for servicing and replacement without removing other items of equipment, and without using special tools.

d. Complete freedom of access should be provided for replenishing the electrolyte and testing the specific gravity and voltage. Loose filler caps should be avoided whenever possible.

e. Dust caps should be provided so battery terminals cannot contact metal surfaces during handling, removal, or replacement.

f. Battery supports, hold-downs, and areas around the installation, which could possibly be affected by dripping or seepage of acids, should be protected with acid-proof paints or coatings. Battery cases should be drained overboard with acid-proof piping, when required.

g. Batteries should be located in well ventilated areas and have facilities to prevent freezing, when necessary.

h. Batteries should not be charged in a poorly ventilated compartment where explosive mixtures of hydrogen and air may result.

i. Batteries should have special filler caps and palladium catalysts to reconvert hydrogen and oxygen into water, thus reducing noxious fumes in the battery area.

j. To prevent gas explosions, only electrical fixtures approved for hazardous locations should be used in battery compartments.

k. Quick-disconnects should be provided on battery leads for power-off maintenance or emergencies.

l. Labeling should be provided as necessary to identify the battery type, voltage, polarity, and safe rate of charge. An example is the rate which will preclude production of dangerous concentrations of hydrogen gas and excessive heat. All related terminals, connectors, contacts, and leads that are part of the battery circuit should be identified. When practical, a block or pictorial wiring diagram of the battery circuit should also be provided.

m. Batteries with "dry" electrolytes should be installed according to the preceding criteria when they apply, except that certain types of dry batteries may be installed in sealed containers without ventilation. Dry electrolytic batteries should be mounted in housings which will keep them dry from water, moisture, and contaminants. "Plug-in" designs installed without tools or loose parts should be used wherever possible.

5.9.20.2 Shelf life of dry batteries. To increase the shelf life of dry batteries, they should be encapsulated in plastic films or in watertight metal cases. Batteries should be stored in cool places.

5.9.21 Climate effects.

5.9.21.1 General. Successful maintainability design should consider the effect of the working environment on human performance. Consideration should be given to adverse as well as normal environmental factors of temperature, humidity, illumination, and dust, which could affect the ability of personnel to perform as required.

5.9.21.2 Temperature extremes. Although the effects of temperature on human performance are not completely quantified, it is known that certain temperature extremes are detrimental to work efficiency. As the temperature increases above the comfort zone, mental processes slow down, motor responses are slower, and the likelihood of error increases. As the temperature decreases below the comfort zone, physical fatigue and stiffening of the extremities begin.

5.9.21.3 Heat. Heat is probably the most important factor in reducing the operational efficiency of personnel. The design recommendations listed below should be considered.

a. Where possible, provide air conditioning if temperatures exceed 29.5° C. In any event, adequate ventilation should be provided in equipment trailers or other locations where personnel are performing monitoring, servicing, or other maintenance tasks.

b. When maintenance technicians must work for periods of time inside equipment which is exposed to the sun, air conditioning should be provided in the enclosure or a large volume of air in compliance with established ventilation criteria should be provided.

c. Where feasible, appropriate heat reflector and absorbent surfaces on equipment which must be maintained should be employed while personnel and equipment are exposed to the sun.

d. Where frequent maintenance, such as checking or adjusting a component, is impossible or delayed because of excessively high temperatures, the equipment should be redesigned so the component is in a cooler area. If this is impossible, provision should be made to cool the component to permit the required maintenance.

5.9.21.4 Cold and windchill.

5.9.21.4.1 Cold. Maintenance personnel on duty in cold regions are physically and psychologically disadvantaged. It has been found that personal discomfort increases rapidly as the temperature drops below -12° C. Performance of organizational maintenance is expected without shelter in the field down to -29° C or equivalent windchill (see FM 31-71, Northern Operations). Maintenance in cold regions is unique. Those measures that are normally within the capabilities of the trained operator of equipment in temperate zones necessarily revert to the maintenance person located at the organizational or aviation unit maintenance (AVUM) level in the polar zone. Also, a considerable number of the tasks that a maintenance person would normally perform revert to direct support or aviation intermediate maintenance (AVIM) unless adequate shelter is provided. Without shelter and heat, most adjustments are impossible. With cold-weather mittens or anti-contact gloves, even the simple task of removing or inserting screws becomes extremely difficult.

5.9.21.4.1.1 Temperature effect on Performance. When workers are properly dressed, they can perform down to between 0° C and -18° C for 30 minutes without interference from the cold (see Figure 69). The figure also indicates that the decrement in performance, below temperatures of-18°C, rapidly increases as the temperature decreases.

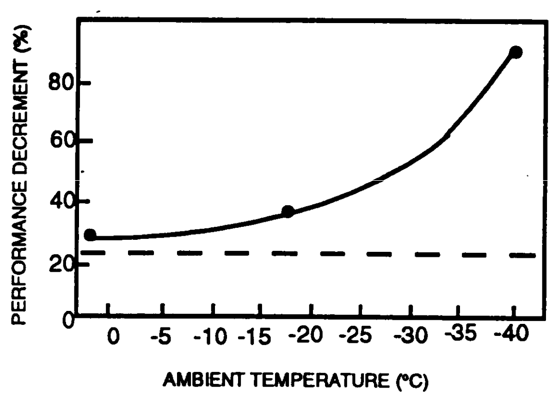


FIGURE 69. Performance decrement at different ambient temperatures.

5.9.21.4.1.2 Desire features. The following features should also be considered by the designer.

a. Maintenance should be able to be performed without shelter at the organizational level when the temperature is as low as -29° C or an equivalent windchill factor exists.

b. In cold environments, heated working areas for maintenance personnel above the organizational level should be provided. For organizational maintenance activities, the equipment should be designed (use quick-disconnect servicing equipment) to require a minimum sustained working time. Procedures should be clear and specific.

c. Equipment should be dried if it is to be returned to out-of-door arctic temperatures after shop maintenance. Moisture which has condensed on such equipment will cause it to freeze with possible resultant damage and subsequent increased maintenance.

d. The following should be considered in design of maintenance accessibility for winterized equipment.

   (1) Winterization equipment, such as preheaters, should be positioned where they do not interfere with accessibility to perform maintenance tasks.

   (2) In locating access doors and panels, consider the effects of rain, snow, and ice formation.

   (3) Where feasible, workspace access openings should be provided to accommodate personnel wearing cold-weather clothing.

   (4) Drains should be provided that can be adequately accessed by personnel wearing cold-weather clothing to drain liquids to prevent freeze damage.

e. In areas where technicians may suffer freezing if bare hands are used when maintaining equipment such as liquid oxygen lines, sufficient access and internal workspace should be provided to permit them to wear the appropriate protective gloves.

5.9.21.4.2 Windchill. No general index, such as effective temperature, is available for expressing all of the factors involved in cold exposure, but the windchill index is a scale commonly used to express the severity of cold environments. This index is an empirical expression of the total cooling power of the environment, and although it is not based on human cooling, it has become a practical guide to the severity of temperature-wind combinations. A windchill chart is shown in Figure 38. It is a usable guide to the severity of exposure conditions for personnel who are appropriately dressed and not wearing heated garments.

This Page Intentionally Left Blank

5.10 Design for remote handling.

5.10.1 Characteristics of equipment to be handled remotely. Reserved.

5.10.2 Feedback. Reserved.

5.10.3 Manipulators. Reserved.

5.10.4 Viewing equipment. Reserved.

5.10.5 Illumination. Reserved.

This Page Intentionally Left Blank

5.11 Small systems and equipment.

5.11.1 Portability and load-carrying. Reserved.

5.11.2 Tracking. Reserved.

5.11.3 Optical instruments and related equipment. Reserved.

This Page Intentionally Left Blank

5.12 Ground and shipboard vehicles.

5.12.1 General. Reserved.

5.12.2 Seating. Reserved.

5.12.3 Controls. Reserved.

5.12.4 Operating instructions. Reserved.

5.12.5 Visibility.

5.12.5.1 Night operation (blackout driving light system).

5.12.5.1.1 Master switch. The blackout master switch should be designed so that it cannot be switched into the normal (bright or dim) modes by accident. In order to change the blackout switch to the normal modes, the operator should have to perform some preliminary action (such as pushing a release button) so that activating the bright lights becomes a deliberate act. This is necessary to prevent enemy detection of military vehicles under blackout conditions.

5.12.5.1.2 Location of light source. If only one blackout light source is provided, it should be mounted on the left-hand side of the vehicle, as far forward and aimed as near the driver's line of sight as practicable.

5.12.5.1.3 Beam criteria. On a level road, the blackout beam should be 9 m wide at a point 6 m in front of the vehicle (decreasing in intensity from 6 m to a point 30.5 m in front of the vehicle) with the top of the beam directed at least one degree below the horizontal.

5.12.5.1.4 Marker lights. Blackout marker lights should follow MIL-L-3976.

5.12.5.1.5 Concealment. Reflectors should be concealed (taped) during blackout conditions to prevent detection by enemy forces.

5.12.5.2 Visual field. The visual field restriction should not be less than 20 degrees of subtends with one eye.

5.12.5.3 Ground view.

5.12.5.3.1 Lighting systems. The lighting system found in military vehicles and equipment usually consists of:

a. headlights to illuminate the road ahead of the vehicle or equipment,

b. parking and side lights to indicate the location of the vehicle or equipment,

c. tail lights to indicate the rear of the vehicle or equipment,

d. instrument panel lights to illuminate the instruments, and

e. exterior lights, such as spot lights, signal lights, blackout lights, stop and, in some cases, backup lights.

5.12.5.3.2 Headlights. Design of headlights should allow the driver the choice of either upper (bright) or lower (dim) distribution of light, illuminate at least 150 m of roadway in front of the vehicle or equipment under clear atmospheric conditions when the upper headlight beam is in use, and be designed so that the regular (bright or dim) headlights cannot be turned on when the blackout system is on.

5.12.5.3.3 Reflectors. Side and rear reflectors should be mounted between 0.6 and 1.5 m above the ground. When reflectors are used on vehicles or equipment which have extending pods, arms, or other devices, the reflector should remain visible when they are extended or in the stowed position.

5.12.5.4 Mirrors. Where two exterior rear-vision mirrors are provided, they should be located so that the driver has rear view capability along both sides of the vehicle. Mirrors should be braced and clamped so that vibration will not blur the view. If the mirror structure is to be used as a handhold for entering the vehicle, or for maintenance operations, it should be securely braced to prevent misalignment of the rearward view. Use of rear-vision mirrors in combat vehicles should be avoided. However, when such vision to the rear is required and no alternative means are available, mirrors should be guarded from tree limbs and flying debris to the maximum extent possible without negating their function.

5.12.5.5 Windshields and windows.

5.12.5.5.1 Windshields. The critical visual area extends to, and often beyond, the vehicle's left corner post. It is better to use a narrow corner post (not over 50 mm wide) than to use a wraparound windshield, which may distort important visual areas. Door posts, windshield wiper motors, and other devices should not obstruct vision. Interior surfaces should not reflect glare into the driver's eyes or onto the windshield.

5.12.5.5.2 Windows.

5.12.5.5.2.1 General. In addition to the windshield area, closed-cab vehicles should have at least one easily opened and closed glass or curtained aperture on each side of the driver's compartment. When possible, there should be a rear window so that the driver can see out over the cargo bed.

5.12.5.5.2.2 Buses. Every bus that seats eight or more passengers, should have provisions for passengers to escape through the windows. Each push-out or other type of escape window should be clearly identified, by prominent, legible instructions, which include the simple steps to open the escape exit.

5.12.6 Heating and ventilation.

5.12.6.1 Heating.

5.12.6.1.1 Exhausts. Any heater that uses oil, gas, liquified petroleum gas, or any other combustible fuel for its operation, should discharge its exhaust products outside of the vehicle.

5.12.6.1.2 Location. Heaters should be located or protected so that personnel cannot touch parts that are hot enough to cause burns (46° C). The heater air inlet should be positioned so it cannot ingest either engine or heater exhaust gases.

5.12.6.1.3 Mounting. Van heaters should be fastened securely so they will stay in place during normal use or in case the vehicle overturns. They should be designed so that they will not come apart, exposing parts (exhaust stacks, pipes or conduits) if the vehicle overturns. It should be possible to replace ignitors, resistors, and other "high-mortality" items without having to remove the heater from the vehicle. Cab heater controls should be accessible to the operator and assistant operator.

5.12.6.2 Ventilation. Reserved.

5.12.7 Trailers, vans, and intervehicular connections.

5.12.7.1 Trailers. Reserved.

5.12.7.2 Vans. Reserved.

5.12.7.3 Ladders for trailers and vans.

5.12.7.3.1 General. Ladders should be used whenever personnel have to change elevation abruptly (more than 400 mm) during operation or maintenance of the vehicle. Surfaces upon which personnel step or walk should be non-skid (expanded metal) and be of sufficient length and width to accommodate arctic boots. Ladders should lock in place during use and have no obstructions, edges, notches or burrs which could injure personnel or damage hoses or cables. Markings should be provided indicating any dangers associated with their use. Wherever possible, ladders should be capable of being carried, handled, and positioned by one person, but should never require more than two.

5.12.7.3.2 Design considerations. The designer should take into consideration spatial limitations and clearances, weather conditions affecting a ladder's use (rain, ice, snow) and traffic flow. When operational vans will remain in one place for an extended period of time, stair ladders should be used.

5.12.7.3.3 Selection. Ladder selection should be based on the required structural strength of the ladder relative to the required slope of the ladder. Ladders should be designed to support the weight of a 95th percentile man dressed in arctic clothing plus the weight of any additional equipment that he may be wearing or carrying (approximately 113 kg). If one person must lift and stow a ladder manually, the ladder's weight and lift distance from ground level should not exceed 11.3 kg for 1.52 m, or 9 kg for 1.83 m.

5.12.8 Cranes, material handling and construction equipment.

5.12.8.1 General. Reserved.

5.12.8.2 Hydraulics. Hydraulic systems are used in tractor and earth-moving equipment. Power pumps and positive-displacement motors are common on industrial, construction, and other types of engineering equipment. Hydraulic systems are used to provide power for braking and for other applications in which an intermittent high amplitude impulse of power is needed. The advantage of the hydraulic system is that effective power may be stored by a small pump over a long duty cycle and expended in a short duty cycle impulse of high power. Use non-flammable fluid only for safety.

5.12.8.2.1 Standardization.

a. Connectors in hydraulic systems should be of standard design and able to be handled with standard tools.

b. Standardize, where practical, valves and cylinders, hose assemblies, couplings, fittings, and filters.

c. Standard hardware should be used for mounting hydraulic components.

d. Ensure that all connectors are standardized by content of lines, and that the number of different sizes are held to a minimum. If there is danger of mismating connectors for adjacent lines carrying different fluids, specify physically incompatible connectors for the two lines.

5.12.8.2.2 Identification.

a. Color coding should be used for hydraulic lines and valves at each end of the line.

b. Permanent identification, instruction markings, periodic inspection dates, and drain schedules should be provided.

c. Inlets, outlets, and connecting lines in hydraulic systems should be identified at least every 460 mm, and at both ends, to facilitate maintenance.

5.12.8.2.3 Drain cocks. All drain cocks should be readily accessible and hand operable without spillage on gloves by the full range of user personnel wearing arctic and/or chemical protective garments. Drain cock handles should be in-line with the corresponding pipe when ON and perpendicular to the pipe when OFF. On vehicular equipment vertical drain cocks should be operable only by upward movement of the handle. On horizontal lines, the handle should be on top or bottom of the line or should be operable only by upward movement if on the side of the line. Drain cocks with high draining rates should be fitted to all air receivers and oil reservoirs.

5.12.8.2.4 Seals. Seals should be used which are externally visible after they are installed. Costly accidents result when seals are left out during assembly or repair (see Figure 70). They should not protrude or extrude beyond the coupling since protruding seals are chipped and shredded by vibration or contact, and the damage spreads internally to destroy sealing power and deposit pieces in the line. For low-temperature operation, special low-temperature materials should be used. Specify couplings which utilize permanent seals rather than those which should be removed and replaced when the seal wears out.

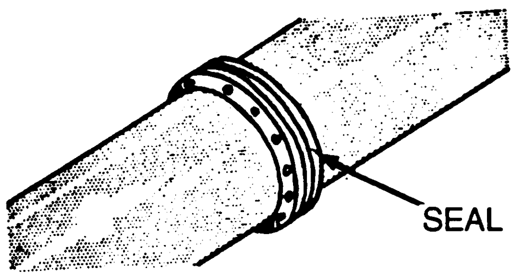


FIGURE 70. Visible seals.

5.12.8.2.5 Design considerations. Hydraulic systems design should make use of the following considerations.

a. All lines should be secured and free from accidental damage.

b. Mechanical stops should be provided for valve handles to prevent the valves from opening because of vibration.

c. Positive locking A-end pumps should be provided when in the traveling position.

d. Self-sealing couplings should be provided on complex hydraulic and pneumatic systems to simplify identification.

e. Hydraulic pumps, valves, and lines, as well as other parts of hydraulic systems should be designed in accordance with the standards laid down in such references as the Society of Automotive Engineers (SAE) Handbook.

f. The use of armor-covered flexible hose should be considered for hydraulic lines to facilitate replacement in the field from bulk stock.

g. Aircraft-type safety fittings with built-in check valves should be used in hydraulic lines to limit fluid loss in the event of a line rupture.

h. Automatic bleeding of hydraulic systems should be utilized whenever possible.

i. Relief valves should be used in hydraulic lines to prevent their bursting and injuring personnel.

j. Quick-release fastening devices should be used on connections that require frequent disconnection. Self-sealing features should be provided to prevent leakage of fluid when disconnect is made.

k. Shock-proof pressure gauges should be used on all mobile equipment.

l. Gauges should be selected that have an external pointer adjustment for ease of adjustment and calibration.

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

n. Valves with integral limit switches should be used where practicable.

o. Permanent or cartridge-type filters should be used.

p. In case of electrical failure, a means for manually operating hydraulic systems should be provided.

q. The connector recommendations shown in Figure 71 should be used.

r. To prevent fluid spraying or draining on the technician or nearby objects when fluid lines are disconnected during maintenance, the following design recommendations should be used.

(1) Provide line drains to ground or container at low level access points.

(2) Reposition line disconnects from sensitive components or shield the component.

(3) Provide a high visibility warning light at disconnect areas which are especially critical.

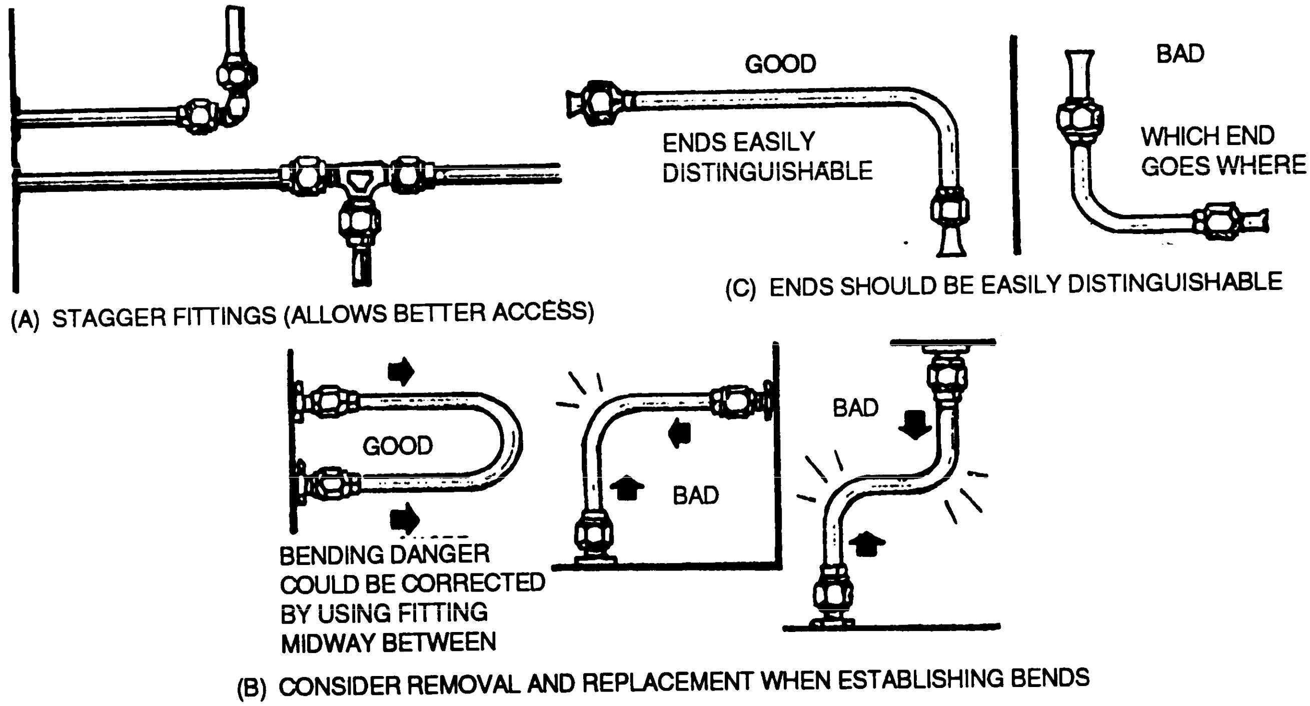


FIGURE 71. Connectors for fluid lines.

5.12.9 Automotive subsystems.

5.12.9.1 Batteries.

5.12.9.1.1 Battery compartments. Batteries should be located away from sources of heat and be environmentally protected to ensure satisfactory functioning within all ambient temperature ranges. Adequate compartment space should be provided around the batteries for the placement of insulation or heating pads when winterizing the equipment.

5.12.9.1.2 Holders. Battery holders should be rugged and have easily operated (without tools) clamping devices to firmly hold the battery in position against all vibration, vehicle motions, and gunfire shocks.

5.12.9.1.3 Mounting racks. Under-the-hood mounting racks for batteries should be placed within the 5th percentile reach, with the hood open. If such access is not feasible, corrosion resistant roll-out racks (or similar devices) should be provided.

5.12.9.1.4 Ventilation. Batteries should be located in well ventilated areas (particularly when being charged) since they may emit hazardous concentrations of toxic or explosive gas and threaten the health and safety of personnel in the area. In areas where batteries are stored, it is recommended that appropriate warning signs be posted which read "NO SMOKING", "DANGER, NOXIOUS FUMES AREA," or "NO OPEN FLAME."

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

5.12.9.1.6 Receptacles. When a slave receptacle is required, it should be installed on the exterior of the vehicle (or equipment) as near as possible to the battery enclosure. It should be accessible from ground level to all personnel. It should also be located away from areas where fuel or other explosive vapors are present.

5.12.9.1.7 Battery servicing. Battery access covers should be fastened with quick-release fasteners and insulated on the inside of the cover to prevent cable shorting if accidentally loosened. It should be readily apparent if the access cover is either loose or secure. If the cover is hinged, there should be enough clearance to open the cover.

5.12.9.1.8 Access. Complete freedom of access for replenishing the electrolyte, seeing into the filler opening, and testing the specific gravity and voltage should be provided. Use of loose filler caps should be avoided whenever possible.

5.12.9.1.9 Maintenance. Batteries and their compartments should be designed so they can be cleaned and serviced without removing any other components. Batteries should be capable of rapid and easy removal by one person for servicing or replacement without removing other items of equipment or without requiring special tools.

5.12.9.1.10 Battery acid. Battery supports, hold-downs, and areas around the installation which could possibly be affected by dripping or seepage of acids should be protected with acid-proof paints or coatings. Battery cases should be drained overboard with acid-proof piping when required.

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

5.12.9.1.12 Battery terminals. Dust caps should be provided so that terminals cannot contact metal surfaces during handling, removal or replacement.

5.12.9.2 Brakes.

5.12.9.2.1 Use. There should be two independent means available to the operator for applying vehicle brakes. One such means should be an auxiliary parking brake. If the two brake systems are not completely independent, the design of the system should be such as not to degrade one braking system should the other system fail.

5.12.9.2.1.1 Air brakes. The design of air or vacuum braking systems for any surface vehicle should provide full braking capability with or without the engine operating.

5.12.9.2.1.2 Towed vehicles. Every vehicle used to tow another vehicle with full air brakes should have a means of activating the towed vehicle's brakes.

5.12.9.2.2 Parking brakes. Manual parking brake controls for trailers should be located so that an operator can reach them easily after positioning or parking the trailer. The controls should not be located on the side of the vehicle normally exposed to road traffic.

5.12.9.2.3 Brake warning.

5.12.9.2.3.1 Air brakes. Vehicles with compressed air brakes should have warning signals that operate continuously as long as pressure is below a fixed threshold level (not less than one-half the cut-out pressure of the compressor governor). These warnings should be designed so they are audible or visible to the operator. In addition, each vehicle should have a pressure gauge which indicates the braking pressure.

5.12.9.2.3.2 Vacuum brakes. Vehicles with vacuum brakes should have an audible or visible warning signal which gives a continuous warning as long as the vacuum in the supply reservoir is less than 200 mm of mercury. In addition, each vehicle should have a vacuum gauge indicating the braking vacuum.

5.12.9.2.4 Brake maintenance. All parts of the brake assembly, drums, discs, shoes, cylinders, support plates, and housing mechanisms should be quickly and easily removable, renewable, and repairable. Appropriate inspection ports, protected by a window or removable cover, should be provided to permit examination of brake linings. Brake system components requiring maintenance action should be both visible and accessible to maintenance personnel.

5.12.9.2.4.1 Accessibility. Rapid accessibility should be provided for such operations as filling, bleeding, and adjusting the brakes. All connections for air, vacuum, or non-flammable hydraulic fluid braking systems should be accessible to the operator. The air reservoir drains, master cylinder, and other such components should be easily accessible for servicing. Brake tubing and hoses should be mounted so that fittings are accessible with ordinary hand tools.

5.12.9.2.4.2 Glad hands. Where service and emergency air brake components are installed on the front or rear of equipment, the glad hands should be rigidly mounted with service glad hand on the curb side and emergency glad hand on the road side. Each glad hand should be equipped with permanent and clear identification tags. A spring-type, metal dust cover should be installed on each glad hand to prevent contaminants from entering the opening. Color coding, when specified, should be blue for service and red for emergency.

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

5.12.9.2.5 Brake adjustment.

5.12.9.2.5.1 Special tools. Brakes should be adjustable without using special tools (including wheel pullers) or removal of any part. Adjustments required to tighten brakes should be clearly marked as to proper rotation or action when operation is not obvious.

5.12.9.2.5.2 Self-adjusting brakes. Self-adjusting brakes are both a desirable and acceptable design feature provided that brake adjustment cannot be changed inadvertently and that actual brake system data prove the self-adjustment system to be effective.

5.12.9.3 Clutches.

5.12.9.3.1 Split line. Whenever possible split-line clutch element design or other appropriate methods should be used so that clutch linings, plates, or discs can be rapidly removed and replaced without removing other power-train components such as the engine and associated gear box.

5.12.9.3.2 Thrust bearings. Thrust bearings should be replaceable by use of split-line design or other appropriate method without removal of any major part of the equipment.

5.12.9.3.3 Dry type. Dry type clutch design should provide generous positive slingers, designed to prevent oil leakage from coming in contact with the surface of the clutch.

5.12.9.3.4 Other features. Well-guarded drain holes and baffles should be provided to prevent any oil from collecting on the clutch face. Any clutch adjustment devices which are provided should include a feature for indicating the amount of clutch lining remaining following each adjustment.

5.12.9.4 Fuel system.

5.12.9.4.1 General. The following should be included in the fuel system design.

a. The capacity of the fuel tank should be clearly marked on the tank.

b. Tactical and combat vehicles' fuel tanks that hold 190 liters or more should be able to accept fuel at 190 liters per minute. Tanks that hold less than 190 liters should accept fuel fast enough to be filled in one minute.

c. The fuel tank drain plug should be located so that the fuel tank can be drained completely. Personnel should be able to remove the drain plug with on-equipment material (OEM).

d. Fuel filters that are accessible and easy to clean should be provided.

e. The replacement of fuel feed pumps should be accomplished as simply as any other roadside repair. If this is not possible, an alternate fuel supply system should be considered.

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

g. The operator should be able to remove the air intake pipe on the carburetor easily.

5.12.9.4.2 Safety. Safety features of tanks for liquid fuels are listed below.

a. As a precaution, in case of collision, the vehicle's fuel tank should not be forward of the front axle.

b. The fuel tank and fuel filler pipe should not be inside or over parts of the vehicle that carry the crew or passengers.

c. The tank, its intake pipe, or its supports should not project beyond the vehicle's overall width. Ideally, these components should be located slightly inward of the overall width.

d. The tank should be designed so that if the vehicle turns over, fuel will not spill out faster than 30 ml per minute.

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

f. Every fuel tank should have a non-spill air vent. It may be mounted separately, or combined with the filler cap, and should be above water during vehicle swimming operations.

g. The nozzle opening in the fuel fill pipe should be located to minimize the likelihood of spilling fuel on the exhaust system, the battery, or inside the vehicle. It should never be more than 1.2 m above the ground or the base of the work platform used for refueling.

5.12.9.5 Engine.

5.12.9.5.1 Accessibility. Engine designs should provide easy access for maintenance.

5.12.9.5.1.1 Engine accessories. Fuel and coolant pumps, starter motors, generators, filters, and other engine accessories should be accessible without removing the engine from the vehicle. It should be possible to replace any engine accessory without removing more than one other engine accessory. Fuel and oil filters should be located where they can be cleaned and replaced without disassembling the engine from the chassis and without first removing engine accessories such as starters, generators, pumps, or manifolds.

5.12.9.5.1.2 Filters and belts. Air cleaners should be located where they are easy to remove, service, and install using OEM tools and equipment. Crankcase sumps should be easy to remove. Fan belts and other drives that require adjustment should be designed to be handled while wearing arctic mittens and so located to provide easy, safe access away from heat sources such as hot manifolds.

5.12.9.5.1.3 Spark plugs. Spark plugs should be accessible. They should be removeable with OEM tools and equipment. Ignition system wiring should be mounted and routed so vehicle vibration or personnel movements cannot break connections accidentally.

5.12.9.5.1.4 Engine timing marks. Engine timing marks should be easily visible and should have a visible reference point on the engine, so that the timing can be checked when the engine is installed in the vehicle.

5.12.9.5.2 Drains. Engines that use diesel or multi-fuels should be designed so that it is easy to drain the primary fuel filter daily. Drains should be located to direct their flow onto the ground, rather than on equipment. Removing oil-drain plugs should allow the pan to drain completely if the vehicle is on a level surface.

5.12.9.5.3 Throttles. Engines used as electric or pneumatic power sources and vehicular engines on radio-carrying vehicles should have a tachometer and throttles which can be locked at selected part throttle positions. Vehicles should be equipped with overspeed governors which are tamper-proof.

5.12.9.5.4 Air restriction gauge. If an air restriction gauge is required, it should be placed where it is visible to the operator of the vehicle.

5.12.9.6 Radiators.

5.12.9.6.1 General. The radiator filler neck should be large enough to accept existing filler nozzles. It should be positioned so that the operator can see the fluid level inside the radiator. There should be an accessible drain in the radiator's lower tank to drain it completely onto the ground or into a suitable container without splashing on vehicle parts. A guard should be provided to protect the radiator during travel through brush and during actions. It should be possible to remove the radiator without removing the engine.

5.12.9.6.2 Tubes and hoses. Radiator coolant tubing and hoses should be designed, constructed, and installed to ensure continued functioning in all environments. They should be sufficiently long and flexible to accommodate all normal motions of the parts to which they are attached without damage. They should be secure from chafing, kinking, or other damage. They should be mounted with airplane-type clamps which are accessible to the operator.

5.12.9.7 Exhaust systems.

5.12.9.7.1 Location. The exhaust system should be located or protected so that personnel will not come into contact with hot surfaces. The design should keep fumes from entering crew and other personnel compartments. Exhaust gases should be deflected away from tires, roadways, and the ground so as not to damage vehicle components, disturb roadway dust or cause brush or grass fires. In addition, the exhaust system should not be capable of being clogged or its function degraded when the vehicle is either operating on a muddy surface or engaged in swimming operations.

5.12.9.7.2 Drains. Gravity draining of the exhaust system should be provided so that it will drain completely when the vehicle is on level ground.

5.12.9.7.3 Mounting. The exhaust system should be mounted to the chassis securely, yet loosely enough so that flexing between components will not cause damage. No part of the exhaust system should cause burning, charring, or other damage to the vehicles electrical wiring, the fuel supply, or any other equipment.

5.12.9.7.4 Mufflers. The exhaust system should include mufflers (silencers) to limit the noise to which any occupant is exposed to the levels specified in MIL-STD-1474.

5.12.9.8 Drains and vents.

5.12.9.8.1 General. Drain valves should be accessible, dependable, and have simple operating mechanisms. Drains that purge pneumatic-system reservoirs should be readily accessible and should drain the tanks completely. Drains and vents should be located where crew members can clear and check them easily. They should be easy to identify and to close and check before fording or swimming operations. Instruction plates, giving drain and vent locations and procedures for operating them, should be provided. Vehicles that swim should be equipped with bilge pumps.

5.12.9.8.2 Design. Vents should be designed so that mud, ice, or other foreign matter will not clog them. Drain plugs and valves should be designed to resist seizing in either the open or closed position. All drain plugs should be the same size. If drain plugs cannot be designed to be the same size, the number of different sizes should be minimized.

5.12.9.8.3 Fluids. Drains should be designed so as to empty lubricants and hydraulic fluids completely onto the ground or into a suitable container. Fluids should drain to the outside of the vehicle, without falling on obstructions or splashing onto vehicle components.

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

5.12.9.9 Filling, draining, and checking procedures.

5.12.9.9.1 Dipsticks. Items such as the engine, transmission, and hydraulic reservoir sumps should be equipped with dipsticks to determine fluid levels. Dipsticks should be etched, sandblasted, knurled, or phosphate-coated to facilitate determination of the fluid level. Other items such as gear cases, differentials, and reservoirs which contain oil should be equipped with either dipsticks, check plugs, or sight glasses, as appropriate. Each pump enclosure should be fastened within the housing.

5.12.9.9.2 Drainage. Removal of drain plugs should result in complete drainage of the fluid from each sump or enclosure. When equipment or a vehicle is in a level position, drainage of all fluids, including engine coolant, should be onto the ground, or into a suitable container without damage to any part of the equipment. Integral tubes, hoses, or troughs may be utilized to carry these fluids from the drains.

5.12.9.9.3 Accessibility. Access to filling ports, fluid-level checking means, and drain plugs and valves of all sumps, enclosures, reservoirs, and radiators should be provided without removal or adjustment of components or parts other than access covers.

5.12.9.10 Chassis.

5.12.9.10.1 General. Cabs and bodies should be easy to remove. Heavy cabs should be provided with lifting points, which are properly marked (LIFT HERE). The skirting plates, track guards, and mud flaps should be easy to remove and be capable of preventing rocks and other debris from being thrown against the crew, passengers, or other personnel in the immediate vicinity. Suspension units and final drives should be removable under field conditions. Replacement parts should be bolted, not riveted or welded, to the frame.

5.12.9.10.2 Alignment. Standard devices for checking chassis alignment should be provided at accessible positions and should be suitably marked. The installation and adjustment of tracks should not require the use of special jacks or tensioners to pull out slack in the track.

5.12.9.10.3 Bumpers. Bumpers should be of standard proportions, located at standard height within the vehicle class, and be rugged and sufficiently strong for towing with the vehicle loaded. Appropriate towing attachments should be provided on the bumper.

5.12.9.10.4 Accessibility. Hoods and other access panels which must be opened for daily checks should be accessible and operable by a single 5th percentile operator.

5.12.9.10.5 Canvas and accessories. The cab of a vehicle should be designed so that one member of the crew can convert it from open to closed configuration and vice versa in 10 minutes or less. Tarpaulins, end curtains, and bows also should be designed so that two crew members can remove or install them in 10 minutes or less. These times do not apply to heavy padded arctic cabs and enclosures. One crew member should be able to gain access to the cargo compartment within three minutes, from front or rear, with the tarpaulin and curtains in place. Pins and other retaining devices should be designed so two crew members, wearing triggerfinger mittens, can remove and replace them.

5.12.9.10.5.1 Cargo vehicles. When cargo vehicles are used for troop transport or workspace, there should be between 1.5 and 1.9 m of clearance between the tarpaulins and bows covering the bed and cargo floor. Tarpaulin bows and ropes should be easy to unfasten. Bows should be designed so that personnel wearing gloves can remove them from sockets under wet, muddy, or freezing conditions. Tarpaulin and cab-top bow sockets should have adequate drain apertures. Cab-tops, tarpaulins, and curtains should be protected from chafing and flapping. Tarpaulins and end curtains should be fire resistant. There should be a provision for rolling up the sides of cargo area tarpaulins to ventilate the area occupied by personnel.

5.12.9.10.5.2 Other features. Pins and other retaining devices should have the maximum working clearances that still assure they will be retained properly. Chains should be used with retaining pins and other similar devices to prevent loss of these items. There should be space to stow stakes and bows on the vehicle. Vehicles that transport troops, should have safety straps at the rear of the vehicle.

5.12.9.11 Intravehicular coupling device.

5.12.9.11.1 General. Coupling devices should be long enough so that they do not restrict the towing vehicles' maneuverability during towing operations. Coupling devices should be designed to preclude mismating and damage under normal use. Suitable measures should be employed to protect intravehicular couplings from accidental disconnection, kinking, entanglement, dragging, abrasion, or pinching during operation.

5.12.9.11.2 Air and hydraulic brakes. Vehicles with air-over-hydraulic brakes or air brakes, should have provisions at the front and rear for connecting to another vehicle's brake system and controlling it during towing operations.

5.12.9.12 Tires.

5.12.9.12.1 Spare tires.

5.12.9.12.1.1 General. The spare tire and the tools for servicing it should be readily accessible. A 5th percentile woman in size and strength should be able to jack up the vehicle, remove the spare tire, remove the damaged tire, install the spare tire, tighten the nuts to the required torque to secure the spare, and stow and secure the damaged tire using OEM. Equipment for stowing and removing the spare tires should be simple to operate and safe to use. It should be possible to remove and replace the spare tire with the vehicle fully loaded.

5.12.9.12.1.2 No spare tire criteria. When there is no spare tire, the vehicle should have a "limp home" device (to temporarily take on the function of the damaged tire) that will permit it to continue traveling for 80 km after the failure.

5.12.9.12.2 Air-over-hydraulic brake systems. Vehicles with air-over-hydraulic brake systems should have a pneumatic outlet and pressure gauge for adjusting tire pressures. The air hose for this outlet should be long enough to reach all the tires, including the spare, from the air compressor on the same vehicle or another vehicle. It should be possible to inflate and check the spare tire with a standard air gauge without removing the spare from its mount.

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

This Page Intentionally Left Blank

5.13 Hazards and safety.

5.13.1 General. Reserved.

5.13.2 Safety labels and placards. Reserved.

5.13.3 Pipe-, hose-, and tube-line identification. Reserved.

5.13.4 General workspace hazards.

5.13.4.1 Stairs. Reserved.

5.13.4.2 Thermal contact hazards. Measures should be taken to guard against inadvertent skin contact with surfaces of different temperatures. Surfaces that personnel touch (gearshift levers, steering wheels, dash controls, seats, side panels, and compartment walls) should have low heat conductivity. If personnel can touch metal surfaces that may get as hot as 49° C, special precautions are indicated such as shielding; insulating; relocating components; or adding warning decals, signs, or labels. Figure 72 shows the burn criteria for human skin. For temperatures at or below 0° C, pain and/or tissue damage (freezing) can occur.

5.13.5 General equipment-related hazards.

5.13.5.1 General. In evaluating equipment's safety characteristics, some of the areas which should be reviewed are:

a. failure modes and hazardous effects,

b. electrical and electronic safety factors,

c. mechanical safety factors, including hydraulics and pneumatics,

d. toxicity, and

e. radiation.

5.13.5.2 Human behavior principles. There are principles concerning human behavior that can help designers design safe equipment. The principles below are based on how people actually use equipment in the field and on what actually does happen to that equipment. These principles give a partial answer to why people make errors, misuse equipment, and do other unsafe things. Armed with such knowledge of why people err, the designer can avoid many rather subtle temptations that give users opportunities to take chances. Relevant behavior principles include:

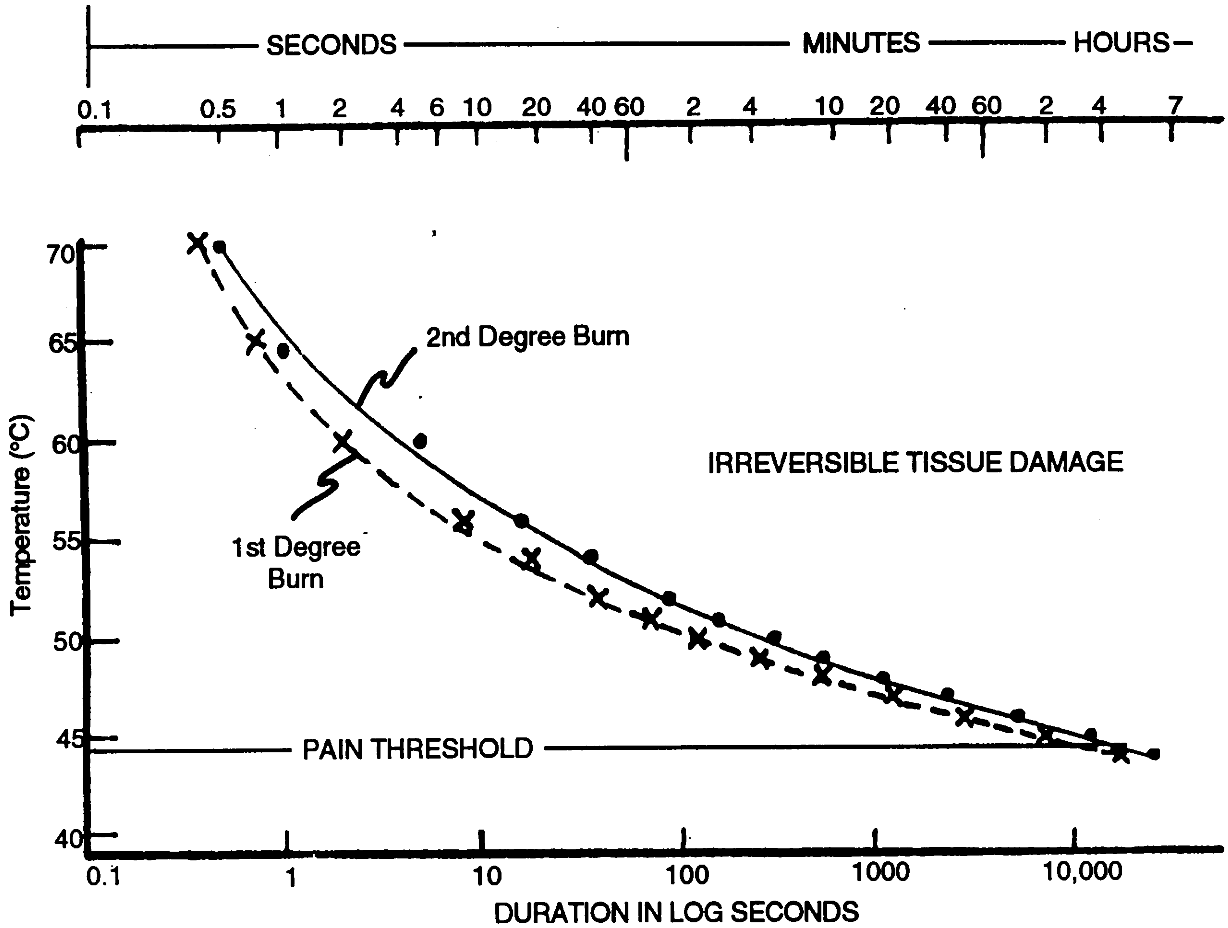


FIGURE 72. Burn criteria for human skin.

If the equipment provided is insufficient or inadequate, users will modify it, or improvise, so they can get the job done.

Procedures should be definite and comprehensive.

c. People often feel that "it can't happen here." They assume that, if someone gets hurt (or damages equipment) by disregarding instructions, it will be someone else in some other place. Because people feel safer than they are, procedures should be as nearly foolproof as possible. Since procedures are shaped by the equipment, equipment should be designed to encourage safe usage.

d. Once a safety problem has arisen, taking corrective action does not necessarily eliminate it. The correction may not be sufficient, or may not be appropriate, or may even fail to attack the cause of the problem. Corrective actions should always be verified to determine if the problem has been solved.

e. Not all safety problems can be anticipated from studying concepts and blueprints. Thorough safety analysis requires realistic tests using mockups and prototypes.

f. Equipment not designed to operate in accordance with user expectancies and stereotypes will eventually lead to mistakes.

g. Warning notes have a limited, supplementary value in making mishaps less probable. However, many users may not have read them, may not remember them, or may not even know where to find them. Warning notes do not prevent safety problems.

h. Accidents seem so unreal to some people that they do not appreciate how careless performance can cause accidents. Before these individuals take their assignment seriously, and do it thoroughly and carefully, they must actually see equipment damaged or people injured.

i. Equipment should be designed so it is inherently safe to use, rather than relying on special safety training to prevent accidents. Not all users get such training, even when it is "required."

j. Equipment users do not visualize the consequences of unsafe acts. These people only realize a practice is dangerous after they have seen someone get hurt.

k. Certain individuals seemingly prefer to work under hazardous conditions, as if their bravery makes the job more important.

l. Instructions, like warning notes, are not enough to ensure operators will work safely.

m. Designers should consider the possibility for errors, listing the possible mistakes the operator can make, and their consequences.

n. Some accidents occur because technicians cannot identify parts correctly. Designers should provide complete, legible, understandable identification of parts in order to avoid personnel injuries and equipment damage.

o. Many designs require compromises, but every effort should be made to minimize conditions which could lead to accidents. If undesirable conditions are tolerated without making an effort to improve them, they often seem to multiply and interact to produce serious safety problems.

p. Equipment should be designed so it can be used safely. If the procedures for safe operation seem needlessly difficult or burdensome, people tend to avoid doing what seems unnecessary. Ideally, equipment should be designed so it is easier to use it safely then to use it unsafely.

q. Designers should anticipate that operators do make mistakes and assure that these mistakes are not likely to injure personnel or damage the equipment. For example, users should be given at least some on-the-job training with operational equipment; these partially trained personnel should be expected to make errors.

r. The designer should understand all of the criteria the equipment must satisfy; comprehending these requirements can assure that the equipment will meet them.

s. The operator's care in using and maintaining items tends to be related to their complexity and cost. People are most careful with complicated, expensive items. Conversely, individuals tend to neglect simple, inexpensive items because they seem relatively unimportant.

t. Since workers often neglect their own safety, each supervisor should take responsibility for certain areas concerning personnel and equipment safety, and particularly for unwise short-cuts and variations from the prescribed procedures.

u. Abbreviated checklists tend to cause mistakes. Checklists may be useful if the personnel are well trained. However, less knowledgeable technicians may not go beyond the checklist when working in unfamiliar areas. Rather than refer to the detailed job procedures, they tend to experiment or fill in the gaps by guessing.

v. The equipment's reputation among users can be very important because it may affect the way they use it and service it. Even rumors that equipment is difficult or hazardous to use can compound and magnify the basic difficulty.

w. Ease of use or maintenance affects equipment reliability. If items are difficult to maintain, technicians will probably not keep them in good operating condition. If equipment is difficult to use, operators will substitute other equipment when they can.

x. Equipment is particularly susceptible to misuse if crew members must communicate with each other to use it. People seldom realize communications are inadequate until they make mistakes.

5.13.6 Platforms.

5.13.6.1 Locks. Adjustable stands and platforms should have foolproof self-locking devices that keep them from collapsing accidentally. Where stands have high centers of gravity and might overturn, they should have anchors or outriggers to stabilize them. To prevent overloading, weight-sharing equipment such as stands, hoists, lifts, and jacks should be marked to show weight capacity.

5.13.6.2 Handrails, safety bars, and chains. Reserved.

5.13.7 Electrical, mechanical, fluid, toxic, and radiation hazards.

5.13.7.1 Electrical hazards. The primary reference in designing electrical equipment is MIL-STD-454. The principal electrical hazard is shock. The effects of electric shock depend on the body's resistance, the current path through the body, the duration of the shock, the amount of current and voltage, the frequency of an alternating current, and the individual's physical condition. The most critical determinant of injuries is the amount of current conducted through the body. Besides the obvious risk of burns and injuries to the nervous system, electric shock can produce involuntary muscular reactions that injure people and can damage equipment.

5.13.7.1.1 Hazards. All electrical systems of 30 volts or more are potential shock hazards. Research reveals that most shock deaths result from contacts with electrical systems ranging from 70 to 500 volts. Under extraordinary circumstances, even lower voltages can cause injury. Shock causes many severe injuries by evoking muscular spasms and reflexes that propel the body against nearby objects. Table 35 summarizes typical effects of various levels of electrical current.

5.13.7.1.2 Power lines. While safety guidelines often concentrate on high-voltage apparatus, power line hazards also deserve close attention. Personnel who touch, short circuit, or ground the incoming power line can receive severe shocks and serious burns. Both ends of the power line and all branches should be fused. Otherwise, a transformer or motor failure could ground the primary supply line.

TABLE 35. Shock current intensities and their probable effects.

CURRENT (milliamperes)		EFFECTS
AC (60 Hz)	DC	
0 - 1	0 - 4	Perception
1 - 4	4 - 15	Surprise
4 - 21	15 - 80	Reflex Action
21 - 40	80 - 160	Muscular Inhibition
41 - 100	160 - 300	Respiratory Block
Over 100	Over 300	Usually Fatal

5.13.7.1.3 Prevention. Personnel should be protected from electrical shock by suitable interlocks, grounding, and enclosures or other protective devices. The main method of alerting personnel to potential shock hazards is through effective visual and audible warnings.

5.13.7.1.3.1 Color. Equipment designed for safety, protective, or emergency functions should be colored in conformance with MIL-STD-1473.

5.13.7.1.3.2 Danger markings. Caution markings should warn personnel about hazardous voltages, and the safety precautions they should take to avoid shock.

5.13.7.1.3.3 Danger signs. Danger signs are necessary, but because they do not actually prevent users from being hurt, signs should always be supplemented by physical barriers or other positive protection where feasible. Signs, reading "DANGER--HIGH VOLTAGE" or "DANGER (insert maximum voltage) VOLTS," should be displayed prominently on safety covers, access doors, and inside equipment where hazardous voltages are exposed. These signs should be durable, easy to read, and located where dust and foreign matter will not eventually obscure wording. Markings on electrical equipment should conform to requirements in Article 510 of the National Electrical Code.

5.13.7.1.3.4 Warning signals. Warning signals such as lights, bells, horns, or other devices should be used to alert personnel of danger. These signals should be located where the people who must take corrective action can perceive them most easily. Multiple redundant warning signals, lights, and bells may be required if ambient noise could mask the audible alarm, or personnel might not be looking at a warning light.

5.13.7.1.4 Safety switches. The two basic types of safety switches for preventing electric shock are interlocks and main-power switches.

5.13.7.1.4.1. Interlocks. An interlock is a switch that automatically turns power off when the equipment's access door, cover, or lid is open. These switches are ordinarily wired into the "hot" lead to the power supply and operate whenever an access cover is opened, thus breaking the circuit whenever personnel enter the enclosure. Every door or cover that provides access to high-voltage potentials should have an interlock. Selection of the type of interlock switch to be used should be based on reliability. The type shown in Figure 73 has proven most satisfactory.

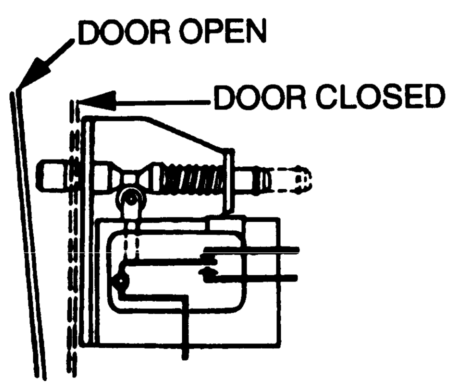


FIGURE 73. Door interlock switch.

5.13.7.1.4.1.1 Maintenance. The use of interlocks assures that power is off during maintenance. If maintenance personnel must open the equipment and work on it while the power is on, there should be some provision for bypassing interlocks. Such bypass switches should be located inside the equipment in a position where closing the access door or cover automatically restores interlock protection. Wherever these bypass switches are used, there should also be a warning signal to show personnel that there is danger because the interlock has been bypassed. These warnings should include a flashing red light as well as an appropriate warning plate or decal.

5.13.7.1.4.1.2 Battle-short switch. Wherever complicated interlocks are used on high priority equipment, there should be a battle-short switch (or terminals for connecting one) which bypasses all interlocks. The circuit consists of a single switch, wired in parallel with the interlock system. Closing the battle-short switch thus short circuits all of the interlock switches, turning power on regardless of whether interlocks have been opened. Whether mounted on the equipment panel or remotely, battle-short switches are for emergency use only, and they should be so marked. They should have adequate protection against accidental operation such as seals which must be broken before the switch can be operated. In addition, switches should also have appropriate warning devices to alert personnel that interlocks have been bypassed.

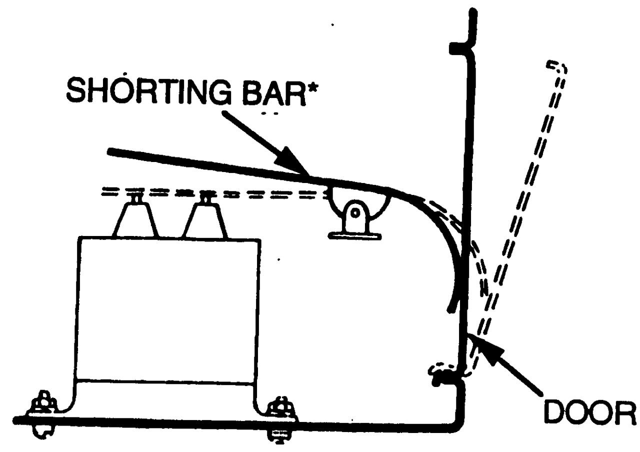
5.13.7.1.4.2 Main power switch. Each item of equipment should have a clearly labeled main-power switch that turns off all power to the item by opening all leads from the main-power service connection. Main-power switches should be safeguarded to prevent heavy arcing. Fuses and conductive metal parts should be isolated from each other with barriers. The switch box should also be designed so the box cannot be opened when the switch is turned on. Such switches are available as standard, commercial equipment.

5.13.7.1.4.3 Discharging devices (bleeders). Because high-quality filter capacitors can store lethal charges for relatively long periods of time, all medium- and high-voltage power supplies should have devices that discharge them when they are turned off. Bleeders should be incorporated in all power supplies where the product of resistance (in ohms) and capacitance (in farads) is three seconds or more. Since no one discharging method meets the criteria for all devices, the examples listed below are presented as guidelines.

a. DC power supplies may be discharged very satisfactorily by permanently connecting a bleeder resistor across the output terminals. This bleeder serves to improve the supply's regulation, and to discharge the filter capacitors when the supply is turned off. Although bleeder current is an additional load on the power supply, the supply should be designed to accommodate this extra load. The bleeder resistance should be the lowest value that does not load the power supply excessively so it can discharge the capacitors quickly after power is turned off. An adequate bleeder should discharge the capacitors fully in one minute or less.

b. Some circuits with large, high-voltage capacitors (high-voltage radar equipment) cannot use bleeder resistors so other methods should be used to discharge the capacitors before doing maintenance. Often capacitors are discharged with a shorting or grounding rod that has a well-insulated handle. It is a better engineering practice to discharge capacitors gradually, rather than shorting them, and high-power resistors are often used in place of a grounding rod; several thousand ohms of resistance is a typical value.

c. Interlocks should remove power before automatic shorting bars (see Figure 74), operated by mechanical releases or electrical solenoids, can discharge the power supply quickly when covers or access doors are opened. These bars should operate automatically whenever the enclosure is opened; they should function quickly, with high reliability.



*Should be spring-loaded to ensure operation in all equipment positions

FIGURE 74. Automatic shorting bars.

5.13.7.1.5 Ground potential. All enclosures, exposed parts, and the chassis should be kept at ground potential by the same common ground system.

5.13.7.1.5.1 Grounding techniques. Various grounding techniques are used to protect personnel from dangerous voltages in equipment. A terminal spot welded to the chassis provides a reliable ground connection. Where welding is not feasible, as with an aluminum chassis, the ground terminal should be fastened down by a machine bolt, lock washer, and nut (see Figure 75). Ground lugs should not be stacked on bolts with any material subject to coldflow. The machine bolts used to mount ground lugs should be large enough that eventual relaxation will not loosen the ground connection. A lock washer should always be used to keep the ground tight. Any non-conductive finish on the chassis should be removed before bolting down the ground lug. Ground lugs should not be attached with rivets because rivets do not give reliable electrical connections.

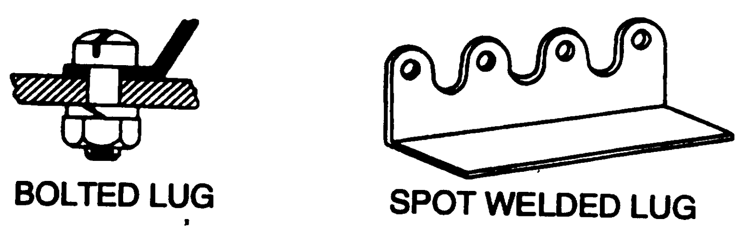


FIGURE 75. Grounding methods.

5.13.7.1.5.2 Common ground. The common ground of each chassis should connect to a through-bolt mounted on the enclosure and clearly marked "ENCLOSURE GROUND." An external safety ground strap should, in turn, be connected to this through-bolt. The external ground strap should be a suitably plated flexible copper strap with a current-carrying capacity at least twice as large as the equipment requires (see Figure 76).

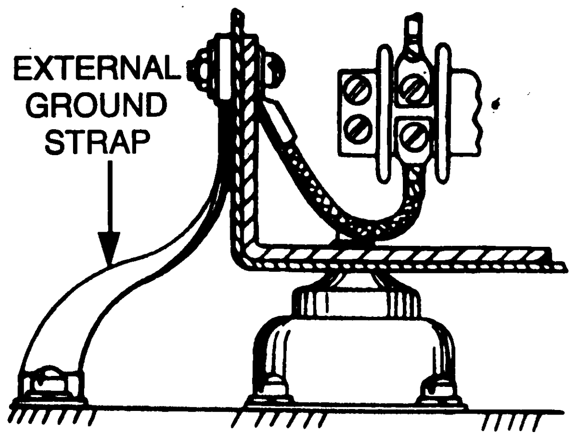


FIGURE 76. Cabinet grounding system.

5.13.7.1.5.3 Panel-mounted components. Panel-mounted components, especially meters and test jacks, are occasionally used to monitor current in power lines. Such items should be connected into the grounded side of the power line rather than into the ungrounded side; this precaution limits current flow if the component should short to the grounded chassis.

5.13.7.1.5.4 Non-grounded lines. Some power-supply lines are not grounded as a means of reducing interference. These lines should be bypassed through capacitors to ground; however, the total current to ground, including any leakage through the capacitor, should be not greater than five milliamperes.

5.13.7.1.6 Electronic equipment.

5.13.7.1.6.1 Test equipment. Electronic test equipment (signal generators, amplifiers, and oscilloscopes) which is plug connected should have an integral ground prong to ensure automatic ground connection. These ground leads provide safe grounding because if a fault in the instrument puts a dangerous voltage on the metal housing, it is bypassed without endangering the operator.

5.13.7.1.6.2 Fusing. Circuits should be fused so that other parts of the circuit will not be damaged if a fuse is removed or if it ruptures. All leads from the primary power lines should be protected by fuses. Fuses should be connected between the main-power switch and the load.

5.13.7.1.6.3 Fusing techniques. Branch-line holders should be designed so that, when correctly wired, fuses can be changed without risk of accidental shock. Where feasible, both of the fuse-holder contacts should be recessed so users cannot touch them. At least one of the fuse-holder contacts should be recessed where personnel cannot touch it, and that contact should be connected to the supply line; the accessible contact, if there is one, should be connected to the load. Figure 77 shows how an instrument-type fuse holder should be wired to keep users from touching the high-potential contact.

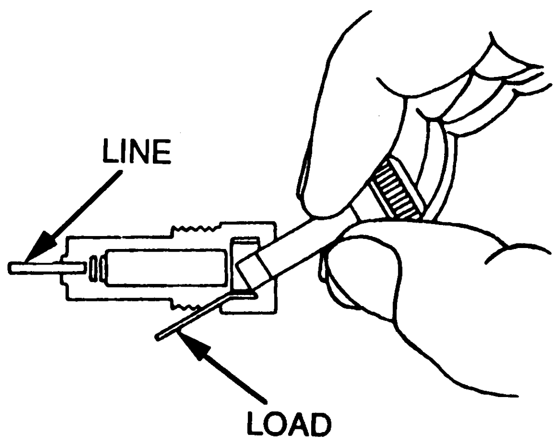


FIGURE 77. Correct instrument-type fuse holder wiring.

5.13.7.2 Mechanical hazards.

5.13.7.2.1 Guards. Equipment should have shields and guards to keep users from accidentally touching rotating or oscillating parts such as gears, couplings, levers, cams, latches, or large solenoids. Moving parts should be enclosed, shielded, or guarded. High-temperature parts should be located (or guarded) so users will not normally touch them. If such protection is not feasible, there should be prominent warning signs. Wherever possible, a guard should be designed so users can inspect parts without having to remove it. Especially if a part's failure can cause a hazardous condition, guards should not interfere with inspecting that part.

5.13.7.2.2 Protrusions. All edges and corners should be rounded, having as large a rounding radius as practical. This prevents injuries from sharp or pointed edges. This rounding is especially important with front and side edges, and with door corners. Designers should avoid thin edges. Units should be designed so users can carry them without risk of cutting their hands on sharp edges. To minimize protrusions from equipment surfaces, flat-head screws should be used where possible; otherwise, pan-head screws should be used. To reduce the risk of skin abrasion, all exposed surfaces should be machined smooth, covered, or coated. In areas where users must make rapid movements, small projecting components should be avoided or covered. If small projecting parts (such as toggle switches or small knobs) must be mounted on a front panel, recessed mountings should be considered.

5.13.7.2.3 Ventilation. There should be enough ventilation to keep parts and materials from getting so hot that they will be damaged or their useful life will be shortened. Exposed parts of the equipment should never, under any condition of operation, get hot enough to endanger personnel. Hot components may be cooled with forced air. Any air-exhaust openings should be located where personnel are not exposed to direct drafts.

5.13.7.2.4 Perforations. Some housings, cabinets, and covers should be perforated to allow air circulation. Many small perforations are better than a few large ones; perforations should be no larger than 13 mm in diameter. Any component which rotates, oscillates, or carries high voltage should be spaced back from perforations so personnel cannot touch it accidentally.

5.13.7.2.5 Instability. Equipment should be designed for maximum stability. Particular attention should be given to portable equipment such as maintenance stands, tables, benches, platforms, and ladders. Walkways, catwalks, and any surfaces used for climbing should have non-skid metallic materials, expanded metal flooring, or abrasive surfaces. Ladders and steps should be designed so they can be de-iced with hot water or steam. There should be hand grips on platforms, walkways, stairs, and around floor openings. Hand grips should ordinarily be fixed, but sometimes hand grips should fold or telescope so they are concealed or flush with the surface except when being used. Folding grips should remain securely folded when not in use, but users should not need tools to open them for use.

5.13.7.2.6 Center of gravity. Equipment should be designed to maximize safety and stability when it is moved on inclines, such as cargo ramps, or lifted by cranes for shipping. The center of gravity and jacking points should be suitably marked to show their locations (see Figure 78). Users should be aware that ramps and inclines change the way weight is distributed among the wheels; the lower wheels bear weight. With heavier equipment, this may mean that weight is concentrated enough to exceed allowable ramp loads. Shifting the center of gravity also increases the risk that equipment will overturn.

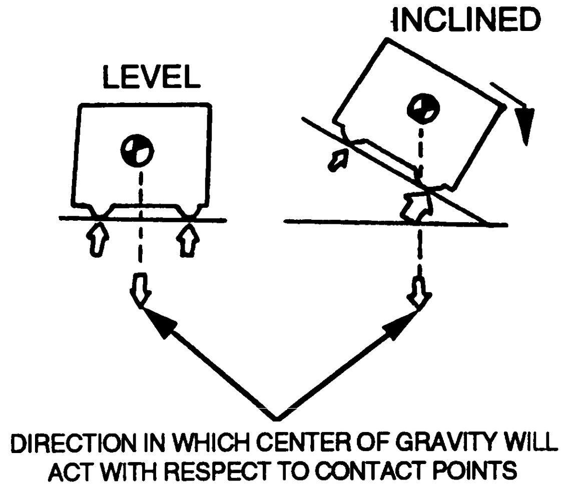


FIGURE 78. Effects of incline on center of gravity location of equipment.

5.13 .7.2.7 Implosion and explosion.

5.13.7.2.7.1 Implosion. CRTs pose a special hazard because minor physical damage (accidental nicks or scratches) may trigger later implosions. Therefore, the face of CRTs should always be shielded by shatter-proof glass attached to the panel. The terminal end of CRTs should be located within the equipment housing whenever possible. If the terminal end must extend outside the equipment housing, it should have a sturdy cover to protect the tube. This cover should be anchored to the main housing structure firmly enough to withstand shipping and rough handling so that external pressures will not be transmitted to the tube and its wiring. There should also be signs inside the equipment warning maintenance personnel that the neck of the tube is fragile and must be handled with caution.

5.13.7.2.7.2 Explosion. Equipment that may be operated, maintained, or stored in an explosive atmosphere should be designed to eliminate the possibility of an explosion. All electrical equipment that will be used near flammable gases or vapors should be explosion-proof. Risk of explosion should be minimized by isolating hazardous substances from heat sources and by using spark arrestors, vents, drains, and other safety techniques as appropriate.

5.13.7.3 Fluid hazards.

5.13 .7.3.1 Connectors. Reserved.

5.13 .7.3.2 Fluid- and fuel-servicing equipment.

5.13.7.3.2.1 Fire. All reasonable precautions should be taken to minimize fire hazards. In particular, if capacitors, inductors, or motors are potential fire hazards, they should have non-combustible enclosures with a minimum of openings. Materials that can produce toxic fumes should not be used because equipment must often be installed in confined spaces. Designers should also avoid materials that, under adverse operating conditions, might liberate combustible materials. Equipment should be designed so it will not emit flammable gases during storage or operation; if any such gases are unavoidably emitted during operation, there should be automatic cutoffs and suitable warnings. Equipment should not produce undesirable or dangerous smoke and fumes. Finished equipment should be checked carefully to verify that protective features are actually effective.

5.13.7.3.2.2 Fire extinguishers. Where fire hazards are known to exist, or may be created by the equipment, there should be portable, hand-operated fire extinguishers. These fire extinguishers should be located so they are immediately and easily accessible. They should be selected for suitability to the class of fires most likely to occur in the area.

a. Class A. Fires of ordinary combustible materials (wood, paper, and rags) which can be extinguished with water or aqueous solutions.

b. Class B. Fires involving flammable liquids (gasoline and other fuels, solvents, greases, and similar substances) which can be extinguished by diluting, eliminating air, or blanketing.

c. Class C. Fires in electrical equipment (motors, transformers, and switches) which should be extinguished by a material that does not conduct electricity.

5.13.7.4 Toxic hazards.

5.13.7.4.1 General. Enclosed vehicle crew compartments are particularly susceptible to accumulations of noxious substances which result primarily from engine and heater exhaust and the firing of weapons from within the vehicle. From the practical standpoint of controlling health hazards, the critical contaminants are carbon monoxide, ammonia, nitrogen oxides, sulphur dioxide, and aldehydes (methane). In sufficient concentrations, the substances may incapacitate personnel or reduce substantially their performance through eye irritation, nausea, reduced mental alertness, and even unconsciousness. However, little is known relative to their interaction which is the primary reason given for the general tendency (in regulatory standards) to reduce allowable exposures for any one toxic element below its experimentally defined toxic influence level. Other contaminants may also create health hazards, particularly when design changes are introduced or new fuels or propellants are used.

5.13.7.4.2 Carbon monoxide. Carbon monoxide (CO) is particularly dangerous in that it is odorless, colorless, and tasteless and is not ordinarily detectable by the human senses. Its effects are cumulative. Doses which may be tolerable by individuals for brief periods may prove to be dangerous to them when repeated often over several hours. CO combines with the blood to form carboxyhemoglobin (COHb). CO accumulates rapidly in the blood; however, the human body is extremely slow in reducing the COHb level in the blood, which may account for its toxic action. Ammonia is a pulmonary irritant and asphyxiant; nitrogen dioxide is both a pulmonary irritant and edemogenic agent.

5.13.7.4.3 Nitrogen oxides. Nitrogen oxides are also dangerous because they produce relatively little discomfort, yet even low concentrations can produce grave damage in the lower respiratory tract. Thus, exposed personnel may experience little irritation while breathing concentrations of nitrogen oxides which will, 12 to 24 hours later, prove fatal.

5.13.7.4.4 Concentrations. The presence of either carbon monoxide or ammonia in excessive concentration has been known to reduce the effectiveness of personnel 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 tolerable limits in personnel compartments. The current occupational health standard as established by the Occupational Safety and Health Administration (OSHA) as a time-weighted average (TWA) for 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 is a ceiling value, which should not be exceeded at any time. Regulations governing personnel exposure to the noxious substances listed above are stated in terms of TWA and ceilings found in Title 29 Code of Federal Regulations (CFR), Labor, Part 1910, OSHA Standards, and also in the Federal Register for recently promulgated revisions. The American Conference of Governmental Industrial Hygienists (ACGIH) also publishes a list of TWA values and short term exposure limits (STEL) from which many of the OSHA standards are taken. ACGIH values are established with consideration to the latest in scientific information. OSHA values require congressional approval which may cause a delay in their implementation. In the interim, discrepancies arising between OSHA and ACGIH TWA values should generally be settled by taking the more stringent of values for purposes of safety. The current ACGIH TWA value for NH_3 is 25 PPM, as compared to the OSHA TWA for NH_3 of 50 PPM. The current ACGIH TWA value for carbon monoxide is 25 ppm and for nitrogen dioxide is 3 ppm as compared to OSHA 50 ppm and 5 ppm respectively. The lower values should be used.

5.13.7.4.5 Evaluation of carbon monoxide toxic hazard. Present procedure governing evaluation of the toxic hazard in enclosed vehicles involves the determination of allowable exposure based upon a TWA of successive exposures over an 8-hour interval using the values (for all toxic elements) listed in the above noted CFR. Because it neglects to account for the CO actually inhaled by the exposed crew member, and it uses limit exposure values which may be inapplicable to the military population, that evaluative procedure is unrealistic. Some findings provide the assurance that non-smoking, healthy personnel will not experience any significant effects on mental acuity or physical ability which are attributable to CO exposures providing COHb levels up to 10% nor is their health impaired by such exposures. However, other experimental evidence suggests that visual acuity may degrade at or below COHb levels of approximately 5%. Because of both the uncertainties evident in the research findings and the critical nature of certain crew tasks involving visual perception (night flight operations), both systems design objective for all systems and the performance limit for aviation systems is specified to be a COHb level of not greater than 5% in MIL-STD-1472. The maximum acceptable CO exposure for personnel operating or maintaining equipment or systems other than aviation systems should be limited to values which will result in COHb blood levels not greater than 10%. The prediction of COHb blood content is determined by the following empirical equation:

$$\%\ COHb_t = \%\ COHb_o\ (e\ \exp\ (-t/A)) + 218\ (1 - e\ \exp\ (-t/A)) \times \left(\frac{1}{B} + \frac{ppm\ CO}{1403}\right)$$

where % $COHb_t$ is the predicted carboxyhemoglobin in the exposed individual; % $COHb_o$ is the amount of COHb usually found in non-smoking adults; t is the exposure duration in minutes; and ppm CO is the carbon monoxide exposure in parts per million of contaminated atmosphere; A and B are constants which are obtained from Table 36 and depend on the estimated physical activity level of the individual during the exposure. This equation accounts for the minute respiratory volume of contaminated atmosphere actually inhaled by an exposed individual whose level of physical activity is either estimated or specified. The equation also accounts for the elimination of CO by the body. It should be noted that the equation is applicable equally to short-duration high-level exposures as well as low-level exposures of long duration. It should be emphasized that the exposure magnitude, frequency and duration is unlimited provided the criterion specified by MIL-STD-1472 is met.

TABLE 36. Constants for predicting COHb blood content.

Work Effort Scale	Work Effort Description	A Value	B Value
1	Sedentary	425	806
2		241	1421
3	Light Work	175	1958
4		134	2553
5	Heavy Work	109	3144

5.13.7.4.6 Weapon combustion products. 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. Carbon monoxide concentrations can cause loss of mental alertness and even disorientation and collapse. Ammonia fumes are highly irritating and, even in small concentrations, produces eye watering.

5.13.7.4.7 Exhaust combustion products.

5.13.7.4.7.1 Composition. The composition of combat system exhaust gases varies with operating conditions. For example, concentrations of noxious substances are highest when starting and idling the engine in cold weather. In addition, exhaust composition depends on the loading conditions of the engine, the ambient temperature in which the engine is operating, and the type of fuel.

5.13.7.4.7.2 Exhaust products. The exhaust products of carbon monoxide and carbon dioxide occur no matter which fuel is used. In addition, when multi-fuel engines are using gasoline, the exhaust products include oxides of nitrogen, formaldehyde and acrolein. The exhaust products of engines operated on CITE, JP4, or kerosene, include aldehydes, water, hydrogen, and free carbon. When diesel fuel is used, the exhaust products include aldehydes, traces of nitrous oxides, sulphur compounds, oxygen, nitrogen, and methane. When multi-fuel engines are operated on CITE and diesel fuels, the exhaust products contain aldehydes which can cause 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 in vehicles in convoy, transportation of troops, and other situations where personnel are subjected to the exhaust stream of multi-fuel engines. Table 37 shows some of the noxious exhaust products of engine fuels.

TABLE 37. Noxious exhaust products of engine fuels.

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

5.13.7.4.7.3 Ventilation. Careful consideration should be given in designing vehicle 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. For maximum allowable concentrations of gases, vapors, fumes, and dusts, the more stringent of the OSHA or ACGIH recommendation should be used.

5.13.7.4.8 Chemical warfare agents. In the event of employment of chemical warfare (CW) agents by an enemy, the first consideration should be the adequate protection of forces, and second, the maintenance of the ability to continue operations. There are basically three ways to provide protection against CW agents:

a. Individual protection, generally consisting of a protective mask, protective clothing, and perhaps a decontamination kit.

b. Collective protection (operator or crew station), wherein each operator or crew member wears a protective mask connected to a centrally located gas particulate filter. The operator may or may not require protective clothing.

c. Collective protection (overpressure), wherein the collective protection system provides an overpressure in the entire personnel occupied compartment. Protective masks and clothing are not required to be worn.

Selection of the best method to provide protection against CW agents should be based upon the operational considerations, cost effectiveness, and the requirements documentation.

5.13.7.4.8.1 General. For ground troops, required to be in the environment during the accomplishment of their duties, the protective ensemble is the only feasible way to accomplish the required protection. However, in other situations, a choice can be made between crew or operator station collective protection and overpressure collective protection.

5.13.7.4.8.2 Overpressure collective protection system. Whereas all three methods will protect personnel, the overpressure collective protection system has distinct advantages over the other two for interior environments. Primarily, the advantage lies in the fact that the overpressure system eliminates the requirement for masks and protective clothing. This eliminates the encumbrance of this equipment and any compatibility problem with equipment to be operated (keyboards, switchboards, telephones, and optical equipment). Additionally, there is no problem of mask hose interference, or reduction of mobility. The advantage of the overpressure system is that the danger of interior compartment contamination is minimized, therefore minimizing the requirement to decontaminate the compartment and its contents. This aspect should not be considered lightly in view of the fact that (1) effective decontamination of electronic or optical equipment will be difficult if not impossible in the field, and (2) because of the intimate contact of the personnel with instruments and controls, as well as other interior surfaces of the compartment, contamination of the interior cannot be tolerated.

5.13.7.4.8.3 Protective ensemble. Wearing the protective ensemble (mask, hood, overgarment, and gloves) poses some serious problems in functional efficiency degradation. The overall ensemble imposes the problem of heat stress as body temperatures rise. This problem is directly related to the amount of exercise or physical activity of the wearer. Heat stress associated with the protective ensemble may be a particular problem in hot environments where vehicle interiors may be expected to reach extreme levels. An associated problem is the loss of visual field and of visual acuity. This is particularly true if there is an operational requirement for use of optical equipment wherein mask-instrument compatibility may well pose a problem. Another associated problem is that of mask lens fogging with attendant loss of vision. The protective gloves reduce tactility, thus the ability to perform rapid, accurate finger tasks, particularly in restricted spaces such as keyboards or control panels. The effect of degradation effected by the bulk of the protective ensemble should be evaluated as a function of the operator's tasks; in some cases this may not necessarily be a major consideration.

5.13.7.4.8.4 Testing. Human engineers should assure that appropriate sub-tests are conducted throughout the development and operational testing of new materiel which will be required to be operated by troops in a CW environment. These tests should have as their objective the quantification and qualification of performance by the operator(s) under toxic-free versus toxic environments. The data thus generated will be useful in evaluating criteria for changes in design and task completion times. They will have the further advantage of providing data to the trainer in the preparation of programs of instruction for the users in operation and maintenance.

5.13.7.5 Radiation. Potential hazards arising from nuclear, microwave, radio frequency, X, and laser radiation should be evaluated by specialized personnel trained in investigating and controlling such hazards.

5.13.7.5.1 General. Radiation problems are becoming increasingly important as new uses for radioactive materials and methods for handling them are developed. Radiation is extremely dangerous and its health hazards are well known. Protective devices, permissible dosages and dosage rates change as new data accumulate.

5.13.7.5.2 Microwave radiation. Reserved.

5.13.7.5.3 Nuclear radiation. To find the maximum nuclear radiation to which personnel may be exposed, designers should refer to Part 20, Title 10, Code of Federal Regulations.

5.13.7.6 Dust.

5.13.7.6.1 Dust concentration. The dust concentrations to which vehicle personnel are exposed vary widely from imperceptible levels to dense clouds which may reduce visibility to almost zero.

5.13.7.6.2 Ventilation system. The ventilation system intake should be located in an area where concentration of dust is minimal when the vehicle is moving. 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.

5.13.7.6.3 Personnel protection. Dust causes temporary eye and throat irritation and at times degrades performance and interferes with operations. Goggles and throw-away dust mask respirators should be provided for use where needed.

5.13.7.7 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.

5.13.7.8 Safety checklist. The checklist below (Table 38) summarizes the general areas designers should consider in protecting personnel and equipment. Several items are included here, although not discussed previously, because they seem so obvious that they tend to be overlooked. A NO answer to any question in the checklist means the equipment should be reevaluated to improve its safety characteristics.

TABLE 38. Safety checklist.

1. Do all moving parts of machinery and transmission equipment have mechanical guards?
2. Are edges of components and access openings either grounded or protected by rubber, fiber, or plastic?
3. Are there portable, hand-operated fire extinguishers near places where fires might occur?
4. Are fire extinguishers the correct type?
5. Are fire extinguishers located so they are readily accessible yet where fires will not block access to them?
6. In vehicles, is the correct type of fire extinguisher mounted on the vehicle at the driver's position?
7. Are audible signals distinctively recognizable and unlikely to be masked by other noises?
8. Are fault-warning systems designed to detect weak or failing parts before an emergency occurs?
9. Are the most critical warning lights grouped together within the operator's normal field of view and separated from other, less important lights?
10. Is the brightness of warning lights compatible with expected ambient illumination levels? (Personnel may not see dim lights in bright sunlight, but bright lights may interfere with dark adaptation.) Are dimmer controls used where necessary?
11. If operators must monitor a display continuously, but may not always be able to watch it, are there supplementary audible warnings?

TABLE 38. Safety checklist - continued.

12. Are covers over fuses transparent so personnel can check them without opening the cover or window?

13. Are indicators color-coded to show normal operating range and danger range?

14. Are warning circuits designed so they actually sense hazardous conditions rather than merely displaying the control settings?

15. Are go/no-go or fail-safe circuits used wherever possible to assure that failures will not produce hazards and that operators know when a failure has occurred?

16. Are discharging (bleeder) devices provided for high-energy capacitors which personnel may touch during maintenance?

17. Are any exposed dangerous voltages kept separated from internal controls such as switches and adjustment screws?

18. Are components and live wires that can store dangerous voltages, even when the equipment is off, located where a technician is not likely to touch them accidentally?

19. Are adjustment screws and commonly replaced parts located away from high-voltage or hot parts?

20. Are covers, structural members, and similar electrically neutral parts of electrical systems either grounded or protected so personnel and tools cannot touch them?

21. Are vehicle electrical systems designed to prevent sparking (or other conditions) that could ignite or explode combustible materials?

22. When tools and equipment are used in an explosive atmosphere, are they non-sparking and explosion-safe?

23. Are jacking and hoisting points identified clearly, conspicuously, and unambiguously?

24. Are all liquid, gas, and steam pipelines clearly labeled or coded to identify them and warn of any specific hazards to personnel or equipment?

25. Do hatches have a positive lock for the open position which is simple to operate yet can withstand all the rigorous requirements of a tactical vehicle in a combat situation?

26. Are struts and latches provided to keep hinged and sliding components from shifting and thus possibly injuring personnel during maintenance?

27. Do drawers and fold-out assemblies have limit stops that keep them from coming out too far, coming loose, or falling?

TABLE 38. Safety checklist - continued.

28. Are conspicuous warning notices mounted near high-voltage or very hot equipment?
29. When switches or controls initiate hazardous operations (such as ignition or crane moving), are they interlocked so a related or locking control must be released first?
30. Are safety interlocks used wherever necessary?
31. Are components located and mounted so maintainers have easy access to them without danger from electrical charges, heat, sharp edges and points, moving parts, and chemical contamination?
32. Are mechanical components with heavy springs designed so the springs cannot come loose and injure personnel or damage components?
33. Are warning plates provided where mechanical assemblies, linkages, or springs are under constant strain or load?
34. When equipment uses internal combustion engines, are the exhausts routed properly to keep carbon monoxide from accumulating in the cab?
35. Are exhausts for vans or trailers designed so gases are directed away from the enclosure or compartment?
36. Are exhaust pipes of internal combustion engines pointed upward to reduce the danger of igniting flammable liquids which may collect on the ground or floor?
37. When equipment may expose personnel to dangerous gases, are warning devices provided to signal when a dangerous concentration is approached?
38. Are vehicles and their components made of materials which will not produce hazards under severe operating conditions? (Some materials, e.g., cadmium and polytetrafluorethylene, emit toxic gases at extremely high temperatures; others may emit substances which are combustible or corrosive.)
39. Are vehicle warning lights provided to alert the driver to fire or excessive heat in areas that they cannot see?

5.13.8 Trainers. Reserved.

5.13.9 Stealth and covert operations. Reserved.

This Page Intentionally Left Blank.

5.14 Aerospace vehicle compartments.

5.14.1 General. Reserved.

5.14.2 Crewstations and passenger compartments. Reserved.

5.14.3 Personnel ingress and egress. Reserved.

5.14.4 Emergency evacuation. Reserved.

This Page Intentionally Left Blank.

5.15 User-computer interface.

5.15.1 General. Reserved.

5.15.2 Data entry. Reserved.

5.15.3 Data display. Reserved.

5.15.4 Interactive control. Reserved.

5.15.5 Feedback. Reserved.

5.15.6 Prompts. Reserved.

5.15.7 Defaults. Reserved.

5.15.8 Error management and data protection. Reserved.

5.15.9 System response time. Reserved.

5.15.10 Other requirements. Reserved.

5.15.11 Data and message transmission. Reserved.

This Page Intentionally Left Blank.

5.16 Visual display terminals. Reserved.

This Page Intentionally Left Blank.

5.17 Weapons systems.

5.17.1 Ammunition.

5.17.1.1 Projectile storage. The term "projectile" in this section is intended to mean a complete round. The ready rack should be designed so that several different types of ammunition can be stowed and removed without shifting other rounds and to minimize interference with the work area. Means should be provided to prevent stowed projectiles from dropping or impacting each other when the vehicle is moving or when the gun is fired. The design should provide for easy stowage and removal of ammunition by hoist or manual means. This should be an easy operation from the rear, side, or front sections of the rack. However, vehicle layout and ammunition rack design will determine the requirement for accessibility from the side or horizontal stowage.

5.17.1.2 Handling. Particular attention should be devoted to stowing ammunition when manual handling is required so that the gun may be loaded safely, rapidly and effectively. For example, if the rounds are stowed horizontally and parallel to the ramming trough, the individual loading the weapon may be required to turn around (180°) to place the projectile(s) into the trough. In such cases, the projectiles should be stowed with their noses pointing away from the breech so that both loader and projectile are oriented correctly when positioning the rounds in the ramming trough.

5.17.1.3 Projectile transfer. Unobstructed workspace should be provided for transferring the projectiles from outside the vehicle to the ready rack and from the ready rack to the breech. Provisions should also be made for disposing of empty shell cases in vehicles using fixed and semi-fixed ammunition.

5.17.1.4 Ammunition hoist. Where an ammunition hoist is used, the projectiles should be prevented from swinging about, thereby endangering personnel or damaging equipment. The ammunition hoist design should include a clamp to prevent accidental release of projectiles, provisions for manual operation of the hoist in case of power failure, and the capability of being stowed without interference with either the ramming trough or breech lock mechanism.

5.17.1.5 Ammunition stowage racks. Ammunition stowage racks, whether loaded or empty, should not impede escape from the crew compartment, obstruct access to controls, obscure displays, or interfere with the footing of crew members and should be located so personnel can remove and replace ammunition from the stowage rack without striking any protrusions.

5.17.1.5.1 Ready racks. Where ready racks are located to the rear of the gun breech, sufficient distance should 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, and an additional 50 mm channel.

5.17.1.5.2 Floor and hull. Floor and hull stowage tube-type ammunition racks should be spring-loaded so that stowed rounds will travel 50 mm out of the rack when the latching mechanism is released. Where spring-loading in not feasible, the end of the tube should be recessed to facilitate gripping by hand.

5.17.1.5.3 Upright mounts. Upright-mounted ammunition weighing over 18.1 kg should have a floor retainer which has sufficient clearance to allow removal by the 95th percentile gloved hand (see Figure 79).

5.17.1.5.4 Latching mechanisms. Ammunition rack latching mechanisms should be of a quick-release design which requires no more than 53 N to operate, and be free of sharp edges or protrusions which can snag clothing or injure personnel during entrance, exit, and movement within the vehicle. They 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. It should be apparent to personnel when the ammunition rack latching mechanisms are in the locked position but not secured. They should have a cushioning material to minimize transmission of undesired dynamic effects to secured rounds. The mechanism should not allow distortion, bursting or rupturing of the round or cartridge case and should prevent damage to the internal components of the missile or rounds.

5.17.1.6 Fuzes. The surface of hand-manipulated fuze controls should be 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 performance of the round.

5.17.1.6.1 Detents. 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. Sufficient resistance should be built into the setting to prevent the inadvertent change of settings.

5.17.1.6.2 Pointers. Markings and pointers should contrast maximally with their backgrounds and should correspond in color, if possible. The pointer tip and index should not be separated by more than 1.5 mm.

5.17.1.6.3 Multi-position selectors. The multi-position selectors should be designed to resist changes of operator settings which may result from the rotational force imparted by the round either during firing or while in flight. Designing the selector mechanism so that linear acceleration will lock the selector in place will prevent such accidental changes in setting.

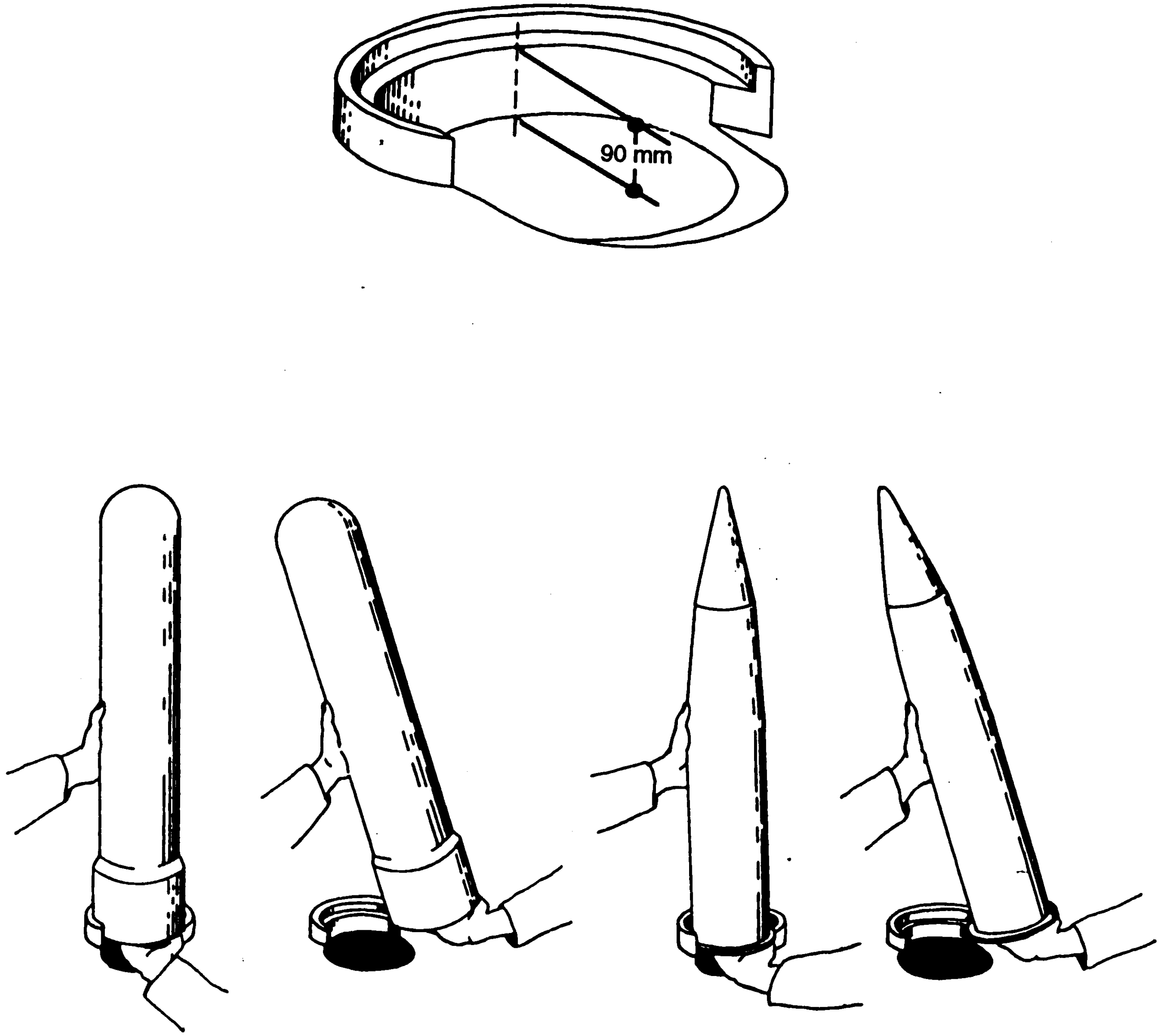


FIGURE 79. Retainers for floor mounted vertical ammunition and missile ready racks.

5.17.2 Armament.

5.17.2.1 Primary armament. Main armament loading procedures should be reversible for efficient and safe round removal. In addition, provision should be made to minimize vibrations of the gunner’s sight from the shock of loading main armament.

5.17.2.1.1 Breech design. A breech weighing over 22.5 kg should not be considered manually removable. For manual breech operation, the operating force should not exceed 130 N for one-handed operation and 220 N for two-handed operations. The controls for power operated breeches should be located away from the breech to protect personnel when the breech is in operation. Stored mechanical energy in the breech block which, if released, could injure the hand, should be protected by interlock from accidental actuation. 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.

5.17.2.1.2 Maintenance. Main armament machined surfaces should be protected from the environment to minimize maintenance requirements. Crew maintenance of the main armament should not require special tools. In addition, the main armament chamber should be capable of being cleaned by suitably-clothed and suitably-equipped personnel with applicable body dimensions between the 5th and 95th percentile. Servicing polished machine surfaces should not require removing the gun tube. The breech design should provide drains where necessary to preclude trapping cleaning fluids.

5.17.2.1.3 Expended rounds. Casing ejection should not endanger personnel or equipment. Space should be provided to store expended casings within the fighting compartment of a means should be incorporated into the design to allow disposal of these casings by another method.

5.17.2.1.4 Boresighting. Boresighting should be capable of being accomplished by the naked eye and without use of tools from within the fighting compartment and without disassembly in order to achieve the specified convergence with the line of sight or to be parallel with the line of sight. Quadrants and other devices mounted on the main armament should be accessible to the gunner throughout the maximum and minimum elevation and depression.

5.17.2.1.5 Electrical components. The potential of electrical power components should be capable of being de-energized at the primary power source. Shielding should be provided to prevent accidental contact with other wires and electromagnetic pulse. A disconnect capability should be provided at the powered component and power source.

5.17.2.2 Secondary armament.

5.17.2.2.1 Removal and replacement. The secondary weapon should be capable of being mounted on the vehicle by crew members from a natural working position with the weapon fully assembled. This armament should be capable of being removed or replaced without the use of tools. The number of turns required for installing or removing threaded fastening devices should be the minimum for proper component functioning.

5.17.2.2.2 Retaining devices. All secondary armament retaining devices (pins or bolts) should be captive or attached to their mounts by a chain or similar captive device. All retaining pins should be provided with L-shaped handles to expedite their removal under conditions or binding or corrosion. In addition, clamps or similar weapon retaining devices should be hinged to clamps or similar weapon retaining devices should be hinged to swing away from the mount and should be the quick-disconnect type.

5.17.2.2.3 Ground mount operation. The secondary armament should be capable of being removed and put into the ground mount while hot. The pintle should be capable of remaining attached to the weapon, be designed to position itself by gravity, and should not need to be held by hand when positioned into the ground mount.

5.17.2.2.4 Sights. For ground mount operation sights, the rear sight notch should be 3 mm or wider and the front sight should be wide enough to fill the notch when taking sight pictures.

5.17.2.2.5 Assembly and disassembly. The secondary armament should be designed in such a manner that barrels are not capable of incorrect assembly and are capable of being changed from the inside of the fighting compartment without affecting the boresight. The design should include spring-loaded retainers, releases, and detents capable of being released by the use of the finger only. 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. After servicing, the weapon should be capable of being dry-fired without damage to ancillary parts.

5.17.2.2.6 Solenoids. Solenoids should be capable of activating the firing mechanism of the weapon both manually and electrically. When checked electrically, the solenoid should produce an audible click or visual signal to indicate that it is functioning. Solenoids should be adjustable or an adjustment should be provided in the linkage, limiting or compensating for tolerance build-up or have sufficient plunger and armature travel to eliminate the need for adjustment.

5.17.2.2.7 Solenoid removal and replacement. Removing and replacing solenoids should not require extensive assembly or disassembly of the weapon. In general, wiring and connectors should be easily removable and mounted such that they will not be caught in turret rings or gun breeches. Wiring should be protected against abrading through abuse or striking a surface when personnel are removing, replacing, or servicing the weapon. To guard against misconnection, the solenoid should have an electrical connector designed to eliminate reverse polarity.

5.17.2.2.8 Operation. A weapon should be capable of being loaded without being cocked, but where this is not possible, a positive lock should be provided on the firing mechanism. The weapon should be capable of being loaded by a 5th and 95th percentile hand in both the vehicle and the ground mount. It is desirable to have a weapon that does not require headspace or timing, but where these are required, a simple go/no-go system should be used to determine correct headspace and timing. A non-destructive feedback is desirable to indicate whether the headspace or timing is correct.

5.17.2.2.8.1 Charging. The weapon should be capable of being charged by suitably-clothed and suitably-equipped user personnel with applicable body dimensions between the 5th and 95th percentile. For ground mount weapons, charging may take place while in the prone position. Where wires or chains are used to charge the weapon, the action of charging should be a non-directional reaction to an applied force. Straight back pull to charge should not be required. Charging resistance should not exceed 340 N•m breakaway or 80 N•m sustained.

5.17.2.2.8.2 Expended rounds. Expended brass and links should be caught by a spent brass container or be ejected outside the fighting compartment. The trajectory and path of the ejected casings should be such that ejection will not injure a crew member, interfere with crew operations, or affect other equipment. The weapon design should permit removing jammed cases simply and quickly by suitably-clothed and suitably-equipped user personnel with applicable body dimensions between the 5th and 95th percentile without disassembly the weapon and without endangering the hand. If a tool is required, it is desirable to have it mounted to, or be captive to, the weapon on which is to be used.

5.17.2.2.8.3 Ammunition chutes. Flexible ammunition-chute openings should be large enough to allow the ammunition to be guided through the chute by a 5th to 95th percentile hand and should be free of sharp edges which could cut the hands of personnel during loading operation.

5.17.2.2.8.4 General. Rate selectors, safeties, or triggers should be clearly identified to indicate their position and should be of sufficient size and resistance to accommodate a 5th and 95th percentile arctic-clothed hand. Detents should be provided for each position on rate selectors or safeties.

5.17.2.3 Small arms.

5.17.2.3.1 General. In this section the term "user" refers to the rifleman or gunner, as appropriate.

a. Weapons should be designed so suitably-clothed and suitably-equipped user personnel, with applicable body dimensions between the 5th and 95th percentiles, can perform all required tasks (both field operations and maintenance) easily and efficiently in daylight and at night, and in either the standing or prone position.

b. When the user must reassemble parts under field conditions, their mating surfaces should be beveled to simplify assembly.

c. Surfaces of the weapon or its attachments that normally contact the user's body or clothing during firing or maneuvering should be smooth, without sharp edges or discontinuities.

d. Any part of the weapon or attachments that contacts the user's skin should have thermal insulation.

e. Weapon design should minimize projections that could impede movement through dense vegetation. Unavoidable projections (such as the front sight post) should be angled toward the back of the weapon rather than perpendicular to its barrel.

f. A weapon's controls or latches should be designed and located so they will not be operated unintentionally during fire or maneuver.

g. Weapons should be designed so users will not damage them by operating controls in the wrong sequence or by using full hand force.

h. Weapons should be designed so parts cannot be assembled improperly.

i. Weapon controls should be sufficiently sturdy and durable to prevent damage from normal handling in the field.

j. Whenever the user is likely to remove retaining pons during field operations or maintenance, captive hardware should be used to prevent pin loss.

k. A weapon's safety should be located so the user can change from SAFE to FIRE (and vice versa) quickly, without moving either hand from its normal firing position.

l. Weapon controls should have distinctive shapes and locations to simplify their identification and use during stressful situations.

m. Safety should be designed into weapons by assuring that no part of the weapon:

   (1) could endanger the user's face during firing if the head is held in the proper eye-sight position, and

   (2) encourages the users to fire their weapon in an unorthodox way that might cause injuries.

5.17.2.3.2 <u>Rifles and machine guns.</u>

a. Figure 80 shows an acceptable range of dimensions for rifles and machine guns.

b. The charging handle should not interfere with the bolt during firing.

c. Magazines should be designed so that:

(1) they can only be loaded correctly (not with cartridges facing the wrong way);

(2) they can be held with one hand, and have a non-slip finish on surfaces the user will hold during all handling operations;

(3) loading requires only inserting the magazine and charging the weapon (but no additional human tasks); and

(4) a particular loading pattern is not required, however, where this is unavoidable, a magazine loading diagram should be provided.

d. When a bipod is used, it should be designed so that:

(1) the user wearing arctic mittens can extend or retract the bipod easily and quickly;

(2) recoil and stresses of field maneuvering will not disturb the bipod's extended or retracted setting;

(3) with bipod retracted, the user should be able to grasp the foregrip without obstruction, in either the prone or standing assault position. In addition, the bipod should accommodate uneven terrain without cant; and

(4) when attached to the weapon, but retracted, the bipod should to tangle with vegetation.

e. The rear sight should be designed so that:

(1) all component parts are positively retained;

(2) the rear aperture and other parts remain secure during the stresses of carrying and firing;

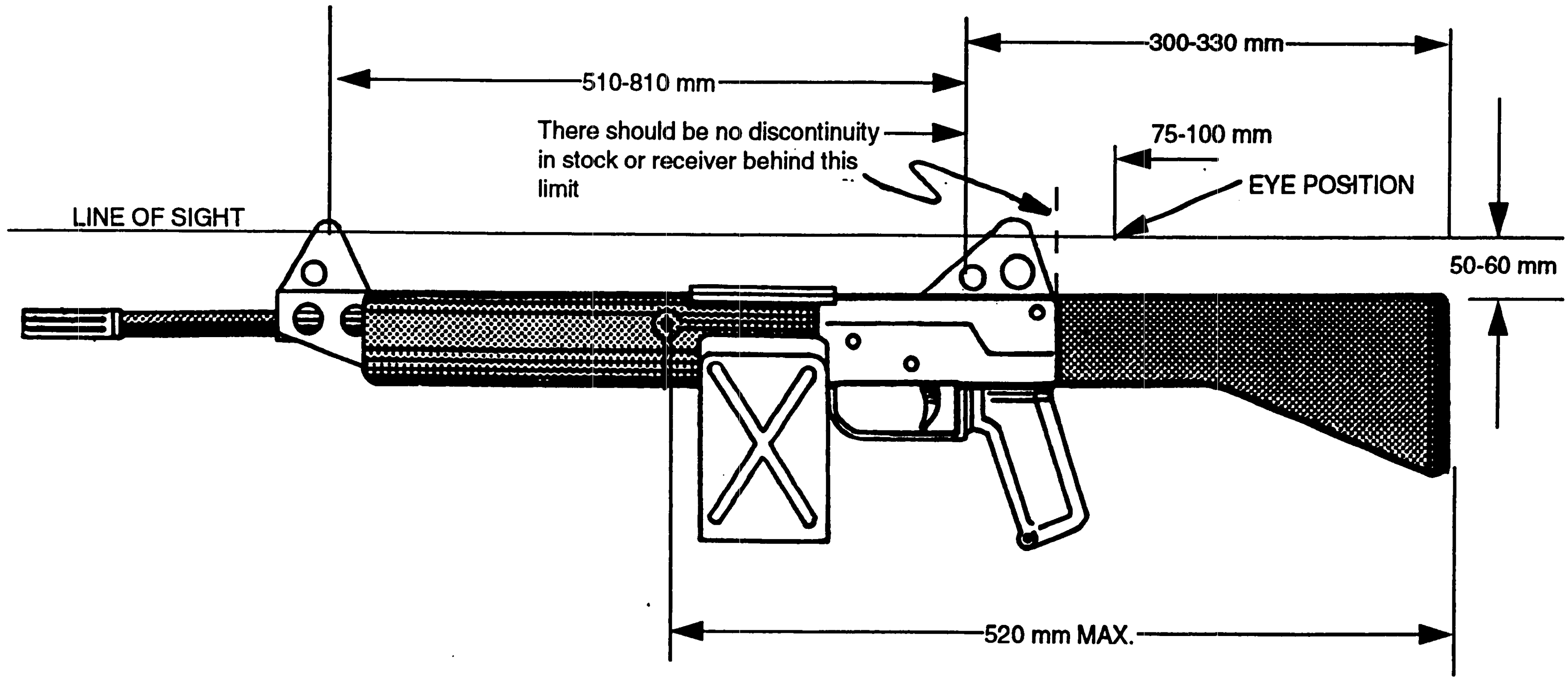


FIGURE 80. Dimensions guidance for rifles and machine guns.

(3) windage and elevation controls have detents to prevent disturbing of settings as a result of combat stresses of carrying and firing;

(4) the design should allow the user wearing arctic mittens to set windage and elevation controls quickly, easily, and precisely, without tools;

(5) windage and elevation controls can be clearly differentiated to minimize confusion;

(6) windage and elevation control settings are immediately obvious, in daylight, when the user is in any normal firing position; and

(7) the user, when in a normal firing position, is able to verify setting quickly without moving the body or the weapon, manipulating any sight component, counting, or requiring visual or auditory cues.

f. Weapons should eject expended cases into the first quadrant (forward and to the right).

6. NOTES

6.1 Intended use. This handbook is intended to provide non-binding human engineering guidelines, preferred practices, and reference data for design of military materiel, both in-house and contracted, during any phase of acquisition, as appropriate, to facilitate achievement of objectives stated in human engineering policy documents. The handbook also serves to provide expanded, supplementary, and relevant human engineering information that may be too detailed, lengthy, or service-oriented for inclusion in military standards, such as MIL-STD-1472.

6.2 Subject term (key word) listing.

Armament
Anthropometry
Communications
Consoles
Controls
Control-display integration
Displays
Environment
Ergonomics
Hazards
Human engineering
Labeling
Maintainability
Safety
User-computer interface
Vehicles
Workspace

6.3 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

This Page Intentionally Left Blank.

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

CONCLUDING MATERIAL

Custodians
- Army - MI
- Navy - AS
- Air Force 11

Preparing Activity:
- Army - MI

(Project HFAC-A025)

Review Activities
- Army - AL, AM, AR, AT, AV, CR, EA, ER, GL, ME
  MD, PT, SC, TE, TM
- Navy - EC, MC, OS, PE, SH, TD, YD
- Air Force - 13, 19
- DoD - HS, IQ, WS

Civilian Agencies
- NASA - MSFC
- DOT - FAA