



Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities¹

This standard is issued under the fixed designation F 1166; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice establishes general human engineering design criteria for marine vessels, and systems, subsystems, and equipment contained therein. It provides a useful tool for the designer to incorporate human capabilities into a design.

1.2 The purpose of this practice is to present human engineering design criteria, principles, and practices to achieve mission success through integration of the human into the vessel system, subsystem, and equipment with the goals of effectiveness, simplicity, efficiency, reliability, and safety for operation, training, and maintenance.

1.3 This practice applies to the design of vessels, systems, subsystems, and equipment. Nothing in this practice shall be construed as limiting the selection of hardware, materials, or processes to the specific items described herein. Unless otherwise stated in specific provisions, this practice is applicable to design of vessel systems, subsystems, and equipment for use by both men and women.

1.4 Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

1.5 This practice is not intended to be a criterion for limiting use of material already in the field in areas such as lift repetition or temperature exposure time.

1.6 **Force Limits**—If it is known that an item is to be used by an already established occupational specialty, for which physical qualification requirements for entry into that specialty are also established, any discrepancy between the force criteria of this practice and the physical qualification requirements shall 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, is selected as a maximum design force limit.

1.7 **Manufacturing Tolerances**—When manufacturing tolerances are not perceptible to the user, this practice shall not be construed as preventing the use of components whose dimensions are within a normal manufacturing upper or lower limit tolerance of the dimensions specified herein.

1.8 This practice is divided into the following sections:

TABLE OF CONTENTS

Section	Title
1	Scope
2	Referenced Documents
3	Terminology
4	Significance and Use
5	Control/Display Integration
6	Visual Displays, General Information
7	Location and Arrangement of Visual Displays
8	Coding of Visual Displays
9	Transilluminated Displays
10	Scale Indicators
11	Cathode Ray Tube (CRT) Displays
12	Large-Screen Displays
13	Other Displays
14	Audio Displays, General Information
15	Audio Warnings
16	Characteristics of Audible Alarms
17	Signal Characteristics in Relation to Operational Conditions and Objectives
18	Verbal Warning Signals
19	Controls for Audio Warning and Caution Devices
20	Speech Transmission Equipment
21	Controls, General Information
22	Arrangement and Grouping of Controls
23	Coding of Controls
24	Rotary Controls
25	Discrete Linear Controls
26	Continuous Adjustment Linear Controls
27	General Requirements for Labeling
28	Label Content
29	Specific Requirements by Label Type
30	Anthropometry
31	Workspace Design Requirements
32	Environment
33	Maintainability
34	Accessibility
35	Cases
36	Lubrication
37	Fasteners
38	Unit Design for Efficient Manual Handling
39	Handwheel Torque
40	Equipment Mounting
41	Conductors
42	Connectors
43	Electrical Wires and Cables

¹ This specification is under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and is the direct responsibility of Subcommittee F25.07 on General Requirements.

Current edition approved June 1, 2006. Published June 2006. Originally approved in 1988. Last previous edition approved in 2000 as F 1166 – 95a (2000).



TABLE OF CONTENTS

Section	Title
44	Test Points
45	Test Equipment
46	Failure Indications and Fuse Requirements
47	Hydraulic Systems
48	Design of Equipment For Remote Handling
49	Small Systems and Equipment
50	Operational and Maintenance Vehicles
51	Hazards and Safety
52	User-Computer Interface
53	Data Display
54	Text/Program Editing
55	Audio Displays, Interface
56	Interactive Control

LIST OF FIGURES

Figure	Title
1	Angle of Incidence
2	Example of Display/Equipment Relationship in Main Propulsion Engine Room with Two Medium Speed Diesel Engines
3	Example of Control/Display/Equipment Relationship in Auxiliary Machinery Space with Two Ship Service Generators
4	Example of Control/Display/Equipment Relationship in Machinery Space with Pump, Motor Controller, and Gage Board Located at Vertical Beam
5	CHT Pump Room with Various Options for Locating the Two Motor Controllers and Their Corresponding Gage Boards Given the Location of the Two Pumps
6	Preferred and Acceptable Alternatives for Multiple Row/Column Display and Control Arrangement
7	Vertical and Horizontal Visual Field
8	Lines of Sight
9	Scale of Markings
10	Scale Graduation, Pointer Position, and Scale Numbering Alternatives
11	Fixed-Scale Azimuth Dials
12	Shape and Color Coding Operating Ranges
13	Zero Position and Pointer Movement for Circular Dial Displays
14	Aligned Pointers for Rapid Check Readings
15	Relative Position of Scale Marks, Numerals, and Pointers on Circular Dials
16	Relative Position of Scale Marks, Numerals, and Pointers on Arcs and Circular Dials
17	Drum-Type Counter Design
18	Acceptable Alarm Types for Emergency and Primary Alarms
19	Control Motion Expectancy
20	Foot-Operated Switches
21	Pedals
22	Foot-Operated Controls
23	Leg Strength at Various Knee and Thigh Angles
24	Rotary Selector Controls
25	Rotating Knob Separation
26	Keylock Criteria
27	Keylock Switch Criteria
28	Thumbwheel Orientation and Movement
29	Discrete Thumbwheel Control
30	Knobs
31	Recommended Knob Shapes
32	Easily Recognizable Knob Shapes
33	Ganged Knobs
34	Thumbwheel Adjustment Controls
35	Cranks
36	Proper Mounting of Rapidly Operated Cranks
37	Handwheels
38	Recommended Mounting Heights for Valve Handwheels
39	Reaching Limits for Bending, Squatting, or Standing on Ladders
40	Pushbutton Switches
41	Toggle Switches
42	Toggle Switch Orientation for "ON"
43	Legend Switch
44	Rocker Switches
45	Slide Switches
46	Push-Pull Controls
47	Lever
48	Slide Levers
49	Isotonic Joysticks
50	Ball Controls

LIST OF FIGURES

Figure	Title
51	Independent Symbols
52	Label Specifications
53	Standing Body Dimensions
54	Seated Body Dimensions
55	Depth and Breadth Dimensions
56	Circumferences and Surface Dimensions
57	Hand and Foot Dimensions
58	Head and Face Dimensions
59	Anthropometric Data for Body Positions Involved in Work Activities
60	95th Percentile Gloved-Hand Dimensions (Male)
61	Helmet Dimensions
62	Aircrewman's Helmet (Size Extra Large)
63	Range of Human Motion
64	Mobile Workspace Dimensions
65	Standing Workspace Dimensions—Cabinets and Electrical Equipment Racks
66	Standing Workspace Dimension—CRTs and Table
67	Standing Workspace Dimensions—Consoles and Work Benches
68	Standing Workspace for Typical Work Positions
69	Display (Top) and Control (Bottom) Locations for Standing Crew Work Stations
70	Seated Workspace Dimensions
71	Dimensions for Single or Multiple Personnel at a Table or Other Duty Station Not Requiring a Desk
72	Seating at CRT-Type Work Stations
73	Swing-Away Seat for Short-Term Operations
74	Standard Console Dimensions Key
75	Example of One- or Two-Tier Wrap-Around Console
76	Examples of Three-Tier Consoles
77	Example of a Desk Top Console
78	Preferred Viewing Area
79	Seated Optimum Manual Control Space
80	Type of Ladder, Stair, or Ramp to be Used in Relation to Angle of Ascent
81	Stair Dimensions
82	Incline-Ladder Dimensions
83	Vertical-Ladder Dimensions
84	Well-Designed Work Platform
85	Door Dimensions
86	Hatches Mounted Overhead
87	Hatches Mounted on Vertical Walls
88	Hatch Dimensions
89	Walkway and Passageway Dimensions
90	Effective Temperature Scale
91	Windchill Chart
92	Equivalent Chill Temperature
93	Ventilation Requirements
94	Workspace Reflectance Values
95	Permissible Distance Between a Speaker and Listener's for Specified Voice Levels and Ambient Noise Levels
96	Range of Acceptable Reverberation Time
97	Vibration Exposure Criteria for Longitudinal (Upper Figure) and Transverse (Lower Figure) Directions with Respect to Body Axis
98	The 90 % Motion Sickness Protection Limits for Human Exposure to Very Low Frequency Vibration
99	Standing, Lateral Reach (Preferred Arm)
100	Seated, Forward Reach (Both Arms)
101	Crosslegged Seated, Forward Reach (Both Arms)
102	Standing, Forward Reach (Both Arms)
103	Standing, Forward Reach (Preferred Arm)
104	Access Opening Dimensions
105	Minimal Two-Hand and Finger Access
106	Covers and Accesses
107	Covers and Cases
108	Examples of Push-Pull Forces
109	Minimum Handle Dimensions
110	Handwheel Torque
111	Methods of Identifying Plugs and Receptacles to Prevent Mismatching
112	Cable Arrangements
113	Suggested Cable Arrangement in Junction Box for Easy Checking
114	Preformed Cables
115	Fluid Line Connector Recommendations
116	Anatomical Limits on Axially Symmetrical Ocular Metal Part
117	Mounting Heights for Common Electrical Fixtures



LIST OF FIGURES

Figure	Title
118	Required Distance Between Hazard and Barrier

LIST OF TABLES

Table	Title
1	Metric Equivalents, Abbreviations, and Prefixes
2	Coding of Simple Indicator Lights
3	Application of Various Types of Mechanical Displays
4	Character Sizes for Mechanical Counters
5	Group Viewing of Optical Projection Displays
6	Range Ring Values
7	Functional Evaluation of Audio Signals
8	Intelligibility Criteria for Voice Communications Systems
9	Control Selection Criteria
10	Recommended Manual Controls
11	Conventional Control Movement Stereotypes
12	Minimum Separation Distances for Controls
13	Advantages and Disadvantages of Various Types of Coding
14	Recommended Control Colors (FED-STD-595)
15	Knob Detentes Placement
16	Keyboards, Inch-pound Units
17	Keyboards, SI Units
18	Limiting Dimensions for Free-Moving X-Y Controller
19	Arm Strength
20	Hand and Thumb-Finger Strength
21	Character Size Versus Luminance
22	Anthropometric Data
23	Range of Human Motion
24	Mobile Work Space Dimensions
25	Standing Work Space Dimensions for Work Clearances
26	Seated Work Space Dimensions
27	Standard Console Dimensions
28	Human Performance Effects at Various Effective Temperatures
29	Physical and Perceptual Responses to Various Temperatures
30	Temperature and Its Effect on the Comfort of the Extremities
31	Human Reaction to Windchill
32	Specific Task Illumination Requirements
33	Recommendations for Display Lighting
34	Low-Frequency and Infrasonic Noise Limits to Prevent Ear Injury
35	Sound Exposure to Avoid Deafness
36	Maximum Permissible Sound Pressure Level
37	OSHA Permissible Daily Noise
38	Effects of Noise on Human Performance
39	Effects of High-Level Noise on Human Performance
40	Upper Noise Limits Recommended for Military Facilities
41	Comfort Limits for Noise by Octave Band
42	Noxious Exhaust Products of Engine Fuels
43	Design Weight Limits
44	Static Muscle Strength Data
45	Weight and Dimensions of Portable Test Equipment
46	General Comparison Fuses and Circuit Breakers
47	Recommended Clearances Around Equipment Operator's Station to Accommodate 95th Percentile Male Dressed in Arctic Clothing. Operator Seat in Rear Most Position
48	Temperature Limits
49	Shock Current Intensities and Their Probable Effects
50	Allowable Exposure Limits to Some Toxic Gases
51	System Response Times

2. Referenced Documents

2.1 ASTM Standards:²

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 Military Specifications:

MIL-C-25050, Colors, Aeronautical Lights and Lighting Equipment, General Requirements for³

2.3 Federal Standard:

FED-STD-595 Color³

2.4 Military Standards:

MIL-STD-12, Abbreviation for Use on Drawings, Specifications, Standards, and in Technical Documents³

MIL-STD-740, Airborne and Structureborne Noise Measurements and Acceptance Criteria of Shipboard Equipment³

2.5 Military Handbook:

DOD-HDBK-743, Anthropometry of US Military Personnel³

2.6 Federal Regulations:

29 CFR 1910, Occupational Safety and Health Standards⁴

46 CFR 113.25-9, U.S. Coast Guard Regulation⁴

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 abort—a capability that cancels all user entries in a defined transaction sequence.

3.1.2 accessible—unless otherwise specified herein or where specific design values are given, an item is considered accessible only where it can be operated, manipulated, removed, or replaced by the suitably clothed and equipped user with applicable fifth and ninety-fifth percentile body dimensions. Applicable body dimensions are those dimensions that are design critical to the operation, manipulation, removal, or replacement task. For example, an adjustment control behind an access opening should be located sufficiently close to the aperture to enable a suitably clothed and equipped user with a fifth percentile depth of reach to grasp and manipulate the adjustment control, while the opening should be sufficiently large to enable passage of a similarly clothed and equipped ninety-fifth percentile hand and arm.

3.1.3 advisory signal—a signal that indicates safe or normal configuration, condition of performance, operation of essential equipment, or that attracts attention and imparts information for routine action purposes.

3.1.4 angle of incidence—the angle between the line of direction of anything (such as a ray of light or line of sight) striking a surface and a line perpendicular to that surface drawn to the point of contact as shown in **Fig. 1**.

⁴ Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

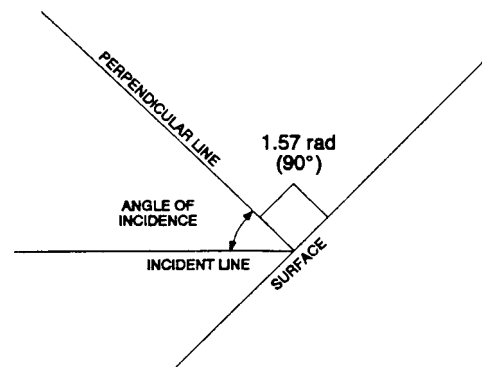


FIG. 1 Angle of Incidence

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.



3.1.5 *backup*—a capability that returns a user to the last previous display in a defined transaction sequence. Also refers to the practice of preserving a second copy of files for data protection purposes.

3.1.6 *brightness*—the amount of emitted or reflected light visible to the eye.

3.1.7 *cancel*—a capability that regenerates or reinitializes the current display without processing or retaining any changes made by the user.

3.1.8 *caution signal*—a signal that alerts the operator to an impending hazardous condition requiring attention, but not necessarily immediate action.

3.1.9 *command and control system equipment*—the main mission element equipment and related ground equipment used in collecting, transmitting, processing, and displaying information for command and control.

3.1.10 *command language*—a type of dialogue in which a user composes control entries with minimal prompting by the computer.

3.1.11 *common hand tools*—items of tools found in common usage or applicable to a variety of operations or to a single operation on a variety of material. Screwdrivers, hammers, and wrenches are examples of common hand tools.

3.1.12 *control entry*—user input for sequence control, such as function key actuation, menu selection, command entry, and so forth.

3.1.13 *data*—the raw materials from which a user extracts information. Data may include numbers, words, pictures, and so forth.

3.1.14 *data display*—output of data from a computer to its users. Generally, the phrase denotes visual output, but it may be qualified to indicate a different modality, such as “auditory display.”

3.1.15 *data entry*—user input of data for computer processing and computer responses to such inputs.

3.1.16 *data field*—an area of the display screen reserved for user entry of a data item.

3.1.17 *data item*—a set of characters of fixed or variable length that forms a single unit of data. Examples of a data item might be a person’s name or a zip code. Data items may be entered by a user or may be supplied by the computer.

3.1.18 *data protection*—functional capabilities that guard against unauthorized data access and tampering, user errors, and computer failure.

3.1.19 *4a decibel (dB)*—sound level, measured between acoustic signals, equal to ten times the common logarithm of the ratio of the two levels.

3.1.20 *4a dB (A)*—the sound level measured through the A-weighting network of a sound level meter.

3.1.21 *de-emphasis*—the inverse of preemphasis, used for the purpose of restoring original vowel-consonant amplitude relationships in preemphasized speech; primarily useful in maintaining the “natural” sound quality. (See 3.1.56)

3.1.22 *default value*—a predetermined, frequently used value for a data field or control entry, intended to reduce required user entry actions.

3.1.23 *dialogue*—a structured series of interchanges between a user and a computer terminal. Dialogues can be computer initiated, for example, question and answer, or user initiated, for example, command languages.

3.1.24 *dichotic*—the condition in which the sound stimulus presented at one ear differs from the sound stimulus presented at the other ear. The stimulus may differ in sound pressure, frequency, phase, time, duration, or bandwidth.

3.1.25 *display format*—the organization of different types of data in a display, including information about the data such as labels, and other user guidance such as prompts, error messages, and so forth.

3.1.26 *effective temperature (ET)*—a single value combining the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air, that would induce an identical sensation.

3.1.27 *emergency*—a condition of danger that requires immediate action.

3.1.28 *emergency alarm*—an alarm that indicates that danger exists and that immediate action must be taken. They include the general emergency alarm, fire alarms, those alarms giving warning of personnel hazard; including fire-extinguishing medium alarm, power-operated sliding watertight door closure alarm, and fire detection alarm.

3.1.29 *enter*—an explicit user action that effects computer processing of user entries. For example, after typing a series of numbers, a user might press an ENTER key that will add them to a database, subject to data validation.

3.1.30 *equipment*—general term designating any item or group of items.

3.1.31 *equipment failure*—the cessation of the ability to meet the minimum performance requirements of the equipment specifications. Further, equipment failure shall imply that the minimum specified performance cannot be restored through permissible readjustment of operator controls.

3.1.32 *facilities*—a physical plant, such as real estate and improvements thereto, including building and equipment, which provides the means for assisting or making easier the performance of a system function. The facilities to which this practice apply are those in which personnel perform system operational or maintenance duties.

3.1.33 *fail-safe design*—a design that, upon failure or malfunction of a component, subsystem, or system, automatically reverts to a predetermined design state of least critical consequence.

3.1.34 *field*—see 3.1.16.

3.1.35 *file*—a collection of data, treated as a single unit, that is stored in a computer.

3.1.36 *function key*—a key whose actuation will effect a control entry.

3.1.37 *help*—a capability that displays information upon user request for on-line guidance. HELP may inform a user generally about system capabilities or may provide more specific guidance in information-handling transactions.

3.1.38 *highlighting*—emphasizing displayed data or format features in some way, for example, through the use of underlining, bolding, or inverse video.



3.1.39 *human engineering design criteria*—the summation of available knowledge that defines the nature and limits of human capabilities as they relate to the checkout, operation, maintenance, or control of systems or equipment, to achieve optimum compatibility between equipment and human performance.

3.1.40 *information*—organized data that users need to perform their tasks successfully. Information serves as an answer to a user's questions about data. It is used here to refer to the effective assimilation of data by a user.

3.1.41 *interrupt*—stopping an ongoing transaction to redirect the course of the processing. Examples of interrupt options are ABORT, BACKUP, CANCEL, and RESTART.

3.1.42 *legibility*—the ability to see and identify the alphanumeric characters, symbols, or other visual information on a display.

3.1.43 *luminance contrast*—the contrast between background and a figure equals the absolute difference between the higher luminance, L_1 , and the lower luminance, L_2 , divided by the higher luminance; that is, $C = (L_1 - L_2)/L_1$. Conversions to the other contrast formulae are as follows:

L_1 (brighter)	L_2 (dimmer)	$L_1 - L_2 / L_2$	$L_1 - L_2 / L_1$	$L_1 - L_2 / L_1 + L_2$	L_1 / L_2
100	150	1.0	0.50 (50 %)	0.33	2.0
100	25	3.0	0.75 (75 %)	0.60	4.0
100	10	9.0	0.90 (90 %)	0.82	10.0

3.1.44 *luminance ratio (LR)*—the difference in luminance between the target subject and the surrounding field or background. For projection systems, the luminance ratio is equal to the light output of a projector (measured with no film in the projector) reflected off the screen (image luminance) divided by all the light falling on the screen (measured from the greatest viewing angle) other than that actually forming the image (non-image or background); as follows:

$$LR = L/L_n \quad (1)$$

where:

L = image or subject luminance and

L_n = non-image or background luminance.

3.1.45 *macro*—the capability to allow the user to assign a single name or function key to a defined series of commands for use with subsequent command entry. Sometimes called “smartkey.” Examples of use are storage of addresses or signature blocks that are frequently used.

3.1.46 *maintainability design*—design considerations directed toward achieving those combined characteristics of the equipment and human beings that will enable the accomplishment of necessary maintenance quickly, safely, accurately, and effectively with minimum requirements for personnel, skills, special tools, and cost.

3.1.47 *master caution (warning) signal*—a signal that indicates that one or more caution (warning) lights has been actuated.

3.1.48 *menu selection*—a type of dialogue in which the user selects one item out of a list of displayed alternatives, whether

the selection is by pointing, by entry of an associated option code, or by actuation of an assigned function key.

3.1.49 *metric equivalents, abbreviations, and prefixes*—**Table 1** has been used herein to reflect the International System of Units (SI).

3.1.50 *noise-cancelling (microphone)*—a feature that reduces the masking effect of ambient noise upon speech impressed on a microphone, usually by providing equal access of the ambient noise to both surfaces of a diaphragm to achieve approximate equilibrium, effectively causing the noise to cancel itself out. Since the talker's own voice output impinges on only one side of the microphone diaphragm, the talker's signals are not subject to this cancellation, and are transmitted more favorably than if both ambient noise and speech fell simultaneously upon one face of the diaphragm.

3.1.51 *nuclear, biological, chemical (NBC), and other contaminated environment survivability*—NBC survivability includes both the instantaneous, cumulative, and residual effects of NBC weapons or environmental contamination upon a system, including its personnel. NBC or other environmental survivability describes the capability of a system to withstand the NBC environment, including decontamination, without losing the ability to accomplish its mission. For any system to be considered survivable in a contaminated environment, it must have at least three essential characteristics: decontaminability, hardness, and compatibility.

decontaminability—the ability of a system to be rapidly

TABLE 1 Metric Equivalents, Abbreviations, and Prefixes

NOTE—Each conversion factor is presented as a number, between one and ten, to six decimal places. The letter E (for exponent), a plus or minus sign and two digits following the number, represent the power of 10 by which the number is to be multiplied.

For example: $3.048\,000\,E-01 = 3.048\,000 \times 10^{-1} = 0.304\,800\,0$
or: $1.076\,391\,E+01 = 1.076\,391 \times 10^1 = 10.763\,91$

Examples of use of tables:

To convert 2 ft³ to m³ multiply 2 by 2.831 685 E – 02

(2 x 0.028 316 85 = 0.056 634 m³)

To convert 22 m³ to ft³ divide 2 by 2.831 685 E – 02

(2/0.028 316 85 = 70.629 325 ft³)

A more complete listing and discussion may be found in IEEE/ASTM/IEEE/ASTM SI 10

To convert from:	To:	multiply by:
Degree (angle) (deg)	radian (rad)	1.745 329 E – 02
Foot (ft)	metre (m)	3.048 000 E – 01
Foot ² (ft ²)	metre ² (m ²)	9.290 304 E – 02
Foot ³ (ft ³)	metre ³ (m ³)	2.831 685 E – 02
Footcandle (ft-C)	lux (lx)	1.076 391 E + 01
Footlambert (ft-L)	candela per metre ² (cd/m ²)	3.426 259 E + 00
Inch (in.)	metre	2.540 000 E – 02
Inch ² (in. ²)	metre ² (m ²)	6.451 600 E – 04
Inch ³ (in. ³)	metre ³ (m ³)	1.638 706 E – 05
Minute (angle) (min)	radian (rad)	2.908 882 E – 04
Ounce—force (ozf)	Newton (N)	2.780 139 E – 01
Ounce—inch (ozf in)	Newton metre (N·m)	7.061 552 E – 03
Pound (lb) avoirdupois	kilogram (kg)	4.535 924 E – 01
Pound—force (lbf)	Newton (N)	4.448 222 E + 00
Pound—inch (lbf-in)	Newton metre (N·m)	1.129 848 E – 01
Second (angle) (sec)	radian (rad)	4.848 137 E – 06

Prefixes				Temperature Conversion	
nano	n	10 ^{–9}	centi	c	10 ^{–2}
micro	μ	10 ^{–6}	kilo	k	10 ³
milli	m	10 ^{–3}	mega	M	10 ⁶
				°C = $\frac{5}{9} (°F - 32)$	
				°F = $\frac{9}{5} °C + 32$	

decontaminated to reduce the hazard to personnel operating, maintaining, and resupplying it.

hardness—the ability of a system to withstand the material damaging effects of NBC contamination and any decontamination agents and procedures required to remove it.

compatibility—the ability of a system to be effectively operated, maintained, and resupplied by persons wearing the full NBC or other protective ensemble.

3.1.52 *page*—for this standard, the data appearing at one time on a single display screen.

3.1.53 *panel*—the front face of an assembly, normally used for mounting controls and displays.

3.1.54 *panning*—an orientation for display framing in which a user conceives of the display as moving over a fixed array of data. The opposite of scrolling.

3.1.55 *peak-clipping (of speech signals)*—a technique for controlling amplitude relationships in speech by limiting the instantaneous peak amplitudes to improve intelligibility of speech, usually followed by amplification of the signal to increase the amplitude of the clipped peaks to their original level, with proportional increase of the weaker speech sounds.

3.1.56 *preemphasis*—systematic distortion of the speech spectrum to improve intelligibility of speech sound by attenuating the low-frequency components of vowels (relatively unimportant for intelligibility) and proportionately increasing the amplitude of high-frequency vowel components and consonants (highly important for intelligible speech transmission).

3.1.57 *primary alarm (essential alarm)*—an alarm that indicates a condition that requires prompt attention to prevent an emergency condition. They include machinery alarms, control fault alarms, alarms indicating faults in emergency or primary (essential) alarm(s) or detection systems or failure of their normal power supplies, steering gear alarms, bilge alarms, engineer's alarms, and personnel alarms.

3.1.58 *prompt*—an indicator provided by the computer that alerts the user that the computer is ready, data should be entered, and so forth.

3.1.59 *query language*—a language that allows users to compose control entries for displaying specified data from a database.

3.1.60 *question and answer*—a type of dialogue in which the computer displays questions, one at a time, for a user to answer.

3.1.61 *readability*—the ability to understand the message imparted by printed material, characters, numbers, or other visual information from a visual display.

3.1.62 *remote-handling system*—the equipment (for example, manipulators, viewing devices, and other aids) that permits personnel to extend their capabilities into remote environments.

3.1.63 *scrolling*—an orientation for display framing in which the user conceives of data as moving behind a fixed display frame. The opposite of panning.

3.1.64 *seat reference point (SRP)*—the point at which the center line of the seat back surface (depressed) and seat bottom surface (depressed) intersect. When the seat is positioned at the midpoint of the adjustment range(s), this intersection point is called the neutral seat reference point.

3.1.65 *signals*—a secondary, nonessential, advisory, or call indication. (Call is a request for contact, assistance, or action from one location to another.)

3.1.66 *sound pressure level (SPL)*—the pressure of an acoustic wave; usually expressed in decibels (dB), equal to 20 times the logarithm to the base 10 of the ratio of the effective root-mean-square (rms) pressure of this sound to the reference pressure, as follows:

$$SPL = 20 \log_{10} \frac{P}{20 \mu\text{Pa}} \quad (2)$$

where:

P = the effective (rms) sound pressure in micropascals (μPa) or micronewtons per square metre ($\mu\text{N}/\text{M}^2$). ($20 \mu\text{Pa} = 20 \mu\text{N}/\text{M}^2 = 0.0002 \text{ microbar} = 0.0002 \text{ dynes}/\text{cm}^2$.)

3.1.67 *source documents*—user's documents, which are a source of data eventually processed by the computer program, such as target lists, supply codes, parts lists, maintenance forms, bills of lading, and so forth.

3.1.68 *spatial relationship*—the placement of controls, displays, and their related equipment so that it is visually obvious to an operator or maintainer that all components of a particular system are related. Further, when controls and displays are used for identical equipments or systems located in different parts of the same compartment, or in different compartments, the controls and displays shall be placed in the same location in respect to the equipments or systems at each installation. Consoles and overall work stations shall be designed and placed so the individual controls and displays on the consoles or work stations are arranged, as viewed by the operator facing the console or work station, in the same spatial arrangement as is the actual equipment being controlled or monitored at the console or work station.

3.1.69 *special tools*—tools not listed in the Federal Supply Catalog or meet the requirements of 3.1.75.

3.1.70 *speech intelligibility*—a measure of the percent of words, phrases, or sentences correctly understood over a given speech communication system in a given noise situation. It may be measured, when complying with this practice, by using either the phonetically balanced Monosyllabic Word Intelligibility Test or the Modified Rhyme Test (MRT), or may be calculated by the Articulation Index (AI).

3.1.71 *speech interference level (SIL)*—a measure of the effectiveness of noise in masking speech, defined as the arithmetic average of the same pressure levels of the interfering noise (in decibels re $20 \mu\text{Pa}$) in the four-octave bands centered on the frequencies 500, 1000, 2000, and 4000 Hz, respectively. The unit of speech interference is the decibel.

3.1.72 *speech signal processing*—the modification of the electrical signal representing speech to enhance the capability of a speech communications channel. Some examples are simple analog processing, Automatic Gain Control (AGC), frequency shaping, peak clipping, and syllabic compression.

3.1.73 *speech spectrum*—a segment of the range of audible frequencies containing the sounds of speech; defined as approximately the range from 80 to 8000 Hz.

3.1.74 *speech-to-noise ratio (peak speech to rms noise)*—the ratio between the arithmetic mean of peak amplitudes of speech and the root-mean-square (rms) amplitude of background noise.

3.1.75 *standard tools*—standard tools (normally hand tools) used for the assembly, disassembly, inspection, servicing, repair, and maintenance of the equipment, and which are manufactured by two or more recognized tool manufacturing companies and are listed in those companies' catalogs.

3.1.76 *string*—in the user's context, a word, phrase, or number (string of characters) in the text or file. Normally used in the context of causing the computer to search for, find, or replace a desired "string."

3.1.77 *text entry*—initial entry and subsequent editing of textual material, typified by messages.

3.1.78 *transaction*—an action by a user followed by a response from the computer. The term is used here to represent the smallest functional "molecule" of user-computer interaction.

3.1.79 *transillumination*—light passed through, rather than reflected off, an element to be viewed, for example, illumination used on console panels or indicators using edge or backlighting techniques on clear, translucent, fluorescent, or sandwich-type plastic materials.

3.1.80 *visibility*—the ability to see a visual display from its surrounding background.

3.1.81 *warning signal*—a signal that alerts the operator to a dangerous condition requiring immediate action.

3.1.82 *wet bulb globe temperature (WBGT)*—an index of the stress incorporating, as a major element, the evaporative cooling available to a natural wet bulb thermometer and calculated as follows:

$$WBGT = 0.7TWB_{np} + 0.2T_g + 0.1T_a \quad (3)$$

where:

- TWB_{np} = nonpsychometric (np) wet-bulb (WB) temperature,
- T_g = temperature at interior center of a 15.2-cm (6-in.) black globe, and
- T_a = nonpsychometric, but shaded, dry bulb (air) temperature.

—In the absence of a radiant heat source (solar, engine, furnace, and so forth), a modified wet-dry (WD85) index shall be used where:

$$WD85 = 0.85TWB_{np} + 0.15T_a \quad (4)$$

4. Significance and Use

4.1 *Objectives*—Vessels, systems, and equipment shall provide work environments that foster effective procedures, work patterns, and personnel safety and health, and that minimize factors which degrade human performance or increase error. Design shall be such that operator workload, accuracy, time constraint, mental processing, and communication requirements do not exceed the operator's physical or mental capacities. Design shall also minimize personnel and training requirements within the limits of time, cost, and performance trade-offs.

4.2 *Standardization*—Controls, displays, marking, coding, labeling, and arrangement schemes (equipment and panel layout) shall be uniform for common functions of all equipment. One criterion for selecting off-the-shelf commercial or government equipment shall be the degree to which the equipment conforms to this practice. Where off-the-shelf equipment requires modification to interface with other equipment, the modification shall be designed to comply with the criteria herein. Redesign of off-the-shelf equipment shall have the approval of the procuring activity.

4.3 *Function Allocation*—The design shall reflect allocation of functions to personnel, equipment, and personnel-equipment combinations to achieve the following:

4.3.1 Required sensitivity, precision, time, and safety.

4.3.2 Required reliability of system performance.

4.3.3 Minimum number and level of skills of personnel required to operate and maintain the system.

4.3.4 Required performance in a cost-effective manner.

4.4 *Human Engineering Design*—The design of vessels, systems, and equipment shall include the human engineering, life support, and biomedical design criteria, when applicable, contained in this practice to provide the following:

4.4.1 Satisfactory atmospheric conditions including composition, pressure, temperature, and humidity, and also safeguards against uncontrolled variability beyond the limits contained herein.

4.4.2 Acceptable limits of acoustic noise, vibration, acceleration, shock, blast, impact forces, and safeguards against uncontrolled variability beyond the safe limits defined in this practice.

4.4.3 Protection from thermal, toxicological, radiological, mechanical, electrical, electromagnetic, pyrotechnic, visual, and other hazards.

4.4.4 Space for personnel, their equipment, and free volume for the movements and activities they are required to perform during operation and maintenance tasks under both normal and emergency conditions.

4.4.5 Physical, visual, auditory, and other communication links between personnel, and between personnel and their equipment, under both normal and emergency conditions.

4.4.6 Efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays.

4.4.7 Natural or artificial illumination for the performance of operation, control, training, and maintenance.

4.4.8 Safe and adequate passageways, hatches, ladders, stairways, platforms, inclines, and other provisions for ingress, egress, and passage under normal, adverse, and emergency conditions.

4.4.9 Provision of acceptable personnel accommodations including body support and restraint, seating, rest, and sustenance, that is, food, water, and waste management.

4.4.10 Provision of nonrestrictive personal life support and protective equipment and clothing.

4.4.11 Provisions for minimizing psychophysiological stress effects of mission duration and fatigue.

4.4.12 Design features to ensure rapidity, safety, ease, and economy of operation and maintenance in normal, adverse, and emergency maintenance environments.

4.4.13 Satisfactory remote handling provisions and tools.

4.4.14 Emergency systems for contingency management, escape, survival, and rescue.

4.4.15 Compatibility of the design, location, and layout of controls, displays, workspaces, maintenance accesses, stowage provisions, and passenger compartments with the clothing and personal equipment (C/PE) to be worn by personnel operating, riding in, or maintaining all systems or equipment. Task allocation and control movements shall be compatible with restrictions imposed on human performance by C/PE.

4.4.16 Compatibility of control/display interfaces and procedures with human information processing capability, decision-making effectiveness, and the limits of short-term memory, long-term memory, and computation skill.

4.4.17 Immediate, accurate, and pertinent feedback to the operator of equipment or system performance after each control movement or other action taken by the operator.

4.5 *Fail-Safe Design*—A fail-safe design shall be provided in those areas in which failure can disable a vital system or cause catastrophe through damage to equipment, injury to personnel, or inadvertent operation of critical equipment.

4.6 *Simplicity of Design*—The equipment shall represent the simplest design consistent with functional requirements and expected service conditions. Where practical, it shall be capable of operation, maintenance, and repair in its operational environment by personnel with a minimum of training.

4.7 *Interaction*—The design of the system shall reflect the interaction requirements of crew-served equipment.

4.8 *Safety*—Design shall reflect applicable system and personnel safety factors, including minimization of potential human error in the operation and maintenance of the system, particularly under the conditions of stress.

4.9 *Ruggedness*—Systems and equipment shall be sufficiently rugged to withstand handling during operation, maintenance, supply, and transport within the environmental limits specified for those conditions in the applicable hardware or system specification.

4.10 *Design for NBC and Other Contaminated Environment Survivability*—As applicable, equipment design shall be compatible with NBC and other contaminated environment protection and shall permit performance of mission-essential operations, communications, maintenance, resupply, and decontamination tasks by suitably clothed, trained, and acclimatized personnel for the survival periods and NBC or other environments required by the system. Equipment design shall also facilitate contaminated environment hardness surveillance and shall minimize susceptibility to reduction of inherent contaminated environment hardness as a result of errors or damage induced by maintenance or operator personnel.

4.10.1 NBC or other contaminated environments hardness shall be easily verifiable by maintenance personnel before and after maintenance actions (hardness surveillance).

4.10.2 NBC or other contaminated environments hardness shall not be degraded when routine (scheduled) and corrective (unscheduled) maintenance are performed.

4.10.3 Maintenance of the equipment's inherent NBC or other contaminated environments hardness shall not be dependent

on maintenance personnel expertise and critical alignments/maintenance actions.

4.11 *Design for Electromagnetic Pulse (EMP) Hardening*—As applicable, equipment design shall be compatible with EMP-hardening requirements, including personal accommodations such as EMP-hardened electrical power outlets and antenna lead-ins within EMP-hardened facilities or spaces. Access shall be provided to EMP-hardened facilities or spaces without the need to open doors or hatches which form part of an electromagnetic barrier protecting the space. Items such as surge arrestors, terminal protection devices, and filters, which form part of an electromagnetic barrier for protection against EMP effects, shall be accessible.

5. Control/Display Integration

5.1 *Control/Display Relationship*—The relationships of a control to its associated display and the display to the control shall be immediately apparent and unambiguous to the operator. Controls shall be located adjacent to (normally under or to the right of) their associated displays and positioned so that neither the control nor the hand normally used for setting the control will obscure the display.

5.2 *Control/Display/Equipment Relationships*—Where controls and displays (such as a motor controller and gage board) are associated with a specific piece of equipment (for example, a pump, filter, heater, and so forth) and the controls or displays are located for local operation of the equipment, they shall be located above, or immediately adjacent to, the equipment so that it is visually obvious that all of the components are functionally related. Where other design considerations or where a deliberate choice is made to place the controls and displays remote from the equipment which precludes this preferred location, the controls and displays shall be mounted in such a manner that the relationship of location of the controls and displays matches the arrangement of the equipment to which they belong. Controls and displays used on identical systems located in different locations in the same compartment, or in different compartments, shall be located in the same spatial relationship to the equipment in each compartment. Figs. 2-5 illustrate these principles.

5.3 *Design*—Control-display relationships shall be apparent through proximity, similarity of groupings, coding, framing, labeling, and similar techniques.

5.4 *Complexity and Precision*—The complexity and precision required of control manipulation and display monitoring shall be consistent with the precision required of the system.

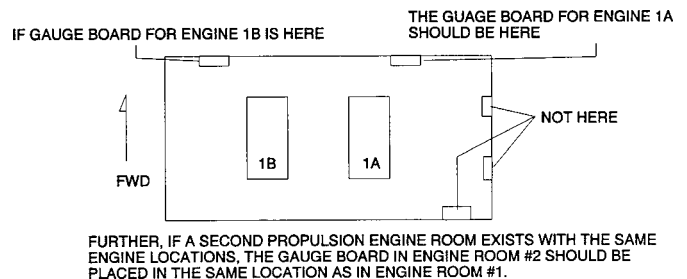


FIG. 2 Example of Display/Equipment Relationship in Main Propulsion Engine Room with Two Medium-Speed Diesel Engines

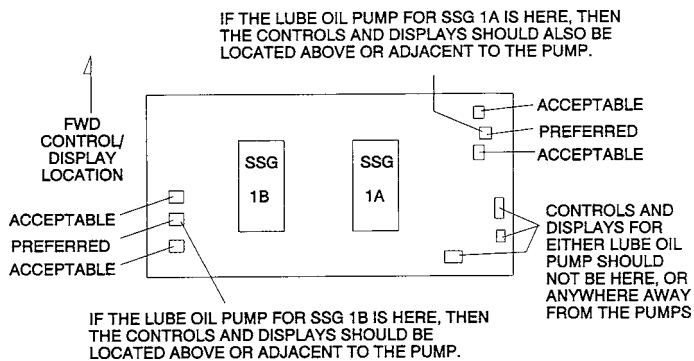


FIG. 3 Example of Control/Display/Equipment Relationship in Auxiliary Machinery Space with Two-Ship Service Generators

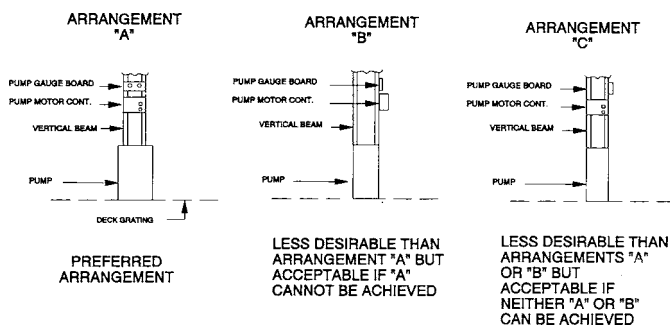


FIG. 4 Example of Control/Display/Equipment Relationship in Machinery Space with Pump, Motor Controller, and Gauge Board Located at Vertical Beam

Control/display complexity and precision shall not exceed the capability of the operator (in terms of discrimination of display detail) or exceed the operator's manipulative capability under the dynamic conditions and environment (in terms of manual dexterity, coordination, or reaction time) in which human performance is expected to occur.

5.5 Feedback—Feedback on control response adequacy shall be provided as rapidly as possible. For keyboards, feedback shall be provided to the operator before entry to ensure that the keyed entry is, in fact, errorless and the one that the operator desires to enter.

5.6 Illumination—Adjustable illumination shall be provided for visual displays, including display, control, and panel labels and critical markings, that must be read at night or under darkened conditions.

5.7 Simultaneous Access—If more than one crew member must have simultaneous access to a particular group of controls or displays to ensure proper functioning of a system or subsystem, the operator assigned to control and monitor a particular function or group of related functions shall have physical and visual access to all controls, displays, and communication capability necessary to perform assigned tasks adequately.

5.8 Position Relationships:

5.8.1 Functional Grouping—Functionally related controls and displays shall be located in proximity to one another and arranged in functional groups, for example, power, status, test.

5.8.2 Functional Group Arrangement:

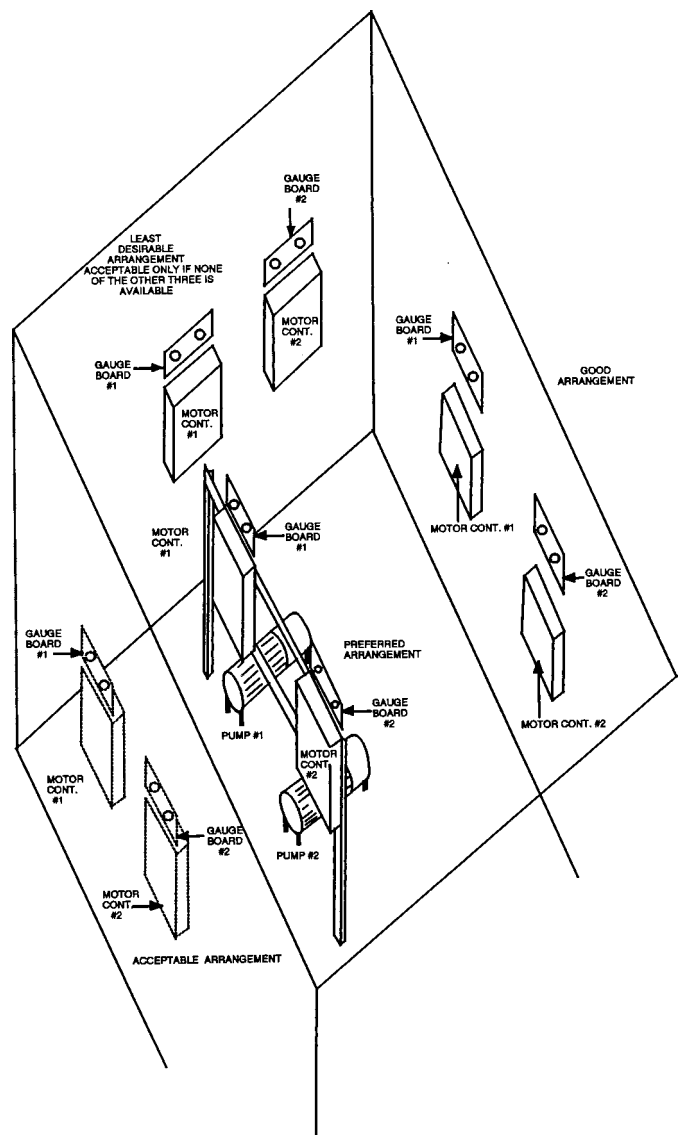


FIG. 5 CHT Pump Room with Various Options for Locating the Two Motor Controllers and Their Corresponding Gauge Boards Given the Location of the Two Pumps

5.8.2.1 Sequence—Functional groups of controls and displays shall be located to provide for left-to-right (preferred) or top-to-bottom order of use, or both.

5.8.2.2 Access—Providing that the integrity of grouping by function and sequence is not compromised, the more frequently used groups and the most important groups shall be located in areas of easiest access. Control-display groups required solely for maintenance purposes may be located in positions providing a lesser degree of access relative to operating groups.

5.8.2.3 Functional Group Marking—Functional groups may be set apart by outlining with contrasting lines that completely encompass the groups. Color numbers in this paragraph are in accordance with **FED-STD-595**. Where such coding is specified by the procuring activity, and where gray panels are used, noncritical functional groups (those not associated with emergency operations) shall be marked with a

1.5-mm ($\frac{1}{16}$ -in.) black border (27038), and those involving emergency or extremely critical operations shall be outlined with a 5-mm ($\frac{3}{16}$ -in.) red border (21136). As an alternate method, contrasting color pads or patches may be used to designate both critical and noncritical functional areas, subject to prior approval by the procuring activity. When red compartment lighting is used, an orange-yellow (23538) and black (27038) striped border shall be used to outline functional groups involving emergency (hazardous or potentially hazardous conditions requiring immediate attention) or extremely critical operations.

5.8.2.4 Consistency—Location of recurring functional groups and individual items shall be similar from panel to panel. Mirror image arrangements shall be used only with the approval of the procuring activity.

5.8.3 Location and Arrangement—Whenever an operator must use a large number of controls and displays, their location and arrangement shall be designed to aid in determining which controls are used with which displays, which equipment component each control affects, and which equipment component each display describes.

5.8.4 Arrangement Within Groups—Controls and displays within functional groups shall be located according to operational sequence or function, or both.

5.8.4.1 Left-to-Right Arrangement—If there is more than one row of displays, and their corresponding controls cannot be located under each display, or placed in the same row arrangement under the displays as the displays are arranged, then the controls shall be located as shown in Fig. 6.

5.8.4.2 Vertical and Horizontal Arrays—If a horizontal row of displays must be associated with a vertical column of controls or vice versa, the farthest left item in the horizontal array shall correspond to the top item in the vertical array, and so forth. However, this type of arrangement shall be avoided whenever possible.

5.8.4.3 Simultaneous Use—A visual display that must be monitored concurrently with manipulation of a related control shall be located so that the operator is not required to observe the display from an extreme visual angle and thus introduce the possibility of parallax error.

5.8.4.4 Multiple Displays—When the manipulation of one control requires the reading of several displays, the control

shall be placed as near as possible to the related displays and preferably beneath the middle of the displays, but not to obscure displays when manipulating the control.

5.8.4.5 Combined Control—When separate displays are affected by a combined control (for example, concentrically ganged knobs), the display shall be arranged from left to right with the combined control underneath the center of the displays, but not to obscure displays when manipulating controls.

5.8.4.6 Separate Panels—When related controls and displays must be located on separate panels and both panels are mounted at approximately the same angle relative to the operator, the control positions on one panel shall correspond to the associated display positions on the other panel. The two panels shall not be mounted facing each other.

5.8.4.7 Component Groups—When a group of equipment components has the same function, the related control and display positions shall be oriented to correspond to those of the controlled and monitored components. (For example, the position of propulsion engine controls shall be oriented as if the operator faces the normal direction of vessel movement.)

5.8.4.8 Emergency Use—Emergency displays and controls are those associated with a hazardous or potentially hazardous condition that requires immediate action to prevent injury to the crew or damage to the ship. They shall be located where they can be seen and reached with minimum delay (for example, warning lights within a 30° cone about the operator's normal line of sight; emergency control close to its related warning display or the nearest available hand in its nominal operating position).

5.9 Movement Relationships:

5.9.1 Lack of Ambiguity—Display indicators shall clearly and unambiguously direct and guide the appropriate control response. The response of a display to control movements shall be consistent, predictable, and compatible with the operator's expectations.

5.9.2 Time Lag—The time lag between the response of a system to a control input and the display presentation of the response shall be minimized, consistent with safe and efficient system operation.

5.9.3 Moving Pointer Circular Scales—Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce a clockwise movement of circular scale pointers and an increase in the magnitude of the reading.

5.9.4 Moving Pointer Linear Scales—Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce a movement up or to the right for horizontal and vertical scale pointers and an increase in the magnitude of the reading.

5.9.5 Fixed Pointer Circular Scale—Displays with moving scales and fixed pointers or cursors shall be avoided. When circular fixed-pointer, moving-scale indicators are necessary, clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall normally produce a counterclockwise movement of the scale and an increase in the magnitude of the reading.

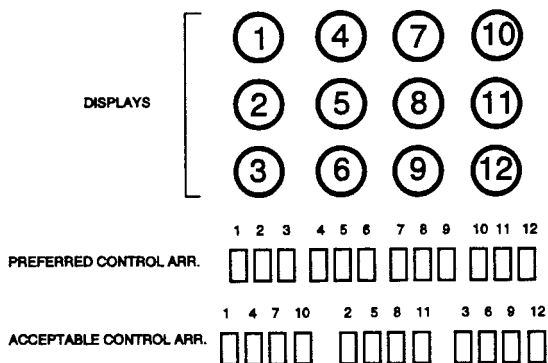


FIG. 6 Preferred and Acceptable Alternatives for Multiple Row/Column Display and Control Arrangement

5.9.6 Fixed Pointer Linear Scale—When use of vertical or horizontal fixed pointer, moving-scale indicators is necessary, clockwise movement of an associated rotary control or movement of a linear control forward, up, or to the right shall normally produce a movement of the scale down or to the left and an increase in the magnitude of the reading.

5.9.7 Direct Linkage—When there is a direct linkage between control and display (for example, radio frequency selector and station pointer), a rotary control shall be used if the indicator moves through an arc of more than 180°. If the indicator moves through an arc of less than 180° a linear control may be used, provided that the path of control movement parallels the average path of the indicator movement and that the indicator and control move in the same relative direction.

5.9.8 Common Plane—Controls shall be selected so that the direction of movement of the control will be consistent with the related movement of an associated display, equipment component, or vessel.

5.9.9 Parallel Movement—Direction-of-movement relationships shall be adhered to when control and display are parallel in line of movement.

5.9.10 Labeling—When control-display relationships specified herein cannot be adhered to, controls shall be clearly labeled (in accordance with Section 27) to indicate the direction of control movement required.

5.9.11 Movement Direction—When a rotary control and a linear display are in the same plane, the part of the control adjacent to the display shall move in the same direction as the moving part of the display.

5.10 Control Display Movement Ratio:

5.10.1 Minimization of Time—Control display ratios for continuous adjustment controls shall minimize the total time required to make the desired control movement (slowing time plus fine adjusting time), consistent with display size, tolerance requirements, viewing distance, and time delays.

5.10.2 Range of Display Movement—When a wide range of display element movement is required, small movement of the control shall yield a large movement of the display element. When a small range of display movement is required, a large movement of the control shall result in small movement of the display, consistent with final accuracy required.

5.10.3 Knob, Coarse Setting—When a knob is provided for making coarse display element settings on linear scales (0.4- to 2.5-mm (0.016- to 0.100-in.) tolerance), an approximately 150-mm (6-in.) display element movement shall be provided for one complete turn of the knob.

5.10.4 Knob, Fine Setting—For fine setting on linear scales (0.2- to 0.4-mm (0.008- to 0.016-in.) tolerance), a 25 to 50 mm (1 to 2 in.) of display element movement shall be provided for one complete turn of the knob.

5.10.5 Bracketing—When bracketing is used to locate a maximum or minimum rather than a specific value (for example, as in tuning a transmitter), the control knob shall swing through an arc of not less than 175 mrad (10°) nor more than 525 mrad (30°) either side of the target value to make the peak or dip associated with that value clearly noticeable.

5.10.6 Lever, Coarse Setting—When a lever is provided for coarse settings (0.4- to 2.5-mm (0.016- to 0.100-in.) tolerance), one unit of display element movement shall be used to three units of lever movement.

5.10.7 Lever, Two-Dimensional Setting—When a lever is provided to make settings in two dimensions to coarse tolerances (2.5 mm (0.100 in.)), one unit of display element movement shall be used to two and one-half units of lever movement.

5.10.8 Counters—When counters are provided, the control-display ratio shall be such that one revolution of the knob produces approximately 50 counts (that is, the right hand drum rotates 5 times).

6. Visual Displays, General Information

6.1 General—Visual displays shall be used to provide the operator with a clear indication of equipment or system conditions for operation under any eventuality commensurate with the operational and maintenance philosophy of the system under design.

6.2 Alerting/Warning—An alerting/warning display shall provide the operator with a greater probability of detecting the triggering condition than normal observation would provide in the absence of the display.

6.3 Display Illumination and Light Distribution:

6.3.1 Display Illumination:

6.3.1.1 Normal—When maximum dark adaptation is not required, low-brightness white light (preferably integral and adjustable as appropriate) shall be used; however, when complete dark adaptation is required, low-level illumination shall be accomplished by use of gray filter sleeves over the lamps. The white light transmittance through the sleeves shall be either 5.0, 2.5, or 1.0 %.

6.3.1.2 Night Vision Device Compatibility—When night vision devices will be worn or used by the operator(s), display illumination color shall be low-density blue-green light (incandescent filament through a high-pass filter with a 600-nm cutoff). The color selected shall provide the operator(s) with the capability to obtain required display information rapidly and accurately with unaided eye vision or via viewing with the night vision device. The color selected shall also provide the operator(s) with the ability to obtain required display information rapidly and accurately during any daylight condition. The lighting shall be continuously variable to the full OFF position. In the OFF position, no current shall flow through the lamps.

6.3.1.3 Field Use Panel Dimming—When control or annunciator panels will be viewed by personnel out of doors at night, maximum panel illumination shall be provided when a dimming rotary control is at its extreme clockwise rotation. Maximum illumination is that in accordance with 32.9. No current shall be provided to luminaries at extreme counter-clockwise rotation of a dimming control. Panel light levels shall be continuously variable from 0.1 cd/m² (0.03 fL) near OFF to 3.5 cd/m² (1 fL) at 50 % of clockwise rotation.

6.3.2 Light Distribution—Where multiple displays are grouped together, lighting shall be balanced across the instrument panel such that the mean indicator luminances of any two instruments shall not differ by more than 33 % across the range of full ON to full OFF. Light distribution shall be uniformity



uniform within an integrally illuminated instrument such that the ratio of standard deviation of indicator element luminances to mean indicator luminance shall not be more than 0.25, using eight or more equally spaced test measurements.

6.3.3 Contrast—Sufficient contrast shall be provided between all displayed information and the display background to ensure that the required information can be perceived by the operator under all expected lighting conditions.

6.4 Information:

6.4.1 Content—The information displayed to an operator shall allow the operator to perform the intended mission, but shall be limited to that which is necessary to perform specific actions or to make decisions.

6.4.2 Precision—Information shall be displayed only within the limits and precision required for specified operator actions or decisions.

6.4.3 Format—Information shall be presented to the operator in a directly usable form. Requirements for transposing, computing, interpolating, or mentally translating into other units shall be prohibited.

6.4.4 Redundancy—Redundancy in the display of information to a single operator shall be avoided unless it is required to achieve specified reliability.

6.4.5 Combining Operator/Maintainer Information—Operator and maintainer information shall not be combined in a single display unless the information content and format are well suited to, and time is compatible for, both users.

6.4.6 Display Failure Clarity—A method shall be provided to determine if a display or circuit has failed.

6.4.7 Display Circuit Failure—Failure of the display circuit shall not cause a failure in the equipment associated with the display.

6.4.8 Unrelated Markings—Trademarks and company names or other similar markings not related to the panel function shall not be displayed on the panel face or on the displays.

6.4.9 Duration—For signals or displays that frequently or consistently change their outputs, the information displayed shall have durations of sufficient length to be reliably detected under expected operator workload and operational environment.

6.4.10 Timeliness—Displays, such as cathode ray tube displays, requiring refreshed information shall be updated in a synchronous manner, and be refreshed to a degree of timeliness required by personnel in the normal operating or servicing mode.

6.4.11 Advisory and Alerting—Displays such as multifunction displays, cathode ray tube displays, and other visual display devices displaying simultaneous and integrated information shall advise or alert operating personnel to information that becomes critical within the display.

6.4.12 NBC Contamination—As applicable, display characteristics (for example, clarity, legibility) shall be compatible with viewing while wearing an NBC or other protective mask. Displays or indicators that show the presence of NBC or other environmental contamination agents shall also show when such agent concentrations decrease to safe levels.

6.4.13 Numeric Digital Displays—Numeric digital displays shall not be used as the only display of information when trends in display change or perception of a display pattern is required of the operator. Numeric digital displays shall not be used when rapid or slow digital display rates inhibit perception of the display.

7. Location and Arrangement of Visual Displays

7.1 Location—Displays, including sight fill tubes on tanks, shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing positions without requiring the operator to assume an uncomfortable, awkward, or unsafe position. Dual gages providing an IN and OUT reading (that is, suction and discharge, voltage in and out, and so forth) shall be arranged so that the gage with the IN reading is on the left (preferred) or top, and the gage with the OUT reading is on the right (preferred) or bottom, unless the IN and OUT displays are a part of a system mimic that does not permit this arrangement.

7.2 Access—Visual displays shall be visually accessible from the normal work position without requiring the operator to stand on equipment components, handrails, wireways or wireway supports, or nearby pipes (especially if they are insulated). Flashlights or other special equipment shall not be required to read the display. No display shall require the removal of a cover (that is, sheathing, deck plate, and so forth) or any other component to be visible, unless the display is noncritical and a clearly marked quick access door is provided. Where possible, the access door shall be of transparent material. Light-emitting diodes (LEDs) used on PC boards inside consoles for calibration or troubleshooting shall be visible from the maintainer's normal work position once the console doors or maintenance access openings are open.

7.3 Orientation—Displays, such as thermometers, pressure gages, and so forth, that are attached directly to a pipe shall be mounted so they are read upright, or turned no more than 90°, from the upright position. Displays located immediately adjacent to walkways shall not be located lower than 460 mm (18 in.) above the deck to prevent them from being kicked and broken, unless the display face is protected by a nonbreakable transparent material. Armored sight gages shall be oriented so the sight gage is directly visible from the normal work position.

7.4 Reflection—Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer as a result of the reflection of the ambient illumination from the display cover. Reflection of instruments and consoles in windows and other reflective enclosures shall be avoided. If necessary, techniques (such as shields and filters) shall be used to ensure that the system performance will not be degraded. Sight gages that contain clear liquid shall have a color backing so as to provide a color contrast between the liquid and the color backing to make the liquid more visible in the gage.

7.5 Vibration—Vibration of visual display shall not degrade user performance below the level required for mission accomplishment (see 32.13).

7.6 Grouping—All displays necessary to support an operator activity or sequence of activities shall be grouped together.

7.7 Function and Sequence—Displays shall be arranged in relation to one another according to their sequence of use.



functional relations of the components they represent. They shall be arranged in sequence within functional groups, whenever possible, to provide a viewing flow from left to right or top to bottom.

7.8 *Frequency of Use*—Displays used most frequently shall be grouped together and placed in the primary visual zone in accordance with Fig. 7 and Fig. 8.

7.9 *Importance*—Important or critical displays shall be located in the primary visual zone or otherwise highlighted.

7.10 *Consistency*—The arrangement of displays within a system shall be consistent from application to application.

7.11 *Maximum Viewing Distance*—The viewing distance from the eye reference point of the seated operator to displays located close to their associated controls shall not exceed 635

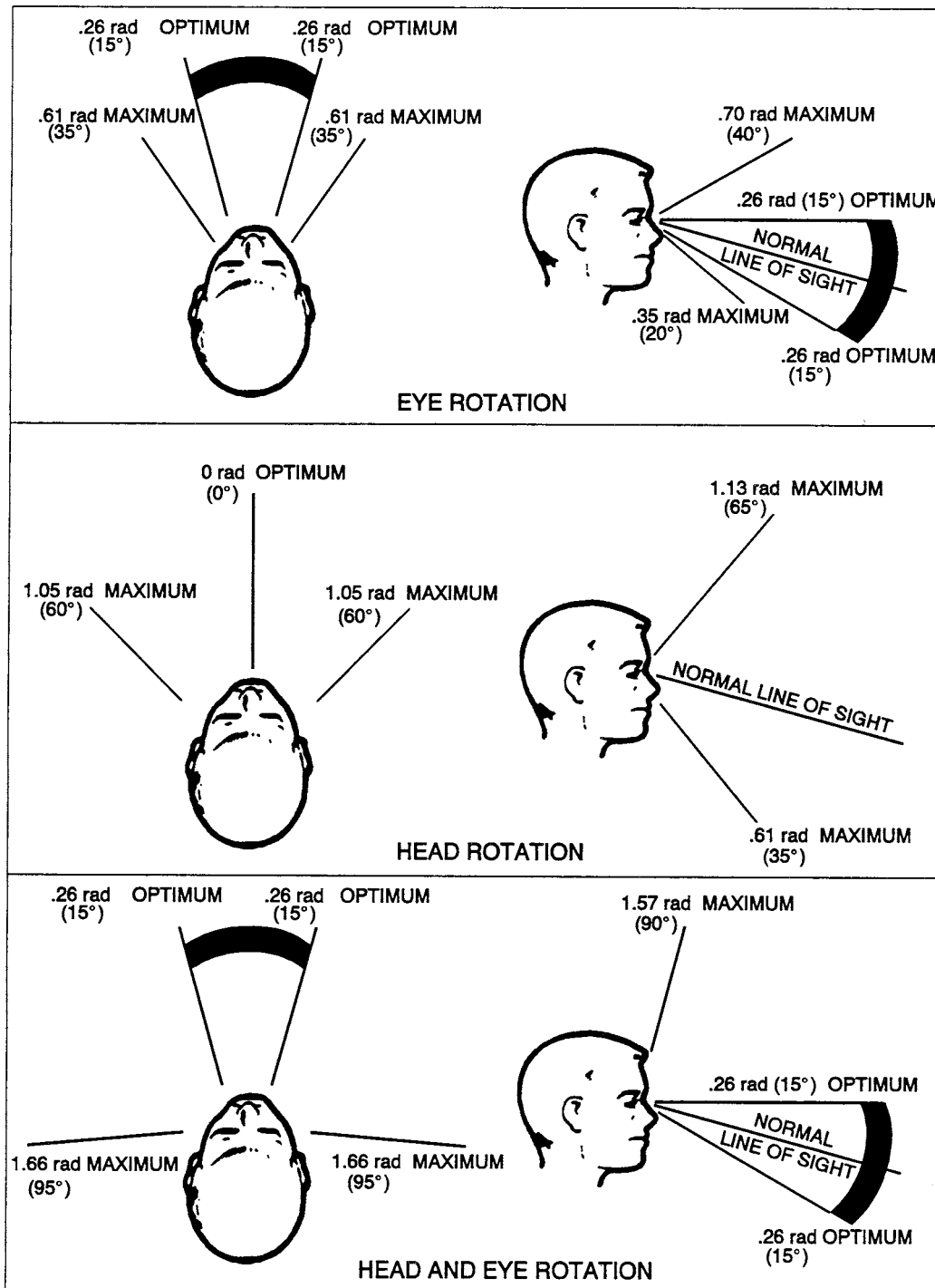


FIG. 7 Vertical and Horizontal Visual Field

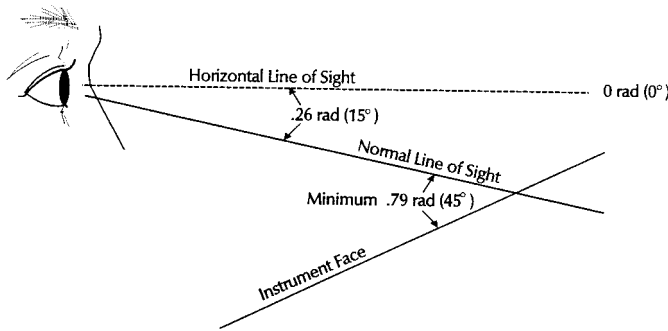


FIG. 8 Lines of Sight

mm (25 in.). Otherwise, there is no maximum limit other than that imposed by legibility limitations, which shall be compensated for by proper design.

7.12 Minimum Viewing Distance—The viewing distance from the operator's eye to the face of the displays, with the exception of cathode ray tube displays and collimated displays, shall never be less than 330 mm (13 in.) and preferably not less than 510 mm (20 in.).

8. Coding of Visual Displays

8.1 Objectives—Coding techniques shall be used to facilitate discrimination between individual displays, identification of functionally related displays, indication of relationship between displays, and identification of critical information within a display.

8.2 Techniques—Displays shall be coded by color, size, location, shape, or flash coding, as applicable.

8.3 Standardization—All coding within the system shall be uniform and shall be established by agreement with the procuring activity.

9. Transilluminated Displays

9.1 Three general types of transilluminated displays that may be used include the following: single- and multiple-legend lights, which present information in the form of meaningful words, numbers, symbols, and abbreviations; simple indicator lights; and, transilluminated panel assemblies, which present qualitative status or system readiness information.

9.2 Use—Transilluminated indicators shall be used to display qualitative information to the operator requiring either an immediate reaction by the operator or to draw attention to an important system status. Such indicators may also be used occasionally for maintenance and adjustment function.

9.3 Equipment Response—Lights, including those used in illuminated push buttons, shall display equipment response and not control position (that is, a lighted ON push button for a pump means that the pump is running, not that the control has been pushed).

9.4 Information—Lights and related indicators shall be used sparingly and shall display only that information necessary for effective system operation.

9.5 Positive Feedback—Changes in display status shall signify changes in functional status rather than simply indicate

that a control has been activated (for example, a lighted VALVE CLOSED indicator shall signify that the valve is actually closed, not that the VALVE CLOSED control has been activated). The absence or extinguishment of a signal or visual indication shall not be exclusively used to denote a malfunction, no go, or out-of-tolerance condition; however, the absence of a power on signal or visual indication shall be acceptable to indicate a power-off condition for operational displays only—not for maintenance displays. The absence or extinguishment of a signal or visual indication shall not be used to indicate a ready or in tolerance condition, unless the status or caution light filament and its associated circuitry can be easily tested by the operator and operator perception of such events is not time critical.

9.6 Grouping—Master caution, master warning, master advisory, and summation lights used to indicate the condition of an entire subsystem shall be discriminable from the lights which show the status of the subsystem components, except as required under 9.9.

9.7 Location—When a transilluminated indicator is associated with control, the indicator light shall be so located that it can be associated with the control without error and shall be visible to the operator during control operation. When a transilluminated indicator is used in conjunction with a meter or readout as an indication of an out-of-tolerance condition (such as, a LOW PRESSURE lighted annunciator associated with a pressure meter), it shall be placed directly above the meter. Other arrangements are permissible with the approval of the procuring activity.

9.8 Location, Critical Functions—For critical functions, indicators shall be located within 265 mrad (15°) of the operator's normal line of sight (as shown in Fig. 8). Warning lights shall be an integral part of, or located adjacent to, the lever, switch, or other control device by which the operator is to take action, or placed as defined in 9.7.

9.9 Maintenance Displays—Indicator lights used solely for maintenance and adjustment shall be covered or nonvisible during normal equipment operation, but shall be readily accessible when required.

9.10 Luminance—The luminance of transilluminated displays shall be compatible with the expected ambient illuminance level, and shall be at least 10 % greater than the surrounding luminance. Where glare must be reduced, the luminance of transilluminated displays shall not exceed 300 % of the surrounding luminance.

9.11 Luminance Control—When displays will be used under varied ambient illuminance, a dimming control shall be provided. The range of the control shall permit the displays to be legible under all expected ambient illuminance. The control shall be capable of providing multiple-step or continuously variable illumination. Dimming to full OFF may be provided in noncritical operations, but shall not be used if inadvertent failure to turn on an indicator could lead to critical operator failures, such as failure to detect or to perform a critical step in an operation.

9.12 False Indication or Obscuration—Provision shall be made to prevent direct or reflected light from making indicators



appear illuminated when they are not, or to appear extinguished when they are illuminated. Self-reflection shall be minimized by proper orientation of the display with respect to the observer.

9.13 *Contrast Within the Indicator*—The luminance contrast (see 3.1.43) within the indicator shall be at least 50 %. This 50 % luminance contrast requirement does not apply to special displays specifically designed for legibility in sunlight or where legibility is obtained through color contrast (and other techniques) rather than luminance contrast. For low ambient illumination applications, this ratio shall be at least 90 %, with the background luminance less than the figure luminance.

9.14 *Lamp Redundance*—Meters, counters, and other displays that use incandescent bulbs to illuminate the display face may incorporate filament redundancy or dual lamps. When one filament or bulb fails, the intensity of the light shall decrease sufficiently to indicate the need for lamp replacement, but not so much as to degrade operator performance. Lighted annunciators need not have this capability provided a lamp test button is provided.

9.15 *Lamp Testing*—When indicator lights using incandescent bulbs are installed on a control panel or console, a master light test control shall be incorporated. Panels containing three or fewer lights may be designed for individual press-to-test bulb testing. Circuitry shall be designed to test the operation of the total indicator circuit. If dark adaptation is a factor, a means for reducing total indicator light brightness during test operation shall be provided.

9.16 *Lamp Removal, Method*—Where possible, lamps shall be removable and replaceable from the front of the display panel. The procedure for lamp removal and replacement shall not require the use of tools and shall be easily and rapidly accomplished. If a tool is required, special stowage for it will be provided on the panel.

9.17 *Lamp Removal, Safety*—Display circuit design shall permit lamp removal and replacement while power is applied without causing failure of indicator circuit components or imposing personnel safety hazards.

9.18 *Indicator Covers*—If design of legend screen or indicator covers does not prevent inadvertent interchange, a means shall be provided for checking the covers after installation to ensure that they are properly installed.

9.19 *Color Coding*—Transilluminated displays shall conform to the following color coding scheme.

9.19.1 *Flashing Red*—Flashing red shall be used to denote emergency conditions that require immediate operator action to avert impending personnel injury, equipment damage, or both. Flash rates shall be in accordance with 9.20. Flashing red lights not installed on consoles shall be limited to general alarm signals only in accordance with U.S. Coast Guard Reg. 113.25-9.

9.19.2 *Yellow*—Yellow shall be used to advise an operator that a condition exists that is marginal or beyond operational limits, but does not require immediate operator action. Yellow shall also be used to alert the operator to situations in which caution, recheck, or unexpected delay is necessary.

9.19.3 *Green*—Green shall be used to indicate that the monitored equipment is operating satisfactorily or that a condition is satisfactory and it is all right to proceed.

9.19.4 *White*—White shall be used to indicate system conditions that do not have right or wrong implications, such as alternative functions (for example, Missile No. 1 selected for launch, and so forth) or transitory conditions (for example, action or test in progress, function available), provided such indication does not imply success or failure of operations.

9.19.5 *Blue*—Blue may be used for an advisory light, but use of blue shall be avoided whenever possible.

9.19.6 Ship specifications shall not mandate the use of any transilluminated display (such as LEDs) that cannot meet the color codes described.

9.20 *Flashing Lights*—The use of flashing lights shall be minimized. Flashing lights shall be used only when it is necessary to notify the operator of some condition that is out of tolerance and requires attention. The flash rate shall be within three to five flashes per second with approximately equal amounts of ON and OFF time. Flashing lights shall become steady beaming once the operator acknowledges the flashing light by activating a control that deactivates the flasher circuit. Flashing lights that could be simultaneously active shall have synchronized flashes. If the indicator is energized and the flasher device fails, the light shall illuminate and burn steadily (see 15.2) or a separate indicator showing flashing circuit failure, shall be provided.

9.20.1 *Red*—Shall be used to alert an operator that the system or any portion of the system is inoperative or that a successful mission is not possible until appropriate corrective or override action is taken. Examples of indicators that shall be coded red are those which display such information as “no-go,” “error,” “failure,” “malfunction,” and so forth.

9.21 *Legend Lights*—Legend lights (also called annunciators) shall be used in preference to simple indicator lights except where design considerations demand that simple indicators be used. The number of legend lights shall be kept to a minimum. Legend lights shall be used to provide qualitative information, not to give commands.

9.21.1 *Color Coding*—Legend lights shall be color coded in conformance with 9.19.

9.21.2 *Positive Versus Negative Legend*—When the operator’s dark adaptation must be maintained, or where legibility in high ambient illumination is critical, the illuminated label/opaque background format shall be used and the illuminated background/opaque label format shall be used only for critical alerting indicators (for example, master warning lights). Where operator dark adaptation is not required, the illuminated background/opaque label format shall be used. Contrast reversal may be used under these conditions to designate displays that have physical appearance similar to legend switches on the same panel.

9.21.3 *Lettering*—The size and other characteristics of lettering shall conform to Section 27 herein or as otherwise specified by the procuring activity.

9.21.4 *Visibility and Legibility*—With the exception of danger and caution indicators, the lettering on single-legend indicators shall be visible and legible whether or not the indicator is energized.

9.21.5 *Multifunction Legends*—Indicators designed to provide alternately presented legends shall present only one legend at a time, that is, only the legend in use shall be visible. If the indicator device uses stacked legends, it shall be designed so that:

9.21.5.1 When the rear legend is energized, it shall not be obscured by the front legend.

9.21.5.2 Parallax is minimized.

9.21.5.3 Rear legends have approximately equal brightness to front legends, and the contrast between rear legends and background is equal to that of the front legend and its background.

9.22 *Simple Indicator Lights*—Simple indicator lights shall be used only when design considerations preclude the use of legend lights.

9.22.1 *Spacing*—The spacing between adjacent edges of simple round indicator light fixtures shall be sufficient to permit unambiguous labeling, signal interpretation, and convenient bulb removal.

9.22.2 *Coding*—Simple indicator lights shall be coded in conformance with [Table 2](#).

9.23 *Transilluminated Panel Assemblies*—Transilluminated (integrally lighted) panel assemblies may be used to perform the following:

9.23.1 Provide illuminated labels for a control panel.

9.23.2 Provide a light source for illuminating transilluminated control knobs.

9.23.3 Provide illuminated association markings on a control panel, such as connecting lines between controls, outlines around a functionally related group of controls or displays, or both.

9.23.4 Create a pictorialized representation of a system process, communication network, or other information/component organization.

9.24 *Large, Single Pictorial Graphic Panels*—Large, single pictorial graphic panels, used to display system processing, communications networks, or similar applications, shall comply with requirements for visibility, legibility, color, and illumination as specified herein.

9.25 *Relamping*—When replaceable incandescent lamps are used as the illuminant source for integral lighting of panel assemblies, lamps shall be accessible without disconnecting the panel(s). A sufficient number of lamps shall be provided so that failure of one lamp will not cause any part of the display to be unreadable.

9.26 *Brightness*—Brightness of illuminated markings and transilluminated controls shall be compatible with the ambient environment and operating conditions (for example, dark adaptation requirements). Brightness control (dimming) by the operator shall be provided where applicable to control/maintain appropriate visibility and operator dark adaptation level.

10. Scale Indicators

10.1 *Types of Scale Indicators*—The types of scale indicators that may be used include the following:

10.1.1 Moving pointer, fixed scale, circular, curved (arc), horizontal straight, and vertical straight.

10.1.2 Fixed pointer, moving scale, circular, curved (arc), horizontal straight, and vertical straight.

10.2 *Use*—The use of scale indicators shall conform to the criteria in [Table 3](#) as well as the specific criteria contained in this section. Moving-pointer, fixed-scale indicators are preferred to fixed-pointer, moving-scale indicators. The latter should be used only when necessitated by operational requirements or other conditions, and when approved by the procuring activity.

10.3 *Type of Information*—Scale indicators shall be used to display quantitative information in combination with qualitative information (such as trend and direction of motion) and where only quantitative information is to be displayed and there is no requirement (such as speed and accuracy of response) which demands the use of printers or counters.

10.4 *Linear Scales*—Linear scales shall be used except where system requirements and the scale clearly dictate non-linearity to satisfy operator information requirements. Nonlinear scales shall be used only with the approval of the procuring activity.

10.5 *Scale Marking and Numbering*:

10.5.1 *Graduation Markings*—Scale graduations shall be in increments of one, two, or five units or decimal multiples thereof (except as noted in [10.5.2](#)). No more than three sizes of marks shall be used on any scale. The scales that require three sizes of marks include those which have numbered values in multiples of ten but are graduated in 5 and 10° intervals.

10.5.1.1 *Intermediate Marks*—The number of intermediate marks between numbered scale pointers shall not exceed nine as shown in [Fig. 9](#) and illustrations of scales graduated in various ways are provided in [Fig. 10](#).

10.5.1.2 *Major Marks*—Except for measurements that are normally expressed in decimals, whose numbers shall be used for major graduation marks.

10.5.2 *Scale Numerals*—Intermediate marks shall ordinarily not be numbered. On fixed scales, numerals shall be

TABLE 2 Coding of Simple Indicator Lights

Size/Type	Color			
	Red	Yellow	Green	White
13-mm (0.5-in.) DIAMETER or SMALL- ER/STEADY	Malfunction; action stop- ped; fail- ure; stop action.	Delay; check; recheck.	Go ahead; in tol- erance; accept- able; ready.	Functional or phys- ical pos- ition; action in pro- gress.
25-mm (1-in.) DIAMETER or LARGER/ STEADY	Master summation (system or subsystem)	Extreme caution (impend- ing danger).	Master summation (system or subsystem).	
25-mm (1-in.) DIAMETER or LARGER/ FLASHING (3 to 5/s)	Emergency condition (impending personnel or equipment disaster).			



TABLE 3 Application of Various Types of Mechanical Displays

Use	Scalar Indicators		Mechanical Counters	Pictorial Instruments	Plotters, Recorders, Printers	Flags
	Moving Pointer	Moving Scale				
Quantitative information	FAIR Difficult to read while pointer is in motion.	FAIR Difficult to read while scale motion.	GOOD Minimum time and error for exact numerical value, but difficult to read when moving.	FAIR Direction of motion/scale relations sometimes conflict, causing ambiguity in interpretation.	GOOD Minimum time and error for exact numerical.	N/A
Qualitative	GOOD Location of pointer easy. Numbers and scale need not be read. Position change easily detected.	POOR Difficult to judge direction and magnitude of deviation without reading numbers and scale.	POOR Numbers must be read. Position changes not easily detected.	GOOD Real world situation more quickly assimilated.	POOR Numbers must be read. Position changes not easily detected.	GOOD Easily detected. Economical of space.
Setting	GOOD Simple and direct relation of motion of pointer to motion of setting knob. Position change aids monitoring.	FAIR Relation to motion of setting knob may be ambiguous. No pointer position change to aid monitoring. Not readable during rapid setting.	GOOD Most accurate monitoring of numerical setting. Relation to motion of setting knob less direct than for moving pointer. Not readable during rapid setting.	GOOD General direct control-display relationship easy to observe.	N/A	N/A
Tracking	GOOD Pointer position readily controlled and monitored. Simplest relation to manual control motion.	FAIR No position changes to aid monitoring. Relation to control motion somewhat ambiguous.	POOR No gross position changes to aid monitoring.	GOOD Same as above.	N/A	N/A
Difference estimation	GOOD Easy to calculate positively or negatively by scanning scale.	FAIR Subject to reversal errors.	POOR Requires mental calculation.	GOOD Easy to calculate either quantitatively or qualitatively by visual inspection.	FAIR Can predict possible future pattern of pen trace.	N/A
Permanent Record General	N/A Requires largest exposed and illuminated area on panel. Scale length limited unless multiple pointers used.	N/A Saves panel space. Only small section of scale need be exposed and illuminated. Use of tape allows long scale.	N/A Most economical of space and illumination. Scale length limited only by numbers of counter drums.	N/A	GOOD Provides hard copy.	N/A

vertically oriented, and on rotating scales, numerals shall be radially oriented and positioned so as to be upright when read against the pointer. Bearing dials shall have numerals (and major graduation marks) at either 10 or 30° as shown in Fig. 11.

10.5.3 Scale Length—Scales shall start and end on a major graduation mark even if this puts either or both ends beyond the usable range of the scale (for example, if the maximum voltage which can be read on an instrument is 23 V, the scale shall go at least to 25 V where there could be a major graduation mark).

10.5.4 Starting Point—Display scales shall start at zero, except where this would be inappropriate for the function involved.

10.6 Pointers—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.

10.7 Tip Configuration—The pointer tip should be tapered at a 350-mrad (20°) angle [(40°) included angle], terminating in a flat tip equal in width to the minor scale graduations.

10.7.1 Relationship of Tip to Graduation Marks—Pointers shall meet, but not overlap, the shortest scale-graduation mark.

The tips shall never be more than 1.5 mm ($\frac{1}{16}$ in.) from the scale graduations. The tip shall be equal in width to the minor scale graduations.

10.7.2 Normal Pointer Position—The normal (or zero) pointer position of a scalar indicator shall be at 12 o'clock for right-left directional information, and at 9 o'clock for up-down directional information. For purely quantitative information, either position may be used.

10.7.3 Pivot Point—Pointers shall be pivoted at the right for vertical scales and at the bottom for horizontal scales.

10.7.4 Mounting—The pointer shall be mounted as close as possible to the face of the dial to minimize parallax.

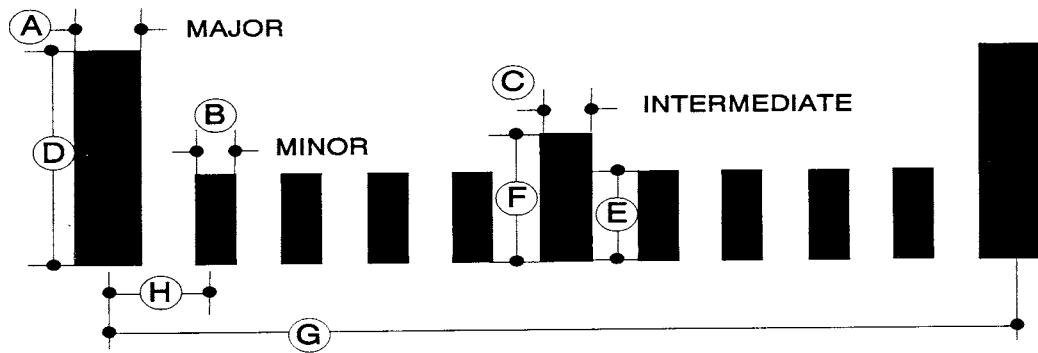
10.7.5 Luminance Contrast—Luminance contrast of at least 75 % shall be provided between the scale face, the markings, and the pointer.

10.7.6 Color—Pointers shall be the same color as the numbers and scale divisions.

10.7.7 Pointers per Shaft—There shall not be more than two pointers on a single shaft.

10.7.8 Reciprocal Pointers—With reciprocal (double-ended) pointers, it shall be easy to distinguish the end that indicates the reading.





Dimension, mm (in)	Viewing Distance		
	710 (28.0)	910 (35.9)	1525 (60.2)
A (Major index width)	0.89 (.035)	1.14 (.045)	1.90 (.075)
B (Minor index width)	0.64 (.025)	0.81 (.032)	1.37 (.054)
C (intermediate index width)	0.76 (.030)	0.99 (.039)	1.63 (.064)
D (Major index height)	5.59 (.221)	7.19 (.283)	12.0 (.473)
E (Minor index height)	2.54 (.100)	3.28 (.129)	5.44 (.214)
F (Intermediate index height)	4.06 (.160)	5.23 (.206)	8.71 (.343)
G (Major index separation between midpoints)	17.8 (.701)	22.9 (.902)	38.0 (1.50)
H (Minor index separation between midpoints)	1.78 (.070)	2.29 (.090)	3.81 (.150)

FIG. 9 Scale of Markings

10.7.9 *Edgewise Indicators*—In edgewise indicators such as rectangular meters with straight scales, only the tip of the pointer may be visible. If so, it shall be distinctive and obvious: a flag, spade, or target pointer.

10.7.10 *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 shall be large enough to show at least one numbered graduation on each side of any setting. If the display is used in tracking, for example, a heading indicator, the whole dial face shall be exposed.

10.7.11 *Coding*—When certain operating conditions (such as normal operating temperature or dangerous pressure level) always fall within a limited range of the total scale, these

ranges shall be made readily identifiable by means of pattern, color, or shape coding applied to the face of the instrument. Use of red color coding shall be limited to critical situations. Operating zones may be shape coded when the indicator must be viewed in very low-light-level work environments, for example, 0.07 to 0.7 cd/m² (0.02 to 0.2 ft-L), or where the illuminant color will cause difficulty in discrimination of colors. See Fig. 12.

10.7.11.1 *Use*—Coding on the face of scale indicators may be used to convey such information as desirable operating range, dangerous operating level, caution, undesirable, and inefficient.

10.7.11.2 *Pattern or Color Coding*—When certain operating conditions always fall within a given range on the scale,

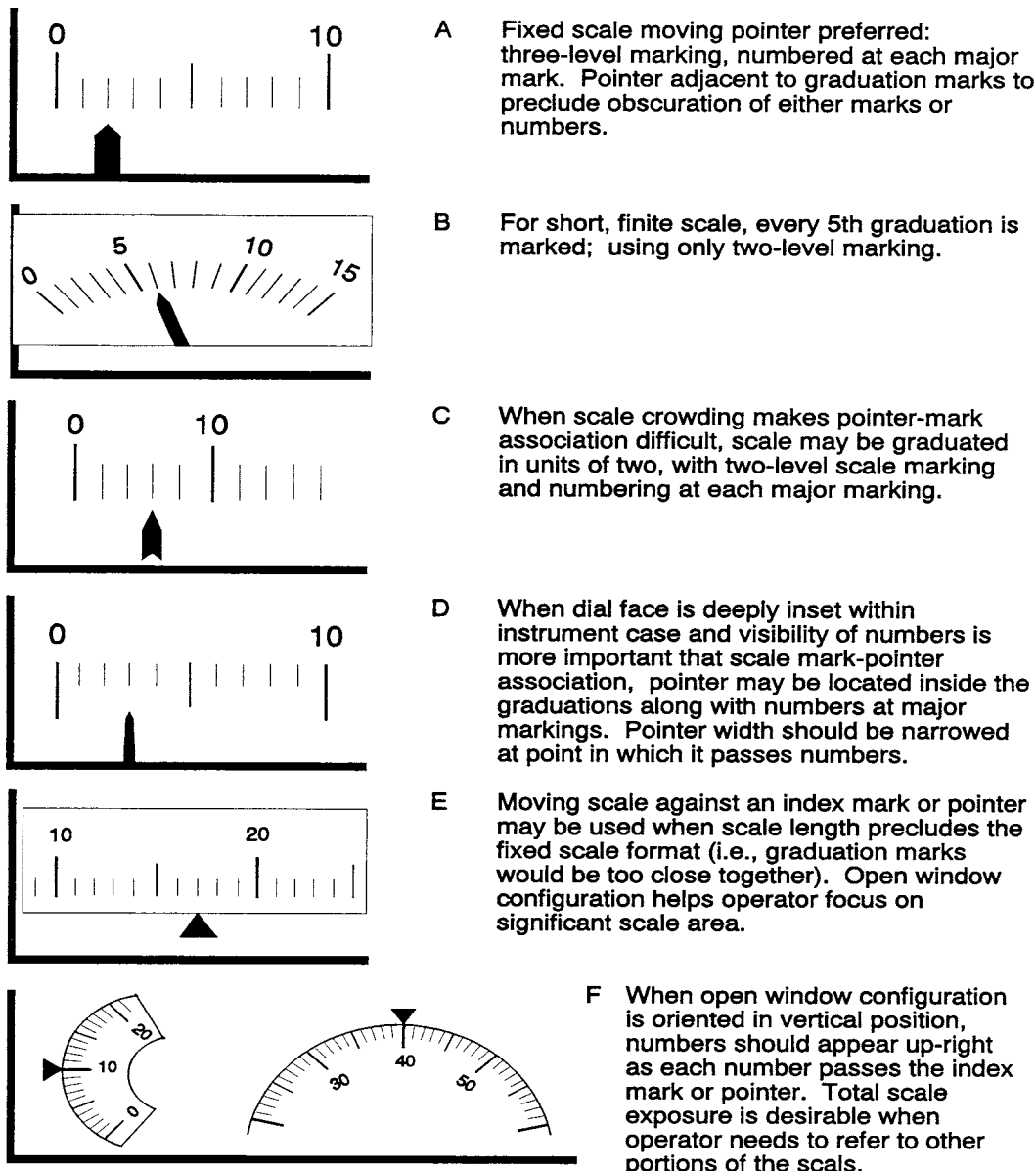


FIG. 10 Scale Graduation, Pointer Position, and Scale Numbering Alternatives

these areas shall be made readily identifiable by means of pattern or color coding applied to the face of the instrument. Color or pattern coding shall be applied to the face of the instrument, not outside the face on the panel or bezel around the instrument. No lines, labels, or any other marks shall be between the instrument pointer and the color or pattern coding.

10.7.11.3 Choice of Colors—Red, yellow, and green may be applied, provided they conform to the meanings specified in 9.19 and are distinguishable under all expected lighting conditions.

10.7.11.4 Pattern Coding—Zone scales may be shape coded when the indicator must be viewed in blackout stations or where the illuminant color will cause difficulty in color band discrimination.

10.8 Moving-Pointer, Fixed-Scale Indicators:

10.8.1 Numerical Progression—Numbered scales shown increase clockwise, from left to right, or from bottom to top,

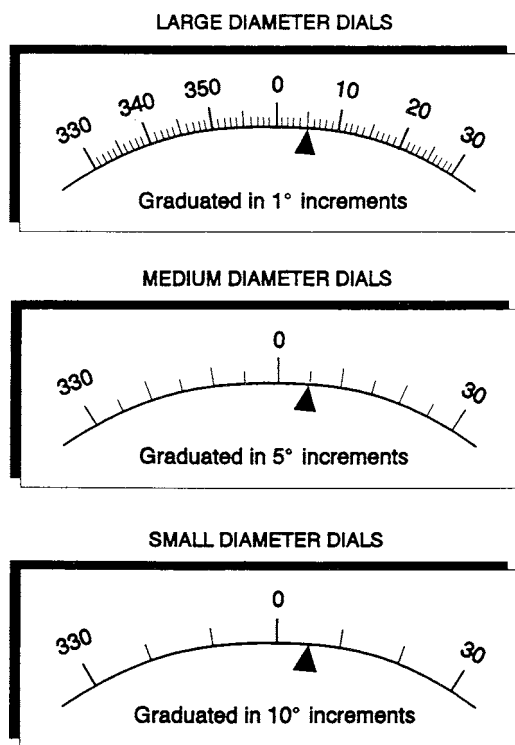
depending on scale layout (circumferential or linear in horizontal or vertical axis).

10.8.2 Orientation of Numerals—Numbers on fixed scales shall appear vertical (upright) to the observer.

10.9 Circular Scales:

10.9.1 Scale Reading and Pointer Movement—To display values ranging from negative through zero to positive, consistently locate the zero point at the 9 or 12 o'clock position. Positive values shall increase when the pointer moves clockwise (to the right), and negative values shall increase when the pointer moves counterclockwise (to the left).

10.9.2 Zero Position and Pointer Movement—When positive and negative values are displayed around a zero point, the magnitude of positive values shall increase with movement of the pointer up or to the right, and the magnitude of negative values shall increase with movement of the pointer down or to the left.



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

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

FIG. 11 Fixed-Scale Azimuth Dials

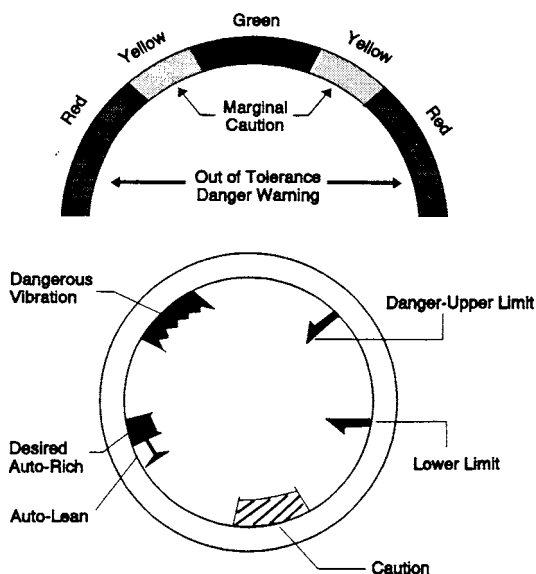


FIG. 12 Shape and Color-Coding Operating Ranges

the left. The position of the zero value on a numbered scale, and the relative pointer movement shall conform to criteria in Fig. 13.

10.9.3 *Scale Break*—There shall be an obvious break of at least 10° of arc between the two ends of the scale, except on multirevolution instruments such as clocks.

10.9.4 *Number of Pointers*—Except for clocks or watches (which often have three hands), not more than two coaxial pointers shall be used on a single-dial indicator without approval from the procuring activity.

10.9.5 *Aligned Pointers for Check Reading*—When a stable value exists for given operating conditions in a group of circular-scale indicators, they shall 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 in accordance with Fig. 14. If a matrix of indicators is needed, preference shall be given to the 9 o'clock position.

10.9.6 *Relative Position of Scale Marks and Numbers*—When reading time and accuracy are critical, circular scale markings and location of associated numbers shall be arranged to prevent pointers from covering any portion of scale marks or numerals, and scale marks/numbers shall be on, or close to, the plane of the pointer tip (that is, to avoid visual parallax) in accordance with Fig. 15. If readout accuracy is not critical (the gross relationship between the pointer and the numeral is all that is required), then arrangement of numerals inside the scale annulus is acceptable. (See examples in Fig. 16.)

10.10 *Curved (Arc), Horizontal, or Vertical Straight Scales:*

10.10.1 *Scale Reading and Pointer Movement*—The magnitude of the scale reading shall increase with movement of the pointer up or to the right.

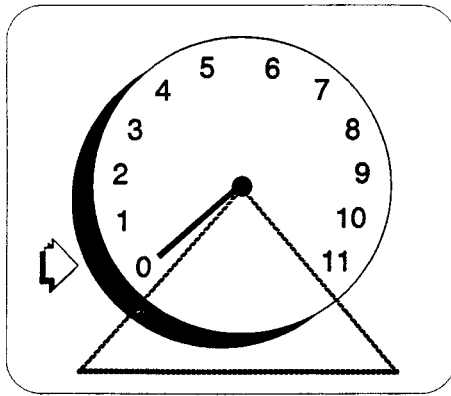
10.10.2 *Zero Position and Pointer Movement*—The position of the zero value on curved or straight scales shall conform to criteria in Fig. 13.

10.10.3 *Relative Position of Pointers, Scales, and Numerals*—The numbers shall be located on the side of the graduation marks opposite the pointer. The graduation marks shall be aligned on the side of the pointer and stepped on the side of the numbers. The relative position of pointers, scales, and numerals shall conform to criteria in Fig. 16.

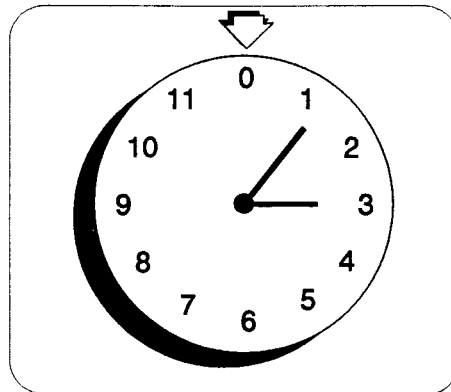
10.11 *Fixed-Pointer, Moving-Scale Indicators:*

10.11.1 *Open Window Display*—When the display will be used primarily for setting in a value (for example, tuning to a desired wavelength), only the portion of the scale of interest shall be exposed, that is, the rest of the scale is covered to reduce visual clutter and confusion. The open window shall be of sufficient size to permit view of at least one numbered graduation either side of the desired setting, that is, at least two number values shall 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 shall be exposed.

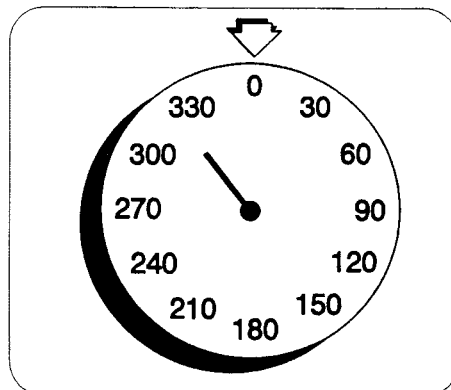
10.11.2 *Circular Scales*—There are ambiguities in associating moving circular scales with control movements; thus moving-scale fixed-pointer indicators are not recommended. Moving circular scales necessarily violates one of these principles of human engineering:



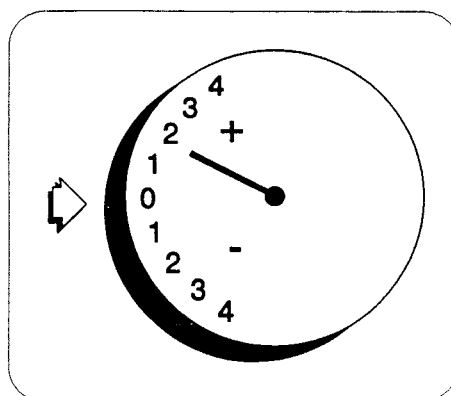
When a dial scale is of finite length, it should be numbered so that value increase is clockwise. The zero starting point should be approximately at the 7 o'clock position. There should be an obvious "break" between the two ends of the scale of at least 10° of arc.



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 shall be used except for special cases, e.g., clock (with second hand).

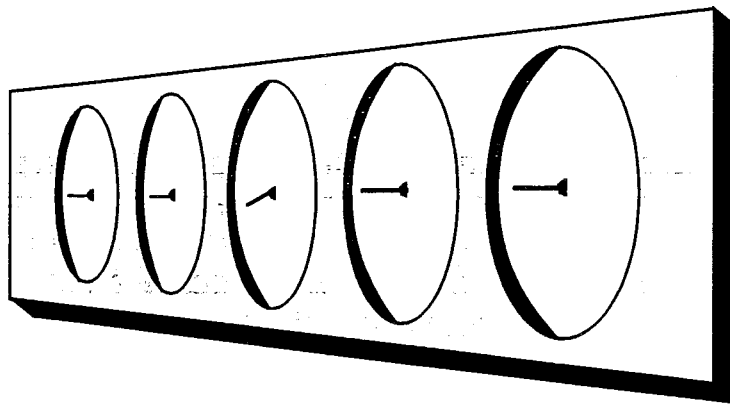


Azimuth dial scales shall be laid out with the zero (or north) reference at the top of the dial, and scale values shall increase clockwise at least every 30° reference should be numbered.

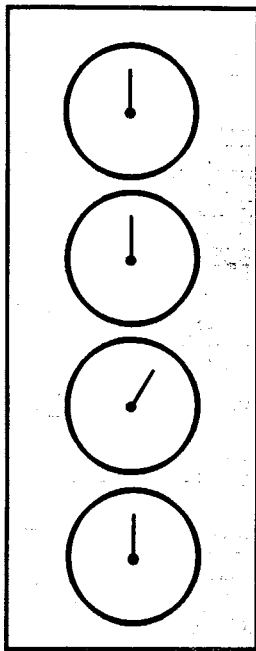


Positive/negative dial formats shall be laid out with the zero (or "null" position) located at the 9-, 12-, or 3-o'clock position. Scale values shall increase right or left, or up or down as appropriate to provide positive/negative pointer movement relationships.

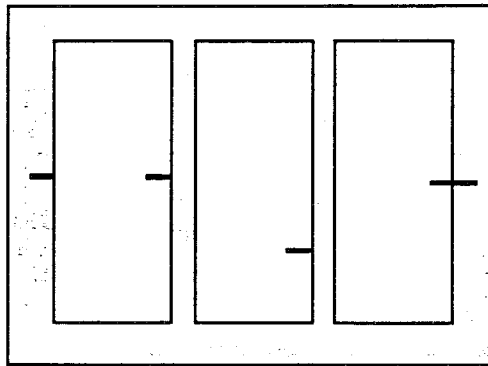
FIG. 13 Zero Position and Pointer Movement for Circular Dial Displays



9-o'clock pointer alignment for horizontal dial array.



12-o'clock pointer alignment for vertical dial array.



Straight-line scale format with "nominal" operating reference common among all displays at the midscale position. Also applicable for "moving-tape" indicators.

FIG. 14 Aligned Pointers for Rapid Check Readings

10.11.2.1 *Principle 1*—Scale numbers shall increase in a clockwise direction. Values on moving circular scales shall therefore increase with counterclockwise rotation of the dial face.

10.11.2.2 *Principle 2*—The direction of movement of the associated control shall be compatible with the direction of movement of the dial, for example, clockwise movement of the control shall result in clockwise movement of the dial.

10.11.2.3 *Principle 3*—Clockwise movement of a control shall result in an increase.

10.11.2.4 If Principle 2 is compromised, for example, clockwise movement of the control results in counterclockwise movement of the dial, operators err in the initial direction of turn. If Principle 3 is compromised, a standard control movement-system relationship is violated.

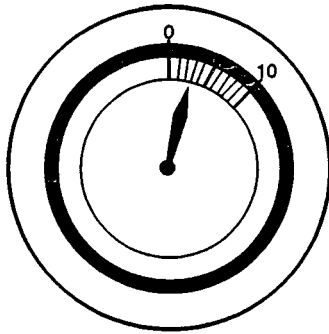
10.11.3 The following practices are recommended for designing circular moving scales to minimize the effects of incompatibilities:

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

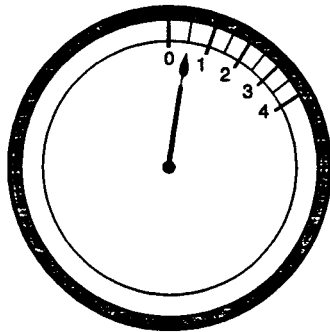
10.11.3.2 If the associated control has no direct effect on the performance of the equipment (such as tuning in radio stations, and so forth), the scale shall rotate counterclockwise (increase) when the associated knob or crank is turned counterclockwise.

10.11.3.3 If the associated control has a direct effect on the performance of the equipment (such as speed, direction, and so forth), the scale shall rotate counterclockwise (increase) with a clockwise, upward, or rightward movement of the associated control.

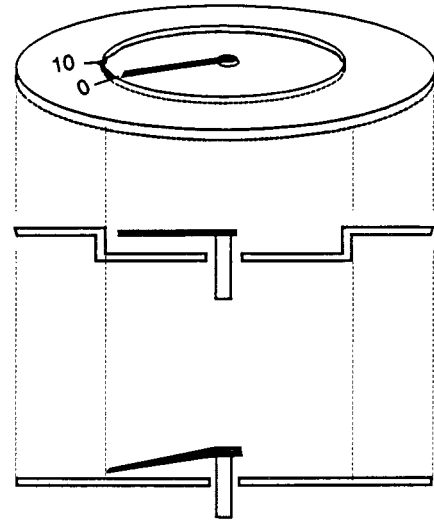
10.11.4 *Straight Scales Moving Vertically and Horizontally*—Straight scales that move vertically and horizontally exhibit the same direction-of-motion ambiguities as circular-moving scales. The numbers shall be printed so they increase from bottom to top or from left to right on the scale plate itself. Then the scale shall increase (move downward or



For maximum reading accuracy, numerals should be placed outside the scale and the inner annulus of scales marks provides an "even" border, against which the pointer tip rides; i.e., the pointer is an equal distance, nominal 0.8 - 1.6 mm (0.03 - 0.06 in), from all scale marks, never overlapping any mark or numeral.



Alternate format when the instrument face is surrounded with a deep bezel, i.e., numerals are



The plane of the numeral/scale information should be coincident with that of the pointer tip - or as near as is practical to prevent or minimize visual parallax.

FIG. 15 Relative Position of Scale Marks, Numerals, and Pointers on Circular Dials

to the left) when the associated knob or crank is moved clockwise or when the associated lever is moved upward or to the right.

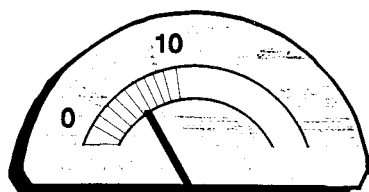
10.11.5 Accepted Deviations—Deviations from the previously listed scale-design principles may be made when other considerations have prime importance. Certain unique applications of scales require other design features and compromises may be required. For example, an azimuth indicator with the numerical progression of 30, 60, 90, and so forth, is less satisfactory than those previously recommended. However, this arrangement represents a compromise between the best numbering progression and a manageable size of the 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 shall be marked by 10's.

10.12 Nonlinear Scales—Nonlinear scales condense a large range into a relatively small 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 shall show enough numbered graduation marks to prevent operators from reading the scale as if it were linear.

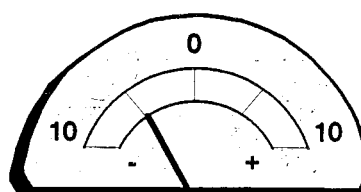
10.13 Moving Tape Displays—When the scale length required for acceptable readout accuracy exceeds the limits of the capacity of the display package, that is, compaction of scale markings would make the display legible or subject to readout error, moving-tape scale format shall be considered.

10.14 Composite Scalar/Pictorial Displays—Combination of scales, pointer, or pictorialized symbols may be used to combine functionally related information into a single instrument or display (for example, artificial horizon/command heading, true/relative bearing, and other similar combinations). Design of significant reference features (or ship symbols, or pitch scales, and so forth) shall conform to the general criteria herein relative to direction-of-motion, scale-pointer relationships, legibility, and so forth. Color contrast shall be used to aid the operator in differentiating between various elements of the combined or composite display (such as dark land versus light sky, and so forth).

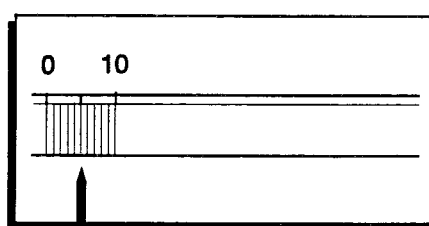
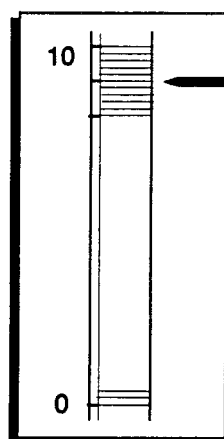
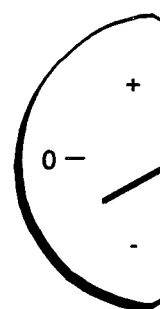
10.15 Head-Up Display—The head-up display (a positional/command type of display) typically projected on the windshield or window in front of an operator to provide information without the operator having to look at instrument panel or the console displays) may be considered only with the express approval of the procuring agency.



Numerals should be located outside scale marks, and pointers should ride against the inner scale annulus just short of the marking. 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, and/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, i.e., pointer should not cover either the scale marks or the numerals. The pointer should emanate from the right side of the vertical format, from the bottom of the horizontal format.

FIG. 16 Relative Position of Scale Marks, Numerals, and Pointers on Arcs and Circular Dials

11. Cathode Ray Tube (CRT) Displays

11.1 *Signal Size*—When a target of complex shape is to be distinguished from a nontarget shape that is also complex, the target signal shall subtend not less than 6 mrad (20 min) of visual angle and shall subtend not less than ten lines or resolution elements. Image quality shall be consistent with the operator's needs.

11.2 *Viewing Distance*—A 400-mm (16-in.) viewing distance shall be provided whenever practicable. When periods of scope observation will be short, or when dim signals must be detected, the viewing distance may be reduced to 250 mm (10 in.). Design shall permit the observer to view the scope from as close as desired. Displays that must be placed at viewing distances greater than 400 mm (16 in.) as a result of other considerations shall be appropriately modified in aspects such as display size, symbol size, brightness ranges, line-pair spacing, and resolution.

11.3 *Screen Luminance*—The ambient illuminance shall not contribute more than 25 % of screen brightness through diffuse reflection and phosphor excitation. A control shall be provided to vary the CRT luminance from 10 % of minimum ambient luminance to full CRT luminance. A control shall be provided

to vary the luminous symbol/dark background or dark symbol/luminous background contrast ratio. CRTs shall comply with 13.11.

11.4 *Faint Signals*—When the detection of faint signals is required and when the ambient illuminance may be above 0.25 fc (2.7 lx), scopes shall be hooded, shielded, or recessed. (In some instances, a suitable filter system may be used, subject to approval by the procuring activity.)

11.5 *Luminance Range of Adjacent Surfaces*—The luminance range of surfaces immediately adjacent to scopes shall be between 10 and 100 % of screen background luminance. With the exception of emergency indicators, no light source in the immediate surrounding area shall be of a greater luminance than the CRT signal.

11.6 *Ambient Illuminance*—The ambient illuminance in the CRT area shall be appropriate for other visual functions (setting controls, reading instruments, maintenance) but shall not degrade the visibility of signals on the CRT display. When a CRT display is used in variable ambient illuminance, illuminance controls shall be provided to dim all light sources, including illuminated panels, indicators, and switches in the immediate area. Automatic adjustment of CRT brightness may

be used if the CRT brightness is automatically adjusted as a function of ambient illuminance, and the range of automatic adjustment is adequate for the full range of ambient illuminance.

11.7 Reflected Glare—Reflected glare shall be minimized by proper placement of the scope relative to the light source, use of a hood or shield, or optical coatings or filter control over the light source.

11.8 Adjacent Surfaces—Surfaces adjacent to the scope shall have a dull matte finish.

11.9 Pictorial/Graphic Situation Formats—Pictorial or situation data such as plan position indicator data, shall be presented as luminous symbols/dark background.

11.10 Font Legibility—Where alphanumeric characters appear on CRT-like displays, the font style shall allow discrimination of similar characters, such as Letter I and Number 1; Letter Z and Number 2.

12. Large-Screen Displays

12.1 Use—Large-scale displays may be used when:

12.1.1 A group of operators frequently refer to the same information and are required to interact as a team based on the same information.

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

12.1.3 Space or other constraints preclude the use of individual displays for each team member to call up commonly used information.

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

12.2 Avoidance—Large-screen displays shall not be used when the environmental conditions do not allow satisfactory observational geometry to ensure that all critical operators have appropriate visual access in terms of viewing distance, angle, and lack of interference from intervening objects, personnel, or ambient lighting. If the display is optically projected, see [13.8](#).

12.3 Viewing Distance—The display shall not be placed further from an observer than will provide appropriate resolution of critical detail presented on the display (see legibility requirements of [Section 27](#)). The display shall not be closer to any observer than one half the display width or height, whichever is greater.

12.4 Physical Interruption of View—Large-screen displays shall not be located with respect to critical observers so that the view of the display is obscured regularly by persons moving about by normal traffic patterns.

12.5 Control of Displayed Information—Large-screen group display systems shall be designed so that critical information cannot be modified or deleted inadvertently or arbitrarily, and therefore:

12.5.1 Control of changes in the group display shall be under the control of designed operators who operate according to preestablished procedures, upon command of a person in charge, or both.

12.5.2 When an individual must make changes that are of interest only to him or her, a separate, remote display shall be provided.

12.6 Content of Displayed Information—The content of displayed information shall be evident to a trained observer without requiring reference to display control settings.

12.7 Mounting Height—Large-screen displays, such as status boards in CIC rooms, which are mounted vertically, shall be no lower than 457.2 mm (18 in.) (preferred), 304.8 mm (12 in.) absolute, above the deck, or no higher than 1981.2 mm (78 in.) above the deck.

13. Other Displays

13.1 Types—Where applicable, direct-reading counters, printers, plotters, flags, optical projection, LED, gas discharge, liquid crystal, and electroluminescent displays may be used providing the color codes of [9.19](#) are not violated.

13.2 Applications—The selection of the above types of displays for various applications shall be based on the following specific criteria as well as the criteria in [Table 2](#). Plotters, printers, and recorders shall not be used as the primary display for systems.

13.3 Counters:

13.3.1 Use—Counters shall be used for presenting quantitative data when a continuous trend indication is not required and when a quick, precise indication is required.

13.3.2 Mounting—Counters shall be mounted as close as possible to the panel surface so as to minimize parallax and shadows and maximize the viewing angle. When counters are used in equipment that is mounted on a vertical surface, the mounting height shall provide for full view of the counter wheel.

13.3.3 Spacing Between Numerals—The horizontal separation between numerals shall be between one quarter and one half the numeral width. Commas shall not be used.

13.3.4 Movement:

13.3.4.1 Snap Action—Numbers shall change by snap action in preference to continuous movement.

13.3.4.2 Rate—Numbers shall follow each other not faster than two per second when the observer is expected to read the numbers consecutively.

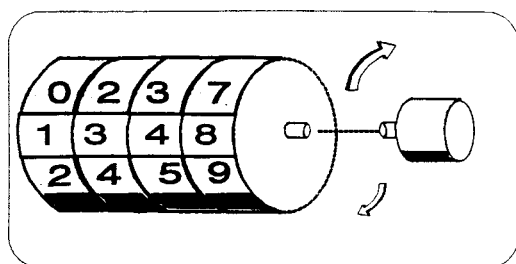
13.3.4.3 Direction—The rotation of the counter reset knob shall be clockwise to increase the counter indication or to reset the counter.

13.3.4.4 Reset—Counters used to indicate the sequencing of equipment shall be designed to be reset automatically upon completion of the sequence. Provision shall also be made for manual resetting. Where push buttons are used to reset mechanical counters manually, actuating force required shall not exceed 16.7 N (60 oz).

13.3.5 Display Design—Numeral design, movement (rate and direction), and arrangement shall be as shown in [Fig. 17](#) and [Table 4](#).

13.3.6 Illumination—Counters shall be self-illuminated when used in areas in which ambient illumination will provide display luminance below 3.5 cd/m (1 ft-L).

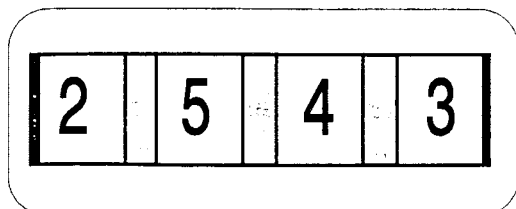
13.3.7 Finish—The surface of the counter drums and surrounding areas shall have a dull finish.



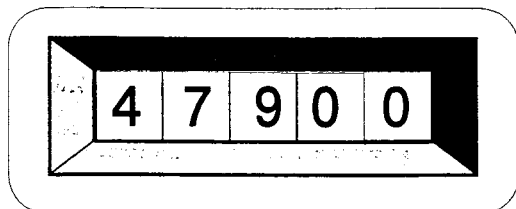
- A Counter drums should be numbered so that a clockwise rotation of drums and/or reset control produce increasing numerical values.

Numerals should "snap" into position so that the entire numeral appears within the viewing window.

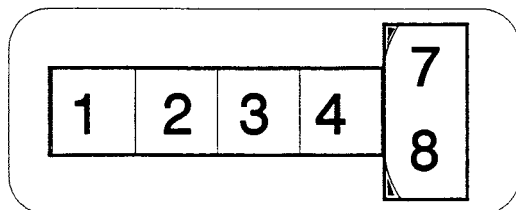
Number height : width proportions should be within the range of 5:3 to 1:1 (1:1 is the preferred ratio) except for number "1".



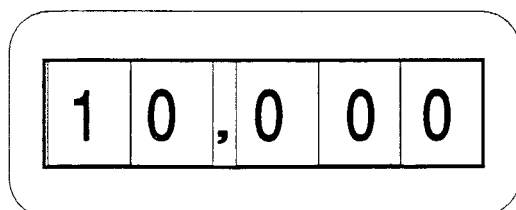
- B Spacing between adjacent numerals should not exceed 1/4th width of wide numerals; 1/2 the width of narrow numerals when several numbers are to read as a total value.



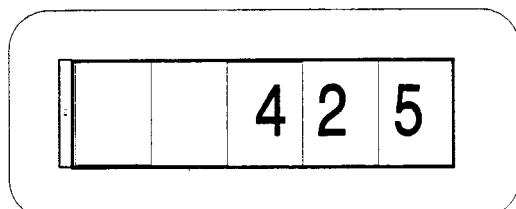
- C Counter drums should be mounted as close to the front panel surface as practical, and the edges of the viewing window should be beveled to provide at least 45° off-angle view of the display.



- D 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 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, provide a blanking system rather than present several preceding zeros (i.e., the blanking device exposes left-hand drums only when numerical value is displayed).

FIG. 17 Drum-Type Counter Design

13.3.8 *Contrast*—Color of the numerals and background shall provide high contrast (black on white or converse, as appropriate).

13.4 *Printers*:

13.4.1 *Use*—Printers shall be used when a visual record of data is necessary or desirable. Use of printers shall conform to Table 3.

TABLE 4 Character Sizes for Mechanical Counters

Viewing Distance, mm (in.)	Height, mm (in.)	Width, mm (in.)	Stroke Width, mm (in.)	Minimum Separation Between Numerals, mm (in.)
Normal Illumination (above 3.4 cd/m)				
710 (28.0 ^A)	3.8 (0.15)	3.8 (0.15)	0.94 (0.04)	0.64 (0.02)
910 (35.8)	4.8 (0.19)	4.8 (0.19)	1.2 (0.05)	0.81 (0.03)
1525 (60.0)	7.9 (0.31)	7.9 (0.31)	1.3 (0.05)	1.3 (0.05)
Low illumination (0.1 to 3.4 cd/m)				
710 (28.0 ^A)	5.6 (0.22)	5.6 (0.22)	0.94 (0.04)	0.94 (0.04)
910 (35.8)	7.1 (0.28)	7.1 (0.28)	1.2 (0.05)	1.2 (0.05)
1525 (60.0)	13.0 (0.51)	13.0 (0.51)	2.1 (0.08)	2.1 (0.08)

^AFor reading distances closer than 710 mm (28.0 in.), characters shall be at least 3 mm (0.118 in.) high.

13.4.2 *Visibility*—The printed matter shall not be hidden, masked, or obscured in a manner that impairs direct reading.

13.4.3 *Contrast*—A minimum of 75 % luminance contrast shall be provided between the printed material and the background on which it is printed.

13.4.4 *Illumination*—The printer shall be provided with internal illumination if the printed matter is not legible in the planned operational ambient illumination.

13.4.5 *Take-up Provision*—A take-up device for printed material shall be provided.

13.4.6 *Annotation*—Where applicable, printers shall be mounted so that the printed matter (for example, paper, metallized paper) may be easily annotated while still in the printer.

13.4.7 *Legibility*—The print output shall be free from character line misregistration, character tilt, or smear.

13.4.8 *Printed Tapes*—The information on the tapes shall be printed in such a manner that it can be read as it is received from the machine without requiring the cutting and pasting of tape sections.

13.4.9 *Control, Replenishment, and Service*—Printers shall conform to the criteria of 13.5.8 for plotters and recorders.

13.5 Plotters and Recorders:

13.5.1 *Use*—Plotters and recorders may be used when a visual record of continuous graphic data is necessary or desirable.

13.5.2 *Visibility*—Critical graphics (those points, curves, and grids that must be observed when the recording is being made) shall not be obscured by pen assembly, arm, or other hardware elements.

13.5.3 *Contrast*—A minimum of 50 % luminance contrast (see 3.1.43) shall be provided between the plotted function and the background on which it is drawn.

13.5.4 *Take-Up Device*—A take-up device for extruded plotting materials shall be provided when necessary or desirable.

13.5.5 *Job Aids*—Graphic overlays should be provided where they may be critical to proper interpretation of graphic data as it is being generated. Such aids shall not obscure or distort the data.

13.5.6 *Smudging/Smearing*—The plot shall be resistant to smudging or smearing under operational use.

13.5.7 *Annotation*—Where applicable, plotters and recorders shall be designed or mounted so that the operator can write on or mark the paper while it is still in the plotter/recorder.

13.5.8 *Control, Replenishment, and Service*—Plotters and recorders shall conform to criteria herein with regard to the following:

13.5.8.1 Controls and displays used to start, stop, or adjust the machine and critical operating elements.

13.5.8.2 Positive indication of the remaining supply of plotting materials (paper, ink, ribbon).

13.5.8.3 Insertion, adjustment for operation, and removal of paper, replenishment of ink supply, replacement of pen, or other items determined to be operator tasks, without requiring disassembly, special equipment, or tools.

13.5.8.4 Minor servicing on site by a technician, such as the adjustment of the drive system, cleaning, or replacement of operating items that ordinarily would not be available to an operator.

13.6 Flags:

13.6.1 *Use*—Flags shall be used to display qualitative, nonemergency conditions. Use of flags shall conform to Table 3.

13.6.2 *Mounting*—Flags shall be mounted as close to the surface of the panel as possible without restricting their movement or obscuring necessary information.

13.6.3 *Snap Action*—Flags shall operate by snap action.

13.6.4 *Contrast*—A minimum of 75 % luminance contrast (see 3.1.43) shall be provided between flags and their backgrounds under all expected lighting conditions.

13.6.5 *Malfunction Indication*—When flags are used to indicate the malfunction of a visual display, the malfunction position of the flag shall obscure part of the operator's view of the malfunctioning display and shall be readily apparent to the operator under all expected levels of illumination.

13.6.6 *Legend*—When a legend is provided on the flag, the lettering shall appear upright when the flag assumes the active or no-go position.

13.6.7 *Test Provision*—A convenient means shall be provided for testing the operation of flags.

13.7 Large-Screen Optical Projection Displays:

13.7.1 *Use*—Providing ambient light can be properly controlled, optical projection displays are suitable for applications requiring group presentation, pictorial and spatial information, past history versus real-time presentation, synthetically generated pictures, simulation of the external world, and superposition of data from more than one source. Rear projection shall be used where physical obstructions to front projection result in poor visibility or where work areas require high ambient illumination for other activities.

13.7.2 *Seating Area*—Viewing distance/image width relationship and off-centering viewing of optical projection displays for group viewing shall conform to the preferred limits of Table 5 and shall not exceed the acceptable limits indicated. For individual viewing from a fixed location, off-centerline viewing shall not exceed 175 mrad (10°).

13.7.3 *Image Luminance and Light Distribution*—Image luminance and light distribution shall conform to the preferred limits and shall not exceed the acceptable limits indicated.



TABLE 5 Group Viewing of Optical Projection Displays

Factor	Optimum	Preferred Limits	Acceptable Limits
Ratio of viewing distance/ screen diagonal	4	3–6	2–8
Angle off centerline	0° (0 mrad)	20° (350 mrad)	30° (525 mrad)
Image luminance (no film in operating projector) ^A	10 ft-L (35 cd/m ²)	8–14 ft-L (27–48 cd/m ²)	5–20 ft-L (17–70 cd/m ²)
Luminance variation across screen (ratio of maxi- mum to minimum luminance)	1	1.5	3.0
Luminance variation as a function of viewing location (ratio of maximum to mini- mum luminance)	1	2.0	4.0
Ratio of ambient light/ brightest part of image	0	0.002–0.01	0.1 max ^B

^AFor still projections, higher values may be used.

^BFor presentations not involving gray scale or color (for example, line drawings, tables), 0.2 may be used.

any case, the luminance of the screen center at maximum viewing angle shall be at least half its maximum luminance.

13.7.4 Legibility of Projected Data:

13.7.4.1 *Style*—A simple style of numerals and letters shall be used. Capital letters shall be used, rather than lowercase, except for extended copy or lengthy messages. Stroke width shall be $\frac{1}{6}$ to $\frac{1}{8}$ of numeral or letter height, but may be narrower for light markings on a dark background. Stroke width shall be the same for all letters and numerals of equal height. Letter and numeral widths, character spacing, and word spacing shall conform to 28.10.

13.7.4.2 *Size*—The height of letters and numerals (except single-stroke characters, such as the Number 1) shall not be less than 4.5 mrad (15 min) of visual angle and, in no instance, shall be less than 3 mrad (10 min) as measured from the longest anticipated viewing distance.

13.7.5 Contrast:

13.7.5.1 *Luminance Ratio*—Under optimal ambient lighting conditions, the luminance ratio (see 3.1.44) for optically projected displays shall be 500:1. The minimum luminance ratio for viewing charts, printed text, and other line work via slides or opaque projectors shall be 5:1. For projections that are limited in shadows and detail, such as animation and photographs with limited luminance range, the minimum luminance ratio shall be 25:1. For images that show a full range of colors or grays (in black-and-white photographs), the minimum luminance ratio shall be 100:1.

13.7.5.2 *Direction of Contrast*—Contrast may be either light on a dark background or vice versa, except where superposition is used. For subtractive superposition (at the source), data shall be presented as dark markings on a transparent background. For additive superposition (at the screen), data shall be presented as light markings on an opaque background. Colored markings against colored backgrounds of comparable brightness shall be avoided.

13.7.6 *Alignment*—Misregistration of superimposed alphanumeric data or other symbols shall be minimized.

13.7.7 *Keystone Effects*—Projector-screen arrangement shall minimize the keystone effect, that is, the distortion of

projected data proportions caused by nonperpendicularity between projector and screen.

13.8 Light-Emitting Diodes (LEDs):

13.8.1 *General*—The standard for LEDs will be the same as the requirements for transilluminated displays, Section 9 of this practice, unless otherwise specified herein.

13.8.2 *Use*—LEDs may be used for transilluminated displays, including legend and simple indicator lights, and for matrix (alphanumeric) displays, only if the display is bright enough to be readable in the environment of intended use enclosure, bright sunlight, low temperature.

13.8.3 *Intensity Control*—The dimming of LEDs shall be compatible with the dimming of incandescent lamps.

13.8.4 *Color Coding*—LED color coding shall conform to 9.19 herein, with the exception that red alphanumeric displays and red bar segments for vertical, horizontal, and circular meters may be used with approval from the procuring activity. However, red LEDs shall not be located in the proximity of emergency red lights used as outlined in 9.19.1.

13.8.5 *Lamp Testing*—LED indicator lights with 100 000 h or longer MTBF (Mean Time Between Failure) shall not require the lamp test capability specified in 9.15.

13.9 Dot Matrix/Segmented Displays:

13.9.1 *General*—The design criteria below shall be applied to those displays (LED, CRT, gas discharge, liquid crystal, and incandescent) used for presentation of alphanumeric and symbolic information.

13.9.2 *Use*—Dot matrix, 14-segment, and 16-segment displays may be used for applications involving interactive computer systems, instruments, navigation, and communication equipment, where the presentation of alphanumeric, vector-graphic, symbolic or real-time information is required. Seven-segment displays shall only be used for applications requiring numeric information.

13.9.3 *Symbol Definition*—The smallest definition for a dot matrix shall be 5 by 7 dots, with 7 by 9 preferred. If system requirements call for symbol rotation, a minimum of 8 by 11 is required, with 15 by 21 preferred.

13.9.4 *Alphanumeric Character and Symbol Sizes*—Alphanumeric and symbolic characters shall not subtend less than 4.7 mrad (16 min) of visual angle.

13.9.5 *Use of Uppercase*—Alphanumeric characters shall be uppercase.

13.9.6 *Viewing Angle*—The optimum viewing angle is perpendicular to the display. Dot matrix or segmented displays shall not be presented for viewing at an angle larger than 610 mrad (35°) off axis.

13.9.7 *Emitter Color*—Monochromatic displays shall use the following colors in order of preference: green (555 nm), yellow (575 nm), orange (585 nm), and red (660 nm). Blue emitters shall not be used.

13.9.8 *Intensity Control*—Dimming controls shall be provided where applicable to maintain appropriate legibility and operator dark adaptation level.

13.9.9 *Lamp Testing*—See 9.15.

13.9.10 *Location of Red Alphanumeric LEDs/Segmented Displays*—Red LEDs/segmented displays shall not be grouped with or located adjacent to red warning lights.





13.10 Electroluminescent Displays:

13.10.1 *Use*—Electroluminescent displays may be used wherever system requirements dictate the use of transilluminated displays provided they comply with 9.19. In addition, they may replace existing mechanical instrumentation while offering advantages of lighter weight, conservation of panel space, lower power requirements, lack of heat production, uniform distribution of illumination, longer life, elimination of parallax, and flexibility of display. Electroluminescent displays may also be used where sudden lamp failure could result in catastrophic consequences.

13.10.2 *Alphanumeric Character and Symbol Sizes*—The height of alphanumeric characters and geometric and pictorial symbols shall not subtend less than 4.5 mrad (15 min) of visual angle. Alphanumerical characters shall be composed of upper-case letters.

13.11 Special Requirements for TV Display:

13.11.1 *Resolution*—Resolution shall be 400 lines or greater both horizontally and vertically except that for low-resolution applications; line spacing need not be closer than needed to subtend 1 min of arc from the normal viewing position.

13.11.2 *Rate and Interlacing*—Except for slow-scan systems for reproduction of static images, the frame rate for sampling of video material shall be a minimum of 30/s. There shall be two display scan fields per frame period (or a minimum of 60/s) with the lines of the second scan in the frame period interlaced with the lines of the first scan.

13.11.3 *Phosphors*—The phosphors for TV screens shall have short or medium persistence and high output such as the P-4 or P-23 for black-and-white monitors and the P-22 or P-27 for color monitors.

13.11.4 *Distortion*—Spot diameter shall not vary by more than a ratio of 1.5 to 1.0 at any two points on the screen. Distortion shall not be sufficient to cause obvious nonlinearity anywhere on the screen when viewing alphanumeric formats or picture images.

13.11.5 *Gray Scale*—There shall be a minimum of at least five distinguishable gray scale levels. When the requirements include interpretation of handwriting, resolution of fine detail, or complex image interpretation, up to eight gray scale levels shall be provided.

13.12 Special Requirements for Radar/Sonar Displays:

13.12.1 *Types of Scans*—The type of scan selected shall be appropriate to the operator's task in using the radar/sonar data. Commonly used scan types shall be selected in preference to novel or experimental scan types except as approved by the procuring activity.

13.12.2 *Display Scale Sizes and Range Ring Values*—Display scale shall be selected on the basis of the following criteria.

13.12.2.1 If rings are to be used, the display scales selected shall be compatible with the use of a constant number of range rings regardless of the scale, as given in Table 6.

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

13.12.3 Appropriate scale limits considering radar/sonar characteristics such as maximum range, range resolution, bearing resolution, and maximum range of detection. For

TABLE 6 Range Ring Values

3 Range Rings Any Decimal Multiples of:	4 Range Rings Any Decimal Multiples of:	5 Range Rings 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

example, the display scales for use with a shipboard surface search radar having a minimum range of 200 m (656.2 ft) and a maximum range of 60 km (57.3 miles) might be as follows:

13.12.3.1 *Minimum*—2 km (1.24 miles) not more than ten times the minimum range value, to capitalize on range determination at close-in ranges as in station keeping.

13.12.3.2 *Maximum*—75 km (46.6 miles) accommodates maximum range of the radar and is a good scale for estimation and interpolation.

13.12.4 Area and scaling limits suggested by representative operational situations including warfare operations, search patterns, maneuvers, flight operations, and so forth. For example, an aircraft carrier that may have a number of missions involving close-in aircraft operations at ranges from 15 to 30 km (9.3 to 18.6 miles) shall have a 30-km (18.6-miles) display scale for monitoring and control of aircraft on such missions.

14. Audio Displays, General Information

14.1 *Use*—Audio displays shall be provided when:

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

14.1.2 The common mode of visual display is restricted by overburdening; ambient light variability or limitation; operator mobility; degradation of vision by vibration, hypoxia, or other environmental considerations; or anticipated operator inattention.

14.1.3 The criticality of transmission response makes supplementary or redundant transmission desirable.

14.1.4 It is desirable to warn, alert, or cue the operator to subsequent additional response.

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

14.1.6 Voice communication is necessary or desirable.

14.1.7 *Signal Type*—When an audio presentation is required, the optimum type shall be presented in accordance with Table 7.

14.2 *False Alarms*—The design of audio display devices and circuits shall preclude false alarms.

14.3 *Failure*—The audio display device and circuit shall be designed to preclude warning signal failure in the event of system or equipment failure and vice versa.

14.4 *Circuit Test*—All audio displays shall be equipped with circuit test devices or other means of operability test.

14.5 *Use with Several Visual Displays*—One audio signal may be used in conjunction with several visual displays, provided that immediate discrimination is not critical to personnel safety or system performance.

15. Audio Warnings

15.1 *Audible Alarms*—Audible alarms shall be provided, as necessary, to warn personnel of impending danger.



TABLE 7 Functional Evaluation of Audio Signals

Function	Type of Signal		
	Tones (Periodic)	Complex Sounds (Nonperiodic)	Speech
Quantitative indication	POOR Maximum of five to six tones absolutely recognizable.	POOR Interpolation between signals inaccurate.	GOOD Minimum time and error in obtaining exact value in terms compatible with response.
Qualitative indication	POOR-TO-FAIR Difficult to judge approximate value and direction of deviation from null setting unless presented in close temporal sequence.	POOR Difficult to judge approximate deviation from desired value.	GOOD Information concerning displacement, direction, and rate presented in form compatible with required response.
Status indication	GOOD Start and stop timing. Continuous information where rate of change of input is low.	GOOD Especially suitable for irregularly occurring signals (for example, alarm signals).	POOR Inefficient; more easily masked; problem of repeatability.
Tracking	FAIR Null position easily monitored: problem of signal-response compatibility.	POOR Required qualitative indications difficult to provide.	GOOD Meaning intrinsic in signal.
General	FAIR Good for automatic communication of limited information. Meaning must be learned. Easily generated.	POOR Some sounds available with common meaning (for example, fire bell). Easily generated.	GOOD Most effective for rapid (but not automatic) communication of complex, multidimensional information. Meaning intrinsic in signal and context when standardized. Minimum of new learning required.

operator to a critical change in system or equipment status, and to remind the operator of a critical action, or actions, that must be taken. An alerting/warning system or signal shall provide the operator with a greater probability of detecting the triggering condition than his normal observation would provide in the absence of the alerting/warning system or signal.

15.2 Audible Alarms and Visual Displays at Consoles and Other Work Stations—Audible alarms shall be used as a supplement to visual alarms at operator consoles and other work stations to notify an operator that a serious malfunction has occurred, the nature of which is discernible through some visual display(s). When a supplemental audible alarm is used at a console or work station, it shall be a siren (used in conjunction with a flashing red light) for a danger situation or a horn (used with a yellow light) for a caution situation. Caution signals shall be readily distinguishable from danger signals and shall be used to indicate conditions requiring awareness, but not necessarily immediate action. The audible alarm shall be silenced when the operator acknowledges the visual alarm display. If a second malfunction occurs in the same equipment or system before the first malfunction has been corrected, both the audible and visual alarms shall operate again. Other types of audible alarms may be used in lieu of the two listed here with the written approval of the procuring agency. Whichever signals are selected, the danger and caution alarms must be readily distinguishable from each other and used consistently throughout the ship. Acceptable alarm types for emergency and primary alarms are shown in Fig. 18.

15.3 General Use Audible Alarms—Audible alarms shall be used throughout the ship to notify crew (and passengers for commercial ships) of hazardous situations such as fire and smoke detection, release of fire-extinguishing material in a closed space, impending collision, and ship exposure to biological, chemical, or radiological agents. In addition, audible alarms may be placed in certain crew accommodation spaces (for example, the engineer's berthing compartment) to notify

EMERGENCY ALARMS

FUNCTION	DEVICE
General Emergency Alarm	Whistle Siren Bell Klaxon
Fire Alarm	Bell Klaxon Siren
Fire (Smoke) Detection Alarm	Bell Klaxon Siren Horn
Machinery Space Fire	Bell Klaxon Siren Horn
Fire Extinguishing Medium Release	Siren Horn
Class 3 Watertight Door Closing	Horn

PRIMARY ALARMS

FUNCTION	DEVICE
Machinery Alarm	Horn Buzzer
Personnel Alarm	Buzzer
Bilge Alarm	Horn Buzzer
Steering Gear Alarm	Bell Horn Buzzer
Engineers Alarm	Horn Buzzer

SIGNALS

FUNCTION	DEVICE
Telephone	Horn Buzzer
Engine Room Telegraph	Bell Buzzer

FIG. 18 Acceptable Alarm Types for Emergency and Primary Alarms

them of a malfunction or problem in a part of the ship for which they are responsible. Audible alarms may also be used to notify an operator of an incoming telephone call or a change in the engine room telegraph (EOT) when the possibility exists that the operator would be in an area where such supplemental alarms would be needed. When general audible alarms are used, they shall comply with the following requirements.

15.4 Visual Alarms Used with General Audible Alarms—Visual alarms (that is, rotating or flashing lights) shall be used



in conjunction with general audible alarms in spaces with high ambient noise levels or under other circumstances where the audio alarms may not be discernible. When used the visual alarms shall comply with the following:

15.4.1 Be clearly visible and distinguishable, either directly or by reflection, in all parts of the space in which they are used;

15.4.2 Be of a color in accordance with 9.19, color coding (for Navy ships) or IMO standards for commercial ships;

15.4.3 Flash in accordance with 9.20; and

15.4.4 Flash as long as the audible alarm is activated, and for those audible alarms which are cancelled by activation of an alarm acknowledge switch the visual alarm shall be cancelled by the same alarm acknowledge switch that is used to silence the audible alarm.

16. Characteristics of Audible Alarms

16.1 Frequency:

16.1.1 *Range*—The range shall be between 200 and 5000 Hz and, if possible, between 500 and 1500 Hz. When signals must travel over 300 m (985 ft), frequencies below 1000 Hz shall be used. Frequencies below 500 Hz shall be used when signals must bend around obstacles or pass through partitions.

16.1.2 *Different Characteristics*—When several different audible alarms are to be used concurrently, discernible differences in the spectral composition or the temporal pattern, or both, shall be provided. When specific recognition of individual alarms is important (for example, the differences between a general alarm and fire detected alarm), their differences shall be coded (that is, the waveforms altered) to ensure that each alarm is quickly and easily distinguished.

16.1.3 *Spurious Signals*—The frequency of a warning tone shall be different from that of the electric power used in the system to preclude the possibility that a minor equipment failure may generate a spurious signal.

16.2 Intensity:

16.2.1 *Compatibility with Acoustical Environment*—The intensity, duration, and source location of audio alarms and signals shall be compatible with the acoustical environment of the intended receiver as well as the requirements of other personnel in the signal areas. See 17.1.

16.2.2 *Compatibility with Clothing and Equipment*—As applicable, audio signals shall be loud enough to be heard and understood through equipment or garments (for example, parka hood, NBC protective hood, hearing protective devices) covering the ears of the listener.

16.2.3 *Discomfort*—Audio warning signals shall not be of such intensity as to cause discomfort or “ringing” in the ears as an aftereffect.

17. Signal Characteristics in Relation to Operational Conditions and Objectives

17.1 *Audibility*—A signal-to-noise ratio of at least 20 dB shall be provided in at least one-octave band between 200 and 5000 Hz at the operating position of the intended receiver. However, in no case shall an audible alarm exceed 120 dB (A) (except in extremely noisy compartments in which case the alarm shall exceed the maximum ambient noise level by 10 dB (A) up to a maximum of 140 dB (A)).

17.2 Alerting Capability:

17.2.1 *Attention*—Signals shall not be so startling as to preclude appropriate responses or interfere with other functions by holding attention away from other critical signals.

17.2.2 *Onset and Sound Pressure Level*—The onset of critical alerting signals shall be sudden, and high sound pressure level shall be provided as specified in 17.1.

17.2.3 *Dichotic Presentation*—When earphones will be worn in the operational situation, a dichotic presentation shall be used whenever feasible, alternating the signal from one ear to the other by means of a dual-channel headset.

17.2.4 *Headsets*—Operators who normally wear earphones covering both ears shall have the audible alarms presented in the headset as well as in the work area. A dichotic presentation shall be used so as to provide the audible alarm to one ear and the normal auditory signals to the other on an alternating basis. Binaural headsets shall not be used in an operational environment below 85 dB (A) when that environment may contain sounds that provide the operator with useful information which cannot be presented through the headsets.

17.3 Discriminability:

17.3.1 *Use of Different Characteristics*—When several different audio signals are to be used to alert an operator to different types of conditions, discriminable difference in intensity, pitch, or use of beats and harmonics shall be provided. If absolute discrimination is required, the number of signals to be identified shall not exceed four.

17.3.2 *Coding*—Where discrimination of warning signals from each other will be critical to personnel safety or system performance, audio signals shall be appropriately coded. Alarms that are perceptibly different shall correlate with different conditions requiring critically different operator responses (such as maintenance, emergency conditions, and health hazards). Such signals shall be sufficiently different to minimize the operator’s search of visual displays.

17.3.3 *Critical Signals*—The first 0.5 s of an audio signal requiring fast reaction shall be discriminable from the first 0.5 s of any other signal that may occur. Familiar signals with established names or associations shall be selected. Speech shall be used whenever feasible.

17.3.4 *Action Segment*—The identifying or action segment of an audio warning signal shall specify the precise emergency or condition requiring action.

17.3.5 *Differentiation From Routine Signals*—Audio alarms intended to bring the operator’s attention to a warning or a caution condition shall be differentiated from routine signals, such as bells, buzzers, and normal operation noises.

17.3.6 *Prohibited Types of Signals*—The following types of signals shall not be used as warning devices where possible as a result of confusion that might exist because of the operational environment:

17.3.6.1 Modulated or interrupted tones that resemble navigation signals or coded radio transmissions.

17.3.6.2 Steady signals that resemble hisses, static, or sporadic radio signals.

17.3.6.3 Trains of impulses that resemble electrical interference whether regularly or irregularly spaced.

17.3.6.4 Simple warbles that may be confused with the type made by two carriers when one is being shifted in frequency (beat-frequency-oscillator effect).

17.3.6.5 Scrambled speech effects that may be confused with cross-modulation signals from adjacent channels.

17.3.6.6 Signals that resemble random noise, periodic pulses, steady or frequency modulated simple tones, or any other signals generated by standard countermeasure devices (for example, “bagpipes”).

17.3.6.7 Signals similar to random noise generated by air conditioning or any other equipment.

17.4 *Compatibility:*

17.4.1 *Existing Signals*—The meaning of audio warning signals selected for a system shall be consistent with warning signal meanings already established for that function.

17.4.2 *Acoustic Environment*—Established signals shall be used provided they are compatible with the acoustic environment and the requirements specified herein for the voice communication system. Standard signals shall not be used to convey new meanings. See 17.1.

17.5 *Masking:*

17.5.1 *Other Critical Channels*—Audio warning signals shall not interfere with any other critical functions or signals or mask any other critical audio signals.

17.5.2 *Separate Channels*—Where a warning signal delivered to a headset might mask another essential audio signal, separate channels may be provided to direct the warning signal to one ear and the other essential audio signal to the other ear.

18. Verbal Warning Signals

18.1 *Nature of Signals*—Verbal warning signals shall consist of the following:

18.1.1 An initial alerting signal (nonspeech) to attract attention and to designate the general problem.

18.1.2 A brief standardized speech signal (verbal message) that identifies the specific condition and suggests appropriate action.

18.2 *Intensity*—Verbal alarms for critical functions shall be at least 20 dB above the speech interference level at the operating position of the intended receiver.

18.3 *Vocal Criteria:*

18.3.1 *Type of Voice*—The voice used in recording verbal warning signals shall be distinctive.

18.3.2 *Delivery Style*—Verbal warning signals shall be presented in a formal, impersonal manner.

18.4 *Message Content*—In selecting words to be used in audio warning signals, priority shall be given to intelligibility, aptness, and conciseness in that order.

18.5 *Message Categories:*

18.5.1 *Critical Warning Signals*—Critical warning signals shall be repeated with not more than a 3-s pause between messages until the condition is corrected or overridden by the crew.

18.5.2 *Message Priorities*—A message priority system shall be established, and more critical messages shall override the presentation of any message occurring below it on the priority list. If two or more incidents or malfunctions occur simultaneously, the message having the higher priority shall be given first. The remaining messages shall follow in order of priority.

In the event of a complete subsystem failure, the system shall integrate previous messages via electronic gating and report the system rather than the component failure.

19. Controls for Audio Warning and Caution Devices

19.1 *Automatic or Manual Shutoff*—When an audio signal is designed to persist as long as it contributes useful information, a shutoff switch controllable by the operator, the sensing mechanism, or both, shall be provided, depending on the operational situation and personnel safety factors.

19.2 *Automatic Reset*—Whether audio and caution warning signals are designed to be terminated automatically, by manual control, or both, an automatic reset function shall be provided. The automatic reset function shall be controlled by the sensing mechanism which shall recycle the signal system to a specified condition as a function of time or the state of the signal system.

19.3 *Redundant Visual Warning*—All nonverbal aural annunciations shall be accompanied by a visual annunciation which defines the condition. This may be an illuminated display.

19.4 *Volume Control:*

19.4.1 *Automatic or Manual*—The volume (loudness) of an audio warning or caution signal shall be designed to be controlled by the operator, the sensing mechanism, or both, depending on the operational situation and personnel safety factors. Control movements shall be restricted to prevent reducing the volume to an inaudible level but in no case shall the volume be less than that of 20 dB.

19.4.2 *Ganging to Mode Switches*—Volume controls may be ganged to mode switches to provide maximum output during mission phases in which intense noise may occur and to provide reduced volume at other times. Ganging shall not be accomplished if there is a possibility that intense noise may occur in an emergency situation during a mission phase in which the volume would be decreased below an audible level.

19.4.3 *Caution Signal Controls*—Audio caution signals shall be provided with manual reset and volume controls.

19.5 *Duration*—Audio warning and caution signals shall continue until the appropriate operator response is made, alarm acknowledged, or malfunction corrected. Completion of a corrective action by the operator or by other means shall automatically terminate the signal.

19.6 *Duration Limitations*—In an emergency situation, signals that persist or increase progressively in level shall not be used if manual shutoff may interfere with the corrective action required.

20. Speech Transmission Equipment

20.1 *Frequency*—Microphones and associated system-input devices shall be designed to respond optimally to that part of the speech spectrum most essential to intelligibility (200 to 6100 Hz). Where system engineering necessitates speech-transmission bandwidths narrower than 200 to 6100 Hz, the minimum acceptable frequency range shall be 250 to 4000 Hz.

20.2 *Dynamic Range*—The dynamic range of a microphone used with a selected amplifier shall be great enough to admit variations in signal input of at least 50 dB.

20.3 Noise-Cancelling Microphones—In very loud, low-frequency noise environments (100 dB overall), noise-cancelling microphones shall be used and shall be capable of effecting an improvement of not less than 10-dB peak-speech to root-mean-square-noise ratio as compared with nonnoise-cancelling microphones of equivalent transmission characteristics.

20.4 Preemphasis—If necessary, speech system input devices shall use frequency preemphasis with a positive slope frequency characteristic no greater than 18 dB per octave from 140 to 1500 to and no greater than 9 dB per octave over the frequency range 1500 to 4800 Hz, when no clipping is used.

20.5 Peak Clipping of Speech Signals—Where speech signals are to be transmitted over channels showing less than 15 dB, peak-speech to root-mean-square-noise ratios, peak clipping of 12 to 20 dB may be used at system input and may be preceded by frequency preemphasis.

20.6 Noise Shields—When the talker is in an intense noise field, the microphone shall be put in a noise shield. Noise shields shall be designed to meet the following requirements:

20.6.1 A volume of at least 250 cm³ (15.25 in.³) to permit a pressure gradient microphone to function normally.

20.6.2 A good seal against the face with the pressure of the hand or the tension of straps.

20.6.3 A hole or combination of holes covering a total area of 65 mm² (0.1 in.²) in the shield to prevent pressure buildup.

20.6.4 Prevention of a standing wave pattern by shape or by use of sound-absorbing material.

20.6.5 No impediment to voice effort, mouth or jaw movement, or breathing.

20.7 Speech Reception Equipment:

20.7.1 Frequency Range—Headphones and loudspeakers shall be subject to the same frequency response restrictions as microphones and transmission equipment, except that loudspeakers for use in multispeaker installations and multiple channels fed into headphones (for example, where several speech channels are to be monitored simultaneously) shall respond uniformly (+5 dB) over the range 100 to 4800 Hz.

20.7.2 Loudspeakers for Multichannel Monitoring:

20.7.2.1 Monitoring of Speakers—When several channels are to be monitored simultaneously by means of loudspeakers, the speakers shall be mounted at least 175 mrad (10°) apart in the horizontal plane frontal quadrant, ranging radially from 788 mrad (45°) left to 788 mrad (45°) right of the operator's normal forward facing position. Loudspeakers used by a single person (in an area in which there is more than one speaker installed) shall be mounted directly in front of the user and be equipped with a volume control and a jack box for use with headphones.

20.7.2.2 Filtering—When additional channel differentiation is required, apparent lateral separation shall be enhanced by applying low-pass filtering (frequency cutoff, $F_c = 1800$ Hz) to signals fed to loudspeakers on one side of the central operator position. If there are three channels involved, one channel shall be left unfiltered, a high-pass filter with 1000-Hz cutoff shall be provided in the second channel, and a low-pass filter with 2500-Hz cutoff shall be provided in the third channel. A visual signal shall be provided to show which channel is in use.

20.7.3 Use of Deemphasis—When transmission equipment uses preemphasis and peak clipping is not used, reception equipment shall use frequency deemphasis of characteristics complementary to those of preemphasis only if it improves intelligibility, that is, deemphasis shall be a negative-slope frequency response not greater than 9 dB per octave over the frequency range 140 to 4800 Hz.

20.7.4 Headsets—If listeners will be working in high ambient noise (85 dB(A) or above), binaural rather than monaural headsets shall be provided. Unless operational requirements dictate otherwise, binaural headsets shall be wired so that the sound reaches the two ears in opposing phases. Their attenuation qualities shall be capable of reducing the ambient noise level to less than 85 dB(A). Provisions shall be incorporated to furnish the same protection to those who wear eyeglasses.

20.8 Operator Comfort and Convenience:

20.8.1 Comfort—Headphones and telephone headsets shall be designed for operator comfort, and no metal parts of the headset shall come in contact with the user's skin.

20.8.2 Hands-Free Operation—Operator microphones, headphones, and telephone headsets shall be designed to permit hands-free operation under normal working conditions.

20.8.3 Accessibility of Handsets—Where communication requirements necessitate the use of several telephone handsets, the accessibility of their standby locations shall be determined by operational priority, that is, the most frequently or urgently needed handset shall be the most accessible. Color coding may also be used where operating personnel will have visual contact with handsets under the working conditions.

20.9 Operating Controls for Voice Communication Equipment:

20.9.1 Volume Controls—Accessible volume or gain controls shall be provided for each communication receiving channel (for example, loudspeakers or headphones) with sufficient electrical power to drive sound pressure level to at least 110 dB overall when using two earphones. The minimum setting of the volume control shall be limited to an audible level, that is, it shall not be possible to disable the system inadvertently with the volume control. While separation of power (on-off) and volume control adjustment functions into a separation of power (on-off) and volume control adjustment functions into separate controls is preferred, shall conditions justify their combination, a noticeable detente position shall be provided between the OFF position and the lower end of the continuous range of volume adjustment. When combined power and volume controls are used, the OFF position shall be labeled.

20.9.2 Squelch Control—Where communication channels are to be continuously monitored, each channel shall be provided with a signal-activated switching device (squelch control) to suppress channel noise during no-signal periods. A manually operated, on-off switch to deactivate the squelch when receiving weak signals shall be provided.

20.9.3 Foot-Operated Controls—When normal working conditions will permit the operator to remain seated at the working position and access to "talk-listen" or "send-receive" control switches are required for normal operation, or if console operation requires the use of both hands, foot-operated

controls shall be provided. Hand-operated controls for the same functions shall be provided for emergency use and for use when the operator may need to move from one position to another.

20.10 Speaker/Side Tone—The speaker’s verbal input shall be in phase with its reproduction as heard on the headset. This side tone shall not be filtered or modified before it is received in the headset.

20.11 Speech Intelligibility:

20.11.1 General—When information concerning the speech intelligibility of a system is required, three recommended methods are available, with the appropriate selection being dependent upon the requirements of the test.

20.11.1.1 The ANSI standard method of measurement of phonetically balanced (PB) monosyllabic word intelligibility, S3.2-1960, shall be used when a high degree of test sensitivity and accuracy is required.

20.11.1.2 The Modified Rhyme Test (MRT) shall be used if the test requirements are not as stringent or if time and training do not permit the use of the ANSI method.

20.11.1.3 The Articulation Index (AI) calculations should be used for estimations, comparison and predictions of system intelligibility based upon ANSI S3.5-1969.

20.11.2 Criteria—The intelligibility criteria shown in **Table 8** shall be used for voice communication. The efficiency of communications needed and the type of material to be transmitted shall determine which of the three communication requirements of **Table 8** is to be selected.

21. Controls, General Information

21.1 Selection Criteria—Criteria in **Table 9** and **Table 10** should be used in determining the type of control to be used on control panels or other applications where controls are required.

21.2 Users—The type of control selected and the location of the motion envelope provided for control operation shall ensure that suitably clothed and equipped user personnel with applicable fifth through ninety-fifth percentile body dimensions and fifth percentile strength can operate them.

21.3 Efficiency—Since more operations are right handed than left handed, equipment shall normally be designed for right-handed operation. Other considerations are that hand manipulation is more precise than foot manipulation and that more force can usually be applied by the foot and leg than the hand and arm.

21.4 Distribution of Work Load—Controls shall be selected and distributed so that none of the operator’s limbs will be overburdened.

21.5 G-loading—Where applicable, control selection shall include consideration of operation under variable g-loading on the operator.

21.6 Multirotation Controls—Multirotation controls shall be used when precision is required over a wide range of adjustment.

21.7 Detente Controls—Detente controls shall be selected whenever the operational mode requires control operation in discrete steps.

21.8 Stops—Stops shall be provided at the beginning and end of the range of control positions if the control is not required to be operated beyond the indicated end positions or specified limits.

21.9 Direction of Movement:

21.9.1 Consistency of Movement—Direction of control movement shall be consistent with the related movement of an associated display, equipment component, or vessel (see **Table 11** and **Fig. 19**). With the exception of valve controls, movement of a control forward, clockwise to the right, or up, or pressing a control, shall turn the equipment or component on, cause the quantity to increase, or cause the equipment or component to move forward, clockwise, to the right, or up.

21.9.2 Multidimensional Operation—When the vessel, the equipment, or the components are capable of motion in more than two dimensions, exception to Section **21.9.1** (Consistency of Movement) may be necessary to ensure consistency or anticipated response (such as forward motion of a directional control causes some vessels to dive, for example, a submarine, or otherwise descend rather than to simply move forward). When several controls are combined in one control device, caution shall be exercised to avoid conflicts (for example, control motion to the right is compatible with clockwise roll, right turn, and direct movement to the right).

21.9.3 Operator-Control Orientation—Controls shall be oriented with respect to the operator. Where the operator may use two or more vehicle operator stations, the controls shall cause movement oriented to the operator at the effecting station, unless remote visual reference is used.

21.9.4 Valve Controls—Rotary valve controls shall open the valve with a counterclockwise motion and close with a clockwise rotation. Valve controls shall be provided with double-ended arrows labeled OPEN in the counter-clockwise direction and CLOSE in the clockwise direction.

22. Arrangement and Grouping of Controls

22.1 Grouping—All controls that function in sequential operational necessary to a particular task, or that operate together, shall be grouped together along with their associated displays. When several steps of a sequence are selected by one control, the steps shall be arranged by order of occurrence to minimize control movements and event cycling through unnecessary steps. Cycling through the control’s ON/OFF position shall be avoided.

22.2 Sequential Operation—Where sequential operations follow a fixed pattern, controls shall be arranged to facilitate

TABLE 8 Intelligibility Criteria for Voice Communications Systems

Communication Requirement	Score		
	PB	MRT	AI
Exceptionally high intelligibility; separate syllables understood	90 %	97 %	0.7
Normally acceptable intelligibility; about 98 % of sentences correctly heard; single digits understood	75 %	91 %	0.5
Minimally acceptable intelligibility; limited standardized phrases understood; about 90 % sentences correctly heard (not acceptable for operational equipment)	43 %	75 %	0.3

TABLE 9 Control Selection Criteria

Function	Control ^A									
	Toggle Switch	Push Button	Bar Knob	Round Knob	Thumb Wheel D ^B	Thumb Wheel C ^C	Crank	Rocker Switch	Lever	Joystick/ Ball
Select system power state ON-OFF	2	1	3					2	1 ^D	
3-State (OFF-STBY-ON)	2		1					3		
Select between OFF/prime mode/ secondary mode(s)	3	2	1					3	1 ^D	
Select one or more of N-related functions	2	1						2		
Select one of N mutually exclusive functions of any order		1						2		
Select one of 3 to 24 discrete alternatives—sequential order			1							
Select digit—discrete		1 KEYBD	2 ^E		2 ^E					
Set value on—continuous scale				1		2	3			3
Select value in—discrete steps		1	1		1					
Select operating condition	1	1	2					1	2	
Enter alphanumeric data		1 KEYBD								
Initiate test subfunction (momentary)	1	1	3					2		
Initiate directional function	1	2 multiple	3			3		1	1 multiple	
Create stepping impulse (momentary hold)	1	1						2		
Slew counters or other numeric readout	1	1		1 rate control			1 manual only			
Reset mechanical counter, manual				1	3	1				
Interrupt countdown sequence—"hold"	2	1						2		
Engage—disengage mechanical function									1	
Adjust light level, cont.				1	3	1			3	
Adjust sound level, cont.				1	3	1			3	
Coarse adjustment				1 small diameter		2 small motion	2 few turns		2 short throw	
Fine adjustment				1 large diameter		2 large motion	2 many turns		2 long throw	
Adjust to null position				1		2	3		3	
Single-coordinate tracking				3			2		1	
Two-coordinate tracking							3			1

^A1 = Most preferred, 3 = least preferred.

^B"D" means discrete.

^C"C" means continuous.

^DLever for heavy-duty power circuits.

^EOnly if sequential selection is acceptable.

TABLE 10 Recommended Manual Controls

Control Function	Control Type
Small actuation force controls:	
2 Discrete positions	key lock pushbutton toggle switch legend switch slide switch
3 Discrete positions	rotary selector switch toggle switch pushbutton
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 controls:	
2 Discrete positions	foot pushbutton hand pushbutton detente lever
3 to 24 Discrete positions	detente lever rotary selector switch handwheel
Continuous setting (linear and less than 360°)	joystick or lever crank
Continuous setting (more than 360°)	two-axis grip handle crank handwheel valve two-axis grip handle

TABLE 11 Conventional Control Movement Stereotypes

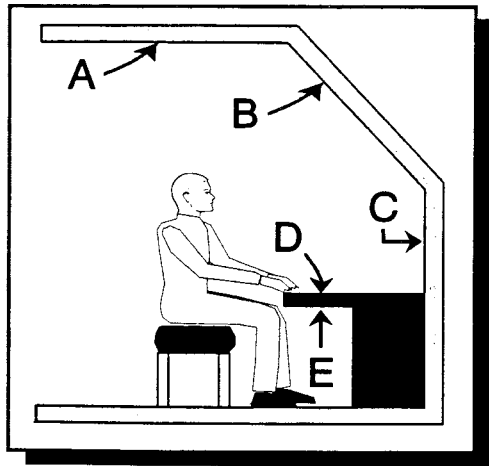
Direction of Movement	Function
Up, right, forward, clockwise, pull (push-pull-type switch)	on
Down, left, rearward, counterclockwise, push	off
Clockwise, right	right
Counterclockwise, left	left
Up, back	raise
Down, forward	lower
Up, rearward, pull	retract
Down, forward, push	extended
Forward, up, right, clockwise	increase
Rearward, down, left, counterclockwise	decrease
Counterclockwise (value)	open value
Clockwise (value)	close value

operation (such as in a fixed pattern left to right and top to bottom, as a printed page).

22.3 Location of Primary Controls—The most important and frequently used controls shall have the most favorable position with respect to ease of reaching and grasping (particularly rotary controls and those requiring fine settings).

22.4 Consistency—The arrangement of functionally similar or identical controls shall be consistent from panel to panel throughout the system, equipment, or vessel.

22.5 Remote Controls—Where controls are operated at a position remote from the display, equipment, or vessel, the controls shall be arranged in a fixed pattern left to right and top to bottom, as a printed page).



- A - CEILING
- B - 45° PANEL
- C - FRONT PANEL
- D - DESK / CONSOLE SURFACE
- E - UNDER CONSOLE
- F - LEFT PANEL
- G - RIGHT PANEL

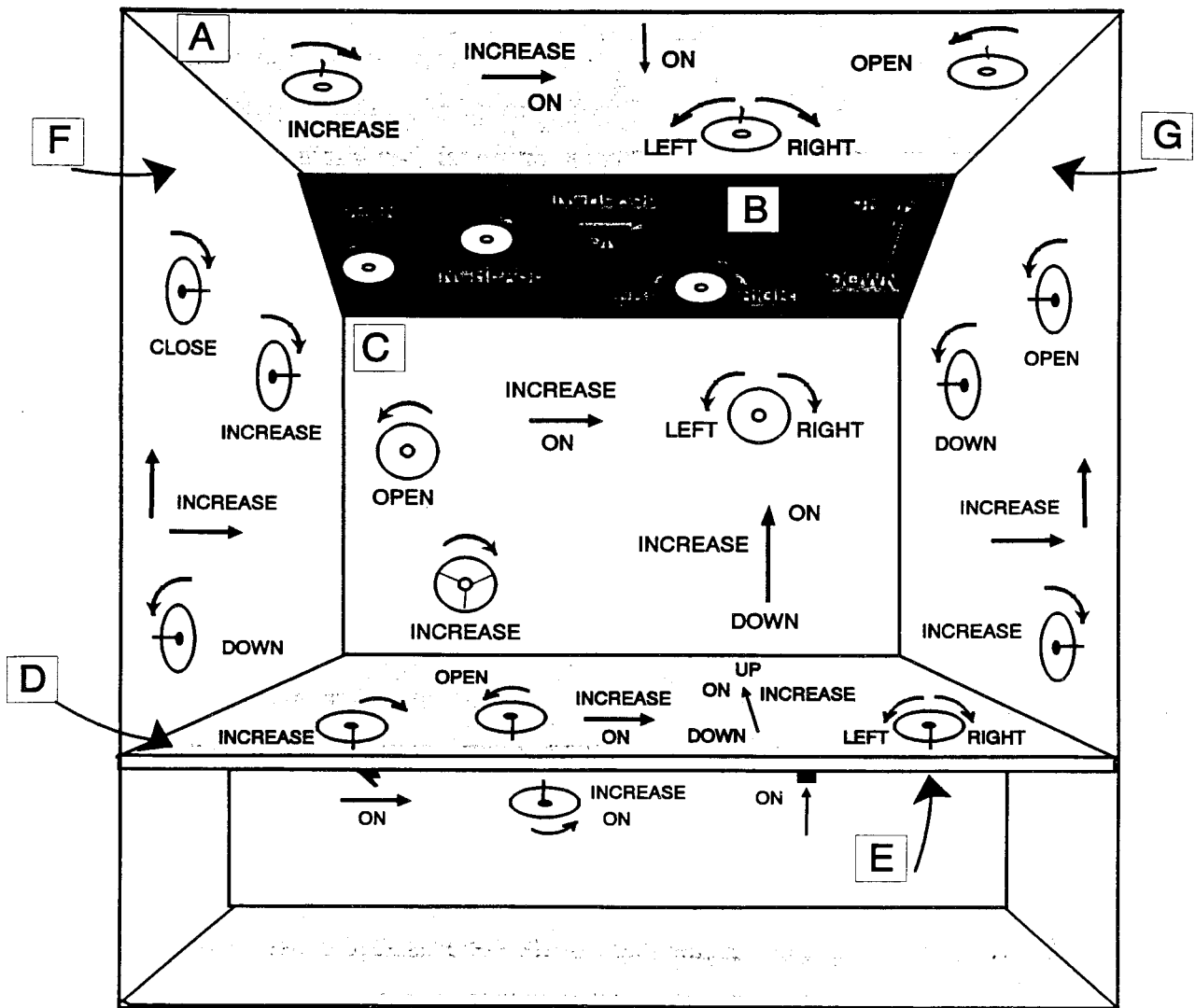


FIG. 19 Control Motion Expectancy

vessel, they shall be arranged to facilitate direction-of-movement consistency.

22.6 Maintenance and Adjustment—In general, controls used solely for maintenance and adjustment shall be covered during normal equipment operation, but shall be directly accessible and visible to the maintenance technician when required.

22.7 Spacing—Minimum spacing between control shall comply with **Table 12** spacing between a control and any adjacent obstruction shall be as shown by the figures referenced by **Table 12**. Minimum spacing shown shall be increased for operation with gloves, mittens, NBC, or other protective handwear when such operation is a system requirement.

23. Coding of Controls

23.1 Methods and Requirements—The use of a coding mode such as size and color for a particular application shall be governed by the relative advantages and disadvantages of each type of coding. Where coding is used to differentiate among controls, application of the code shall be uniform throughout the system. (See **Table 13** for advantages and disadvantages.)

23.2 Location Coding—Controls associated with similar functions shall be in the same relative location from operator work station to work station and from panel to panel.

23.3 Size Coding—No more than three different sizes of controls shall be used in coding controls for discrimination by absolute size. Controls used for performing the same function on different items of equipment shall be the same size. When knob diameter is used as the coding parameter, differences between diameters shall not be less than 13 mm (0.5 in.). When knob thickness is the coding parameter, differences between thicknesses shall not be less than 10 mm (0.4 in.).

23.4 Shape Coding—Primary use of shape coding for controls is for identification of control knobs or handles by “feel;” however, shapes shall be identifiable both visually and tactually. When shape coding is used:

23.4.1 The coded feature shall not interfere with ease of control manipulation.

23.4.2 Shapes shall be identifiable by the hand regardless of the position and orientation of the control knob or handle.

23.4.3 Shapes shall be tactually identifiable when gloves are worn, where applicable.

23.4.4 A sufficient number of identifiable shapes shall be provided to cover the expected number of controls that require tactual identification.

23.4.5 Shape-coded knobs and handles shall be positively and nonreversibly attached to their shafts to preclude incorrect attachment when replacement is required.

23.4.6 Where possible, control shapes shall resemble the equipment, system, or control function that the control operates.

23.4.7 Color Coding:

23.4.7.1 Lighting—Color coding of control surfaces shall not be used when visibility of the controls is restricted or obstructed, or when illumination lighting is below 0.35 cd/m² (0.1 ft-L) or of some color other than white.

23.4.7.2 Related Controls—When related controls and displays are color coded, they shall be coded the same color.

23.4.7.3 Emergency Controls—All emergency controls used under only white lighting shall be colored red. If red lighting is to be used during any portion of a mission, controls which would have been coded red shall be coded by orange-yellow and black striping. To give emergency controls visual emphasis, color coding of other controls shall be kept to a minimum.

23.4.7.4 Choice of Colors—Controls shall be black (17038, 27038, or 37038) or gray (26231 or 36231). If color coding is required, the following colors identified in **Table 14** shall be selected for control coding.

23.4.7.5 Relation to Display—When color coding must be used to relate a control to its corresponding display, the same color shall be used for both the control and the display.

23.4.7.6 Control Panel Contrast—The color of the control shall provide contrast between the panel background and the control.

23.4.7.7 Ambient Lighting and Color-Coding Exclusion—Color coding shall be compatible with anticipated ambient lighting throughout the mission. Color coding shall not be used as a primary identification medium if the operator’s adaptation to that light, varies as the result of such factors as solar glare, filtration of light, and variation from natural to artificial light. If red lighting is to be used during a portion of the mission, controls which would otherwise be coded red shall be coded by orange-yellow and black striping.

23.5 Labeling of Controls—Control labeling shall conform to the criteria in **29.7**.

23.6 Compatibility with Handwear—Controls shall be compatible with handwear to be used in the anticipated environment. Unless otherwise specified, all dimensions cited herein are for bare hands and shall be revised where necessary for use with gloves or mittens.

23.7 Blind Operation—Where “blind” operation is necessary, hand controls shall be shape coded or separated from adjacent controls by at least 125 mm (5 in.).

23.8 Prevention of Accidental Actuation:

TABLE 12 Minimum Separation Distances for Controls

^A	Toggle Switches, mm (in.)	Pushbuttons, ^B mm (in.)	Continuous Rotary Controls, mm (in.)	Rotary Selector Switches, mm (in.)	Discrete Thumbwheel Controls, mm (in.)
Toggle switches	see Fig. 41	13 (0.5)	19 (0.75)	19 (0.75)	13 (0.5)
Pushbuttons ^B	13 (0.5)	see Fig. 40	13 (0.5)	13 (0.5)	13 (0.5)
Continuous rotary controls	19 (0.75)	13 (0.5)	see Fig. 30 and Fig. 33	25 (1.0)	19 (0.75)
Rotary selector switches	19 (0.75)	13 (0.5)	25 (1.0)	see Fig. 24	19 (0.75)
Discrete thumbwheel controls	13 (0.5)	13 (0.5)	19 (0.75)	19 (0.75)	see Fig. 29 and Fig. 34

^AAll values are for one hand operation. Distances are measured from edge to edge of each control.

^BFor pushbuttons not separated by barriers.



TABLE 13 Advantages and Disadvantages of Various Types of Coding

Advantages	Type of Coding					
	Location	Shape	Size	Model of Operation	Labeling	Color
Improves visual identification	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic)	X	X	X	X		
Helps standardization	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting.	X	X	X	X	(when trans-illuminated)	(when trans-illuminated)
May aid in identifying control position (settings)		X		X	X	
Requires little (if any) training: is not subject to forgetting.					X	
Disadvantages						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use).	X	X	X	X		
Limited in number of available coding categories.	X	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (that is, must be within visual areas and with adequate illumination present).					X	X

TABLE 14 Recommended Control Colors (FED-STD-595)

Use	Color	Gloss	Semi-Gloss	Flat
Standard	black	17038	...	...
	gray	...	26238	...
	green	14187	...	...
	orange-yellow	13538	23538	33538
	white	17875	27875	37875
Supplement to standard if required	blue	15123	...	...
Emergency	red	11105	21105	31105

23.8.1 *Location and Design*—Controls shall be designed and located so that they are not susceptible to being moved accidentally, particularly critical or emergency controls whose inadvertent operation might cause damage to equipment, injury to personnel, or degradation of system functions.

23.8.2 *Internal Controls*—Internal or hidden controls shall be protected, because it is usually not obvious that such controls have been disturbed and it may be difficult and time consuming to locate and readjust them.

23.8.3 *Rapid Operation*—Any method of protecting a control from inadvertent operation shall not preclude operation within the time required.

23.8.4 *Methods*—For situations in which controls must be protected from accidental actuation, one or more of the following methods, as applicable, shall be used:

23.8.4.1 Locate and orient the controls so that the operator is not likely to strike or move them accidentally in the normal sequence of control movements.

23.8.4.2 Recess, shield, or otherwise surround the controls by physical barriers. The control shall be entirely contained within the envelope described by the recess or barrier.

23.8.4.3 Cover or guard the controls. Safety or lock wire shall not be used.

23.8.4.4 Provide the controls with interlocks so that extra movement (for example, a side movement out of a detente position or a pull-to-engage clutch) or the prior operation of a related or locking control is required.

23.8.4.5 Provide the controls with resistance (that is, viscous or coulomb friction, spring loading, or inertia) so that definite or sustained effort is required for actuation.

23.8.4.6 Provide the controls with a lock to prevent the control from passing through a position without delay when strict sequential activation is necessary (that is, the control moved only to the next position, then delayed).

23.8.4.7 Design the controls for operation by rotary action.

23.8.5 *Dead Man Controls*—Dead man controls, which will result in system shutdown to a noncritical operating state when force is removed, shall be used wherever operator incapacity can produce a critical system condition.

23.9 *Foot-Operated Controls*:

23.9.1 *Use*—Foot-operated controls may be used under the following conditions:

23.9.1.1 Control operation requires either greater force than the upper body can provide or force close to an upper body fatigue threshold.

23.9.1.2 The operator's hands are generally occupied by other manual control tasks at the same moment that an additional control action is required.

23.9.1.3 A safety shutdown control is required during an operation in which the operator's hands cannot be freed to reach a safety switch.

23.9.2 *Avoidance*—Foot-operated controls shall not be used under the following conditions:

23.9.2.1 Where a standing operator is confronted with a sensitive balancing requirement (for example, a moving platform where balancing on the nonoperating foot may become difficult as the operating foot is moved from a support to actuating position).

23.9.2.2 Precise control operations are required.

23.9.2.3 Selection from among a great many separate controls is required.

23.9.3 *Operation*—Foot controls shall be located and designed so they can be operated in as natural a pattern as practicable. Specifically, the following shall be avoided:

23.9.3.1 Frequent, maximum reaching

23.9.3.2 Requirement to hold the leg or foot in awkward position for extended periods of time.

23.9.3.3 Requirement for the operator to operate a control frequently or for an extended period of time while sitting in a twisted position, the pedals shall be laid out symmetrically with reference to the operator's principal operating orientation.

23.9.3.4 Maximum force application frequently or for extended duration.

23.9.3.5 Requirement that the operator search for a particular foot control in order to select the proper one.

23.9.3.6 Placement of a foot control where it might be stepped on and inadvertently actuated or where typical shifting from one foot control to another creates conditions where the foot or clothing might be entrapped by an intervening control.

23.9.4 *Configuration and Placement*—Configuration and placement of foot operated controls shall accommodate the anthropometry of the operator's foot wearing operational shoes or boots (See Section 30). They shall be located so that the activation of a control by one foot does not interfere with the activation of a control by another foot and so that the movements of feet and legs are natural and easily accomplished within the work station where foot controls are located.

23.9.5 *Foot-Operated Switches:*

23.9.5.1 *Use*—Foot-operated switches shall be used only where the operator is likely to have both hands occupied when switch activation may be required, or when load sharing among limbs is desirable. Because foot-operated switches are susceptible to accidental activation, their uses shall be limited to noncritical or infrequent operations such as press-to-talk communication or vehicle headlight dimming.

23.9.5.2 *Operation*—Foot switches shall be positioned for operation by the toe and the ball of the foot rather than by the heel. They shall not be located so near an obstruction that the operator cannot center the ball of the foot on the switch button. A pedal may be used over the button to aid in location and operation of the switch. When the switch may become wet and slippery, the switchcap surface shall possess a frictional surface to minimize the possibility of the foot slipping off the switch.

23.9.5.3 *Dimensions, Resistance, and Displacement*—Dimensions, resistance, and displacement of foot-operated switches shall conform to the criteria in Fig. 20. Although not recommended (only one switch per foot is preferred), when one foot is required to operate more than one switch, such

switches shall be at least 75 mm (3 in.) apart (horizontal); 200 mm (18 in.) apart vertical.

23.9.5.4 *Feedback*—A positive indication of control activation shall be provided (for example, snap feel, audible click, association visual, or auditory display).

23.10 *Foot Pedals:*

23.10.1 *Use*—Pedal controls should be used only when the operator is likely to have both hands occupied when control operation is required or control system force is too high for manual force capability of the operator, or standardized use of pedals has created a stereotype expectancy (for example, vehicle pedal control configurations such as clutch, brake, accelerator, rudder).

23.10.2 *Location*—Pedal controls shall be located so that the operator can reach them easily without extreme stretching or torso twisting and can reach the maximally displaced pedals within anthropometric limits and force capabilities (see Fig. 21). Pedals that may be held or must be adjusted shall be located so the operator can "rest" and "steady" the foot, that is, the pedal shall be appropriate critical distance above the floor so the operator's heel can rest on the floor while articulating the ankle/foot. When this cannot be done (and the pedal angle is more than 350 mrad (20°) from the horizontal floor), a heel rest shall be provided. Lateral spacing of individual pedals shall conform to criteria in Fig. 22. However, the overall array shall not exceed 760 mm (29 in.) as measured between the outermost pedal centerlines.

23.10.3 *Control Return*—Except for controls that generate a continuous output (for example, rudder controls), pedals shall return to the original null position without requiring assistance from the operator (for example, brake pedal). For pedals in which the operator may normally rest the foot on the control between operations, sufficient resistance shall be provided to prevent the weight of the foot from inadvertently actuating the control (for example, accelerator pedal).

23.10.4 *Pedal Travel Path*—The travel path shall be compatible with the natural articulation path of the operator's limbs (that is, thigh, knee, ankle).

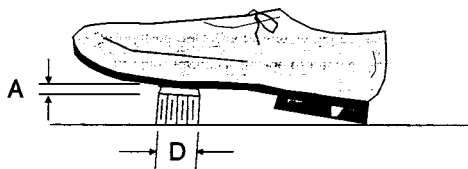
23.10.5 *High-Force Application Aids*—When foot controls requiring high control forces are to be used, the push force push exerted by the leg depends on the thigh angle and the knee angle. Fig. 23 specifies the mean maximum push at various knee and thigh angles. The maximum push is at about the 160° angle, referred to as the limiting angle of Fig. 23 apply to males only and shall be corrected for females. (Two thirds of each value is considered to be a reasonable value for females.) Appropriate aids shall be provided to assist the operator in applying maximum force including the following where applicable:

23.10.5.1 Seat backrest.

23.10.5.2 Optimized seat height-to-pedal and normal reach distance for maximum force, the seat reference point (SRP), and pedal are at the same vertical height.

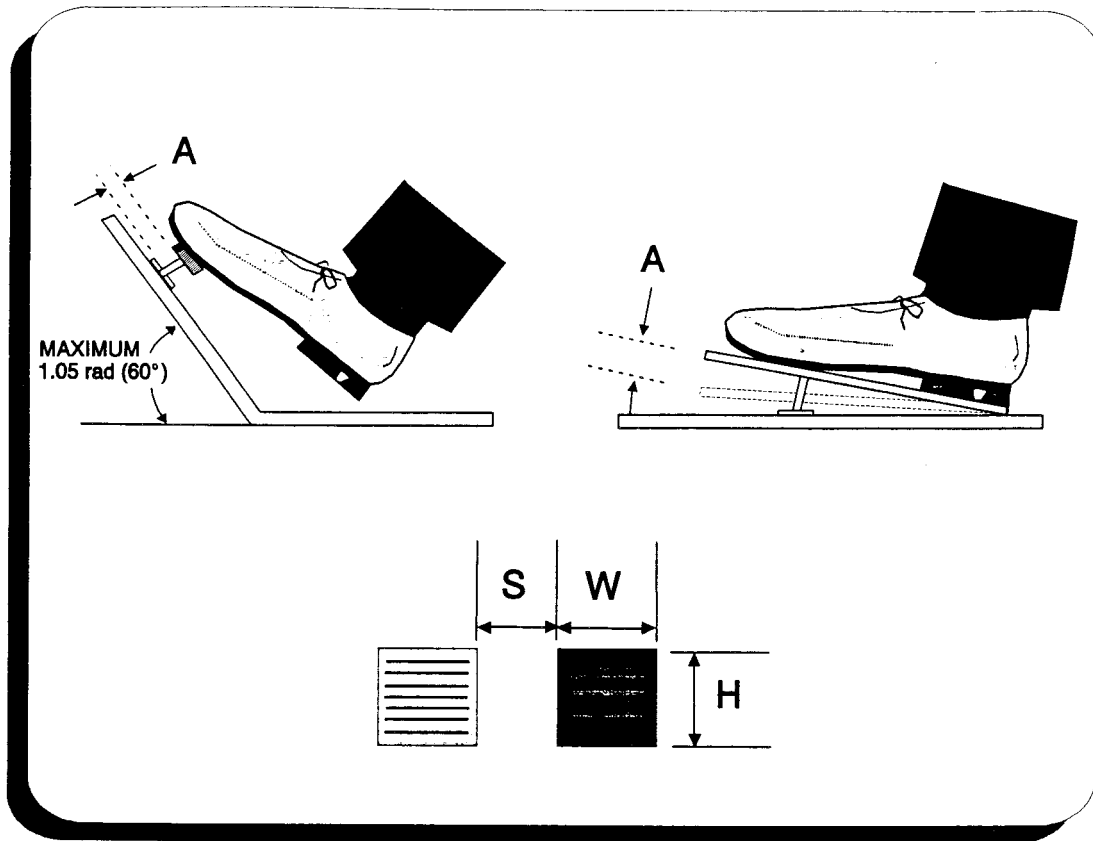
23.10.5.3 Double-width pedal so that both feet can be used.

23.10.6 *Nonslip Pedal Surface*—Pedals used for high force applications shall be provided with a nonskid surface. Similar surfaces are desirable for all pedals.



	DIAMETER D	RESISTANCE		DISPLACEMENT A			
		Foot Will Not Rest On Control	Foot Will Rest On Control	Normal Operation	Heavy Boot Operation	Ankle Flexion Only	Total Leg Movement
Minimum	13 mm (1/2 in)	18 N (4 lb)	45 N (10 lb)	13 mm (1/2 in)	25 mm (1 in)	25 mm (1 in)	25 mm (1 in)
Maximum	—	90 N (20 lb)	90 N (20 lb)	65 mm (2 1/2 in)	65 mm (2 1/2 in)	65 mm (2 1/2 in)	100 mm (4 in)

FIG. 20 Foot-Operated Switches



	DIMENSIONS		DISPLACEMENT			
	H	W	A			
	Height	Width	Normal Operation	Heavy Boots	Ankle Flexion	Total Leg Movement
Minimum	25 mm (1 in)	75 mm (3 in)	13 mm (1/2 in)	25 mm (1 in)	25 mm (1 in)	25 mm (1 in)
Maximum	—	—	65 mm (2 1/2 in)	65 mm (2 1/2 in)	65 mm (2 1/2 in)	180 mm (7 in)
	RESISTANCE					
	Foot Not Resting on Pedal	Foot Resting on Pedal	Ankle Flexion Only		Total Leg Movement	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Minimum	18 N (4 lb)	45 N (10 lb)	—		45 N (10 lb)	
Maximum	90 N (20 lb)	90 N (20 lb)	45 N (10 lb)		800 N (180 lb)	
	SEPARATION					
	S					
	One Foot Random		One Foot Sequential			
Minimum	100 mm (4 in)		50 mm (2 in)			
Maximum	150 mm (6 in)		100 mm (4 in)			

FIG. 21 Pedals

23.10.7 *Dimensions, Resistance, Displacement, and Separation*—Dimensions, resistance, displacement, and separation of pedals shall conform to the criteria of Fig. 21.

23.10.8 *Foot Controls Force (High)*— Where foot controls requiring high control forces are to be used, the force push exerted by the leg depends on the thigh angle and knee angle.

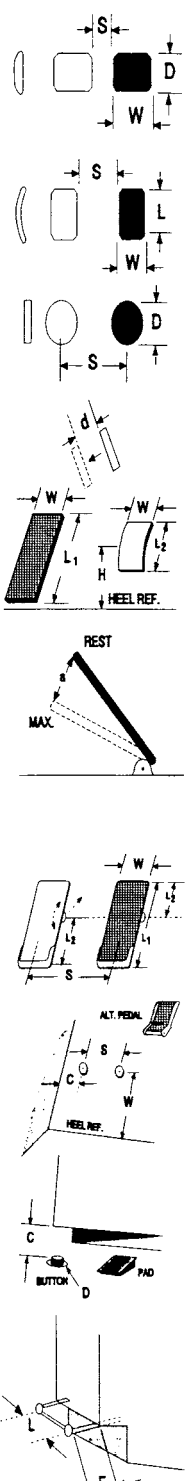
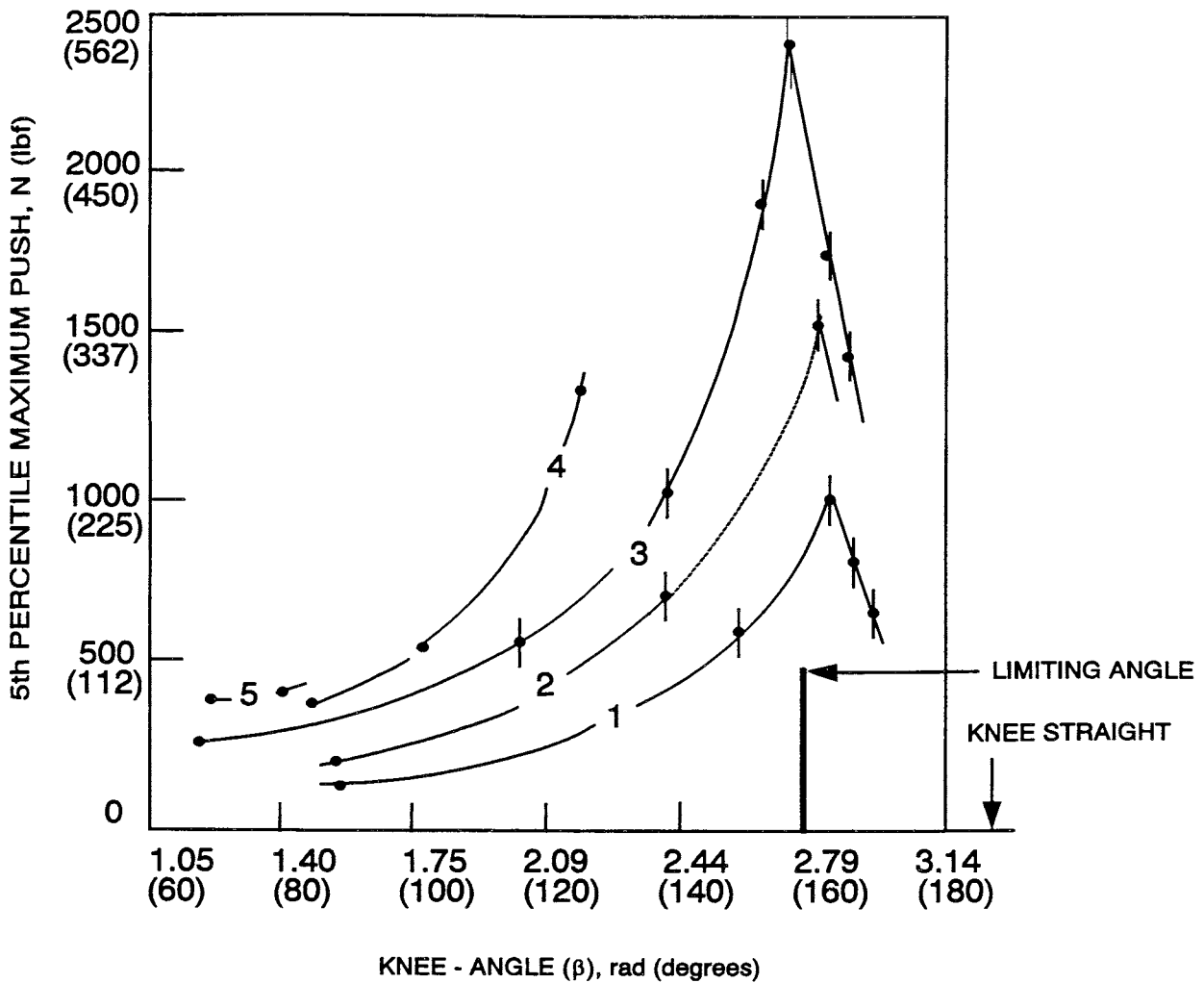
	APPLICATION CRITERIA	DESIGN CRITERIA			
		DIMENSIONS		DISPLACEMENT	SEPARATION
	BRAKE PEDAL APPLICATIONS CLUTCH-BRAKE-CONVEX-THREAD SURFACE FORCE REQUIREMENTS: CLUTCH - 450 N (MAX). BRAKE - 70 N (MIN), 450 N (MAX) ALTERNATE PEDAL SHAPE ACCEPTABLE FLAT, TREAD SURFACE ROUND PEDAL SHAPE ACCEPTABLE. FLAT, TREAD SURFACE 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/FOOT, INCLUDED ANGLE TO BE BETWEEN 90°-105° FORCE REQUIREMENTS MAX - 90 N MIN - 4.5 N NOMINAL CRUISE - LEVEL GRADE, AVG. SPEED FOR APPLICATION TWO FOOT PEDAL ASSEMBLY. SHOULD HAVE MIN FOR AFT ADJUSTMENT OF 230mm. FORCE REQUIREMENTS: SEE MIL-F-8785 FOOT SWITCHES. NORMALLY USE ONLY ONE PER FOOT (MAX TWO) FORCE REQUIREMENTS: MAX 4.5 N FOOT SWITCHES, STAND OPN'S: NORMAL FREQUENT ACTIVATION, SPEED NOT CRITICAL FORCE REQUIREMENTS PREFERRED MAX. 90 N EMERGENCY OPERATION, SPEED IMPORTANT	$W \times D - \text{MIN} - 75 \times 50 \text{ mm}$ $(3 \times 2 \text{ in})$ $W + L - \text{MIN} - 50 \times 75 \text{ mm}$ $(2 \times 3 \text{ in})$ $D - \text{MIN} - 57 \text{ mm}$ $(2 \frac{1}{4} \text{ in})$ $W - 50 \text{ mm}$ $(2 \text{ in}) \text{ MIN}$ $L_1 - 255 \pm 50 \text{ mm}$ $(10 \frac{1}{4} \pm 2 \text{ in})$ $L_2 - 80 \text{ mm}$ $(3 \frac{1}{2} \text{ in}) \text{ MIN}$ $W - \text{MIN} - 150 \text{ mm}$ (6 in) $D - \text{MIN DIAM} - 25 \text{ mm}$ (1 in) $D - \text{MIN BUTTON DIAM} - 25 \text{ mm}$ (1 in) LARGER PREFERRED $E - \text{EXTENSION MIN} - 100 \text{ mm}$ (4 in)	$S - \text{COMFORT SEPARATION} - 305 \pm 50 \text{ mm}$ $(12 \frac{1}{4} \text{ in} \pm 2 \text{ in})$ MAX - 405 mm $(16 \frac{1}{5} \text{ in})$ MIN - 200 mm (8 in) H - 150 mm (6 in) OPTIMUM $L_1 - \text{MIN} - 255 \text{ mm}$ $(10 \frac{1}{4} \text{ in})$ $L_2 - \text{MIN} - 125 \text{ mm}$ (5 in) $H - \text{DISTANCE FROM HEEL REF} - 180-255 \text{ mm}$ $(7 \frac{1}{4}-10 \frac{1}{4} \text{ in})$ $L - \text{ACCESSIBLE TO EITHER FOOT FULL WIDTH OF THE EXPECTED WORK ENVELOPE}$	$d - \text{MAX REST TO ACTIVATE} - 180 \text{ mm}$ $(7 \frac{1}{4} \text{ in})$ MIN - 25 mm (1 in) PREFERRED 85-100 mm $(2 \frac{1}{2}-4 \text{ in})$ $d - \text{MAX DISPLACEMENT} - 30^\circ$ $(20^\circ \text{ WITH HEAVY BOOTS})$ MIN - 13mm $(\frac{1}{2} \text{ in})$ MAX - 85mm $(2 \frac{1}{2} \text{ in})$ FOR BOOTS, INCREASE MIN 25 mm (1 in) C - CLEARANCE BENEATH UNDEPRESSED BAR FOR TOE. MIN - 85 mm $(2 \frac{1}{2} \text{ in})$ OR 75 mm (3 in) WITH BOOTS	$S - \text{MIN TO PREVENT FOOT SLIPPING BETWEEN PEDALS} - 50 \text{ mm}$ (2 in) $S - \text{MIN SEPARATION TO ALLOW FOOT TO PASS BETWEEN PEDALS} - 125 \text{ mm}$ $(5 \text{ in}); 180 \text{ mm}$ $(7 \frac{1}{4} \text{ in})$ FOR HEAVY BOOTS (NOTE: EDGE E TO EDGE PEDAL SEPARATIONS OF BETWEEN 50 mm (2 in) AND 115 mm $(4 \frac{1}{2} \text{ in})$ SHOULD GENERALLY BE AVOIDED BECAUSE OF POSSIBILITY OF GETTING FOOT CAUGHT) $S \text{ MIN} - 380 \text{ mm}$ $(15 \frac{1}{4} \text{ in})$ MAX - 530 mm $(21 \frac{1}{4} \text{ in})$ $S - \text{MIN} - 75 \text{ mm}$ (3 in)

FIG. 22 Foot-Operated Controls

Fig. 23 specifies the mean maximum push at various knee and thigh angles. The maximum push is about the 160° angle, referred to as the limiting angle. The values of Fig. 23 apply to

males only and shall be corrected for females. For females, use two thirds of the male value.



THIGH ANGLE (α) rad (degrees)	
1	-.26 - .10 (-15 - 6)
2	.09 & .17 (5 & 10)
3	.26 - .33 (15 - 19)
4	.58 - .63 (33 - 36)
5	.84 - .86 (48 - 49)

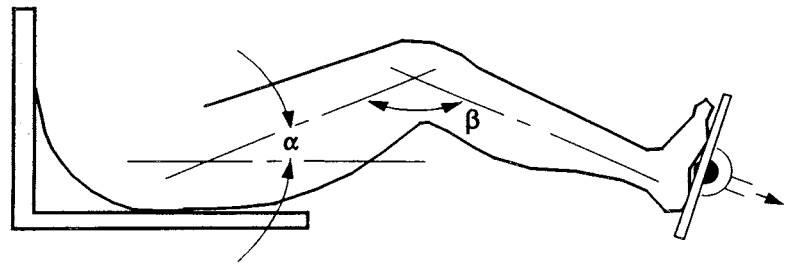


FIG. 23 Leg Strength at Various Knee and Thigh Angles

24. Rotary Controls

24.1 Discrete Rotary Controls:

24.1.1 *Rotary Selector Switches*—Rotary selector switches shall be used for discrete functions when three or more

detented positions are required. Rotary selector switches shall not be used for a two-position function unless prompt visual identification of control position is of primary importance and speed of control operation is not critical.

24.1.2 Moving Pointer—Rotary selector switches shall be designed with a moving pointer and a fixed scale.

24.1.3 Shape—Moving pointer knobs shall be bar shaped, with parallel sides, and the index end shall be tapered to a point. Exceptions may be justified when pointer knobs are shape coded or when space is restricted and torque is light. Shape coding shall be used when a group of rotary controls, used for different functions, is placed on the same panel and control confusion might otherwise result.

24.1.4 Positions—A rotary selector switch that is not visible to the operator during normal system operation shall have no more than 12 positions. A rotary switch that is constantly visible to the operator shall have not more than 24 positions. Recommended switch setting parameters are provided in [Fig. 24](#). In addition, the following criteria shall apply:

24.1.4.1 Rotary switch positions shall not be placed opposite each other unless knob shape precludes confusion as to which end of the knob is the pointer.

24.1.4.2 The switch resistance shall be elastic, building up, then decreasing as each position is approached, so that the control snaps into position without stopping between adjacent positions.

24.1.4.3 Mechanical detentes shall be provided as the switch cannot be positioned in between nominal switch positions.

24.1.4.4 Stops shall 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 (that is, if the switch is not a multirotation control, see [21.6](#)).

24.1.5 Contrast—A reference line shall be provided on rotary switch controls. This line shall have at least 75 % luminance contrast with the control color under all lighting conditions.

24.1.6 Parallax—The knob pointer shall be mounted sufficiently close to its scale to minimize parallax between the pointer and the scale markings. When viewed from the normal operator's position, the parallax error shall not exceed 25 % of the distance between scale markings.

24.1.7 Dimensions, Resistance, Displacement, and Separation—Rotary control dimensions, switch displacement, and control separation shall conform to criteria in [Fig. 24](#) and [Fig. 25](#).

24.1.8 Torque for Actuation—Actuating torque requirements shall be compatible with control knob sizes, that is, knob dimensions of 25 mm (1 in.) or less shall not require a torque of more than 350 N/m (Newton per metre) (2 lbf-in) (pounds force per inch). Medium-sized knobs, 25 to 50 mm (1 to 2 in.), shall have a torque of less than 1050 N/m (6 lbf-in.). The larger knobs, diameters of 75 mm (3 in.), shall not require an actuation torque greater than 1576 N/m (9 lbf-in.).

24.2 Key-Operated Switches (KOS)—KOS are used to prevent unauthorized operation. Ordinarily, they control system operation by go no-go.

24.2.1 Dimensions, Displacement, and Resistance—Dimensions, displacement, and resistance shall conform to the criteria in [Fig. 26](#) and [Fig. 27](#).

24.2.2 Color, Shape, and Size Coding—Color, shape, or size coding or a combination may be used as follows:

24.2.2.1 Color may be used to aid in identifying various keys by function or use location and when illumination is adequate to differentiate the colors. Red shall be reserved for emergency functions.

24.2.2.2 Shape coding may be used when it is desirable to identify a given key by feel. When shape coding is used, sharp corners shall be avoided.

24.2.2.3 Size coding may be used as a valid discriminator such as shape if there are only two keys.

24.2.3 Marking and Labeling—Keylock switch applications shall include appropriate positional markings and labels (see [Section 28](#)).

24.2.4 Other Requirements:

24.2.4.1 Keys with teeth on both edges, which fit the lock with either side up or forward, are preferred.

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

24.2.4.3 Locks shall be oriented so the key's vertical position is the OFF position.

24.2.4.4 Operators shall normally not be able to remove the key from the lock unless the switch is turned OFF.

24.2.4.5 Activation of an item by a key-operated switch shall be accomplished by turning the key clockwise from the vertical OFF position.

24.3 Discrete Thumbwheel Controls—Thumbwheel controls may be used if the function requires a compact digital control-input device (for a series of numbers) and a readout of these manual inputs for verification. The use of thumbwheels for any other purpose is discouraged. Detente indexing units shall provide ten positions (0 to 9) in digital or binary (three or four bits and complement) outputs.

24.3.1 Shape—Each position around the circumference of a discrete thumbwheel shall have a concave surface or shall be separated by a high-friction area which is raised from the periphery of the thumbwheel. The thumbwheels shall not preclude viewing the digits within 30° viewing angle to the left and right of a perpendicular to the thumbwheel digits.

24.3.2 Coding—Thumbwheel controls may be coded by location, labeling, and color (for example, reversing the colors of the least significant digit wheel as on typical odometers). Where used as input devices, thumbwheel switch OFF or NORMAL positions shall be color coded to permit a visual check that the digits have been reset to their normal position.

24.3.3 Direction of Movement—Moving the thumbwheel edge forward, or upward, or to the right shall increase the setting (see [Fig. 28](#)).

24.3.4 Internal Illuminance of Numerals—For areas in which ambient illumination will provide display brightness below 3.5 cd/m² (1 ft-L), the thumbwheel shall be internally illuminated. Digits shall appear as light- or white-illuminated characters on a black background, and their dimensions shall approximate the following:

24.3.4.1 Height, 4.8 mm (3/16 in.).

24.3.4.2 Height-to-width ratio, 3:2.

24.3.4.3 Height-to-stroke width ratio, 10:1.

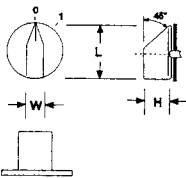
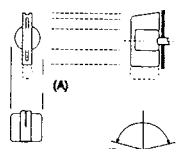
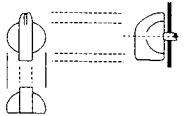
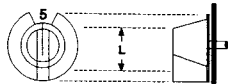
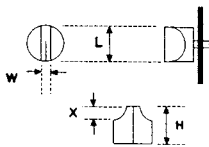
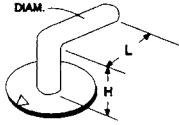
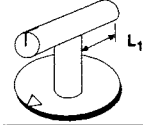
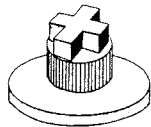
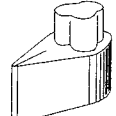
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	PREFERRED FOR ACCURATE IDENTIF. OF KNOB POSITION BY FEEL, CONTROL PANELS WHERE HIGH FORCE SWITCHES ARE NOT REQUIRED, SKIRT OPTIONAL SWITCH RESISTANCE APPROX. MAX: L = 38 mm = 0.11 N m (1 in.(1 in-lb)) L = 50 mm = 0.34 N m (2 in. (3 in-lb)) L = 100 mm = 0.88 N m (4 in. (6 in-lb))	L = 38 mm to 100 mm (1 1/2 in to 4 in) IF GLOVES ARE WORN, ADD 13 mm (1/2 in)	W = 13 mm to 25 mm (1/2 in to 1 in)	H = 16 mm to 75 mm (5/8 in to 3 in)	MIN = 15° MIN POS'N ID = 30° MAX = 40°; MAX FOR BLIND POSITIONING = 90°	SEE FIG. 25 FOR SIMULTANEOUS OPERATION OF ADJACENT KNOBS (TWO HANDS) ADD 25 mm (1 in), 38mm (1 1/2 in) FOR GLOVES
	ACCEPTABLE ABOVE CRITERIA APPLICABLE AS LONG AS KNOB POS'NS REMAIN IN UPPER 180° HEMISPHERE (A) EXTENDED TAIL HELPFUL FOR TORQUE USE ONLY WHEN POINTER MARKING CLEARLY VISIBLE	SEE ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE
	ACCEPTABLE ALTERNATIVE TO ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE
	ACCEPTABLE ALTERNATIVE TO A ABOVE WHEN ONLY GROSS SETTING IS REQUIRED (MAJOR NUMBERED POS'N'S)	L = MIN 25 mm (1 in) OTHER SAME AS A	SEE ABOVE	SEE ABOVE	SEE ABOVE	SEE ABOVE
	ACCEPTABLE ONLY FOR APPLICATIONS WHERE PANEL SPACE IS LIMITED, GLOVES NOT WORK, SWITCH RESISTANCE LESS THAN .842 N m	L = MIN 19 mm (2/3 in)	W = MIN 6.5 mm (1 1/4 in)	Y = MIN 13 mm (1/2 in)	SEE ABOVE	25 mm (1 in)
	FOR HEAVY DUTY, HIGH TORQUE SWITCHES: PREFERRED	D = 18-25 mm (5/8 in - 1 in)	L = MIN 100 mm (4 in)	R = 32 mm (1 1/4 in.) MIN	MIN = 10°	END TO END HANDLE SEPARATION = 75 mm (3 in)
	ACCEPTABLE ALTERNATIVE	D = SAME	L ₁ = MIN 50 mm (2 in.)	H = SAME	SAME	SAME
	TACTILE CONTROL IDENTIFICATION PREFERRED METHOD FOR ROTARY CONTROLS	D = MIN 16 mm (5/8 in.)	H = MIN 3.2 mm TO 19 mm (2/3 in)	—	N/A	N/A
	TACTILE CAP FOR ROTARY SELECTOR KNOB	SAME AS ABOVE	SAME AS ABOVE			

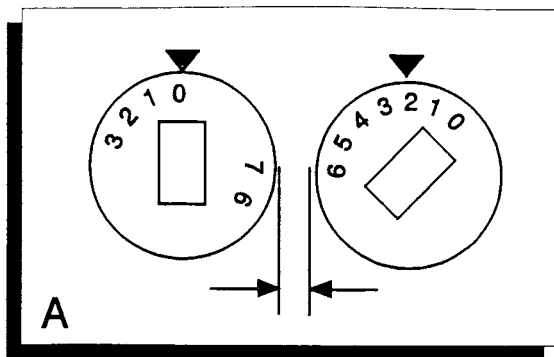
FIG. 24 Rotary Selector Controls

24.3.5 *External Illuminance of Numerals*—In areas in which ambient illumination will provide a display luminance above 3.5 cd/m² (1 ft-L), internal illumination is not required. Digits shall be bold, black numerals engraved on a light (or white) thumbwheel background. The dimensions shall approximate those specified in 24.3.4, except that the height-to-stroke width ratio shall be approximately 5:1.

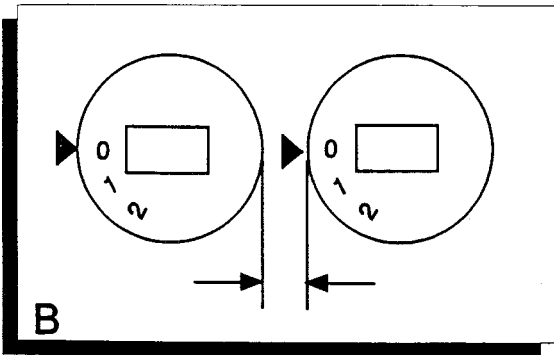
24.3.6 *Visibility*—Thumbwheel design shall permit viewing of inline digital readout from all operator positions.

24.3.7 *Dimensions*—Control dimensions shall conform to the criteria in Fig. 29.

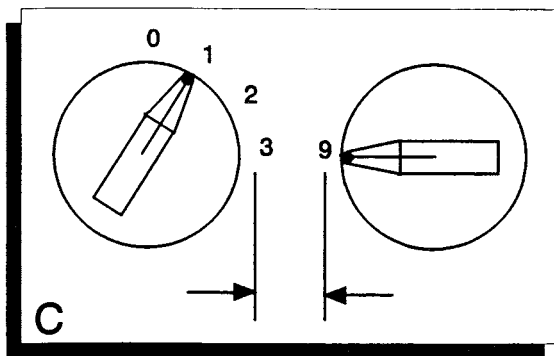
24.3.8 *Resistance*—Detentes shall be provided for discrete position thumbwheels. Resistance shall be elastic, building up and then decreasing as each detente is approached so that the



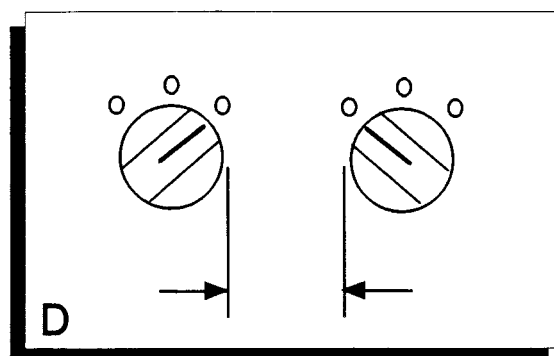
Nominal separation between moving-scale knobs requires only that there is adequate physical separation between the knob skirts to prevent knob movement interference when the zero or referencing index is at the 12-o'clock position.



Separation between moving-scale 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 the 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 (1 in) separation between knobs when they are end to end.



Separation between small, detented knob configurations as shown should be at least 25mm (1 in) 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 (1 in) criterion, whichever is greater.

FIG. 25 Rotating Knob Separation

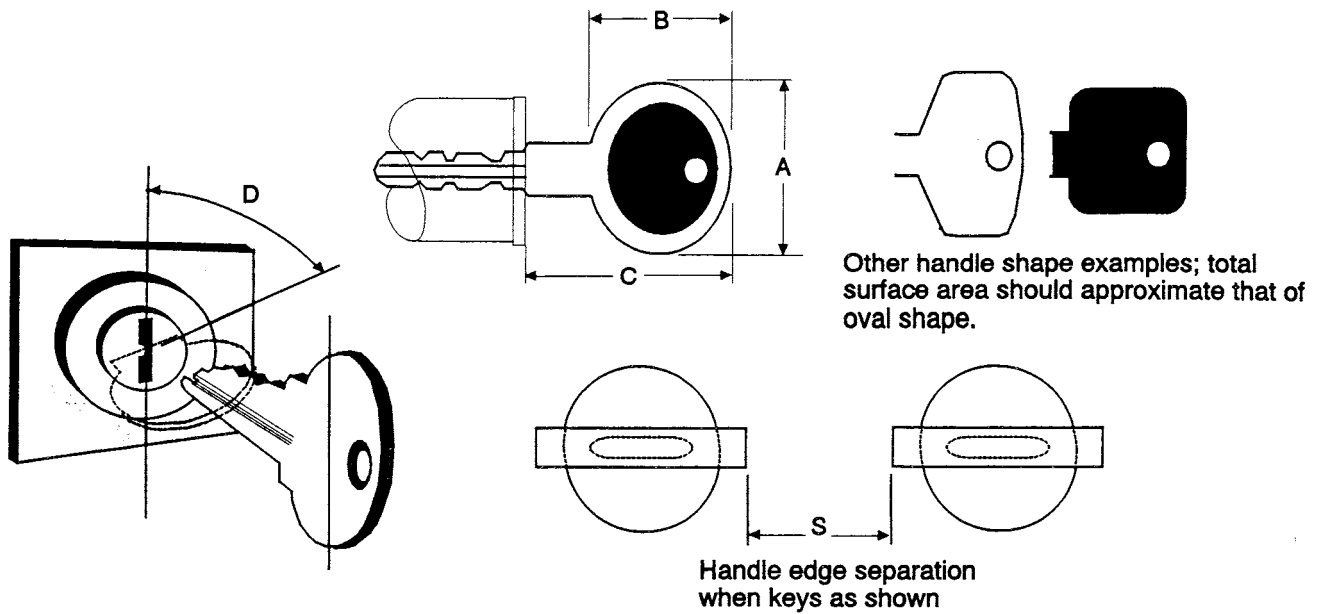
control snaps into position without stopping between adjacent detentes. The resistance shall be within the limits indicated in Fig. 29.

24.3.9 *Separation*—The separation between adjacent edges of thumbwheel controls shall conform to the criteria in Fig. 29

and shall be sufficient to preclude accidental activation of adjacent controls during normal setting.

24.4 *Continuous Adjustment Rotary Controls:*

24.4.1 *Knobs*—Knobs shall be used when low forces or precise adjustments of a continuous variable are required.



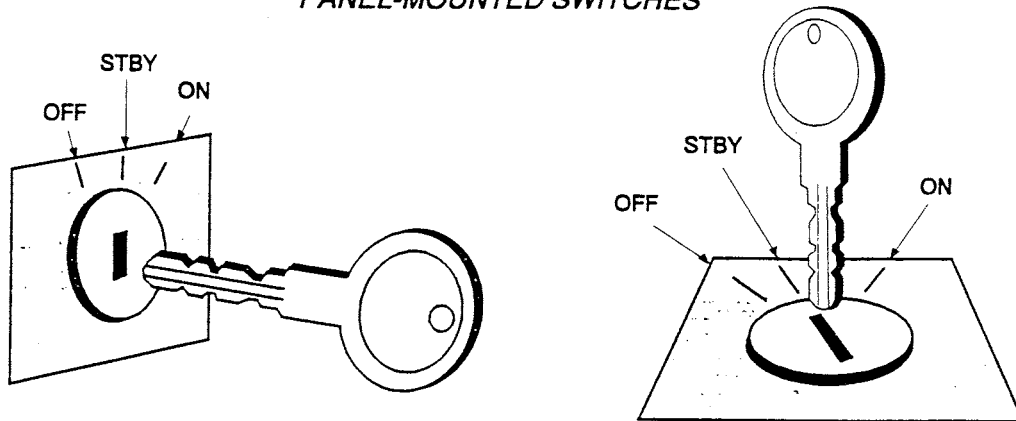
	A	B	C	S-Separation	Resistance**	Displacement
Minimum	13 mm (1/2 in)	13 mm (1/2 in)	20 mm (3/4 in)	25 mm (1 in)	0.1 N-m	.525 rad (30°)
Maximum	75 mm** (3 in)	38 mm* (1 1/2 in)	-	25 mm (1 in)	0.7 N-m	1.57 rad (90°)

* Practical for carrying key in pocket.

** When locks are new.

FIG. 26 Keylock Criteria

PANEL-MOUNTED SWITCHES



Note 1 - Switchlocks should generally be oriented so that the pivotal off key position is vertical or forward, or both (for example, horizontal panel).

Note 2 - Key displacement between functional positions should be at least .53 rad (30°). Mechanical detents should preclude positioning the key in between designated positions.

Note 3 - When only two functional positions occur (that is, on-off), displacement between the two positions shall be 1.57 rad (90°).

Note 4 - Total displacement of multi-position keyswitches shall not exceed 2.09 rad (120°).

FIG. 27 Keylock Switch Criteria



DATE:
PROJECT:
FEATURE:
CLIENT:

CALIBRAT BY:
CONE #: 361
FSO TIP: 100 MPA
FSO SLEEVE: 1000 KPA
TIP AREA: 10 CM²
SLEEVE AREA: 150 CM²

CALIBRATOR DATA: ^m 0.00992 ^b -0.012668
CALIBRATOR SETTING: 20kN

TARGET GAUGE READING	ACTUAL GAUGE READING	APPLIED FORCE X kN	FULL SCALE OUTPUT FSO - %	MEASURED SLEEVE RESISTANCE Y fs - kPa	MEASURED CONE RESISTANCE qc - mPa	ACTUAL SLEEVE RESISTANCE fsa kPa	BEST STRAIGHT LINE* Y'=mX+b kPa	LINEARITY Y-Y'/FSO % FSO	CALIBRATION ERROR fsa-Y'/fsa % MO
0.000	BASELINE			-9.8	-0.3				
0	0	-0.013	-0.1	0.0	0.0	-0.8	3.113	0.31	
30	30	0.285	1.9	20.3	0.0	19.0	22.970	0.27	
75	75	0.731	4.9	51.2	0.0	48.7	52.757	0.16	
150	149	1.465	9.8	101.2	0.0	97.6	101.739	0.05	
375	378	3.735	24.9	249.1	0.0	249.0	253.320	0.42	1.73
750	749	7.414	49.4	495.3	0.0	494.2	498.893	0.36	0.94
375	375	3.705	24.7	260.2	0.1	247.0	251.334	0.89	
150	153	1.504	10.0	110.7	0.0	100.3	104.387	0.63	
75	77	0.751	5.0	57.7	0.0	50.1	54.081	0.36	
30	32	0.305	2.0	24.1	0.0	20.3	24.294	0.02	
0	0	-0.013	-0.1	0.2	0.0	-0.8	3.113	0.29	
0.000	BASELINE			-9.8	-0.3				

	RESULT	UNIT	ALLOWABLE	APPROVAL
*BEST FIT LINE (Y=mX+b)	m= 66.760 b= 3.958			
MAXIMUM LOAD TRANSFER -CONE	0.1	%FSO	0.5	YES
MAXIMUM LINEARITY ERROR	0.9	%FSO	2.0	YES
MAXIMUM CALIBRATION ERROR	1.73	%MO	3.0%MO>20%FSO	YES
MAXIMUM ZERO LOAD ERROR -CONE	0.0	%FSO	0.5	YES
MAXIMUM ZERO LOAD ERROR - SLEEVE	0.0	%FSO	1.0	YES

COMMENTS:

FIG. 28 Thumbwheel Orientation and Movement

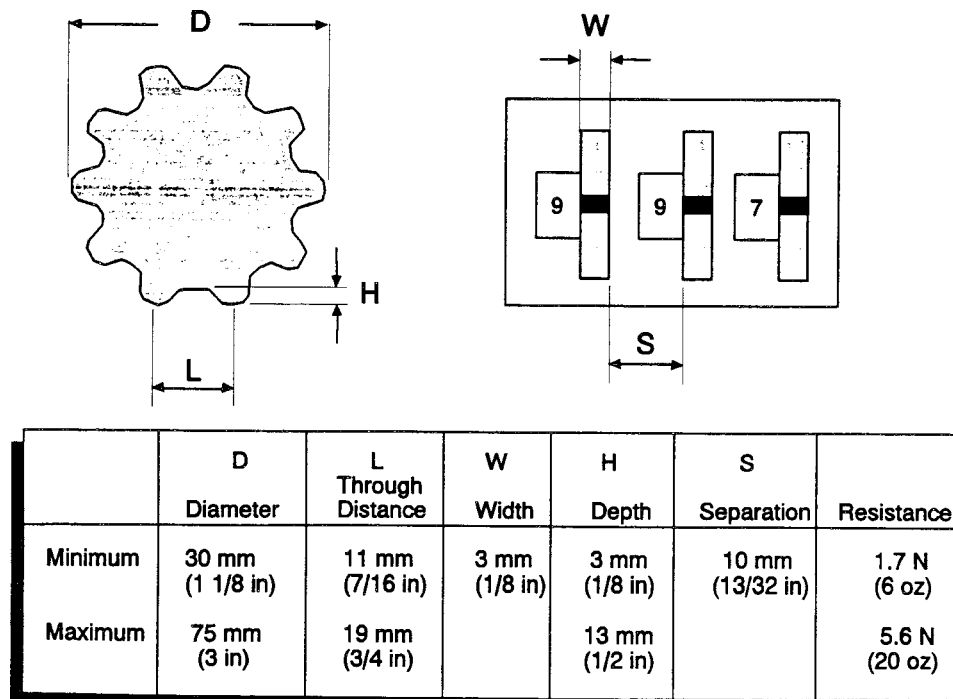


FIG. 29 Discrete Thumbwheel Control

moving knob with fixed scale is preferred over a moving scale with fixed index for most tasks. If positions of single revolution controls must be distinguished, a pointer or marker shall be available on the knob.

24.4.2 *Dimensions, Torque, and Separation*—The dimensions of knobs shall be within the limits specified in Fig. 30. Within these ranges, knob size is relatively unimportant, provided the resistance is low and the knob is easy

