HUMAN ENGINEERING DESIGN CRITERIA STUDY

FINAL REPORT

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Prepared by:

S Truax

S. Truax, Ph.D.
Principal Investigator

W. R. Harmer, Ph.D.
Co-Principal Investigator

Co-Authors:

T. J. Wong, M.A.
D. L. Van Kekerix, M.A.
L. R. Uyeda, M.A.

Approved by:

K. H. Houghton, M.D.
Chief Engineer
Advance Biotechnology Department

Approved by:

E. W. Pickrel, Ph.D.
Project Director

ABSTRACT

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The document is a human engineering design criteria study which includes design criteria for the following areas: control, display, control-diplay interaction, human capabilities, human responses, anthropometry, work space, illumination, vibration, noise, temperature, clothing, safety and maintainability. Check lists, rating scales and references are provided. The document is designed to be used by design engineers and by human factors engineering personnel to assist them in their design of earth launch systems.

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Douglas Aircraft Company project director was E. W. Pickrel, Ph.D. For the first year, W. R. Harmer, Ph.D., was Principal Investigator. For the extension of the contract S. Truax, Ph.D., was Principal Investigator.

T. J. Wong, M.A., was the major co-author, working on the project from the inception through its completion. Other major contributors were D. L. Van Kekerix, M.A., and L. R. Uyeda, M.A. Individual contributions were made by W. F. Childs, B.S., and S. B. Danielson, M.D. Pat Nelson and Frieda Dickman were secretaries. Editorial assistance was supplied by D. R. Fowler and Ann DeChenne. Art work was supplied by R. D. Keays, C. B. Teal and R. G. MacGlashan.

FOREWORD

This standard is intended for use by design engineers engaged in the development of all aspects of earth launch systems. The standard is also intended for human factors engineering personnel and provides specialized information to assist them in their design support activities. This information, acquired in a systematic literature search, deals with the adequacy of current human factors engineering rules and practices and identifies areas of weakness and strength.

The basic intent of the standard is to optimize the use of man as a component in launch vehicle systems by controlling the design of any piece of equipment which interfaces with him. It can also be used as a source in the development of human factors engineering checklists to validate optimal man/machine compatibility. As such, it is available for use as a basic document in any human factors engineering program which might be performed; eg, in compliance with MSFC-STD-391, "Standard Human Factors Engineering Program Plan."

This revision of the standard contains two unique features to increase its usefulness. They are source references and adequacy ratings. Source references are provided so that the design engineer may refer to the primary source if he so desires. Sources are indicated in parenthesis by primary author's name and a reference number. Names were included as an aid in associating authors with literature areas and as a means of insuring the use of the correct reference. References applicable to each section are found at the end of that section.

Adequacy ratings are provided for most of the specific design criteria statements. Not all criteria statements are of equal importance. The adequacy scale provides an evaluation of the design criteria statements. The categories and ratings of the adequacy scales are as follows:

(a) Category S (supported). - These criteria are supported by empirical studies. They provide the most concrete basis for human factors recommendations.

(b) Category C (common sense). - These criteria often reflect long-standing usage and acceptance and seem "right" logically or instinctively. They emphasize the obvious and tend to reduce controversy over points which lack empirical support.

(c) Category A (arbitrary decision). - These are criteria for which there is no empirical or logical support. Their main virtue is that of providing standardization which in turn saves time in the design process and permits more efficiency at the operational stage.

(d) Ratings. - The ratings used in the adequacy scale are as follows:

(1) (Excellent: no deviation)

Excellent research support
or
Unquestionable logic
or
Experience indicates this is necessary

(2) (Good: deviation permitted with strong justification)

Good research support
or
Good logic
or
Experience indicates this is good

(3) (Fair: deviation permitted with justification)

Incomplete or questionable research support
or
Questionable logic
or
Experience indicates some success

(4) (Poor)

Poor research support
or
Poor logic
or
Experience indicates little or no success

Adequacy scale ratings are placed at the end of criteria statements and are preceded by XR-. Category is indicated first and is followed by the rating; eg, XR-C-2 indicates a good, common sense criterion.

Overviews are provided for each sub-section. These overviews can be used both as a detailed index and as a checklist. It is recommended that the design engineer use the overview as a tool for identifying those human factor considerations which require design consideration.

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HUNTSVILLE, ALABAMA

HUMAN ENGINEERING DESIGN CRITERIA,

STANDARD FOR

1.0 SCOPE

1.1 Purpose. - The purpose of this standard is to present human engineering design principles and practices to be used by engineers in designing equipment for achievement of satisfactory performances of operator, maintenance, and control personnel, to reduce skill requirements and training time, to increase reliability of personnel-equipment combinations, and to provide a basis for design standardization of large earth-launch booster systems.

1.2 Scope. - This standard establishes human engineering design criteria for use in designing earth launch vehicle systems and associated equipment.

REFERENCED DOCUMENTS

2.0 REFERENCED DOCUMENTS

2.1 Use. - The issues of the following documents, in effect on the date of invitation for bids, form a part of this standard to the extent specified herein.

2.1.1 Specifications.

(a) MIL-T-27474 Training equipment, ground, general requirements for.

(b) ARDCM 80-6 Handbook of instructions for aerospace ground equipment design.

(c) AFSCM 80-3 Handbook of instructions for aerospace personnel subsystem design (HIAPSD).

(d) AF Manual 160-39 The handling and storage of liquid propellants. 1 April 1964.

(e) MIL-C-12527A Coverall rocket fuel handlers. 2 November 1956.

(f) AFTO 11C-1-6-3 General safety precautions missile liquid propellants. 18 October 1961.

(g) AFTO 11C-1-6C (supplement) General safety precautions missile liquid propellants. 31 August 1962.

(h) MIL-G-4244A Gloves, protective, acid resistant, vinyl coated cotton. Type R-1. 6 May 1954.

2.1.2 Standards.

(a) MIL-STD-12 Abbreviations for use on drawings and in technical type publications.

(b) MSFC-STD-391 Standard human factors engineering program.

(c) FED. STD No. 595 Colors.

(d) MIL-STD-803A-1 Human engineering design criteria for aerospace systems and equipment. Part 1. Aerospace system ground equipment. 27 January 1964.

(e) MIL-STD-803A-2 Human engineering design criteria for aerospace systems and equipment. Part 2. Aerospace system facilities and facility equipment. 1 December 1964.

2.1.3 Publications.

(a) ANA bulletin No. 261 Abbreviations and contractions; approved list of.

(b) Grave, C., Hitt, J. D., Mabry, J. E. and Mendenhall, E. L. S-1C human engineering and safety standards. Contract No. NAS8-5608. 14 June 1963. Prepared by the Boeing Co.

REFERENCED DOCUMENTS

3.0 DEFINITIONS

3.1 Application. - For the purpose of this standard, the definitions specified in 3.1.1 through 3.1.87 are applicable.

3.1.1 Abduction. - Act of going away from a particular reference point. Specifically, in anthropological terms, limb movement away from the medial line of the body. See 5.5.1.8 for illustration.

3.1.2 Adduction. - Act of going toward a particular reference point. Specifically, in anthropological terms, limb movement toward the medial line of the body. See 5.5.1.8 for illustration.

3.1.3 Acoustic reflex. - A physiological reflexive response that reduces the transmission of sound through the middle ear and acts to minimize possible cochlear damage from overstimulation by loud sounds. This reflex is usually elicited by certain tones above approximately 70 db sound pressure level.

3.1.4 Anthropometry. - The science of measuring the human body, its parts and functional capacities.

3.1.5 Anthropometric tables. - Tables of body measurements, organized in terms of percentile distribution, for use by workplace designers in determining size and space requirements of the population to be employed in the workplace under consideration.

3.1.6 Articulation index (AI). - A measure of intelligibility that should be used in design of speech-communication systems. The index formulation is based on the fact that in order to obtain high intelligibility a high portion of the speech bandwidth must reach the listener's ear and that the signal-to-noise ratio at the listener's ear must be high. The important frequencies are between 200-6100 cps. When the Al = 1.00 the listener will make essentially no error; when Al = 0.00, the listener will rarely be able to understand anything.

3.1.7 Assembly. - A combination of components, parts or subassemblies joined together, or so arranged, that they perform a specific function or functions.

3.1.8 Auditory threshold (Absolute). - The minimum sound pressure level can be perceived through the human ear in the absence of extraneous noise. The threshold for a pure tone is a function of both frequency and amplitude, and the function varies considerably from one individual to another. Measured in decibels (db), the normal threshold for a standard 1,000 cycle tone is 0 db, while the threshold for a 100 cycle tone is approximately 35 db. The threshold may be expressed in decibels relative to 2×10^{-4} dynes per square centimeter or 2×10^{-4} microbar.

3.1.9 Brightness. - An attribute of visual sensation determined by intensity of light radiation reaching the eye, resulting in variations along the achromatic scale of black to white. Also, brightness is a photometric measure of light emission per unit of a luminous body or a translucent or reflecting surface.

3.1.10 Clo. - A unit of clothing expressed as:

$$1 \text{ Clo} = 0.88^{\circ}\text{F/BTU/Ft}^{2}\text{Hr} \quad \text{or}$$

$$= 0.18^{\circ}\text{C/KCal/M}^{2}\text{Hr}$$

3.1.11 Component. - A functional part of a subsystem or equipment that is essential to its operational completeness.

3.1.12 Console. - Denotes a cabinet designed for mounting of panels.

3.1.13 Control. - That part of the equipment which is used by the operator to bring about changes in equipment performance. The most commonly used controls are the hand push button, foot push button, toggle switch, rotary selector switch, knob, crank, handwheel, lever, and pedal.

3.1.14 Control coding. - Designing controls for optimum tactual, kinesthetic, or visual identification and discrimination by taking into consideration such factors as shape, size, position (or location), color, and mode of operation.

3.1.15 Control display ratio. - The ratio of the amount of control movement to the magnitude of displacement in a corresponding display. Research indicates that the time required to make accurate control adjustments depended more on control display ratio than on such factors as inertia, back-lash, setting tolerance, or control size.

3.1.16 Control ratio. - The relationship between the amount of movement of a control and the amount or degree of movement of that which it is controlling.

3.1.17 Criterion. - Any standard by which the general validity of a method, measuring device, or formula is judged.

3.1.18 Dark adaptation. - The process whereby the eye attains greater sensitivity to light when placed in an illumination lower than that to which it was previously exposed.

3.1.19 Decibel (db). - One-tenth of a bel. It is a dimensionless, logarithmic unit expressing the ratio of two amounts of power. Arithmetically, this ratio in decibels is 10 times the logarithm to the base 10 of the ratio of the two amounts of power. Usually the standard reference sound pressure level of 0.0002 dynes per square centimeter (the average threshold intensity for a tone of 1,000 cycles per second) is used.

3.1.20 Depth perception. - Direct appreciation of the distance of a given object from the observer, or direct appreciation of the relative distance from front to back in the perception of solid objects.

3.1.21 Discrete movement. - A single motion of a part of the human body.

3.1.22 Discrimination. - The process of responding differentially or selectively to one cue (or a set of cues) when presented in a context of other cues. Discrimination may occur with or without conscious awareness on the part of the individual.

3.1.23 Display. - A pattern of sensory cues, usually visual or auditory, presented by means of instruments and arranged to provide information concerning the functioning of a machine or apparatus.

3.1.24 Display, compensatory. - An instrument that is used in tracking tasks and contains only one moving indicator to represent error. Error is the difference between an actual output (indicator) and the desired output (zero mark), and is sometimes called a "null indicator."

3.1.25 Display, pictorial. - An instrument which simulates the actual visual observation of an event while it is occurring. As in the case of an attitude indicator, the instrument usually provides information relative to position in space.

3.1.26 Display, pursuit. - Any instrument used in pursuit tracking which contains two moving indicators, one representing an actual output (operator) and the other the desired output (command). Error is estimated from the difference between these two indicators.

3.1.27 Effective temperature (ET). - An empirical thermal index that expresses the combined effect of air temperature, humidity, and air movement in terms of the subjective feeling of warmth. Combination of temperature, humidity, and air velocity that produce the same subjective feelings of warmth are assigned the same ET value.

3.1.28 Evaluation. - Consists of (1) the review and analysis of data and information collected during a test spectrum, (2) the reporting of results as determined by this analysis, and (3) any recommendations by the evaluator for action to be taken to correct any deficiencies found.

3.1.29 50th percentile man concept. - An over simplified method, based upon media measurements, of describing the combined characteristics of a varied population. Human characteristics are reported and design requirements are usually specified to include 90% of the population, or the range from the 5th percentile to the 95th percentile. This can be misleading as a basis for design criteria. Design criteria should be established upon specific percentile requirements.

3.1.30 Finger tip knob. - A control knob of relatively small size (diameter), and requiring relatively small force for actuation such that it is usually manipulated by the finger tips.

3.1.31 Footcandle. - The illumination falling on the inner surface of a sphere one foot in radius with an international candle as its center.

3.1.32 Footlambert. - A unit of brightness equal to the brightness of a perfectly diffusing and reflecting surface illuminated by one footcandle.

3.1.33 Frequency-of-use principle. - A human engineering principle which states that most frequently used items should be positioned in preferred locations, and that less frequently used items should be positioned in less preferred locations, such as around the fringes of a panel.

3.1.34 Function allocation. - A process of assigning the work to be performed by a system to personnel and equipment so as to achieve a resulting system that is maximally effective. This is based on functional analysis which takes into consideration the relative capabilities and limitations of man and machines.

3.1.35 Functional principle. - A human engineering principle which states that controls and displays should be grouped according to the function they serve.

3.1.36 Human engineering. - The engineering (or designing) of equipment to be compatible with the capabilities and limitations of the personnel who will operate, maintain, or control the equipment.

3.1.37 Ground support equipment. - Any equipment (mechanical, electrical or electronic) used on the ground to test, check-out, launch and, if necessary, retrieve a missile or space vehicle.

3.1.38 Human factors (HF). - The scientific determination of facts about human behavior, the development of systematic methods for considering man in the design of systems, and the application of these facts and methods throughout design. Human factors includes the development and application of procedures and principles for the design of controls, displays, maintenance equipment, safety procedures, training, work spaces, environmental control, human tasks and measurement of human performance.

3.1.39 Importance principle. - A human engineering principle which states that displays and controls critical to the work activity should be positioned in the "best" location, such as in the center of a panel where a display can be most easily seen.

3.1.40 Integrated display. - Any of a number of instrument panels designed to combine, in a minimum number of instruments, the information traditionally displayed in many. Current "attitude directors" and "situation displays" are examples of partial integration.

3.1.41 Kinesthesis. - Sensations attending movements of any members of the body that arise from stimulation of special receptors situated in the muscular tissue, joints, and tendons; the stimulus being some mechanical effect of the contracting muscle or moving members.

3.1.42 Legend plate. - The surface on which the legend (words, symbols, or numbers) is depicted.

3.1.43 Light: simple indicator. - An indicator light containing no legend plate. Examples are pilot lights, and jewel indicators.

3.1.44 Light: single legend indicator. - An indicator light having a single legend plate.

3.1.45 Light: multiple legend indicator. - An indicator light having two or more legend plates. Examples are annunciator systems and in-line readout displays.

3.1.46 Maintainability. - A quality of the combined features of material design and installation which permits or enhances the accomplishment of maintenance by personnel of average skill and under the environmental conditions in which the maintenance will be performed. It includes repairability and serviceability, and is a function of the rapidity and ease with which maintenance operations can be performed to avert malfunctions or correct them if they occur.

3.1.47 Maintainability characteristics. - Design features that minimize the requirements for special tools, ground support equipment, facilities, high skill levels, training, inspection, servicing, and test, as well as removal, replacement, and overhaul operations.

3.1.48 Maintainability requirements. - A comprehansive statement of required or desired features or characteristics to be incorporated into equipment design to enhance or permit the ease of maintenance.

3.1.49 Medial plane. - The median vertical longitudinal plane that divides a bilaterally symmetrical animal into right and left halves.

3.1.50 Motor skill. - The ability to achieve the more or less complicated adjustments of hands, fingers, legs, feet, or other parts of the body in an integrated, smoothly-flowing sequence resulting in the performance of some act.

3.1.51 Noise criteria (NC). - A standard for evaluating the effects of noise on speech communication and the annoyance factors in various places such as offices, conference rooms and factory workplaces.

3.1.52 Normal operating range. - That area over which an operator can easily perform a given task without undue reaching or bending.

3.1.53 Operator. - The human component in any man-machine system.

3.1.54 Palm grasp knob. - A control knob of moderately large size or requiring relatively large force for actuation such that is is usually manipulated by the entire hand grasping it.

3.1.55 Panel. - Denotes the front plate of an assembly upon which operational controls and displays are normally mounted.

3.1.56 Parallax. - The apparent displacement of an object, or the apparent difference in its position, if viewed from two different points.

3.1.57 Part (detail part; component part). - An article that is not operationally useful by itself but is an element of subassembly, assembly, or a component and is of such construction that it is practically, or economically, not amenable to further disassembly for maintenance purposes. Examples: resistor, transformer, switch, connector, fixed capacitor, and potentiometer.

3.1.58 Percentile. - The value of the statistical variable that marks the boundary between the consecutive intervals in a distribution of 100 intervals each containing one per cent of the total population. This value indicates the percentage of people falling at or below this particular value of measurement.

3.1.59 Perception. - The awareness of external objects, qualities, or relations, which ensues directly upon sensory processes.

3.1.60 Perceptual span. - The amount of perceptual material which a subject is able to grasp at a single brief presentation.

3.1.61 Peripheral field of vision. - The visual field extending beyond the central field and included within the area of 120 degrees vertically by 160 degrees horizontally, varying somewhat according to the features of the individual.

3.1.62 Procuring activity. - The procuring activity is the design or purchasing activity having cognizance of the item being procured.

3.1.63 Rack. - A tall, vertically straight frame upon which standard panels are mounted.

3.1.64 Reflectance. - The ratio of luminous flux reflected from a surface to the luminous flux striking it.

3.1.65 Relative humidity (RH). - The ratio of absolute humidity to the maximum possible density of water vapor in the air at the same temperature.

3.1.66 Reliability (equipment). - The probability that an item, when used in a manner and for the purpose intended, will perform satisfactorily for a specified period of time.

3.1.67 Repairability. - The probability that (1) when maintenance action, due to equipment malfunction, is taken the system will be restored to a satisfactory operating condition in a given period of time, with a given manpower expenditure, and (2) that the equipment will then remain in satisfactory operating condition for a specified period of time.

3.1.68 Seat reference point. - The point where median lines of the seat bottom and back rest intersect, or where the projected lines intersect when the seat is in the occupied position.

3.1.69 Serviceability. - A function of equipment design, configuration, installation, and operation which results in minimization of maintenance requirements and includes the use of special tools, support equipment, skills, and manpower. It enhances the ease of performing maintenance and reduces expenditure of time and material.

3.1.70 Signal to noise ratio. - The ratio, in decibels, of signal intensity, to noise intensity.

3.1.71 Speech interference level (SIL). - A simple (not as exacting as the Articulation Index) method for predicting the intelligibility of face-to-face speech communication. Used in situations in which the noise has a relatively continuous spectrum. It is the average value of the decibel level in the three octave bands of 600-1,200, 1,200-2,400, and 2,400-4,800 cps.

3.1.72 Stress, psychological. - A strained condition generated by a variety of causal factors usually producing a decrement in human performance. Stimulus conditions which produce stress include failure (or feelings of failure), distractions, fear inducing situations, physical discomfort, hazards, confinement or isolation.

3.1.73 Subassembly. - Two or more parts that form a portion of an assembly or a unit replaceable as a whole but having a part or parts which may be individually replaceable.

3.1.74 Subsystem. - A major functional part of a system, usually consisting of several equipments or components, which is essential to operational completeness of the system (such as airframe, navigation, and communication).

3.1.75 System. - An organized arrangement of assemblies, subassemblies, and component parts in which each acts, reacts, or interacts in accordance with an overall design which adheres in the arrangement. It includes all equipment and associated personnel integrated to perform a defined task.

3.1.76 Tactual. - Pertaining to the sense of touch.

3.1.77 Task. - A group of related job elements performed within a work cycle. More specifically, it is a group of discriminations, decisions, and effector activities related to each other by temporal proximity, immediate purpose, and a common man-machine output.

3.1.78 Test point-primary. - Operational test points used for isolating a malfunction to a removable subassembly.

3.1.79 Test points-secondary. - Maintenance test points used for isolating a malfunction to the part level after a subassembly has been removed from the assembly.

3.1.80 Threshold. - That value or intensity at which a stimulus just produces a sensation or comes just within the limits of perception. Statistically, this value is given at a point where 50 percent of a particular stimulus is perceived and 50 percent is not perceived by a given population. Differential or relative threshold is that difference between two stimuli which is (also on the average) just noticeable.

3.1.81 Transillumination. - An indirect type of illumination used on some console panels and which utilizes edge and back lighting techniques on clear, fluorescent, or sandwich-type plastic materials.

3.1.82 Transmittance factor. - The percentage of incident light which passes, or is transmitted, through a medium as opposed to that which is absorbed or reflected. Selective transmittance refers to the transmittance of particular wavelengths of light through a transparent or translucent medium, such as a red filter.

3.1.83 UDMH. Unsymmetrical dimethyl hydrazine. - A very powerful and extremely reactive fuel. Hypergolic, usually used together with nitrogen tetroxide and hydrazine. Extremely toxic requiring great care in handling.

3.1.84 Unit. - An assembly or any combination of parts, subassemblies, and assemblies which, for convenience or practicality, are grouped together. A unit may or may not be functional in itself.

3.1.85 Visual field. - The totality of visual stimuli which act upon the unmoving eye at a given moment. Also the area, measured in degrees, which can be seen by the fixated eye.

3.1.86 Visual threshold. - The minimum intensity of light that can be seen by the human eye after complete dark adaptation, generally considered to be about 1/1,000,000,000 of a lambert. Theoretically, as few as half a dozen quanta of light reaching the retina have a good probability of yielding a visual sensation.

3.1.87 Windchill index. - An empirical expression for the total cooling power of the environment and includes both temperature and wind severity.

GENERAL REQUIREMENTS

4.0 GENERAL REQUIREMENTS

4.1 Standardization. - Where feasible, selection of components, marking, coding, labeling, and arrangement schemes (equipment layout) shall be standard for all system equipment.

4.2 Reliability. - Design activities and contractors shall comply with the human engineering design criteria specified herein. Where adherence to the criteria results in degradation of the system reliability, the reliability considerations shall govern if they are approved by the procuring activity.

4.3 Automation. - Functions should be automated when the following conditions exist:

(a) The operators already required as system components are unable to perform the function within the required sensitivity, precision, reliability, time, and risk.

(b) The reliability of the system performance can be increased.

(c) The total number of qualified personnel required to operate and maintain the system are not available.

4.4 User capabilities. - Consideration shall be given to the capabilities and limitations of the intended user relative to the following areas:

(a) Intellectual, physical and psychomotor capabilities.

(b) Sensory capabilities such as visual, auditory, tactile, and thermal.

4.5 Control and display arrangements. - Controls and displays shall be designed and arranged with consideration being given to the human elements used in operating and maintaining the equipment.

4.6 Space limitations. - Consideration shall be given to human space limitations for operation and maintenance.

4.7 Safety. - Consideration shall be given to safety factors, including minimization of potential human error in the operation and maintenance of the system. Where adherence to the design practices contained in this standard will result in degradation of the system safety, the safety consideration shall have priority as specified by the procuring activity.

4.8 Environment. - Consideration shall be given to environmental factors-such as temperature, humidity, illumination, sound, dust, vibration, radiation, and airflow-that affect the ability of personnel to perform as required.

4.9 Comfort. - Consideration shall be given to comfort factors only as they relate to efficiency of operation.

4.10 Interaction. - An operator assigned to control and monitor a particular function, or group of related functions, shall have at his disposal, within acceptable reach and visual range, all controls and displays necessary to adequately fulfill the assignment. It shall not be necessary for more than one man to have simultaneous access to a particular group of controls or displays in order to insure proper functioning of a system or subsystem.

4.11 Simplicity. - The equipment shall be of the most simple design possible that will fulfill functional requirements, meet expected service conditions, and permit maximum operation, maintenance, and repair by semi-skilled personnel.

DETAILED REQUIREMENTS
CONTROL CRITERIA

CONTROL CRITERIA 5.1

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Other: further design standards are:	5.1.3.15.5
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Safety: position to avoid accidental actuation	5.1.5.2.1
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Coding requirements: to more easily identify controls	5.1.6.1
Location coding: standardize	5.1.6.2
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Selection and use of coded shapes: consider	5.1.6.4.2
Shape selection: select dissimilar shapes	5.1.6.4.2.(a)
Mounting: mount shaped knobs in upright position	5.1.6.4.2.(b)
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Size coding: avoid different sizes for coding. See text	5.1.6.5
Mode-of-operation coding: avoid. See text	5.1.6.6
Control movement: see 5.3.3 in text	5.1.7

5.0 DETAILED REQUIREMENTS

5.1 Control criteria.

5.1.1 Control requirements. - A control is that part of the equipment which is used by the operator to bring about changes in equipment performance. The most commonly used controls are the toggle switch, push button, legend switch, knob, crank, handwheel, lever and pedal. The element controlled is usually some output, expressed as rate, quantity or direction. In many cases, use of the improper type of control may mean only the difference between efficiency or inefficiency of operation. In other cases, it could mean the difference between success or failure of a mission; therefore, there are no "good" or "poor" controls per se. A push button by itself (ie, without an associate display feedback) may be quite satisfactory for turning on the power to some unit, but it is a poor choice if knowledge of that "on-off" status is critical to the system. A small rotary indicator knob may be acceptable for adjusting a meter which is located close to the operator and at eye level, but it is a poor choice if it is located high overhead such that the control setting cannot be read or it is incorrectly read. Thus, the "goodness" or "poorness" of a control depends on the appropriateness of the task and condition assigned to it. (Ely, 1) XR-C-2

5.1.2 Control selection.

5.1.2.1 Selection analysis. - The following four factors shall be considered in selecting the proper control: function of the control, task requirements, informational requirements for the operator, and work space requirements. It should be noted that these factors are not separate and distinct, but are interrelated.

5.1.2.1.1 Function of the control.

(a) The purpose and importance of the control to the system shall be taken into full consideration. XR-C-1

(b) The control shall encompass the range of characteristics of that which is to be controlled. XR-C-1

(c) Controls that serve a special function shall be distinguished from the others; eg, emergency control identified by a red border. XR-C-2

5.1.2.1.2 Task requirements.

(a) The precision, range, speed and force requirements in using the control shall be considered in control selection. XR-C-1

(b) The operation requirements of the controls shall be within the capability of the operator. XR-C-1

(c) Where a control has several requirements (eg, precision versus speed) the final selection shall be based on consideration of which has the most important effect on system performance. XR-C-2

5.1.2.1.3 Information requirements for the operator.

(a) The operator's requirement for locating and identifying the control, determining control position (setting), and sensing any change in control position shall be taken into consideration. XR-C-1

(b) Where the control by itself cannot give the required feedback, a supplementary display (eg, legend indicators) shall be used. See Display 5.2. XR-C-1

5.1.2.1.4 Work space requirements.

(a) Space availability on the panel for layout of components shall be considered. XR-C-2

(b) Space availability for operating the control in front, back, side, and above the plane of the control location shall be taken into consideration. XR-C-2

5.1.2.2 Selection of control mode. - In order to appropriately select the correct control mode, consideration shall be given to the following parameters: selection of limbs to be used; definition of control function as to rotary or linear types; definition of control function as to discrete or continuous types; and selection of controls which can be easily identified. Each of these parameters is discussed in detail.

5.1.2.2.1 Use of limb. - In complex tasks, controls shall be distributed so that the limb members are used optimally and effectively. (Barnes, 2; Fitts, 3; Grether, 4, 5) XR-S-2

5.1.2.2.1.1 Hand controls.

(a) Controls requiring rapid and precise manipulation shall be assigned to the hands. (Barnes, 6; Craig, 7, 8; Reed, 9) XR-S-2

(b) Where there is choice between locating a control for either right or left hand operation, the right hand orientation shall be preferred. (Baines, 10; Craig, 7, 8; Reed, 9) XR-S-2

(c) Where a control requires critical manipulation or large force for actuation, it shall be assigned to the right hand. (Hunsicker, 11, 12) XR-S-2

(d) When hand control requires a large force or movement for actuation, consideration shall be given for the use of the entire arm and shoulder, including the wrist and hand. (Henschke, 13) XR-S-3

(e) In situations where complex coordination is involved, eg, tracking, two-hand operation shall be used. (Craig, 7, 8; Warrick, 14) XR-S-2

5.1.2.2.1.2 Foot controls.

(a) Foot controls shall be used when the advantage of freeing the hands for other tasks is mandatory. XR-C-2

(b) Foot controls shall be used when the superior strength of the legs is mandatory for task performance. XR-C-2

(c) Foot controls shall be placed to ensure ease of identification and location. (Hunt, 15) XR-S-3

(d) Foot controls shall be located to prevent accidental actuation. XR-C-2

(e) Not more than two foot controls shall be assigned to each foot. XR-C-3

5.1.2.2.2 Rotary versus linear controls. - Rotary controls will be preferred to linear controls for the following reasons:

(a) Range of movement of rotary controls is greater than linear controls. XR-C-2

(b) Control setting time is more affected by the ratio of control movement to display movement than by factors such as control size, friction, setting tolerance and backlash. (Jenkins, 16, 17, 18, 19, 20) Ratio of control movement to display movement is more easily controlled using rotary controls than by using linear controls. XR-S-3

(c) Linear controls require an optimal friction coefficient to ensure accurate adjustment. (Burke, 21; Jenkins, 22) XR-S-3

(d) For small adjustment and given proper control-display linkage, rotary and linear controls adjustment are equally precise. For large adjustment, rotary control is superior to linear control. (Ely, 1) XR-S-3

5.1.2.2.3 Discrete (detent) and continuous controls.

(a) Discrete adjustment (detent) controls, rather than continuous adjustment controls, shall be used when performance requirements are such that the controlled object can be adjusted in a limited number of discrete steps. Not only is there saving in time, but the detent is not likely to be knocked out of the set position. (Ely, 1) XR-C-2

(b) Where possible, consideration shall be given to detent controls instead of continuous controls since positioning requires only gross movement rather than a combination of slewing and fine adjustment movements. (Ely, 1) XR-S-2

(c) Detent controls should be considered in preference to continuous controls where speed of actuation is critical. XR-C-3

(d) Detent control positioning shall be preferred to continuous control positioning where protection of setting position is required. XR-C-2

(e) Continuous adjustment controls shall be used when precise adjustments are needed along a continuum. XR-C-2

(f) Where flexibility of control is required, continuous controls shall be preferred to discrete controls. See items (b), (c) and (d) above where speed is a consideration. XR-C-2

(g) When precision and accuracy are critical, all control forces (amplitude, terminal torque, and relative torque change per unit of amplitude) shall be considered with respect to system requirement. (Bahrick, 23) XR-S-2

(h) Where required, locking mechanisms should be considered to minimize accidental actuation. XR-C-2

(i) Where a combination of gross and fine adjustment are required, selection of discrete control for gross adjustment and a continuous control for fine adjustment shall be considered. XR-C-2

5.1.2.2.4 Control identification. - Controls shall be selected which are easily identified.

(a) Standardized controls usage shall be adopted throughout the system for ease of identification. XR-C-2

(b) Special identification for controls shall be limited to special control situations, eg, emergency controls. Excessive use of special identification shall not be used. XR-C-2

(c) See Control Coding subsection 5.1.6 and Control-display interaction 5.3 for further details.

5.1.3 Types of controls.

5.1.3.1 Requirements. - The following criteria shall apply for size, displacement, resistance and other requirements.

5.1.3.2 Toggle switches.

5.1.3.2.1 Application. - The following is a list of characteristics pertaining to toggle switches: these shall be considered in the selection of controls.

(a) Requires little space for location and operation. (Bradley, 24) Only the bat handle and the mounting hex-nut are exposed on the panel surface. Actuation is usually accomplished using the ball of the thumb or the bend of the index finger, thus requiring a relatively small swept area. (Jones, 25) XR-S-2

(b) Usually has two positions. May have more positions, but speed and ease of operation are sacrificed. As the number of positions is increased, greater care and hence greater amount of time are required to actuate a toggle to the desired position. (Ely, 1) XR-C-2

(c) Control setting (position) is identifiable both visually and non-visually provided there are a small number of positions and the viewing angle is proper. The two position type is preferable, but the three position type is acceptable if used in non-critical tasks. If position identification is critical, other types of switches which afford distinct position indication (eg, detent rotary) should be used instead. The momentary spring-return type is not a problem as deliverate manual operation is required. XR-C-2

(d) Can be operated quickly and simultaneously with other toggles in a line or array. When arranged in an array, identification is aided by its proximity to its associated display marking or by its location to the other switches. (Ely, 1; Bradley, 24) XR-S-2

(e) Very quickly actuated by a simple motion of the hand. (Schultz, 26) This is true for a range of spring tension. Actuation time under different spring loading (200 to 1320 grams) is very similar. (Stump, 27) XR-S-2

5.1.3.2.2 Size. - The size of toggle switches should be as follows:

(a) Minimum control tip diameter - 0.125 inch.

Maximum control tip diameter - 1 inch. XR-C-2

(b) Minimum lever arm length - 0.5 inch.

Maximum lever arm length - 2 inches. XR-C-2

5.1.3.2.3 Displacement. - Displacement of toggle switches should be as follows: See figure 1.

Figure 1. Minimum displacement angle for toggle switch

(a) Minimum (between adjacent control positions) - 30 degrees. XR-A-2

(b) Maximum (total displacement) - 120 degrees. XR-A-2

5.1.3.2.4 Resistance. - The resistance factors apply to discrete position toggle switches only. No studies have been done to determine the acceptable resistance values for leverlock or momentary contact types of toggle switches. Resistance is described in terms of linear resistance rather than torque. Requirements should be as follows:

(a) Minimum resistance - 10 ounces. XR-C-2

(b) Maximum resistance - 40 ounces. XR-C-2

5.1.3.2.5 Other requirements.

(a) Snap-action contact will be provided with audible clicking to indicate actuation. XR-C-2

(b) Toggle switches will be vertically oriented with "up" for "on" and "down" for "off". They shall be mounted to operate horizontally only to be consistent with the orientation of the controlled function or equipment location. See Control-Display Interaction section for details. XR-S-2

5.1.3.3 Rocker arm switch. - The rocker arm switch will not be used where reliability and safety are considerations. This type of switch has two inherent disadvantages:

(a) Ambiguity of position status. Switch positions can be mistaken if viewing angle is not proper. XR-C-3

(b) Accidental actuation. Unless a switch guard is provided, it is easy to accidentally actuate the rocker switch. XR-C-3

5.1.3.4 Thumbwheels.

5.1.3.4.1 Application. - Thumbwheel controls may be used where the function requires a compact digital control-output device and, in addition, a readout of these manual inputs is provided. There are two main types: continuous and discrete. XR-C-2

5.1.3.4.2 Continuous thumbwheels.

(a) Can be used for fine calibration. XR-C-2

(b) Requires a locking device to prevent accidental positional change. XR-C-2

(c) Requires associated display for clear feedback. XR-C-2

5.1.3.4.3 Discrete thumbwheels.

(a) Provide snap action for inserting discrete values into the system. XR-C-2

(b) Require a protective guard to prevent accidental actuation. XR-C-2

(c) Legends shall be placed to the left of the knurled position or between the serrated positions. XR-C-2

5.1.3.4.4 Other features. - Thumbwheels shall have these additional features.

(a) Setting values shall increase with upward stroke on the thumbwheel. (See Control and Display section 5.3, direction of movement.) XR-S-2

(b) Readout shall not be obscured when viewed from the side. XR-C-2

(c) Size, displacement, and resistance shall be determined by system requirements. XR-C-2

(d) When required, thumbwheels may be coded by position, labelling, and color (eg, as in automobile odometer). XR-C-3

5.1.3.5 Push buttons (finger actuated)

5.1.3.5.1 Application. - There are three major types: (1) push-on and push-off; (2) push-on and release-off; and (3) push-on and lock-on. The following applies to all three types and shall be taken into consideration in the selection of controls:

(a) Requires little space for mounting and operation. (Bradley, 28) Compared with other switch types and assuming most features (mechanical and electrical) to be similar, the finger push button requires the least amount of space for mounting on a panel surface. XR-S-2

(b) Operation is performed using one finger with a motion along an axis that is a right angle to the mounting surface--a sweeping motion is not required. (Jones, 25) XR-S-2

(c) Can be operated quickly and simultaneously with other push buttons arranged in an array. (Bradley, 28; Klemmer, 29; Wassertheil, 30) XR-S-2

(d) Usually has two status positions--these being some variations of "on" and "off". Status position is not easily identified visually or non-visually, especially push-on push-off types. (Hunt, 15) Associated display for feedback shall be required if knowledge of status is important. XR-S-2

(e) Easily coded by color or size (Hunt, 15), the button can be made of different colors and sizes. Location coding and identification, eg, as with digited computer numeral insertions, are also advisable when arranged properly or with proper display markings. (Knowles, 31) XR-S-2

5.1.3.5.2 Size. - Finger actuated push button will be the following sizes:

(a) Minimum diameter for fingertip operation - 0.5 inch. XR-C-2

(b) Minimum diameter for emergency controls which can be activated by thumb or heel of hand - 0.75 inch. XR-C-2

(c) Maximum diameter - no limitation set by operator performance. XR-C-2

5.1.3.5.3 Displacement. - Displacement of finger actuated push button will be as follows:

(a) Minimum - 0.125 inch. XR-A-2

(b) Maximum for thumb or fingertip operation - 1.5 inches. XR-A-2

5.1.3.5.4 Resistance. - Resistance of finger actuated push button will be as follows:

(a) Minimum for fingertip operation - 10 ounces. XR-A-2

(b) Maximum for fingertip operation - 40 ounces. XR-A-2

5.1.3.5.5 Other requirements.

(a) Whenever feasible, the button shall be concave to prevent slippage. XR-C-2

(b) The button shall be recessed where accidental actuation would endanger the system. The recess or barrier shall be a minimum of 0.0625 inch in a guard which shall protrude from the surface of console. XR-A-2

(c) The button will have a snap action with an audible click to indicate control actuation. XR-C-2

(d) Visual indication of control actuation shall be provided for critical function. XR-C-2

(e) Marking shall be in upright position at all times. XR-C-2

(f) Marking shall be readable and legible after wear from use. XR-C-2

5.1.3.6 Push buttons (foot).

5.1.3.6.1 Application. - There are two major foot operated push-button types: (1) push-on and release-off; and (2) push-on and push-off. These considerations apply to both types and shall be taken into consideration in the selection of controls.

(a) Leaves the hand free for other operations. This fact alone may be the primary reason for using the foot push button. XR-C-2

(b) Requires large space area for operation because of foot size and swept volume. XR-C-2

(c) Control status is not easily identifiable. (Hunt, 15) Care should be exercised in deciding the location and selecting the resistance value so accidental actuation is minimized or eliminated. XR-C-2

5.1.3.6.2 Size. - Push button foot switches will have the following size requirements:

(a) Minimum diameter - 0.75 inch. XR-C-2

(b) Maximum diameter - no limitation set by operator performance. XR-C-2

5.1.3.6.3 Displacement. - Displacement of push button foot switches will be as follows:

(a) Minimum for normal operation - 0.5 inch. XR-C-2

(b) Minimum for heavy boots - 1 inch. XR-C-2

(c) Maximum for controls operated by ankle flexion only - 2.5 inches. XR-C-2

(d) Maximum for controls operated by leg movements - 4 inches. XR-C-2

5.1.3.6.4 Resistance. - Resistance of push button foot switches will be as follows:

(a) Minimum resistance when foot will not rest on control - 4 pounds. XR-C-2

(b) Minimum resistance when foot may rest on control - 10 pounds. XR-C-2

(c) Maximum resistance for normal operation, foot resting or not resting on control - 20 pounds. XR-C-2

5.1.3.6.5 Other requirements.

(a) The control shall be designed for ball of the foot operation. If space permits, foot push buttons shall be actuated by a pedal hinged at the heel. XR-S-2

(b) Snap action with an audible click will be provided to indicate control actuation. XR-C-3

(c) Visual indication of control actuation shall be provided. XR-C-2

5.1.3.7 Legend switch.

5.1.3.7.1 Application. - The legend switch combines the display in a control. It has many of the features of a push button switch plus those of the legend switch. The following characteristics of the legend switch shall be considered in the selection of controls.

(a) Displays qualitative information which requires the operator's attention to system status. XR-C-2

(b) Permits minimal interpretation by operator while interpretation depends on legend characteristics, it usually permits better feedback than a push button. XR-C-2

(c) Can be used singly or in some matrix. The space required for mounting is less than that required for a push button and legend indicator separately. XR-C-2

5.1.3.7.2 Size. - Legend switch will have the following size requirements (either length or height).

(a) Minimum - .75 inch. XR-C-2

(b) Maximum - 1.25 inch. XR-C-2

5.1.3.7.3 Displacement. - Legend switch will have the following displacement requirement.

(a) Minimum - .125 inch. XR-C-2

(b) Maximum - .25 inch. XR-C-2

5.1.3.7.4 Resistance. - Legend switch will have the following resistance requirements:

(a) Minimum - 10 ounces. XR-C-2

(b) Maximum - 45 ounces. XR-C-2

5.1.3.7.5 Separation. - Separation of legend switches between rows or between adjacent switches will be as follows:

(a) Minimum - .125 inch. XR-C-2

5.1.3.7.6 Barrier height (from panel surface). - Barrier height shall be:

(a) Minimum - .187 inch. XR-C-2

(b) Maximum - .25 inch. XR-C-2

5.1.3.7.7 Other requirements.

(a) For positive indication of switch activation, the legend switch will be provided with a detent or click. XR-C-2

(b) The legend shall be legible when only one lamp is operating within the switch. XR-C-1

(c) There shall be press-to-test or dual lamp reliability. XR-C-1

(d) Lamps within the legend switch shall be replaceable from the front of the panel by hand. XR-C-2

(e) There shall be a maximum of three lines of lettering on the legend plate. XR-C-2

5.1.3.8 Knobs. - The following general features apply to knobs and shall be taken into consideration when they are evaluated for use as controls.

5.1.3.8.1 Application.

(a) The number of knob positions shall be between 3 to 24. Speed and accuracy of setting and checking are sacrificed with too many settings. (Ely, 1) XR-C-2

(b) A spacing of 35 degrees between settings is desirable. (Hunt, 32) The horizontal and vertical axes provide the operator definite cues for more accurate settings. Areas between the horizontal and vertical axes provide poorer reference cues. If the spacing between settings is too small, misreading can occur due to parallax. (Chapanis, 33, 34) XR-S-2

(c) The associated labels can cause a clutter if there are too many positions and can lead to errors in setting and reading. XR-C-2

(d) Require more space for location and operation than do push buttons and toggles. (Bradley, 35) Generally the knobs for operating a rotary switch are large. The markings about the positions take up additional space. The swept area for operating a rotary switch is large as it involves more fingers for manipulation. (Jones, 25) XR-S-2

(e) When a large number of discrete settings are required, one rotary switch takes up less space than an array of toggles or push buttons. (Bradley, 35) XR-S-2

(f) Easily identified by color or shape. Control settings (positions) are easily identifiable visually and tactually with proper design. (Ely, 1) XR-S-2

(g) Actuation speed depends on the torque requirement and the number of positions used. The higher the torque required and greater the number of positions, the slower the actuation time. (Siegel, 36) XR-S-2

(h) Can be used with either a rotatable indicator (pointer) and stationary label, or a stationary indicator and label on a rotatable skirt. If the label on a rotatable skirt is used, care must be taken to insure that the orientation of the label is correct (upright to the viewer) throughout all the reading positions. (Ely, 1) XR-S-2

(i) See Human capabilities and human responses 5.4.1 for data on maximum actuation torque on knobs. Notice that these maximum torque values are much larger than the operating values given below. The operating values are for ease of operation and shall be used. The maximum value will be used only when exceptional conditions are required.

5.1.3.9 Multiple rotation knobs.

5.1.3.9.1 Application. - Multiple rotation knobs shall be used for controls that have an adjustment range of one full turn or more. Multiple rotation knobs shall be used for controls that require twirling or spinning. XR-C-2

5.1.3.9.2 Feedback. - Multiple rotational knobs shall have an information feedback, such as a gage, unless the system provides other adequate safeguards or position indicator. XR-C-2

5.1.3.9.3 Size. - Within the ranges listed below, the knob sizes are relatively unimportant when the resistance is low and the knob is easily grasped and manipulated. General size design will be followed.

(a) Minimum depth (fingertip grasp knob) - 0.5 inch. Maximum depth (fingertip grasp knob) - none. XR-C-2

(b) Minimum diameter (fingertip grasp knob) - 0.375 inch. Maximum diameter (fingertip grasp knob - 4 inches. XR-C-2

(c) Minimum diameter (palm grasp knob) - 1.5 inches. Maximum diameter (palm grasp knob) - 3 inches. XR-C-2

(d) Minimum diameter (thumb and finger encircled) - 1 inch. Maximum diameter (thumb and finger encircled) - 3 inches. XR-C-2

5.1.3.9.4 Displacement. - Displacement shall be determined by the desired control display ratio. XR-C-2

5.1.3.9.5 Resistance (torque). - Resistance of multiple rotation knobs will be as follows:

(a) Minimum - no practical limit is set by operator performance. Jarring, vibration or other contions shall determine minimum resistance limit. See 5.4.1 for resistance values under vibration. XR-C-2

(b) Maximum for fingertip operation with small (1-inch diameter) knobs - 4.5 inch-ounce of torque. XR-C-2

(c) Maximum for fingertip operation with larger knobs (above 1 inch diameter) - 6 inch-ounces of torque. XR-C-2

5.1.3.10 Fractional rotation knobs.

5.1.3.10.1 Application. - Fractional rotation knobs shall be used on controls that do not require spinning or twirling, or controls that have an adjustment range less than one full turn.

5.1.3.10.2 Feedback. - Fractional rotational knobs shall have an information feedback, such as a gage, unless the system provides other adequate safeguards or position indicator. XR-C-2

5.1.3.10.3 Size. - Same as multiple-rotation knobs. XR-C-2

5.1.3.10.4 Displacement. - Same as multiple rotation knobs. XR-C-2

5.1.3.10.5 Resistance. - Same as multiple-rotation knobs. XR-C-2

5.1.3.11 Detent positioning knobs.

5.1.3.11.1 Application. - Detent positioning knobs shall be used on controls that do not require spinning or twirling, on controls that have an adjustment range of not more than one full turn, or on controls that have a knob position that is a critical item of information in the control operation.

5.1.3.11.2 Size. - The size of detent positioning knobs will be as follows:

(a) Minimum pointer length - 1 inch. Maximum pointer length - 0.75 of the knob diameter. XR-C-2

(b) Minimum pointer width - at extremity shall be equal to the line width of the numeral of letter designation or of the incremental indicator. Maximum pointer width - 1 inch. XR-C-2

(c) Minimum pointer depth - 0.5 inch. Maximum pointer depth - 3 inches. XR-C-2

5.1.3.11.3 Displacement. - Displacement of detent positioning knobs will be as follows:

(a) Minimum displacement (between adjacent detents) for visual positioning - 15 degrees. XR-C-2

(b) Minimum displacement (between adjacent detents) for non-visual positioning - 30 degrees. XR-C-2

(c) Maximum displacement (between adjacent detents) for facilitating operator performance - 40 degrees. XR-C-2

(d) Maximum displacement (between adjacent detents) when special engineering requirements demand large separations - 90 degrees. XR-C-2

5.1.3.11.4 Resistance. - Resistance of detent positioning knobs shall be as follows:

(a) Minimum - 12 inch-ounces.

(b) Maximum - 48-inch-ounces.

5.1.3.11.5 Other requirements. - Other requirements of detent knobs will be as follows:

(a) No more than 24 switch positions will be incorporated into one detent positioning knob. XR-C-2

(b) The pointer will have a tapered tip and adequate gripping surface. XR-C-2

(c) Position of the pointer knob in relation to the scale will be such as to minimize parallax. XR-C-2

5.1.3.12 Cranks.

5.1.3.12.1 Application. - The following features relating to cranks shall be considered in the selection of controls.

(a) Effective in making adjustments on a continuum when larger distance must be covered and high rates of turning are required. (For short adjustment distance and slow turning rate, other control types should be considered.) (Helson, 37) XR-C-2

(b) The preferred hand (hence mostly the right hand) is more efficient and faster in cranking. (Baines, 10; Craig, 7, 8; Reed, 9) XR-S-2

(c) For low friction small crank radii produce fastest performance but for great amount of friction larger radii are best. (Gerall, 38) XR-S-2

(d) Cranks of high mass produce greater accuracy of manipulation than cranks of low mass. (Helson, 37) XR-S-2

(e) Require more space for location than most other controllers. Crank operation requires large amounts of space as the entire hand is involved in a large swept area. XR-C-2

(f) Since it is usually multi-rotational in operation, the handle or any marking on the crank generally does not indicate the control setting. (Hunt, 15) XR-S-2

(g) Can have an unlimited range of gross or fine control movement with the proper gearing. (Ely, 1) XR-S-2

5.1.3.12.2 Size. - Size of cranks will be as follows:

(a) Minimum radius - 0.5 inch. XR-C-2

(b) Maximum radius (heavy load) - 20 inches. XR-C-2

(c) Maximum radius (minimum load and high rate - up to 275 rotations per minute) - 4.5 inches. XR-C-2

5.1.3.12.3 Displacement. - Displacement shall be determined by the control display ratio. See Control-Display section 5.3. XR-S-2

5.1.3.12.4 Other requirements.

(a) Cranks will have a grip that is free to turn on its own axis. XR-C-3

(b) As the load increases, the crank size shall be increased to maintain a desired turning rate. (Helson, 37) XR-S-2

(c) Handles for cranks will be 1.500 inches in length by 0.500 inch in diameter for operations requiring fast wrist and finger movement and 3.750 inches in length by 1.000 inch in diameter for operations requiring arm movement of heavy loads. XR-C-3

(d) Cranks may be mounted either to the right or left of the center of the operator's position. (Hunsicker, 12) XR-S-3

(e) Cranks that require extreme torque shall be mounted so that the turning axis is parallel to the frontal plane of the body. (Helson, 37) See figure 2. XR-S-2

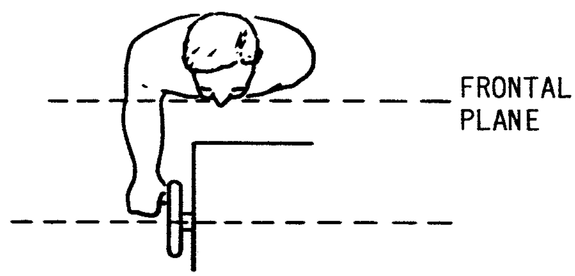


Figure 2. Cranks requiring extreme torque

(f) Crank controls that are to be turned rapidly shall be mounted so that the turning axis lies within a range from perpendicular to about 60 degrees off the frontal plane of the operator. (Helson, 37) See figure 3. XR-S-2

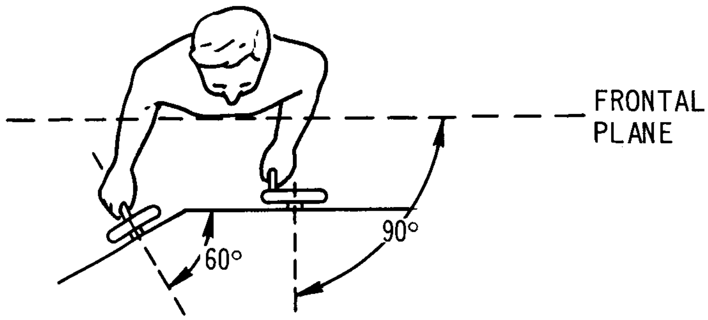


Figure 3. Cranks requiring rapid turning

(g) Crank diameters shall be in accordance with table I for optimum efficiency. (Douglas, 39) XR-S-2

5.1.3.13 Handwheels.

5.1.3.13.1 Application.

(a) Designed to be operated by two hands for situations requiring an initial rotational force too large for one hand. (A rotatable handle may be attached to the rim of any part of the wheel to facilitate one hand operation. When this is done it takes on the properties of the crank. When such rotary controls are small enough to be grasped by one hand, they are classified as knobs.) XR-C-2

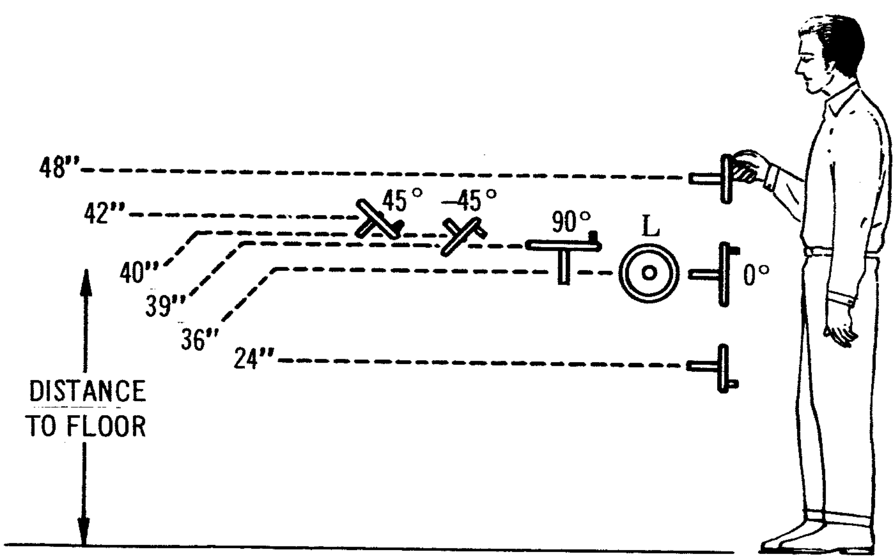
(b) Useful for exerting greater force than is possible with other rotary controls of equal radius. (Orlansky, 40, 41) XR-S-2

Table I.

Optimum control diameters and torque

HEIGHT (IN.)	POSITION (DEG.)	TYPE	SIZE HANDWHEEL (W), DIAMETER IN INCHES; CRANK (C), RADIUS IN INCHES — AT TORQUE OF 0 in. lb	40 in. lb	90 in. lb
24	0	W	3 - 6	10	16
36	0	W	3 - 8	10 - 16	16
	L	W	3 - 6	10	10
	0	C	1 1/2 - 4 1/2	4 1/2 - 7 1/2	4 1/2 - 7 1/2
39	90	W	3 - 10	10 - 16	16
	90	C	2 1/2 - 4 1/2	4 1/2 - 7 1/2	4 1/2 - 7 1/2
40	-45	W	3 - 6	6 - 16	10 - 16
	-45	C	2 1/2 - 7 1/2	4 1/2 - 7 1/2	4 1/2 - 7 1/2
42	45	W	3 - 6	10	10 - 16
	45	C	2 1/2 - 4 1/2	2 1/2 - 4 1/2	4 1/2
48	0	W	3 - 6	8 - 16	10 - 16
	0	C	2 1/2 - 4 1/2	4 1/2	4 1/2 - 7 1/2

These data were based on setting the control device in only one revolution. For less than a 90-degree turn, handwheels would be more effective than cranks. (Douglas, 39)



(c) Requires large amount of space for location and operation. Generally, in order to exploit the advantage of the handwheel, its radius has to be quite large. (Helson, 37) XR-S-2

(d) The handwheel itself can be color-coded effectively. The exact setting of multirotationa handwheels is difficult to determine unless an indicator is provided. (Hunt, 15) XR-S-2

(e) Handwheels are useful as part of a combined control. Smaller controls can usually be attached to its parts eg, horn button on steering wheel. Unless these attachments are located in the handwheel center, their position may vary with the position of rotation. XR-C-2

5.1.3.13.2 Displacement. - Displacement requirements for handwheels associated with displays shall be determined by the desired display ratio. A maximum displacement of 90 to 120 degrees is desirable. XR-C-2

5.1.3.13.3 Resistance. - Minimum resistance for handwheels will be 5 pounds. Maximum resistance for one hand operations will be 30 pounds and will be 50 pounds for two-hand operations.

5.1.3.13.4 Other requirements.

(a) The gripping surface of the handwheel shall be knurled or indented to provide a firm grip. XR-C-2

(b) The handwheel shall rotate clockwise for on or for an increase in the associated display or controlled function and counter-clockwise for off or for a decrease in associated display or controlled function. The reverse is true for handwheels associated with valves such as fluid lines, pressure lines and reheostats. (See Control-Display Interaction section 5.3 for details.) XR-S-2

(c) Direction of motion should be indicated on the handwheel, or immediately adjacent thereto, by means of arrows and appropriate legends. XR-A-2

(d) Handwheel diameters shall be in accordance with table I for optimum efficiency. (Douglas, 39) XR-S-2

(e) Information should be displayed either electrically or mechanically to indicate the position of the control. XR-A-2

5.1.3.14 Levers.

5.1.3.14.1 Application. - Levers shall be used when large amounts of force or displacement are required and when movement of the control about more than one axis is required. XR-C-2

NOTE:
Levers. The amount of force that the limbs can exert depends on two very important variables--the position of the control relative to the body and the type of support (back rests) given the body. Given a back rest the limb acts as a mechanical "toggle" with the control. This toggle action markedly increases the exertable force and the relationship between control and back rest is highly critical. The toggle action stops at a well-defined "limiting angle". For the lower limbs it is 160 degrees while for the upper limbs it is 135 degrees. See 5.4.1 for details. (Hugh-Jones, 42; Rees, 43) XR-S-2

5.1.3.14.2 Size. - Length shall be determined by the mechanical advantage required. XR-C-2

5.1.3.14.3 Displacement. - Lever resistance requirements shall dictate displacement with minimum resistance requiring minimum displacement. Maximum fore-aft movement will be 14 inches and maximum lateral movement using one hand shall be 30 inches, and with two hands maximum shall be 38 inches. XR-C-2

5.1.3.14.4 Resistance. - Minimum resistance of levers will be two pounds force. Maximum resistance requirements will be as follows:

(a) Push-pull one-hand operations with control along the medial plane of the body and 10 inches forward from seat reference point - 30 pounds. XR-C-2

(b) Push-pull one-hand operations with control along the medial plane of the body and 16 to 24 inches forward from seat reference point - 50 pounds. XR-C-2

(c) Push-pull two-hand operations with the control 10 to 19 inches forward from seat reference point - 75 pounds. XR-C-2

(d) Right-left one-hand operations with the control 10 to 19 inches forward from seat reference point - 20 pounds. XR-C-2

(e) Right-left two-hand operations with the control 10 to 19 inches forward from seat reference point - 30 pounds. XR-C-2

5.1.3.14.5 Other requirements.

(a) Displacement of the lever arm will not exceed convenient arm reach of the operator and shall not move through an arc greater than 90 degrees in any direction. XR-C-2

(b) Long lever arms will be used for large displacements. XR-C-2

(c) For making precise, continuous adjustments, support will be provided as follows: XR-C-2

(1) Elbow support for large hand movements.

(2) Forearm support for small hand movements.

(3) Wrist support for finger movements.

(d) Lever handles should be colored to facilitate discrimination and should be equipped with safety locks to prevent accidental tripping or actuation. XR-C-2

5.1.3.15 Pedals.

5.1.3.15.1 Application. - Pedals will be used when a large amount of displacement and force are required and foot activation is necessary.

NOTE:
Pedals. The amount of force that the limbs can exert depends on two very important variables--the position of the control relative to the body and the type of support (back rests) given the body. Given a back rest the limb acts as a mechanical "toggle" with the control. This toggle action markedly increases the exertable force and

the relationship between control and back rest is highly critical. The toggle action stops at a well-defined "limiting angle". For the lower limbs it is 160 degrees while for the upper limbs it is 135 degrees. (Hugh-Jones, 42; Rees, 43) XR-S-2

5.1.3.15.2 Size. -

(a) Minimum - 1 by 3 inches. XR-C-2

(b) Maximum size shall be determined by the available space and danger of accidental activation. XR-C-2

5.1.3.15.3 Displacement. -

(a) Minimum, normal operation - 0.5 inch. XR-C-2

(b) Minimum, heavy boots - 1 inch. XR-C-2

(c) Maximum, ankle flexion - 2.5 inches. XR-C-2

(d) Maximum, leg movement - 7 inches. XR-C-2

5.1.3.15.4 Resistance. -

(a) Minimum, foot not resting on the control - 4 pounds. XR-C-2

(b) Minimum, foot resting on control - 10 pounds. XR-C-2

(c) Maximum, ankle flexion only - 20 pounds. XR-C-2

(d) Maximum, leg movement - 180 pounds. XR-C-2

5.1.3.15.5 Other requirements.

(a) Where time of actuation is important, the fulcrum of the pedal shall be located under the heel of the operator's foot. (Barnes, 44) XR-S-2

(b) Pedals shall be spring loaded to return to neutral position when applied force is removed. XR-C-1

(c) Pedals shall have non-skid surfaces. XR-C-1

(d) Pedals will be located to minimize accidental actuation. XR-C-2

5.1.4 Other controls. - The more recent and more sophisticated types of controls have not been examined. Present literature has lagged behind the state of the art and many control concepts are proprietary designs. The designer is encouraged to use the more recent control devices. These devices shall be designed and used following the criteria set forth at the beginning of this section.

5.1.5 Spacing of controls.

5.1.5.1 General. - The specific recommended distance for separating controls depends upon the tasks to be performed. XR-C-1

5.1.5.2 Spacing factors.

5.1.5.2.1 Effect accidental actuation. - Adverse effects upon system performance by inadvertent or accidental actuation of controls shall be considered. Where a problem exists, optimal spacing shall be used. See table II. Clear labelling, increased actuation force, and locking devices shall also be considered. (Bradley, 24, 28, 35, 45, 46) XR-S-1

5.1.5.2.2 Hindrance by personal equipment. - Where it is necessary for the operator to wear any type of clothing that might interfere with manipulation of controls, extra separation shall be allotted. (Bradley, 47) XR-S-2

5.1.5.2.3 Need for blind positioning. - Where a control is operated with little or no visual aid, spacing between controls shall be the maximum that space will allow. (Fitts, 48, 49, 50) XR-C-1

5.1.5.2.4 Space availability and size of control. - Where space is at a premium, small (miniature) controls which allow greater separation shall be preferred to full size controls. (Jones, 25) See table III. XR-S-2

5.1.5.2.5 Simultaneous use of controls. - When a series of similar controls are to be simultaneously actuated, the spacing between controls shall be sufficient to promote ease and speed of operation. Sequential ordering shall be determined from task sequence requirements. See Control-display interaction, 5.3. Care shall be exercised to ensure clarity of labelling. XR-C-2

5.1.5.3 Optimum spacing between controls. - The values in table II shall be used for optimum spacing. (Ely, 51) See following note. XR-S-2

Table II.

Recommended separation between control - optimum space

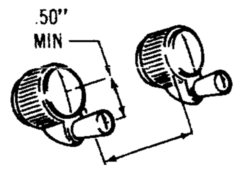
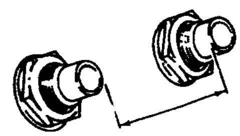
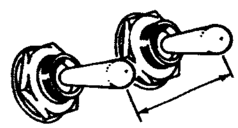
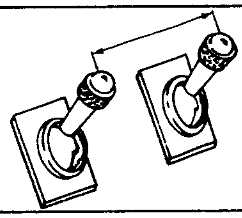
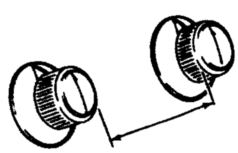
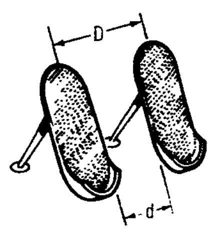
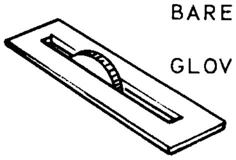
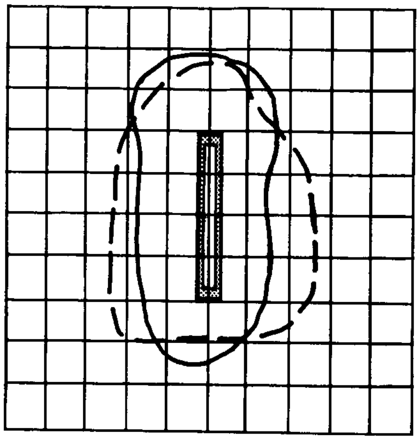
CONTROL	MEASURE OF SEPARATION	TYPE OF USE	EDGE TO EDGE SEPARATION	
			DESIRABLE MINIMUM FOR STATIONARY SITUATION	DESIRABLE DISTANCE FOR MOVING VEHICLE SITUATION
CRANKS		ONE HAND INDIVIDUALLY	2"	4"
		TWO HANDS SIMULTANEOUSLY	3"	5"
PUSH BUTTON		ONE FINGER INDIVIDUALLY	.50"	2"
		ONE FINGER SEQUENTIALLY	.25"	1"
		DIFFERENT FINGERS INDIVIDUALLY OR SEQUENTIALLY	.50"	.50"
TOGGLE SWITCH		ONE FINGER INDIVIDUALLY	.75"	2"
		ONE FINGER SEQUENTIALLY	.50"	1"
		DIFFERENT FINGERS INDIVIDUALLY OR SEQUENTIALLY	.62"	.75"
LEVER LOCK TOGGLE SWITCH		FINGER AND THUMB INDIVIDUALLY	1"	2"
KNOBS		ONE HAND INDIVIDUALLY	1"	2"
		TWO HANDS SIMULTANEOUSLY	3"	5"
PEDALS		ONE FOOT – RANDOMLY	d 4" D 8"	6" 10"
		ONE FOOT – RANDOMLY	d 2" D 6"	4" 8"

Table III.

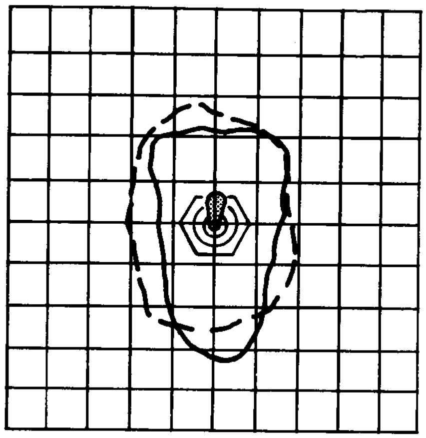
Limited spacing between control

TYPE: ROLLER (CONTINUOUS)
LENGTH = 1.000
WIDTH = .375
SWEPT AREA:
BARE HAND: MAJOR AXIS = .8
MINOR AXIS = 1.8
GLOVED HAND:
MAJOR AXIS = 2.12
MINOR AXIS = 1.25

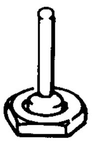


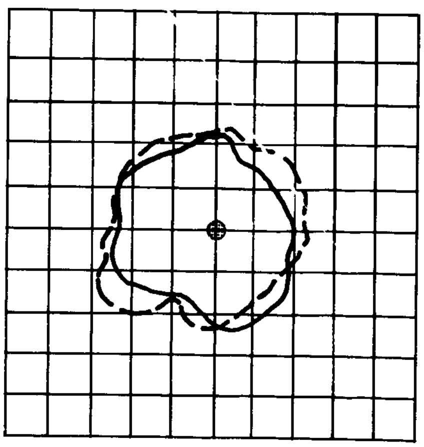


TYPE: TOGGLE SWITCH
DIAMETER = .125
HEIGHT = .375
SWEPT AREA:
BARE HAND: MAJOR AXIS = 1.30
MINOR AXIS = .85
GLOVED HAND: MAJOR AXIS = 1.30
MINOR AXIS = .85

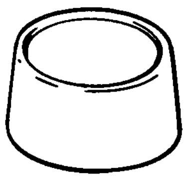


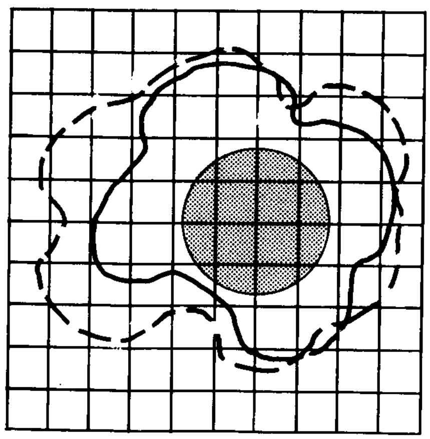
TYPE: ROUND KNOB
DIAMETER = .125
HEIGHT = .500
SWEPT AREA:
BARE HAND: DIA = 1.2
GLOVED HAND: DIA = 1.4





TYPE: ROUND KNOB
DIAMETER = .875
HEIGHT = .500
SWEPT AREA:
BARE HAND: DIA = 1.8
GLOVED HAND: DIA = 2.4

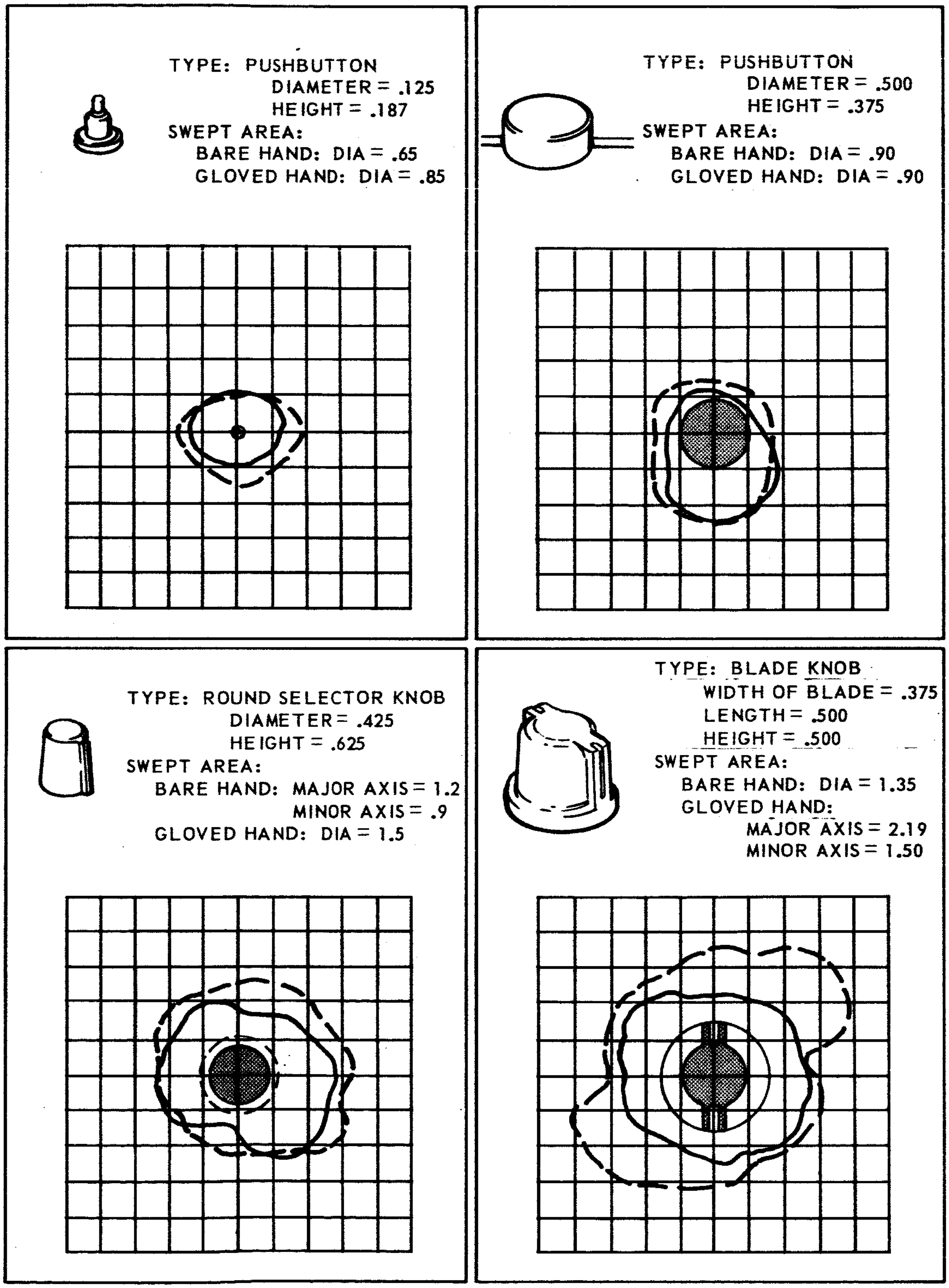




BARE HAND ———— GLOVED HAND — — —

Table IIIa.

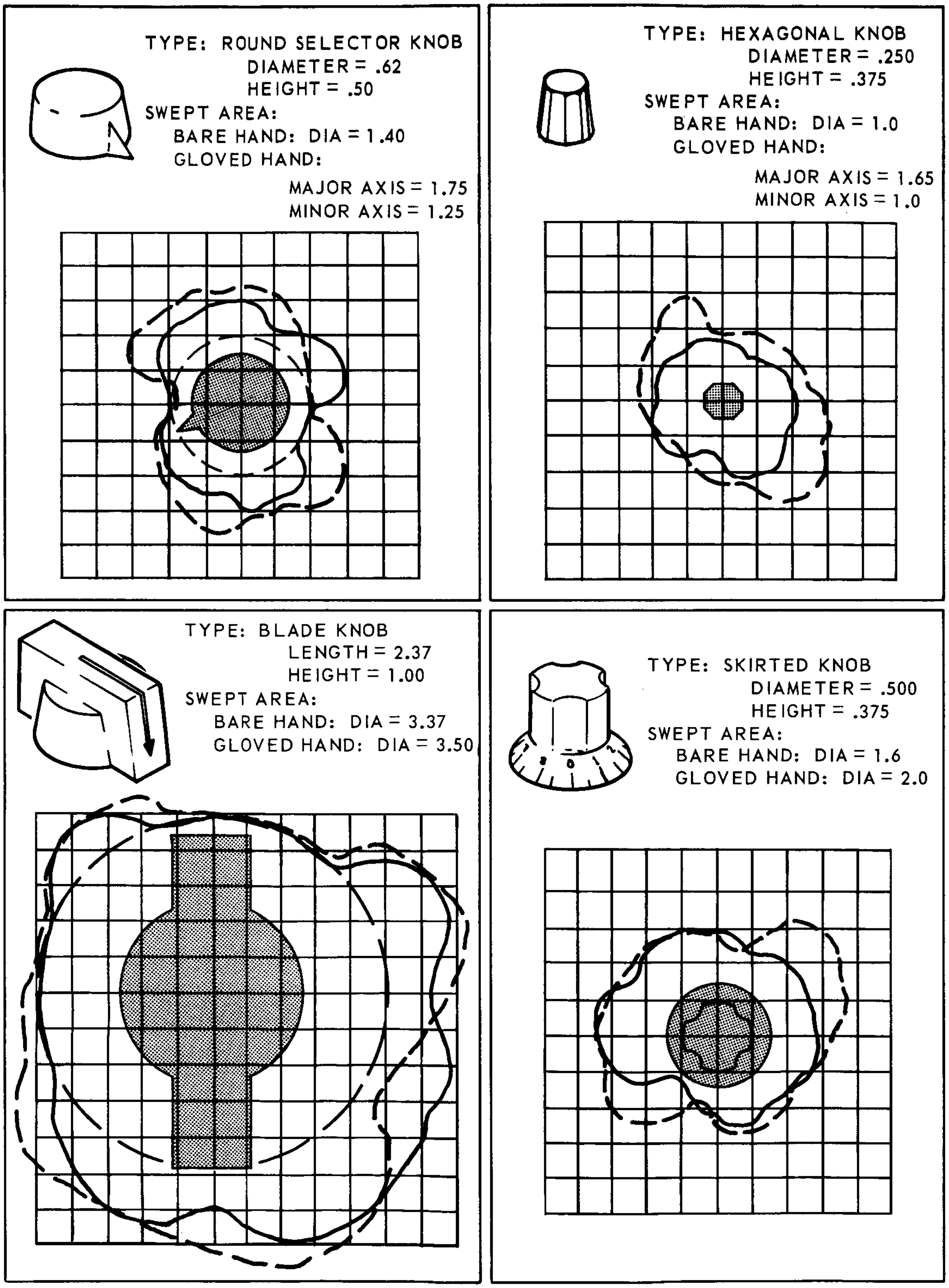
Limited spacing between control



BARE HAND ———— GLOVED HAND — — —

Table IIIb.

Limited spacing between control



BARE HAND ——— GLOVED HAND — — —

5.1.5.4 Limited space availability. - The values in table III shall be used where space is limited. (Jones, 25) See following note. XR-S-2

NOTE:
The spacing values in table II are derived in large part from "Layout of Workspace". (Ely, 51). While no formal experimental evidence is available, general usage has shown these values to be acceptable. Where it is possible to use full size controls and optimum spacing, the values in table II shall be used. When available space is limited and miniature controls have to be used, the values in table III shall be used to determine separation between controls. Adjacent controls should not be within the swept area of one another.

5.1.5.5 Size consistency. - On any given subsystem panel, control size and control spacing will be consistent. See items 5.1.5.3 and 5.1.5.4 and Control-display interaction 5.3 for other details. XR-C-2

5.1.5.6 Special cases.

5.1.5.6.1 Ganged controls. - To conserve space or to aid in sequential operation, several knobs may be mounted on a concentric shaft.

(a) Two concentric knobs shall be preferred (three may be acceptable, but no more) because of possible labelling difficulties and chance of accidental actuation. XR-C-2

(b) Chances of accidental operation are increased if either the knob diameter or thickness is too large, too small, or differ by too small an amount. (Bradley, 46) See figure 4. XR-S-3

5.1.5.6.2 Groups of levers. - When a group of levers is used simultaneously by the same hand, their maximum separation shall be 6 inches or less for the group so as to be taken into the span width of the average hand. (Ely, 51) XR-S-3

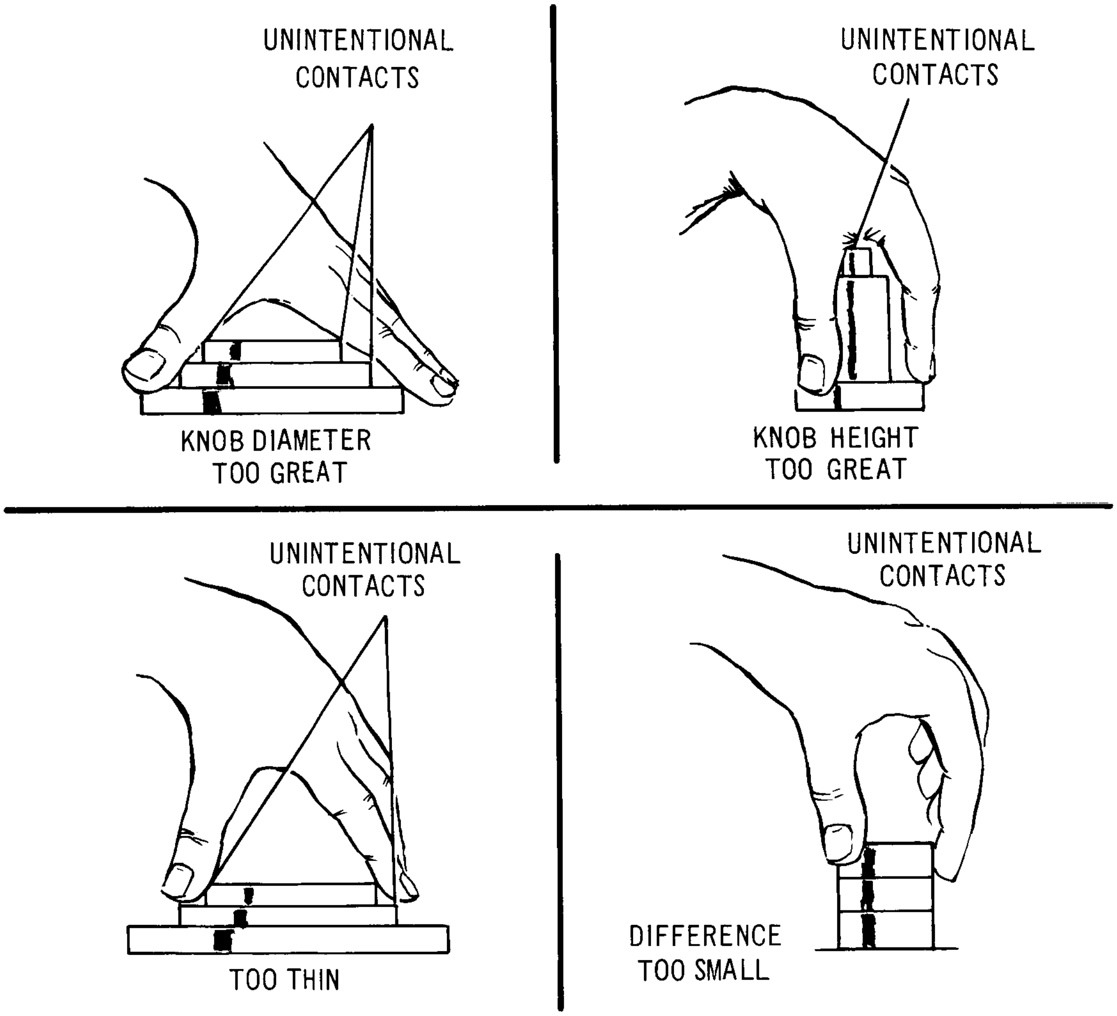


Figure 4. Problems in using knobs on a concentric shaft

5.1.6 <u>Control coding</u>.

5.1.6.1 <u>Coding requirements</u>. - The primary purpose of control coding is to make controls easier to identify. The benefits gained with proper coding, in varying degrees, are several: reduce the time required to find the correct control, minimize possible actuation of wrong control, and reduce the amount of time necessary to train personnel. (Ely, 1) XR-S-2. Several of the most common coding methods are enumerated in this sub-section. These methods shall be used whenever appropriate.

5.1.6.2 Location coding. - A specific location for a specific control type aids control identification. Consistency of location is an important factor in attaining standardization within a system.

(a) The most important and most frequently used controls shall be located in front of the operator at slightly below the shoulder level. (Ely, 51) XR-S-2

(b) Controls that serve the same function eg, panel on-off switch, will be located in the same relative position from panel to panel. Some peripheral, not too often used spot such as the lower left-hand corner of a panel is preferred. XR-C-2

(c) Blind positioning (manipulating a control without looking) shall be avoided unless absolutely necessary. If used, other coding methods such as shape coding shall be considered. XR-C-1

5.1.6.3 Color coding. - In general, color should not be used as the primary method of control coding. The reason is that the color of the control depends on the illuminant. If the intensity of illumination is reduced or if there is some different color illuminant, the color of the control changes or it is masked. If it is necessary to use color coding, the following factors shall be considered:

(a) Color coding shall conform with existing standards. See Color coding display 5.2 for other details. XR-S-2

(b) In general, only the four discrete colors shall be used; red, yellow, green and white. XR-S-2

5.1.6.4 Shape coding. - Shape coding shall be used only sparingly. Generally, standardized knob type can be used without any difficulty in identification. Shape coding should be used only when ordinary means are not adequate. (Hunt, 15, 52) XR-S-2

5.1.6.4.1 Type of shape coding. - Shape coding may be visual, tactile or a combination. Its effectiveness depends upon the ease with which shapes can be identified. Of all the controls, knobs most easily lend themselves to shape coding. Figures 5, 6, and 7 show three classes of coded shape, each designed to serve some specific function. (Hunt, 15, 52) Classes A and B are for continuous rotary, and while class C is for the discrete rotary. See paragraphs 5.1.6.4.1.1 through 5.1.6.4.1.3.

5.1.6.4.1.1 Class A. - Class A (figure 5) shapes shall be selected when: XR-S-2

(a) More than one full turn is required.

(b) Control motion is twirling or spinning.

(c) The radial position is not a source of information.

5.1.6.4.1.2 Class B. - Class B (figure 6) shapes shall be selected when: XR-S-2

(a) Less than one full turn is required.

(b) Control motion is other than twirling or spinning.

(c) The radial position is not a source of information.

5.1.6.4.1.3 Class C. - Class C (figure 7) shapes shall be selected when: XR-S-2

(a) Less than one full turn is required.

(b) Control motion is other than twirling or spinning.

(c) The radial position of the knob is a source of information.

5.1.6.4.2 Selection and use of coded shapes.

(a) When it is necessary to use shape coding, selection shall be made from that class knob that is maximally dissimilar. (Hunt, 15, 52) XR-S-2

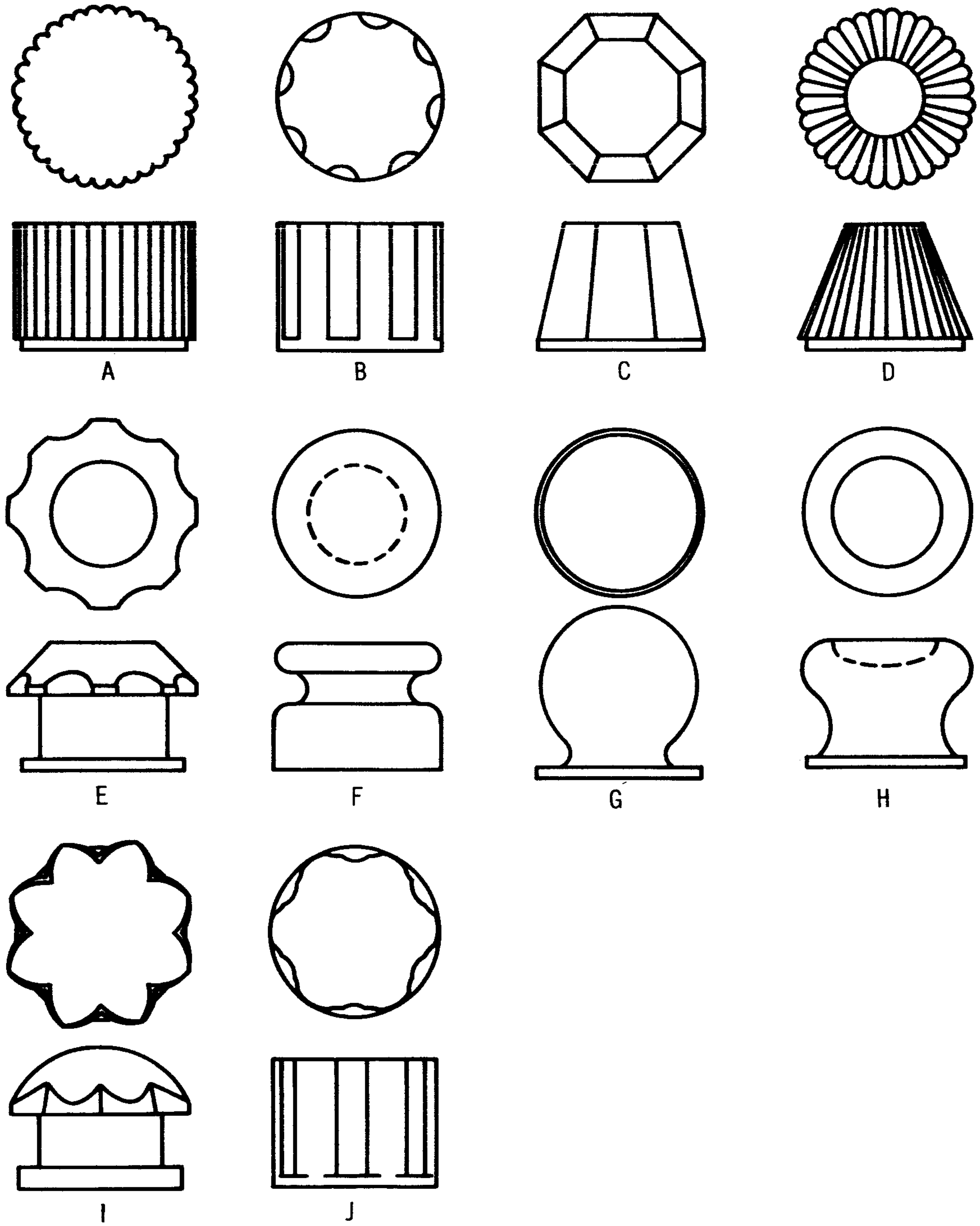


Figure 5. Class A knobs

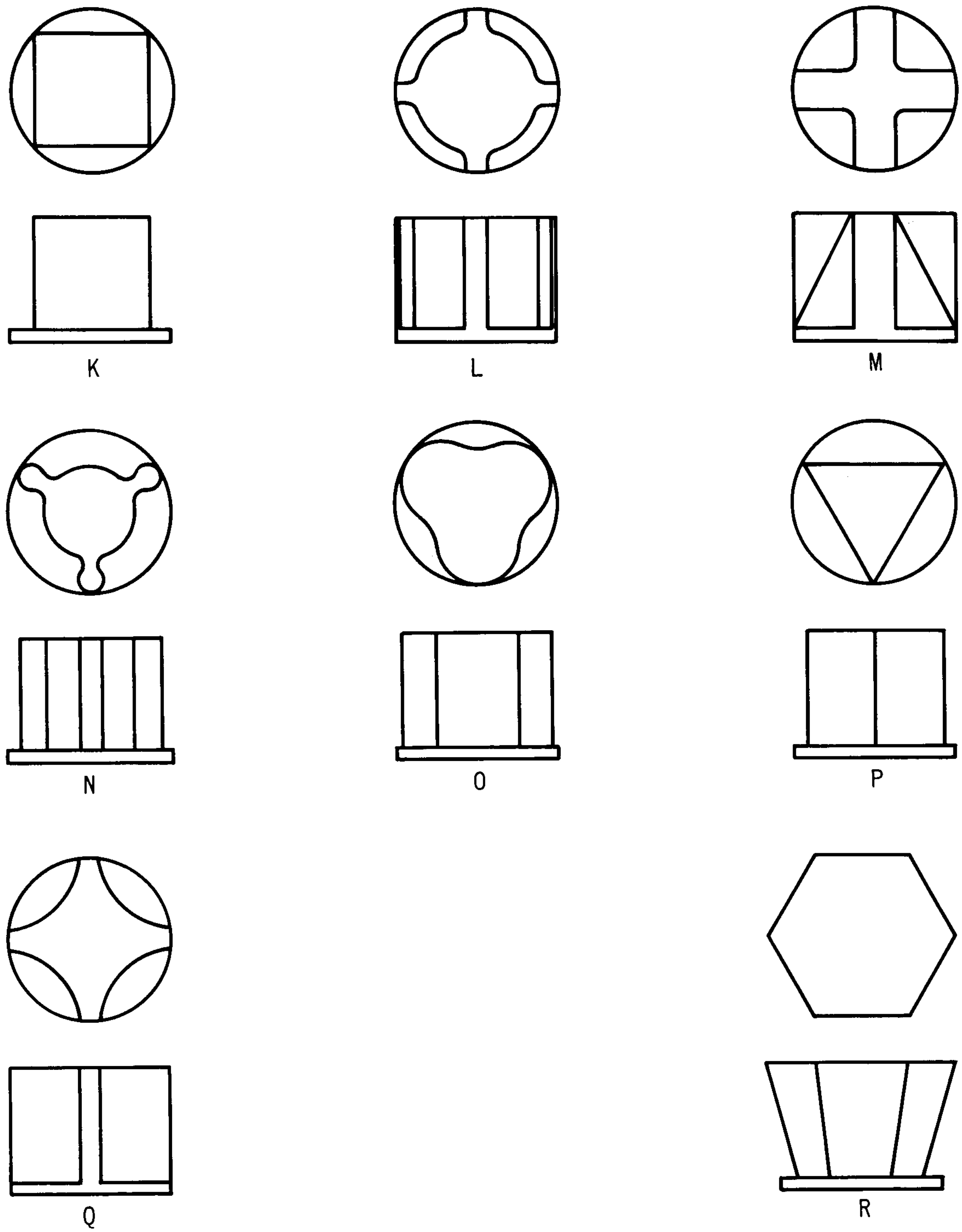


Figure 6. Class B knobs

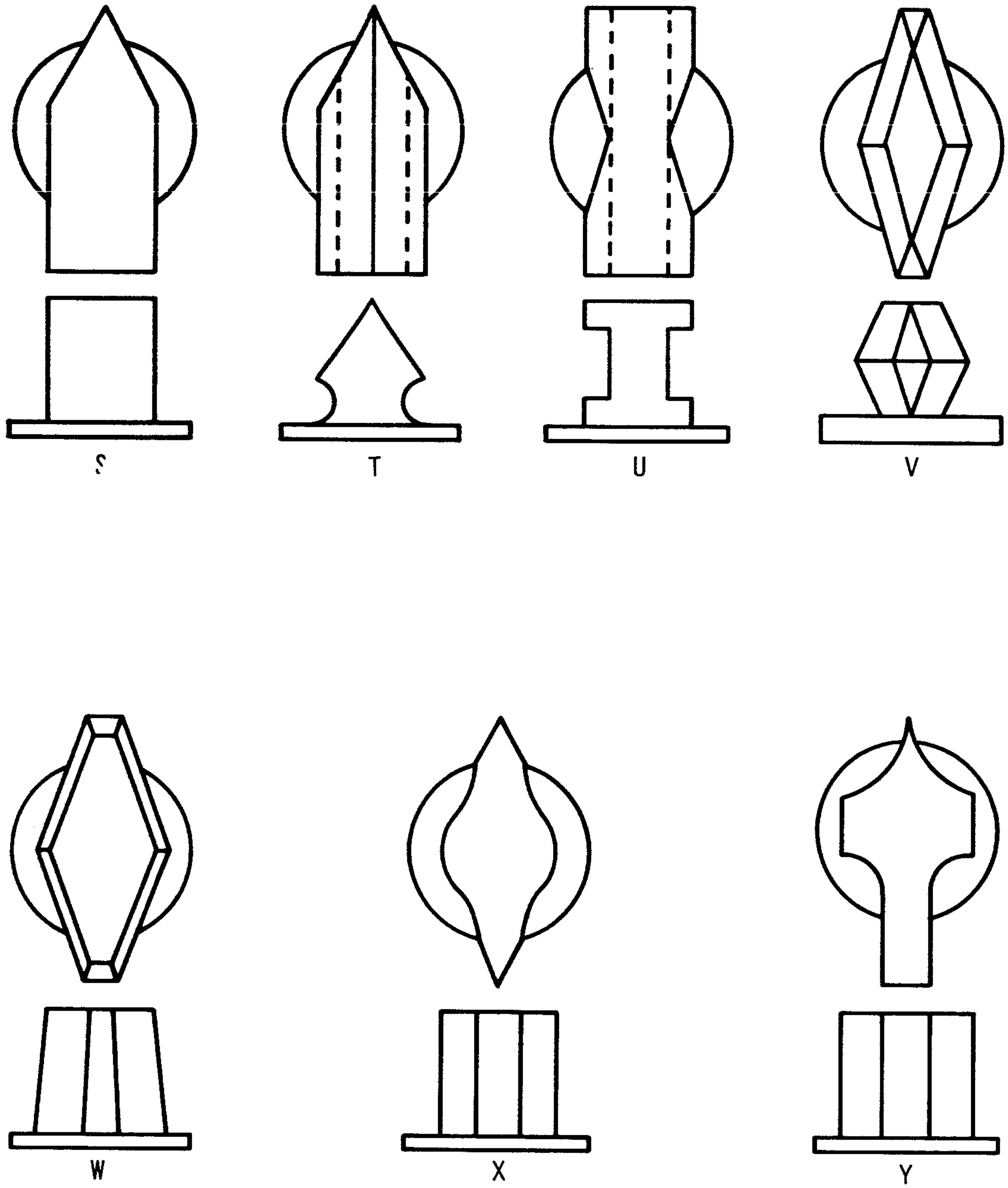


Figure 7. Class C Knobs

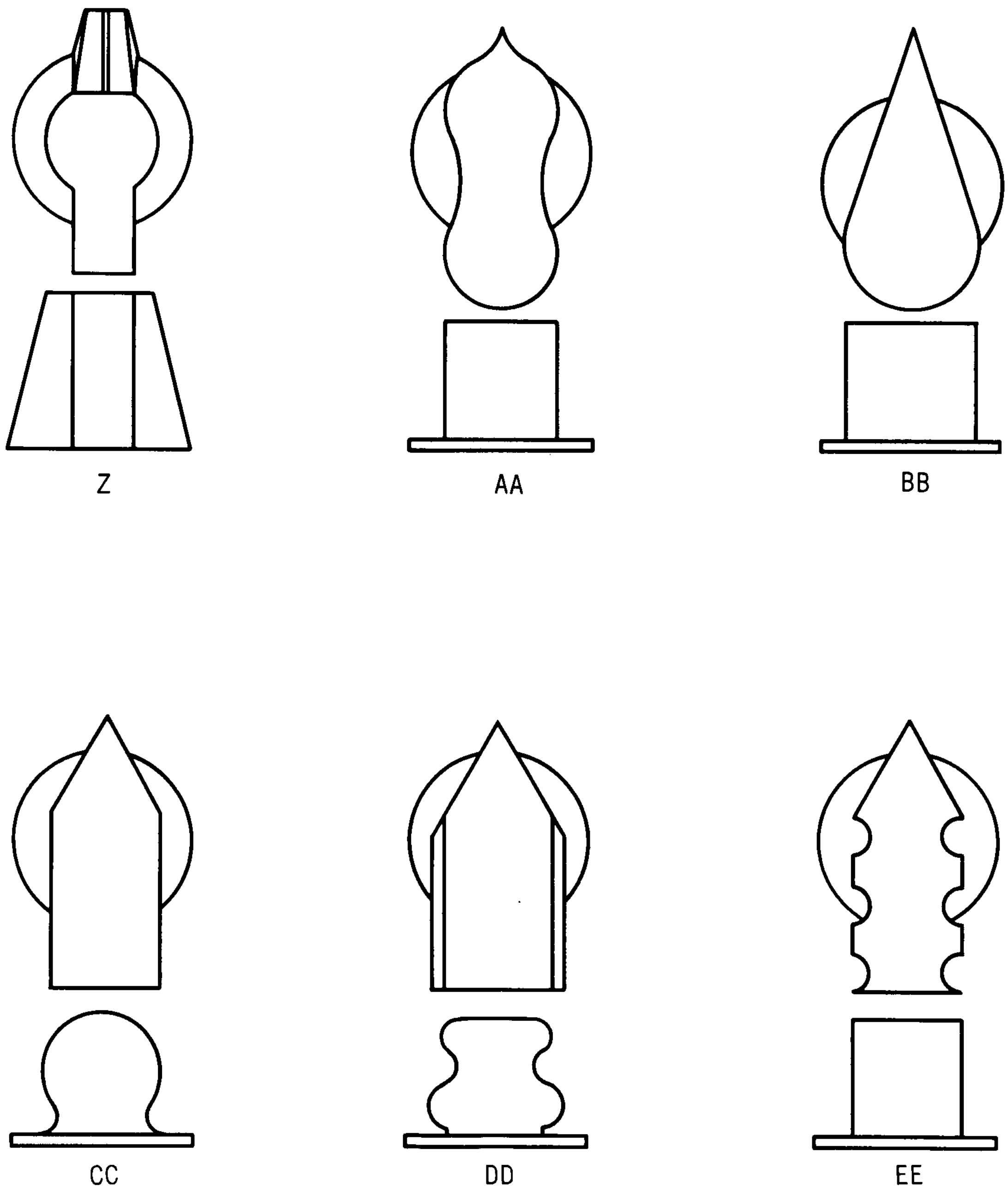


Figure 7a. Class C knobs

(b) Coded shapes shall be mounted and used in the upright position relative to the operator. The shapes lose their coded meaning in other positions. XR-S-2

(c) Coded shapes shall not be miniaturized. The coded meaning is lost when reduced in size. XR-S-2

5.1.6.5 Sizing coding. - Size coding will be avoided whenever possible. If necessary, use shall be limited to only two or three different sized controls--small, medium and large. XR-C-2

5.1.6.6 Mode-of-operation coding. - The effectiveness of this method is limited by three facts: (1) the operator must activate (or try to) the control in order to identify the control, (2) the operator must acquire experience in actual operation, and (3) other principles of control design may easily be violated. Mode-of-operation coding will be avoided whenever possible. If necessary, mode-of-operation coding shall be used with caution and only after such factors as training time, accidental actuation, etc. have been considered. XR-C-2

5.1.7 Control movement coding. - See Control-display 5.3 for details.

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DETAILED REQUIREMENTS
DISPLAY CRITERIA

DISPLAY CRITERIA 5.2

Display design considerations: consider,	5.2.1
Man has limited information storage and retrieval	5.2.1.(a)
Man has limited integration capabilities	5.2.1.(b)
Man has limited sensory capabilities	5.2.1.(c)
Design for operator	5.2.1.(d)
Selection and design criteria: consider,	5.2.2
Design for ease of reading	5.2.2.1
Omit unnecessary information	5.2.2.2
Present information in meaningful form	5.2.2.3
Define required feedback information	5.2.2.4
Present displayed information in logical format	5.2.2.5
Displays shall supply current information	5.2.2.6
Displays shall be error free	5.2.2.7
Labels shall be consistent from panel to panel	5.2.2.8
Usable under varying conditions; e.g., different illumination	5.2.2.9
Avoid use of special displays except for warning	5.2.2.10
Displays shall indicate when malfunctioning	5.2.2.11
Label correctly	5.2.2.12
Use proper units of measure	5.2.2.13
Be brief in label	5.2.2.14
Avoid abbreviations	5.2.2.15
Trade marks should not appear	5.2.2.16
Do not use abstract symbols	5.2.2.17
Types of displays: Select from the following:	5.2.3
Transilluminated indicators: simple versus legend	5.2.3.1
Simple indicators: consider,	5.2.3.1.1
Use when space precludes use of legend	5.2.3.1.1.1
Locate above associated control	5.2.3.1.1.1.(a)
To indicate control position	5.2.3.1.1.1.(b)
Brightness greater than ambient light	5.2.3.1.1.1.(c)

Determine if dimmer is required	5.2.3.1.1.1.(d)
Protect from high intensity light - shade	5.2.3.1.1.1.(e)
Flash rate: 3-5 flashes per second. Fail on	5.2.3.1.1.1.(f)
Design for easy bulb replacement	5.2.3.1.1.1.(g)
Legend indicators: consider,	5.2.3.1.2
Use in preference to simple indicators	5.2.3.1.2.1
Legend light lettering: consider,	5.2.3.1.2.2
Lettering legible whether illuminated or not	5.2.3.1.2.2.(a)
Marking minimum: 0.120 inch	5.2.3.1.2.2.(b)
Lettering: capitals in gothic style	5.2.3.1.2.2.(c)
Placement: horizontally, only three lines	5.2.3.1.2.2.(d)
Other:	5.2.3.1.2.3
Stacked legends shall be equally legible	5.2.3.1.2.3.(a)
Shall be legible within 30 degrees arc	5.2.3.1.2.3.(b)
Stacked legends shall be equally bright	5.2.3.1.2.3.(c)
Master lights: set apart; see text	5.2.3.1.3
Critical indicator location: within 30 degrees line of sight	5.2.3.1.4
Scale indicators: consider,	5.2.3.2
Application: to display qualitative or quantitative info	5.2.3.2.1
Color banding: avoid color banding if possible	5.2.3.2.2
Scale design: consider,	5.2.3.2.3
Magnitude increases clockwise	5.2.3.2.3.(a)
Minor marks shall be nine or less	5.2.3.2.3.(b)
Numerals shall have vertical orientation	5.2.3.2.3.(c)
Black on white background preferred	5.2.3.2.3.(d)
Pointer design: consider,	5.2.3.2.4
Pointer tip shall extend to graduation marks	5.2.3.2.4.(a)
Width at least width of finest graduation mark	5.2.3.2.4.(b)
Pointer shall be same color as scale marking	5.2.3.2.4.(c)
Pointer shall be close to scale surface	5.2.3.2.4.(d)
Pointer design shall be simple	5.2.3.2.4.(e)

Design requirements: consider,	5.2.3.5.2
Trace shall be visible and with good contrast	5.2.3.5.2.(a)
Interpretation aids shall be provided	5.2.3.5.2.(b)
Provide efficient take up and temporary storage	5.2.3.5.2.(c)
Time displays: consider,	5.2.3.6
Application: where time is required	5.2.3.6.1
Design requirements: consider,	5.2.3.6.2
Determine if elapsed time or time to go	5.2.3.6.2.(a)
Provide reset	5.2.3.6.2.(b)
If more than one clock, use consistent design	5.2.3.6.2.(c)
Cathode ray tubes: consider,	5.2.3.7
Application: to present electronic information	5.2.3.7.1
Design requirements: consider,	5.2.3.7.2
Provide adequate detail	5.2.3.7.2.(a)
Provide adequate contrast	5.2.3.7.2.(b)
Provide sealing	5.2.3.7.2.(c)
If coding is used, use distinctive codes	5.2.3.7.2.(d)
Other display types: see text	5.2.3.8
Labelling and marking criteria: consider,	5.2.4
Labelling association: above associated controls	5.2.4.1
Label spacing: spaced to avoid clutter	5.2.4.2
Label orientation: read horizontally, left to right	5.2.4.3
Label readability and legibility: consider,	5.2.4.4
Spacing between words: one letter width	5.2.4.4.(a)
Spacing between lines: 75 percent of letter height	5.2.4.4.(b)
Use arabic numerals	5.2.4.4.(c)
Labels should be parallel to viewer	5.2.4.4.(d)
Use upper case letters	5.2.4.4.(e)
Style: use simple gothic	5.2.4.4.(f)
Letters: black on white preferred	5.2.4.4.(g)
Use uniform stroke width	5.2.4.4.(h)
Provide adequate illumination	5.2.4.4.(i)

Panel labelling: consider,	5.2.4.5
Label size: see text	5.2.4.5.1
Panel label style: gothic	5.2.4.5.2
Panel label placement: see text	5.2.4.5.3
Functional group title: see text	5.2.4.5.4
Marking criteria: consider,	5.2.4.6
Graduation mark dimension: see text	5.2.4.6.2
Numerical progression markings: see text	5.2.4.6.3
Display coding: consider,	5.2.5
Display coding requirements: for ease of identification	5.2.5.1
Color coding: consider,	5.2.5.2
Color coding advantages:	5.2.5.2.1.1
Color can provide coding	5.2.5.2.1.1.(a)
Color is attention getting	5.2.5.2.1.1.(b)
Color provides an additional dimension	5.2.5.2.1.1.(c)
No training required	5.2.5.2.1.1.(d)
Self luminous colors can be used	5.2.5.2.1.1.(e)
Color coding disadvantages:	5.2.5.2.1.2
Distinguishing between hues can be difficult	5.2.5.2.1.2.(a)
8 percent males are color blind	5.2.5.2.1.2.(b)
Color lighting destroys color coding	5.2.5.2.1.2.(c)
Color phosphors deteriorate with age	5.2.5.2.1.2.(d)
Color changes under different lighting conditiions	5.2.5.2.1.2.(e)
Maintenance of color difficult	5.2.5.2.1.2.(f)
Number of available colors: only red, yellow, green and white	5.2.5.2.2
Color meaning: see text	5.2.5.2.3
Color aid in display search: useful	5.2.5.2.4
Position coding: consistency important	5.2.5.3
Shape coding: avoid	5.2.5.4

5.2 Display criteria.

5.2.1 Display design considerations. - A display is a pattern of sensory cues, usually visual or auditory, arranged and presented in a meaningful fashion to provide information concerning the functioning of the system or any of its parts. Display systems include such items as dials, cathode ray tubes, labels, coding, legend lights, and the interrelations and interaction between them. The lack of proper display or ambiguity in display can lead to delays or serious errors which can result in failure of the mission. (Fitts, 1; Woodson, 2) XR-S-2

(a) Man has a limited capability for information storage and information retrieval. The design engineer shall consider this limited memory capability in the design of displays. XR-C-1

(b) Man has limited mental capabilities, such as the limited ability to process multiple information concurrently and the limited ability to perform higher order integration functions. The designer shall consider these mental limitations in the design of displays. XR-C-1

(c) Man has limited sensory capabilities such as visual and hearing thresholds. The designer shall consider such limitations in the design of displays. XR-C-1

(d) The system designer is usually not the operator. The designer shall consider the information requirements needed by the operator and shall provide the displayed information in a form which the operator can interpret easily and with a minimum of error. XR-C-1

5.2.2 Selection and design criteria.

5.2.2.1 Ease of reading. - Displays shall be easily and quickly read for quantitative, qualitative or status information. See Labelling and marking criteria 5.2.4 for further details. (Sender, 3) XR-S-2

5.2.2.2 Accuracy of reading. - Displays shall provide all necessary discrimination and interpolation and be free of unnecessary information that may unduly complicate the reading and produce deleterious results. For example, if a valve gauge is to be read only to the nearest 10th, graduation markings to the 0.01 tolerance is needless. (Sender, 3) XR-S-2

5.2.2.3 Meaningful information form. - The displays shall present information in an immediately meaningful and useful form without requiring translation or calculation into other forms or units. Each additional step required to get useful information increases the probability of making errors. (Bamford, 4; Sender, 3) XR-S-2

5.2.2.4 Feedback information. - Feedback information will be provided to inform the operator when, how much and how far to move the control. The display shall provide true feedback of component status. For example, if the display is a legend indicator with the markings "LOX Tank Valve Opened", it should be the actual talk-back from the valve having been opened (possibly from a microswitch) not merely that the circuit to the valve has been energized. XR-C-2

5.2.2.5 Logical display layout. - Layout of displays shall be logical and systematic. For example, in a system objective, many subsystems objectives have to be achieved before there is a "go" condition. The subsystem status should not be displayed randomly or any place where there is space. Rather they should be in a logical pattern so as to permit the operator to become informed by a quick scanning. See Control-display interaction 5.3 for details on panel layout. (Sender, 3) XR-S-2

5.2.2.6 Minimum lag in status change feedback. - Displays shall provide the operator current information with minimum lag time. The direction, amount and rate of change shall be recognizable, as well as the initiation of change per se. (Sender, 3) XR-S-2

5.2.2.7 Error free features. - Displays shall be error free. This requirement depends upon the type of display instrument used. Anything that is psychologically not expected or consistent, or that which is ambiguous, shall be avoided whenever possible. Inherent confusion in multi-rotational and multi-pointer dials, direction of control-display reversal, clutter in spacing and marking are examples. (Sender, 3) XR-S-2

5.2.2.8 Consistency of placement. - Placement of functional labels and legends relating to displays shall be consistent from panel to panel throughout the system. See Control-display interaction 5.3. XR-S-2

5.2.2.9 Usable within specified operating conditions. - The display shall be usable through the entire range of anticipated operating conditions, such as variations in illumination, temperature and vibration. Unusual conditions which may be imposed upon the operator, such as physiological and psychological shock shall be considered. (Sender, 3) XR-S-2

5.2.2.10 Special displays. - Special displays shall not be unnecessarily distracting. For example, warning signals shall not be distracting any longer than is necessary to attract attention and to apply appropriate corrective action. (Sender, 3) XR-S-2

5.2.2.11 Failure of displays. - Displays shall have provisions to indicate when it is not functioning, such as a press-to-test feature to check. Failure of display circuitry shall not cause an erroneous reading or cause failure in the equipment associated with the display. (Sender, 3) XR-S-2

5.2.2.12 Function label. - Displays shall be functionally labelled in terms of what is being displayed and controlled, not the control and display itself. Unnecessary words shall be avoided. (Baker, 5) XR-C-1 For example:

Temperature Malfunction	INSTEAD OF	Thermometer Indicator light

5.2.2.13 Units of measurement. - In addition to the function label, the units of measurement shall be applied when required for viewer comprehension. For example: (Baker, 5) XR-C-1

1. Degrees
2. Feet
3. Percent
4. Minutes
5. Psia or psig

5.2.2.14 Brevity. - The display shall have labels and units of measurement that is as brief as possible, but fully comprehensible to the operator. Complete words shall be used unless space limitation necessitates the use of abbreviation. (Baker, 5; Murdock, 6) XR-C-1

5.2.2.15 Abbreviation. - Abbreviation shall be used only if it is as easily interpretable or as common as the word itself. See MIL-STD-12 and ANA Bulletin 261. XR-C-1

5.2.2.16 Trade marks. - Manufacturers' names, labels, trade marks, etc, should not appear on the visible portions of the display. This applies especially to gauges and meters where space is limited. (Baker, 5) XR-A-2

5.2.2.17 Abstract symbols. - Abstract symbols such as the Greek alphabet or squares will not be used. Common symbols such as percent or plus-minus are acceptable. (Baker, 5) XR-C-2

5.2.3 Types of displays.

5.2.3.1 Transilluminated indicators. - Transilluminated indicators shall be of two general types: simple-type indicators (pilot lights, bulls-eye lights, jewel lights) and single and multiple legend indicators.

5.2.3.1.1 Simple type indicator lights.

5.2.3.1.1.1 Application. - Simple indicator lights will be used when design considerations preclude the use of legend lights. If the simple indicator light cannot be identified easily by labelling or design, then a legend light shall be used. XR-C-2

(a) Unless space prohibits, the indicator lights shall be located above their associated control. XR-C-2

(b) If a control position cannot be made apparent by labelling or design, then an indicator light shall be used. XR-C-2

(c) The brightness of indicator lights shall be noticeably greater than the ambient illumination level. They shall be of sufficient contrast with their surroundings to provide ready detection. XR-C-1

(d) A diming control shall be provided for panels subjected to extreme variation in illumination. XR-C-1

(e) Provisions shall be made to prevent sunlight, or other high intensity light sources, from making an indicating light appear illuminated. XR-C-1

(f) The flash rate for flashing warning lights shall be from 3 to 5 flashes per second with on time being equal to off time. The indicator shall be so designed that it glows steadily if the flasher device fails when energized. (Pratt, 7) XR-S-2

(g) The indicating light shall be designed for bulb replacement from the front of the display panel, without the use of tools. XR-C-2

5.2.3.1.2 Legend indicator lights.

5.2.3.1.2.1 Application. - Legend lights shall be used in preference to simple indicator lights unless design considerations demand otherwise. XR-C-1

5.2.3.1.2.2 Legend light lettering.

(a) Lettering will be legible whether the display is self illuminated or not. This does not apply to stacked displays (one legend stacked behind the other). XR-C-2

(b) Markings on legend plates will be a minimum of 0.120 inch in height. Maximum height shall be determined by the procuring activity. XR-C-2

(c) Lettering shall be all capitals and Gothic in style. (Bendix, 8) See Labelling and marking criteria 5.2.4. XR-S-2

(d) Only horizontal lettering shall be used, and the number of lines per legend plate shall not exceed three. See Labelling and marking criteria 5.2.4 and Control-display interaction panel layout for more details. XR-S-2

5.2.3.1.2.3 Other considerations.

(a) Indicating lights having legend plates stacked one behind the other shall be designed so that the rearward legends are clearly legible when energized. XR-C-2

(b) The rearward legend plates on stacked multiple-legend lights shall be placed so that the entire legend is observable within 15 degrees to each side of the normal line of sight. XR-C-2

(c) Legend plates on multiple-legend indicating lights shall be equal in brightness. Rearward legends on stacked displays shall have contrast (between the legend and its background) that is equal to the front legends. XR-C-2

5.2.3.1.3 Master lights. - Master caution, master warning, and summation lights used to indicate the condition of an entire subsystem shall be set apart from the lights which show the status of the subsystem component. This may be accomplished by using a larger size light, positioned coding, or other visual aids. (Siegel, 9) XR-S-2

5.2.3.1.4 Critical indicator location. - For critical functions, indicators shall be located within 30 degrees of the operator's normal line of sight. (Enoch, 10; Anderson, 11) XR-S-2

5.2.3.1.5 Brightness. - See Illumination 5.6 for details.

5.2.3.1.6 Coding. - See Coding 5.2.5.

5.2.3.2 Scale indicators.

5.2.3.2.1 Application. - Scale indicators shall be used to display qualitative or quantitative information in combination with trend and direction of motion information. Scale indicators shall also be used when quantitative information is to be displayed, and when the speed and accuracy of response requirements do not dictate the use of printers or counters. XR-A-2

5.2.3.2.2 Color banding (zone marking). - Color marking (banding) should be used to facilitate the scale indicator reading where quantitative values fall within an expected range. XR-C-2

(a) Color banding shall be used only for a limited number of critical instruments. XR-C-2

(b) Color banding shall be used only when the instrument (dial) is white light illuminated. XR-C-2

(c) If banding is required under non-white illumination, a chromatic shading (eg, hash markings) may be used. (Smith, 12, 13) See figure 8. XR-S-2

(d) For extremely critical functions, eg, over pressurization, a warning light will be provided in association with banding (critical zone). XR-C-2

(e) Color banding shall indicate various operating conditions, eg, red is danger, yellow is caution and green is normal. See Color coding 5.2.5.2 for details. XR-S-2

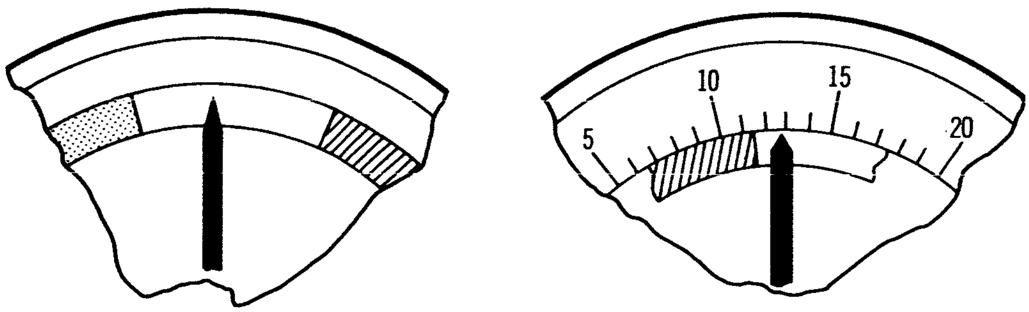


Figure 8. Example of dial banding (zone marking)

5.2.3.2.3 Scale design. - Scale design shall be in accordance with the following requirements. See Labelling 5.2.4 for other details.

(a) Magnitude of scale values shall increase clockwise, from left to right, or from bottom to top. See Control-display interaction 5.3 for other details. XR-S-2

(b) The number of minor graduation marks within the major scale intervals shall be nine or less. (Kappauf, 14, 15) See Labelling 5.2.4.6 XR-S-2

(c) On moving scales all numerals shall have vertical orientation at the reading position. (Mengelkoch, 16, 17, 18) XR-S-2

(d) Numerals and graduation marks shall be black on white background or white on black background except where it is necessary to distinguish one scale from multiple scales or a portion of one scale on a single indicator. In such cases, the background may be color coded. See Labelling 5.2.4 and Color coding 5.2.3.2.2.

(e) Scale graduation. - See Labelling 5.2.4.6.

5.2.3.2.4 Pointer design.

(a) The pointer tip shall extend to, but not overlap, the index or graduation marks. (Lee, 19; Morgan, 20; Woodson, 2)

(b) The width of the pointer tip shall be the same as the finest graduation marking. (Kappauf, 14, 15) XR-S-3

(c) Except for special cases, the entire length of the pointer shall be the same color as the scale marking. (Loucks, 21) XR-S-3

(d) The pointer shall be as close to the scale surface as possible to minimize parallax. (Morgan, 20; Woodson, 2) XR-S-2

(e) The pointer design shall be simple, eg, shafted and V-shaped are better than the heart-shaped pointer. (Bartlett 22; White 23) See figure 9. XR-S-2

5.2.3.2.5 Types of scale indicators. - See table IV for summary of usage. (Christensen, 24, 25; Cohen, 26; Connell, 27; Elkin, 28; Thomas, 29; Warrick, 30; White, 23) See Control-display interaction 5.3 for further details.

5.2.3.2.5.1 Circular fixed scale (moving pointer). - A circular fixed scale with a moving pointer is preferred for most applications requiring scale indicators and will be used when applicable. Specific design requirements shall be as follows: See Control-display interaction 5.3 for further details.

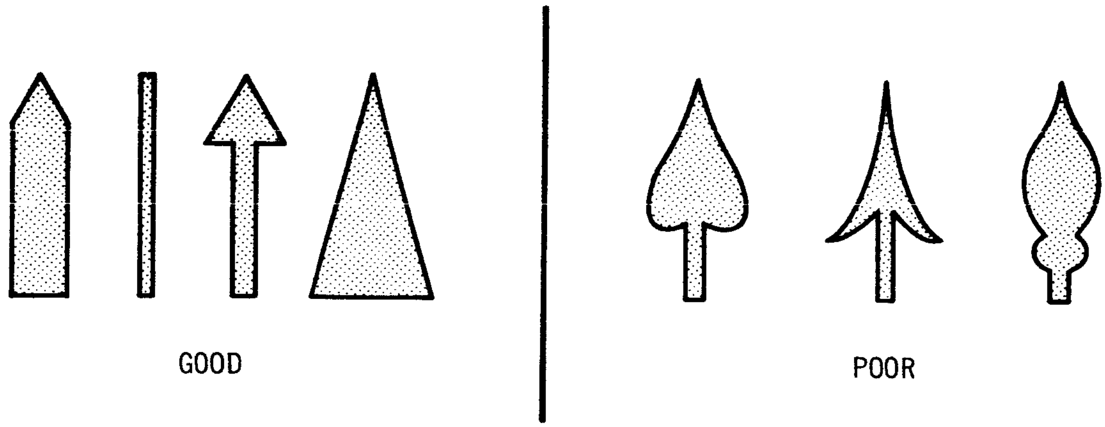


Figure 9. Pointer design

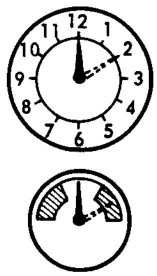
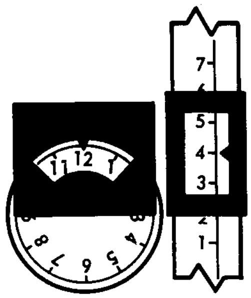
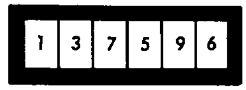
(a) In cases where positive and negative values are being displayed on the same circular scale, the zero shall be located at the 12 o'clock position (preferred) or the 9 o'clock position. The positive values shall increase with clockwise movement of the pointer, and the negative values shall increase with counterclockwise movement. XR-S-2

(b) Clockwise movement of the pointer shall result from clockwise movement of the associated rotary control or movement forward, upward, or to the right of an associated lever or switch. XR-S-2

(c) Counterclockwise movement of the pointer shall result from counterclockwise movement of the associated rotary control or movement backward, downward, or to the left of an associated lever or switch. XR-S-2

Table IV.

Recommended indicators according to use

METHOD OF USE	MOVING POINTER	MOVING SCALE	COUNTER
			
1. QUANTITATIVE READING	FAIR	FAIR	GOOD MINIMUM TIME AND ERROR IN OBTAINING EXACT NUMERICAL VALUE.
2. QUALITATIVE AND CHECK READING	GOOD LOCATION OF POINTER EASILY DETECTED. NUMBERS AND SCALE NEED NOT BE READ. CHANGE IN POSITION EASILY DETECTED. EASY FOR REQUIRED CHECK READING.	POOR DIFFICULT TO JUDGE DIRECTION AND MAGNITUDE OF DEVIATION WITHOUT READING NUMBERS AND SCALE.	POOR NUMBERS MUST BE READ POSITION CHANGES NOT EASILY DETECTED.
3. SETTING	GOOD SIMPLE AND DIRECT RELATION OF POINTER MOTION TO MOTION OF SETTING KNOB. POINTER POSITION CHANGE AIDS MONITORING.	FAIR SOMEWHAT AMBIGUOUS RELATION TO MOTION OF SETTING KNOB. NO POINTER POSITION CHANGE TO AID MONITORING. NOT READABLE DURING RAPID SETTING.	GOOD MOST ACCURATE MONITORING OF NUMERICAL SETTING KNOB. LESS DIRECT THAN FOR MOVING POINTER. NOT READ DURING RAPID SETTING.
4. COMMENTS	REQUIRES GREATEST EXPOSED AREA ON PANEL. SCALE LENGTH LIMITED UNLESS MULTIPLE POINTERS ARE USED.	OFFERS SAVING OF PANEL SPACE. ONLY SMALL SECTION OF SCALE NEED BE EXPOSED. LONG SCALE POSSIBLE BY USE OF TAPE.	MOST ECONOMICAL OF SPACE SCALE LENGTH LIMITED ONLY BY NUMBER OF COUNTER DRUMS.

(d) There shall be a break between the two ends of the scale. The break should be at least 1.5 times the width of the major scale intervals except on multi-revolution instruments such as the clock. XR-C-2

(e) Numerals shall be placed outside of the scale graduation marks unless such placement necessitates constriction of the scale. Where space is limited, the numerals may be placed inside the scale graduation marks. XR-S-3

5.2.3.2.5.2 Fixed scale (moving pointer). - The fixed scale with moving pointer may be either vertical or horizontal. Specific design requirements shall be as follows: See Control-display interaction 5.3 for further details.

(a) Magnitude of scale reading shall increase with movement of the pointer upward or to the right. XR-S-2

(b) When positive and negative values are to be displayed on the same scale, the positive values shall increase with movement of the pointer upward or to the right, and negative values shall increase with movement of the pointer downward or to the left. XR-S-2

(c) Movement of the pointer upward or to the right shall result from the clockwise movement of an associated rotary control or movement forward, upward or to the right of an associated lever or switch. Movement of the pointer downward or to the left shall result from the counterclockwise movement of an associated rotary control or movement backward, downward, or to the left of an associated lever or switch. XR-S-2

(d) Scale numbers shall be placed on the side of the graduation marks away from the pointer and shall be located at the right of vertical scales and at the bottom of horizontal scales. XR-C-3

5.2.3.2.5.3 Circular moving scale (fixed pointer). - The circular moving scale with fixed pointer is not recommended for general use and shall not be used without approval of the procuring activity. The following requirements shall apply if this design is utilized: See Control-display interaction 5.3 for further details. XR-S-2

(a) If the associated control has a direct effect on behavior of the equipment being controlled, the scale shall rotate counterclockwise with clockwise movement of an associated rotary control or movement forward, upward, or to the right of a lever or switch. XR-C-2

(b) If the associated control has no direct effect on the behavior of the equipment being controlled, the scale and its associated rotary control shall rotate counterclockwise. XR-C-2

(c) The pointer or lubber line position shall be at 12 o'clock for right-left directional information and at 9 o'clock for up-down information. For quantitative information either position may be used. XR-S-2

(d) If the display is to be used for setting purposes, the unused portion of the scale shall be covered. The open window of the scale shall be large enough to permit at least one numbered graduation mark to appear at each side of any selected setting. XR-C-2

5.2.3.2.5.4 Straight moving scale (fixed pointer). - The straight moving scale with fixed pointer is not recommended for general use and shall not be used without approval of the procuring activity. The following requirements shall apply if this design is utilized. See Control-display interaction 5.3 for further details. XR-S-2

(a) The pointer shall be located on the right side of vertical scales or at the bottom of horizontal scales. XR-C-2

(b) The scale numbers shall be placed on the side of the graduation marks opposite the pointer. XR-C-2

(c) The direction of motion relationship between the display and the associated controls, levers, or switches shall be the same as for the circular moving scale with fixed pointer. XR-S-2

5.2.3.3 Digital readout indicators.

5.2.3.3.1 Application. - Digital readout indicators shall be used when precise quantitative information is required. Where precise quantitative information is not required, circular or linear fixed scale shall be used. See 5.2.3.2.5.1 and 5.2.3.2.5.2. Digital readout indicators require very little searching interpretation such as in pointer scale relationship and can be read rapidly and precisely. There are several kinds of digital readout indicators. XR-C-2

5.2.3.3.2 Counter wheels.

5.2.3.3.2.1 Design requirements.

(a) The numerals shall change by snap action. XR-C-2

(b) Numerals shall have a height to width ratio of 1.5 to 1, and space between the numerals shall be not more than half the numeral width. See Labelling 5.2.4 for details. XR-S-3

(c) Counters shall have white numerals on a lusterless black background. See Legibility under 5.2.4.4. XR-A-3

(d) Counters shall be mounted to maximize viewing angle and minimize parallax and shadows. XR-C-2

(e) Counters shall be mounted horizontally. See 5.2.4.3 and Control-display interaction 5.3 for details. XR-S-2

(f) Counters used to indicate sequencing of equipment shall be designed with automatic or manual change controls for resetting. XR-C-2

(g) The manual reset knob shall require clockwise rotation for resetting or increasing the counter indication. See Control-display interaction 5.3 for details. XR-S-2

5.2.3.3.3 Other type indicators. - There are other types of indicators that have gained wide use by the industry. Several types are listed below. Each has its desirable and undesirable features; they shall be considered in the selection of digital readout displays (Fried,31; Lincoln, 32; Woodson, 2)

(a) Rear projection type. - Different character configuration can be employed, thus allowing for optimization. In viewing distance and viewing angle, this type is superior to most other types of indicators. Large mounting area is required, especially if used in multiple. Character heights to about 3 3/4 inches are available; larger ones could easily be devised. Response rate depends on switching. See figure 10. XR-C-2

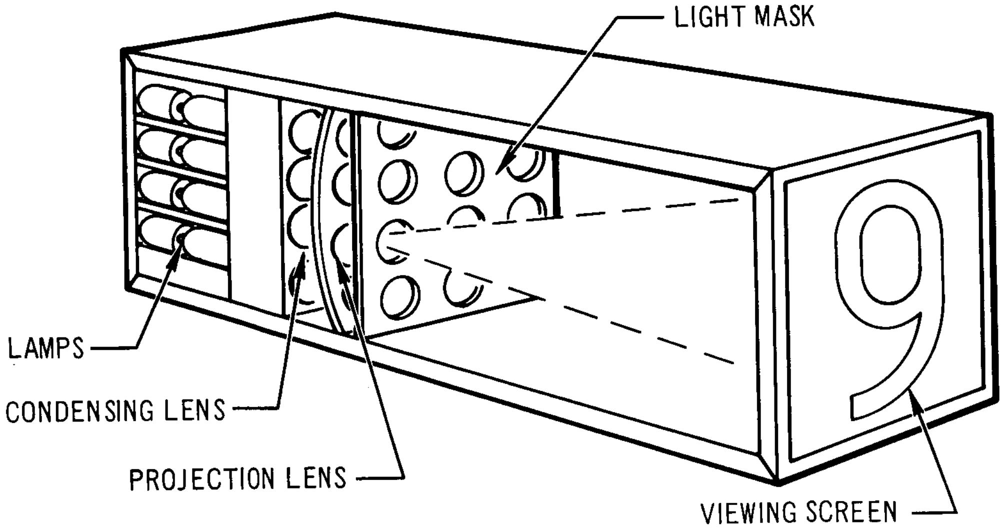


Figure 10. Rear projection type indicator

(b) Edge-lighted type. - Character configuration is reasonably good; viewing angle is limited due to the tunnel effect of the stacked plates. Primary disadvantages are: ambient illumination should be relatively low to maintain good contrast; and viewing distance is limited to about 30 feet, although greater distances could be obtained with special engraving techniques. See figure 11. XR-C-2

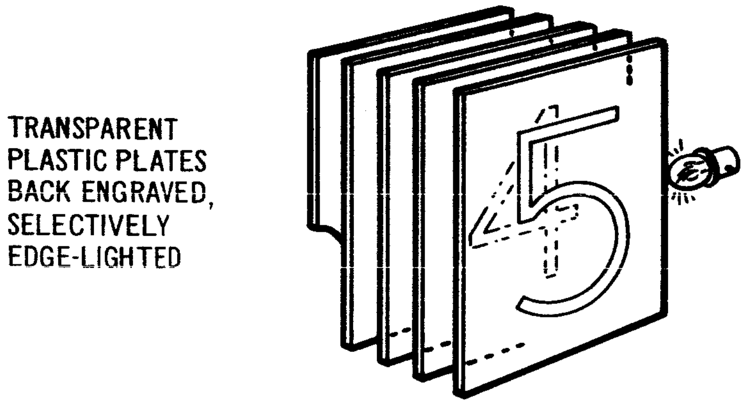


Figure 11. Edge-lighted type indicator

(c) Electronic register-tubes. - Characteristics are similar to the edge-lighted displays. These neon glow displays are good to many hours and can be read up to 30 feet and 120 degree cone. A response rate as low as 10 microseconds is possible. Care must be taken to shield the tube from ambient light to avoid spectral reflection from the curved surface of the tube. In the case of component failure, it is difficult to identify number. See figure 12. XR-C-2

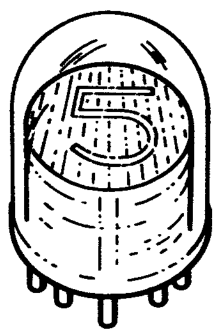


Figure 12. Electronic register tubes indicator

(d) Matrix displays. - A variety of displays are available which form characters from prepared matrices. Some use lamps banked in mosaic patterns; others use electro-luminescent sections to build up a given character. In general, all such displays suffer in terms of character legibility. Legibility requirements shall be considered before using. In the case of component failure, it is difficult to identify number. See figure 13. XR-C-2

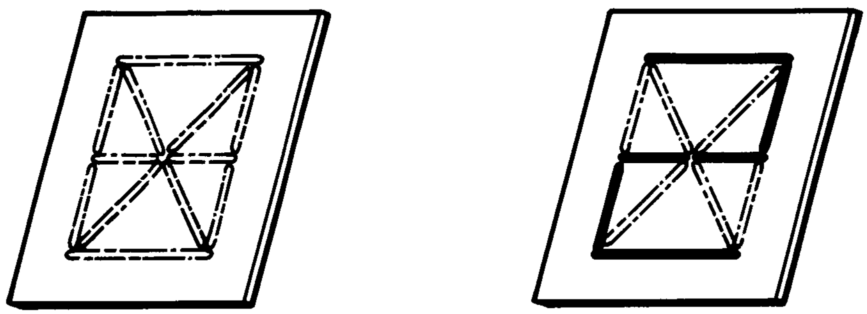


Figure 13. Matrix display indicator

(e) Decimal arrays. - Not generally recommended, owing to reading difficulty and potential transposition error by the observer. See figure 14. XR-C-2

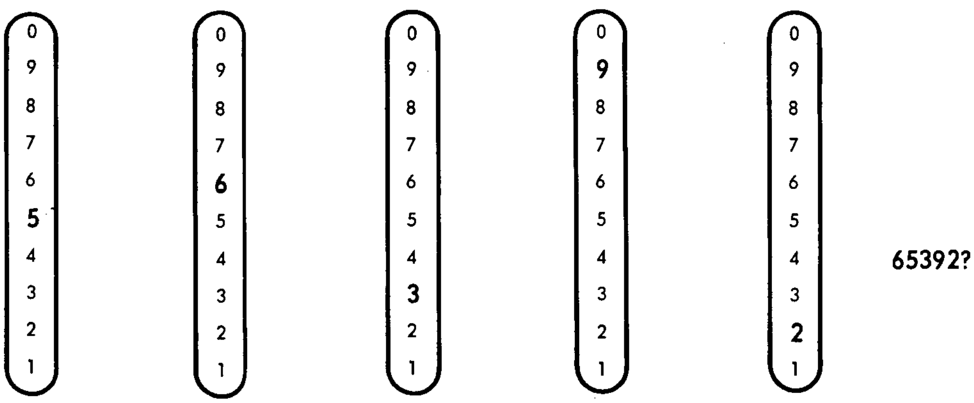


Figure 14. Decimal array indicator

5.2.3.4 Printers.

5.2.3.4.1 Application. - Printers shall be used when a permanent record of quantitative data is desired. XR-C-2

5.2.3.4.2 Design requirements.

(a) Where quantitative data must be immediately used, printed information shall be presented in a direct usable form with no requirement for conversion, transformation, or decoding. XR-C-2

(b) The printer shall be designed to permit quick, easy insertion and removal of printing materials. XR-C-2

(c) Positive indication shall be given of the remaining supply of printing material (paper, ink). XR-C-2

(d) There shall be provisions for efficient take-up and temporary storage of the printed material. XR-C-2

(e) If an operator is required to write on the paper while on the printer, access openings shall be provided. XR-C-2

5.2.3.5 Plotters.

5.2.3.5.1 Application. - Plotters shall be used to permanently record desired graphic data. XR-C-2

5.2.3.5.2 Design requirements.

(a) The plotting point and trace shall be readily visible to the operator with adequate contrast between the trace and its background. XR-C-2

(b) When interpretation of graphic data is required, adequate instructions and aids shall be provided. XR-C-2

(c) Provisions shall be made for efficient take-up and temporary storage of the printed material. XR-C-2

5.2.3.6 Time displays.

5.2.3.6.1 Application. - Visual time displays shall be used when an operator is required to use time as a basis for decision or action. XR-C-2

5.2.3.6.2 Design requirements.

(a) Time shall be displayed in a form appropriate to the application, such as elapsed time or time to go, and appropriately labelled. XR-C-2

(b) Rapid reset capability should be provided. XR-C-2

(c) When two or more time displays are required for the same application, the designs shall be consistent. (Sender, 3) XR-S-2

5.2.3.7 Cathode ray tubes.

5.2.3.7.1 Application. - Cathode ray tubes or scopes are used for presenting information electronically, usually real time data. XR-C-2

5.2.3.7.2 Design requirements.

(a) The display shall resolve as much detail as is required for adequate interpretation of the displayed information. (Bowen, 33) XR-C-2

(b) The brightness contrast relationship between the signal and background shall be sufficiently high to afford good visibility. (Bowen, 33) See Illumination 5.6. XR-S-2

(c) The design of scales and other quantitative data from the display should be such as to maximize accuracy and speed. XR-C-2

(d) If information is to be coded, the coding method shall provide a display that is easily interpreted. (Bowen, 33) XR-S-2

5.2.3.8 Other display types. - The more recent and more sophisticated types of displays have not been examined. Present literature has lagged behind the state of the art and many display concepts are proprietary designs. The designer is encouraged to use the more recent display devices. These devices shall be designed and used following the criteria set forth at the beginning of the section.

A partial list of recent display systems that can be used are:

(a) Electroluminescence

(b) Three dimensional

(c) Predictor analog

(d) Predictor instruments

(e) Multi-functional

5.2.4 Labelling and marking criteria. - The effectiveness of controls and displays and their interaction depend in a large part upon proper labelling and marking. The following criteria shall be used:

5.2.4.1 Labelling association. - Labels shall be centered immediately above their associated controls so they cannot be disassociated. See Panel label 5.2.4.5 and Control-display interaction 5.3 for further details. XR-S-2

5.2.4.2 Label spacing. - Labels shall be spaced so that the panel will not appear cluttered. XR-C-2

NOTE:
The importance of an uncluttered panel is not merely that clutter detracts from the "look"; clutter adds confusion. Appropriate spacing (through proper selection of words, proper layout of components, etc.) minimizes possible confusion.

5.2.4.3 Label orientation. - Labels shall read horizontally and be oriented to read from left to right. XR-S-2

NOTE:
Culturally we have been taught to read from left to right in a horizontal sequence. This is the dominant orientation to all types of reading. Studies have shown that, compared to the vertical orientation, the horizontal orientation is more readily perceived and is easier to read. This orientation becomes more deeply developed as one becomes more educated. (Foley, 34; Forgay, 35; Heron, 36; Kimura, 37; Lincoln, 38; Miskin, 39; Schackel, 40; Thomas, 41) Vertical reading has been found to be about 50 per cent slower than horizontal. While there was improvement with

practice for the vertical reading, the proficiency of horizontal reading was never achieved. (Tinker, 42) Vertical orientation may be used only in special cases such as when space restriction does not permit horizontal labelling. (Kearns, 43)

5.2.4.4 Label readability and legibility. - Labels shall be readable. The following shall apply for optimum readability.

(a) Spacing between words shall be one letter width (M or W). XR-A-2

(b) The space between the bottom of a line of lettering and the top of the next line shall be a minimum 75 percent of letter height. XR-A-2

(c) Arabic numerals shall be preferred over Roman numerals. (Perry, 44) XR-S-2

(d) Labels shall be located on surfaces parallel to the viewer whenever possible. If slanting surface is required, it shall be less than 45 degrees away from the viewer. (Tinker, 45, 46) XR-S-2

(e) Upper case (capital) letters shall be used for panel lables. (Tinker, 47) XR-S-2

(f) Styles of letter characters shall be simple and unadorned. (Bendix, 8; Breland, 48; Crook, 49, 50; Forbes, 51; Preston, 52; Sanford, 53; Schaprio, 54) XR-S-2

(g) Letters shall be black on a light background (preferred) or white on a dark background (less preferred). Whichever method is used, it shall be used consistently. This does not hold for emergency indicators. For criteria on glare, see 5.6.1.4 (Berger, 55, 56; Holmes, 57; Paterson, 58; Saul, 59; Sumner, 60; Taylor, 61; Tinker, 62, 63) XR-S-2

(h) The labels on panels shall be of uniform stroke width. (Bendix, 8) XR-S-2

(i) Illumination shall be adequate for optimum readability and legibility. (Kuntz, 64) XR-S-2

5.2.4.5 Panel labelling. - Panel labelling criteria shall be as follows:

5.2.4.5.1 Label size. - Size of panel label shall be as in table V. (Bendix, 8; Berger, 55, 56; Glanville, 65) XR-S-3

Table V.

Panel label size

Purpose	Nominal height	Nominal width
Panel title	1/4 ± 1/64 inches	all 1:5 ratio to height
Subdivision or functional group title	3/16 ± 1/64 inches	
Position of control and single control title	1/8 ± 1/64 inches	
Legend and light indicator	1/8 ± 1/64 inches	

5.2.4.5.2 Panel label style. - Style of labels shall be uniform for the system. It shall be simple and unadorned. The modern Gothic style is suitable. (Gothic is defined as any character which is of uniform stroke width and the stroke terminates without decoration or embellishments called "serif"). (Bendix, 8) See 5.2.4.4 for other details. XR-S-2

5.2.4.5.3 Panel label placement. - The placement of panel label shall conform to placement shown in figure 15. XR-A-2

5.2.4.5.4 Functional group title. - Functional group title positioning shall consider the following factors: See figure 15.

(a) Controls and displays which are functionally grouped together shall have a group title. XR-C-2

(b) The group title shall be placed centrally above the control and display group. XR-C-2

(c) Bracketing shall be used when it clearly identifies a subsystem unit. See figure 16. XR-C-2

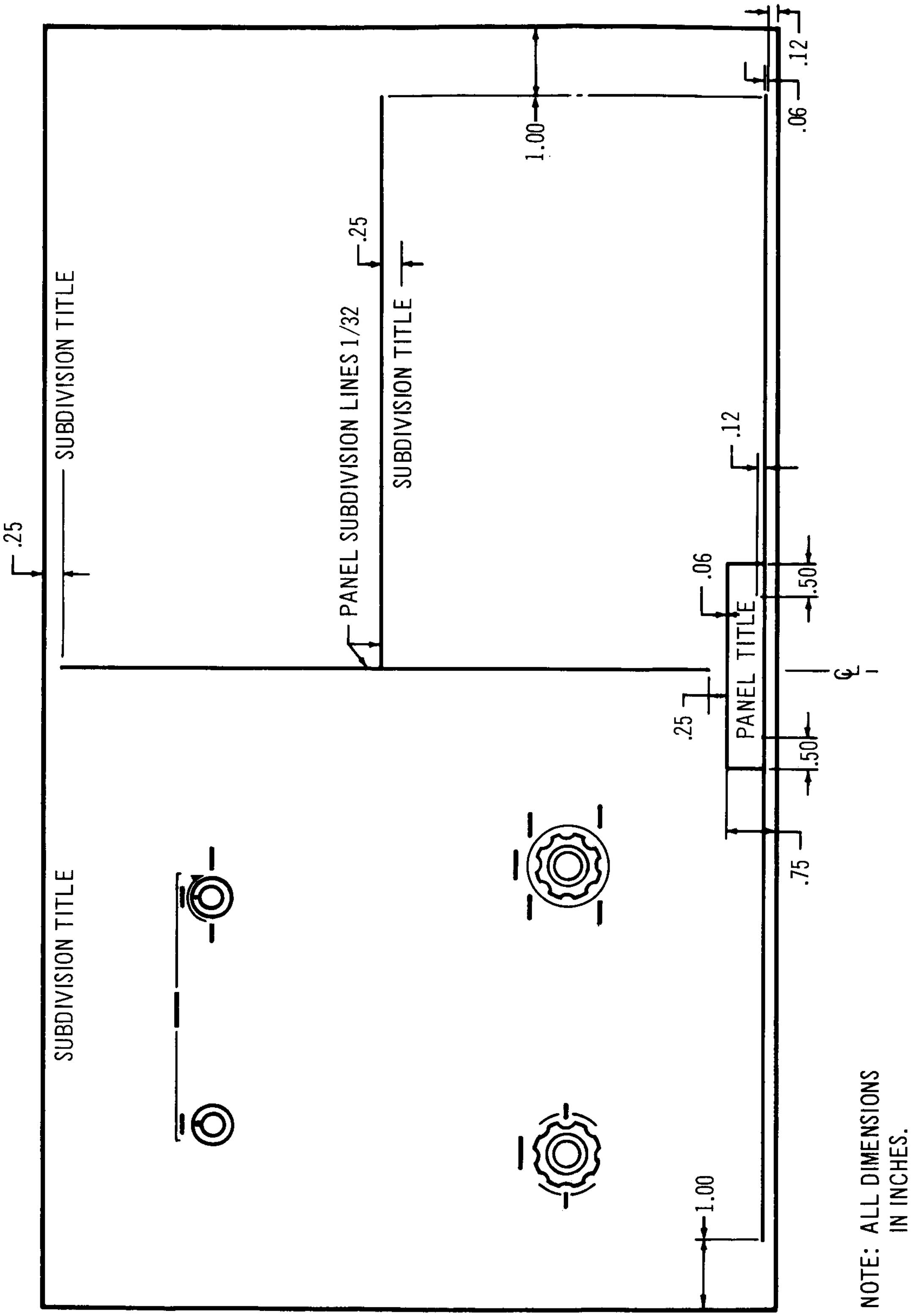


Figure 15. Panel label placement

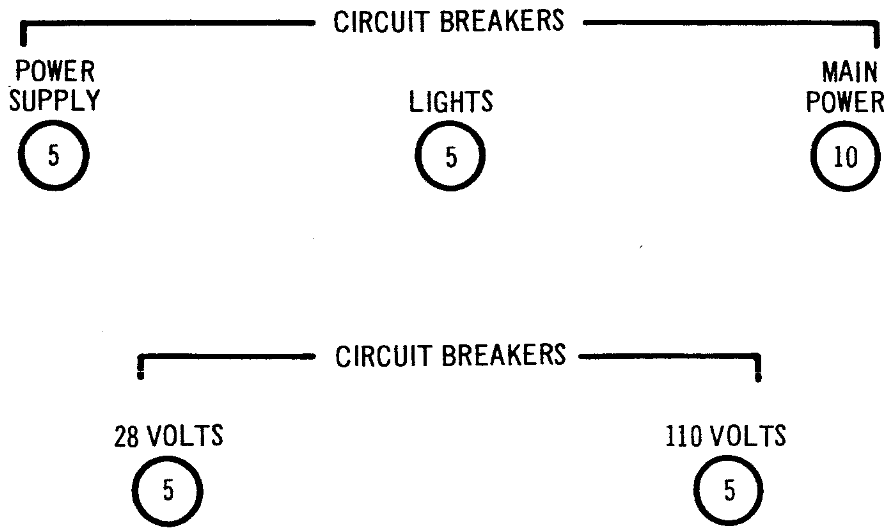


Figure 16. Functional group title and bracketing

5.2.4.6 Marking criteria.

5.2.4.6.1 Application. - Markings, such as the graduation marks on scales and dials, shall comply with the following criteria:

5.2.4.6.2 Graduation mark dimension. - Dimension of graduation marks shall be as specified in figure 17. These figures are relative proportions with an assumed viewing distance of 28 inches. For other viewing distances the dimension shall be x/28 multiple of those values. (X equals distance in inches) (Baker, 5; Ely, 66) XR-S-2

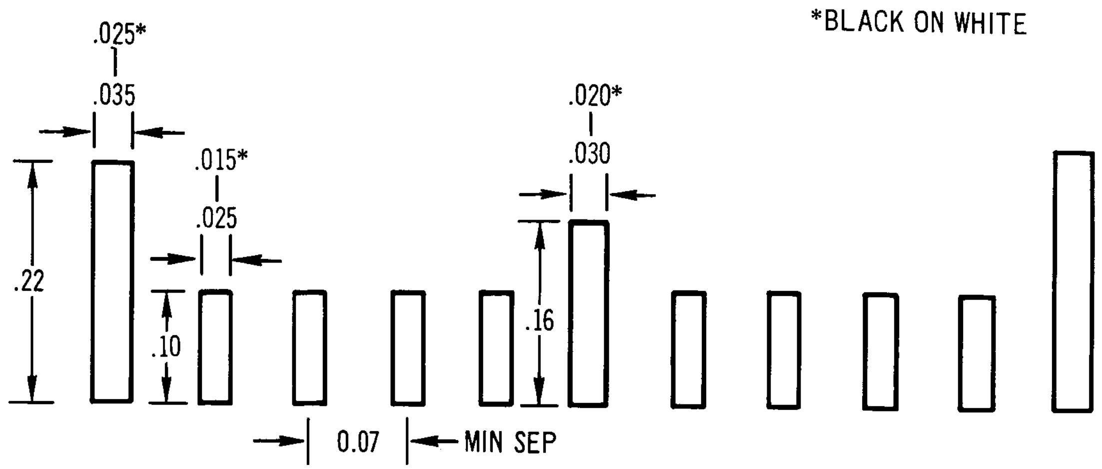
5.2.4.6.3 Numerical progression markings. - Certain combination of graduation intervals and numbering are better than others. Numerical graduation shall comply with the recommendations found in table VI. (Barber, 67; Chapanis, 68; Churchill, 69; Coonan, 70; Grether, 71, 72; Vernon, 73) XR-S-2

5.2.5 Display coding.

5.2.5.1 Display coding requirements. - Displays, as well as controls, may be coded in certain situations for ease of identification. XR-C-2

5.2.5.2 Color coding.

5.2.5.2.1 Color coding requirements. - The use of color for coding displays has both advantages and disadvantages. (Conover, 74; Green, 75; Jones, 76) XR-S-2



NOTE: THESE DIMENSIONS APPLY TO ALL MARKINGS, BLACK ON WHITE OR WHITE ON BLACK, EXCEPT AS INDICATED BY ASTERISKS.

Figure 17. Graduation mark dimension

Table VI.

Scale numerical progression

Good					Fair					Not Acceptable			
1	2	3	4	5	2	4	6	8	10	0	2.5	5	7.5
5	10	15	20	25	20	40	60	80	100	4	8	12	16
10	20	30	40	50	200	400	600	800	1000	0	15	30	45
50	100	150	200	250						30	60	90	120
100	200	300	400	500						0	60	120	180

5.2.5.2.1.1 Advantages of use.

(a) In certain situations (railroad signals, airport signals, etc), color is the most practical means for encoding information. (Jones, 76) XR-S-2

(b) The attention-getting value of color as a coding symbol is widely recognized (eg, the use of red for emergency indication.) (Jones, 76) XR-S-2

(c) The use of color in coding provides an additional dimension for the presentation of information. (Jones, 76) XR-S-2

(d) The awareness of color is an experience common to all color-normal individuals. Color recognition does not require additional training for the operator. (Jones, 76) XR-S-2

(e) Self-luminous colors (lights, excited phosphors) can be utilized under a wide range of ambient lighting conditions. (Jones, 76) XR-S-2

5.2.5.2.1.2 Disadvantages of use.

(a) The average color-normal person can discriminate only about nine hues of surface colors on an absolute basis under favorable conditions, even fewer under unfavorable conditions. (Jones, 76) XR-S-2

(b) Some people are color-defective; about 8 percent of males, and 0.4 percent of females. (Jones, 76) XR-S-2

(c) Color discrimination is seriously degraded when surface colors (produced by paints or dyes) are viewed under highly chromatic light sources. (Jones, 76) XR-S-2

(d) Even after the recent advent of colored phosphors for use on cathode ray tubes, the production of satisfactory colored symbols of electronic means in video displays still presents serious technical problems. (Jones, 76) XR-S-2

(e) Character and stability of the visual environment (of the display) is difficult to create and control. Color judgments are influenced by many aspects of the surrounding conditions. Homogeneity of backgroud, color and intensity of adjacent areas, differences between expected and actual illumination, perceived location of color relative to its surrounds, and the visual impression that the color is abstract or attached to an object are examples of these factors. (Jones, 76) XR-S-2

(f) All color coding methods present practical problems in maintenance. Surface colors have a tendency to fade with age. Surface colors must be kept clean and care must be taken to present the colored symbols under appropriate viewing conditions. Signal lenses may crack or become obscured by dirt. Electronically generated color symbols are subject to distortion and (colored) noise burst. (Jones, 76) XR-S-2

5.2.5.2.2 Number of available colors. - When color coding is used, it shall optimally be limited to four colors--red, amber (yellow), green, and white. If other colors are necessary, blue and purple may be used but precaution shall be taken to insure that no confusion exists with the other colors. (Halsey, 77, 78, 79; Reed, 80; Smith, 81) XR-S-1

5.2.5.2.3 Color meaning. - When the four colors are used for color coding, they shall have the meanings as listed in table VII. These colors have generally been accepted to have the indicated meanings by the public as well as the United States Railway System and the American Standard Association. Other colors, such as blue and orange, may be used only when approved by the contracting agency. (American Standard Association, 82) XR-S-2

5.2.5.2.4. Color aid in display search. - In addition to the color coding as stated above, these colors may also provide aid in visual search. (Green, 75; Smith, 12, 13) They shall be used when the situation is appropriate. XR-S-2

5.2.5.3 Position coding. - Consistency on locating display shall be used wherever possible as an aid to display identification. See Control-display interaction 5.3 for details. XR-S-2

5.2.5.4 Shape coding. - Shape coding shall not be used for display coding except in special cases. The research on shape has been inconclusive and not generalizable.

Table VII.

Color coding

COLOR	OPERATOR RESPONSE	MEANING
IDENTIFICATION RED	OPERATOR SHOULD ADOPT SOME ABNORMAL PROCEDURE OR INITIATE REMEDIAL EMERGENCY ACTION. IMMEDIATE ACTION REQUIRED	DANGER. KILLER WARNING (PERSONNEL OR EQUIPMENT) MASTER SUMMATION (SYSTEM OR SUBSYSTEM) MALFUNCTION, ACTION, STOPPED, FAILURE, STOP ACTION
IDENTIFICATION AMBER (YELLOW)	OPERATOR SHOULD MONITOR IN PREPARATION TO ADOPTING AN ABNORMAL PROCEUDRE OR REMEDIAL ACTION. (IMMEDIATE ACTION MAY BE NECESSARY.)	EXTREME CAUTION (IMPENDING DANGER) TECHNICAL HOLD, OR CONTROLLED TEMPORARY INTERRUPTION
IDENTIFICATION GREEN	OPERATOR SHOULD CONTINUE NORMAL MONITORING AND/OR NORMAL OPERATING PROCEDURES	MASTER SUMMATION (SYSTEM OR SUBSYSTEM) GO AHEAD, IN TOLERANCE ACCEPTABLE, READY, NORMAL
IDENTIFICATION LUNAR-WHITE	AWARENESS OF FUNCTIONAL CONDITIONS NO ACTION REQUIRED	FUNCTION, PHYSICAL POSITION, OR ACTION IN PROGRESS

DOUGLAS DWG 1A02680

DISPLAY CRITERIA

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DETAILED REQUIREMENTS
CONTROL – DISPLAY INTERACTION

CONTROL-DISPLAY INTERACTION	5.3
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Associated up-down meanings: See text	5.3.4.4.2.4

5.3 Control-display interaction.

5.3.1 Control-display relationship: panel layout.

5.3.2 General requirements. - Design of a panel layout is more complex than just arrangement of selected displays and controls on a panel face. There are interactions between controls and displays and interactions with the operator(s). (Knowles, 1) Consideration must be given to the operator's perceptual (visual, auditory, tactual and kinesthetic) skills and the operator's motor (muscular activities) skills. An operator's integrated task performance is not predictable from knowledge of his single-task ability. (Humphries, 2; Smith, 3) Ease of operation shall be a foremost design consideration of panel layout. XR-S-2

5.3.3. Panel layout criteria.

5.3.3.1 Function and efficiency. - Functional and efficiency considerations shall be of more importance than esthetic considerations in panel design and layout. XR-C-2

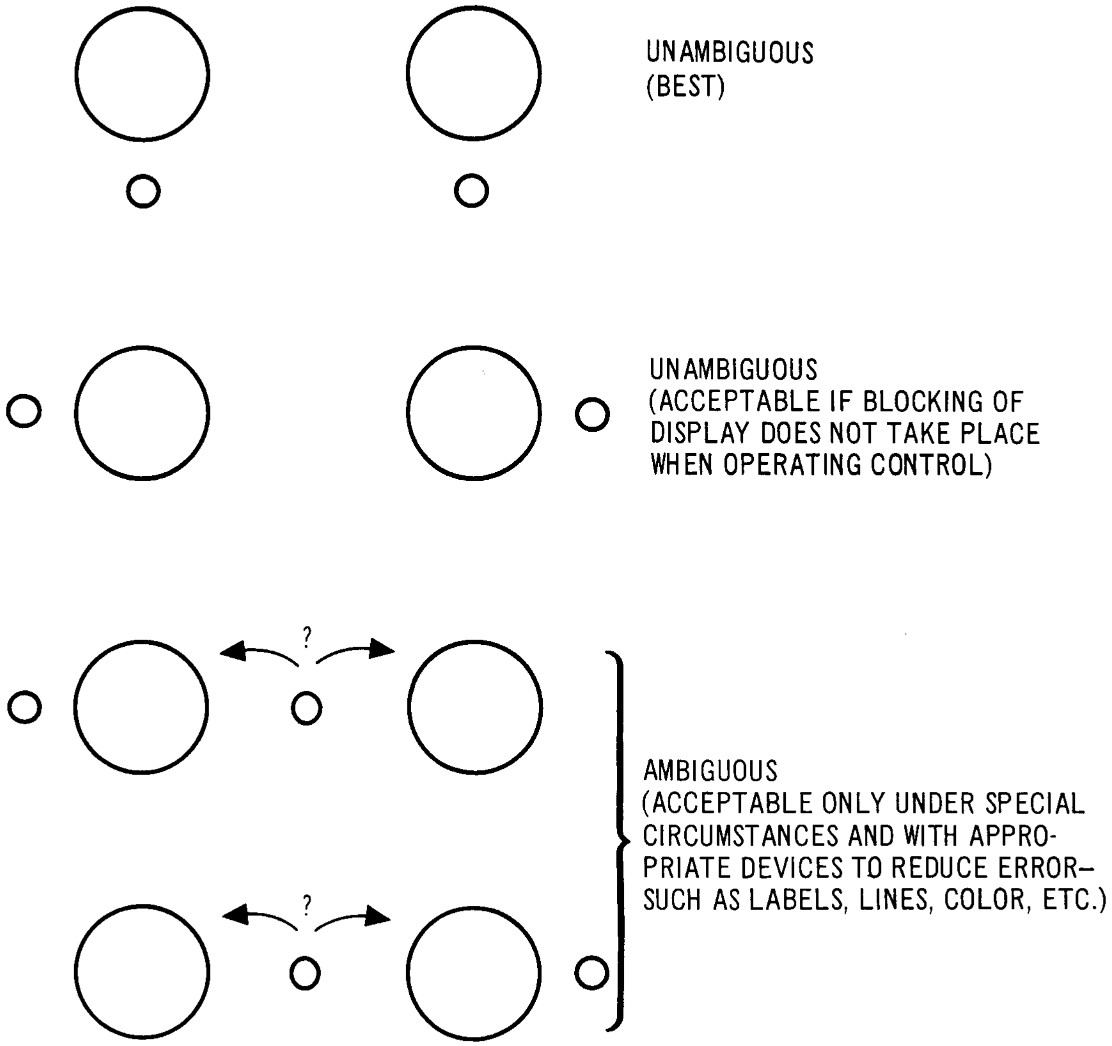
5.3.3.2 Consistency. - Layout and relationship of controls and displays shall be consistent from panel to panel within the limits imposed by the requirements of each panel. (Murray, 4) XR-S-2

5.3.3.2.1 Display location. - Displays shall be placed above their associated controls. Where it is not possible to locate displays above their associated controls, the displays should be located below or to the side in a consistent manner. Markings shall be provided to clearly indicate which display or label is associated with the particular control. Prior to locating a display in a place other than directly above the associated control, the following inherent disadvantages of other placements shall be considered. (Andreas, 5; Mitchell, 6). XR-S-2

5.3.3.2.1.1 Ambiguity. - A possible layout for left and right hand control is shown in figure 18. Because there are only two groups the association is not ambiguous. Ambiguity would exist if there were many such groups or if there were no clearcut distinction between left or right handed operation. (Andreas, 5; Mitchell, 6) XR-S-2

5.3.3.2.1.2 Blocking. - Displays located below their associated controls are more likely to be blocked.

(a) If the label or display was placed below the component (eg, control), the hand manipulating the control obscures the label or display. XR-C-2



NOTE:

DISPLAYS SHALL BE PLACED ABOVE THEIR CONTROL. FOR EXAMPLE, FIGURE 18 SHOWS A POSSIBLE LAYOUT FOR LEFT AND RIGHT HAND CONTROL. BECAUSE THERE ARE ONLY TWO GROUPS, THE ASSOCIATION IS NOT AMBIGUOUS. (ANDREAS, 5; MITCHEL, 6) AMBIGUITY WOULD EXIST IF THERE WERE MANY SUCH GROUPS OR IF THERE WERE NO CLEARCUT DISTINCTION BETWEEN LEFT OR RIGHT HANDED OPERATOR. XR-S-1

Figure 18. Inconsistency of control-display relationship

(b) Most racks are about 7 1/2 feet high. This means that for the standing operator there is only a small portion of the rack above the average eye level while the greater part is below. Often there are many controls and displays located in the lower portion due to space restriction. This being the cases, there is a greater chance of labels or displays being obstructed from view if labels or displays are located below the components. See figure 19. XR-C-2

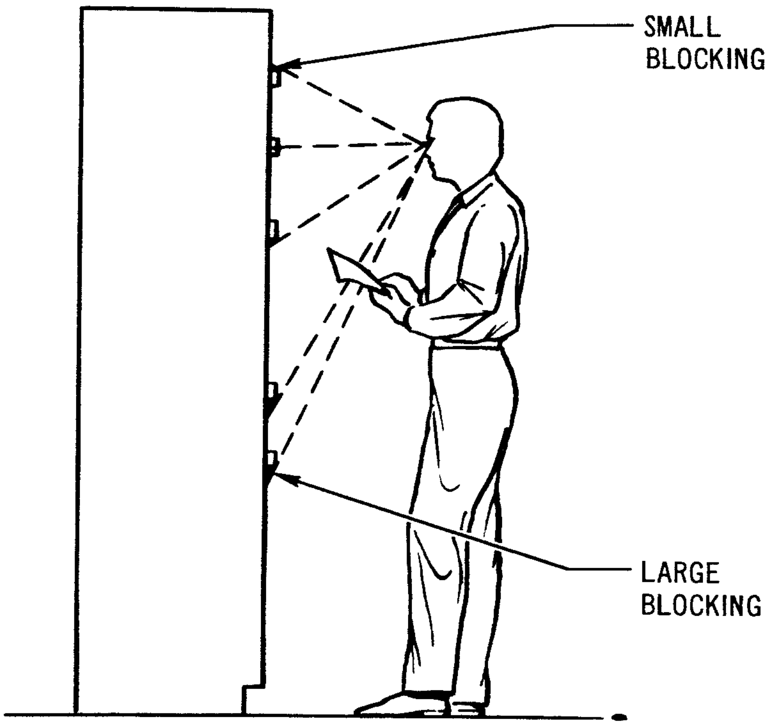


Figure 19. Possible blocking of label or display by components

(c) Console operators are usually seated when they operate components mounted on a slanted surface. Hence the panel is viewed at an oblique angle. Be sure projecting components do not block labelling or displays due to the oblique angle. Locate the labelling or displays high enough above the components so they can be seen but not so high as to be disassociated. See figure 20. XR-C-2

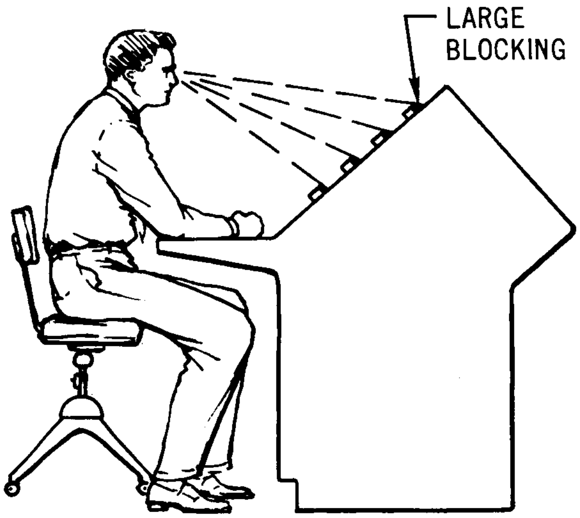


Figure 20. Display and label blocking considerations for seated operator

5.3.3.2.2 Relative positions. - Specific control and display types shall be located in the relatively same position from panel to panel within the system.

(a) Panel power switch shall be located on the lower left-hand corner of the panel. XR-A-2

(b) Emergency controls and displays shall be conspicuously but not obtrusively located. XR-C-2

(c) An area of emergency or extremely critical operation shall be distinguished by a 3/16-inch red line. XR-A-2

5.3.3.3 Control and display relationship. - Relation of a control with its display shall be immediately apparent, eg, by virtue of approximity, grouping, coding, framing and labelling. (Boring, 7; Woodworth, 8) XR-S-2

5.3.3.4 Functional grouping.

(a) Sequential grouping shall be used within functional groups when appropriate. (See Sequential grouping 5.3.3.5 below.) (Sender, 9) XR-S-2

(b) Controls and displays used together in a specific task, identical in function, or related to one equipment or system component shall be put under a functional grouping. XR-C-2

(c) Controls and displays shall be placed close to other controls and displays within the functional group so that the relationship is apparent to the operator. (Boring, 7; Woodworth, 8) XR-S-2

(d) Bracketing shall be used to minimize labelling and to aid the forming of a functional group. See figure 21. XR-C-2

(e) The general name of the group shall be centered within the bracket above the group of controls and displays. See figure 21. XR-C-2

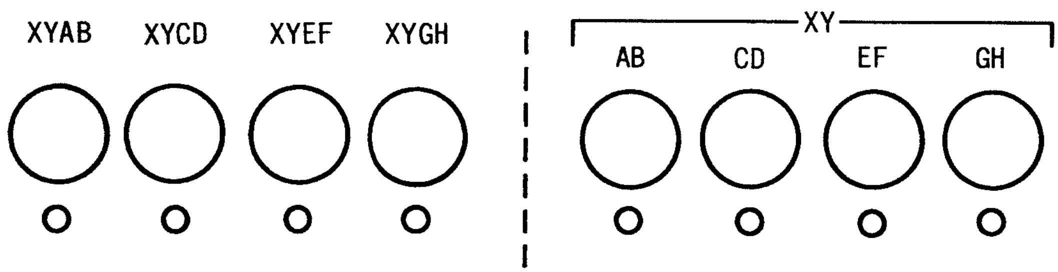


Figure 21. Example of bracketing

5.3.3.5 Sequential grouping. - Sequential grouping shall be used when the system operations require continuity, connection and order. Requirements for sequential grouping shall be as follows: XR-S-2

(a) Experimental evidence indicates the continuity between control and displays leads to optimum performance. The order of arrangement is also an important factor. The pattern of detection for a panel surface and the scanning habits are highly related to previously learned reading habits. That is, for the Western culture, it is from left to right. This habit is more developed as one is better educated. (Forgays, 10; Heron, 11; Kimura, 12; Lincoln, 13; Miskin, 14; Murray, 15; Sender, 9; Shackel, 16; Tinker, 17)

(b) The sequential order shall be from left to right in horizontal rows and top to bottom in vertical columns. XR-S-2

(c) If vertical arrangement is necessary, the orientation shall be from top to bottom. XR-S-2

(d) If required, block diagraming will be used. XR-C-2

(e) If required, links between events will be schematized by black lines. XR-C-2

(f) Primary flow lines shall be distinguished by lines 0.062 inch wide. XR-A-2

(g) Secondary lines shall be distinguished by lines 0.031 inch wide. Arrows shall be used to indicate direction of flow. XR-A-2

5.3.3.6 Examples of simple panel layout arrangement. - The following show some typical and possible panel arrangements. These configurational concepts shall be used whenever possible within the limits of other design considerations.

(a) Controls directly beneath its associated display. (Ely, 18) See figure 22. XR-C-2

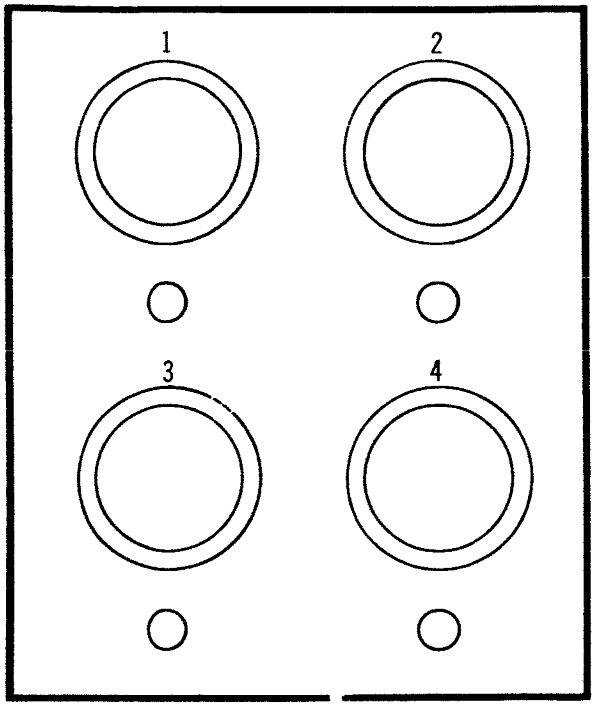


Figure 22. Controls beneath associated display

(b) All displays located in the upper portion of the panel and all controls in the lower. (Ely, 18) See figure 23. XR-C-2

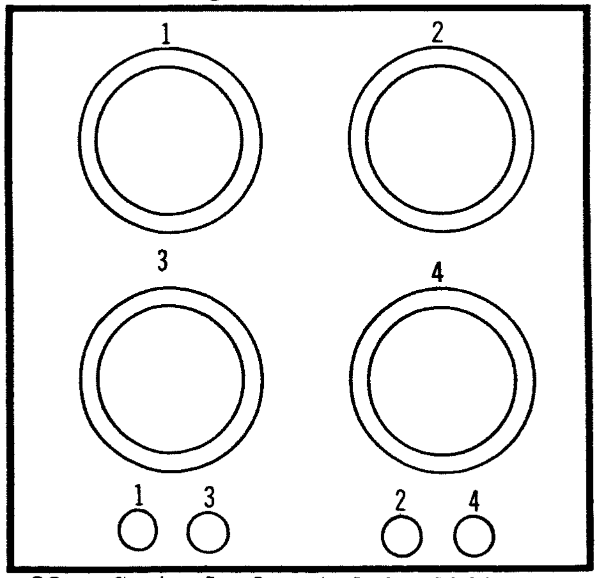
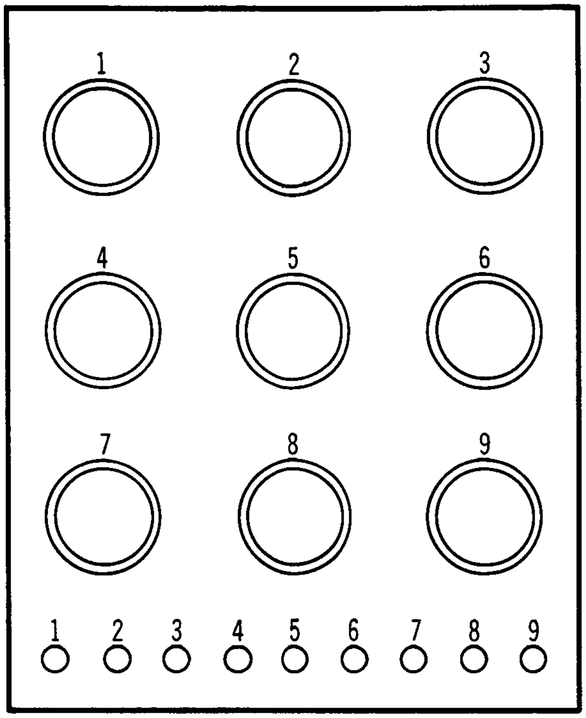


Figure 23. Controls located in different portion of panel from displays

(c) Controls are arranged in fewer rows than the displays. (Ely, 18) See figure 24. XR-C-2



NOTE:
THIS ARRANGEMENT IS ACCEPTABLE ONLY WHERE A SMALL NUMBER OF CONTROLS AND DISPLAYS ARE INVOLVED. THE ARRANGEMENT IS DIFFERENT WHERE LARGE NUMBER OF CONTROLS AND DISPLAYS ARE INVOLVED. SEE 5.3.2.7 BELOW.

Figure 24. Controls arranged in fewer rows than displays

(d) Horizontal row of displays associated with vertical columns of control, either left or right. (Ely, 18) See figure 25.

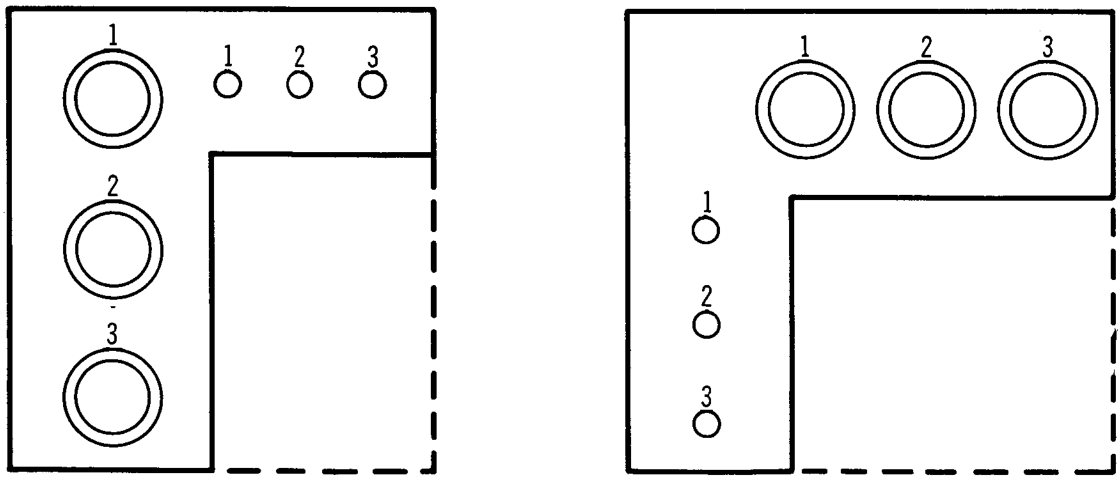


Figure 25. Controls oriented differently from displays

5.3.3.7 Example of complex panel layout arrangements. - Panel arrangement for a large number of control and display components may have different requirements than for a few numbers, as in certain analog computer applications. These configurational concepts shall be used whenever possible within the limits of other design considerations. Compare this with the above 5.3.2.6 (c). (Shackel, 16) XR-S-2

(a) Controls arranged in fewer rows than displays. See figure 26.

(b) Patch panel arrangement. A typical patch panel, as found in analog computer design, has many jacks and plugs. Reference lines shall be considered. The number of reference lines depend on the number of rows and columns; too many reference lines are undesirable. Division into grouping of 5's and 10's shall be considered. (eg, in a panel of 100 by 100, reference lines shall form groups of 10 by 10's) (Garvey, 19, 20) XR-S-2

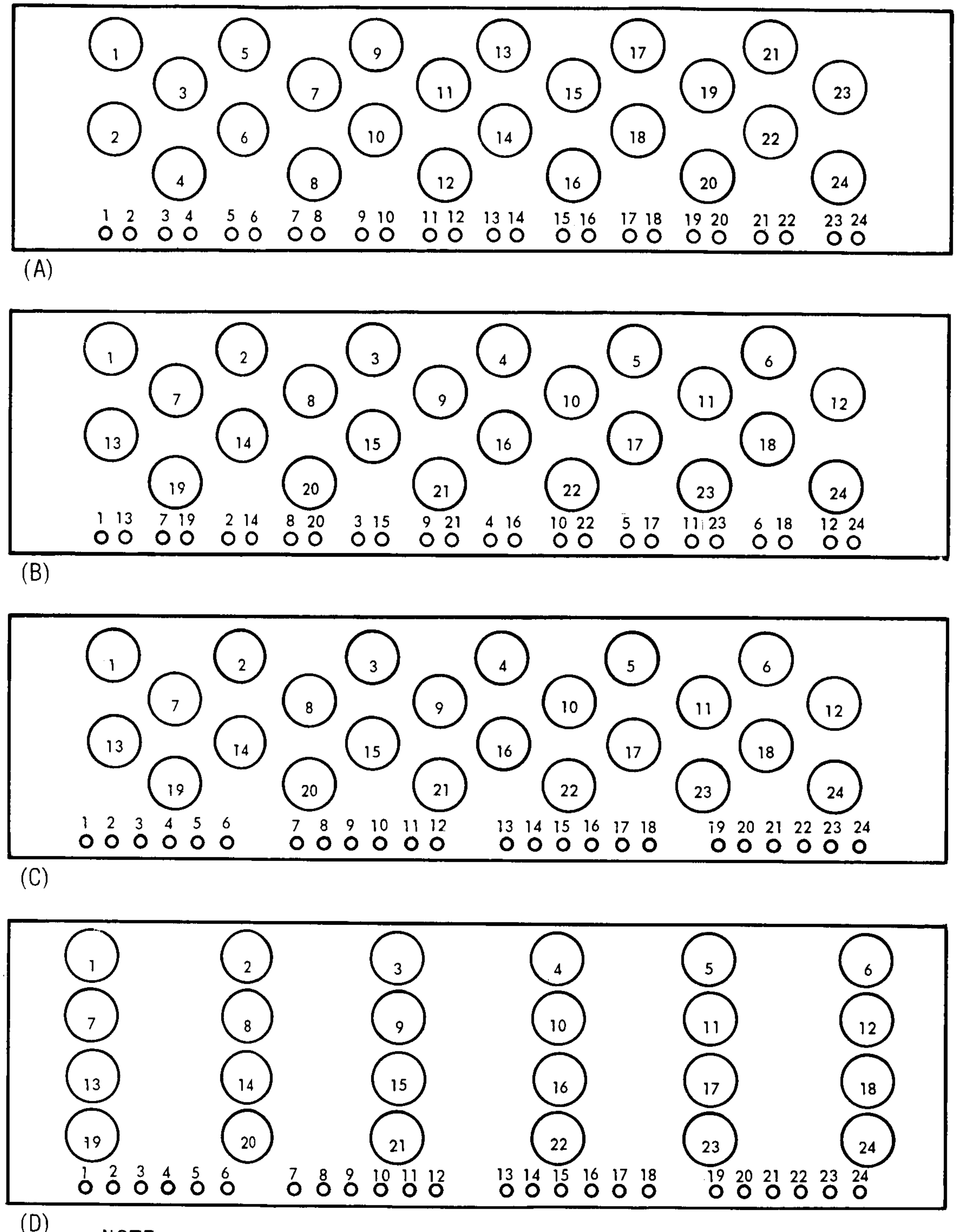
5.3.3.8 Priority. - Controls and displays location. Priority shall be given to location of controls and displays that will be used most often. The choice shall depend upon the functional requirements such as reading distance, angle of view, illumination, presence of other instruments and method of actuation of related controls. (Ely, 18) XR-S-2

5.3.3.9 Location and label. - Displays and controls shall be located and labelled to insure quick and accurate identification. See also Consistency, 5.3.3.2.

(a) Each control shall be located directly beneath its associated display. Care shall be exercised to avoid misidentification with a display at a different location and to avoid obscuring the display by any control parts or the operator's hand. XR-C-2

(b) When a control is operated predominately by the right hand and if space is a restricting factor, it may be located to the right of its associated display. XR-C-2

(c) When a control is operated predominately by the left hand and if space is a restricting factor, it may be located to the left of its associate display. This shall be avoided if possible as it may not be consistent with the system and can cause confusion. XR-C-2



NOTE:
(A) AND (B) OF FIGURE 26 ARE MORE DESIRABLE THAN (C) AND (D) BECAUSE THE OPERATOR CAN GLANCE DOWN AND ORIENT HIMSELF BY ROWS.

Figure 26. Example of complex panel layout

(d) Controls and displays most frequently used shall be located between shoulder and waist levels with reference to the normal position of the operator. XR-C-2

(e) Controls and displays that are less frequently used shall be located further from the control location of the panel relative to the operator's normal position. XR-C-2

(f) Controls and displays requiring fine adjustment and accurate readout shall be closer to the operator's normal line of sight than controls and displays requiring gross positioning or monitoring. XR-C-2

5.3.3.10 Separate panels. - When necessity requires related controls and displays to be mounted on separate panels, the controls shall be located in the same relative position as their associated displays. (Chapanis, 21; Green, 22) XR-S-2

5.3.3.11 Combined controls. - When combined (ganged) controls affect separate displays, the arrangement of the display shall be from left to right with the combined controls centered below the displays. The smallest control shall affect the display on the left and the largest control shall affect the display on the rights. (See Control-display interaction 5.3.4 direction of motion.) (Bradley, 23) XR-S-3

5.3.3.12 Positional restrictions. - Allowing for normal head rotation and restrictions imposed by earphones or other head gear, all instruments and legends shall be readable from the normal head position. There shall be no obstruction by other equipment or blocking of dials because of the oblique angles of view. XR-C-2

5.3.3.13 Panel hardware. - Display panels often necessarily have such hardware as drawer handles, hinges, fasteners, etc. Use of such hardware shall be minimal. Individual displays and controls shall be kept clear of such hardware so as not to be confused, obscured or obstructed by it. XR-C-2

5.3.4 Control-display movement.

5.3.4.1 Requirements. - The direction of movement of the control shall be related appropriately to the change which it induces in its associated display, equipment component or the system as a whole. The most important relational basis is that which is expected or in accord with the population stereotype (behavior patterns which are consistent from person to person without special training or instruction). Other bases may be: (1) existing design practice, and

(2) standardization and consistency. Sometimes these two may conflict with what is natural or expected. In such cases the possibility of adverse consequences shall be taken into account and changes made accordingly. (Ely, 18) XR-S-2

5.3.4.2 Application. - The correct control-movement to display-movement relationship shall be used where the following considerations are important. (Adams, 24; Gagne, 25; Mitchell, 6; Vince, 26, 27; Warrick, 28, 29) XR-S-1

(a) Possibility that incorrect control movement can mean mission failure or damage to equipment and personnel. The most important endorsement for providing the correct control-display relationship comes in a time of emergency or where there is a great deal of stress and anxiety. Under stress the operator, however well he may have learned an unexpected relationship, is likely to revert to a "natural" or prelearned relationship movement; disaster can result. This affect seems to be more pronounced in older people. (Vince, 27)

(b) Manipulation of control is complex or precise.

(c) Fast reaction or decision time is required.

(d) Time is limited for training of operating personnel.

(e) Operating sequence is discontinuous or has interruptions.

5.3.4.3 General criteria.

5.3.4.3.1 Movement of control. - The direction of movement of a control shall be considered in relation to the following factors:

5.3.4.3.1.1 Operator's position. - Whenever possible, controls and displays shall be placed in front of the operator. (Andreas, 5) XR-S-2

5.3.4.3.1.2 Display position and relation.

(a) Whenever possible, the controls shall always be on the same plane as their associated displays. (Norris, 30, 31) XR-S-2

(b) Controls and displays shall be related to each other, in an obvious manner. XR-C-1

5.3.4.3.1.3 Equipment component response. - Without the intermediary of some display mechanism and where the feedback is direct to the sensory modalities, the movement of controls shall be the same as when displays are provided. See 5.3.4.4 for details. XR-S-2

5.3.3.3.1.4 Consistency. - Control-display movements shall be consistent for all equipment throughout the system. Where control-display movements are consistent and natural, there is less chance of error and less time is required for training. (Duncan, 32) XR-S-2

5.3.4.4 Specific criteria. - The following subsection is divided into two categories: rotary controls and linear controls.

5.3.4.4.1 Rotary controls.

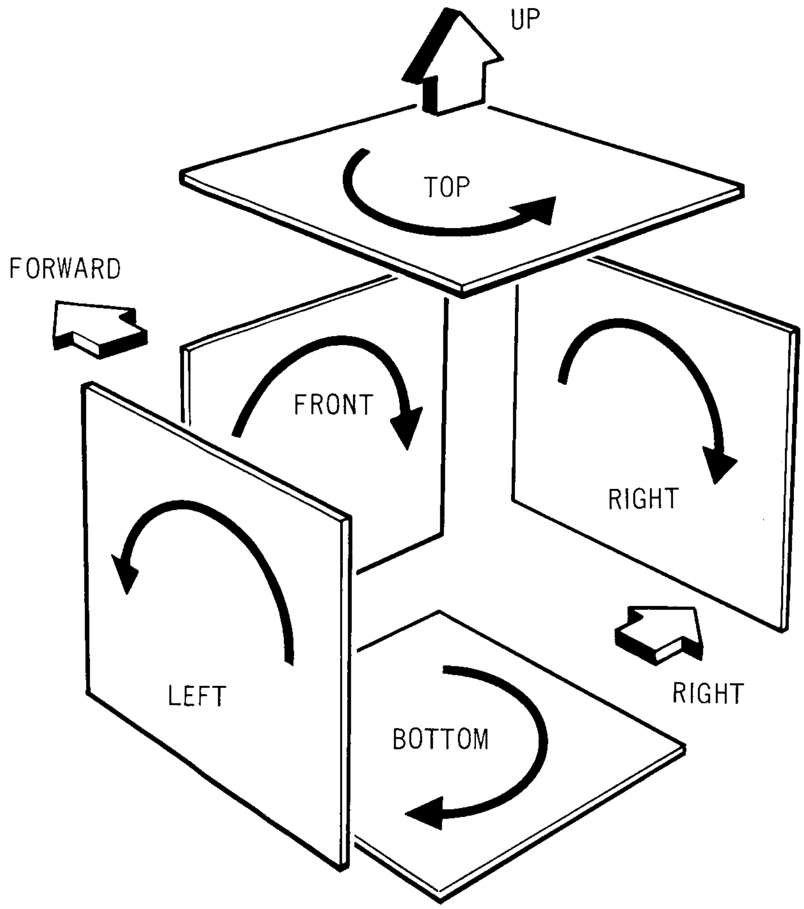
5.3.4.4.1.1 Operator orientation. - Basically there are two planes of orientation: vertical and horizontal. In using rotary controls the operator orients himself with a certain point on the control. He pictures himself as moving in the direction in which this point is moving. When the control effects the direction of movement of an instrument indicator or vehicle, the point of the control with which the operator is oriented should move in the same direction as the desired direction of the indicator or vehicle.

(a) Vertical plane. The operator orients himself with respect to the TOP of the control, as in steering a boat at the helm. The vertical may be in front to the left or right of the operator. See figure 27. XR-S-2

(b) Horizontal plane. The operator orients himself with respect to the forward point of the control, as in driving a bus that has its steering wheel mounted horizontally. The horizontal may be above or below the operator. See figure 27. XR-S-2

5.3.4.4.1.2 Operator orientation--special cases.

(a) Sloping panel. A sloping panel may be used in either the vertical or horizontal orientation depending on its degree of inclination with respect to the vertical. (For simplicity this is not shown in the above illustration.) See Linear control orientation 5.3.4.4.2.1 where the situation is more complicated with respect to sloping. XR-S-3



CURVED ARROWS POINT TO DIRECTION OF INCREASE

NOTE:
The orientation to all planes is the same were the operator to face them. The arrows indicate the direction of "increase".

Figure 27. Operator orientation for rotary control

(b) Operator inside moving vehicle. When the operator is inside a moving vehicle, the orientation shall be as in figure 28. (Matheny, 33) XR-S-3

(c) Different plane. While it is not desirable, sometimes it is necessary to mount the controls different from the display plane. Studies have not found any strong population stereotype for these situations. (Loveless, 34; Ross, 35) The orientation shown in figure 29 shall be as follows in order to conform to a standard procedure. XR-A-2

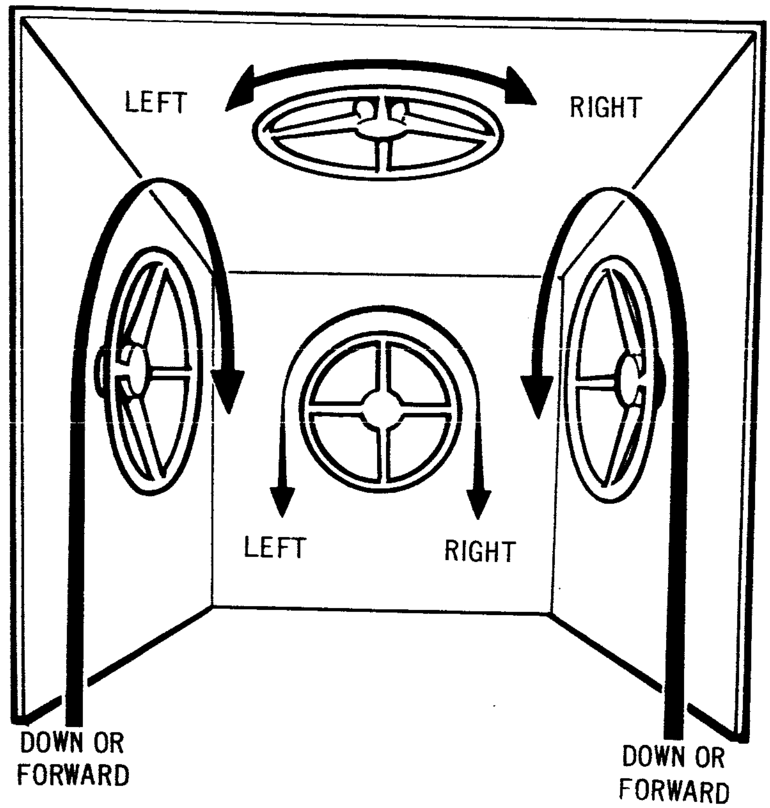
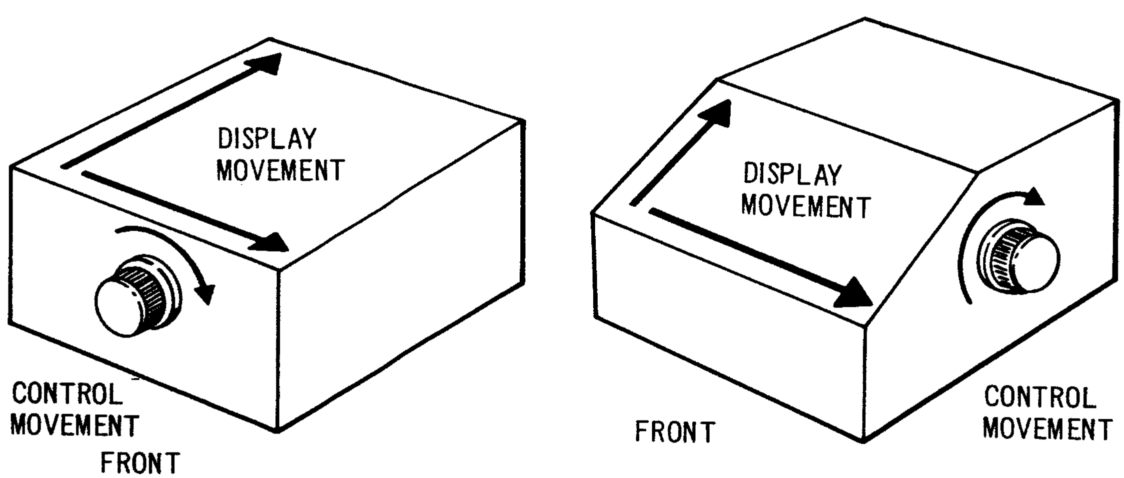


Figure 28. Control display orientation for operator inside moving vehicle



NOTE:
THIS ILLUSTRATION IS MEANT TO REPRESENT A GENERAL CONTROL-DISPLAY RELATIONSHIP WHEN CONTROLS ARE MOUNTED ON A DIFFERENT PLANE FROM THE DISPLAYS. THE SIZE OF THE CONTROL AND CONSOLE IS NOT TRUE TO LIFE.

Figure 29. Orientation for control mounted on a different plane from display

5.3.4.4.1.3 Associated meaning. - The following direction of movement shall have the associated meaning indicated. (Bradley, 36; Ely, 18, 37; Loveless, 34; Mitchell, 6; Ross, 35; Wade, 38; Warrick, 28, 29) XR-S-2

(a) Clockwise. A rotating clockwise movement has the same meaning as an upward linear movement, eg, as used with toggles. In general, it shall have the connotation of "on", "action", "up", or "increase" of some kind. XR-S-2

(b) Counterclockwise. A rotating counterclockwise movement has the same meaning as a downward linear movement. In general, it shall have the connotation of "off", "inaction", "down" or "decrease" of some kind. XR-S-2

(c) Rotary control as linear control. When a rotary control is largely concealed, the operator responds to the exposed portion as it were a linear control. The associated meaning and label shall be as above. See figure 30. XR-C-2

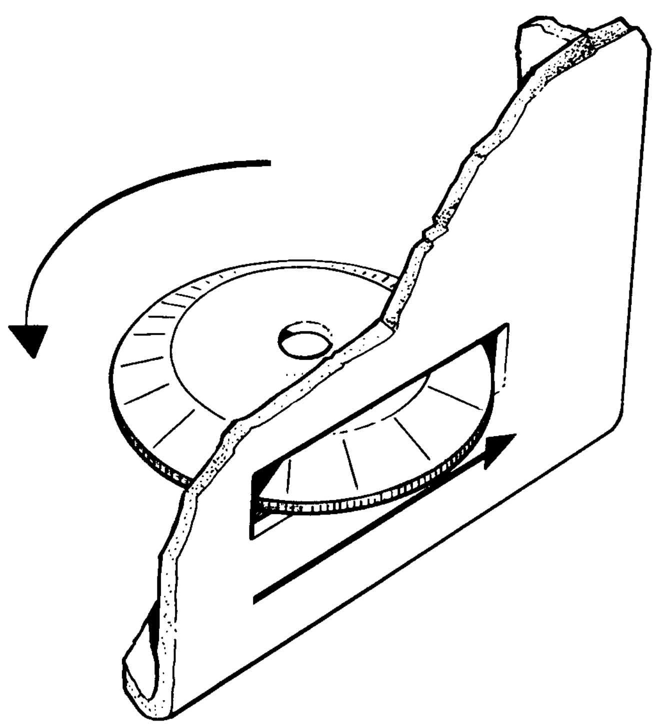


Figure 30. Rotary control with linear orientation

(d) Conflicting associated meaning. Rotary hydraulic valve controls, as opposed to electrical controls, generally turns clockwise for "close" or "off". Since this exception is well ingrained in our culture, this associated meaning shall remain unchanged. To minimize confusion, there shall be clear labelling; the label shall be in accordance to the end purpose which it serves. XR-C-2

5.3.4.4.1.4 Rotary display (with rotary control).

(a) When the display has a moving pointer and a stationary dial, a clockwise rotation of the rotary control shall result in a clockwise rotation of the pointer. (Loveless, 34; Simon, 39, 40; Stellar, 41) See figure 31. XR-S-2

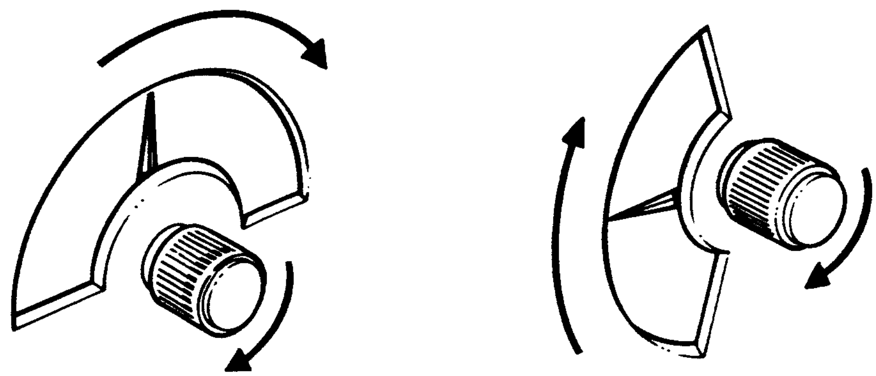


Figure 31. Rotary display with rotary control

(b) A rotary control shall be on the concave side of a rotary display when the movement traverses less than a full circle. (Simon, 39, 40; Warrick, 28, 29) See figure 31. XR-S-3

(c) When the display has a moving dial and a fixed pointer, or lubber line, it will usually cause direction-of-movement inconsistency. Wherever possible, it shall be replaced by a fixed dial and moving pointer. (Baker, 42; Bradley, 36; Loucks, 43) XR-S-2

5.3.4.4.1.5 Linear displays (with rotary control).

(a) When a rotary control and a linear display are on 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. (Andreas, 44; Gardner, 45, 46) See figure 32. XR-S-2

(b) When possible, a rotary control shall not be placed above any display or to the left of a vertical display. (Simon, 39, 40; Warrick, 28, 29) See figure 32. XR-S-2

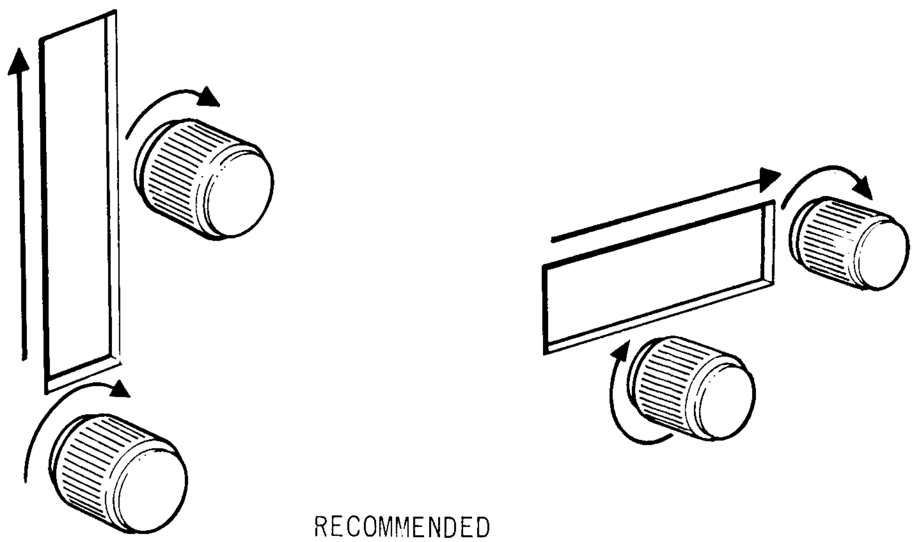


Figure 32. Linear display with rotary control

5.3.4.4.2 Linear controls.

5.3.4.4.2.1 Operator orientation and associated meaning. - The following factors shall be considered where linear control is used:

(a) Sloping panels can be used up to, but not exceeding, a 135 degree angle from the floor (or desk). Linear control movements shall follow the same criteria as outlined for the vertical and horizontal plane. See 5.3.4.4.2.2 and 5.3.4.4.2.3. XR-S-2

(b) Overhead sloping panels shall be avoided because of reverse movement problems with linear controls. Note the differences in orientation between linear and rotary controls for overhead sloping panels. See figure 33. (Adams, 24; Grahm, 47; Lazar, 48) XR-S-2

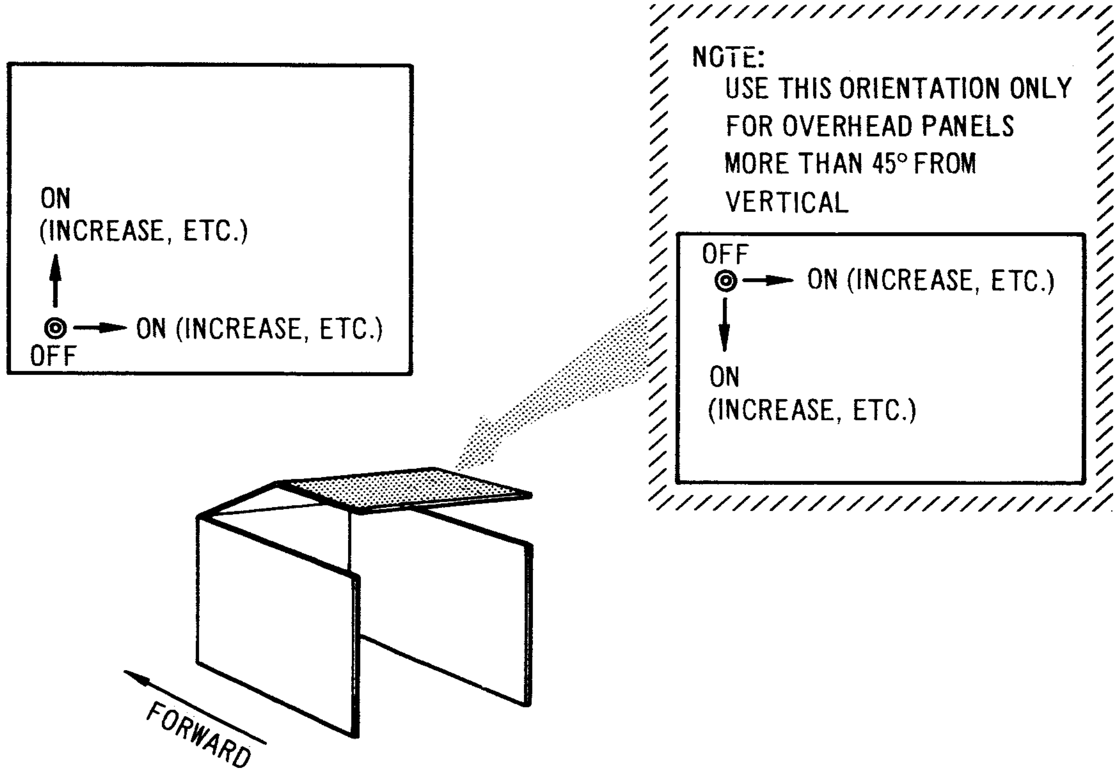


Figure 33. Control display movement orientation for linear control

5.3.4.4.2.2 Vertical plane.

(a) Upward or forward (away from operator) movements shall be associated with "on", "increase", or "up". XR-S-2

(b) Downward or rearward (toward operator) movements shall be associated with "off", "decrease" or "down". XR-S-2

5.3.4.4.2.3 Horizontal plane.

(a) Facing forward or overhead, forward (away from operator) movement shall be associated with "on" and "increase". XR-S-2

(b) Rearward (toward operator) movement shall be associated with "off" and "decrease". XR-S-2

CAUTION NOTE
A confusion factor exists when the horizontal plane orientation is compared with aircraft pilots' experience. Forward on the control stick causes the aircraft to go downward while rearward causes the aircraft to go upward.

5.3.4.4.2.4 Associated up-down meanings. - The following is a list of commonly used labels for up-down positions and shall be used where applicable:

On-off	Automatic-manual
Start-stop	Accelerate-decelerate
High-low	Energize-deenergize
Up-down	Internal-external
In-out	Forward-reverse
Fast-slow	Over-under
Arm-safe	Fire-hold
Raise-lower	Alternating-direct
Increase-decrease	Moving-stationary
Open-close	Caged-uncaged
Engage-disengage	Positive-negative

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DETAILED REQUIREMENTS
ANTHROPOMETRY AND WORKSPACE
WORKSPACE

HUMAN CAPABILITIES & HUMAN RESPONSES — 5.4

Human strength capabilities: consider,	5.4.1
Arm strength: consider,	5.4.1.1
Seated body position: consider,	5.4.1.1.1
Direction of exertion: Pull preferred. See text	5.4.1.1.1.1
Provide back rest	5.4.1.1.1.2
Values of force exerted: See tables VIII, IX and X	5.4.1.1.1.3
Prone body position: consider,	5.4.1.1.2
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Sex: females 1/3 less strong than men	5.4.1.4.2
Sides differences: slight	5.4.1.4.3
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Muscle tissue: differences in strength due to muscle condition	5.4.1.4.5
Testing of muscles indicates strength	5.4.1.4.6
Increase and decrease strength: exercise, food, rest important	5.4.1.4.7
Exercise must important for strength	5.4.1.4.8
Weight lifting and carrying: consider,	5.4.2

Factors to consider: consider,	5.4.2.1
Physical size (bulk): keep weight of large objects minimum	5.4.2.1.1
Frequency of move: See table XIII	5.4.2.1.2
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Limb and body support: and of body members increases strength	5.4.2.1.6
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Other methods of carry: consider,	5.4.2.1.8
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Thigh carry: avoid	5.4.2.1.8.2
Weight distribution: distribute over wide area	5.4.2.1.8.3
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Human reaction time:	5.4.4
The senses: consider,	5.4.4.1
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Visual: for large amounts of information	5.4.4.1.2.1
Auditory or tactual: when visual channel occupied	5.4.4.1.2.2
Signal (stimuli) characteristics: consider,	5.4.4.2
Single sense: stimulate both eyes and ears	5.4.4.2.1
Two or more: simultaneous stimulation is best	5.4.4.2.2
Intensity: high intensity, faster reaction	5.4.4.2.3
Number of receptors: larger, faster reaction	5.4.4.2.4
Stimulus change: more change, faster reaction	5.4.4.2.5
Alerting signal: precedes critical signal. See text	5.4.4.2.6
Irrelevant signals: useful in monitoring tasks	5.4.4.2.7
Signal shall be easily discriminable	5.4.4.2.8
Number of signals: keep to a minimum. See fig. 50	5.4.4.2.9
Time uncertainty: avoid, if possible	5.4.4.2.10

Auditory signals: See text	5.4.4.2.11
Visual signals: See text	5.4.4.2.12
Operator and decisional characteristics: consider,	5.4.4.3
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Amount of training: overtrain	5.4.4.3.2
Simplicity of response: keep response simple & direct	5.4.4.3.3
Number of signals: keep to a minimum. See text.	5.4.4.3.4
Signal rate: keep within operator's ability	5.4.4.3.5
Signal channels: avoid using too many	5.4.4.3.6
Control-display relationship shall be meaningful and clear	5.4.4.3.7
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Response characteristics: consider,	5.4.4.4
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Other factors: See text	5.4.4.4.2

5.4 Human capabilities and human responses.

5.4.1 Human strength capabilities. - Various limb movements are required in the operation of controls. The operator's strength varies with the position of his limbs and the direction of his movement. In the design of equipment both the amount and direction of force exertable are important and shall be within the capabilities of the operator. The following subsection contain strength data for various body and limb positions; the values shall be used as limits wherever applicable. XR-C-1

5.4.1.1 Arm strength.

5.4.1.1.1 Seated body position.

5.4.1.1.1.1 Direction of exertion. - In descending order of ability the arm forces that can be exerted by the seated operator are: push, pull, up, down, abduction and adduction. The pull is subjectively more pleasant to actuate than the push. Most hand controls may be designed to be pulled. (Hugh-Jones, 1; Hunsicker, 2). XR-S-2

5.4.1.1.1.2 Provision for back-rest. - A back-rest shall be provided for the seated operator to aid him to exert the maximum force. The back-rest shall be mandatory where the operator has to extend his arm to angles of 135 to 160 degrees. (Caldwell, 34; Hugh-Jones, 1; Provins, 5, 6, 7). XR-S-2

5.4.1.1.1.3 Value of force exerted. - Tables VIII, IX, and X give the strength values for various arm angles in the seated position. These values shall apply as limits where applicable. (Hunsicker, 8). XR-S-2

5.4.1.1.2 Prone body position.

5.4.1.1.2.1 Direction of exertion. - Controls requiring great force for actuation by the proned operator shall be designed to be pulled. Other directions, in descending order of exertion ability shall be the push, up, adduction, down and abduction. (Hunsicker, 18; Brown, 9, 10, 11). XR-S-2

5.4.1.1.2.2 Value of force exerted. - Table XI gives the strength values for various arm angles in the prone position. These values shall apply as limits where applicable. (Hunsicker, 8). XR-S-2

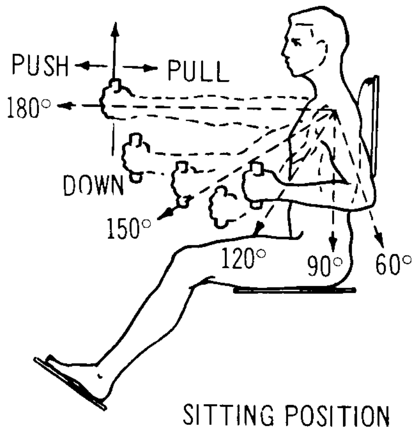
5.4.1.1.3 Maximum torque for one hand. - Table XII gives the maximum torque that can be exerted on knobs of various diameters. These values shall be used wherever maximum values are applicable. Note that these values are much higher than the ideal values given in the control section 5.1. The ideal values are for ease of

Table VIII.

Maximum force exerted in the sitting position on a vertical handgrip at various elbow angles by the right and left arms of male college students

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB)						S.D.	
		5TH		50TH		95TH			
		L	R	L	R	L	R	L	R
PUSH	60	22	34	79	92	164	150	31	38
	90	22	36	83	86	172	154	35	33
	120	26	36	99	103	180	172	42	43
	150	30	42	111	123	192	194	48	45
	180	42	50	126	138	196	210	47	49
PULL	60	26	24	64	63	110	74	23	23
	90	32	37	80	88	122	135	28	30
	120	34	42	94	104	152	154	34	31
	150	42	56	112	122	168	189	37	36
	180	50	52	116	120	172	171	37	37
LEFT	60	12	20	32	52	62	87	17	19
	90	10	18	33	50	72	97	19	23
	120	10	22	30	53	68	100	18	26
	150	8	20	29	54	66	104	20	25
	180	9	20	30	50	64	104	20	26
RIGHT	60	17	17	50	42	83	82	21	20
	90	16	16	48	37	87	68	22	18
	120	20	15	45	34	89	62	21	17
	150	15	15	47	33	113	64	27	18
	180	13	14	43	34	92	62	22	24
UP	60	15	20	44	49	82	82	18	18
	90	17	20	52	56	100	106	22	22
	120	17	24	54	60	102	124	25	24
	150	15	18	52	56	110	118	27	28
	180	9	14	41	43	83	88	23	22
DOWN	60	18	20	46	51	76	89	18	21
	90	21	26	49	53	92	88	20	20
	120	21	26	51	58	102	98	23	23
	150	18	20	41	47	74	80	16	18
	180	13	17	35	41	72	82	15	18

HUNSICKER, 1955.



SITTING POSITION

Table IX.

Maximum force exerted in the sitting position with the hand grasping (thumb away from body palm forward) at various elbow angles by the right and left arms of male college students

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB) 5TH		50TH		95TH		S.D.	
		L	R	L	R	L	R		
PUSH	60	35	34	89	96	176	172	42	39
	90	25	25	59	65	104	117	27	24
	120	15	20	40	43	80	71	18	17
	150	13	17	38	36	69	59	30	14
	180	14	12	30	32	47	58	10	15
PULL	60	23	16	54	51	87	93	23	25
	90	13	13	42	43	68	74	21	19
	120	14	11	40	40	66	63	18	17
	150	16	11	40	37	62	66	15	17
	180	17	15	40	39	70	73	18	19
RIGHT	60	16	18	38	44	64	73	12	19
	90	12	18	32	39	46	72	12	24
	120	14	17	31	34	55	64	13	15
	150	12	15	32	32	62	60	15	14
	180	12	14	29	29	43	48	9	12
LEFT	60	17	13	42	36	81	70	20	17
	90	16	13	33	31	52	48	12	12
	120	14	12	28	30	45	46	8	11
	150	12	12	26	31	43	52	10	14
	180	8	10	27	28	44	44	10	10
UP	60	20	17	49	45	89	78	22	22
	90	24	21	75	63	131	107	29	27
	120	38	41	94	88	152	143	33	33
	150	44	37	104	103	164	161	36	40
	180	45	51	111	113	173	165	40	34
DOWN	60	20	20	58	59	138	132	41	35
	90	23	17	80	80	160	143	43	37
	120	35	29	84	92	136	148	33	13
	150	43	37	84	93	136	150	29	35
	180	36	44	78	87	124	135	28	32

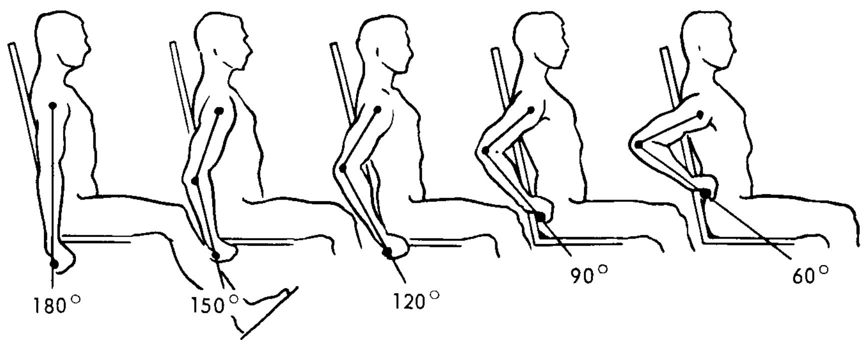
HUNSICKER AND GREEY, 1957.

Table X.

Maximum force exerted in the sitting position with the hand grasping (thumb toward body, palm rearward) at various elbow angles by the right and left arms of male college students

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB) 5TH		50TH		95TH		S.D.	
		L	R	L	R	L	R	L	R
PUSH	60	33	40	86	94	138	156	35	36
	90	27	25	60	65	93	100	28	24
	120	17	23	43	46	71	70	17	15
	150	15	18	37	40	69	66	18	18
	180	12	17	32	32	59	59	13	12
PULL	60	20	13	39	37	64	50	18	16
	90	17	14	37	32	65	54	18	13
	120	12	13	30	26	56	43	14	10
	150	15	12	32	29	52	48	13	10
	180	16	11	34	28	61	48	15	12
RIGHT	60	20	19	42	41	66	72	15	19
	90	17	12	38	31	60	64	12	15
	120	17	9	34	26	53	53	8	13
	150	17	9	31	21	54	39	11	11
	180	15	10	28	19	41	34	8	7
LEFT	60	18	16	36	48	51	73	15	18
	90	11	16	27	39	54	59	11	15
	120	10	15	22	34	39	47	10	11
	150	9	18	23	32	53	45	16	7
	180	10	16	20	31	49	57	13	13
UP	60	22	23	57	49	100	79	22	20
	90	37	28	77	69	123	112	24	29
	120	45	41	91	91	145	138	30	30
	150	58	43	100	99	159	165	32	38
	180	47	35	101	95	171	156	11	35
DOWN	60	18	23	74	81	139	158	35	35
	90	23	22	75	83	136	142	34	35
	120	29	37	75	92	148	161	40	35
	150	39	40	79	90	136	154	29	34
	180	34	41	76	87	138	143	31	31

HUNSICKER AND GREEY, 1957.



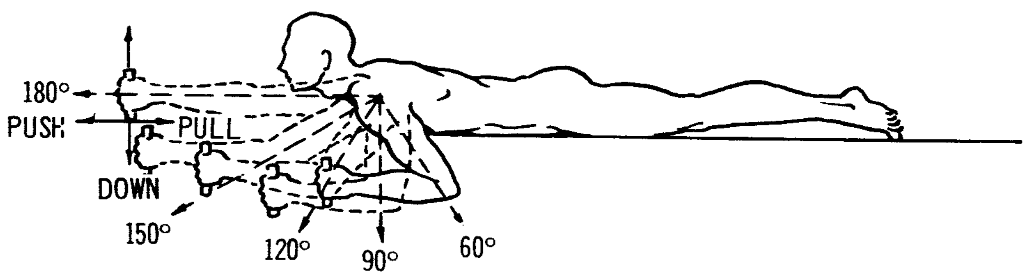
SITTING POSITION

Table XI.

Maximum force exerted in the prone position on a vertical handgrip at various elbow angles by the right and left arms of male college students

DIRECTION OF FORCE	ELBOW ANGLE (DEG)	PERCENTILES (LB)						S.D.	
		5TH		50TH		95TH			
		L	R	L	R	L	R	L	R
PUSH	60	17	24	52	66	87	119	21	26
	90	18	26	54	63	91	103	22	23
	120	21	29	63	73	108	128	27	28
	150	24	29	65	73	111	127	26	30
	180	26	31	67	79	116	123	28	26
PULL	60	17	21	57	61	97	113	24	26
	90	23	24	66	73	118	121	26	30
	120	22	31	74	86	126	147	30	34
	150	21	29	70	81	122	133	28	33
	180	18	31	61	69	111	118	26	26
LEFT	60	8	16	24	48	49	91	12	22
	90	6	16	22	46	45	87	10	21
	120	6	15	20	48	38	97	9	25
	150	5	15	20	45	56	93	15	26
	180	4	12	22	37	57	71	19	17
RIGHT	60	11	12	44	29	99	57	24	12
	90	13	13	40	28	92	51	22	11
	120	9	11	38	28	91	58	23	12
	150	8	12	34	28	79	60	23	14
	180	10	9	31	24	67	61	19	14
UP	60	13	13	35	44	71	85	17	21
	90	15	15	40	52	78	94	18	22
	120	11	13	40	50	81	91	21	21
	150	7	13	31	41	62	83	17	23
	180	5	8	18	23	44	47	12	12
DOWN	60	10	13	30	34	51	61	12	13
	90	12	16	31	36	57	60	12	13
	120	11	15	31	35	57	61	14	15
	150	10	15	28	34	48	60	11	13
	180	7	13	25	25	41	47	10	10

HUNSICKER, 1955.



PRONE POSITION

Table XII

Mean and Standard Deviation of
Maximum Torque by Knob Size
(Torque in Inch-Ounces)

Knob Size (Inches)	RIM SURFACE					
	Rectangular Knurl		Diamond Knurl		Smooth	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1/8	8.4	3.1	9.1	3.1	3.0	1.5
1/4	18.6	5.4	19.6	5.4	8.3	3.3
3/8	27.7	7.6	31.8	9.1	13.4	4.4
1/2	42.6	12.8	45.9	13.5	21.8	7.6
5/8	60.3	17.3	64.9	21.5	27.2	8.6
3/4	85.4	28.7	93.1	33.1	39.8	10.6
7/8	104.9	35.1	112.6	40.2	47.9	15.6
1	115.6	31.8	116.0	35.5	59.1	21.3
1-1/4	120.7	35.6	132.9	37.7	59.9	17.2
1-1/2	156.6	41.0	146.8	37.5	97.4	26.4
1-3/4	199.6	51.5	205.3	52.8	124.7	38.7
2	244.5	64.7	210.2	48.9	148.0	46.7
2-1/4	294.4	78.5	287.5	74.5	187.0	52.0
2-1/2	367.9	103.2	371.9	113.6	236.2	63.1
2-3/4	403.1	95.1	423.9	108.4	238.9	69.2
3	444.3	114.2	477.7	136.6	267.2	81.1
3-1/2	553.4	147.1	607.3	158.9	400.4	116.6
4	694.8	180.8	698.0	173.9	454.2	135.3
4-1/2	814.8	219.7	855.7	236.0	542.4	150.9
5	898.5	219.5	973.4	262.8	716.4	225.8

operation and should be followed wherever possible. (Hedberg, 12; Sharp, 13; Worms, 14).

5.4.1.1.4 Maximum torque for two hands. - For gross mechanical application, the following torque value will be used as maximum values. (Graves, 15; McFadden, 16). XR-S-2

Average worker:	260 pound-inches
Above average worker:	400 pound-inches

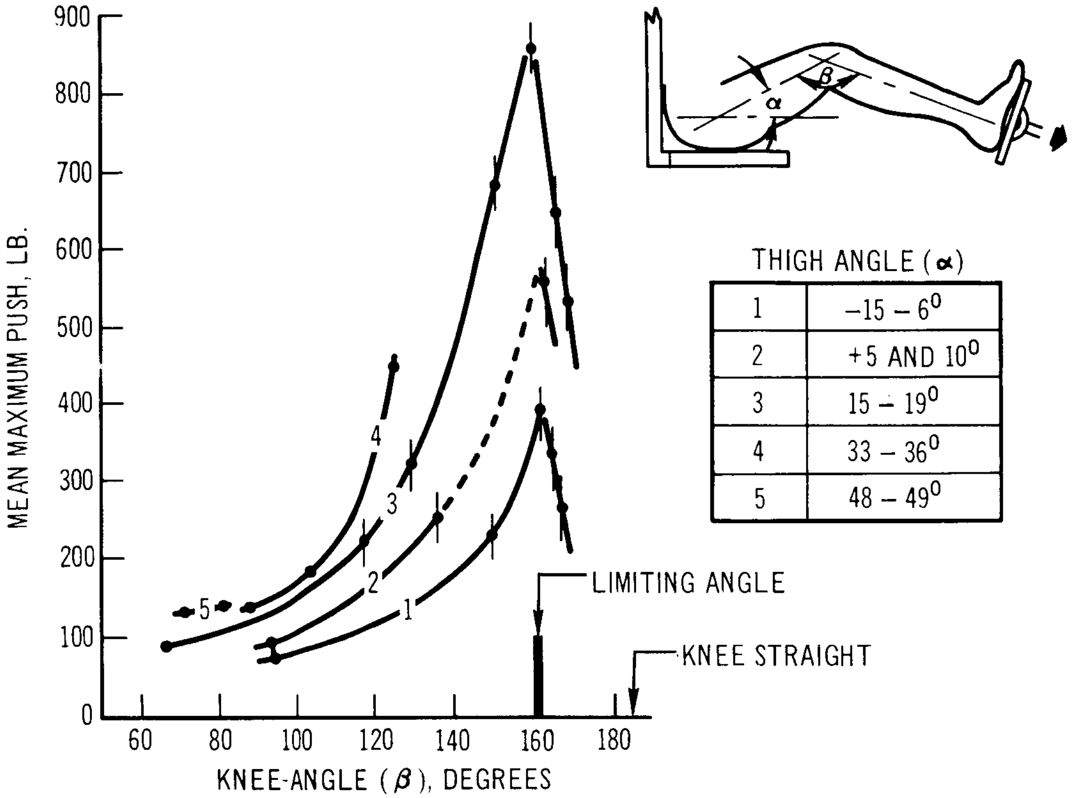
5.4.1.2 Leg strength.

5.4.1.2.1 Provision for back-rest. - A back-rest shall be provided for the operator for maximum force exertion. (Brozek, 17; Caldwell, 3, 4; Elbel, 18, 19; Hansen, 20; Hugh-Jones, 1; Rees, 21). XR-S-2

5.4.1.2.2 Value of force exerted. - The amount of force exerted (pushed) by the leg depends on the thigh angle and knee angle. The angle of the seat usually determines the thigh angle. The maximum push is at about the 160 degree angle called the limiting angle. See figure 34 for values. (Dempster, 72; Hugh-Jones, 1). XR-S-2

5.4.1.3 Strength of various body members. - Maximum strength values are listed in figures 35 and 36. These values shall be used as limits in system design wherever applicable. The valves are for the following body parts. (Clarke, 23, 24, 25). XR-S-2

(a)	Trunk flexion	127 pounds
(b)	Trunk extension	235 pounds
(c)	Trunk lateral flexion	159 pounds
(d)	Trunk rotation	36 pounds
(e)	Hip flexion	109 pounds
(f)	Hip extension	175 pounds
(g)	Hip adduction	112 pounds
(h)	Hip abduction	109 pounds
(i)	Ankle inversion	39 pounds
(j)	Ankle eversion	31 pounds



THIGH ANGLE (α)

1	−15 – 6°
2	+5 AND 10°
3	15 – 19°
4	33 – 36°
5	48 – 49°

Figure 34. Leg strength at various knee angles

5.4.1.4 Facts relating to human strength. - The following subsection lists facts about human strength. These facts shall be considered in deciding values of strength requirements. (Hunsicker, 2). XR-S-2

5.4.1.4.1 Age. - Strength increases with age for the first twenty years; remains at this level for five or ten years; then decreases gradually throughout the rest of life. Physical exercise can delay the decrease. (Burke, 26; Fisher, 27). XR-S-2

5.4.1.4.2 Sex. - Adult females have about one third less strength than males. (Hunsicker, 2). XR-S-2

5.4.1.4.3 Sides differences. - There is only a slight difference in the strength of the two sides of the body. (Hunsicker, 2; Provins, 5, 6, 7). XR-S-2

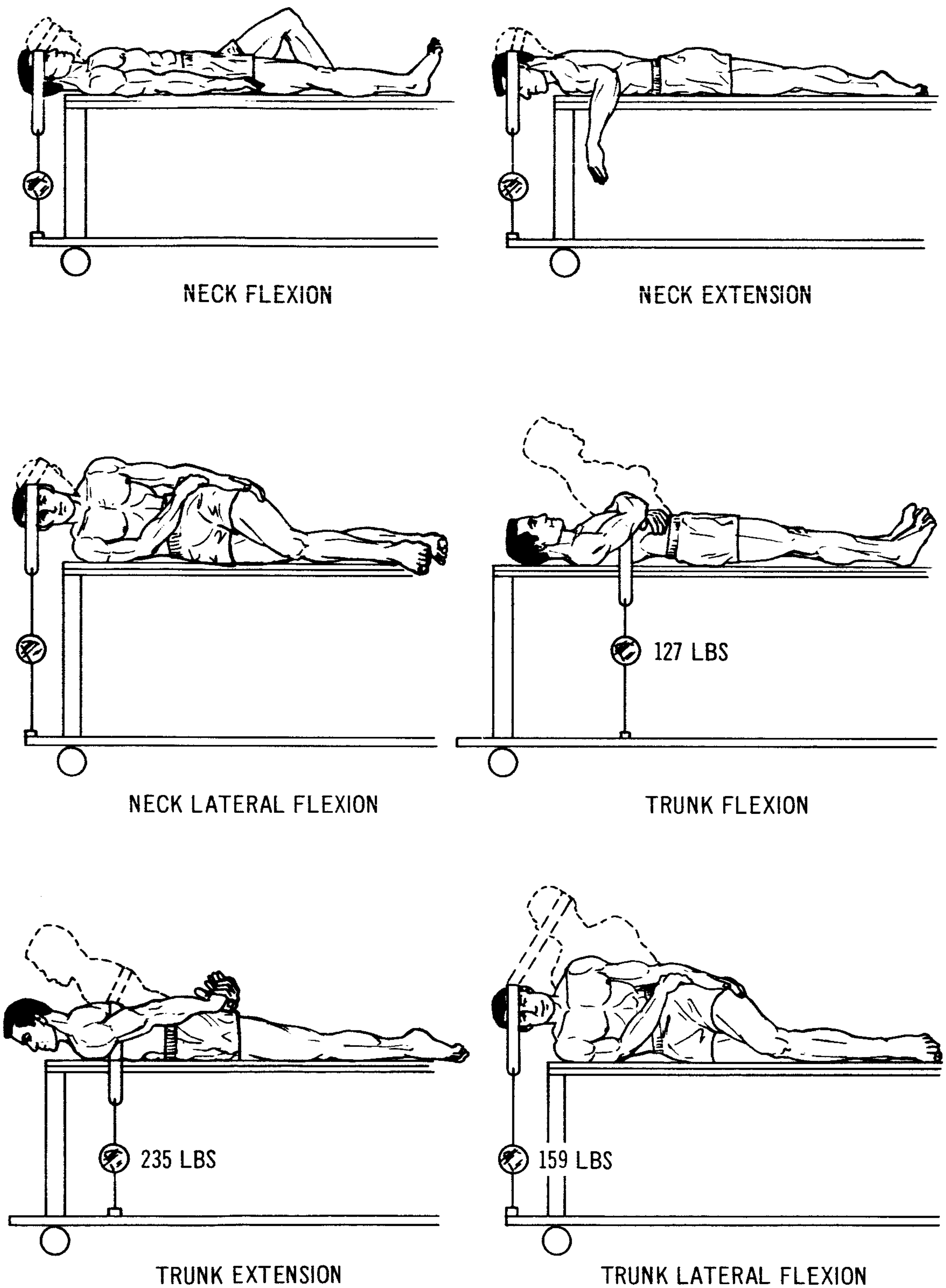


Figure 35. Strength of various body members, view A

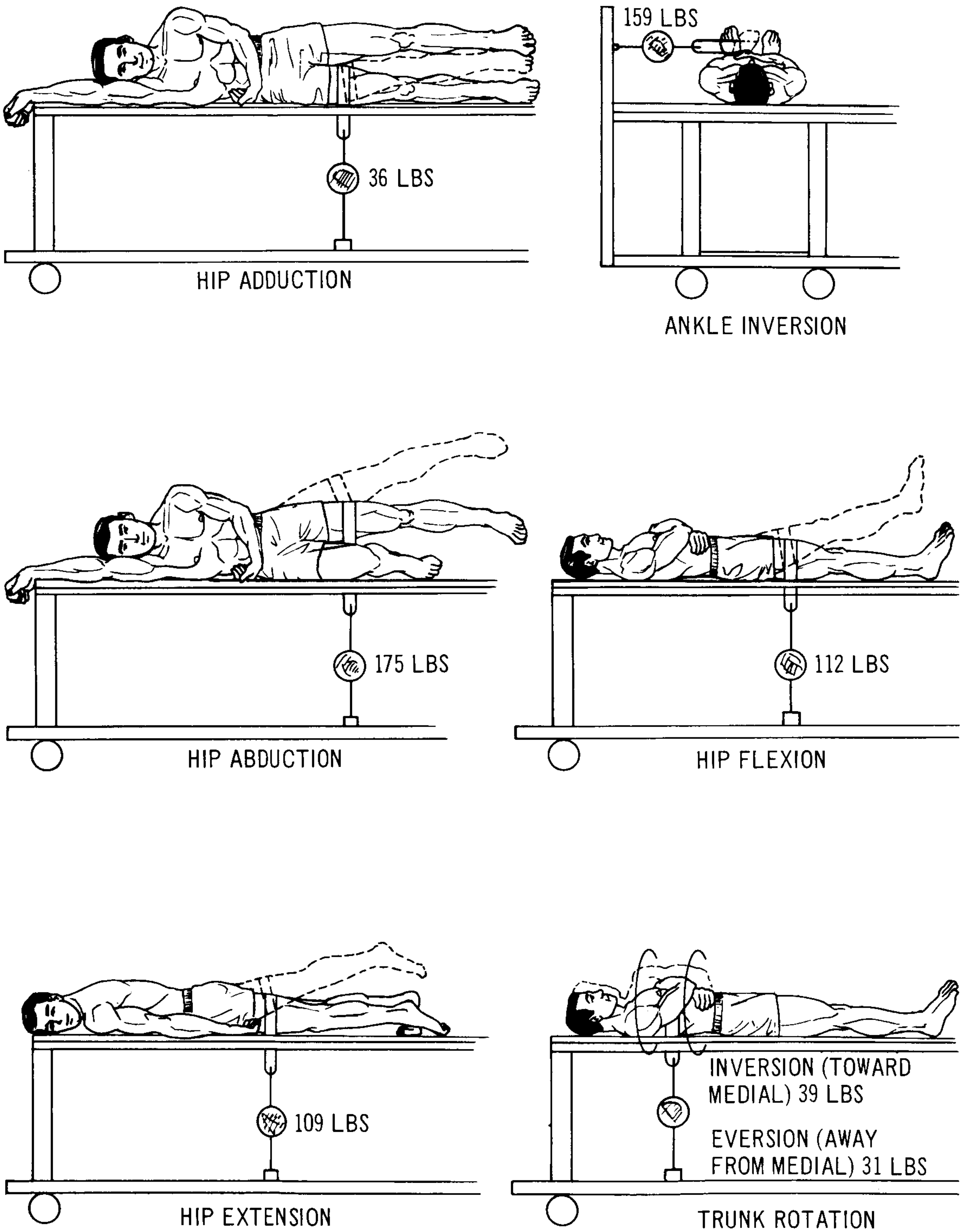


Figure 36. Strength of various body members, view B

5.4.1.4.4 Static and dynamic strength. - There is a difference between static strength and dynamic strength and the correlation between the two is not high. (Hunsicker, 2). XR-S-2

5.4.1.4.5 Muscle tissue. - Difference in strength may be due to the amount of muscle tissue, bodily configuration, muscle quality, and innervation. (Hunsicker, 2). XR-S-2

5.4.1.4.6 Testing. - It is possible to test several of the larger muscle groups of the body and get a good overall picture of the individual's strength. (Hunsicker, 2). XR-S-2

5.4.1.4.7 Increase and decrease strength. - Exercise, rest and food will normally increase muscular strength while fatigue and hunger will decrease strength. (Hunsicker, 2). XR-S-2

5.4.1.4.8 Exercise. - The exercise of one limb will increase the strength of the contralateral limb. (Hunsicker, 2). XR-S-2

5.4.2 Weight lifting and carrying. - The preceding subsection, 5.4.1, on strength is concerned more with the static aspects of muscular activities. This subsection shall deal more with the dynamic aspect. In general static strength connotes a brief maximum effort with a person in a relatively fixed position while dynamic strength connotes some complex repetitive effort with the person in a state of motion. While a clear cut distinction between static strength and dynamic strength is not possible, it is nevertheless necessary to make some distinction for one important reason. Namely, data derived from studies of static muscle strength are not necessarily applicable to a weight lifting and carrying situation. (Carlock, 28; Hunsicker, 2). XR-S-2

5.4.2.1 Factors to consider. - The following factors shall be considered in determining optimum weight load. (See Maintainability 5.8.7 for ideal limits.)

5.4.2.1.1 Physical size (bulk).

(a) To maintain easy portability, the weight of a package shall bear an inverse relation to its size. That is, weight of large-size packages shall be kept to a minimum. XR-C-2

(b) If a package is designed for one-man carry, the package's center of gravity shall be kept as close to the body of the carrier as possible. The body trunk shall be allowed to maintain a vertical position while carrying whenever possible. A maximum of 20 inches from the body is advisable. (ARDCM 80-6, 29; Davis, 30; Whitney, 31). XR-S-2

5.4.2.1.2 Frequency of move. - As the frequency of move increases, the load carrying capability decreases. If the frequency of move is high, the weight of the package shall be kept at a minimum. See table XIII. (ARDCM 80-6, 29). XR-A-3

5.4.2.1.3 Horizontal distance. - As the distance of the carry increases, the load carrying capability decreases. If the package is to be moved over long distances, its weight shall be kept to a minimum. See table XIII. (ARDCM 80-6, 29). XR-A-3

Table XIII.

Recommended weight limit for different distance and frequency of movement

Size	Occasional Movement or Short Distances	Frequent Movement or Long Distances
Compact	60 using both hands	35 using both hands
Bulky (30" per side)	20 using both hands	-- using both hands
Compact	30 using one hand	20 using one hand
from ARDCM 80-6, 29.		

5.4.2.1.4 Vertical distance. - As the height to which the package to be lifted increases, the weight lifting capability decreases. See figure 37 for weight lift values. (ARDCM 80-6, 29; Emanual, 32; Switzer, 33). XR-S-2

The following facts shall be considered when weight lifting is required:

(a) Lifting force is greatest when the weight lifted is in the same vertical plane as the body. This force decreases sharply as the weight moves away from the body. (Davis, 30; Whitney, 31). XR-S-2

(b) There is a sharp drop in weight lift capacity in the transition from 2 to 3 feet (roughly waist level); a 5 percentile man can lift 139 pounds at 2 feet and only 77 pounds at 3 feet. (Emanuel, 32). XR-S-2

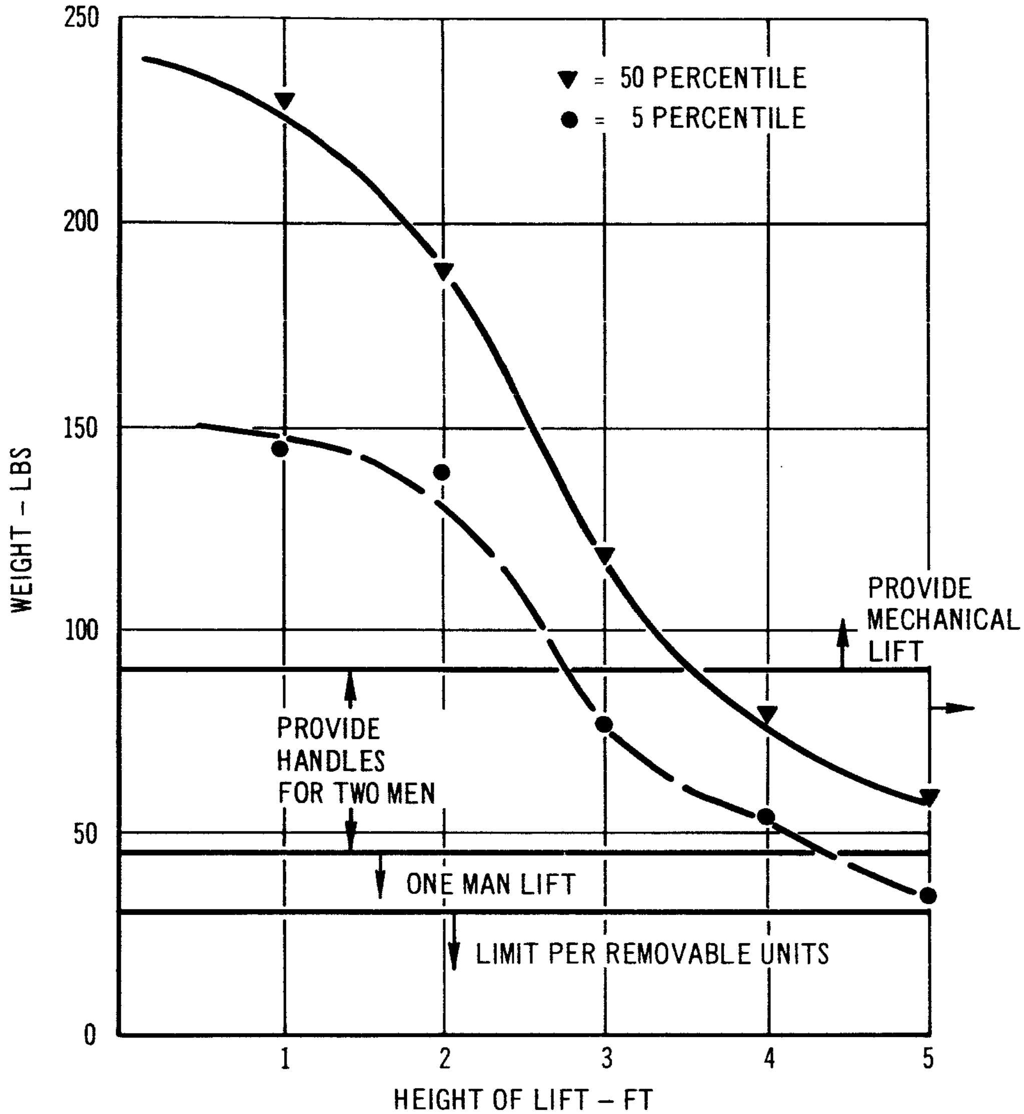


Figure 37. Vertical weight lift capacity

NOTE:
The origin of the lower limit recommendation is unknown. Some studies have found that, subjectively, a weight feels "heavy" at 35 percent of the body weight, and that there is a high rise in energy expenditure when loads in excess of 30 to 40 percent of body weight is carried. Thirty to 35 percent of the average body weight is about 45 pounds. (Bailey, 34; Bedale, 35; Teeple, 36). However, as high as 75 percent of body weight has been carried without adverse decrement in performance. (Carlock, 28; Cathcart, 37; Daniels, 38, 39; Kolnicker, 40; Tolcott, 41; Vanderbie, 42). Weight data from Emanuel (32). Figure adapted from Boeing D5-11136, assumed good handling surface.

(c) Three muscle components are involved in vertical lifting: the legs, arm-back, and arms. These are used in different combinations depending on the height of the lift. Objects lifted to knee height (18 inches) involves primarily the leg components, waist level (42 inches) involves a combination of arm and back components, and shoulder level (63 inches) or higher requires all 3 components. (Switzer, 33). XR-S-2

5.4.2.1.5 Relationship to body.

(a) Wherever possible, the package shall be designed to be carried by the upper part of the body (waist or higher). (Kolnicker, 40; Tolcott, 41). XR-S-2

(b) The package shall be designed to be carried relative to a vertical plane of the carrier's body. (Davis, 30; Whitney, 31). XR-S-2

5.4.2.1.6 Limb and body support.

(a) Two hands may carry twice the weight that one hand may carry. (Hunsicker, 2; Provins, 5). XR-S-2

(b) Heavier loads may be lifted and carried for short distances if some parts of the body (eg, thigh, chest) are used for support. (Hunsicker, 2). XR-S-2

5.4.2.1.7 Handling or gripping surface. - Suitable handles or gripping surfaces shall be provided. See Maintainability 5.8.7 for details on handles. XR-S-2

5.4.2.1.8 Other methods of carry. - In addition to hand carry, there are other methods of carrying loads, eg, back packs. The following shall apply for methods other than hand carry.

5.4.2.1.8.1 Back carry. - The package for back carry shall be designed for carry by the upper part of the body (above waist). Carriage high on the back is preferable to low pack carriage for most purposes and for any load over 46 pounds. (Hale, 43; Kolnicker, 40; Malhotra, 44; Tolcott, 41). XR-S-2

5.4.2.1.8.2 Thigh carry. - Thigh carry shall not be used where energy expenditure is of an important consideration. (Kolnicker, 40; Tolcott, 41). XR-S-2

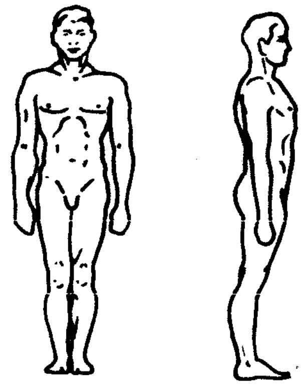


Figure 38. Anatomic neutral position

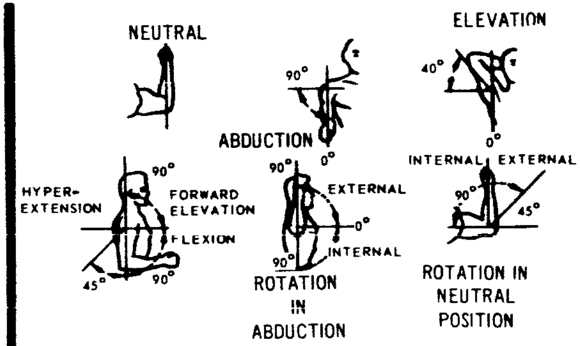


Figure 41. Average normal range of motion of the shoulder

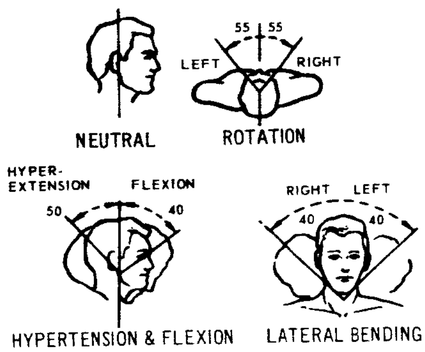


Figure 39. Average normal range of motion of the neck

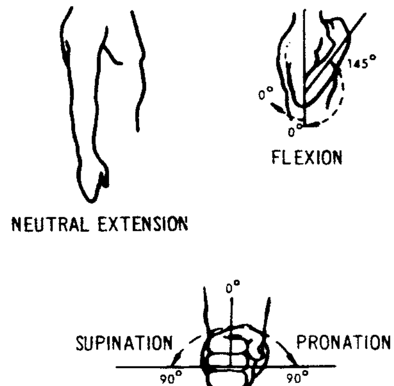


Figure 42. Average normal range of motion of the elbow

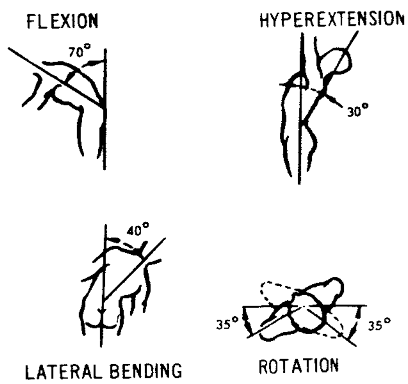


Figure 40. Average normal range of motion of the spine

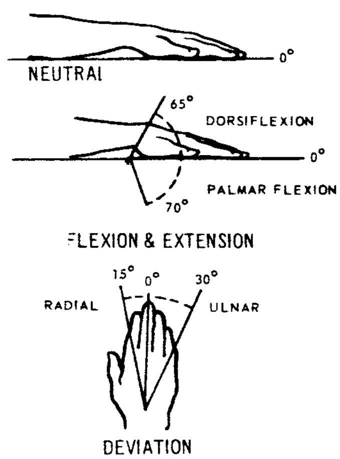


Figure 43. Average normal range of motion of the wrist

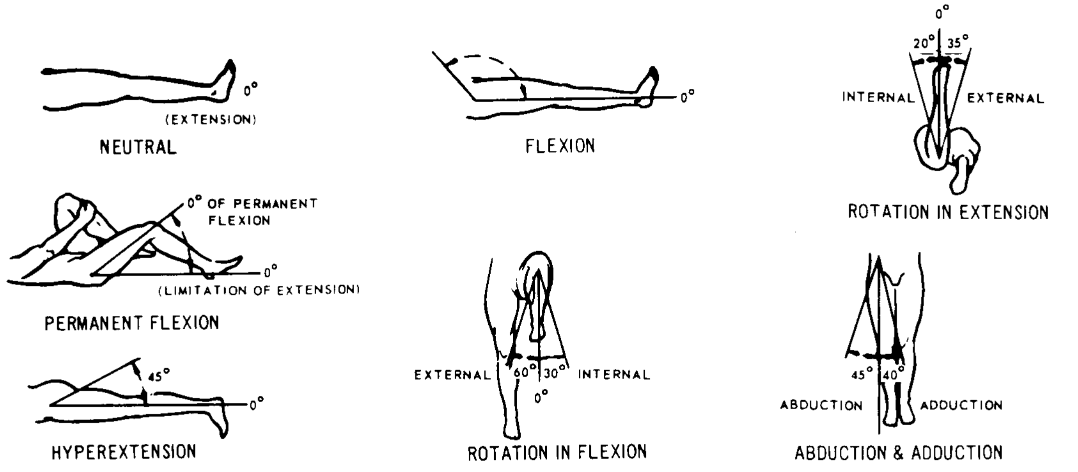


Figure 45. Average normal range of motion of the hip

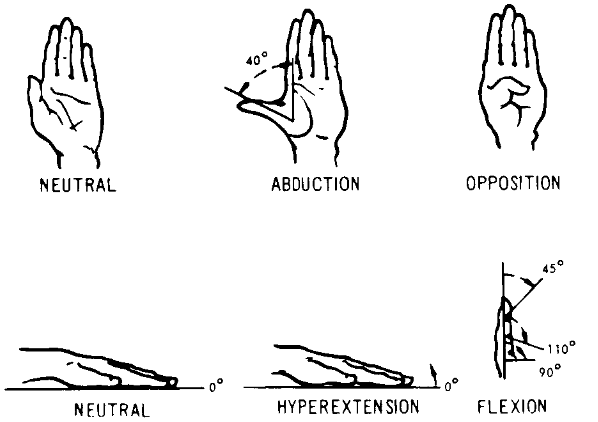


Figure 44. Average normal range of motion of the finger

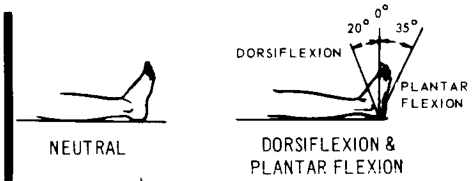
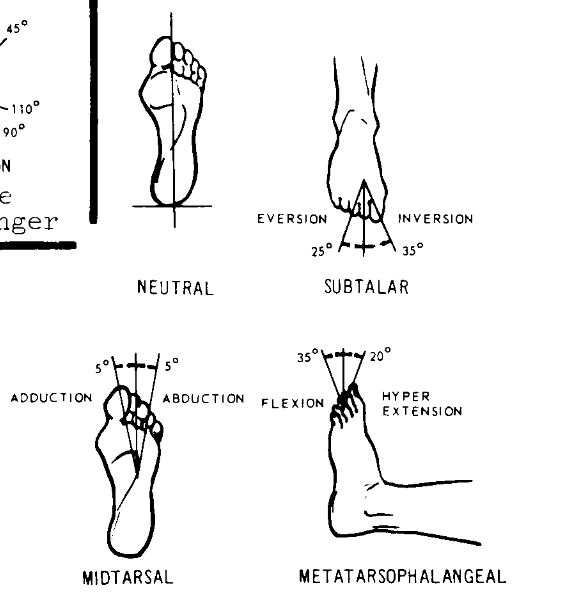


Figure 47. Average normal range of motion of the ankle



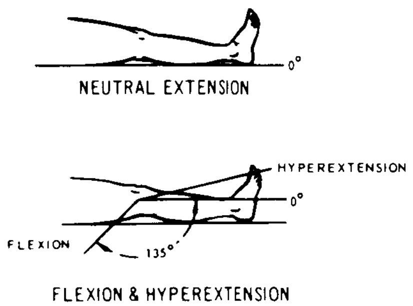


Figure 46. Average normal range of motion of the knee

Figure 48. Average normal range of motion of the foot

5.4.2.1.8.3 Weight distribution. - The weight of the load for back carry shall be distributed over a wide area of the back. (Kolnicker, 40; Tolcott, 41). XR-S-2

5.4.3 Body movement.

5.4.3.1 Requirements. - The design of equipment shall take into consideration the degree and extent the human body can move. The parts of the body and the normal range of motion are as listed below with reference to their respective figure numbers. These values shall be used wherever applicable. See Anthropometry 5.5.1.8 for other related values. (Batch, 45). XR-S-2

(a) Body position figure 38

(b) Neck figure 39

(c) Spine figure 40

(d) Shoulder figure 41

(e) Elbow figure 42

(f) Wrist figure 43

(g) Finger figure 44

(h) Hip figure 45

(i) Knee figure 46

(j) Ankle figure 47

(k) Foot figure 48

5.4.4. Human reaction time. - Human reaction time (human lag time) is defined as the total time required to sense a signal (stimulus) and to make the decision and the movement appropriate to that signal. This time lag contributes to the total operating time of the man-machine system and its importance depends upon the effect it has on the over-all mission of the system. If this time lag is of critical importance to the success of the mission, the following subsection shall be taken into consideration in system design. Only simple reaction time will be considered here. In general, the data are from ideal conditions. (Gottsdanker, 46, 47; Teichner, 48). XR-S-2

5.4.4.1 The senses.

5.4.4.1.1 Senses used. - Any sense organ can be used for receiving a signal if the proper and adequate stimulus is given. Generally, only three, visual, auditory, and tactual are used. The fastest reaction times are, in order, for stimuli presented to the ear, the skin and the eye. See figure 49. Realistically, the differences are not significant for most applications. (Ely, 49; Teichner, 48). XR-S-2

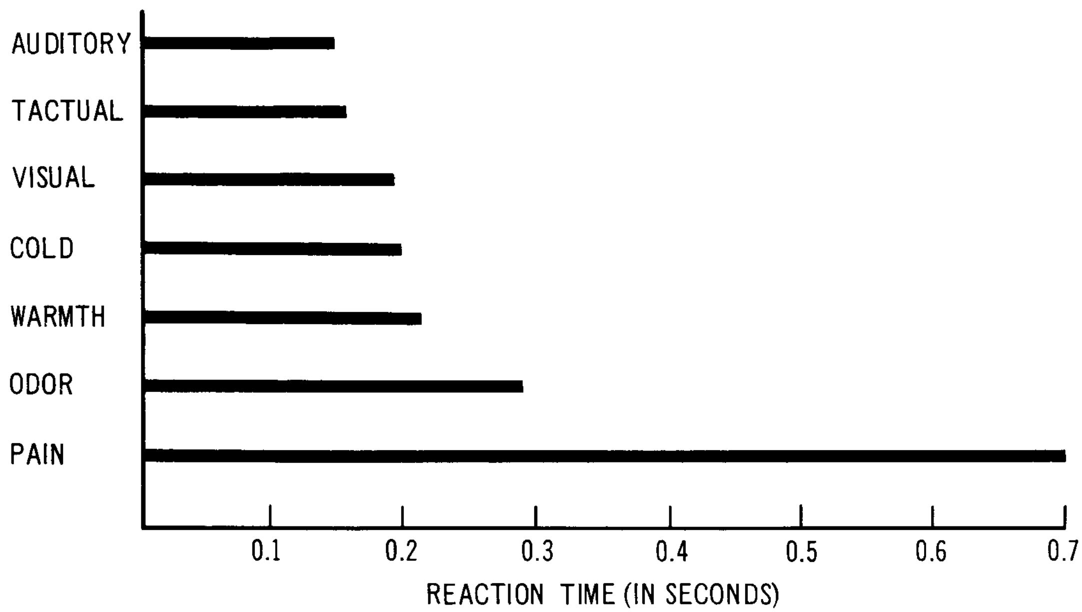


Figure 49. Human time lag for seven sense modalities

NOTE:
The total man-machine response time includes the time lag of the machine to respond to the control and the time required to complete the machine response. While machine characteristics are not the concern of this study, the designer shall consider them in addition to the human lag time where it is important.

The illustrated reaction times are useful in making comparisons among senses. They are not necessarily representative of reaction times in a practical situation where other factors may distract the operator.

5.4.4.1.2 Selection. - Selection of signal mode shall be as follows:

5.4.4.1.2.1 Visual signal. - In general, the visual channel shall be used where the amount of information to be presented by a single signal is large. (Woodworth, 50). XR-S-2

5.4.4.1.2.2 Auditory or tactual signal. - When the operator's visual channel is occupied or where it is desirable to avoid head movement in order to receive stimulus, the auditory or tactual modes shall be used. (Ely, 49). XR-S-2

5.4.4.2 Signal (stimuli) characteristics. - The following subsection shall apply to the various stimuli where optimal reaction time is desired.

5.4.4.2.1 Single (one) sense. - Both eyes or ears shall be stimulated simultaneously for faster reaction time. (Teichner, 48). XR-S-2

5.4.4.2.2 Two or more senses. - Two or more senses shall be stimulated simultaneously for faster reaction time. Successive stimulation shall be avoided as it produces slower reaction time due to physiological inhibition. (McCormick, 51; Teichner, 48; Vince, 52).

5.4.4.2.3 Intensity. - The intensity of the stimulus shall be increased for faster reaction time. This applies for an intensity above threshold to a "moderate" value; after this, reaction time may be slowed. Magnitude and duration of a signal have a marked effect upon reaction performance. The more intense, bright, loud, or larger the signal, the easier it is to detect and respond to rapidly. (Adams, 53; Bakan, 54; Broadbent, 55; Teichner, 48). XR-S-2

5.4.4.2.4 Number of receptors. - The number of receptors stimulated shall be enlarged for faster reaction time; eg, increasing amplitude of a warning signal increases number of receptors stimulated and increases probability of recognition. (Teichner, 48; Woodworth, 50). XR-S-2

5.4.4.2.5 Stimulus change. - The amount of stimulus change shall be increased for shorter reaction time. No more than one change shall be used within a short period of time and the change shall be decremental (reduction) rather than incremental (increase) in nature. (Teichner, 48). XR-S-2

5.4.4.2.6 Alerting or warning signal. - A ready or warning signal shall precede the critical signal wherever possible. Simple reaction time may be reduced by 40 percent. (Siegel, 56; Teichner, 48). XR-S-2

(a) Alerting signal shall precede action signal by from 2.0 to 8.0 seconds for isolated signal and by from 0.3 to 2.0 seconds for signals occurring in sequence. (Leonard, 57; Woodworth, 50). XR-S-2

(b) Very short alerting period (less than 0.1 second) shall be avoided. (Ely, 49). XR-S-2

(c) Flashing rate: see 5.2.3.1.1.1 (f).

(d) Insofar as signal frequency is controllable, it shall be kept high. As an approximate guide, these factors shall be considered: (Ely, 49). XR-S-2

   (1) For 1 to 10 signals per hour expect considerable decrement in reaction behavior.

   (2) For 10 to 20 signals per hour expect moderate decrement in reaction behavior.

   (3) For over 20 signals per hour expect little decrement in reaction behavior.

5.4.4.2.7 Irrelevant signals. - Intermittent irrelevant signals may be introduced where monitoring is required and optimal reaction is desired. (Colquhoun, 58; Lawson, 59). XR-S-2

5.4.4.2.8 Signal discrimination. - The signal shall be easily discriminable for faster reaction time. (Baxter, 60; Crossman, 61). XR-S-2

5.4.4.2.9 Number of signals. - The number of signals shall be kept to a minimum for faster reaction. As the number of signals increases the time required to respond to any single one also increases. See figure 50. (Crossman, 61; Gottsdanker, 46, 47; Hick, 62; Saltzman, 63; Sender, 64). XR-S-2

5.4.4.2.10 Time uncertainty. - When the operator is not informed as to when a signal will occur, his reaction time to that unexpected signal is greater than when he knows when to expect the signal. Unexpected signals should be avoided wherever possible. (Klemmer, 65). XR-S-2

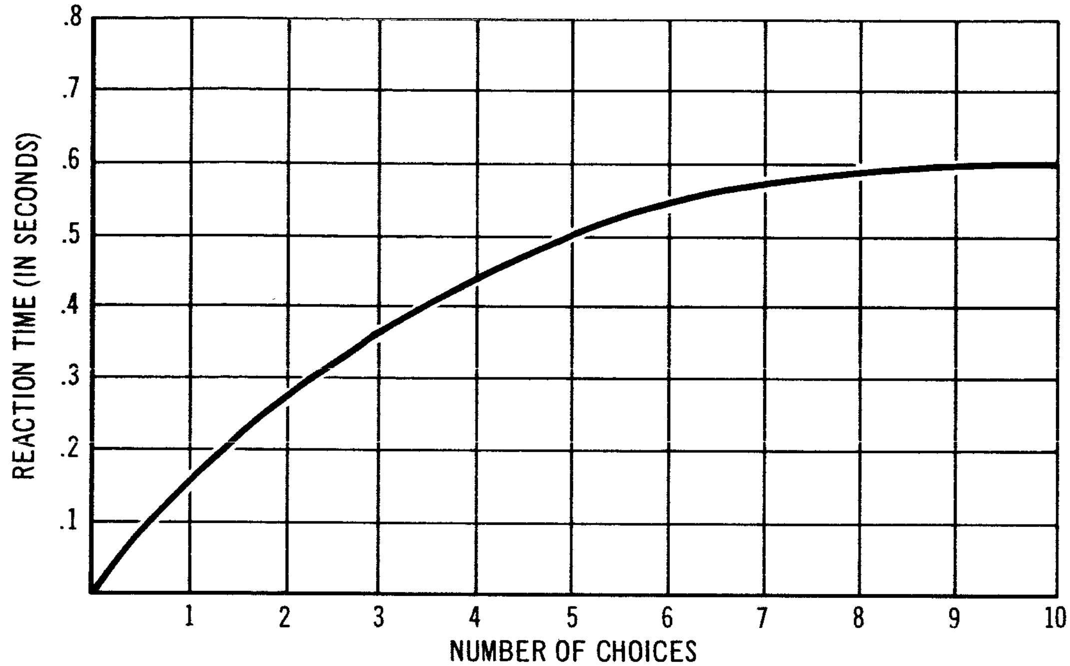


Figure 50. Operator reaction time versus number of choices

5.4.4.2.11 Auditory signals. - In addition to the preceding statement on auditory signals, the following shall apply specifically to auditory signals.

(a) An auditory signal shall be distinguished from background noise. XR-C-2

(b) High frequency sound shall be preferred over low frequency sound as it is not as easily masked and it is easier to detect. (Broadbent, 55; Stevens, 66). XR-S-2

(c) Signals shall be at least 0.5 seconds long. Normally, it shall continue until the appropriate response has been made. (Ely, 49). XR-S-2

(d) Auditory signals shall be used when accompanying visual tasks are liable to distract the operator. XR-C-2

5.4.4.2.12 Visual signals. - In addition to the preceding statements on visual signals, the following shall apply specifically to visual signals.

(a) For light adapted eyes, visual signal shall strike the center (fovea) of the eyes, rather than the peripheral. (Stevens, 66). XR-S-2

(b) For dark adapted eyes, visual signals shall strike the peripheral of the eyes. (Stevens, 66). XR-S-2

(c) Minimum duration of the signals shall be 0.5 seconds. The signal shall persist until it has been responded. (Ely, 49). XR-S-2

5.4.4.3 Operator and decisional characteristics. - The following subsection shall apply to the operator for optimal decision making in reaction behavior.

5.4.4.3.1 Training emphasis. - Training of the operator shall emphasize the preparation to respond rather than (but not to the exclusion of) preparation to receive stimulation. (Mowbray, 67; Teichner, 48). XR-S-2

5.4.4.3.2 Amount of training. - The amount of training and practice shall be increased for shorter reaction time. (Chapanis, 68; Gibson, 69; Karpovich, 70; Leonard, 57; Mowbray, 67; Woodworth, 50). XR-S-2

5.4.4.3.3 Simplicity of response. - The response shall be planned and designed to be as simple and direct as possible. XR-C-2

5.4.4.3.4 Number of signals or choices. - When fast operator reaction is required, the number of signals or choice to be reacted to shall be kept at a minimal. In general, decision time is proportional to the logarithm of the number of alternative choices. The exceptions are as listed below. See figure 50.

(a) The signal with the greatest probability of occurrence is reacted to more quickly. (Edwards, 71, 72, 73, 74; Goodnow, 75, 76). XR-S-2

(b) Signals in a meaningful sequence are reacted to more rapidly. (Ely, 49). XR-S-2

(c) Signals grouped in a meaningful fashion are reacted to more readily. (Murdock, 77; Thorpe, 78). XR-S-2

5.4.4.3.5 Signal rate. - The signal shall not exceed the operator's ability. If the signal arrives at a rate too fast for the operator to handle, he can either (1) keep himself current with the new signal by omitting a certain percentage of responses or (2) lag behind the current signals and, by relying on his memory, hope to catch up when the signal rate decreases. Under these conditions total failure may result in loss of contact with incoming signals. (Cardozo, 79; Ely, 49; Hayes, 80; Mayzner, 81; Miller, 82; Murdock, 77; Pollack, 83). XR-S-2

5.4.4.3.6 Signal channels. - The use of many signal channels (sources) shall be avoided. Operator performance will be better (eg, he can handle a greater number of signals) with fewer channels and a relatively high signal rate rather than with many channels and a relatively low signal rate. (Conrad, 84; Ely, 49; Hayes 80).

5.4.4.3.7 Proper control-display relationship. Control-display relationship shall be meaningful and immediately apparent for shorter reaction delay. (Grahm, 85). See section 5.3. XR-S-2

5.4.4.3.8 Anticipatory information. - Some means of anticipatory information; eg, ready signal, shall be provided whenever possible. (Ely, 49; Teichner, 48). XR-S-2

5.4.4.3.9 Feedback. - Feedback concerning the operator's proficiency shall be provided to the operator wherever practical for shorter reaction time. (Leonard, 57; Pruitt, 86). XR-S-2

5.4.4.3.10 Comfort. - The operator shall be situated in a comfortable operating environment or work space for shorter reaction time. Discomfort from such factors as extreme temperature is detrimental to optimal reaction behavior. (Williams, 87). XR-S-2

5.4.4.3.11 Noise level. - The operator shall be located in a work environment below 90 db. Above this critical level noise can affect reaction behavior adversely. (Woodhead, 88, 89). See section 5.6.3. XR-S-2

5.4.4.3.12 "Feel" of control. - The controls used shall contain the minimum force consistent with proper "feel" condition. XR-C-2

5.4.4.4 Response characteristics.

5.4.4.4.1 Limbs used. - Reaction time for the various limbs show only a small difference. These facts shall be considered in selecting the limbs used.

(a) When controls must be selected on the basis of speed of activation, the following shall be the order of selection (assuming being right handed): right hand, left hand, right foot, left foot. The preferred limb is about 3 percent faster than the non-preferred limb. The feet take about 20 percent longer to respond than the hands. (Ely, 49; Teichner, 48). XR-S-2

(b) No appreciable difference in reach time exists for distances up to 15 inches. Controls requiring fast reaction time shall be kept within 15 inches of the operator. (Ely, 49). XR-S-2

5.4.4.4.2 Other factors. - Response time depends also on factors such as the complexity of the response, the work space available and the limitation of special equipment. These are independent variables which shall not be dealt with here. The designer shall consider such variables and consult with the appropriate human factors engineering group in accordance with MSFC STD 391. XR-C-2

HUMAN CAPABILITIES AND HUMAN RESPONSES

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DETAILED REQUIREMENTS
ILLUMINATION, VIBRATION & NOISE

VIBRATION

ANTHROPOMETRY	5.5.1
General: anthropometric measurement important	5.5.1.1
Decision factors: consider,	5.5.1.2
Physical measurement of man	5.5.1.2.(a)
Task requirements	5.5.1.2.(b)
Position of body	5.5.1.2.(c)
Mobility requirements	5.5.1.2.(d)
Identify obstacles	5.5.1.2.(e)
Identify tools, test equip., garments, etc.	5.5.1.2.(f)
Specific criteria: consider,	5.5.1.3
Range: design for 95%. See text, fig. 51 & table XIV	5.5.1.3.1
Inclusive: 95%. See text	5.5.1.3.2
Exclusive: 5%. See text	5.5.1.3.3
Adjustable: 5% thru 95%. See text	5.5.1.3.4
Trade offs: See table XIV	5.5.1.3.5
Factors affecting human-body measurement: consider,	5.5.1.4
Human variability: man is highly variable	5.5.1.4.1
Man's parts vary as well (hand size, etc.)	5.5.1.4.1.1
Designer must accommodate for variability	5.5.1.4.1.2
Allow for slump. See text	5.5.1.4.1.3
Clothing and personal equipment: consider,	5.5.1.4.2
Allow for increment of clothing	5.5.1.4.2.1
Heavy winter clothing: See tables XV & XVI	5.5.1.4.2.2
Street and winter clothing: See table XVII	5.5.1.4.2.3
Sitting height: 0.2 to 0.3 inch where heavy clothes	5.5.1.4.2.4
Shoes: plus 1 inch	5.5.1.4.2.5
Headgear: no rule, measure. See table XVII	5.5.1.4.2.6
Handwear: See fig. 52	5.5.1.4.2.7

Determination of anthropometric data: consider,	5.5.1.5
Validity: only valid when correct population is used	5.5.1.5.1
Size: sample size must be at least 50	5.5.1.5.2
Measuring techniques: see figs. 53 & 54	5.5.1.5.3
Static human body dimensions: nude and erect	5.5.1.6
Application: See tables XV and XVI and figs. 53 & 54	5.5.1.6.1
Standard deviation: See text	5.5.1.6.2
Dynamic human body dimensions: See fig. 55	5.5.1.7
Working positions: kneeling, crawling & prone	5.5.1.7.1
Kneeling: See fig. 55 & table XVIII	5.5.1.7.1.1
Crawling: See fig. 55 & table XVIII	5.5.1.7.1.2
Prone: See fig. 55 & table XVIII	5.5.1.7.1.3
Functional arm reach: consider,	5.5.1.7.2
Vertical reach, seated: See fig. 56	5.5.1.7.2.1
Horizontal reach, seated: See fig. 56	5.5.1.7.2.2
Push buttons: 5% + 2.5 inch	5.5.1.7.2.2.1
Lever controls: within 5%	5.5.1.7.2.2.2
Infrequently used devices: See text	5.5.1.7.2.2.3
Reduction of reach: See text	5.5.1.7.2.2.4
Forward reach, standing: See fig. 57 & table XIX	5.5.1.7.2.3
Overhead reach, standing: See fig. 57 & table XIX	5.5.1.7.2.4
Unrestrained seated reach: See table XX	5.5.1.7.2.5
Range of movement of body members: check individual differences	5.5.1.8
Joint movement: See text	5.5.1.8.1
Joint of neck: See 5.4.3.1	5.5.1.8.1.1
Joint of hand & arm: See fig. 58 & table XXI	5.5.1.8.1.2
Joint of foot and leg: See fig. 59 & table XXII	5.5.1.8.1.3
Estimation of correlated measures: See table XXIII	5.5.1.9

5.5 Anthropometry and work space.

5.5.1 Anthropometry. - Anthropometry shall be considered as the science of human body measurement. Such measurement shall include body dimensions (both static and dynamic), range of movement of body members, and muscle strength. (Also see section 5.4.1) XR-C-1

5.5.1.1 General criterion. - The selection of appropriate dimensions for the design of equipment that will be operated or maintained by personnel shall be considered as a critical factor in the success of the equipment. For efficient operation, the equipment shall match the range of the physical sizes of the personnel using the equipment. The basic principle to be observed shall be the designing of equipment to suit the operator instead of selecting operators to fit the equipment. (McFarland, 1) XR-S-2

5.5.1.2 Decision factors. - Equipment dimensions and related work area dimensions shall be determined after taking the following into consideration: (McFarland, 1) XR-S-2

(a) The physical measurements of man himself, his size, shape and capabilities.

(b) The nature, frequency, difficulty, and duration of the task.

(c) The general position of the body during execution of the task.

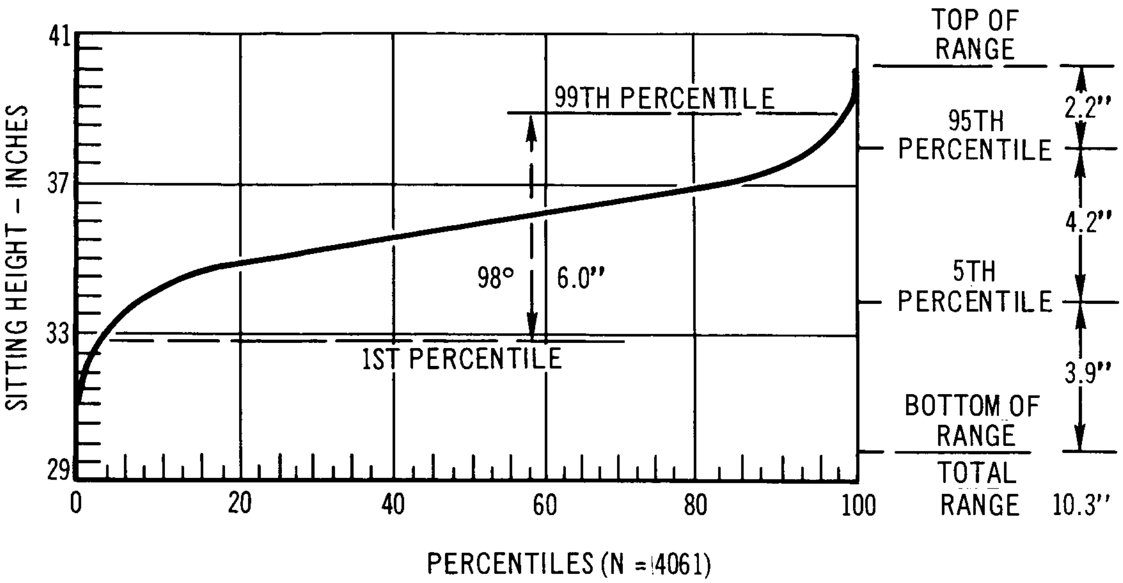
(d) The mobility requirements of the task.

(e) The existance of obstacles or projections which would reduce usable work space dimensions.

(f) The tools, test equipment, lines, and protective garments and devices that increases the work space dimensions.

5.5.1.3 Specific criteria.

5.5.1.3.1 Range. - Work spaces and equipment shall accommodate the greatest possible range of the users. This shall be interpreted to include the range from the 5th to the 95th percentile. This percentile range embraces 90 per cent of all individuals in any given population. (McFarland, 1). XR-S-2. See figure 51 for meaning of percentiles and table XIV for its relationship to population accommodated.



<u>THE MEANING OF PERCENTILE.</u> PERCENTILES COMPRISE THE 100 EQUAL PARTS INTO WHICH THE ENTIRE RANGE OF VALUES IS DIVIDED FOR ANY GIVEN DIMENSION. AS AN ILLUSTRATION, SITTING HEIGHTS OF A LARGE SAMPLE OF MEN WERE MEASURED AND THE VALUES DISTRIBUTED GRAPHICALLY INTO THE 100 PERCENTILES AS SHOWN IN THE GRAPH ABOVE.

THE DESIGNER SHOULD DESIGN ACCORDING TO THE CONCEPT OF "DESIGN LIMITS" OR "RANGE OF ACCOMMODATION." THIS CONCEPT, EXEMPLIFIED IN THE GRAPH, INVOLVES THE EVALUATION OF PERCENTILE RANGES. NOTE THAT THE VARIABILITY OF THE EXTREME 10% (THE LARGEST 5% AND THE SMALLEST 5% COMBINED) EXCEEDS THE VARIABILITY OF THE CENTRAL 90%, AND SO DOES THE VARIABILITY OF THE EXTREME 2% (LARGEST 1% AND SMALLEST 1% COMBINED). BY PROPER ANALYSIS OF THE DATA ON THE USING POPULATION, THE DESIGNER CAN EFFICIENTLY PROVIDE PRECISELY THE ADJUSTABILITY NEEDED FOR ANY DESIRED SEGMENT OF THE POPULATION.

Figure 51. Meaning of percentiles

Table XIV.

Factors for computing percentiles from the standard deviation*

Percentile		Factor (S.D.)	Percent of population accommodated
0.5	99.5	2.576	99
1.0	99.0	2.326	98
2.5	97.5	1.960	95
5.0	95.0	1.645	90
10.0	90.0	1.282	80
15.0	85.0	1.036	70
20.0	80.0	0.842	60
25.0	75.0	0.674	50
30.0	70.0	0.524	40

*Use of this table assumes a normal or near normal distribution. For most linear measurements this is a safe assumption, however, weight has a skewed distribution which lends to errors of estimation, being too low for the smallest portion of the population and too high for the largest portion of the population.

5.5.1.3.2 Inclusive dimensions. - Passageways, accesses, overhead clearances, knee clearances, and safety clearances shall be based on 95th percentile values. These dimensions that provide clearance and must accommodate the large members of the population shall be considered minimum design dimensions. (Morgan, 2) XR-S-2

5.5.1.3.3 Exclusive dimensions. - Reaching distances, control movements, seating height, and openings in protective screens shall be based upon the 5th percentile values. These dimensions that must accommodate the small members of the population shall be considered as maximum design dimensions. (Morgan, 2) XR-S-2

5.5.1.3.4 Adjustable items. - Seats, safety equipment, belts, and adjustable controls shall be adjustable in the critical dimension from the 5th to the 95th percentile. If the situation permits a greater range, the adjustment shall cover the 1st to the 99th percentile values. (Morgan, 2) XR-S-2

5.5.1.3.5 Tradeoffs. - Tradeoffs shall be made among alternative tasks or body positions, but the final design shall accommodate the 5th to the 95th percentiles. Table XIV shall be employed to indicate the loss in per cent of the population accommodated when tradeoff of percentiles is employed. XR-C-1

5.5.1.4 Factors affecting human-body measurements.

5.5.1.4.1 Human variability. - The human body shall be considered as highly variable in its dimensions from person to person as a function of age, sex, race, occupation, posture, body position and the many interactions of these variables. (Morgan, 2). XR-S-2

5.5.1.4.1.1 Extent of variability. - It shall be recognized that the average man is not average in all or several dimensions. The attainment of average in one dimension shall not imply an average for another body dimension. This principle shall be considered valid even for correlated dimensions. (Daniels, 3). XR-S-1

5.5.1.4.1.2 Accommodation. - To accommodate the variation in size of the potential users of equipment, the designer shall attempt to provide for the greatest range of users from smallest to largest. (See section 5.5.1.3.1). XR-C-1

5.5.1.4.1.3 Corrections for slump. - Static human body dimensions shall be considered as based upon nude measures of subjects in rigid and artifically erect position. Normal sitting or standing height is significantly less than comparable erect measurements due to a natural slump factor inherent in man. Data from static anthropometric tables shall be considered as 0.8 inch less for standing measurements and 1.75 inches less for sitting positions. (Morgan, 2). XR-S-1

5.5.1.4.2 Clothing and personal equipment. - Allow sufficient room for personnel clothed for the full range of environments in which the equipment must be operated and serviced. (See 5.7.2). XR-C-1

5.5.1.4.2.1 Increment for clothing. - The use of nude body dimensions of width, depth, and circumference shall be avoided. XR-C-1

5.5.1.4.2.2 Heavy winter clothing. - Tables XV and XVI shall be employed to determine increments for heavy winter flying gear or arctic gear. (White, 4; Damon, 5). XR-S-1 (See section 5.5.1.6.1)

5.5.1.4.2.3 Street and winter clothing. - Table XVII shall be employed to determine increments for street and winter clothing. If protective garments of other types are worn, determination of appropriate increments shall be obtained from the manufacturer or by measurement of an appropriately sized subject wearing the garment. (Woodson, 6; Hertzberg, 7). XR-S-1

Table XV.

Body dimensions

NOTE: WEIGHT IN POUNDS, ALL OTHER VALUES IN INCHES	BODY DIMENSIONS						
		DESIGN VALUES (PERCENTILES)			DISTRIBUTION PARAMETERS		HVY WINTER CLOTHING INCREMENT
	1ST	5TH	95TH	99TH	MEAN	S.D.	
WEIGHT (IN POUNDS)	123.1	132.5	200.8	215.9	163.66	20.86	
A							
1. STATURE (INT. CANTHUS)	63.1	65.2	73.1	74.9	69.11	2.44	1.9
2. EYE HEIGHT	59.2	60.8	68.6	70.3	64.69	2.38	
3. EAR HEIGHT (TRAGION)	58.4	60.0	67.8	69.6	63.20	2.39	
4. SHOULDER HEIGHT (ACROM.)	51.2	52.8	60.2	61.9	56.50	2.28	
5. NIPPLE HEIGHT	45.6	47.0	53.9	55.3	50.41	2.08	
6. KNEECAP HEIGHT (PATELLA)	17.9	18.4	21.9	22.7	20.22	1.03	
7. PENALE HEIGHT	30.6	31.6	37.4	38.7	34.52	1.75	
8. SUBSTERNALE HEIGHT	44.0	45.6	52.1	53.5	48.71	2.02	
9. SUPRASTERNALE HEIGHT	51.3	52.7	59.9	61.5	56.28	2.19	
B							
10. NASAL ROOT HEIGHT	59.4	61.0	68.9	70.7	64.95	2.39	
11. CHEST DEPTH	7.6	8.0	10.4	11.1	9.06	0.75	1.4
12. WAIST DEPTH	6.3	6.7	9.5	10.3	7.94	0.88	1.4
13. BUTTOCK DEPTH	7.2	7.6	10.2	10.9	8.81	0.82	
14. CROTCH HEIGHT (INSEAM)	29.3	30.4	35.7	37.0	32.83	1.73	
C							
15. CHEST BREADTH	10.4	10.8	13.4	14.1	12.03	0.80	0.6
16. WAIST BREADTH	8.9	9.4	12.3	13.3	10.66	0.94	
17. HIP BREADTH	11.3	12.1	14.4	15.2	13.17	0.73	1.3
18. GLUTEAL FURROW HEIGHT	27.9	29.0	34.3	35.5	31.57	1.62	
19. KNUCKLE HEIGHT	26.7	27.7	32.4	33.5	30.04	1.45	
20. WRIST HEIGHT	30.1	31.0	36.1	37.1	33.52	1.54	
21. WAIST HEIGHT	37.7	39.1	45.0	46.4	42.02	1.81	
22. ELBOW HEIGHT (RADIALE)	39.5	40.6	46.4	47.7	43.50	1.77	
23. CERVICALE HEIGHT	53.7	55.3	62.9	64.6	59.08	2.31	
D							
24. SITTING HEIGHT	32.9	33.8	38.0	38.9	35.94	1.29	0.6
25. SHOULDER HT. (ACROM.)(S)	20.6	21.3	25.1	25.8	23.26	1.14	0.6
26. SHOULDER ELBOW LENGTH	12.8	13.2	15.4	15.9	14.32	0.69	0.3
27. WAIST HEIGHT (S)	7.4	7.9	10.4	10.9	9.24	0.76	
28. THIGH CLEARANCE HT. (S)	4.5	4.8	6.5	6.8	5.61	0.53	
29. BUTTOCK-KNEE LENGTH (S)	21.2	21.9	25.4	26.2	23.62	1.06	0.5
30. BACK OF KNEE HEIGHT (S)	15.3	15.7	18.2	18.8	16.97	0.77	
31. KNEE HEIGHT (S)	19.5	20.1	23.3	24.0	21.67	0.99	1.8
32. BUTTOCK-LEG LENGTH	38.2	39.4	46.1	47.7	42.70	2.04	
33. FOREARM-HAND LENGTH	17.0	17.6	20.2	20.7	18.86	0.81	
E							
34. BIACROMIAL DIAMETER	14.0	14.6	16.9	17.4	15.75	0.74	
35. SHOULDER BREADTH	15.9	16.5	19.4	20.1	17.88	0.91	0.7
36. ELBOW-TO-ELBOW BREADTH	14.5	15.2	19.8	20.9	17.28	1.42	4.4
37. HIP BREADTH, SITTING	12.2	12.7	15.4	16.2	13.97	0.87	
38. KNEE-TO-KNEE BREADTH	7.0	7.2	8.8	9.4	7.93	0.52	2.5
39. BREADTH OF BOTH FEET	6.8	7.0	8.2	8.7	7.60	0.38	2.4
40. ELBOW REST HEIGHT	6.6	7.4	10.8	11.5	9.12	1.04	
41. EYE HEIGHT (INT. CANTHUA)	28.5	29.4	33.5	34.4	31.47	1.27	0.4
F							
42. FUNCTIONAL REACH (FORWARD)	28.8	29.7	35.0	36.4	32.33	1.63	0.4
43. ARM REACH FROM WALL	30.9	31.9	37.3	38.6	34.59	1.65	0.4
44. MAXIMUM REACH FROM WALL	34.1	35.4	41.7	43.2	38.59	1.90	
45. SPAN	63.9	65.9	75.6	77.6	70.80	2.94	
46. FUNCTIONAL REACH (OVERHEAD)*	74.8	76.8	88.5	90.2	82.50	3.33	

(S) – INDICATES MEASUREMENT TAKEN IN A SITTING POSITION.
* – ADAPTED FROM WADC TR-52-321 FROM WADC TR-54-520.

Table XVI

Body dimensions for body circumferences, clothing, foot and hand

NOTE: ALL VALUES IN INCHES	BODY DIMENSIONS						
		DESIGN VALUES (PERCENTILES)			DISTRIBUTION PARAMETERS		HVY WINTER CLOTHING INCREMENT
	1ST	5TH	95TH	99TH	MEAN	S.D.	
A. BODY CIRCUMFERENCES:							
1. NECK CIRCUMFERENCE	13.3	13.8	16.2	16.8	14.96	.74	
2. SHOULDER CIRCUMFERENCE	40.2	41.6	49.4	51.5	45.25	2.43	
3. CHEST CIRCUMFERENCE	33.7	35.1	43.2	44.8	38.80	2.45	9.1
4. WAIST CIRCUMFERENCE	26.5	27.8	37.5	40.1	32.04	3.02	
5. BUTTOCK CIRCUMFERENCE	33.0	34.3	41.8	43.5	37.78	2.29	
6. THIGH CIRCUMFERENCE	18.3	19.6	25.3	26.4	22.39	1.74	
7. LOWER THIGH CIRCUMFERENCE	14.2	15.1	19.6	20.9	17.33	1.41	
8. CALF CIRCUMFERENCE	12.2	12.9	16.0	16 7	14.40	0.96	6.0
9. ANKLE CIRCUMFERENCE	7.8	8.1	9.8	10.5	8.93	0.57	
10. WRIST CIRCUMFERENCE	6.0	6.3	7.5	7.8	6.85	0.40	
B. CLOTHING DIMENSIONS:							
11. POSTERIOR NECK LENGTH	2.3	2.7	4.7	5.2	3.64	0.61	
12. WAIST BACK	14.8	16.1	19.4	20.2	17.72	1.07	
13. GLUTEAL ARC	9.7	10.4	13.1	14.8	11.71	1.07	
14. CROTCH LENGTH	23.7	25.1	31.6	33.5	28.20	2.00	
15. WAIST FRONT	12.3	13.5	17.0	18.1	15.24	1.12	
16. SCYE CIRCUMFERENCE	15.1	16.1	20.5	21.8	18.09	1.38	
17. ANTERIOR NECK LENGTH	1.8	2.3	4.4	4.9	3.40	0.64	
18. AUXILIARY ARM CIRCUMFERENCE	10.2	10.9	14.4	15.2	12.54	1.10	
19. VERTICAL TRUNK CIRCUM.	58.3	60.2	69.7	71.7	64.81	2.88	
20. LOWER ARM CIRCUM. (FLEXED)	9.9	10.4	12.7	13.3	11.50	0.73	
21. ELBOW CIRCUM. (FLEXED)	10.7	11.1	13.6	14.3	12.26	0.80	
22. BICEPS CIRCUM. (FLEXED)	10.5	11.2	14.6	15.4	12.79	1.07	
23. SHOULDER LENGTH	5.5	5.9	7.7	8.1	6.77	0.56	
24. SLEEVE INSEAM	17.1	18.0	21.7	22.6	19.83	1.14	
25. INTERSCYE	16.3	17.2	22.0	22.9	19.62	1.40	
26. INTERSCYE MAXIMUM	19.8	20.7	25.1	26.0	22.85	1.33	
27. BUTTOCK CIRCUM., SITTING	36.1	37.4	46.7	49.3	41.74	2.82	
28. KNEE CIRCUM., SITTING	13.4	14.0	16.9	17.7	15.39	0.92	
C. FOOT DIMENSIONS:							
29. ANKLE BREADTH	2.61	2.70	3.19	3.32	2.95	0.15	
30. ANKLE HEIGHT (MEDIAL)	3.0	3.1	3.8	4.0	3.45	0.21	
31. ANKLE HEIGHT (LATERAL)	2.2	2.4	3.1	3.3	2.73	0.22	
32. FOOT BREADTH	3.40	3.50	4.10	4.36	3.80	0.19	1.2
33. BALL OF FOOT CIRCUM.	8.6	8.9	10.4	10.8	9.65	0.48	
34. FOOT LENGTH	9.5	9.8	11.3	11.6	10.50	0.45	2.7
35. INSTEP LENGTH	6.9	7.1	8.2	8.4	7.64	0.34	
36. HEEL BREADTH	2.30	2.40	2.87	3.01	2.64	0.15	
D. HAND DIMENSIONS:							
37. GRIP DIAMETER (INSIDE)	1.52	1.62	2.05	2.16	1.90	0.14	
38. GRIP DIAMETER (OUTSIDE)	3.58	3.72	4.44	4.57	4.09	0.21	
39. FIRST PHALANX III LENGTH	2.40	2.49	2.85	2.95	2.67	0.12	
40. FIST CIRCUMFERENCE	10.2	10.7	12.4	12.0	11.56	0.57	
41. THICKNESS AT METACARP. III	1.00	1.05	1.28	1.39	1.17	0.07	
42. FINGER DIAMETER III	0.77	0.79	0.93	0.96	0.86	0.05	
43. HAND LENGTH	6.7	6.9	8.0	8.3	7.49	0.34	0.3
44. HAND BREADTH AT METACARP	3.12	3.22	3.74	3.86	3.48	0.16	
45. PALM LENGTH	3.77	3.89	4.60	4.74	4.24	0.21	
46. HAND BREADTH AT THUMB	3.59	3.73	4.42	4.57	4.07	0.21	0.4
47. DIGIT TO CROTCH HEIGHT	3.79	3.99	5.01	4.21	4.50	0.31	
48. THUMB THICKNESS	0.66	0.69	0.84	0.87	0.76	0.05	
49. THUMB LENGTH	1.92	2.03	2.61	2.–	2.32	0.17	

Table XVII

Effect of various types of clothing on human body dimensions

ALL DIMENSIONS IN PARENTHESES ARE NEGATIVE VALUES

DIMENSION	STREET CLOTHES		WINTER CLOTHES		HEAVY FLIGHT CLOTHING	PRESSURE SUITS [a]	
	MEN	WOMEN	MEN	WOMEN		UNPRES-SURIZED	PRES-SURIZED
WEIGHT	5 LB	3½ LB	10 LB	7 LB	12–15 LB	21 LB	21 LB
STATURE	1 IN	½–3¾ IN	1 IN	½–3¾ IN	3 IN	3½ IN	2½ IN
VERTICAL REACH	1	½–3¾	1	½–3¾	1	(−2½)	(−16½)
EYE HEIGHT, STANDING	1	½–3¾	1	½–3¾	1	(−3½)	2½
CROTCH TO FLOOR	1	½–3¾	1	½–3¾	1	(−1)	(−1)
FOOT LENGTH	1¼	½	1½	½–¾	1	1	1
FOOT WIDTH	½–¾	¼–(−½) [b]	½–1	¼–½	¾	¾	¾
HEAD LENGTH	–	–	– [c]		4½	4½	4½
HEAD WIDTH	–	–	– [c]		4½	4½	4½
HAND LENGTH	–	–	¾	½	½	½	¼
HAND WIDTH	–	–	½	¼	½	½	1
HAND THICKNESS	–	–	½	¼	½	¾	1¼
FIST CIRCUMFERENCE	–	–	1	¾	1	1¼	3
SHOULDER WIDTH	½	¼	2–3	1	1½	1	½
HIP WIDTH	½	¼	2–3	1	1½	1	2¾
ELBOW-TO-ELBOW WIDTH	¾	¼	2–3½	1–1½	1	6	9
THIGH CLEARANCE	½	¼	1	¾	2	1¾	2
FOREARM-TO-FIST LENGTH	½	¼	¾	½	1	1½	5½

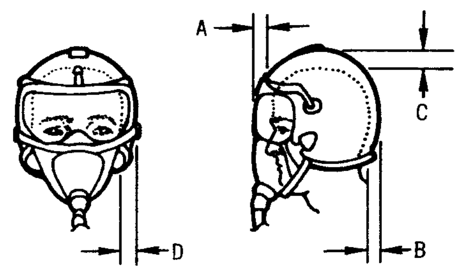
[a] CERTAIN PRESSURIZED GARMENTS ARE DESIGNED FOR SEATED POSITION AND THEREFORE SHORTEN CERTAIN DIMENSIONS. THE HELMET HOWEVER, TENDS TO RISE UNDER PRESSURE. THIS IS PROVIDED AS AN APPROXIMATION TO "SCAPE" EQUIPMENT DIMENSIONS.

[b] WOMEN'S DRESS SHOES CONFINE AND SHRINK FOOT WIDTH.

[c] AN ARMY STEEL HELMET IS APPROXIMATELY 12 BY 10¼ INCHES.

TYPICAL FLIGHT HELMET DIMENSIONAL CHARACTERISTICS:

	A	B	C	D
LOMBARD	1.25	1.00	2.60	1.55
MA–2	1.45	1.40	1.80	2.15
P–4	1.25	1.25	2.13	1.73



5.5.1.4.2.4 Increments for heavy clothing. - For sitting height measurements 0.2 to 0.3 inch shall be added for heavy clothing. (Damon, 5) XR-S-1

5.5.1.4.2.5 Increment for shoes. - Use of nude standing heights shall be avoided. An increment of 1 inch for regular shoes shall be added to all standing heights. (Morgan, 2) XR-S-1

5.5.1.4.2.6 Increment for headgear. - Additional increment shall be made where headgear is required or is typically worn by personnel. The size of these increments will depend upon the type of headgear worn. XR-C-1 See table XVII.

5.5.1.4.2.7 Increment for handwear. - Additional increment shall be made where gloved hand is required to perform task. Size of increments shall be obtained from figure 52. XR-C-2

5.5.1.5 Determination of anthropometric data. - In order to insure maximum validity and reliability of data, the following requirements shall be observed: XR-C-1

5.5.1.5.1 Validity of anthropometric data. - The groups actually measured for anthropometric data or the table selected for body dimensions shall be representative of the equipment user. See section 5.5.1.4.1 for human variability and the necessity for specifying the several variables that make up the population in question. (Morgan, 2) XR-S-2

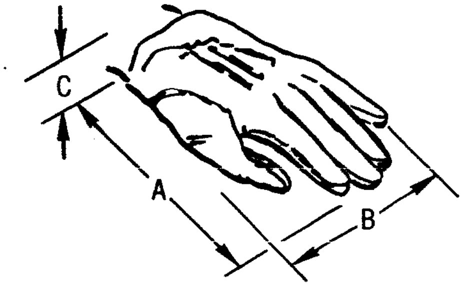
5.5.1.5.2 Reliability on anthropometric data. - When groups are actually measured for anthropometric data, the sample size shall be a minimum of 50 persons in order to insure reliability of data. (Morgan, 2) XR-S-2

5.5.1.5.3 Standardization of anthropometric data. - Measuring techniques, tools, and statistics employed shall be specified and standard in order to insure comparability of anthropometric data from differing sources. (Morgan, 2) XR-S-2 See figures 53 and 54 for measuring techniques and applications.

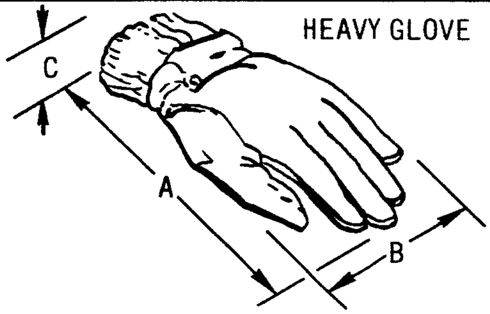
5.5.1.6 Static human body dimensions. - Static dimensions are based upon nude measures of subjects in rigid and artifically erect positions. XR-C-1

5.5.1.6.1 Application. - Tables XV, XVI, and figures 53 and 54 shall be employed to obtain the central 98 per cent of the range for 94 commonly used body measurements. Dimensions are given for the 1st, 5th, 95th, and 98 percentiles as well as the mean (50th percentile) and standard deviation. (Hertzberg, 7) XR-S-1

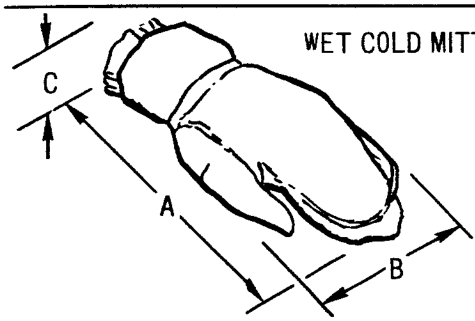
NOTE:
ALL DIMENSIONS IN INCHES



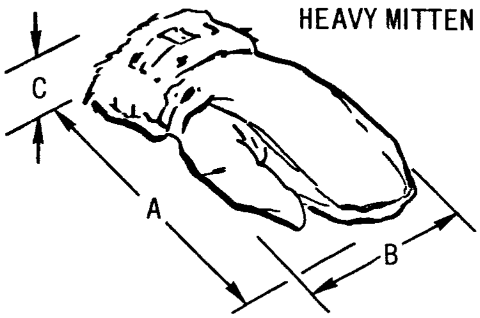
LIGHT GLOVE



HEAVY GLOVE



WET COLD MITTEN



HEAVY MITTEN

		HAND ATTITUDE		GRASPING HANDLE (DIAMETER)			GRASPING KNOB (DIAMETER)		
		FLAT	FIST	.25"	1"	2"	.25"	1"	2"
LIGHT GLOVE	A	10.3	7.0	7.0	7.0	7.5	8.0	9.0	9.5
	B	4.5	5.0	5.0	5.0	4.5	3.8	3.5	3.7
	C	2.5	3.3	3.5	3.5	4.2	4.3	4.0	3.7
HEAVY GLOVE	A	10.5	7.3	7.3	7.3	8.0	9.0	9.0	9.2
	B	5.5	5.8	5.5	5.3	4.7	4.6	4.5	4.5
	C	3.0	3.7	3.5	4.0	4.0	4.0	4.0	4.2
WET COLD MITTEN	A	14.0	11.5	11.0	11.0	12.0	11.5	12.0	12.5
	B	5.8	5.8	5.7	5.2	5.2	5.0	5.0	4.6
	C	3.2	3.8	4.2	4.5	4.7	4.2	4.0	4.4
HEAVY MITTEN	A	16.4	14.3	14.0	14.7	15.0	15.5	15.8	16.0
	B	5.2	5.2	5.5	5.2	5.4	4.8	4.8	4.7
	C	3.2	5.4	4.5	4.5	5.0	4.5	4.8	4.5

Figure 52. Gloved hand

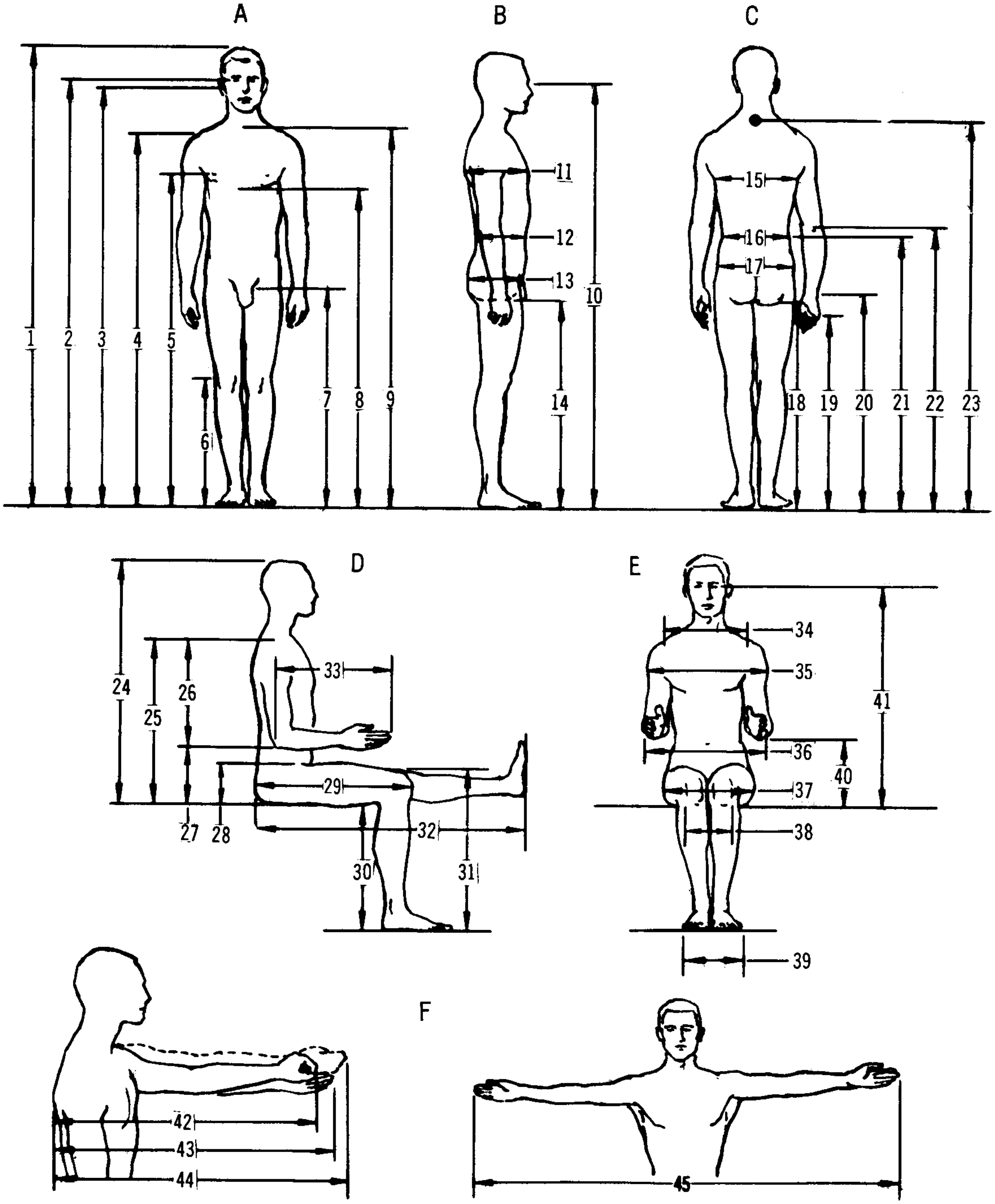


Figure 53. Points of measurement for body dimensions

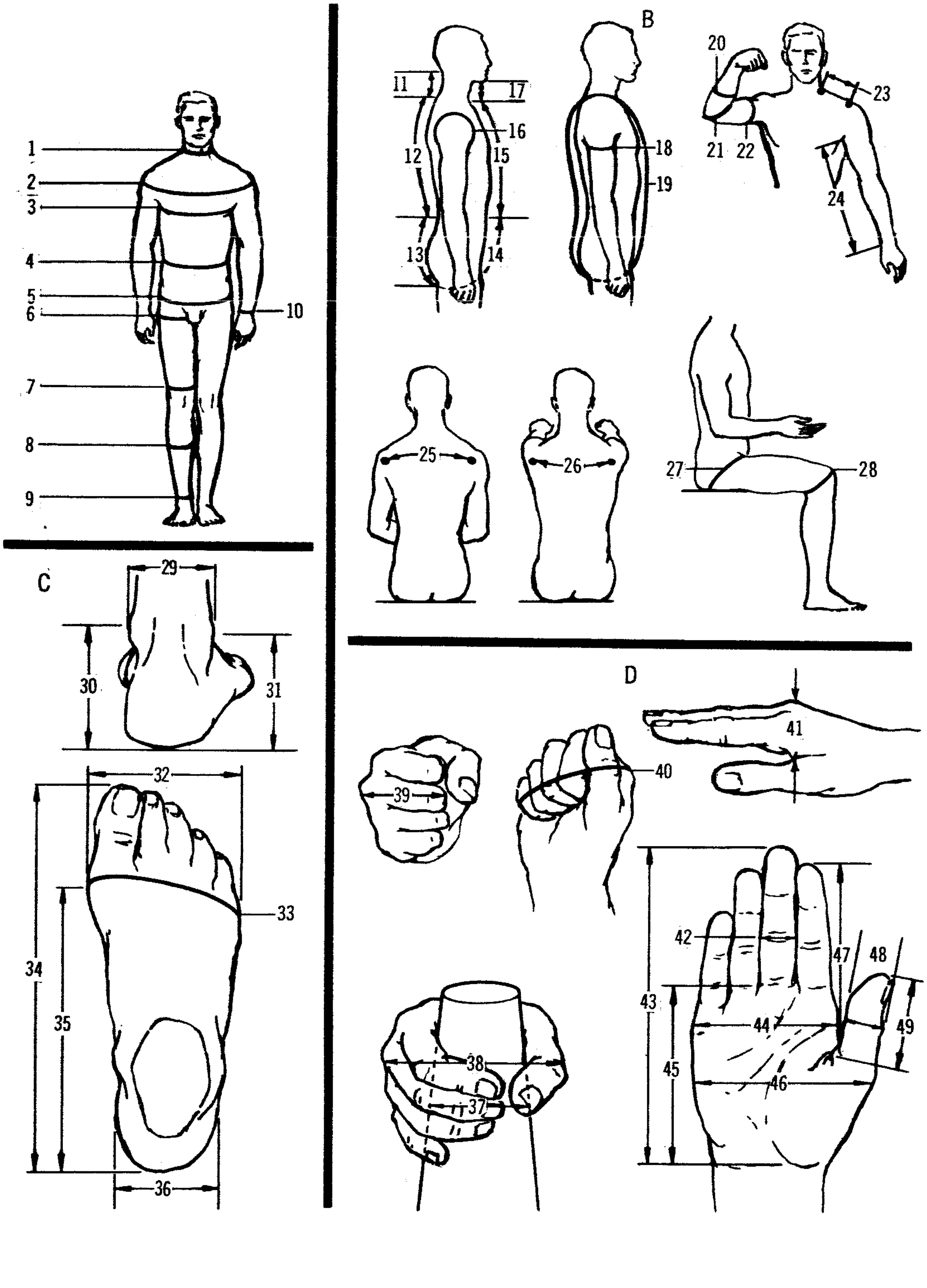


Figure 54. Points of measurement for body dimensions (extremities)

5.5.1.6.2 Standard deviation. - The standard deviation (S.D.) shall serve as an indicator of variability between measurements within the sample. A small S.D. shall indicate a small range. If the distribution is normal or bell-shaped, the 5th and 95th percentile values shall be derived from the mean plus or minus 1.65 S.D. (Senders, 8) XR-S-1

5.5.1.7 Dynamic human body dimensions. - Dynamic body dimensions shall include those measurements that vary with body movements. These measurements shall be differentiated from static dimensions which shall be measured with the subject in rigid standarized position. See figure 55. Dynamic measurements shall include those made with subjects in various working positions and functional arm and leg reaches. (Morgan, 2) XR-S-1

5.5.1.7.1 Working positions. - Three working positions shall be considered as critical elements in the design of spatially restricted areas where ground support personnel often perform their tasks. These are the kneeling, crawling and prone positions. (Morgan, 2) XR-S-2

5.5.1.7.1.1 Kneeling. - Measurements for the kneeling position shall be taken with the knees and feet together, fist clenched and on the floor in front of knees, arms vertical, and head in line with the long axis of body as shown in figure 55. Kneeling dimensions for the 5th, 50th and 95th percentile shall be obtained from table XVIII. (Hertzberg, 9) XR-S-1

5.5.1.7.1.2 Crawling. - Measurements shall be made with subject resting on his knees and flattened palms, arms and thighs vertical, feet extended, and head in line with long axis of the body as shown in figure 55. Crawling dimensions for the 5th, 50th, and 95th percentile shall be obtained from table XVIII. (Hertzberg, 9) XR-S-1

5.5.1.7.1.3 Prone position. - Measurements shall be made with subject lying in prone position with feet together and extended, arms extended forward, and fists clenched as shown in figure 55. Prone position dimensions for the 5th, 50th and 95th percentile shall be obtained from table XVIII. (Hertzberg, 9) XR-S-1

5.5.1.7.2 Functional arm reach. - Functional arm reach dimensions shall be considered as critical in the design of outer limits of work place for placement of controls, tools or materials to be handled. (Morgan, 2) XR-S-2

5.5.1.7.2.1 Vertical reach, seated. - Measurements shall be made with subjects seated (seat back angle 13 degrees), right arm and hand fully extended, and with both shoulders against backrest as shown in figure 56. Maximum distances which can be reached by 97 per cent of a navy pilot population shall be obtained from the same figure. (King, 10) XR-S-1

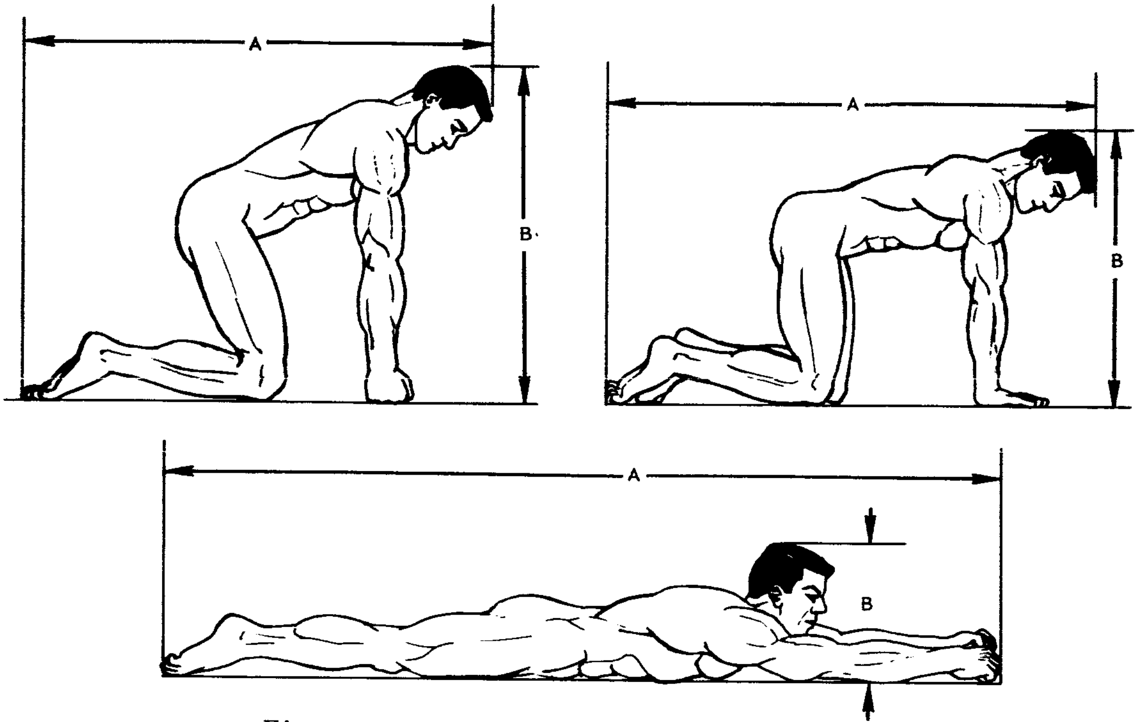
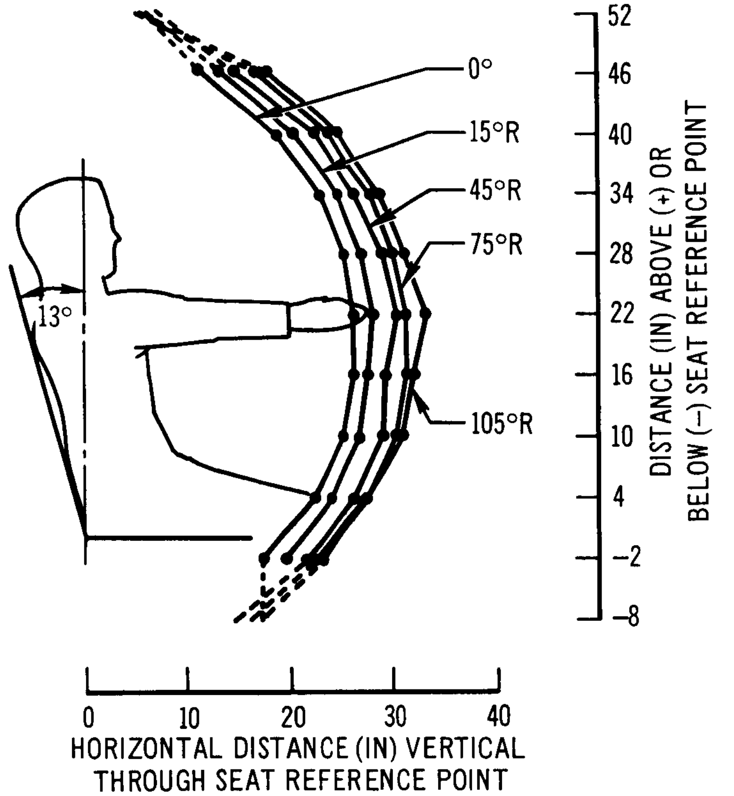


Figure 55 Dynamic human body positions

Table XVIII.
Working-Position Dimensions of Male Air Force Personnel

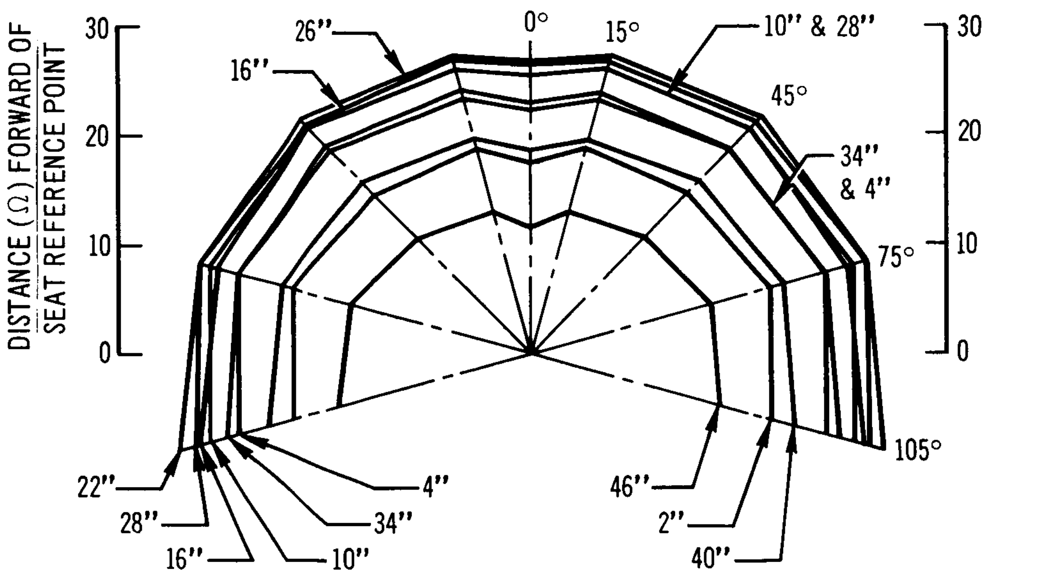
DIMENSION	PERCENTILES (IN.)			
	5TH	50TH	95TH	S.D.
KNEELING				
HEIGHT	29.7	32.0	34.5	1.57
LENGTH	37.6	43.0	48.1	3.26
CRAWLING				
HEIGHT	26.2	28.4	30.5	1.30
LENGTH	49.3	53.2	58.2	2.61
PRONE				
HEIGHT	12.3	14.5	16.4	1.28
LENGTH	84.7	90.1	95.8	3.41

HERTZBERG, 9



MAXIMUM DISTANCES WHICH CAN BE REACHED BY 97% OF THE POPULATION* AT EACH POSITION. THE ELLIPTICAL ARCS INDICATE THE MAXIMUM BOUNDARIES OF THE WORKING AREA FOR OPERATION OF MANUAL CONTROLS (AT RIGHT ANGLES FROM 0° TO 105° TO THE RIGHT) FOR THIS GROUP. SEAT BACK ANGLE 13°.

* 139 NAVY PILOTS & NON-PILOTS



MAXIMUM DISTANCES WHICH CAN BE REACHED BY 97 PER CENT OF THE POPULATION AT EACH POSITION. THE ELLIPTICAL ARCS INDICATE MAXIMUM BOUNDARIES FOR THIS GROUP FOR OPERATION OF MANUAL CONTROLS AT VARIOUS HORIZONTAL LEVELS. SEAT BACK 13° FROM VERTICAL.

Figure 56. Vertical and horizontal reach distances

5.5.1.7.2.2 Horizontal reach, seated. - Measurements and presentation of data are identical to section 5.5.1.7.2.1. (King, 10) XR-S-1

5.5.1.7.2.2.1 Push buttons. - Push buttons shall be located up to a maximum of 2.5 inches beyond the 5th percentile grasp reach envelope. (Kennedy, 11) XR-S-1

5.5.1.7.2.2.2 Lever controls. - The entire range of a lever's travel shall fall within the 5th percentile grasp reach envelope. XR-C-1

5.5.1.7.2.2.3 Infrequently used devices. - Infrequently used devices that can be mounted on a movable boom, telescoping arm, or other flexible mounting shall be located at the outer limits of the reach envelope. XR-C-1

5.5.1.7.2.2.4 Reduction of reach. - All possible conditions resulting in a reduction in functional reach shall be considered in the location of manipulated controls. Analysis shall include the following: XR-C-1

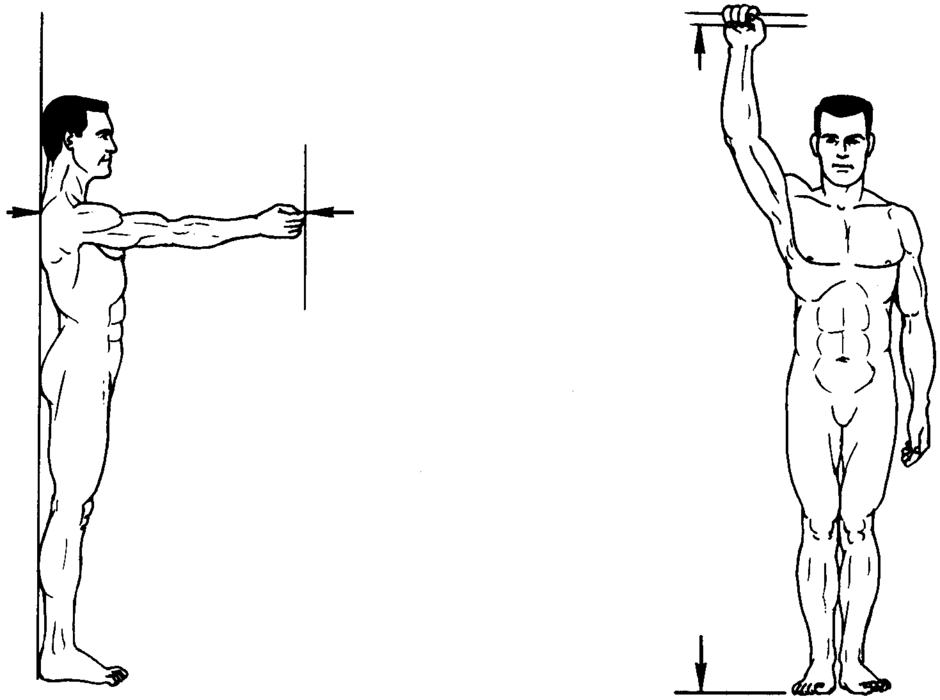
(a) Bulky garments that reduce joint movement and reduce clearances so that contact with consoles, desks, and writing materials restrain free movement.

(b) Necessity to manipulate widely spaced controls with both hands at approximately the same instance.

(c) Torques, pressures, or pulls required to manipulate the control.

5.5.1.7.2.3 Forward reach, standing. - Measurements shall be obtained with subject standing erect, heels, buttocks, and shoulders against a wall, right arm extended horizontally to its maximum length, and tips of thumb and forefinger pressed together as shown in figure 57. Forward reach dimensions in the standing position for the 1st through the 99th percentiles (male Air Force personnel) shall be obtained from table XIX. (Hertzberg, 9) XR-S-1

5.5.1.7.2.4 Overhead reach, standing. - Measurements shall be obtained with subject standing erect, and grasping a bar which he raises to the highest position attainable without strain as shown in figure 57. Overhead reach dimensions in the standing position for the 1st through 99th percentile (male Air Force personnel) shall be obtained from table XIX. (Hertzberg, 9) XR-S-1



FORWARD REACH, STANDING

OVERHEAD REACH, STANDING

Figure 57. Dynamic reach, standing.

Table XIX.

Functional Arm Reach (Standing) of Male Air Force Personnel

REACH	PERCENTILES (IN.)					
	1ST	5TH	50TH	95TH	99TH	S.D.
FORWARD [1]	28.8	29.7	32.3	35.0	36.4	1.60
OVERHEAD [2]		76.8	82.5	88.5		3.33

HERTZBERG, 7
HERTZBERG, 9

5.5.1.7.2.5 Unrestrained seated reach envelope. - The Kennedy data as presented in table XX shall be considered as information that most nearly duplicates the unrestrained work position that permits normal rotation of the shoulders and bending from the waist. Measurements for the Kennedy data were obtained under the restraint of an inertia (reel shoulder-harness) system, and shall be considered as a conservative estimate of the reaches possible without restraint. (Kennedy, 11) XR-S-2

5.5.1.8 Range of movement of body members. - The range of joint motion shall be considered to vary from person to person for structural reasons and as a function of age, sex, body build, occupation, posture, and body position. (Morgan, 2) XR-S-2

5.5.1.8.1 Joint movement measurement. - Joint motion shall be measured at the angle formed by the long axes to two adjoining body segments, or at the angle formed by one body segment and a vertical or horizontal plane. (Morgan, 2) XR-S-2

5.5.1.8.1.1 Movement at the joint of the neck. - See 5.4.3.1.

5.5.1.8.1.2 Movement at the joints of the hand and arm. - Movement at the joints of the hand and arm shall be measured as shown in figure 58. Range of various movement at the joints of the hand and arm shall be obtained from table XXI. (Barter, 12) XR-S-2

5.5.1.8.1.3 Movement at the joints of the foot and leg. - Movement at the joints of the foot and leg shall be measured as shown in figure 59. Range of various movement at the joints of the foot and leg shall be obtained from table XXII. (Barter, 12) XR-S-2

5.5.1.9 Estimation of correlated measures. - Correlation coefficients shall be employed to derive an estimate of an unknown or unavailable body dimension. The correlation coefficients for many of the commonly used measurements shall be obtained from table XXIII. (Anthropometry Project-Antioch College, 13) XR-S-1

Table XX.

Means and standard deviations of linear distances from srp within the minimum grasping-reach envelope

		LEVEL									
		SRP	5	10	15	20	25	30	35	40	45
L165	X*										
	SD										
L150	X										12.36
	SD										2.83
L135	X										11.44
	SD										2.77
L120	X										10.67
	SD										2.69
L105	X										10.54
	SD										2.70
L 90	X								15.70	14.49	11.29
	SD								3.17	2.34	2.73
L 75	X								17.57	15.83	11.78
	SD								3.03	2.61	2.86
L 60	X					20.97	21.63	21.04	19.03	16.99	12.75
	SD					2.54	2.74	2.79	2.95	2.63	3.09
L 45	X					23.50	23.73	23.14	21.08	18.28	13.80
	SD					2.49	2.61	2.63	2.92	3.04	3.08
L 30	X				23.66	25.34	25.63	24.83	22.85	19.86	15.23
	SD				2.91	2.10	2.15	2.40	2.81	3.10	3.47
L 15	X				25.74	26.88	26.98	26.30	24.54	21.49	16.65
	SD				2.67	2.01	1.96	1.96	2.24	2.59	3.47
0°	X				28.58	28.65	28.86	28.13	26.00	23.01	18.43
	SD				2.47	2.12	1.97	2.10	2.26	2.62	3.19
R 15	X				30.54	30.60	30.81	29.99	27.66	24.80	20.11
	SD				2.23	2.12	2.10	2.07	2.56	2.59	3.15
R 30	X		26.13	29.38	31.60	32.34	32.10	31.11	29.05	26.38	21.35
	SD		2.07	2.07	2.12	2.00	2.00	2.07	2.20	2.60	3.54
R 45	X	21.95	27.53	30.36	32.31	33.06	33.24	32.25	30.39	27.64	22.83
	SD	2.45	2.04	1.98	1.77	2.09	1.77	1.99	2.01	2.33	3.48
R 60	X	22.33	27.55	30.74	32.39	33.26	33.38	32.29	30.65	27.84	23.48
	SD	2.12	1.75	1.51	1.77	1.51	1.51	1.68	1.82	2.15	2.49
R 75	X	22.25	27.64	30.68	32.55	33.41	33.55	32.63	30.88	28.09	23.81
	SD	2.35	1.71	1.46	1.58	1.48	1.40	1.57	1.78	1.87	2.38
R 90	X	22.06	27.23	30.48	32.21	33.39	33.33	32.71	30.98	28.05	23.80
	SD	2.38	27.03	1.52	1.82	1.51	1.54	1.57	1.69	2.01	2.79
R105	X	21.64	27.03	29.98	32.05	33.04	33.40	32.65	30.86	28.35	24.18
	SD	2.22	1.70	1.49	1.39	1.80	1.58	1.56	1.78	1.97	2.33
R120	X	20.40	26.14	29.31	31.23				30.34		23.74
	SD	2.04	1.95	1.55	1.68				1.88		2.18
R135	X	18.86	25.41								
	SD	2.52	1.97								
R150	X										
	SD										
R165	X										
	SD										
180°	X										
	SD										

* N = 20

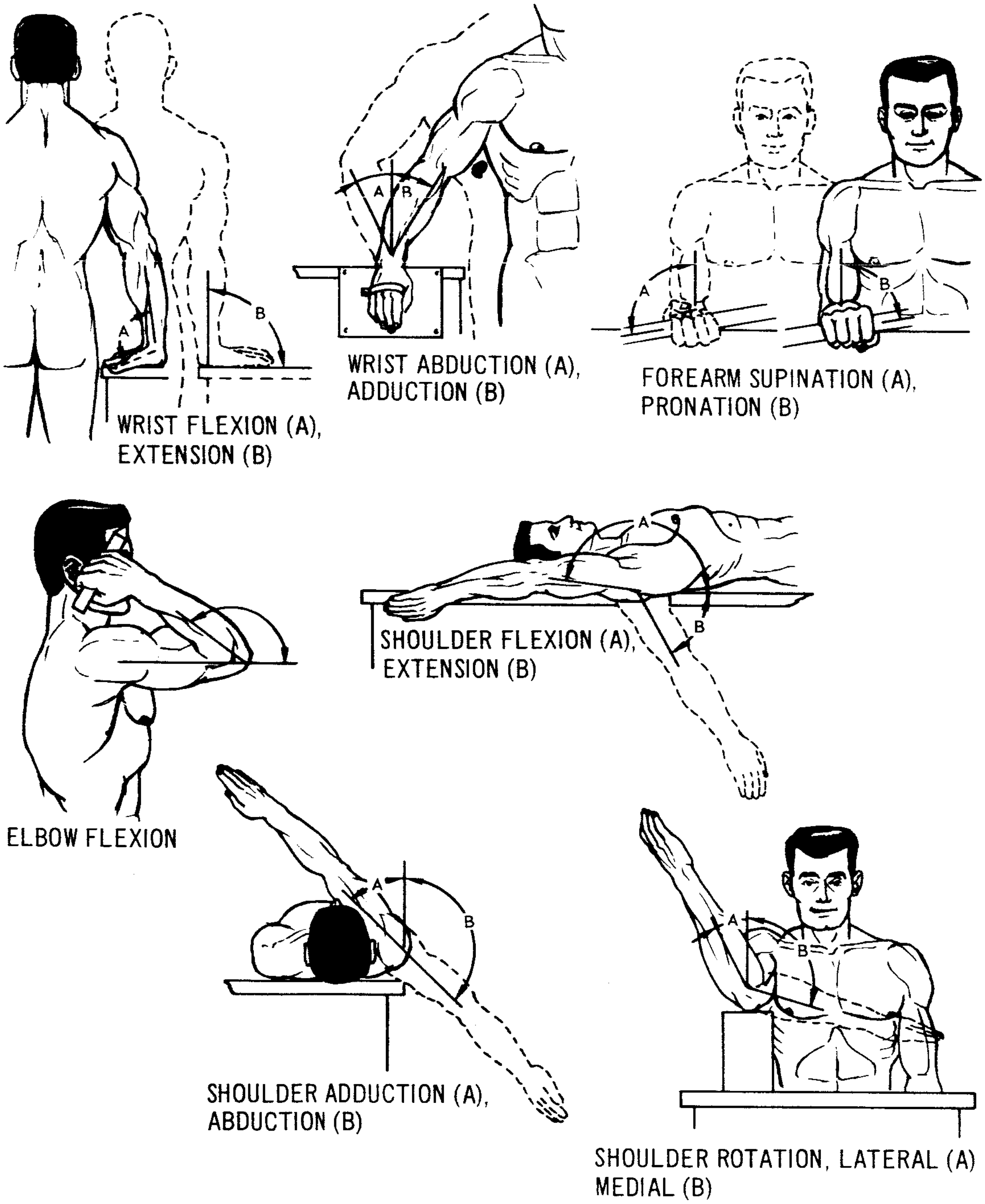


Figure 58. Movement at the joints of the hand and arm

Table XXI.

Range of movement at the joints of the hand and arm of male Air Force personnel

MOVEMENT[1]	RANGE (DEG)	
	AVG	S.D.
WRIST FLEXION	90	12
WRIST EXTENSION	99	13
WRIST ADDUCTION	27	9
WRIST ABDUCTION	47	7
FOREARM SUPINATION	113	22
FOREARM PRONATION	77	24
ELBOW FLEXION	142	10
SHOULDER FLEXION	188	12
SHOULDER EXTENSION	61	14
SHOULDER ADDUCTION	48	9
SHOULDER ABDUCTION	134	17
SHOULDER ROTATION		
MEDIAL	97	22
LATERAL	34	13

[1] BARTER, 12

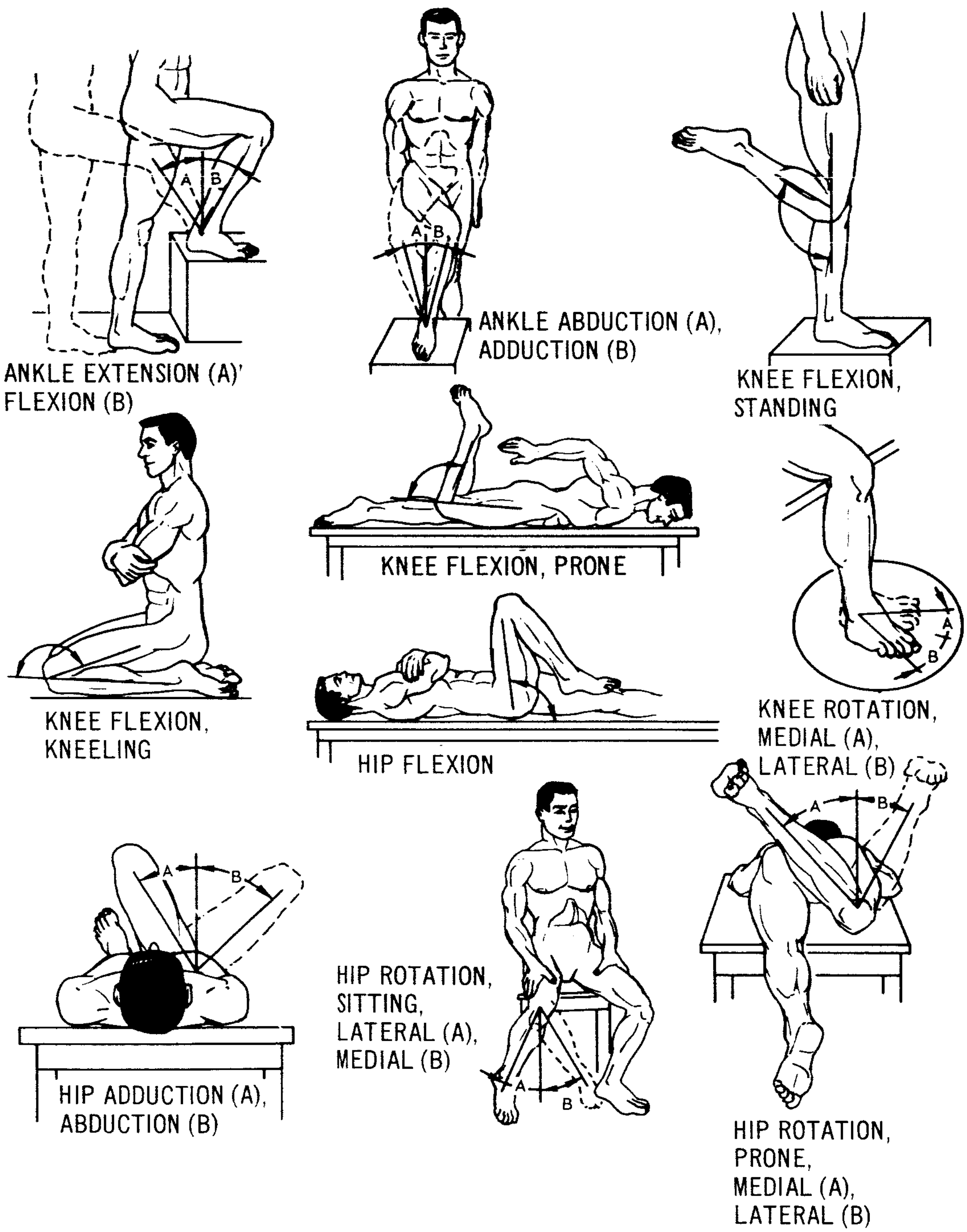


Figure 59. Movement at the joints of the foot and leg

Table XXII.

Range of movement at the joints of the foot and leg of male Air Force personnel

MOVEMENT[1]	RANGE (DEG)	
	AVG	S.D.
ANKLE FLEXION	35	7
ANKLE EXTENSION	38	12
ANKLE ADDUCTION	24	9
ANKLE ABDUCTION	23	7
KNEE FLEXION		
STANDING	113	13
KNEELING	159	9
PRONE	125	10
KNEE ROTATION		
MEDIAL	35	12
LATERAL	43	12
HIP FLEXION	113	13
HIP ADDUCTION	31	12
HIP ABDUCTION	53	12
HIP ROTATION (SITTING)		
MEDIAL	31	9
LATERAL	30	9
HIP ROTATION (PRONE)		
MEDIAL	39	10
LATERAL	34	10

[1]BARTER, 12

INDEX NUMBER	1.	2.	15.	19.	25.	27.	28.	32.	36.	39.	46.	47.	48.	49.	50.	51.	53.	57.	59.
1. WEIGHT		478	304	410	530	583	468	411	819	793	647	795	824	815	894	824	733	730	728
2. STATURE	478		848	757	872	805	819	659	330	314	211	266	264	194	350	200	236	106	217
15. CROTCH HEIGHT	304	848		461	870	775	772	622	152	173	62	129	162	77	179	69	117	-018	117
19. SITTING HEIGHT	410	757	461		502	427	454	384	320	279	210	218	220	124	313	202	225	121	122
25. KNEE HEIGHT –S.	530	872	870	502		809	828	670	377	368	267	352	348	299	407	285	327	184	287
27. BUTTOCK-KNEE LENGTH	583	805	775	427	809		804	624	433	422	299	393	416	387	488	370	343	260	306
28. BUTTOCK-LEG LENGTH	468	819	772	454	828	804		642	330	304	239	293	290	275	362	236	231	149	199
32. ARM REACH FROM WALL	411	659	622	384	670	624	642		273	325	240	305	290	230	304	197	214	160	249
36. HIP BREADTH –S.	819	330	152	320	377	433	330	273		656	536	676	675	704	849	768	628	624	578
39. SHOULDER BREADTH	793	314	173	279	368	422	304	325	656		606	825	766	673	710	653	592	667	649
46. NECK CIRCUMFERENCE	647	211	62	210	267	299	239	240	536	606		639	597	575	589	542	495	588	573
47. SHOULDER CIRCUMFERENCE	795	266	129	218	352	393	293	305	676	825	639		790	708	747	701	620	700	664
48. CHEST CIRCUMFERENCE	817	264	162	221	348	416	290	290	675	766	597	790		757	744	696	583	695	660
49. WAIST CIRCUMFERENCE	815	193	78	125	299	387	275	230	704	673	575	708	757		791	715	569	662	608
50. BUTTOCK CIRCUMFERENCE	894	349	181	319	407	488	362	304	849	710	589	747	744	791		840	697	681	648
51. THIGH CIRCUMFERENCE	824	200	69	202	285	370	236	197	768	653	542	701	696	715	840		707	683	622
53. CALF CIRCUMFERENCE	733	236	117	225	327	343	231	214	628	592	495	620	583	569	697	707		595	617
57. BICEPS CIRCUMFERENCE –F.	730	106	018	121	184	260	149	160	624	667	588	700	695	662	681	683	595		713
59. LOWER ARM CIRCUMFERENCE –F.	728	217	117	222	287	306	199	249	578	649	573	664	660	608	648	622	617	713	
61. SLEEVE INSEAM	179	620	641	362	609	536	541	545	93	91	35	55	74	-005	75	9	47	-058	22
62. SLEEVE LENGTH	494	708	671	460	711	678	641	642	348	458	293	400	408	283	364	249	279	210	310
70. VERTICAL TRUNK CIRCUMFERENCE	798	552	282	598	472	507	437	366	680	625	513	616	621	609	737	644	557	549	555
75. FOOT LENGTH	452	699	629	490	702	610	624	563	328	326	268	296	290	221	357	230	324	171	285
77. FOOT BREADTH	470	419	297	347	434	377	363	350	372	371	347	353	330	279	394	334	418	305	366
82. BALL OF FOOT CIRCUMFERENCE	523	404	297	335	444	395	354	332	425	418	388	388	396	334	432	387	453	361	434
83. HAND LENGTH	378	649	587	437	651	542	564	588	251	286	235	265	233	236	357	160	227	152	263
86. HAND BREADTH AT METACARPALE	427	398	314	350	408	345	324	360	294	371	352	343	337	251	322	267	335	318	455
92. FIST CIRCUMFERENCE	463	358	265	318	388	326	308	344	335	415	375	398	392	305	373	325	379	381	487
93. HEAD LENGTH	270	258	181	231	239	201	198	183	176	228	236	216	222	167	209	166	181	167	201
94. HEAD BREADTH	312	103	48	110	131	126	101	80	280	284	306	283	281	263	267	253	244	245	248
103. NOSE LENGTH	101	204	184	196	174	140	142	156	53	102	43	65	106	33	64	31	35	15	69
108. MENTON-SUBNASALE LENGTH	146	178	127	175	165	129	129	120	107	95	131	103	102	78	108	75	108	82	110
116. HEAD HEIGHT	218	204	119	218	170	122	147	114	174	132	171	163	168	153	159	165	136	149	130
122. HEAD CIRCUMFERENCE	472	276	167	244	295	279	250	216	377	399	425	400	397	358	402	354	346	332	344

DECIMAL POINTS HAVE BEEN OMITTED.

Table XXIII.
Correlations between body dimensions

INDEX NUMBER	61.	62.	70.	75.	77.	82.	83.	86.	92.	93.	94.	103.	108.	116.	122.
1. WEIGHT	179	494	798	452	470	523	378	427	463	270	312	101	146	218	472
2. STATURE	620	708	552	699	419	404	649	398	358	258	103	204	178	204	276
15. CROTCH HEIGHT	641	671	282	629	297	297	587	314	265	181	48	184	127	119	167
19. SITTING HEIGHT	362	460	598	490	347	335	437	350	318	231	110	196	175	218	244
25. KNEE HEIGHT –S.	609	711	472	703	434	444	651	408	388	239	131	174	165	170	295
27. BUTTOCK-KNEE LENGTH	536	678	507	610	377	395	542	345	326	201	126	140	129	122	279
28. BUTTOCK-LEG LENGTH	541	641	437	624	363	354	564	324	308	198	101	142	129	147	250
32. ARM REACH FROM WALL	545	642	366	563	350	332	588	360	344	183	80	156	120	114	216
36. HIP BREADTH –S.	93	348	680	328	372	425	251	294	335	176	280	53	107	174	377
39. SHOULDER BREADTH	91	458	623	326	371	418	287	371	415	228	284	102	95	132	399
46. NECK CIRCUMFERENCE	35	293	513	268	347	388	235	352	376	236	306	43	131	172	425
47. SHOULDER CIRCUMFERENCE	55	400	616	296	353	388	265	343	398	216	283	65	103	163	400
48. CHEST CIRCUMFERENCE	74	408	621	290	330	396	233	337	392	222	281	106	102	168	397
49. WAIST CIRCUMFERENCE	5	283	609	221	279	334	236	251	305	167	263	33	78	153	358
50. BUTTOCK CIRCUMFERENCE	77	364	737	357	394	432	357	322	373	209	267	64	108	199	402
51. THIGH CIRCUMFERENCE	9	249	644	230	334	385	160	267	326	166	253	31	75	165	354
53. CALF CIRCUMFERENCE	47	279	557	324	418	453	227	335	379	181	244	35	108	136	346
57. BICEPS CIRCUMFERENCE –F.	58	210	549	171	305	361	152	318	381	167	245	15	82	149	332
59. LOWER ARM CIRCUMFERENCE –F.	22	310	555	285	366	434	263	455	487	210	248	69	110	130	344
61. SLEEVE INSEAM		592	176	481	257	262	486	260	227	134	5	113	93	70	121
62. SLEEVE LENGTH	592		424	576	376	399	558	398	388	219	151	177	129	121	295
70. VERTICAL TRUNK CIRCUMFERENCE	176	424		424	418	446	360	374	395	217	224	111	121	191	366
75. FOOT LENGTH	481	576	424		499	487	720	468	444	223	153	211	158	134	274
77. FOOT BREADTH	257	376	418	499		717	443	545	498	224	164	131	169	121	311
82. BALL OF FOOT CIRCUMFERENCE	262	399	446	487	717		405	528	500	227	169	106	161	122	327
83. HAND LENGTH	486	558	360	720	443	405		552	465	225	112	191	187	110	253
86. HAND BREADTH AT METACARPALE	260	398	374	468	545	528	552		643	223	163	194	263	106	275
92. FIST CIRCUMFERENCE	227	388	395	444	498	500	465	643		228	150	128	161	112	295
93. HEAD LENGTH	134	219	217	223	224	227	225	223	228		118	110	198	203	667
94. HEAD BREADTH	5	151	224	153	164	169	112	162	150	118		79	43	235	537
103. NOSE LENGTH	113	177	111	211	131	106	191	194	128	110	79		199	64	121
108. MENTON-SUBNASALE LENGTH	93	129	121	158	169	161	187	263	161	198	43	199		162	187
116. HEAD HEIGHT	70	121	191	134	121	122	110	106	112	203	235	64	162		262
122. HEAD CIRCUMFERENCE	121	295	366	274	311	327	253	275	295	667	537	121	187	262	

DECIMALS POINTS HAVE BEEN OMITTED.

PREPARED BY USAF ANTHROPOLOGY PROJECT AT ANTIOCH COLLEGE, SEPTEMBER 1955

Table XXIII.
Correlations between body dimensions (continued)

WORK SPACE	5.5.2
General: consider,	5.5.2.1
Decision factors: consider,	5.5.2.1.1
Specific points where operation occurs	5.5.2.1.1.(a)
Identify body positions	5.5.2.1.1.(b)
Identify space & clearance requirements	5.5.2.1.1.(c)
Identify access requirements	5.5.2.1.1.(d)
Identify size and weight of tools	5.5.2.1.1.(e)
Identify environmental conditions	5.5.2.1.1.(f)
Identify space requirements for manipulation	5.5.2.1.1.(g)
Identify light requirements	5.5.2.1.1.(h)
Identify possible hazards	5.5.2.1.1.(i)
Identify passages for equipment	5.5.2.1.1.(j)
Identify reductions of unusable space by doors, etc.	5.5.2.1.1.(k)
Allow for posture changes: kneeling, crawling, crouching	5.5.2.1.2
Provide for safety	5.5.2.1.3
Provide equipment aids: electrical outlets, etc.	5.5.2.1.4
Walking surface requirements: consider,	5.5.2.2
Traction: provide non-skid surfaces	5.5.2.2.1
Slope: non-skid, resist wear, provide for drainage	5.5.2.2.2
Equipment surfaces: non-skid, non-glare	5.5.2.2.3
Standing operations: consider,	5.5.2.3
Display height: See text and fig. 60 (40 to 80 inches)	5.5.2.3.1
Control dimensions: between 30 to 70 inches	5.5.2.3.2
Precise controls: between 40 to 64 inches	5.5.2.3.2.1
Control reach: less than 18 inches	5.5.2.3.2.2
Clearance: between vertical panels - at least 30 inches	5.5.2.3.3
Seated operations: consider,	5.5.2.4
Sloped surface: use when continuous monitoring required	5.5.2.4.1
Panel slope: 13-15° from vertical plane. See fig. 61	5.5.2.4.2

Arm reach: Max width displays: 60 inch; for controls 44 inch	5.5.2.4.3
Writing surface: 14 to 16 inches deep	5.5.2.4.4
Knee room: Min. 26 high, 20 wide, 18 deep inches, See fig. 62	5.5.2.4.5
Desk tops: 30 inches. See figs. 61-62	5.5.2.4.6
Seating height: See text and fig. 62	5.5.2.4.7
Arm rests: See text and fig. 62	5.5.2.4.8
Sit or stand operations: consider,	5.5.2.5
Toe space: 4 high and 4 deep inches. See fig. 60	5.5.2.5.(a)
Slope: See fig. 61	5.5.2.5.(b)
Recess handles	5.5.2.5.(c)
Seating and footrests: See text	5.5.2.5.(d)
Passageways: consider,	5.5.2.6
Decision factors: consider,	5.5.2.6.1
Identify maximum traffic load required	5.5.2.6.1.(a)
Provide adequate illumination	5.5.2.6.1.(b)
Provide identification of entrances & exits	5.5.2.6.1.(c)
Passage width: 36 inch (one man); 54 inch (two man)	5.5.2.6.2
Clearance: 80 inches high. See fig. 63	5.5.2.6.3
Horizontal work surfaces: consider,	5.5.2.7
General: See fig. 64	5.5.2.7.1
Work surface height: consider,	5.5.2.7.2
Standing operations: 42 inches	5.5.2.7.2.1
Seated operations: 30 inches	5.5.2.7.2.2
Access openings: See fig. 65. Consider,	5.5.2.8
Rectangular vertical access: 18 inches square min.	5.5.2.8.(a)
Circular vertical access: 18 inches diameter min.	5.5.2.8.(b)
Horizontal rectangular access: 18 wide by 15 high inches min.	5.5.2.8.(c)
Circular horizontal access: 18 inches diameter min.	5.5.2.8.(d)
Crawl space: 25 in/sq or 25 in. dia.	5.5.2.8.(e)
Doorways: 24 inches wide by 80 inches high min.	5.5.2.9

Work positions: consider,	5.5.2.10
Mobile workspace requirements: consider,	5.5.2.10.1
Identify duration of task	5.5.2.10.1.(a)
Identify dimensions of equipment	5.5.2.10.1.(b)
Identify weight of equipment	5.5.2.10.1.(c)
Identify if protective garments required	5.5.2.10.1.(d)
Identify space required by doors, etc.	5.5.2.10.1.(e)
Kneeling workspace: See fig. 66 and table XXIV	5.5.2.10.2
Stooping workspace: See fig. 66 and table XXIV	5.5.2.10.3
Squatting workspace: See fig. 64 and table XXIV	5.5.2.10.4
Supine workspace: See fig. 65 and table XXIV	5.5.2.10.5
Prone work or crawl space: See fig. 65 and table XXIV	5.5.2.10.6
Kneeling crawl space: See fig. 66 and table XXIV	5.5.2.10.7
Workspace inclines: consider,	5.5.2.11
General: provide incline when abrupt change is 12 inches or more	5.5.2.11.1
Incline decision factors: See text	5.5.2.11.1.1
Additional: to cover low objects	5.5.2.11.1.2
Angle of incline: See fig. 67	5.5.2.11.1.3
Stairs preferred to ramps, unless equipment prohibits	5.5.2.11.1.4
Ramps: consider,	5.5.2.11.2
Use for 20 degrees or less. See fig. 67	5.5.2.11.2.(a)
Ramp width: largest vehicle plus 15 inches	5.5.2.11.2.(b)
Handrails: See table XXV	5.5.2.11.2.(c)
Stairs: consider,	5.5.2.11.3
Angle: Use when angle is 20 to 50 degrees. See figs. 67, 68	5.5.2.11.3.1
Strength: Weight of personnel plus equipment plus safety	5.5.2.11.3.2
Treads and risers: consider,	5.5.2.11.3.3
Tread of stairs: 9.5 to 12 inches deep	5.5.2.11.3.3.(a)
Risers: 5 to 8 inches high	5.5.2.11.3.3.(b)
Steep stairway: See text	5.5.2.11.3.3.(c)
Use low risers (5 inch) when loads greater than 20 pounds	5.5.2.11.3.3.(d)
Treads: Non-skid. See fig. 68	5.5.2.11.3.3.(e)
Length of flight: See text	5.5.2.11.3.4
Rails: See table XXV	5.5.2.11.3.5

Stair ladders: Use when incline 58 to 75 degrees. See figs. 67, 69	5.5.2.11.4
Width: See table XXV and fig. 69	5.5.2.11.4.1
Treads: See text and fig. 69	5.5.2.11.4.2
Handrail: See table XXV	5.5.2.11.4.3
Ladders: consider,	5.5.2.11.5
Angle: used for inclines between 75 and 90 degrees	5.5.2.11.5.1
Between levels: offset and provide guarded landings	5.5.2.11.5.2
Fixed ladders: See fig. 68	5.5.2.11.5.3
Cages: Use for ladders 20 feet or more. See text	5.5.2.11.5.4
Rungs: Non-skid. consider,	5.5.2.11.5.5
Rung diameter (wooden): 1.12 to 1.5 inches	5.5.2.11.5.5.(a)
Rung diameter (metal): 1.0 to 1.5 inches	5.5.2.11.5.5.(b)
Spacing: 11 to 12 inches	5.5.2.11.5.5.(c)
Width side rails: 18-21 inches	5.5.2.11.5.5.(d)
Portable ladders: non-skid and light	5.5.2.11.5.6
Handgrips: provide handgrips for all ladders	5.5.2.11.5.7
Platforms and work stands: consider,	5.5.2.11.6
Provide railing 24 and 42 inches above standing surface	5.5.2.11.6.(a)
Anchor platforms with high center of gravity	5.5.2.11.6.(b)
Label load limits	5.5.2.11.6.(c)
Knock-down shall be lockable at joints	5.5.2.11.6.(d)
Climbing surface of platform: non-skid	5.5.2.11.6.(e)
Platforms for accessibility: See text	5.5.2.11.6.1
Equipment color: Follow Federal Standard No. 595. Consider,	5.5.2.12
Console exterior: color 24300 (green)	5.5.2.12.(a)
Console interior: color 24300 (green)	5.5.2.12.(b)
Panels: color 24300 (green)	5.5.2.12.(c)
Panel lettering: color 27038 (black)	5.5.2.12.(d)
Design of equipment for remote handling: See text. Consider,	5.5.2.13
Prime equipment: consider,	5.5.2.13.1
Fasteners shall be captive	5.5.2.13.1.(a)
Components shall be self-aligning	5.5.2.13.1.(b)
Provide quick-disconnect devices	5.5.2.13.1.(c)

DETAILED REQUIREMENTS
TEMPERATURE, CLOTHING & SAFETY

TEMPERATURE

Tools: See text. Compatible with remote handling system.	5.5.2.13.2
Remote viewing equipment: consider,	5.5.2.13.3
Viewing system: three dimensional	5.5.2.13.3.(a)
Provide shielding window, if required	5.5.2.13.3.(b)
Provide television, etc. where required	5.5.2.13.3.(c)
Viewing shall be within 60 degrees line of sight	5.5.2.13.3.(d)
Provide illumination (100 foot candles)	5.5.2.13.3.(e)
Monochroniatic lighting may be used	5.5.2.13.3.(f)
Stereoscopic periscope shall be aligned	5.5.2.13.3.(g)
Lettering by TV shall be white on black	5.5.2.13.3.(h)
Environmental toxicity: consider,	5.5.2.14
Treat toxic substance in terms of threshold & bodily effects	5.5.2.14.(a)
Concentration and time of exposure critical factors	5.5.2.14.(b)
Concentrations: See table XXVI	5.5.2.14.(c)

5.5.2 Work space. - The careful design of the work space envelope shall be considered as one of the critical factors necessary for the attainment of an optimal man-machine interface. XR-C-1

5.5.2.1 General considerations. - The layout and design of equipment shall be such that the operator or technician is able to accomplish all of the necessary functions related to or involved in the task. XR-C-1

5.5.2.1.1 Decision factors. - The layout and design of equipment shall always be preceded by a task analysis of sufficient thoroughness to determine: (Rigby, 14; McFarland, 15). XR-S-2

(a) Specific points where the operation is carried out.

(b) The approximate body positions normally assumed to perform the operation.

(c) The space and clearance requirements necessary to accommodate the body positions and movements required by the operation.

(d) The requirements for access or passage to the work point.

(e) The size and weight of tools and other needed equipment that will be carried to the work point.

(f) The existence of environmental conditions that would require protective garments and devices.

(g) Space requirements for the manipulation of the items involved in the operation; eg, fasteners, tools, modules, covers, and test instruments.

(h) Light and space requirements to enable the technician to see and control the manipulations.

(i) The existence of electrical, chemical, thermal, or mechanical hazards which require additional clearances for safety.

(j) Passage through the space of other equipment, vehicles, or loads not involved in the specific operation of that work point.

(k) Reductions of usable space caused by doors, shelves, covers, and other protuberances opening into the workspace, as well as those reductions resulting from test equipment, tool boxes, and workstands brought into the area.

5.5.2.1.2 Posture change. - The workspace shall allow the technician to change posture if the task requires kneeling, crawling, or crouching for a prolonged period of time. (Morgan, 16; Ely, 17). XR-S-2

5.5.2.1.3 Safety. - Provisions shall be made to protect the technician from the hazards enumerated in section 5.7.3.

5.5.2.1.4 Equipment. - The following aids shall be provided at the work place to assist the technician wherever possible. (Rigby, 14). XR-S-2

(a) Auxiliary hooks, holders, lights, outlets, stands or shelves.

(b) Low cabinets, mirrors, or open spaces necessary to allow visual contact with related displays, moving parts, and other hazards.

(c) Features which facilitate or permit communication between operation team members.

5.5.2.2 Walking surface requirements. - The following walking surface requirements shall be observed.

5.5.2.2.1 Traction. - Non-skid surfaces, expanded metal flooring, or abrasive coatings shall be provided on all surfaces which may be used for walking, climbing, or footholds. (Rigby, 14). XR-S-2

5.5.2.2.2 Slope. - These surfaces shall be perforated or sloped to provide drainage and shall be durable enough to resist wear without becoming slippery. (Rigby, 14). XR-S-2

5.5.2.2.3 Equipment surfaces. - The top surfaces of equipment that may be used as work stands shall be provided with a non-skid surface and reinforced if necessary. (Rigby, 14). XR-S-2

5.5.2.3 Standing operations.

5.5.2.3.1 Display height. - Visual displays on vertical panels shall be mounted in an area of adequate vision. Displays shall not extend more than 80 inches above the standing surface nor shall they be located below 40 inches above the standing surface. Indicators requiring precise reading shall be placed no more than 64 inches above the standing surface nor less than 48 inches above the standing surface. See figure 60. (Morgan, 16). XR-S-1

5.5.2.3.2 Control dimensions. - Controls mounted on vertical panels shall be located between 30 inches and 70 inches above the standing surface. (Ely, 17). XR-S-2

5.5.2.3.2.1 Precise controls. - Precise controls and those frequently operated shall be located between 40 inches and 64 inches above the standing surface. (Ely, 17). XR-S-2

5.5.2.3.2.2 Control reach. - The operator should have to reach across less than 18 inches of workspace to manipulate the controls. (Squires, 18; Barnes, 19). See figure 60. XR-S-1

5.5.2.3.3 Clearance. - Clearance between vertical panels and walls or other vertical surfaces shall be at least 30 inches. If the work space is also used as a corridor ample clearance shall be provided to permit passage without interference. (Rigby, 14). XR-S-2

5.5.2.4 Seated operations.

5.5.2.4.1 Sloped surface. - When continuous monitoring or control is required of a seated operator, controls and displays shall be mounted on a sloped console surface. See figure 61. (Woodson, 20; Morgan, 16). XR-S-2

5.5.2.4.2 Panel height. - For normal seated operations, the slope of the control-display panel shall be 13-15° from the vertical panel height. (Morgan, 16). XR-S-2

5.5.2.4.2.1 Console height. - If direct line of sight beyond the console is required the console shall extend less than 30 inches above the seating point for seated operators. See figure 61. (Woodson, 20). XR-S-1

5.5.2.4.3 Arm reach. - The location of controls and displays along the horizontal axis of the panel shall be such that they are within comfortable reach of the operator. See figure 61. Maximum width for displays shall be 60 inches and 44 inches for controls. (Ely, 17). XR-S-2

5.5.2.4.4 Writing surface. - A writing surface at least 14 inches and not more than 16 inches in depth shall be provided if record keeping and writing are required. (Rigby, 14). XR-S-2

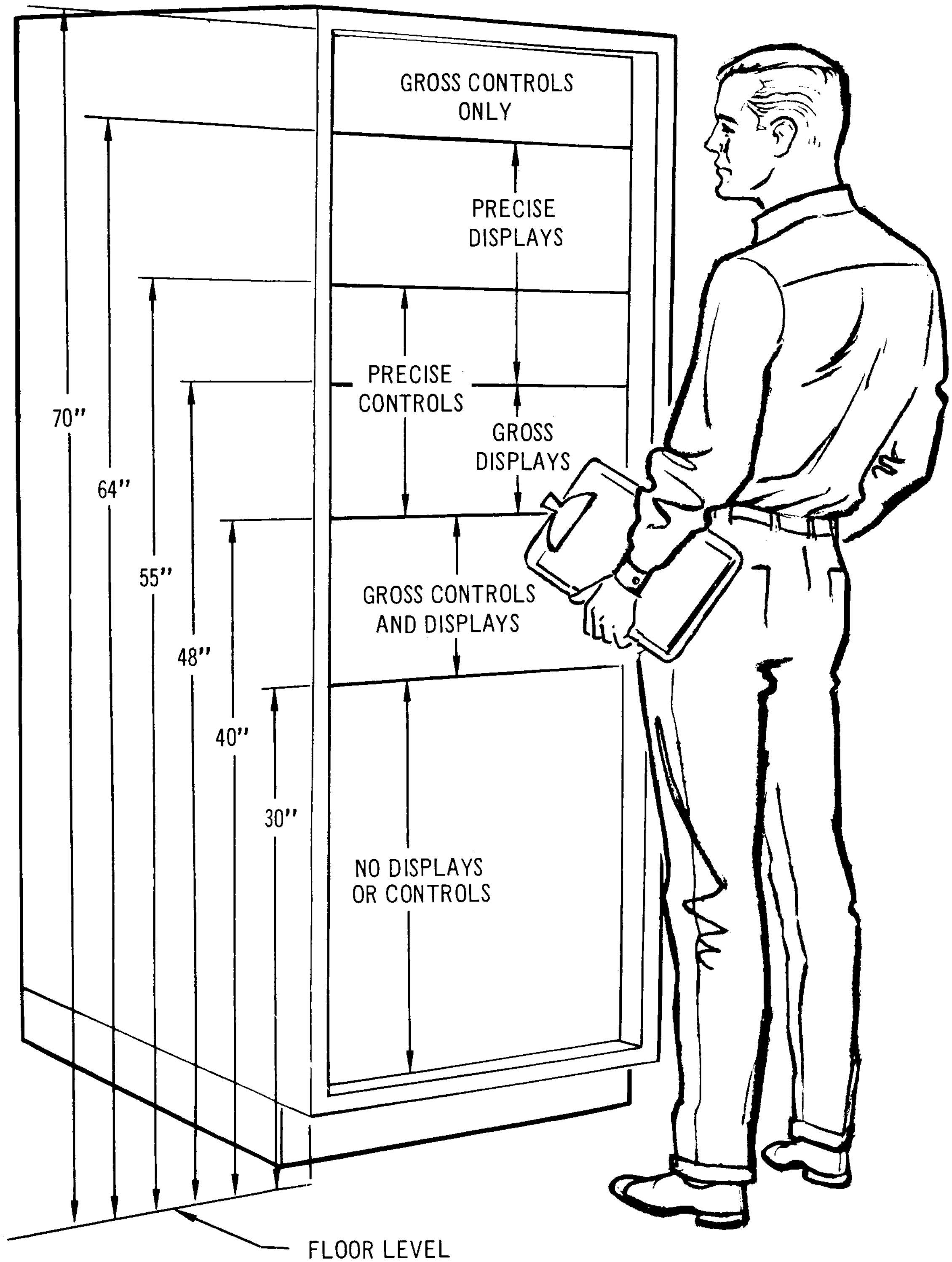
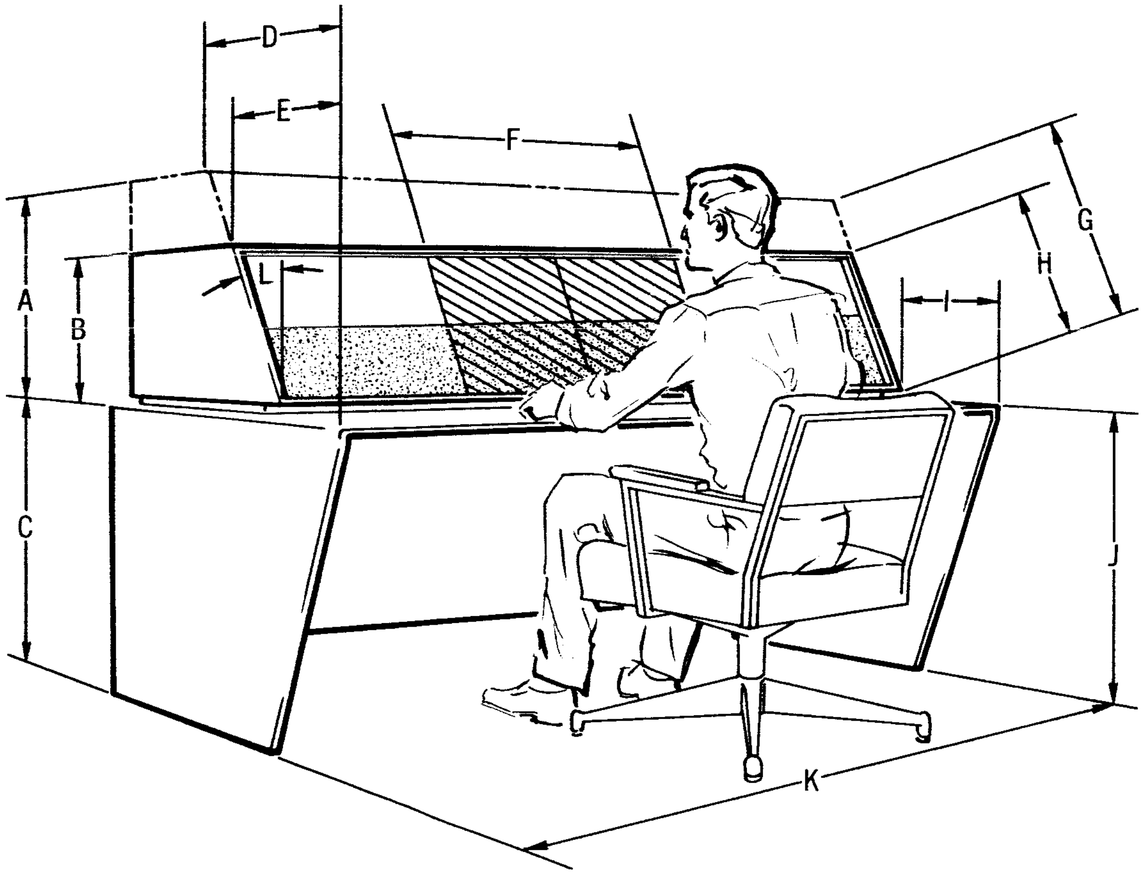


Figure 60. Cabinet control and display area



CODE	MIN	MAX	OPT
A		24"	
B		16"	
C	28"	31"	
D		30"	
E		25"	
F		24"	
G		25"	
H		19-1/2"	
I	14"	16"	
J	26"	31"	30"
K		60"	
L	5°	20°	13-15°

LEGEND

DISPLAYS

MANUAL CONTROLS

CRITICAL DISPLAYS AND CONTROLS

Figure 61. Seated console display

5.5.2.4.5 Knee room. - Knee and foot room adequate for the 95th percentile user shall be provided beneath the console panel surface. Minimum dimensions shall be 26 inches high, 20 inches wide and 18 inches deep. If a footrest is provided, the height requirements shall be determined from that point. See figure 62. (Rigby, 14). XR-S-2

5.5.2.4.6 Desk tops. - Desk tops, writing surfaces and other seated work surfaces shall be 30 inches above the standing surface. If other considerations make this rule impractical, the minimum height may be as low as 28 inches and the maximum allowable height shall be 31 inches, provided the minimal knee clearance height is maintained. See figures 61 and 62. (Woodson, 20; Rigby, 14). XR-S-2

5.5.2.4.7 Seating height. - Seat or chair tops shall be a minimum of 7 inches below the overhanging console surface or desk top under surface. A minimum of 4 inches of vertical adjustment shall be provided. If cushioned seating is provided the compression of the cushioning material shall be compensated for. See figure 62. (Woodson, 20; Rigby, 14). XR-S-2

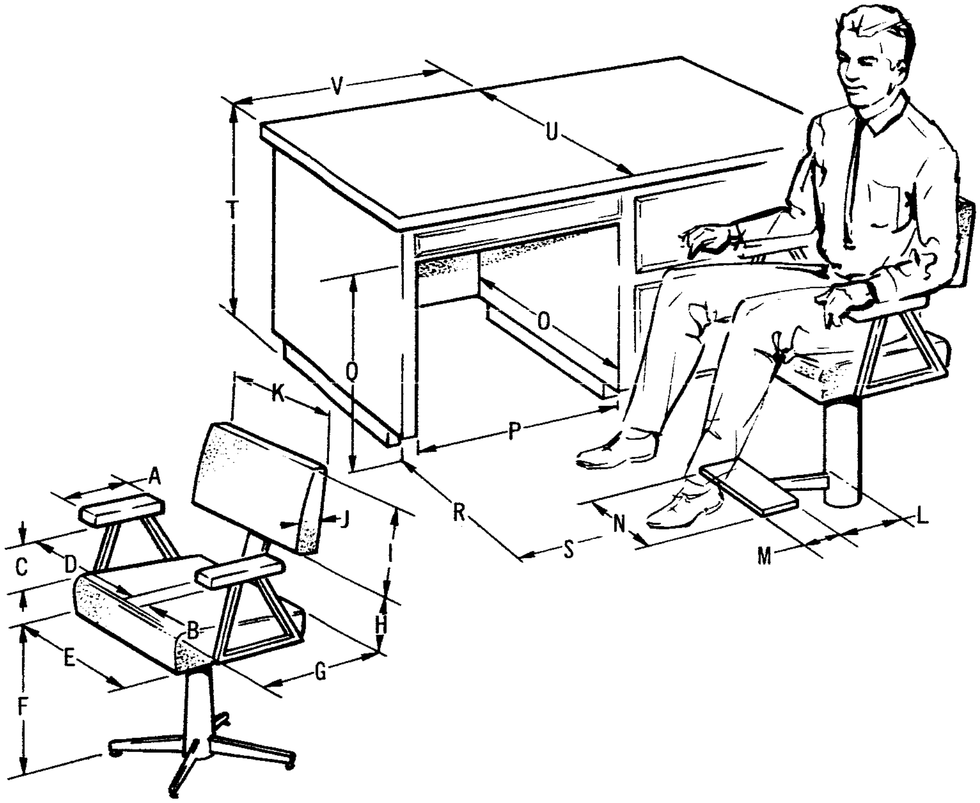
5.5.2.4.8 Arm rests. - Arm rests shall be provided at all consoles. The rests shall either be a part of the console or be a part of the operator's chair. See figure 62. Arm rests which are part of the console shall project at least 8 inches and preferably 12 inches horizontally from the front of the console. Arm rests on the operator's chair shall be a minimum of 2 inches wide and 10 inches long and shall support the arm in the same plane as the writing surface of the console. (Rigby, 14). XR-S-2

5.5.2.5 Sit or stand operations. - All sit or stand operations shall have the following requirements:

(a) Cabinets, consoles, and work surfaces requiring the operator to stand close to the front surface shall have a toe space at the base 4 inches high and 4 inches deep. See figure 60. XR-C-1 (Rigby, 14). XR-S-2

(b) The slope of the console and general design shall be as in figure 61. (Morgan, 16). XR-S-2

(c) Handles on cabinets and console shall be recessed when practical to eliminate projections on the cabinet surfaces. XR-C-2



CHAIR DIMENSIONS:	FIXED	ADJUST*
ARM RESTS:		
A. Length:	10"	± 2"
B. Width:	2"	
C. Height:	8.5"	± 2.5"
D. Separation:	18"	
SEAT:		
E. Width:	16"	
F. Height:	18"	± 2"
G. Depth:	16"	
BACK REST:		
H. Space:	6"	± 2"
I. Height:	15"	
J. Max curve:	4"	
K. Width:	16"	
FOOTRESTS* (where required):		
L. From center	7"	
M. Width:	6"	
N. Length:	10"	

REQUIREMENTS	FIXED	ADJUST*
MINIMUM CLEARANCE REQUIREMENTS:		
O. Kneehole depth:	18"	
P. Kneehole width:	20"	
Q. Kneehole height:	26"	
R. Desk to wall:	32"	
S. Lateral work clearance:		
(1) Shoulders:	23"	
(2) Elbows:	25"	
(3) Best overall:	40"	
DESK OR WORK SURFACE DIMENSIONS:	MIN	BEST
T. Height of work surface:	29"	30"
U. Width of work surface		
(1) Elbow rest alone:	4"	8"
(2) Writing surface:	12"	16"
(3) Desk work area:		36"
V. Length of work area:	30"	–

*Adjustment range. Adjustability is preferred for these dimensions.

Figure 62. Desk and chair dimensions

(d) Seating for sit stand operations shall be 34 inches with plus or minus 3 inch adjustment range. A foot rest shall be provided 16 inches above the standing surface. If an adjustable foot rest is provided, the range of adjustment shall be plus or minus 4 inches. Footrests provided on seating or sit or stand operations shall be in accord with the requirements for chair seat height. (Morgan, 16; Ely, 17). XR-S-2

5.5.2.6 Passageways.

5.5.2.6.1 Decision factors. - Passageways shall be designed to expedite the flow of traffic. Some design factors to be considered are: (Woodson, 20). XR-S-2

(a) The maximum traffic load at any one time.

(b) Adequate illumination and intelligible indentification of exits and entrance.

(c) The number and location of entrances and exits.

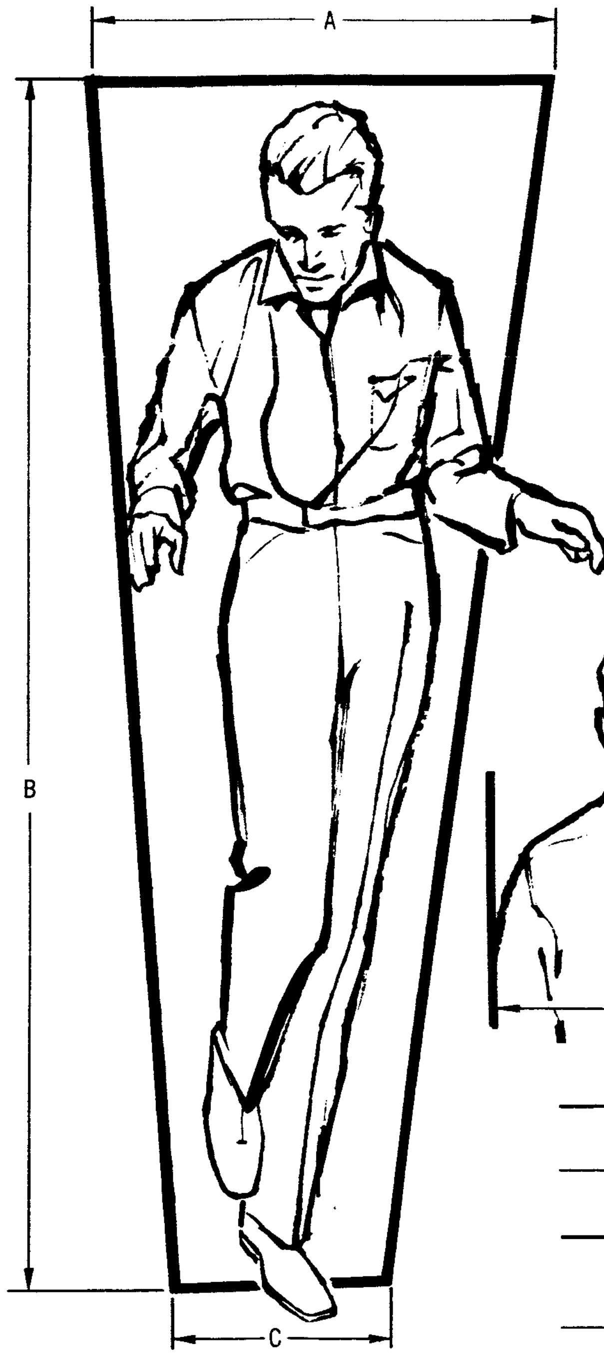
5.5.2.6.2 Passage width. - Passageways shall be free of obstructions. The minimum width of a passageway shall be 24 inches if there is no likelihood of personnel passing each other. If passing facing each other, the minimum width shall be 30 inches, with a 36 inch width or greater preferred. If the personnel must pass abreast, the minimum width shall be 42 inches and the preferred width 54 inches. See figure 63. (Rigby, 14; Morgan, 16). XR-S-2

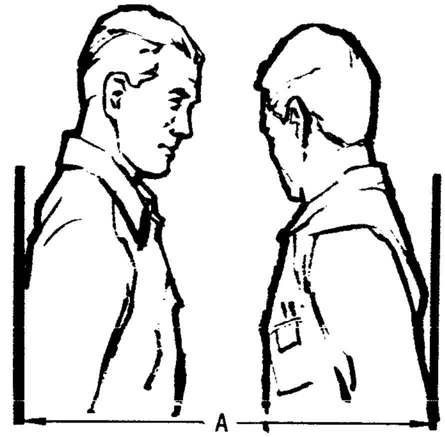
5.5.2.6.3 Clearance. - The following clearance dimensions shall be observed: (Morgan, 16). XR-S-2

(a) The minimum overhead clearance height shall be 80 inches. See figure 63.

(b) Where doors open into a passageway or corridor, the corridor shall be the width of the door plus 30 inches. If the door opens only in the end of the corridor, the corridor width shall be the door width plus 15 inches.

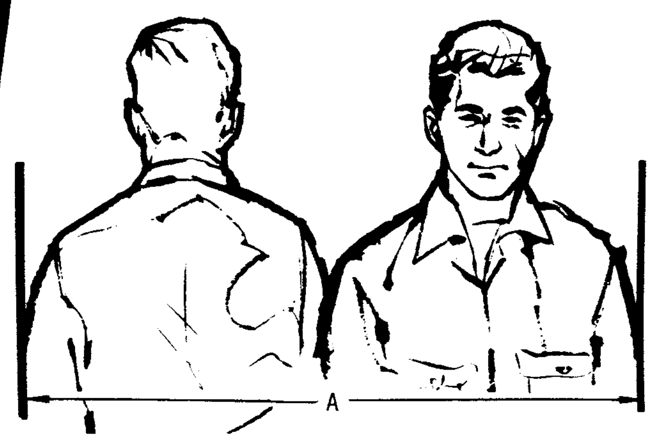
(c) Corridors through which trucks, dollies, or other vehicles pass shall allow space for the vehicle plus 10 to 15 inches clearance on each side.





2 MEN PASSING FACING

A	36" ADEQUATE. 30" MIN.



2 MEN PASSING ABREAST

A	54" ADEQUATE. 42" MIN.

CATWALK

A	32" MIN BULKY PROTECTIVE CLOTHING. 24" MIN LIGHT CLOTHING.
B	80" MIN UPRIGHT. 63" MIN CROUCHING.
C	15" MIN BULKY PROTECTIVE CLOTHING. 12" MIN LIGHT CLOTHING.

Figure 63. Work space requirements

5.5.2.7 Horizontal work surfaces.

5.5.2.7.1 General. - The arrangement of horizontal work surfaces shall be such that all critical or precise controls lie within the normal area (the area that can be conveniently reached with a sweep of the forearm when the upper arm is in a normal position). All controls shall be within the limits of the maximum reach. See figure 64. (Squires, 18; Barnes, 19). XR-S-2

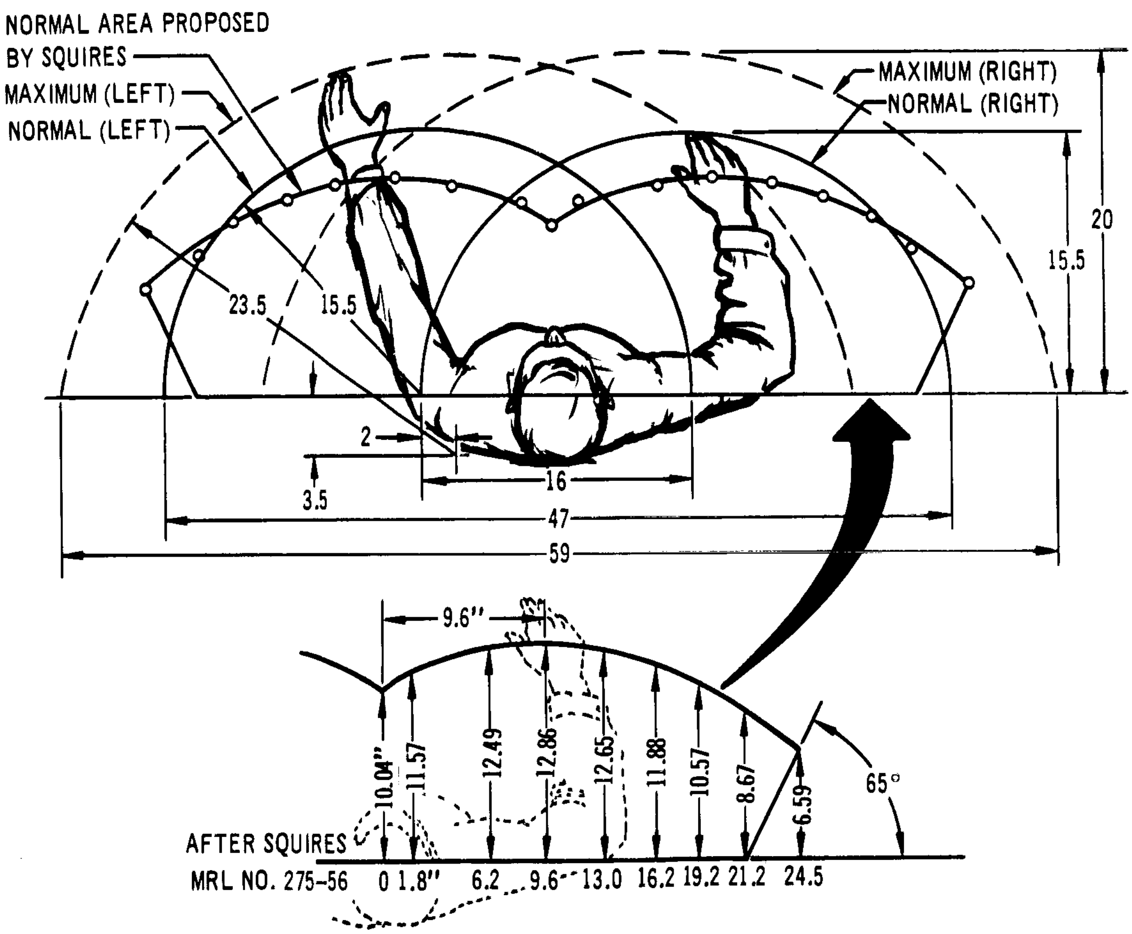


Figure 64. Horizontal work areas

5.5.2.7.2 Work surface height.

5.5.2.7.2.1 Standing operations. - For standing operations the height of horizontal work surfaces shall be two to four inches below the elbow, the optimum height being 42 inches. (Ellis, 21; Barnes, 19). XR-S-2

5.5.2.7.2.2 Seated operations. - Horizontal work surfaces for seated operations shall be 30 inches above the standing surface or foot rest. Deviation of ± 1 inch shall be tolerated if other conditions make the above criteria impracticable. (Barnes, 19). XR-S-2

5.5.2.8 Access openings. - Access openings and hatches for personnel shall be determined from figure 65. (Rigby, 15; Woodson, 20). XR-S-2. The absolute minimum in dimensions for various access openings shall be as follows: (Rigby, 14). XR-S-2

(a) Rectangular vertical access openings and hatches shall be an absolute minimum of 18 inches square.

(b) Circular vertical access openings and hatches shall be an absolute minimum of 18 inches in diameter.

(c) Horizontal rectangular access openings and hatches shall be an absolute minimum of 18 inches wide and 15 inches high.

(d) Circular horizontal access openings and hatches shall be an absolute minimum of 18 inches in diameter.

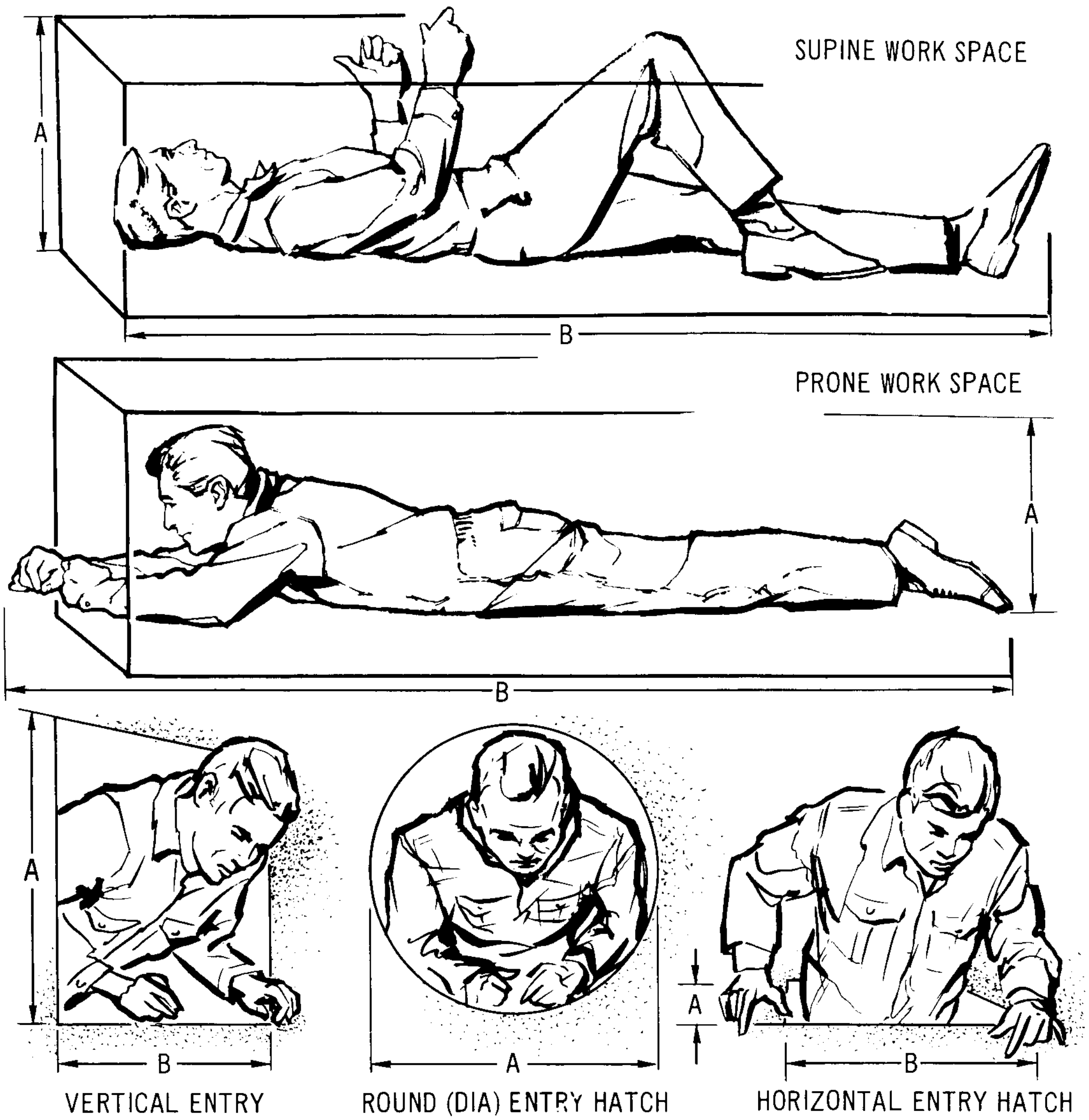
(e) Crawl through pipes or passages shall be an absolute minimum of 25 inches square or 25 inches in diameter.

All above dimensions are for lightly dressed personnel. Cold weather and protective garments shall require additional clearance. (Rigby, 14). XR-S-2

All situations requiring access openings will demand complete analysis and the minimal dimensions will be adjusted accordingly. XR-C-1

For access requirements for hands and arms see section 5.8 Maintainability.

5.5.2.9 Doorways. - Doorways shall be rectangular openings in vertical surfaces and shall be a minimum of 24 inches in width with a minimum height of 80 inches. (Rigby, 14). XR-S-2



		BULKY PROTECTIVE CLOTHING	LIGHT CLOTHING
SUPINE WORK SPACE	"A"	26" MIN	20" MIN
	"B"	78" MIN	78" MIN
PRONE WORK SPACE	"A"	24" MIN	17" MIN
	"B"	96" MIN	96" MIN
VERTICAL ENTRY HATCH	"A"	20" MIN	12" MIN
	"B"	32" MIN	24" MIN
ROUND (DIA) ENTRY HATCH	"A"	32" MIN	24" MIN
HORIZONTAL ENTRY HATCH	"A"	24" MIN	
	"B"	32" MIN	22" MIN

Figure 65. Work space requirements (access)

5.5.2.10 Work positions.

5.5.2.10.1 Mobile workspace requirements. - Where personnel are required to work in limited spaces, the task shall be analyzed to determine the body position that will be assumed and the appropriate dimensions selected. XR-C-1

Additional factors that will affect the necessary dimensions are:

(a) Duration of the task and the comfortableness of the position.

(b) Dimensions of the tools, test equipment, and aids required to execute the task.

(c) Dimensions and weight of units and components that will be removed and replaced.

(d) Protective garments or devices worn by the personnel.

(e) Doors, access covers, and other projections into the workspace.

The absolute minimum width of all work space envelopes shall be 18 inches plus sufficient lateral clearance to accomplish the task. XR-C-1

5.5.2.10.2 Kneeling workspace. - Where personnel must work in a kneeling position, the minimum height shall be 56 inches and the minimum length shall be 42 inches. See figure 66. If displays and controls are required, the optimum display area is between 28 and 44 inches above the standing surface. The optimum control area is between 20 and 35 inches above the standing surface. The optimum work height is 27 inches above the standing surface. See figure 66 and table XXIV. (Rigby, 14; Dempster, 22; Hertzberg, 23). XR-S-2

5.5.2.10.3 Stooping workspace. - Where personnel must work in a stooping position, a minimum length of 36 inches shall be provided. Optimum height for displays is between 32 and 48 inches above the standing surface. The optimum area for controls is between 24 and 39 inches above the standing surface. See table XXIV and figure 66. (Rigby, 14). XR-S-2

5.5.2.10.4 Squatting workspace. - Where personnel must work in a squatting position, the minimum height shall be 48 inches above the standing surface. The minimum width shall be 27 inches. The optimum area for displays is between 27 and 43 inches above the standing surface. The optimum area for controls is between 19 and 34 inches above the standing surface. See figure 64 and table XXIV. (Rigby, 14). XR-S-2

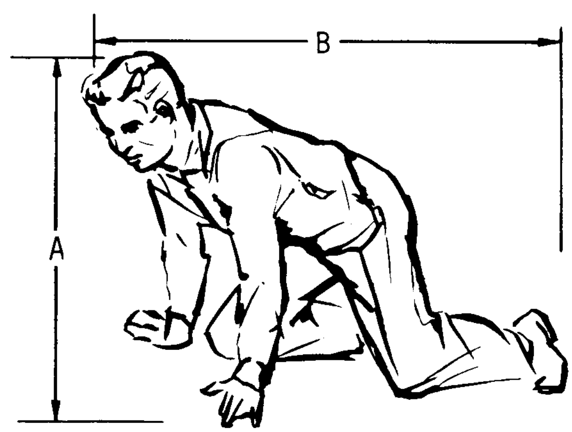
SQUATTING WORK SPACE

KNEELING WORK SPACE

		BULKY PROTECTIVE CLOTHING	LIGHT CLOTHING
SQUATTING WORK SPACE	"A" "B"	51 MIN 40 MAX	48 MIN 36 MIN
KNEELING WORK SPACE	"A" "B"	59 MIN 50 MIN	56 MIN 42 MIN
STOOPING WORK SPACE	"A"	44 MIN	36 MIN
KNEELING CRAWL SPACE	"A" "B"	38 MIN 62 MIN	31 MIN 59 MIN

NOTE: ALL DIMENSIONS IN INCHES.

STOOPING WORK SPACE



KNEELING CRAWL SPACE

Figure 66. Work space requirements (limited spaces)

Table XXIV.

Mobile work space requirements

Passageways	Min	Best	Arctic
A. Two men passing abreast	42"	54"	60"
B. Two men passing facing	30"	36"	36"
Catwalk dimensions			
A. Shoulder width	22"	24"	32"
B. Height	77"	80"	80"
C. Walking width	12"	15"	15"
Horizontal entry hatch			
A. Shoulder width	18"	22"	32"
B. Height	15"	20"	24"
Vertical entry hatch			
A. Round or square	18"	22"	32"
Crawl through pipe			
A. Round or square	25"	30"	32"
Supine work space			
A. Height	20"	24"	26"
B. Length	73"	75"	78"
Squatting work space			
A. Height	48"	--	51"
B. Width	27"	36"	40"
Optimum display area	27"	43"	
Optimum control area	19"	34"	
Stooping work space			
A. Width	36"	40"	44"
Optimum display area	32"	48"	
Optimum control area	24"	39"	
Kneeling work space			
A. Width	42"	48"	50"
B. Height	56"	--	59"
C. Optimum work point		27"	
Optimum display area	28"	44"	
Optimum control area	20"	35"	
Kneeling crawl space			
A. Height	31"	36"	38"
B. Length	59"	--	62"
Prone work or crawl space			
A. Height	17"	20"	24"
B. Length	96"	--	--

5.5.2.10.5 Supine workspace. - Where personnel must work in a supine position, the minimum length of the workspace shall be 78 inches and the minimum height shall be 20 inches. See figure 65 and table XXIV. If a creeper is employed, the height of the creeper shall be added to the minimum height. (Rigby, 14). XR-S-2

5.5.2.10.6 Prone work or crawl space. - Where personnel must work in a prone position, the minimum length of the workspace shall be 96 inches and the minimum height shall be 17 inches. See figure 65 and table XXIV. (Dempster, 22). XR-S-2

5.5.2.10.7 Kneeling crawl space. - Where personnel must work or crawl on all fours, the minimum length of the work area shall be 59 inches and the minimum height shall be 31 inches. See figure 66 and table XXIV. (Dempster, 22; Rigby, 14). XR-S-2

5.5.2.11 Workspace inclines.

5.5.2.11.1 General requirement. - Stairs, ladders or ramps shall be provided at all locations where personnel are required to abruptly change elevation by 12 inches or more. (Rigby, 14). XR-S-2

5.5.2.11.1.1 Incline decision factors. - The use of a ramp, stair, or ladder shall be dependent upon: a) the amount and type of traffic, b) distance between the two levels, c) the space available, d) the safety of the user. (Woodson, 20). XR-S-2

5.5.2.11.1.2 Additional considerations. - Stairs or ramps shall also be used to provide safe and easy passage over low objects (pipe, lines, and ducts) in corridors and passageways. XR-C-2

5.5.2.11.1.3 Angle of incline. - The angle of incline shall be considered as the critical difference between ramps, stairs, stair ladders and ladders. This angle shall provide the basis for the decision as to the type of structure to employ. Figure 67 shall be employed to determine both the preferred and the critical angles of incline suitable for each type of structure. (Rigby, 14). XR-S-2

5.5.2.11.1.4 Preferences. - Stairs shall generally be preferred as allowing the fastest and safest passage of personnel, particularly personnel carrying loads. Ramps are of value only when wheeled equipment must be moved between different levels and the space must also be used for pedestrian traffic. Requirements for personnel to push or pull wheeled equipment up ramps shall be carefully evaluated in terms of safety and human strength. XR-C-1

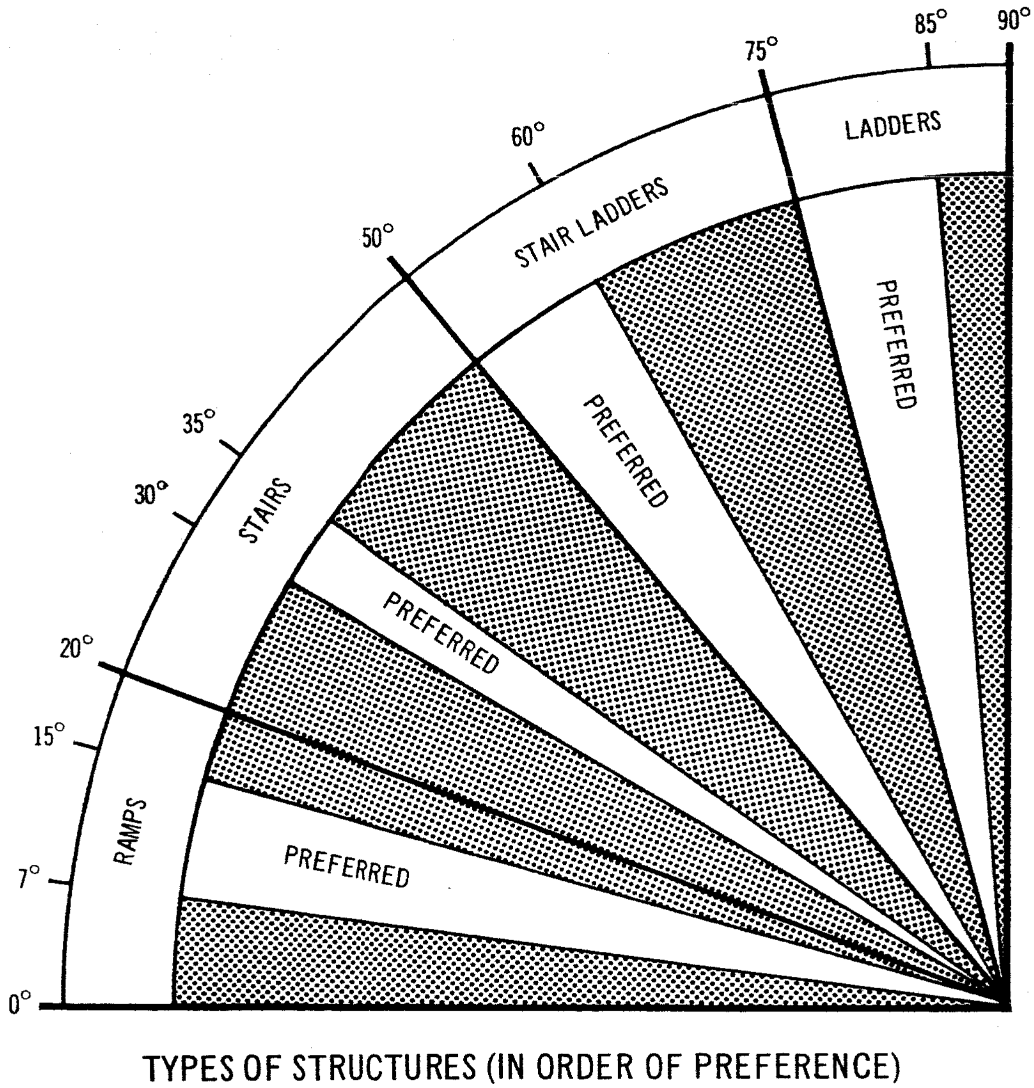


Figure 67. Angles for ascent structures

5.5.2.11.2 Ramps. - Ramps shall be consistent with the following criteria:

(a) Ramps shall be used for inclines of 20 degrees or less; the preferred angles being 7 to 15 degrees. See figure 67. (Woodson, 20). XR-S-2

(b) Ramps shall be wide enough to accommodate the largest vehicle that will be used with 10 to 15 inches clearance on each side. XR-C-3

(c) Hand rails shall be employed when the ramp is open on either side. The height and diameter of the hand rail shall be determined from table XXV. (Woodson, 20). XR-S-2

Table XXV.

Handrail dimension requirements for stairs and ramps

Dimension	Min.	Max.	Best
Stair			
Width (hand rail to hand rail)			
One way stairs	20"	--	22"
Two way stairs	48"	--	51"
Height of hand rail	30"	36"	33"
Diameter of hand rail	1.25"	3.0"	1.4"
Hand clearance	1.75"	--	2.0"
Stair Ladder			
Width (hand rail to hand rail)	21"	24"	22"
Height of hand rain	34"	37"	35"
Diameter of hand rail	1.25"	2"	1.4"
Clearance around hand rail	2"	--	3"
Ramp			
Width determined by loads and vehicle size			
Height of hand rail	38"	44"	42"
Diameter of hand rail	1"	3"	1.4"
Clearance around hand rail	2"	--	3"
Safety Bar or Chain			
Bar	--	--	33"
Chain, single	--	--	33"
Chain, double	--	--	24" & 48"

5.5.2.11.3 Stairs.

5.5.2.11.3.1 Angle. - Stairs shall be used when inclines of 20° to 50° are encountered. The preferred angles are between 30° and 35°. See figures 67 and 68. (Rigby, 14). XR-S-2

5.5.2.11.3.2 Strength. - Stairs shall be made strong enough to withstand the combined weights and strengths of the largest number of personnel likely to be on them at any one time, times a safety factor of two. (Rigby, 14). XR-S-2

5.5.2.11.3.3 Treads and risers. - Treads and risers shall comply with the following: (Morgan, 16; Woodson, 20). XR-S-2

(a) Treads of stairs shall be at least 9.5 inches in depth and no greater than 12 inches in depth.

(b) Risers shall be at least 5 inches high and no more than 8 inches high.

(c) The steeper the stairway the shorter shall be the tread depth and the greater the riser height.

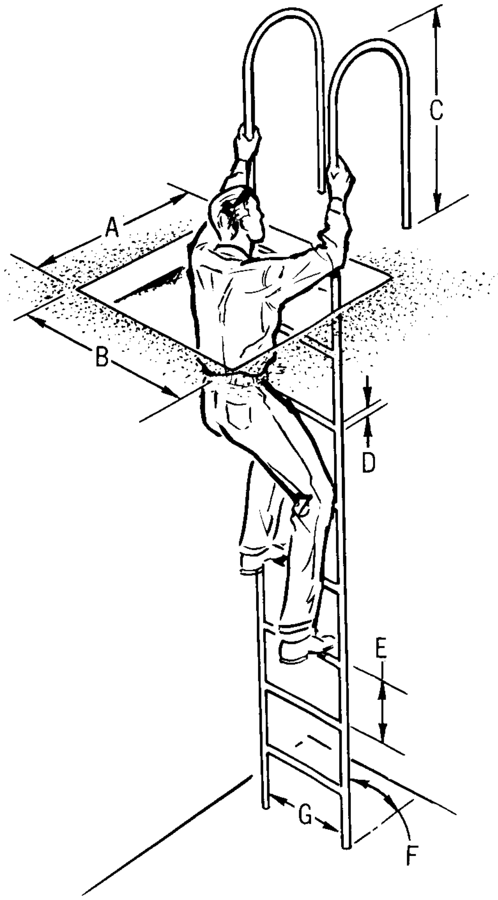
(d) Low risers (5 inches) shall be used where loads in excess of 20 pounds are to be carried or stairs are over two stories high.

(e) Treads shall be provided with non-skid surfaces. See figure 68.

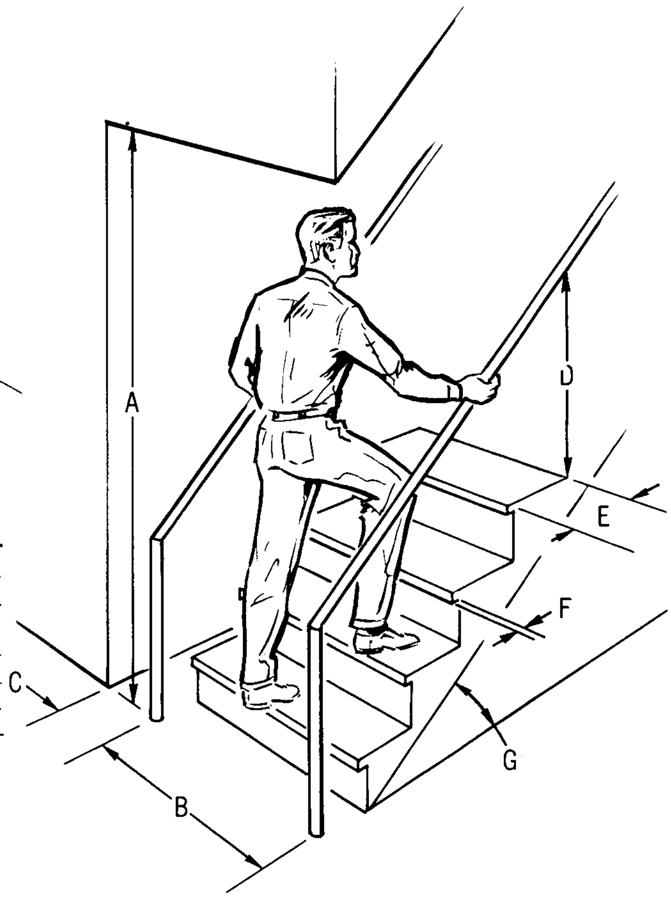
5.5.2.11.3.4 Length of flight. - Long flights of stairs shall be avoided. Landings shall be provided for every story (8-12 feet of elevation). Where space permits, landings shall be provided for every 10-12 treads. (Morgan, 16). XR-S-2

5.5.2.11.3.5 Rails. - Hand rails shall be provided on at least one side of stairs for safety and cnnvenience in accordance with table XXV. (Morgan, 16). XR-S-2

5.5.2.11.4 Stair ladders. - Stair ladders shall be used for inclines falling between 58° and 75°, with the preferred angles being 50-60°. See figures 67 and 69. (Rigby, 14). XR-S-2

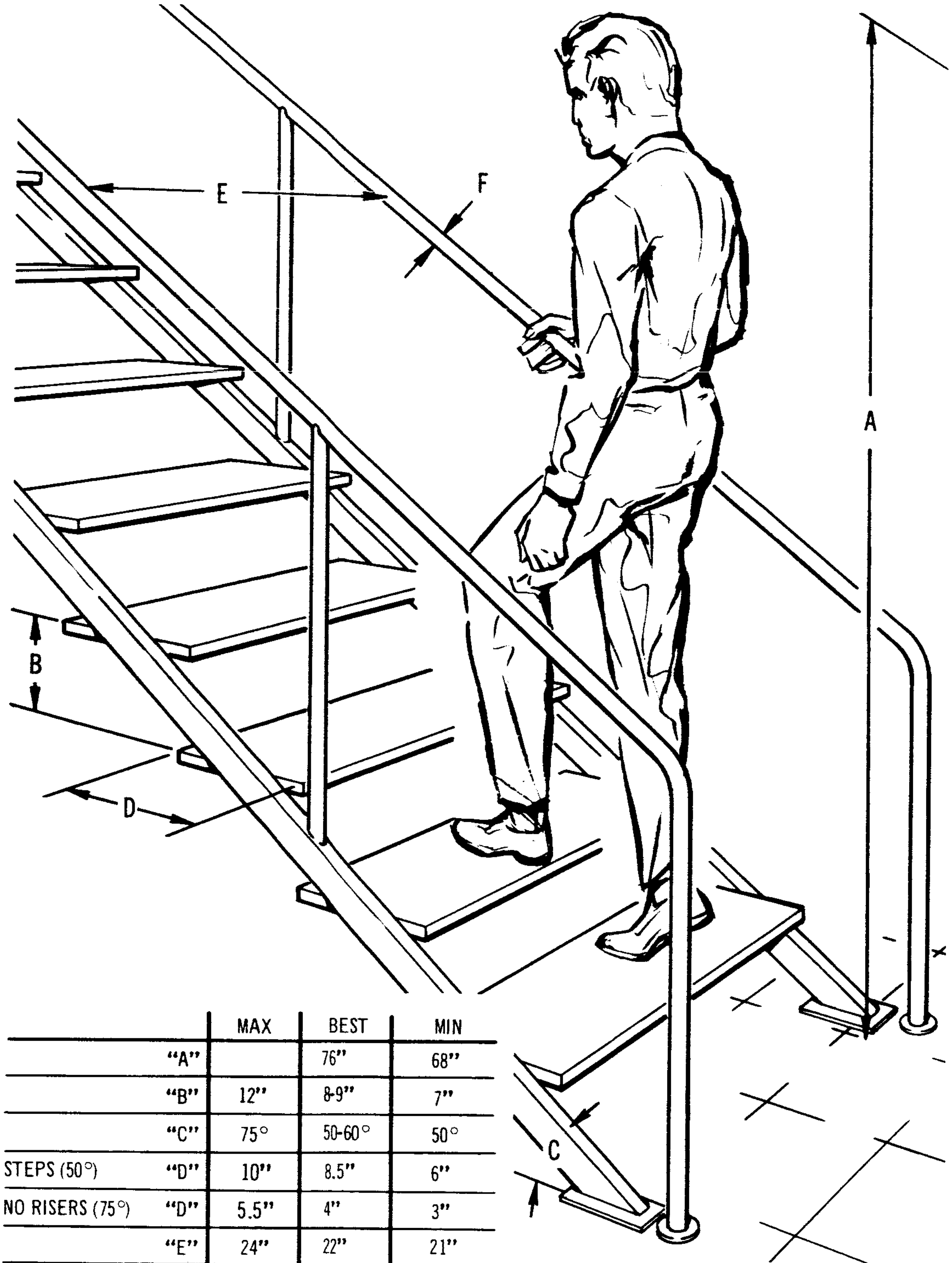


LADDER	MAX	BEST	MIN
IN BACK OF LADDER "A"		8"	6"
ON CLIMBING SIDE "A"		36" FOR 76°	30" FOR 90°
"B"		30"	24"
"C"		36"	
WOOD "D"	1.5"	1.4"	1.3"
PROTECTED METAL "D"	1.5"	1 4"	1.0"
"E"	16"	11-12"	9"
"F"	90°	80°	75°
"G"		8-21"	12"



	MAX	BEST	MIN
STAIRS "A"		78"	76"
ONE WAY "B"		22"	20"
TWO WAY "B"		51"	48"
"C"		2.0"	1.75"
"D"	36"	33"	30"
"E"		11-12"	9.5"
"F"	1.5"	1"	
"G"	50°	30°-35°	20°

Figure 68. Ladder and stairs requirements



		MAX	BEST	MIN
	"A"		76"	68"
	"B"	12"	8-9"	7"
	"C"	75°	50-60°	50°
STEPS (50°)	"D"	10"	8.5"	6"
NO RISERS (75°)	"D"	5.5"	4"	3"
	"E"	24"	22"	21"
HANDRAILS AND LADDER RUNGS	"F"	3.0	1.25"	1.12"

Figure 69. Stair ladders

5.5.2.11.4.1 Width. - Stair ladders shall be wide enough for one person only. See table XVI. If simultaneous up and down traffic is desired, separate up and down stair ladders shall be provided. These may be located side by side with a double center hand rail. The separation between hand rails shall be at least 6 inches, with 8 inches the preferred separation. See table XXV and figure 69. (Rigby, 14). XR-S-2

5.5.2.11.4.2 Treads. - Stair ladder treads shall be as follows: (Morgan, 16). XR-S-2

(a) Treads on stair ladders shall be open (without risers).

(b) Metal screening or other appropriate material shall be fastened to the underside where required to protect equipment and personnel.

(c) Tread depth shall be proportionate to the incline angle. At 50° incline treads shall be a minimum of 6 inches and a maximum of 10 inches deep with 8.5 inches the preferred depth. For inclines of 75° the minimum depth of tread shall be 3 inches, the maximum depth shall be 5.5 inches with the preferred depth being 4 inches. See figure 69. XR-C-2

(d) Treads shall be provided with a non-skid surface.

5.5.2.11.4.3 Handrail. - Handrails shall be provided in accordance with table XXV. XR-C-2

5.5.2.11.5 Ladders.

5.5.2.11.5.1 Angle. - Ladders shall be used for inclines between 75° and 90°, with 80° the preferred angle. See figure 68. (Rigby, 14). XR-S-2

5.5.2.11.5.2 Between several levels. - If ladders are used between several levels, they shall be offset and provided with guarded landings at each level. XR-C-2

5.5.2.11.5.3 Fixed ladders. - Fixed ladders shall be in accordance with figure 68. Vertical ladders more than 8 feet tall shall be avoided. (Woodson, 20). XR-S-2

5.5.2.11.5.4 Cages. - Permanent ladders 20 feet or longer in length shall have a cage affixed conforming to the following: (Rigby, 14). XR-S-2

(a) Cages shall begin 7 feet above standing surface.

(b) Cage depth from center of ladder shall be 28 inches with a flare to 32 inches at the bottom of the cage.

(c) Maximum spacing between cage ribs shall be 18 inches.

(d) Cage shall be 27 inches wide.

(e) Inside of the cage shall be absolutely free of obstructions.

5.5.2.11.5.5 Rungs. - Rungs shall have a non-skid surface and comply with the following: (Rigby, 14). XR-S-2

(a) Rungs on all wooden ladders shall be at least 1.12 inches in diameter, but not larger than 1.5 inches in diameter.

(b) Metal rungs may be 1.0 inch diameter but not more than 1.5 inch diameter. The preferred diameter is 1.4 inches for both wood and metal rungs.

(c) The spacing between rungs shall be 11-12 inches. If conditions necessitate deviation, the absolute minimum spacing shall be 9 inches and the absolute maximum spacing shall be 16 inches.

(d) The minimum width between the side rails of a ladder shall be 12 inches. The minimum width shall be increased by .25 inch for each additional two feet of length beyond 10 feet. The preferred width is 18-21 inches.

5.5.2.11.5.6 Portable ladders. - Portable ladders shall have non-skid, pivoted feet or other non-skid devices. XR-C-1

Portable ladders should be light enough to be moved and positioned by one or not more than two men. XR-C-1

5.5.2.11.5.7 Handgrip. - Handgrips shall be provided on all ladders. (Woodson, 20). XR-S-2

5.5.2.11.6 Platforms and work stands. - For assembly, maintenance, and repair functions outside of vehicle requirements of work stands and platforms shall be as follows: (Rigby, 14; Morgan, 16; MIL-STD-803A-1, 24). XR-S-2

(a) Platforms and work stands shall have railings 24 and 42 inches above the standing surface.

(b) Platforms having a high center of gravity shall be anchored.

(c) Load limits of platforms and work stands shall be prominently displayed at point of access and shall be in terms of men and pounds of equipment.

(d) Knock-down type work stands shall be securely locked at all joints.

(e) The climbing and standing surfaces of the platforms and work stands shall be of the non-skid type.

5.5.2.11.6.1 Platforms. - Platform requirements for accessibility, maintenance, and repair functions inside vehicles shall be as follows: (Rigby, 14; Morgan, 16). XR-S-2

(a) Platforms shall have a handrail with an optimum height of 35 inches.

(b) Platforms shall have a kick-plate a minimum of 3 inches high (perpendicular to the standing surface) and painted yellow, color number 13655 conforming to Federal Standard No. 595.

(c) In areas where step ladder accessibility is required, provisions shall be made to secure the ladder to the platform.

(d) If space permits, the platform shall be positioned to allow maintenance and repair functions to be performed from the standing position.

5.5.2.12 Equipment color. - With the exception of training equipment, operational and maintenance equipment consoles and panels shall have color schemes conforming to Federal Standard No. 595 and shall be as follows: (FED STD-595, 25). XR-S-2

(a) Console exterior - color 24300 (green).

(b) Console interior - color 24300 (green).

(c) Panels - color 24300 (green).

(d) Panel lettering - color 27038 (black).

5.5.2.13 Design of equipment for remote handling. - Remote handling equipment shall be planned and designed concurrently with the equipment and material to be handled by remote manipulation in order to insure maximum compatibility. XR-C-1.

5.5.2.13.1 Prime equipment. - Design of prime equipment for remote handling shall be as follows: (Crawford, 26; MIL-STD-803A-1, 24). XR-S-2

(a) Fasteners, bolts, and nuts shall be captive but replaceable by remote handling techniques.

(b) Self-alignment devices shall be provided for components that must be jointed together.

(c) Quick-disconnect devices shall be provided to reduce remote handling difficulties.

5.5.2.13.2 Tools. - Tools required for remote handling tasks shall be provided with adaptors or otherwise designed for compatibility with the remote handling system. The torque or force reaction that a power tool may transmit to the manipulator shall not exceed the capacity of the remote manipulator for which it is designed. (Crawford, 26; MIL-STD-803A-1, 24). XR-S-2

5.5.2.13.3 Remote viewing equipment. - Remote viewing equipment shall be as follows: (Crawford, 26; MIL-STD-803A-1, 24). XR-S-2

(a) The viewing system shall provide the operator with three-dimensional information of the work space.

(b) If shielding requirements permit, direct viewing through shielding windows shall be provided.

(c) Closed circuit television systems, periscopes, and microscopes shall supplement direct viewing when required.

(d) Direct viewing of objects near the viewing window or viewing from a position where the line of sight angle of incidence is greater than 60 degrees shall be avoided.

(e) At least 100 foot-candles of illumination shall be provided in the remote work area.

(f) Monochromatic (single wavelength) lighting shall be employed where highly unfavorable viewing situations exists. Such situations may exist when viewing at high angles of incidence through refractive materials.

(g) The two images provided by a stereoscopic periscope shall be perfectly aligned and of the same magnification.

(h) Contrary to requirements for direct viewing conditions, letters, numerals, and important details that must be viewed by means of television shall be light against a dark background. Dull light grays against dull dark greys give best contrast. Glazed or reflecting surfaces shall be avoided.

5.5.2.14 Environmental toxicity. - Environmental toxicity shall be considered in the design of enclosures and in areas where toxicity may occur. The following factors shall be considered: (aviation toxicology, 27). XR-S-2

(a) Each toxic substance must be treated in terms of its own threshold value and its bodily effects.

(b) Concentration and time of exposure shall be considered as critical factors in environmental toxicity.

(c) Table XXVI shall be employed to determine the maximum allowable concentration of common toxic agents.

Table XXVI

Common Sources and Maximum Allowable Concentrations of Some Toxic Agents

COMMON SOURCE	TOXIC AGENT	MAXIMUM ALLOWABLE CONCENTRATION (PPM)
FUELS AND PROPELLANTS	AMMONIA	100
	ANILINE	5
	ETHYL ALCOHOL	1,000
	GASOLINE	250
	KEROSENE	500
	METHYL ALCOHOL	200
	NITROGEN TETROXIDE	5
ENGINE EXHAUSTS (INCLUDING ROCKET ENGINES)	ALDEHYDES:	
	ACETALDEHYDE	200
	ACROLEIN	0.5
	FORMALDEHYDE	5
	FURFURAL	5
	CARBON DIOXIDE	5,000
	CARBON MONOXIDE	100
	BROMINE	1
	NITROGEN DIOXIDE	5
	SULFUR DIOXIDE	5
HYDRAULIC FLUIDS	BUTYL CELLOSOLVE	50
	DIACETONE	50
	ARYL PHOSPHATES	0.06
	DIOXANE ALCOHOL	100
FIRE EXTINGUISHANTS	CARBON DIOXIDE	5,000
	CARBON TETRACHLORIDE	25
	CHLOROBROMETHANE	400
	METHYL BROMIDE	20
OIL SPRAYS AND FUMES	ALDEHYDES: (SEE ABOVE)	
REFRIGERANTS	CARBON DIOXIDE	5,000
	FREON	1,000
	METHYL BROMIDE	20
	SULFUR DIOXIDE	5
SMOKE	PHOSGENE (PLUS SAME AS FOR ENGINE EXHAUSTS)	1

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DETAILED REQUIREMENTS
TEMPERATURE, CLOTHING & SAFETY

CLOTHING

ILLUMINATION	5.6.1
Foot-candle provision: see table XXVII	5.6.1.1
Provide even distribution of illumination	5.6.1.2
Method of illumination: see fig. 70. Consider,	5.6.1.3
Direct light: subject to shadows and glare	5.6.1.3.1
Indirect light: reduces shadows and glare	5.6.1.3.2
Diffused light: subject to shadows and glare	5.6.1.3.3
Semi-indirect light: generally preferred	5.6.1.3.4
Glare: consider,	5.6.1.4
Direct glare: avoid. Consider,	5.6.1.4.1-2
Locate light source 60° angle or more	5.6.1.4.2.(a)
Place lights high and directly over working area	5.6.1.4.2.(b)
Use indirect lighting	5.6.1.4.2.(c)
Use several light sources	5.6.1.4.2.(d)
Use protective shields	5.6.1.4.2.(e)
Indirect glare: avoid, consider,	5.6.1.4.3
Use diffused light	5.6.1.4.3.(a)
Use dull working surfaces	5.6.1.4.3.(b)
Place so view angle not equal to angle of incidence	5.6.1.4.3.(c)
Place displays so as to avoid glare, where possible	5.6.1.4.3.(d)
Brightness contrast: consider,	5.6.1.5
Definition: see text	5.6.1.5.1
Requirements: good contrast important	5.6.1.5.2
Brightness ratio: consider,	5.6.1.6
Definition: see text	5.6.1.6.1
Requirements: consider,	5.6.1.6.2
Task area: 3 to 1	5.6.1.6.2.(a)
Remote surroundings: less than 10 to 1	5.6.1.6.2.(b)

5.6 Illumination, vibration and noise.

5.6.1 Illumination. - Visual efficiency is directly dependent on illumination. Human performance is also dependent on illumination to the extent that vision is a requirement. While insufficient illumination may be an obvious contributor to performance degradation, too much light in the form of glare or an adequate amount of illumination which is applied improperly, may also have the same effect.

5.6.1.1 Foot-candle provision. - Illumination shall be provided in work areas to allow task performance in accordance with the general conditions and requirements presented in table XXVII. These requirements assume normal vision in all personnel. XR-C-1

5.6.1.2 Distribution.

(a) An even distribution of illumination of the necessary intensity and an avoidance of shadows and glare shall be provided wherever possible. XR-C-1

(b) Supplemental lighting shall be used to attain the proper amount of light for specific tasks where a general application is not feasible. (Hopkinson, 12). XR-S-2

(c) Illumination shall be supplied in conformance to human requirements since too much as too little illumination can contribute to reduced visual performance and eye fatigue. XR-C-1

5.6.1.3 Method of illumination. - See figure 70.

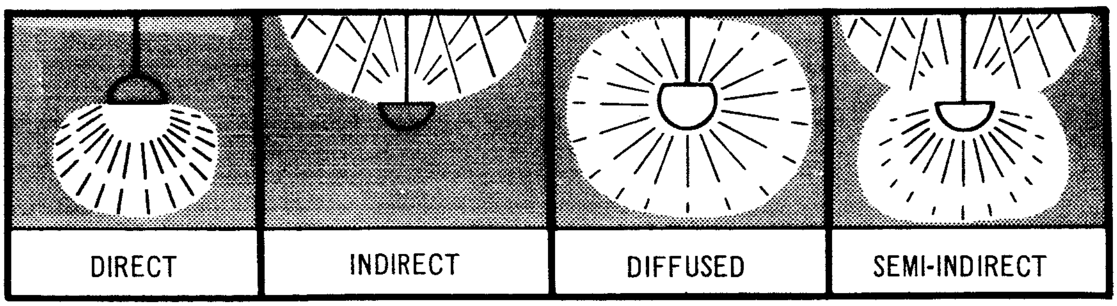


Figure 70. Light distribution methods

Table XXVII.

General illumination requirements

TASK CONDITIONS	FOOT-CANDLES AT WORK POINT
ROUGH SEEING TASKS INACTIVE STORAGE, HALLWAYS, LARGE OBJECTS	1 TO 5
CASUAL SEEING TASKS ACTIVE STORAGE, SERVICE AREAS, STAIRWAYS	5 TO 10
VISUAL TASKS COMPARABLE TO READING 10 OR 11 POINT PRINT ON GOOD QUALITY PAPER (I.E., GOOD LEGIBILITY)	10 TO 15
VISUAL TASKS COMPARABLE TO READING NEWSPRINT	15 TO 20
ORDINARY SEEING TASKS INVOLVING MODERATELY FINE DETAIL WITH NORMAL CONTRASTS READING,HANDWRITING, ORDINARY BENCH AND ASSEMBLY WORK	20 TO 30
VISUAL TASKS REQUIRING VERY FINE DISCRIMINATION, SMALL DETAIL, FINE FINISHING, FINE ASSEMBLY	30 TO 50*
DIFFICULT VISUAL TASKS WITH POOR CONTROL AND PRECISION REQUIREMENTS EXTRA FINE FINISHING OR ASSEMBLY UNDER LOW BRIGHTNESS CONTRAST CONDITIONS	50 TO 100*

NOTE:

MUCH DISAGREEMENT EXISTS REGARDING GENERAL AND SPECIFIC ILLUMINATION REQUIREMENTS. ILLUMINATION PRACTICES IN THE USA HAVE CALLED FOR GREATLY INCREASED QUANTITIES OF FOOT-CANDLES OF LIGHT DURING THE LAST 20 YEARS. THE ILLUMINATING ENGINEERING SOCIETY (IES) LIGHTING HANDBOOKS REFLECT THESE INCREASES. THE WORK OF BLACKWELL, 1; LUCKIESH, 2, 3, AND 4, SUPPORT THESE INCREASES WHILE BITTERMAN, 5; HOFFMAN, 6; TINKER, 7, 8, 9, AND 10, CRITICIZE REVISED ILLUMINATION REQUIREMENTS AS UNNECESSARILY HIGH. WESTON, 11 ALSO CRITICIZES "SUPERHIGH" REQUIREMENTS.

WHERE TASKS INVOLVE OBSERVATION OR MANIPULATION OF VERY SMALL ITEMS, VISUAL MAGNIFICATION SHALL BE EMPLOYED BEFORE EXTREMELY HIGH ILLUMINATION IS USED.

5.6.1.3.1 Direct light.

(a) In using direct light, the light travels directly from its source to the task area.

(b) Direct light furnishes maximum illumination but is subject to shadows and glare.

5.6.1.3.2 Indirect light.

(a) In using indirect light, the light is reflected from walls and ceilings to the task area. An opaque bowl is usually placed under the light source.

(b) Indirect lighting is technically less efficient since it requires greater bulb wattage to illuminate a given area. This is compensated by eliminating shadows and glare, thus reducing eye fatigue.

5.6.1.3.3 Diffused light.

(a) In using diffused light, the light source is enclosed in a translucent bowl so that light is scattered evenly.

(b) Diffused lighting is technically efficient compared to indirect lighting but does cause glare and shadows.

5.6.1.3.4 Semi-indirect light.

(a) A combination of diffused and indirect light can be achieved by using a translucent bowl under the light source as in the indirect light method.

5.6.1.4 Glare.

5.6.1.4.1 General. - Direct glare is encountered when a light source is located within the visual field; eg, headlights of oncoming cars at night. Specular glare is encountered when the image of a light source is reflected from a surface within the visual field; eg, bright lights reflected from shiny desk tops. Glare (direct and specular) shall be avoided since they may produce discomfort and interfere with visual performance. (Luckiesh, 4). XR-S-1

5.6.1.4.2 Direct Glare. - Direct glare shall be avoided by:

(a) Not locating any light sources within 60 degrees of the center of the visual field. (Luckiesh, 13). XR-S-2

(b) Placing lights high and directly above the working area. XR-C-2

(c) Using indirect lighting. XR-C-3

(d) Using several light sources of low intensity rather than one of high intensity. XR-C-3

(e) Placing hoods or shields in front of light sources. XR-C-3

5.6.1.4.3 Indirect glare. - Indirect glare shall be avoided by:

(a) Using diffused light. XR-C-3

(b) Using dull, unpolished surfaces in the visual field. XR-C-2

(c) Placing direct light sources so that the viewing angle of the work area is not equal to the angle of incidence. XR-C-1

(d) Displays shall be constructed, arranged and mounted so as to minimize the reflectance of ambient illumination from the glass or plastic display cover. (Particularly vulnerable to high reflectance are those displays which are inclined from the vertical, away from the operator.) (Morgan, 14). XR-S-2

5.6.1.5 Brightness contrast.

5.6.1.5.1 General. - Brightness contrast is the term used to denote variation in the brightness of the object being observed. It is expressed as a percentage (reflected light/delivered light) or as an amount of reflected light (foot lamberts). A good example is the use of black print on white paper. As a percent or an amount, brightness contrast is derived as follows:

$$\frac{B_1 - B_2}{B_1} \times 100 = \text{contrast}$$

B_1 = brighter of two contrasting areas

B_2 = less bright of two contrasting areas

5.6.1.5.2 Requirements.

(a) Brightness contrasts up to 100 percent shall be considered desirable for good visual acuity. It shall also be noted that attention tends to be held by objects which contrast strongly with their surroundings in regard to brightness, color, texture or form. (Hopkinson, 12). XR-S-2

(b) Contrast requirements are not specified for given situations because they vary with the amount of illumination present. (Luckiesh, 2, 3). XR-S-2

5.6.1.6 Brightness ratio.

5.6.1.6.1 General. - Brightness ratio is the term used to denote the ratio of brightness between the object being observed and its surrounding environment. A low brightness ratio enhances visual acuity and helps avoid visual strain. (Luckiesh, 2, 3; Guth, 15). XR-S-2

5.6.1.6.2 Requirements. - Required brightness ratios shall be as follows:

(a) Task area and immediate surroundings - no greater than 3:1. XR-C-2

(b) Task area and remote surroundings that remain in the field of vision - no greater than 10:1. XR-C-2

5.6.1.7 Illumination and visual displays.

5.6.1.7.1 Contrast of an object and its immediate background.

(a) The degree of contrast between an object and its immediate background shall always be made as great as possible. (Weston, 16). XR-S-2

(b) Accuracy and speed of visual discrimination improve with contrast. (Weston, 16). XR-S-2

(c) See 5.6.1.5.

5.6.1.7.2 Brightness of portions of the visual field which surround an object and its immediate background.

(a) Bright glare sources in the visual field shall be avoided since they reduce the visibility of an object. XR-C-1

(b) The central portion of the visual field, within 5 to 30 degrees of the line of sight, shall be illuminated as uniformly as possible at about the same level as the object or its background. XR-C-2

(c) Areas adjacent to the working area shall be at the same or lower level of brightness in order to aid visual acuity and reduce reaction time. (Johnson, 17). XR-S-2

5.6.1.7.3 Size and brightness of an object.

(a) These two variables shall be considered together. When size becomes too small or brightness too low, discrimination fails completely. XR-C-1

(b) Reading proceeds at nearly its maximum speed as soon as illumination is sufficient to permit the required pattern recognition. XR-C-1

(c) Ten to 20 foot-candles shall be considered adequate for all reading. (Tinker, 7; Hoffman, 6). XR-S-2

5.6.1.7.4 Direction of contrast between an object and its immediate background.

(a) For printed materials (books), black on white shall be used since it is superior to white on black for reading speed. (Holmes, 18; Taylor, 19). XR-S-2

(b) For panels, letters shall be black on a light background (preferred) or white on a dark background (less preferred). Whichever method is used, it shall be used consistently. (Berger, 20, 21; Holmes, 18; Paterson, 22; Saul, 23; Sumner, 24; Taylor, 19; Tinker, 25, 26). XR-S-2

(c) Stroke width and figure size shall be considered. (Berger, 20, 21; Ferree, 27; Holmes, 18; Paterson, 28; Taylor, 19). See 5.2.4.4. XR-S-2

5.6.1.7.5 Color of the illuminant.

(a) General area illumination shall be white or shall approximate the color characteristics of diffused daylight, which is the best illuminant. (Ferree, 29). XR-S-2

(b) Colored lighting shall be avoided since it may distort the perception of colors used in visual displays. XR-C-2

(c) Yellow light from sodium vapor lamps may be used at visual threshold levels (where no color perception requirements exist) since it is slightly superior to white light at these low levels. (Luckiesh, 30). XR-S-2

(d) Selection and intensity of red or white illumination shall be determined from the information obtained in table XXVIII. (Baker, 31). XR-S-1

5.6.1.8 Dark adaptation.

5.6.1.8.1 General. - Work areas shall be illuminated such that dark adaptation will not be required. Where this is impossible, the following factors shall be considered. XR-C-1

5.6.1.8.2 Determination of dark adaptation time. - Determination of the time required for dark adaptation shall be obtained from figure 71. (Sloan, 32). XR-S-1

5.6.1.8.3 Dark adaptation time versus system time. - Allowance shall be made for dark adaptation time with regard for system time requirements. Where required, all personnel shall be dark adapted before system operation. XR-C-1

5.6.1.8.4 Inadvertent illumination. - The use of matches or flashlights can affect the dark adapted eye. XR-C-2

5.6.1.8.5 Protection of low illuminated areas. - Areas requiring low level illumination shall be protected from external light sources. XR-C-1

(a) All windows and potential light sources shall be provided with protective light shields (shades, curtains, etc.). XR-C-2

(b) All doors shall have a light-protective entrance way which shall prevent outside light from entering work areas. XR-C-2.

Table XXVIII

General Illumination Recommendation

General recommendations for instrument, cockpit and console lighting are consolidated in the accompanying table.

CONDITION OF USE	RECOMMENDED SYSTEM	BRIGHTNESS OF MARKINGS	BRIGHTNESS ADJUSTMENT
Instrument lighting, dark adaptation critical	Red flood, indirect, or both with operator choice	.02 to 0.1 ft.L	Continuous thru range
Instrument lighting dark adaptation not critical	Red flood or low color temperature white, indirect or both with operator choice	.02 to 1.0 ft.L	Continuous thru range
Instrument lighting, no dark adaptation required	White flood	1 to 20 ft.L	May be fixed
Control console lighting, dark adaptation required	Red edge lighting, additional red flood lighting desirable.	.02 to 1.0 ft.L	Continuous thru range
Control console lighting, dark adaptation not required	White flood	1 to 20 ft.L	May be fixed
Possible exposure to bright flashes	White flood	10 to 20 ft.L	Fixed
Simulated instrument flying (blue amber)	White flood	10 to 20 ft.L	Fixed
Very high altitude, daylight restricted by cockpit design	White flood	10 to 20 ft.L	Fixed
Chart reading, dark adaptation required	Flood, operator's choice of red or white	0.1 to 1.0 ft.L. on white portions of chart	Continuous thru range
Chart reading, dark adaptation not required	White flood	5 ft.L or above	May be fixed

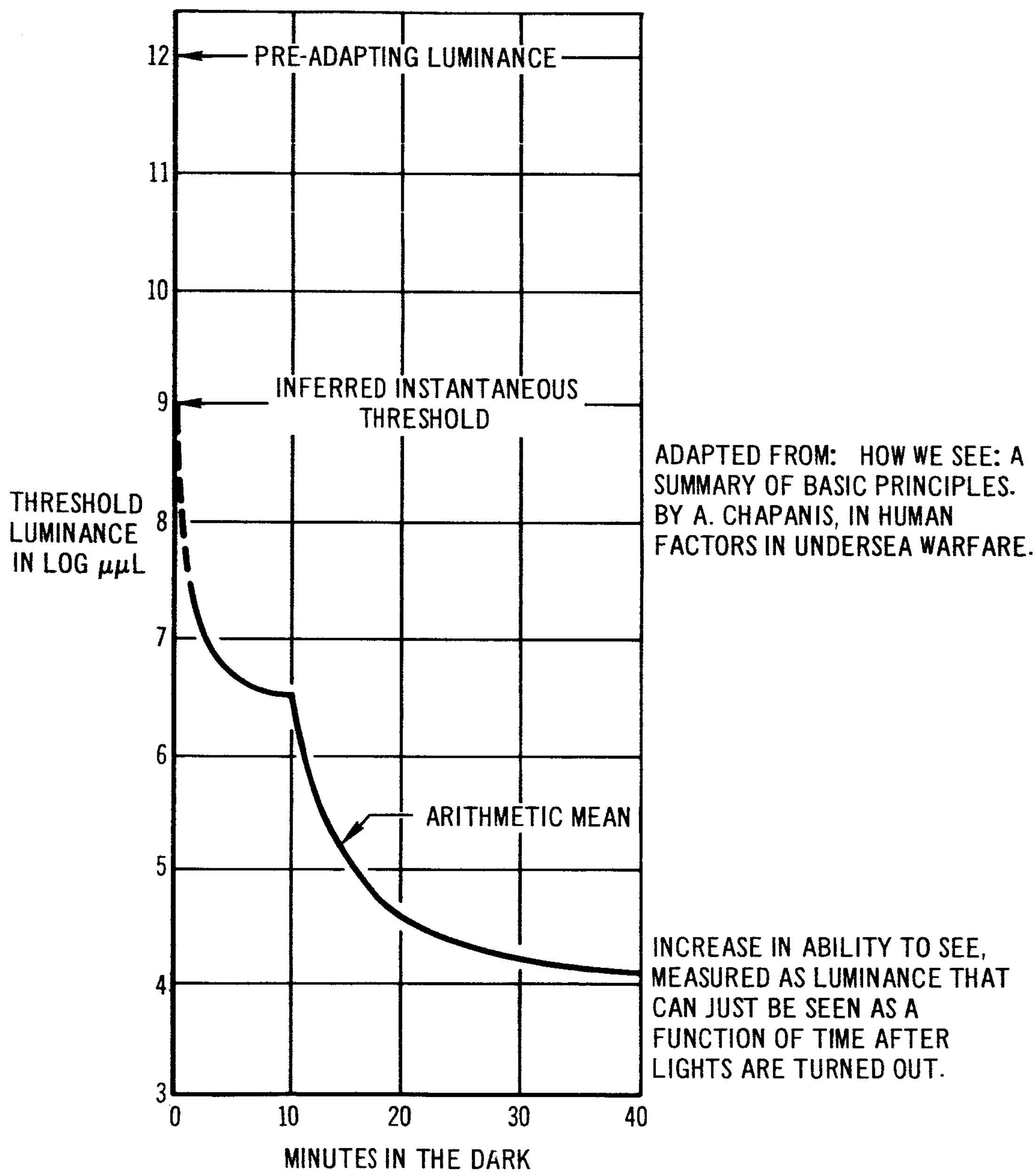


Figure 71. Dark-adaptation curve

5.6.1.8.6 Eye protection. - Dark-adapted personnel shall wear protective glasses when going to a high intensity illuminated area. This requirement does not apply under conditions where the low intensity area is gradually brought up to an intensity equivalent to outside ambient lighting. XR-C-2

DETAILED REQUIREMENTS
TEMPERATURE, CLOTHING & SAFETY

SAFETY

VIBRATION	5.6.2
Localized vibration: consider,	5.6.2.1
Soft tissues: not above 1000 cps, small amplitude	5.6.2.1.(a)
Joints: not below 1000 cps, large amplitude	5.6.2.2.(b)
Whole body vibration: consider,	5.6.2.2
Avoid whole body vibration, especially 0.5 to 20 cps range	5.6.2.2.1
Short time exposure: consider,	5.6.2.2.2
Personnel can tolerate lesser vibrations for longer periods	5.6.2.2.2.(a)
Human leg can protect: see text	5.6.2.2.2.(b)
Tolerance to vibration: see figs. 72, 73, 74	5.6.2.2.2.(c)-(d)
Long term exposure: avoid	5.6.2.2.3
Vibration and performance: consider,	5.6.2.3
General: consider,	5.6.2.3.1
Vibration increases energy spent	5.6.2.3.1.(a)
Fatigue is important	5.6.2.3.1.(b)
Cannot perform critical adjustments	5.6.2.3.1.(c)
Performance decrement lasts after vibration	5.6.2.3.1.(d)
Hearing and speech less effected (1 to 30 cps)	5.6.2.3.1.(e)
Performance decrements: consider,	5.6.2.3.2
Avoid tracking tasks (1 to cps)	5.6.2.3.2.(a)
Foot tracking: see text	5.6.2.3.2.(b)
Avoid reading at low frequency (5 cps, 1/16" amp.)	5.6.2.3.2.(c)
Vibration-performance determinations: see fig. 75	5.6.2.3.2.(d)
Protection from vibration: consider,	5.6.2.4
Isolation methods: consider,	5.6.2.4.1
Provide cushions above 10 cps	5.6.2.4.1.(a)
Use shocks, torsion, coil or leaf springs to damp	5.6.2.4.1.(b)
Technical info: see Handbook of Shock and Vibration (Harris)	5.6.2.4.1.(c)

Other methods: consider,	5.6.2.4.2
Support body	5.6.2.4.2.(a)
Design special suits and belts	5.6.2.4.2.(b)
Body alignment important	5.6.2.4.2.(c)
Work cycle is rigidly controlled	5.6.2.4.2.(d)

5.6.2 Vibration. - Vibration can adversely affect man and therefore his performance. The following criteria present those vibration conditions which man can tolerate before injury and performance decrement result.

Injury may result from short term exposure to vibration conditions which are immediately annoying or painful or from long term exposure to vibration conditions which are not noticeably harmful at first.

Performance problems such as visual difficulties and tracking errors may result when work must be carried on under certain vibration conditions.

5.6.2.1 Localized vibration.

(a) Soft tissues of arms, hands and shoulders shall not be subjected to small amplitude vibration above 1,000 cps. (Guillemin, 33). XR-S-2

(b) Joints of arms, hands and shoulders shall not be subjected to large amplitude vibrations below 1,000 cps. (Guillemin, 33). XR-S-2

5.6.2.2 Whole body vibration.

5.6.2.2.1 General.

(a) Whole body vibration shall be avoided since the various body parts tend to vibrate independently. The resulting alternating displacement of the body parts, organs and supportive structures can produce tension, deformation and localized pain. (Magid, 34). XR-S-2

(b) Vibration conditions in the 0.5 to 20 cps range shall be avoided since man's vibration isolation capacity is least effective in this range. Within this range he shall not be exposed to frequencies between 4 and 8 cps because his tolerance is lowest for these frequencies. (Magid, 34, 35). XR-S-2

(c) Although sinusoidal vibration affects performance on certain human activities, it shall not be considered independent of frequency and intensity. (Buckhout, 36; Chaney, 37, 38). XR-S-2

5.6.2.2.2 Short term exposure.

(a) Equipment design shall reflect the findings that personnel can tolerate greater vibrations for shorter time periods and lesser vibrations for longer time periods. (Linder, 39). XR-S-2

(b) The human leg shall be considered to provide isolation from low frequency vibration (2 to 5 cps with 1 inch double amplitude) for approximately 2 minutes. (Hornick, 40). XR-S-2

(c) Figure 49 presents current criteria for tolerance to vibrations of various frequencies and intensities. (Webb, 41; von Gierke, 42). XR-S-2

(d) Personnel shall not be involuntarily exposed to vibration conditions which cause subjective reactions more severe than voluntary tolerance as noted in figures 72, 73 (Webb, 41; Magid, 43) and figure 74. (Webb, 41; Linder, 39). XR-S-2

5.6.2.2.3 Long term exposure.

(a) Tolerance criteria for long term exposure to vibration is presently unavailable.

(b) Repeated exposure to vibration of various high frequencies shall be avoided. (Guilleman, 33). XR-S-2

5.6.2.3 Vibration and performance.

5.6.2.3.1 General.

(a) Vibration exposure which significantly increases the energy spent in working and thus affects the general emotional response of personnel shall be avoided or otherwise reduced. (Goldman, 44). XR-S-2

(b) Fatigue shall be considered an important factor in the vibration-performance relationship but at this time cannot be adequately measured. (Goldman, 44). XR-S-2

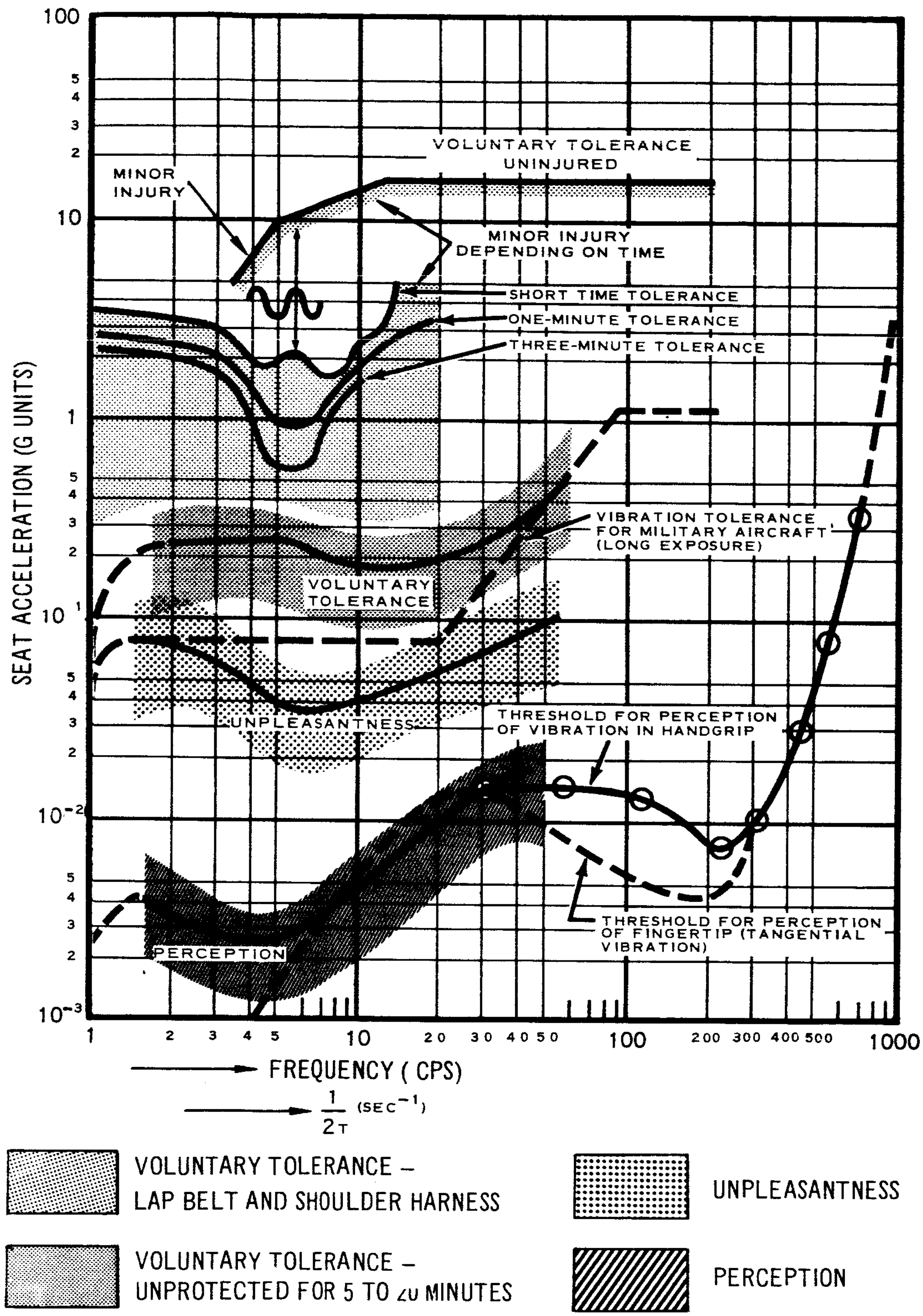


Figure 72. Criteria for vibration tolerance

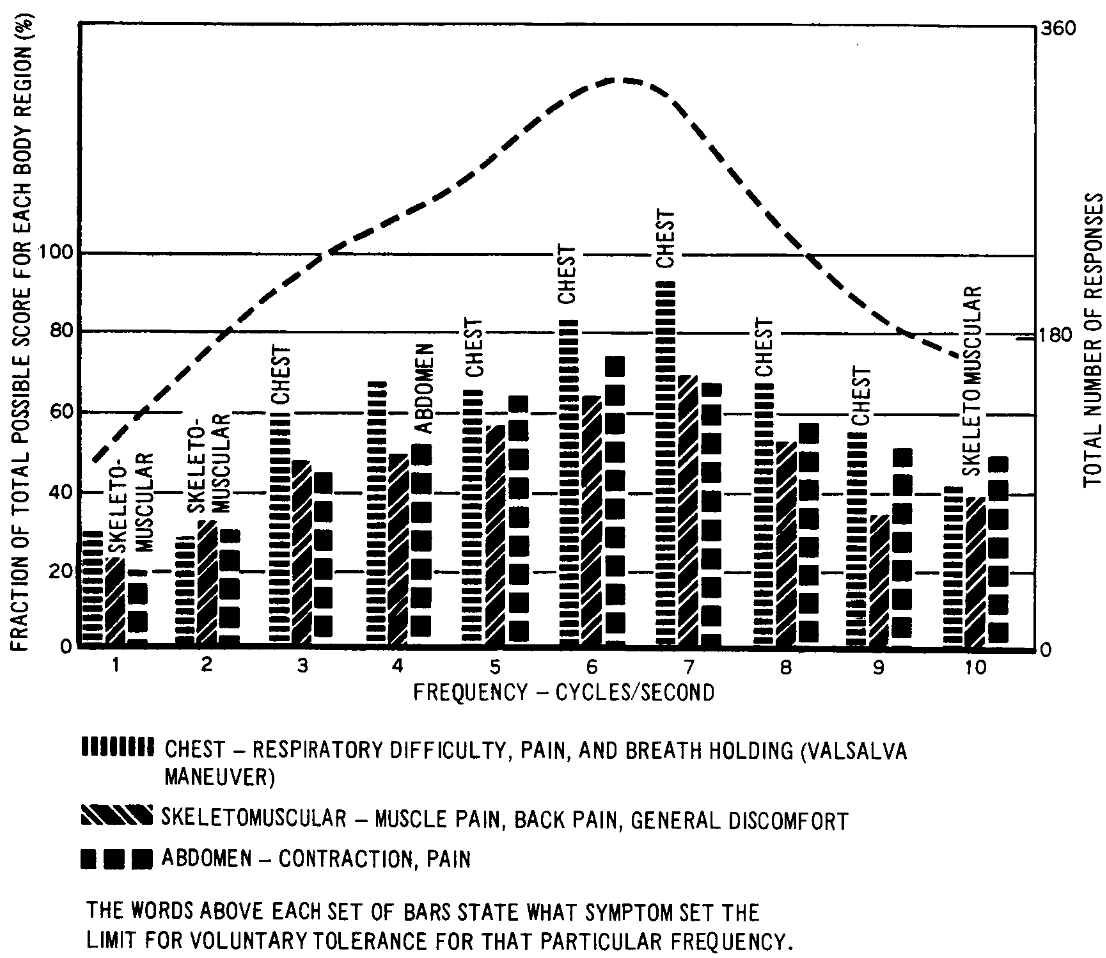
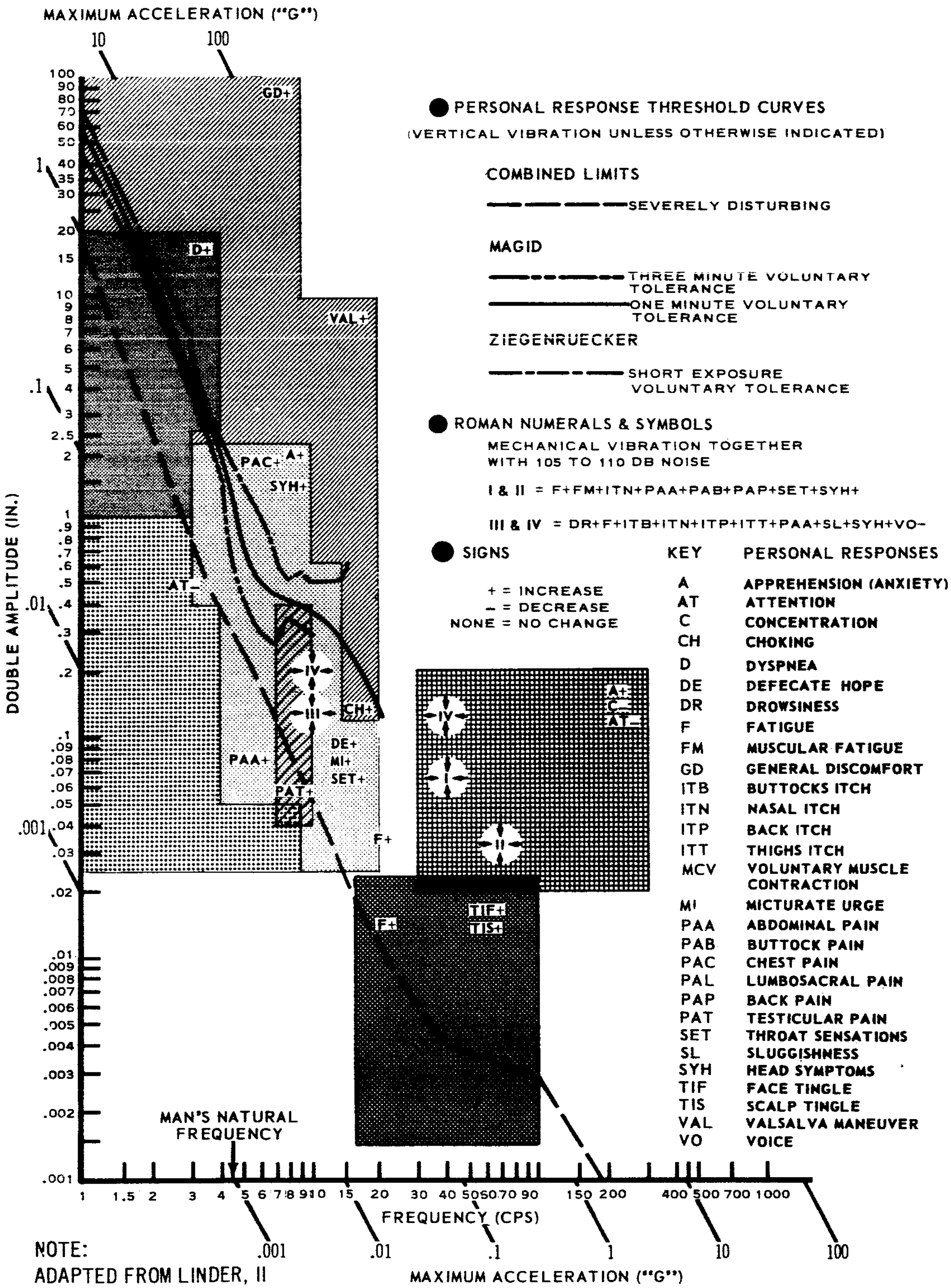


Figure 73. Subjective responses to vertical sinusoidal vibration



NOTE:
ADAPTED FROM LINDER, II

Figure 74. Subjective response and tolerances to vibration

(c) Personnel shall not be exposed to vibration when performing critical procedures. (Buckhout, 36). XR-S-2

(d) Performance decrement shall be considered to continue a short time after vibration conditions end. (Lange, 45). XR-S-3

(e) Hearing and speech decrements due to low frequency (1 to 30 cps) vibration shall not be considered to be of design significance. (Teare, 46). XR-S-3

5.6.2.3.2 Performance decrements.

(a) Efficient tracking performance (both vertical and horizontal) shall not be required when personnel must be exposed to whole body low frequency vibration (1 to 20 cps). (Buckhout, 36; Chaney, 37). XR-S-2

(b) When foot tracking performance impairment is due to low frequency vibrations, it shall be partially corrected by reducing the force requirement. (Chaney, 37). XR-S-2

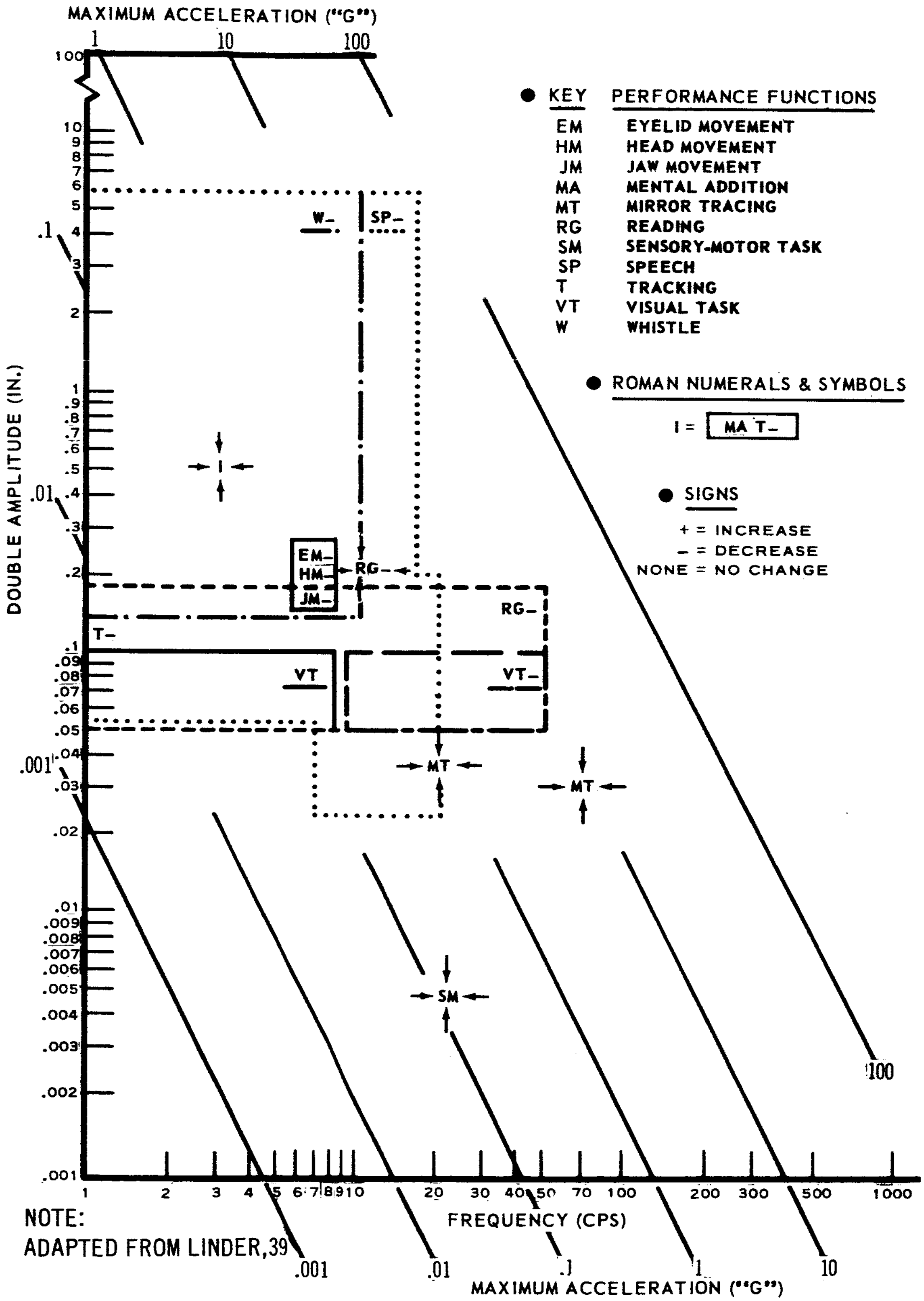
(c) Efficient rapid reading comprehension tasks shall not be required when reading material must vibrate at low frequency; eg, 5 cps, 1/16 inch amplitude. (Tinker, 47). XR-S-2

(d) Figure 75 shall be employed for vibration-performance determinations. (Linder, 39). XR-S-2

5.6.2.4 Protection from vibration.

5.6.2.4.1 Isolation methods. - Protection from vibration shall ideally be achieved by isolating man to reduce vibration transmission. XR-C-3

(a) Cushions shall be provided to damp vibrations above 10 cps. Beneath that frequency cushions shall not be used because they may tend to amplify existing vibrations. (Goldman, 44). XR-S-2



NOTE:
ADAPTED FROM LINDER,39

Figure 75. Effect of vibration on performance

(b) Hydraulic shock absorbers, rubber torsion bars, coil springs or leaf springs shall be used in suspension seats to reduce vibration transmission. (Goldman, 44). XR-S-2

(c) Technical information regarding various other means of isolating man from vibrations is available in the Handbook of Shock and Vibration. (Harris, 48).

5.6.2.4.2 Other methods. - Other protection from vibration shall be provided when necessary.

(a) The body shall be supported over as wide an area as is possible. XR-C-3

(b) Well designed suits and belts shall be used to reduce mobility of body parts; eg, the abdominal mass. XR-C-3

(c) The body shall be aligned for work in the most favorable position when intense vibration exposure is required. XR-C-3

(d) Working hours under vibration shall be rigidly controlled to prevent cumulative damage and fatigue. (Goldman, 44). XR-S-2

NOISE	5.6.3
Exposure limits	5.6.3.1
General: see text for discussion	5.6.3.1.1
Necessary exposure: above 115 db only briefly	5.6.3.1.1.1
Absolute limit: never above 150 db	5.6.3.1.1.2
Pure-tone and wide band noise: consider,	5.6.3.1.2
Pure-tone more damaging than wide band (10 db)	5.6.3.1.2.1-2
Damage risk criteria: see fig. 76	5.6.3.1.2.3
Long term exposure limits: see fig. 77	5.6.3.1.3
Short term exposure limits: see fig. 78	5.6.3.1.4
Temporary hearing loss: always avoid	5.6.3.2
Permanent hearing loss: always avoid	5.6.3.3
Noise control: at source, at transmission, at ear	5.6.3.4
Ear protectors: consider,	5.6.3.5
Use when risk criteria limits are reached	5.6.3.5.1
Use ear inserts, ear muffs, helmets	5.6.3.5.2
Acoustic reflex: see text and section 3.0	5.6.3.6
Noise and human performance: consider,	5.6.3.7
General: noise effects only certain human performance	5.6.3.7.1
Vigilance tasks and counting tasks most affected	5.6.3.7.2
Length of exposure: 100 db for less 1 1/2 hrs is maximum	5.6.3.7.3
Physiological effects: avoid sudden exposure to loud noise	5.6.3.8

5.6.3 Noise. - Noise presents problems in two major areas of human concern. It can cause hearing loss and it can reduce the clarity of voice communication.

A hearing loss limits man's effectiveness. When he has difficulty in hearing oral instructions or sounds indicating the status of a machine, his ability to act promptly and without error is impaired. Preventing hearing loss of launch vehicle personnel is not merely a matter of humanitarian concern but one of safeguarding an important system component to insure its efficiency and extend its usage life.

Man's efficiency is also impaired when noise interferes with his voice communication. When this occurs, the penalty is an increase in time required to accomplish communication through slower, more deliberate verbal exchanges. This results in increased possibilities of human error due to misunderstandings. Man's communication limitations must be considered an integral part of the system in which he performs.

Noise reduction is the ideal solution to the problems noted. Noise reduction techniques can be applied to the source of noise, to traveling noise, or to noise at the human ear. Early recognition of noise as a possible limiting factor in personnel activities permits the use of noise reducing design features. If this is not feasible, protective devices and procedures can be specified. The most effective methods of controlling noise are those exerted on its source.

5.6.3.1 Exposure limits.

5.6.3.1.1 General.

(a) Exposure to intense sound results in hearing loss. The severity of the loss shall be considered dependent upon the duration of exposure, the physical characteristics of the sound (intensity, frequency, pure or wide band) and the nature of the exposure (continuous or intermittent).

(b) For various exposure times to a given amount of noise energy, continuous noise shall be recognized as a greater cause for temporary hearing loss for unprotected ears as compared to impulse noise.

5.6.3.1.1.1 Necessary exposures. - Necessary exposures to high intensity sounds (above 115 db) shall be as brief as possible. XR-C-2

5.6.3.1.1.2 Absolute limit. - In no case shall personnel be exposed to noise levels that exceed 150 db since severe temporary hearing loss is incurred rapidly. (AFSCM 80-3, 50). XR-S-1

(a) High intensity sound shall be avoided since it may cause dizziness and disorientation. (AFSCM 80-3, 50). XR-S-2

(b) Exposure to high intensity sounds at frequencies between 700 and 1,500 cps shall be avoided to prevent the occurrence of blurred vision. (Parrack, 51). XR-S-2

5.6.3.1.2 Pure-tone and wide band noise.

5.6.3.1.2.1 Differences. - Noise concentrated in one or more frequency components (narrow-band or pure-tone) shall be avoided since it is more damaging to hearing than noise which is more uniformly distributed in all the octave ranges (wide-band noise). (Fletcher, 52; Hawkins, 53). XR-S-2

5.6.3.1.2.2 Difference limits. - The sound pressure level damage limit for noise containing narrow-band or pure-tone components shall be considered 10 db lower than for wide-band noise. (Kryter, 54). XR-S-2

5.6.3.1.2.3 Damage risk criteria. - Figure 76 presents wide-band and pure-tone damage risk criteria which shall not be exceeded. (Kryter, 54). XR-S-2

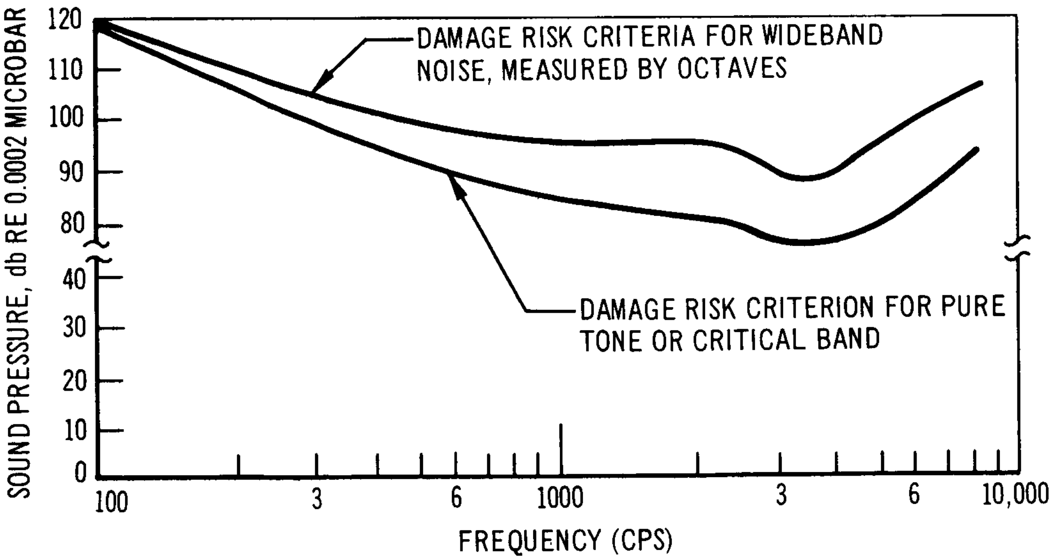


Figure 76. Pure tone and wide band noise damage risk criteria

5.6.3.1.3 Long term exposure limits.

5.6.3.1.3.1 Assumption. - Criteria for long term exposure shall assume a continuous unprotected exposure (8-hour workday) for 25 years.

5.6.3.1.3.2 Ear protection criteria. - Figure 77 presents the long term damage risk curves where ear protection shall be mandatory for both narrow-band and wide-band noise. (Beranek, 55; Rosenblith, 56, 57). XR-S-2

5.6.3.1.4 Short term exposure limits.

5.6.3.1.4.1 General. - A few minutes exposure to a noise shall be considered less harmful than an 8-hour exposure to the same noise. XR-C-2

5.6.3.1.4.2 Exposure limit variations. - Beginning with an 8-hour exposure at 95 db, as exposure time is halved, the sound pressure level exposure limit shall be raised by 6 db. (Davis, 58). XR-S-2

5.6.3.1.4.3 Damage risk criteria. - Figure 78 presents the short term damage risk criteria for exposure time and sound pressure level. (Ward, 59, 60, 61 and 62; AFSCM 80-3, 50). Personnel shall not be exposed to sound pressure levels in excess of those stated without adequate protection. See 5.6.3.5. XR-S-2

5.6.3.2 Temporary hearing loss. - Conditions contributing to or causing temporary hearing loss shall be avoided. XR-C-1

5.6.3.3 Permanent hearing loss. - Conditions contributing to or causing permanent hearing loss shall be avoided. XR-C-1

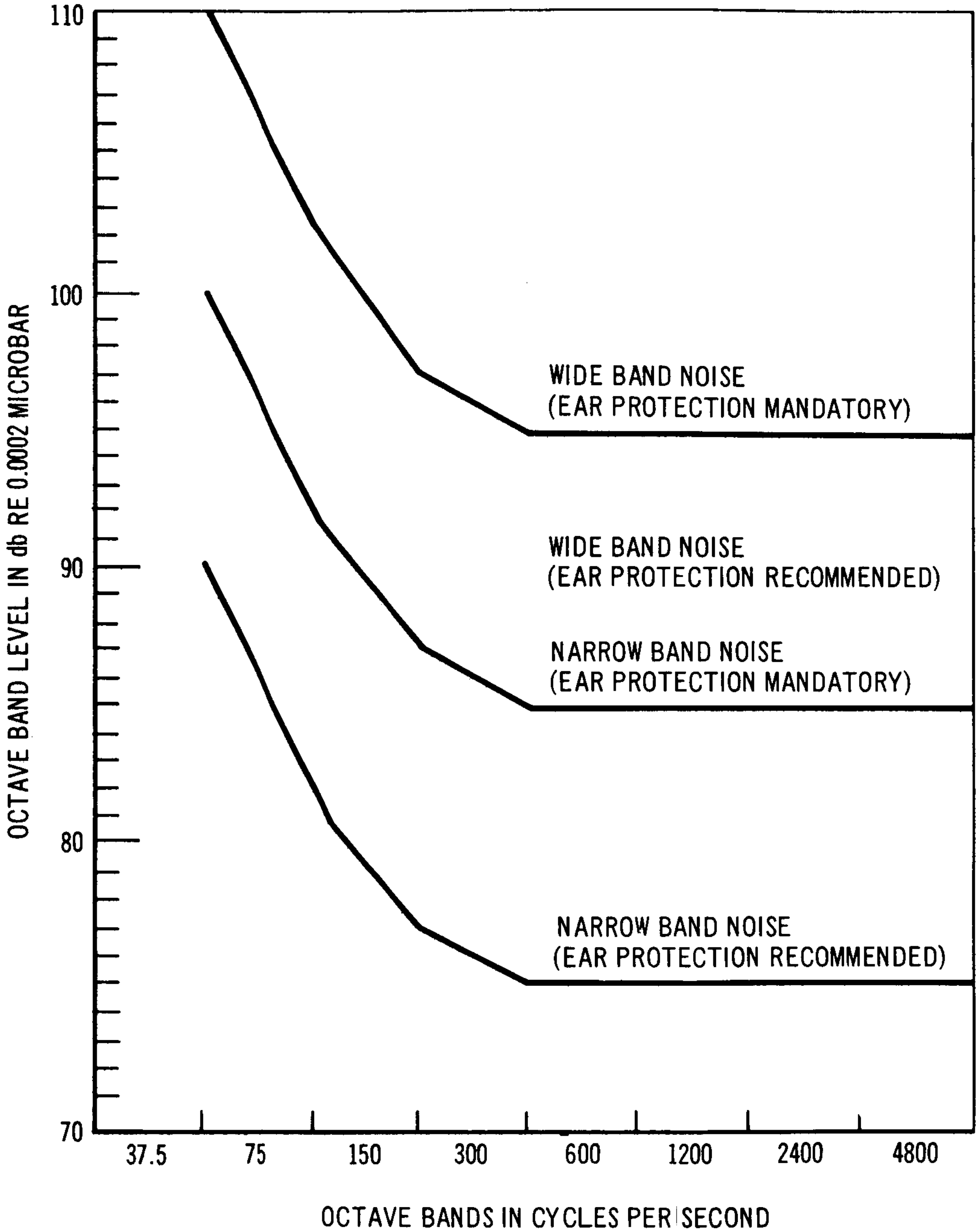
5.6.3.4 Noise control.

5.6.3.4.1 General. - Noise controls shall be considered as divided into three areas: noise control at the source, noise control during transmission and noise control at the ear. XR-C-2

5.6.3.4.1.1 Control at source. - The most effective method of noise control is to relocate the noise source or reduce its output. This method shall be used wherever possible. XR-C-2

5.6.3.4.1.2 Control elsewhere. - Additional means of controlling noise by reducing it in transmission, by using sound absorbing materials, and by reducing it at the ear with ear protectors shall be used where noise hazards exist. XR-C-2

5.6.3.4.2 Procedures. - Procedures for achieving maximum control of noise sources and noise in transmission shall be used where feasible. Technical information on noise control is available in Lukasik, 63; Harris, 64; and Beranek, 65. XR-S-2



NOTE: DIFFERENCES IN STANDARDS AND CRITERIA FOR NOISE TOLERANCES ARE QUITE WIDE AND NO SIMPLE CRITERION IS PRESENTLY AGREED TO BE VALID BY ALL INVESTIGATORS. (BERANEK, 55; ROSENBLITH, 56.)

Figure 77. Long term (8 hr) damage risk criteria

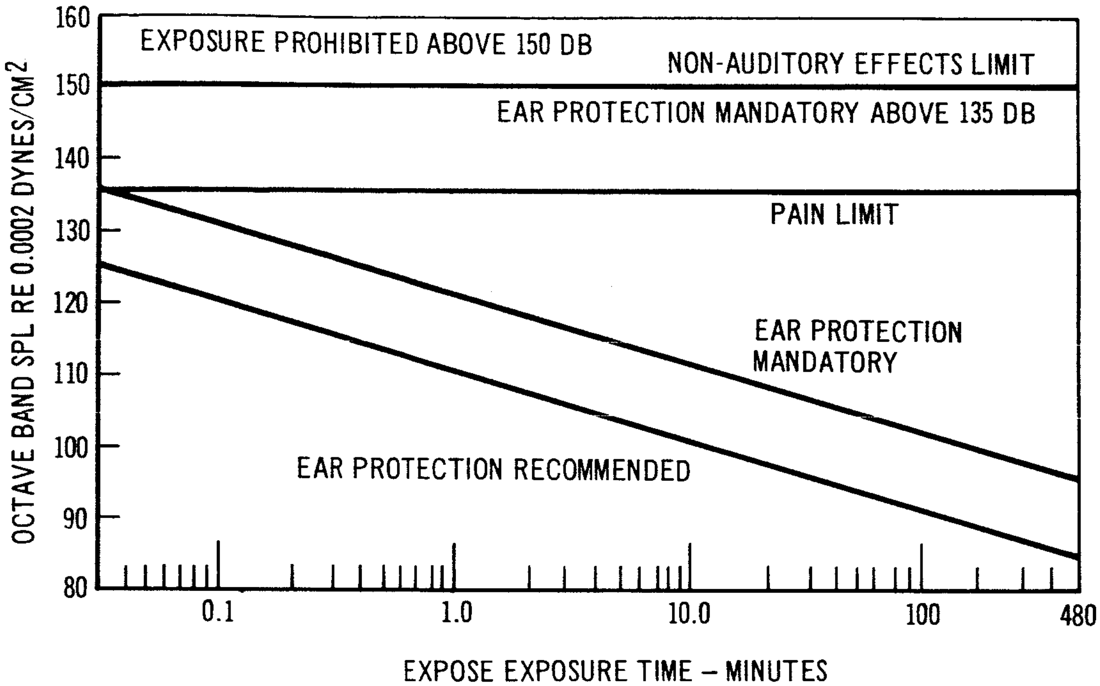


Figure 78. Short term damage risk criteria (wide band noise)

5.6.3.5 Ear protectors.

5.6.3.5.1 Use. - Ear protectors shall be used whenever damage risk criteria are exceeded. See figures 76, 77, and 78. (AFSCM 80-3, 50). XR-S-2

5.6.3.5.2 Type. - The use of ear inserts, ear muffs, helmets or other attenuating devices shall be prescribed where necessary. (Zwislocki, 66). XR-S-2

5.6.3.6 Acoustic reflex. - The acoustic reflex (AR) shall be considered for ear protection in appropriate situations. (Chisman, 67, Fletcher, 68). XR-S-2

5.6.3.7 Noise and human performance.

5.6.3.7.1 General. - Noise does not degrade all human performance but it shall be considered as adversely affecting certain kinds of performance. (Broadbent, 69, 70, 71, 72; Jerison, 73). XR-S-1

5.6.3.7.2 Types of performance affected. - Vigilance tasks and mental counting tasks are susceptible to degradation in noisy environments and shall be avoided wherever possible. (Broadbent, 69, 70, 71, 72, 74; Jerison, 75, 76). XR-S-2

5.6.3.7.3 Length of exposure. - Exposure to noise levels in excess of 100 db shall not be longer than 1 1/2 hours since performance degradation is likely to appear after that period of time. (Jerison, 73, 75, 76). XR-S-2

5.6.3.8 Physiological effects of noise. - Sudden exposure to loud noise shall be avoided since it can cause temporary physiological changes in personnel. (Harmon, 77; Kryter, 54). XR-S-3

5.6.3.9 Noise and oral communication.

5.6.3.9.1 General. - The adverse effect of noise on oral communication is an obvious problem. The resolution of the problem is dependent upon noise frequency, noise intensity, continuous or intermittent noise and the criticality of the communication. The use of the following criteria shall be determined by the degree of criticality of communications. XR-C-3

5.6.3.9.2 Speech interference level.

5.6.3.9.2.1 General. - The speech interference level (SIL) is a gross means of relating speech intelligibility to noise. Its use shall be limited to noise environments that are steady, flat and within a range of 600 to 4,800 cps. (Dreher, 78; Rosenblith, 56). XR-S-2

5.6.3.9.2.2 Computation. - SIL shall be computed by averaging the sound pressure levels (in db) of the three octave bands: 600-1,200, 1,200-2,400 and 2,400-4,800 cps. The SIL shall be considered as a measure of the extent to which noise interferes with the ability of individuals to converse. (von Gierke, 79). XR-S-2

5.6.3.9.2.3 Criteria. - SIL criteria shall be determined from table XXIX. (von Gierke, 79). XR-S-2

5.6.3.9.3 Noise criteria.

5.6.3.9.3.1 General. - Noise criteria (NC) shall be employed as a general measure to determine the effect of noise on communication. (Beranek, 80, 55). XR-S-2

5.6.3.9.3.2 Computation. - The NC for a given communication situation shall be obtained by determining the average sound pressure level (in db) in each octave band. These figures shall then be plotted and compared to the NC curves. XR-S-2

5.6.3.9.3.3 Criteria. - The NC curves found in figure 79 (Beranek, 80) and the noise criteria as shown in table XXX (von Gierke, 79) shall be employed to determine the effects of noise on communication. XR-S-2

Table XXIX.

SIL criteria

SPEECH INTERFERENCE LEVEL (db)	PERSON-TO-PERSON COMMUNICATION
30–40	COMMUNICATION IN NORMAL VOICE SATISFACTORY.
40–50	COMMUNICATION SATISFACTORY IN NORMAL VOICE 3 TO 6 FT; AND RAISED VOICE 6 TO 12 FT; TELEPHONE USE SATISFACTORY TO SLIGHTLY DIFFICULT.
50–60	COMMUNICATION SATISFACTORY IN NORMAL VOICE 1 TO 2 FT; RAISED VOICE 3 TO 6 FT; TELEPHONE USE SLIGHTLY DIFFICULT.
60–70	COMMUNICATION WITH RAISED VOICE SATISFACTORY 1 TO 2 FT; SLIGHTLY DIFFICULT 3 TO 6 FT. TELEPHONE USE DIFFICULT. EAR PLUGS AND/OR EAR MUFFS CAN BE WORN WITH NO ADVERSE EFFECTS ON COMMUNICATIONS.
70–80	COMMUNICATION SLIGHTLY DIFFICULT WITH RAISED VOICE 1 TO 2 FT; SLIGHTLY DIFFICULT WITH SHOUTING 3 TO 6 FT. TELEPHONE USE VERY DIFFICULT. EAR PLUGS AND/OR EAR MUFFS CAN BE WORN WITH NO ADVERSE EFFECTS ON COMMUNICATIONS.
80–85	COMMUNICATION SLIGHTLY DIFFICULT WITH SHOUTING 1 TO 2 FT. TELEPHONE USE UNSATISFACTORY. EAR PLUGS AND/OR EAR MUFFS CAN BE WORN WITH NO ADVERSE EFFECTS ON COMMUNICATIONS.
OVERALL SPEECH LEVEL (db) MINUS SIL (db)*	COMMUNICATIONS VIA EARPHONES OR LOUDSPEAKER.
+10 db OR GREATER	COMMUNICATION SATISFACTORY OVER RANGE OF SIL 30 TO MAXIMUM SIL PERMITTED BY EXPOSURE TIME.
+5 db	COMMUNICATION SLIGHTLY DIFFICULT. ABOUT 90 PERCENT OF SENTENCES ARE CORRECTLY HEARD OVER RANGE OF SIL 30 TO MAXIMUM SIL PERMITTED BY EXPOSURE TIME.
0 db TO -10 db	SPECIAL VOCABULARIES (IE, RADIO-TELEPHONE VOICE PROCEDURES) REQUIRED. COMMUNICATION DIFFICULT TO COMPLETELY UNSATISFACTORY OVER RANGE OF SIL 30 TO MAXIMUM SIL PERMITTED BY EXPOSURE TIME.

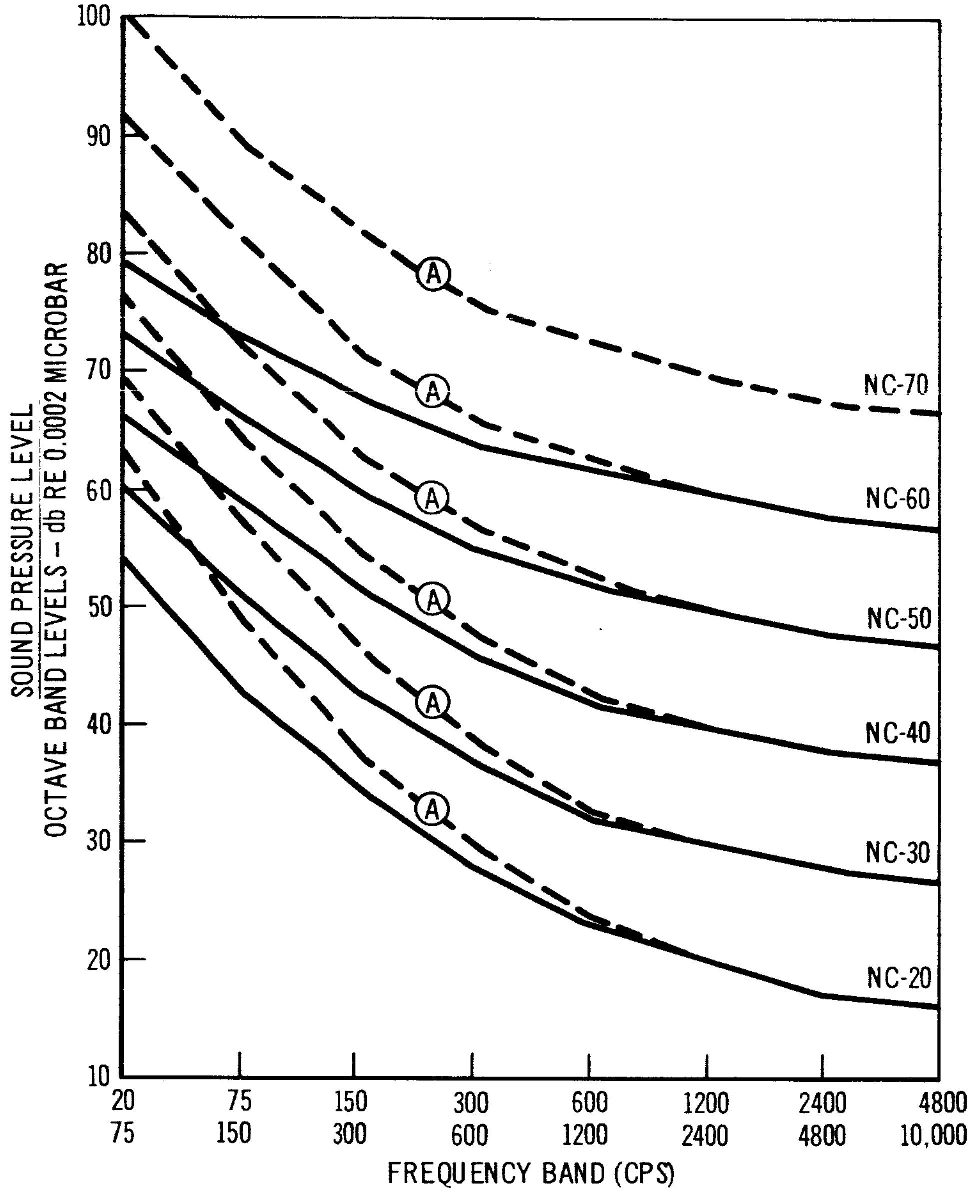
*THE OVERALL LONG-TIME RMS SOUND PRESSURE LEVEL OF SPEECH AND THE SIL FOR THE NOISE MUST BE MEASURED AT OR ESTIMATED FOR A POSITION IN THE EAR CANAL OF THE LISTENER. THE LONG-TIME RMS VALUE OF SPEECH CAN BE APPROXIMATED BY SUBTRACTING 4 db FROM THE PEAK VU METER READINGS ON MONOSYLLABIC WORDS.

**EAR PLUGS AND/OR MUFFS WORN IN NOISE HAVING SIL'S ABOVE 60 db WILL NOT ADVERSELY AFFECT COMMUNICATION AND WILL EXTEND MAXIMUM PERMISSIBLE SIL IN ACCORDANCE WITH PROTECTION PROVIDED.

Table XXX.

NC for offices and workspaces

OFFICES	
Noise measurements made for the purpose of comparing the noise in an office with these criteria should be performed with the office in normal operation, but with no one talking at the particular desk or conference table where speech communication is desired (ie, where the measurement is being made). Background noise with the office unoccupied should be lower, say by 5 to 10 db.	
NC (or NCA) curve	Communication environment
NC-20 to NC-30	Very quiet office - telephone use satisfactory - suitable for large conferences.
NC-30 to NC-35	"Quiet" office, satisfactory for conferences at a 15-ft table; normal voice 10 to 30 ft; telephone use satisfactory.
NC-35 to NC-40	Satisfactory for conferences at a 6- to 8-ft table; telephone use satisfactory; normal voice 6 to 12 ft.
NC-40 to NC-50	Satisfactory for conferences at a 4- to 5-ft table; telephone use occasionally slightly difficult; normal voice 3 to 6 ft; raised voice 6 to 12 ft.
NC-50 to NC-55	Unsatisfactory for conferences of more than two or three people; telephone use slightly difficult; normal voice 1 to 2 ft; raised voice 3 to 6 ft.
Above NC-55	"Very noisy," office environment unsatisfactory; telephone use difficult.
	Work spaces, shop areas
NC-60 to NC-70	Person-to-person communication with raised voice satisfactory to 1 to 2 ft; slightly difficult 3 to 6 ft. Telephone use difficult.
NC-70 to NC-80	Person-to-person communication slightly difficult with raised voice 1 to 2 ft; slightly difficult with shouting 3 to 6 ft. Telephone use very difficult.
Above NC-80	Person-to-person communication extremely difficult. telephone use unsatisfactory.



NOTE:
THESE CRITERION CURVES ARE TO BE USED WITH TABLE XXXI IN DETERMINING THE PERMISSIBLE SOUND PRESSURE LEVELS IN 8 OCTAVE FREQUENCY BANDS. THE NC CURVES (SOLID LINES) ARE RECOMMENDED FOR SPECIFICATIONS WHENEVER A FAVORABLE RELATION BETWEEN THE LOW AND THE HIGH FREOUENCY PORTION OF THE SPECTRUM IS DESIRED. THE NCA CURVES ARE THE MAXIMUM RECOMMENDED DEVIATION FROM THE NC CURVES WHENEVER ECONOMY DICTATES A MAXIMUM COMPROMISE AND WHERE, IN ADDITION, THE NOISE IS STEADY AND FREE OF BEATS BETWEEN LOW FREOUENCY COMPONENTS.

Figure 79. Noise criteria curves

5.6.3.9.4 Articulation index.

5.6.3.9.4.1 General. - The articulation index (AI) shall be considered as the most general criterion for the effects of noise on communication since it predicts how well speech can be understood within a specified noise environment. AI is concerned only with those frequencies lying between 200 and 6,100 cps as shown in table XXXI. This range of frequencies is divided into 20 bands contributing equally to speech intelligibility. (French, 81). XR-S-2

Table XXXI.

Frequency bands that contribute equally to speech intelligibility

Band Number	Frequency (cps)			Bandwidth
	Lower	Middle	Upper	
1	200	270	330	130
2	330	380	430	100
3	430	490	560	130
4	560	630	700	140
5	700	770	840	140
6	840	920	1,000	160
7	1,000	1,070	1,150	150
8	1,150	1,230	1,310	160
9	1,310	1,400	1,480	170
10	1,480	1,570	1,660	180
11	1,660	1,740	1,830	170
12	1,830	1,920	2,020	190
13	2,020	2,130	2,240	220
14	2,240	2,370	2,500	260
15	2,500	2,660	2,820	320
16	2,820	2,900	3,200	380
17	3,200	3,400	3,650	450
18	3,650	3,950	4,250	600
19	4,250	4,650	5,050	800
20	5,050	5,600	6,100	1,050

5.6.3.9.4.2 Computation. - AI for wide-band noise shall be computed as follows:

(a) Draw a curve using table XXXI showing the speech-spectrum level as a function of frequency on a chart like that of figure 80.

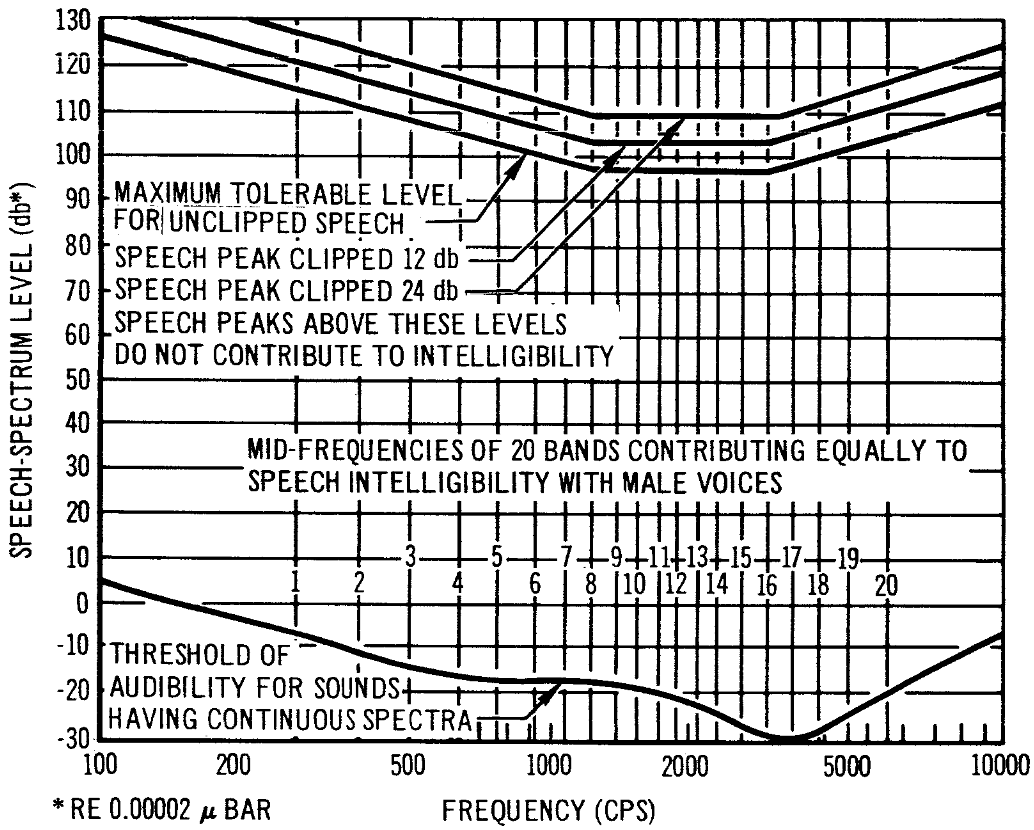


Figure 80. Worksheet for computing the AI by the 20-band method

(b) Draw a curve showing the spectrum level of the noise on the same chart.

(c) At every one of the lines numbered 1 to 20, measure the difference between the speech-peak level and the noise-spectrum level. If, at any line, the noise level is below the threshold of audibility, use the threshold curve rather than the noise curve. If, at any line, the speech-peak curve is above the appropriate limiting curve at the top of the figure, use that curve rather than the speech-peak curve.

(d) Convert each of the differences measured to its fractional contribution to the AI by means of figure 81. Differences of 30 db or greater are given a fractional contribution of 0.05, differences of 0 db are given a contribution of zero.

(e) Add all 20 contributions to obtain the final AI.

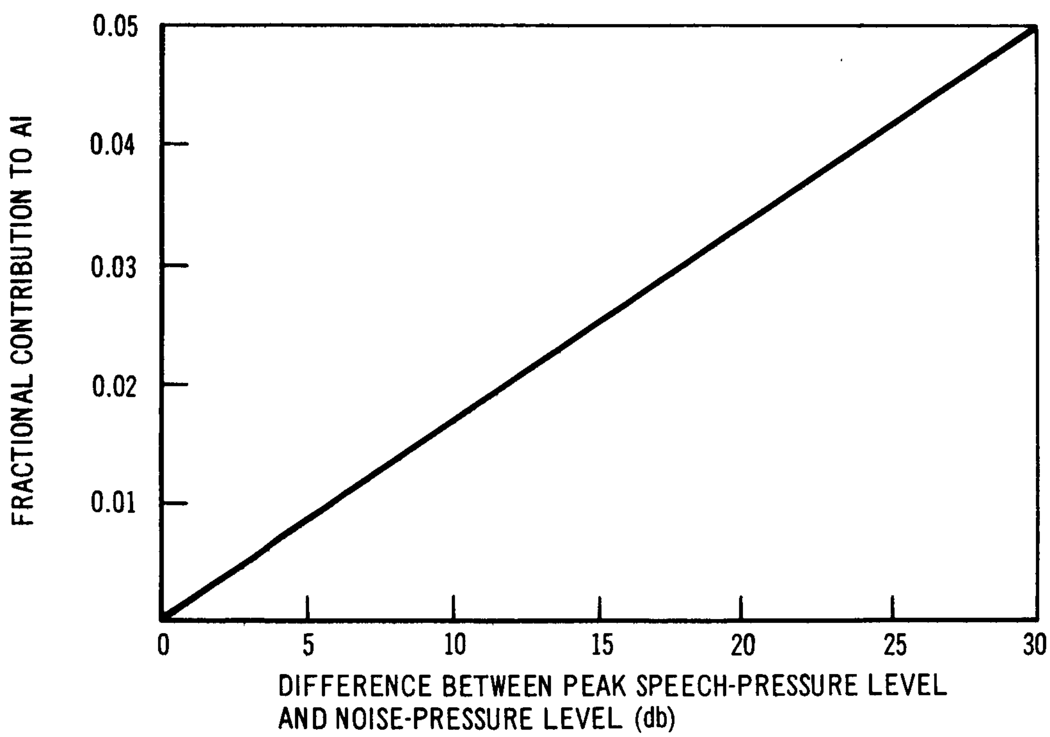


Figure 81. Contribution to the AI due to peak speech/noise level ratio

5.6.3.9.4.3 Criteria. - Intelligibility criteria derived from the AI are presented in figure 82. For any given voice communication system, within the environment and under actual conditions of use, the AI shall be in excess of 0.30. (AFSCM 80-3, 50). XR-S-2

5.6.3.9.4.4 Alternate methods. - A weighted-octave-band method of computing AI's for wide-band noise and a method of computing AI's for narrow-band noise shall be employed whenever necessary. (AFSCM 80-3, 50). XR-S-2

5.6.3.9.5 Auditory communication equipment.

5.6.3.9.5.1 General. - The choice of auditory equipment shall be made by taking into consideration the total operator requirements and responsibilities of a given task. Intelligibility characteristics shall be at or above a speech articulation index of 0.60. XR-C-2

5.6.3.9.5.2 Hand-held equipment. - Hand-held equipment shall be of convenient size for use by the operator with average size hands. Average length of hand is 7.9 inches and average width is 3.6 inches. The equipment shall have non-kink or self-retracting cords and press-to-talk switches that may be used conveniently by either hand. Handsets shall have proper mounts in a place to prevent interference with movements and accidental dislodging during transportation. XR-C-2

5.6.3.9.5.3 Head-supported equipment. - Head-supported equipment shall be used when the operator's hands must be available for other tasks.

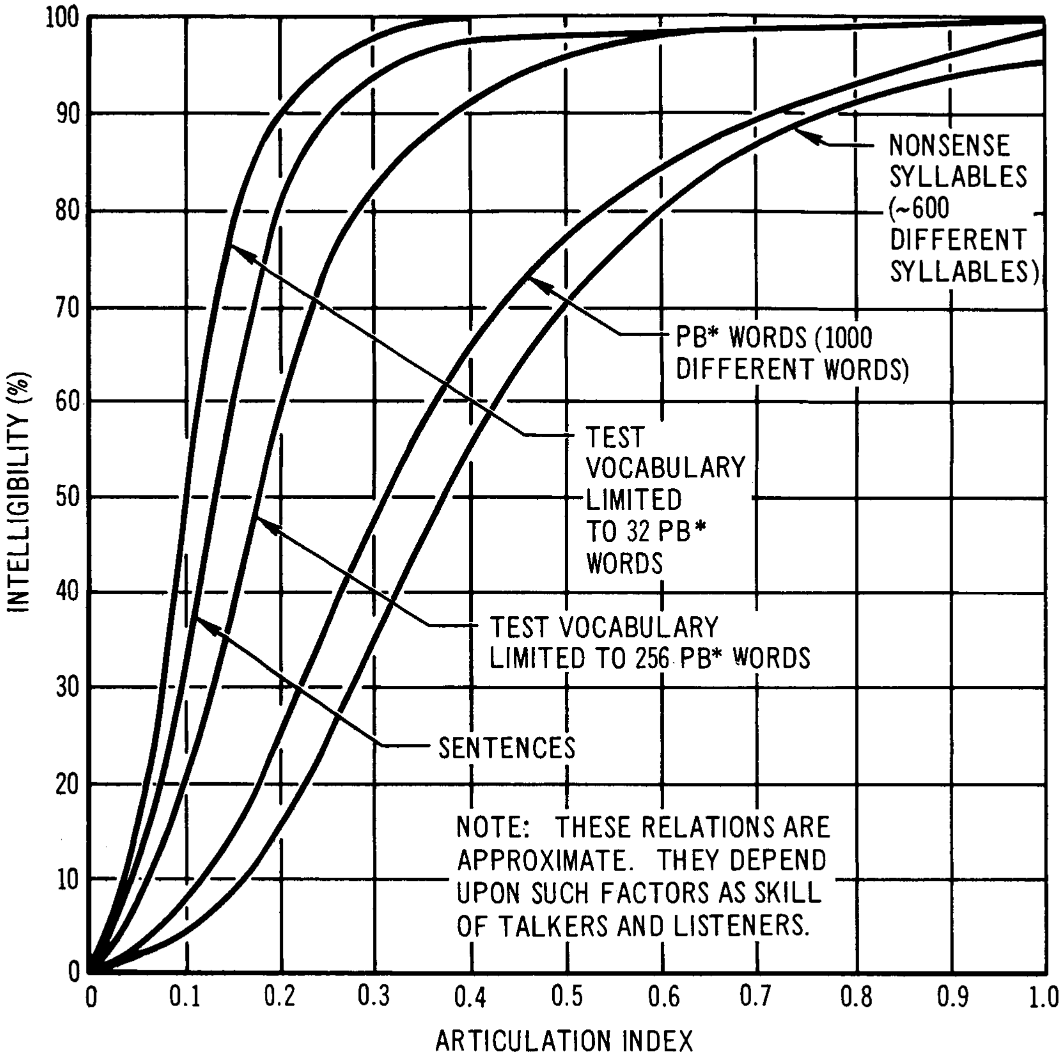
(a) The headset package shall consist of adjustable mouth and earpiece to ensure comfort by proper fitting and positioning for efficient operation. XR-C-1

(b) Earpieces shall be designed to snug-fit the head in order to minimize noise interference from outside sources. XR-C-1

(c) Supporting structures for the earpieces shall not impose discomforts of weight, concentrated pressures, or metal contact with the skin. XR-C-1

5.6.3.9.5.4 Loudspeakers.

(a) Speakers shall be placed in front of and directed toward the listener at head level or slightly above. XR-C-2



INTELLIGIBILITY CRITERIA

AN AI OF . . .	PROVIDES COMMUNICATIONS . . .
0.7 TO 1.0	SATISFACTORY TO EXCELLENT
0.3 TO 0.7	SLIGHTLY DIFFICULT TO SATISFACTORY – UP TO 98% OF SENTENCES ARE HEARD CORRECTLY
0.0 TO 0.3	IMPOSSIBLE TO DIFFICULT – SPECIAL VOCABULARIES AND RADIO-TELEPHONE VOICE PROCEDURES ARE REQUIRED

*PB – PHONETICALLY BALANCED

Figure 82. Intelligibility criteria

(b) Single loudspeakers with single signal inputs shall have associated volume and tone controls. XR-C-2

(c) A single loudspeaker having two or more simultaneous inputs shall have associated controls necessary to individually adjust the volume and tone of each of the inputs. XR-C-2

(d) When use of two or three loudspeakers is required, they shall be horizontally positioned so that the location of the sound source may be readily identified without operator head movement. XR-C-2

(e) Three loudspeakers shall be the maximum directed to any one operator. XR-C-2

ILLUMINATION, VIBRATION AND NOISE

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TEMPERATURE 5.7.1

Effective temperatures: consider,	5.7.1.1
Factors: consider,	5.7.1.1.1
Employ effective temperature (ET): See fig. 83	5.7.1.1.1.(a)
How to use ET: See text and fig. 83	5.7.1.1.1.(b)
Comfort zone: consider,	5.7.1.1.2
Comfort zone: See fig. 83	5.7.1.1.2.(a)
Environmental temperature: between 63 and 75° F	5.7.1.1.2.(b)
Heat and performance: consider,	5.7.1.2
General: avoid ET above 80° F	5.7.1.2.1
Long term exposure: ET up to 80° F	5.7.1.2.2
Short term exposure: consider,	5.7.1.2.3
Without protective clothing: consider,	5.7.1.2.3.1
122 to 140° F: tolerable for 1 hour	5.7.1.2.3.1.(a)
158 to 248° F: tolerable for 20 to 80 minutes	5.7.1.2.3.1.(b)
248 to 500° F: tolerable for 10 secs. to 8 mins	5.7.1.2.3.1.(c)
Abrupt: 500° F for 10 seconds	5.7.1.2.3.1.(d)
Exposure time limits: See text	5.7.1.2.3.1.(e)
Precooling extends exposure time limits	5.7.1.2.3.1.(f)
Tolerance limits: See fig. 84	5.7.1.2.3.1.(g)
With protective clothing: consider,	5.7.1.2.3.2
With protective clothing: See fig. 85	5.7.1.2.3.2.(a)
Precooling extends tolerance times	5.7.1.2.3.2.(b)
Cold and performance: consider,	5.7.1.3
General: consider,	5.7.1.3.1
Avoid temperatures below comfort zone, if possible	5.7.1.3.1.(a)
Long term exposure: See fig. 86	5.7.1.3.1.(b)
Finger dexterity poor under cold conditions	5.7.1.3.1.(c)
Long term exposure: See figs 86 and 87	5.7.1.3.2
Short term exposure: See figs. 83,84,85 and 86	5.7.1.3.3

Windchill: consider,	5.7.1.3.4
Windchill: See fig. 88	5.7.1.3.4.(a)
Critical visual reaction time: avoid wind speed above 10 mph.	5.7.1.3.4.(b)
Humidity and performance: consider,	5.7.1.4
Avoid high humidity above 70%	5.7.1.4.1
Comfort and performance deteriorates under high humidity	5.7.1.4.2
High humidity under low temperatures not critical	5.7.1.4.3
Effective temperature table: See fig. 89	5.7.1.4.4
Air movement: consider,	5.7.1.5
Air movement rate: See text and fig. 83	5.7.1.5.1
Convective cooling: See fig. 90	5.7.1.5.2
Humidity effects air movement considerations	5.7.1.5.3
Avoid high temperature-humidity	5.7.1.5.4

5.7 Temperature, clothing, and safety.

5.7.1 Temperature. - Although man can survive through a wide range of temperature and humidity, his efficiency is markedly affected by extreme conditions. Whenever practicable, environmental temperatures shall be maintained within the "comfort zone" of the effective temperature range. The effects of departures from this range and personnel protection required are presented in this section.

NOTE:
Designers shall consult with appropriate human factors engineering personnel in accordance with MSFC STD 391 when unusual environments are anticipated.

5.7.1.1 Effective temperatures.

5.7.1.1.1 Factors.

(a) Effective temperature (ET) shall be employed as an index which combines temperature, humidity and air movement into a single value of warmth or cold as felt by the human body. See figure 83. (ASHRAE, 1) XR-S-2

(b) As shown in figure 83, different combinations of temperatures and relative humidities (RH) shall result in the same ET; eg, 70 degrees Fahrenheit (dry bulb) at 100 percent RH and 81 degrees Fahrenheit (dry bulb) at 10 percent RH both yield an ET of 70 degrees with air movement (turbulent flow) of 15-25 feet per minute. (ASHRAE, 1). XR-S-2

5.7.1.1.2 Comfort zone.

(a) The comfort zone of figure 83 shall be considered as representing those conditions of temperature and humidity in which most personnel will feel comfortable and perform with greatest efficiency. (ASHRAE, 1). XR-S-2

(b) Environmental temperatures shall be maintained within the 63 degree to 75 degree ET range whenever feasible. (ASHRAE, 1). XR-S-2

5.7.1.2 Heat and performance.

5.7.1.2.1 General. - ET above 80 degrees Fahrenheit shall be avoided since both quantity and quality of physical performance deteriorate beyond that point. (Morgan, 2; Blyth, 3). XR-S-2.

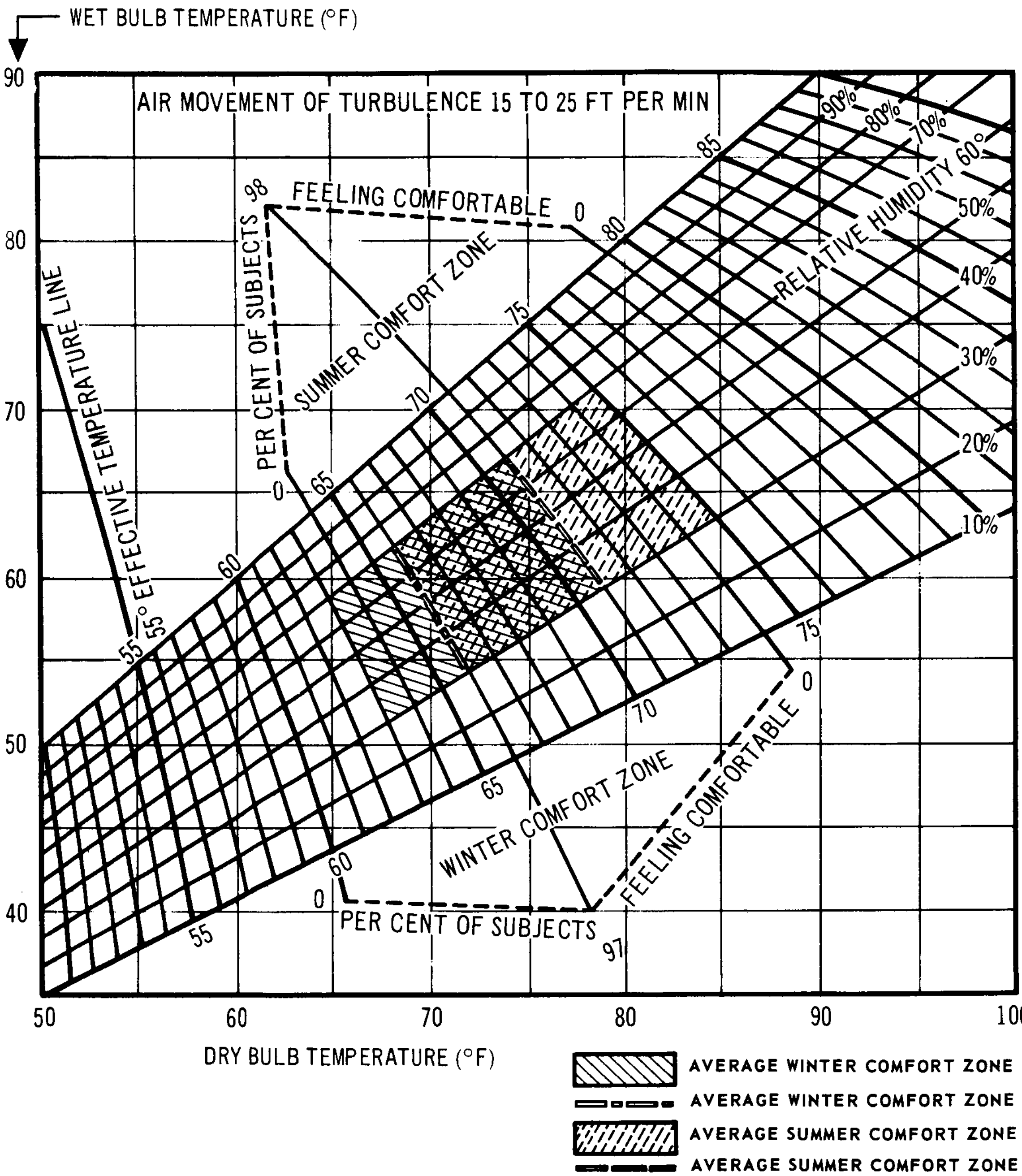


Figure 83. Effective temperature for comfort requirements

Consideration shall be given to the possible occurrence of heat stroke in personnel working in above normal thermal environments.

5.7.1.2.2 Long term exposure.

(a) ET up to 80 degrees Fahrenheit shall be permissible for acclimatized men since they can achieve and maintain an efficient performance at this ET level. (Morton, 2; Eichna, 4). XR-S-2

(b) ET of 90 degrees to 94 degrees Fahrenheit shall be the upper limits for long term working exposure of men without protective clothing. At this ET level, symptoms of fatigue, nausea and dizziness become marked. (Viteles, 5; Eichna, 4; Morton, 2). XR-S-2

(c) Figure 84 shall be employed to determine long term heat exposure tolerance limits for men at rest. (Webb, 6). XR-S-2.

5.7.1.2.3 Short term exposure.

5.7.1.2.3.1 Without protective clothing.

(a) Temperatures ranging from 122 degrees to 140 degrees Fahrenheit shall be considered as tolerable for periods of an hour or more since sweating usually keeps heat storage low.

(b) Temperatures ranging from 158 degrees to 248 degrees Fahrenheit shall be considered as tolerable for periods of 20 to 80 minutes. Storage of heat in the body is the limiting factor. (Webb, 7; Blockley, 8). XR-S-2

(c) Temperatures ranging from 240 degrees to 500 degrees Fahrenheit shall be considered as tolerable for periods of 10 seconds to 8 minutes. (Webb, 7). XR-S-2

(d) Temperature limits (for shorter times) shall be considered as higher when heat exposures to steady-state temperatures are abrupt; eg, 500 degrees Fahrenheit for 10 seconds. (Webb, 7, 9). XR-S-2

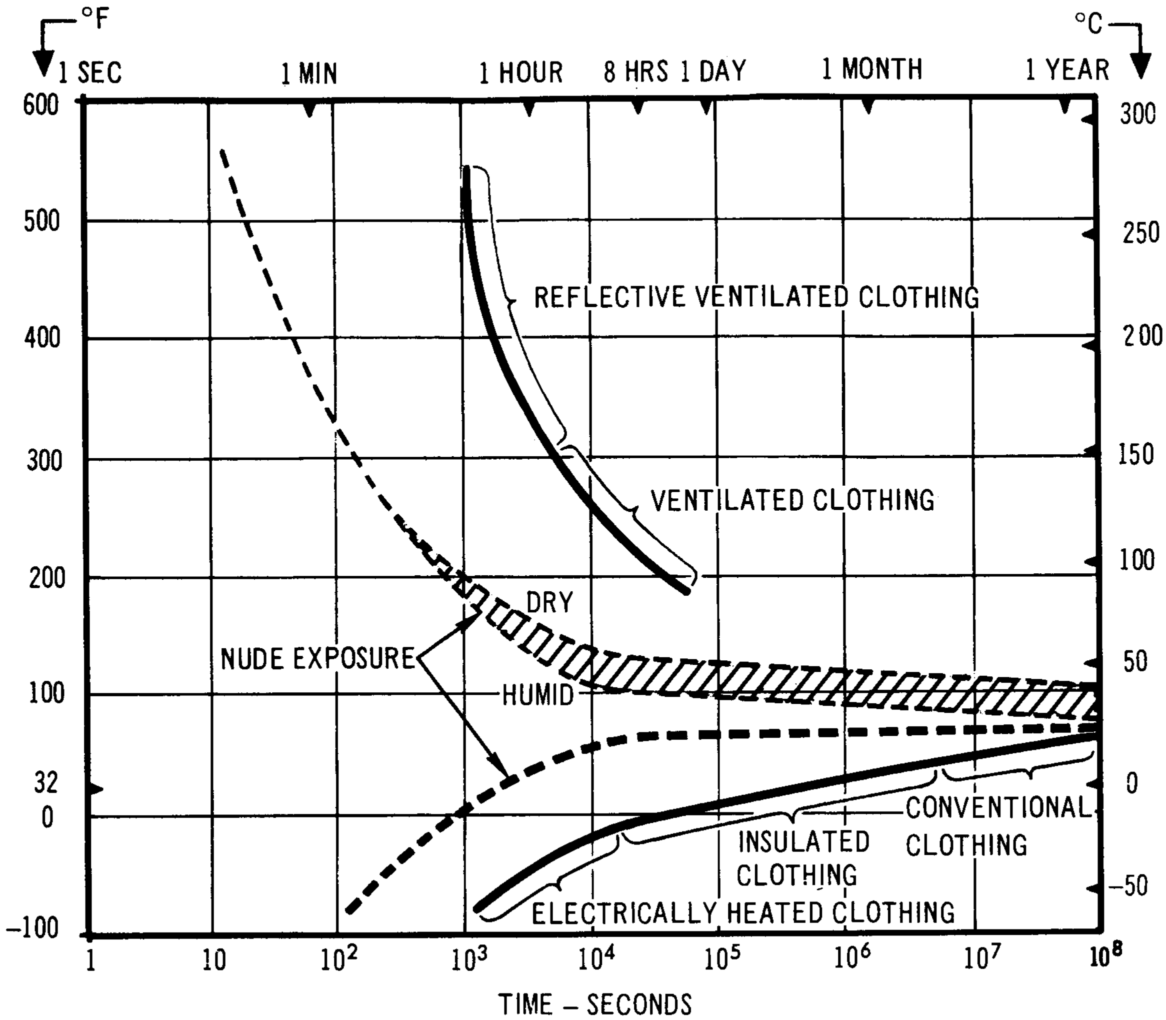


Figure 84. Human thermal tolerance limits

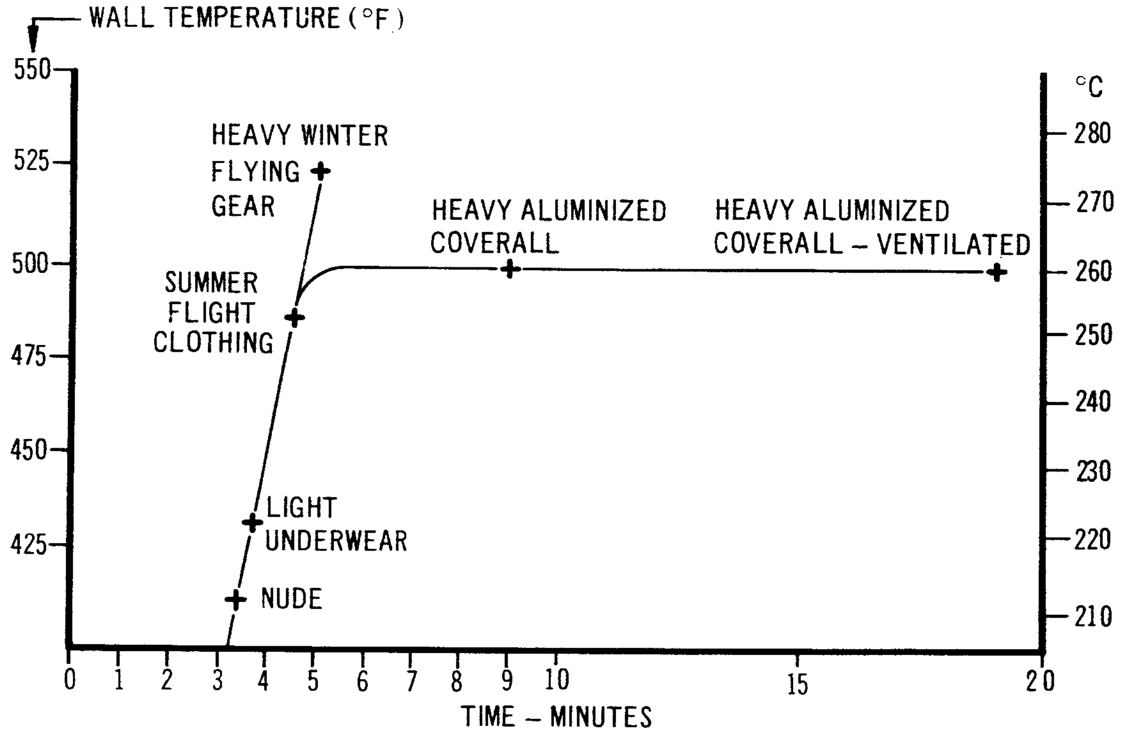
(e) Exposure time limits shall be considered as longer when temperature increases steadily from ambient conditions; eg, from 75 degrees to 400 degrees Fahrenheit at 100 degrees Fahrenheit per minute--3 1/4 minutes. (Webb, 7, 9). XR-S-2

(f) Exposure time limits shall be extended by precooling; eg, reducing average body temperature by 4 degrees Fahrenheit extends time of exposure to 160 degrees Fahrenheit from 60 minutes to almost 120 minutes. (Veghte, 10). XR-S-2

(g) Figure 84 shall be employed to determine short term heat exposure tolerance limits for men without protective clothing.

5.7.1.2.3.2 With protective clothing.

(a) The average increase in time and temperature permitted by different types of clothing shall be determined from the information presented in figure 85. (Webb, 7). XR-S-2



NOTE:
AVERAGED TOLERANCE LIMITS WITH VARIOUS CLOTHING ASSEMBLIES TO A SLOW HEAT PULSE. THE LINE TRACES THE FINAL COURSE OF THE HEAT PULSE WHILE THE ASTERISKS INDICATE ENDPOINTS FOR EACH CLOTHING ASSEMBLY. TEMPERATURE INCREASE WAS STOPPED AND HELD AT 500°F FOR BOTH COVERALL ASSEMBLIES. (ADAPTED FROM WEBB)

Figure 85. Thermal tolerance limits with different clothing assemblies

(b) Precooling shall be considered in extending tolerance times. See 5.7.1.2.3.1 (f). (Veghte, 10). XR-S-2

5.7.1.3 Cold and performance.

5.7.1.3.1 General.

(a) Cold or hot temperatures falling below this comfort zone shall be avoided wherever possible. XR-C-2

(b) Under conditions of long exposure to cold temperatures, protective clothing shall be furnished. See figure 86. XR-C-2

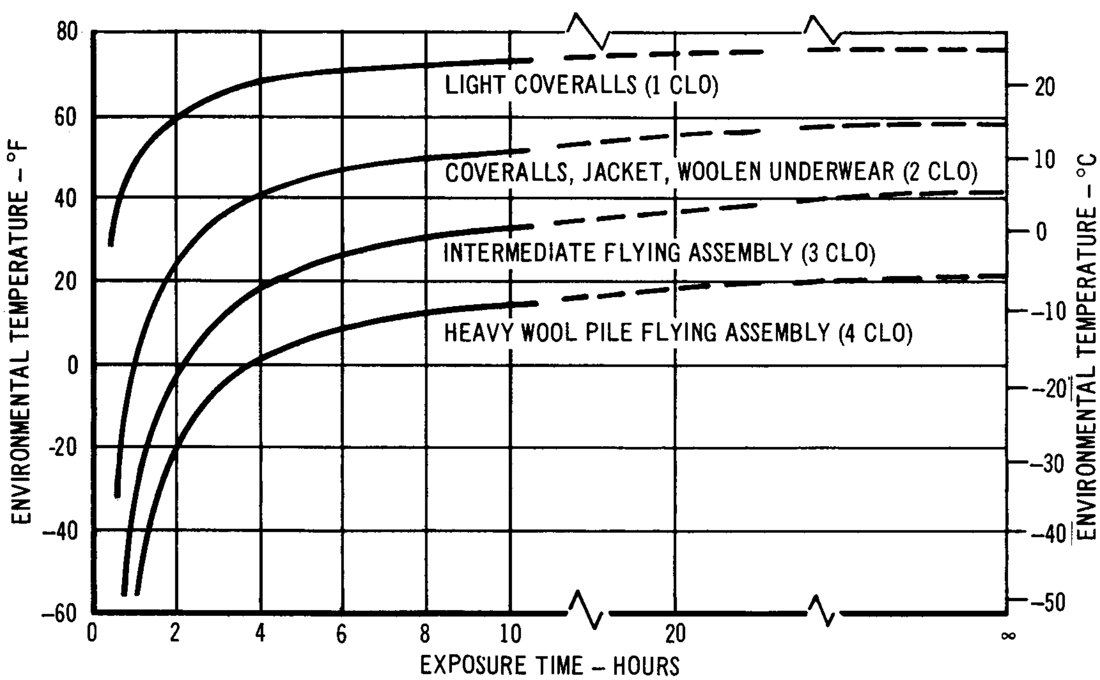


Figure 86. Low temperature limits for low activity work (sitting)

(c) Tasks involving finger dexterity or hand strength shall be avoided in cold environments wherever possible since these activities are first to suffer performance decrements due to low temperatures. (Horvath, 11; LeBlanc, 12). XR-S-2

5.7.1.3.2 Long term exposure. - Long term cold exposure criteria shall be determined from figures 86 and 87. (Webb, 6). XR-S-2

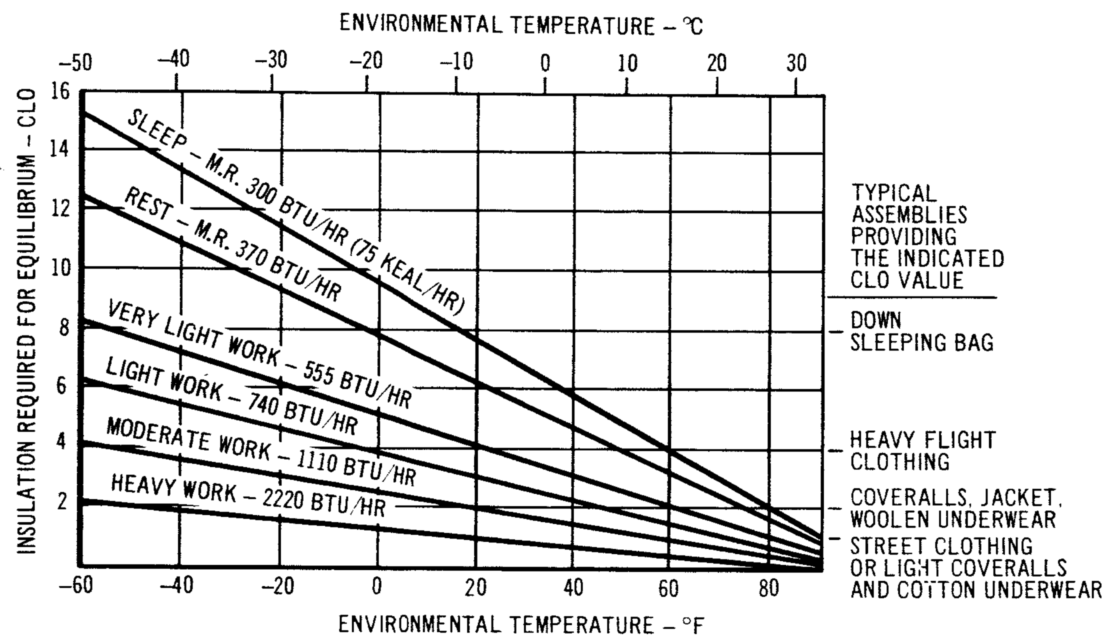


Figure 87. Low temperature limits for different activity levels

5.7.1.3.3 Short term exposures. - Short term cold exposure criteria with and without protective clothing shall be determined from figures 83, 84, 85 and 86. (Webb, 6). XR-S-2

5.7.1.3.4 Windchill

(a) Figure 88 shall be used to determine the interactive effect of wind velocity and temperature to produce windchill indices. By placing a straight edge across the two variables, the windchill index is obtained at the interaction point of the straight edge and windchill axis. The figure also permits a comparison of different combinations of wind speed, temperature, and windchill index but does not include consideration for physiological adaptation. (Consolazio, 13; Webb, 6). XR-S-2

(b) Tasks with critical visual reaction time shall be avoided at wind speeds in excess of 10 mph and low ambient temperature. (Teichner, 14). XR-S-2

5.7.1.4 Humidity and performance.

5.7.1.4.1 High humidity. - High relative humidity levels (above 70 percent) at high temperatures shall be avoided since they limit the amount of body cooling the perspiration-evaporation process can provide. This increases problems of discomfort and performance decrement already present with high temperatures. (ASHRAE, 1). XR-S-2

5.7.1.4.2 Comfort and performance. - Humidity shall be considered as exerting a limited effect on comfort and performance in the normal temperature range. (Kock, 15). XR-S-2

5.7.1.4.3 Low temperature. - High relative humidity levels at low temperatures shall be considered less detrimental since body heat loss is accomplished largely by convection and radiation. (ASHRAE, 1). XR-S-2

5.7.1.4.4 Effective temperature table. - Figure 89 shall be employed to indicate the importance of humidity in determining ET as dry bulb temperatures rise above 60 degrees Fahrenheit. (MIL-STD-803A-2, 16). XR-S-2

5.7.1.5 Air movement.

5.7.1.5.1 Air movement rate. - Air movement of 15 to 20 feet per minute shall be a general requirement. Criteria presented in figure 83 are based on this rate. (ASHRAE, 1). XR-S-2

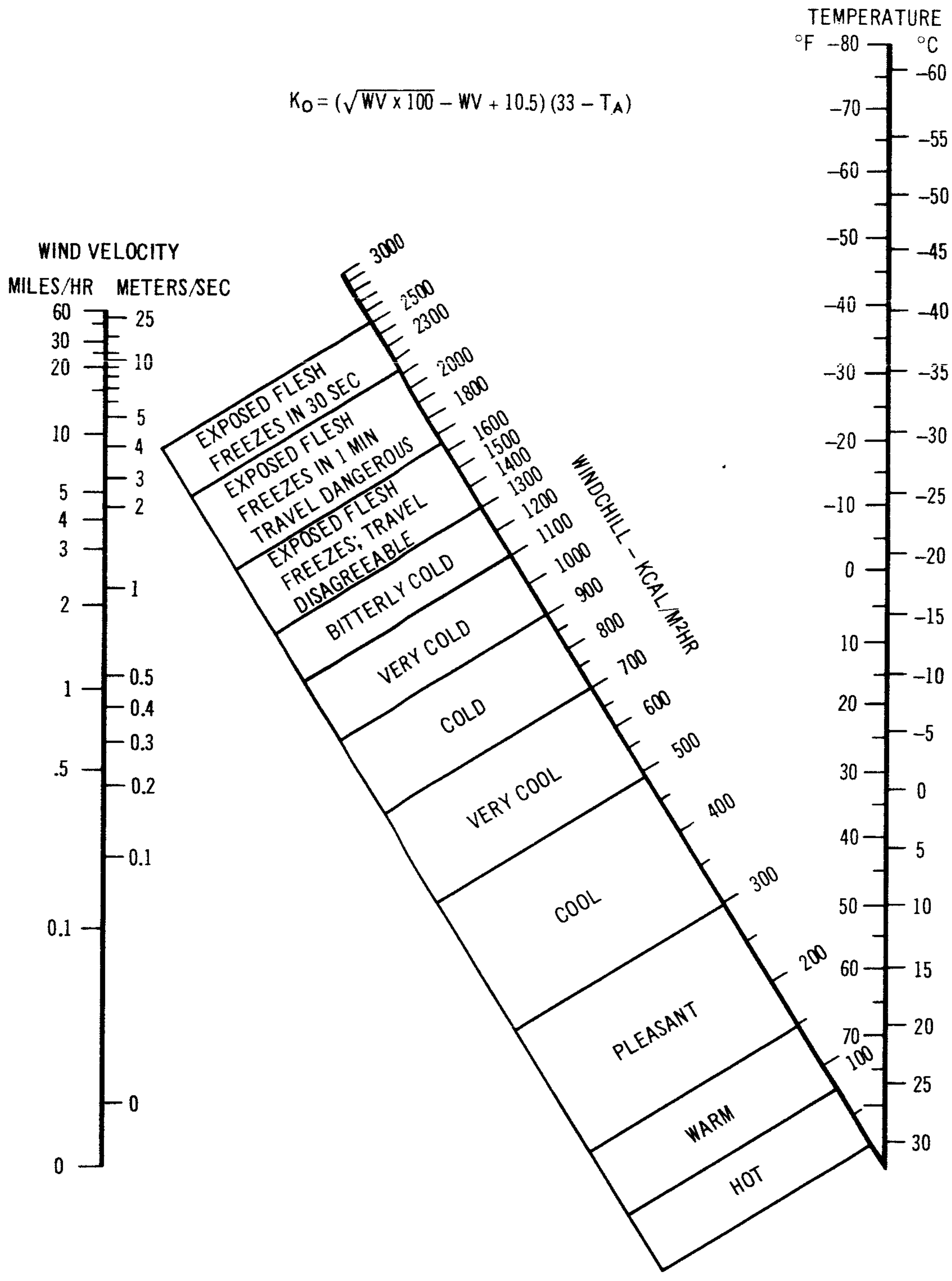


Figure 88. Windchill index

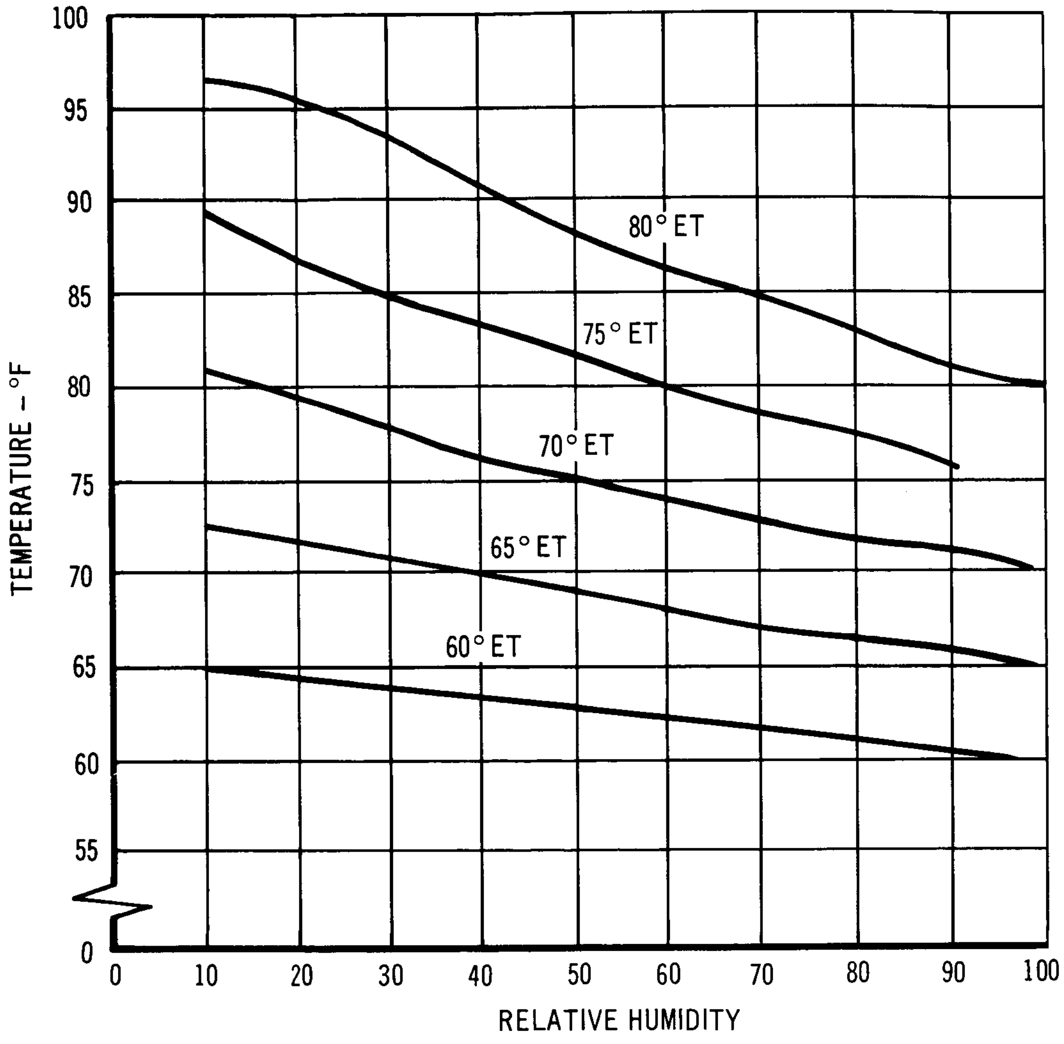


Figure 89. Effective temperature in relation to dry bulb temperature and relative humidity

5.7.1.5.2 <u>Convective cooling</u>. - Figure 90 shall be employed to determine the rate of convective cooling that shall be supplied to a seated man at rest to maintain a comfortable skin temperature of 90 degrees Fahrenheit over a range of hot operative conditions. The man is assumed to be wearing typical aviation clothing. (Webb, 6). XR-S-2

The graph shows the rate of convective suit cooling which must be supplied a seated man at rest wearing typical aviation clothing to maintain a comfortable skin temperature of 90°F (32°C) for a range of hot conditions. Suit convective heat removal is computed from the mass flow of ventilating air and the difference between inlet air temperature and the desired surface temperature:

$$q_v = 0.24\,(90 - t_v)\,W_v$$

where q_v = suit convective heat removal in Btu/min,

t_v = temperature of ventilating air in °F, and

W_v = mass flow of ventilating air in lbs/min.

When air and wall temperature are equal, the operative temperature is the same; otherwise it lies between them; it is their average, weighted according to the convective and radiative conductance coefficients respectively.

The data points marked with hollow squares, which are farthest from the curve drawn through the other points, are from experiments where there was moderate sweating and some heat storage, although the subjects judged themselves to be comfortable. The adjustments and corrections for these cases could only be approximate. Webb (6)

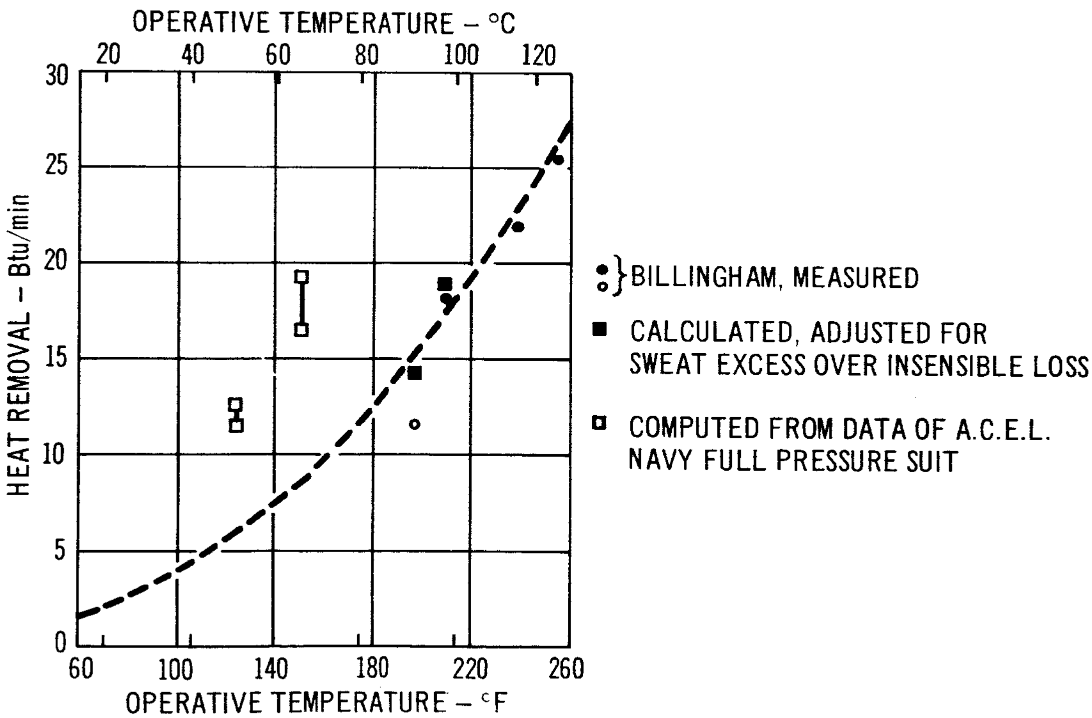


Figure 90. Cooling by ventilated clothing

5.7.1.5.3 Humidity. - When air temperatures are at or above body surface temperatures, the effect of air movement shall be considered as dependent on humidity. XR-C-2

5.7.1.5.4 High temperature-humidity. - High temperature-humidity conditions shall be avoided since a heat gain due to convection from moving air, rather than a heat loss from evaporation, may occur. XR-C-2

CLOTHING	5.7.2
General requirements: consider,	5.7.2.1
Minimize number of garments required	5.7.2.1.1
Provide proper tailoring and fitting	5.7.2.1.2
Clothing shall be free from obstructions	5.7.2.1.3
Provide adequate closures and fasteners	5.7.2.1.4
Design for emergency removal	5.7.2.1.5
Provide adequate seaming.	5.7.2.1.6
Label for intended use	5.7.2.1.7
Design for heat generation and perspiration	5.7.2.1.8
Provide adequate visibility	5.7.2.1.9
Provide gloves, where required	5.7.2.1.10
Glove surface: provide adequate gripping surface	5.7.2.1.11
Boots: provide adequate foot and ankle movement	5.7.2.1.12
Boot soles: provide non-slip surface	5.7.2.1.13
Protection from toxic materials: See text	5.7.2.2
Specific requirements: consider,	5.7.2.3
Provide independent breathing air supply, preferred	5.7.2.3.1
Label breathing air supply limits	5.7.2.3.1.1
Provide warning device when supply is low	5.7.2.3.1.2
Provide communication equipment, when necessary	5.7.2.3.2
Clothing design criteria for temperature extremes: consider,	5.7.2.4
Exposure to heat: See fig. 91, consider,	5.7.2.4.1
Tolerance - clothing worn: See fig. 92	5.7.2.4.1.1
Tolerance - body storage rate: See fig. 93	5.7.2.4.1.2
Tolerance - various body areas: See table XXXII	5.7.2.4.1.3
Exposure to cold: See fig. 87, consider,	5.7.2.4.2
Duration of exposure to cold: See fig. 85	5.7.2.4.2.1
Material of construction: See text	5.7.2.4.2.2

Clothing and metabolic activity rate: See fig. 87	5.7.2.4.2.3
Clothing values: avoid excess of 4.5 clo.	5.7.2.4.2.4

5.7.2 Clothing. - The clothing of launch vehicle personnel shall warrant design consideration when unusual or hazardous environmental conditions exist. Those environmental conditions considered hazardous, or unusual shall include extremes of temperature, presence of toxic materials or gases, high noise levels, and radioactive materials. Sections 5.6.3 (Noise), 5.7.1 (Temperature), and 5.7.3 (Safety) contain criteria and supplementary information which are related to these conditions. Section 5.5 (Anthropometry) contains information which may be used in determining size requirements of clothing. XR-C-1

5.7.2.1 General requirements for protective clothing.

5.7.2.1.1 Minimum number of garments. - Garments shall provide a full range of protection for a normal work cycle in order to preclude multiple clothing changes in a short period of time, unless such changes are required to preclude the dangerous mixing of materials and it is impractical to use different individuals. XR-C-1

5.7.2.1.2 Tailoring and fitting. - Tailoring and fitting shall permit adequate freedom of movement so that the full range of intended wearers can perform assigned tasks. XR-C-1

5.7.2.1.3 Freedom from obstructions. - External surfaces shall be free of loops, straps and obstructions which could impede the free movement of the wearer. Internal surfaces will be free of items which would impede free movement or cause undue wearer discomfort. XR-C-1

5.7.2.1.4 Closures and fasteners. - Closures and fasteners shall be capable of operation by the wearer and shall provide the same protection as permanent seals and seams against leakage of contaminants. XR-C-1

5.7.2.1.5 Emergency removal. - The garment shall be capable of emergency removal by the wearer, preferably by the use of normal closures and fasteners. XR-C-1

5.7.2.1.6 Seaming. - Seaming shall not permit leakage of contaminants, nor should they be of such bulk or location as to cause wearer discomfort. XR-C-1

5.7.2.1.7 Labelling. - The intended use and limitations and cautions shall be clearly stated on a conspicious label attached to the garment. XR-C-1

5.7.2.1.8 Wearer effects. - The effects from the wearer's body heat generation and perspiration shall be considered in the design of garments and selection of materials. XR-C-1

5.7.2.1.9 Visibility. - Visibility of task area shall not be unduly hampered by devices located near the eye region. XR-C-2

5.7.2.1.10 Gloves. - Gloves shall be sufficiently flexible and insure the necessary tactile sensing to perform the required tasks. (See 5.5.1.4.2.7). XR-C-1

5.7.2.1.11 Glove surface. - Glove surface shall be such that it provides an adequate gripping surface. XR-C-1

5.7.2.1.12 Boots. - Boots shall permit adequate foot and ankle movement. XR-C-2

5.7.2.1.13 Boot soles. - Boot soles shall be provided with non-slip surface. XR-C-1

5.7.2.2 Protection from toxic materials. - As new rocket fuels are developed, new protective materials must also be provided. For specific requirements, the contractor shall contact the purchasing agency. For guidelines for protective materials, refer to AFTO 11C-1-6-C, 17, AF Manual 160-39, 18; MIL-C-12527A, 19; and MIL-G-4244A, 20.

5.7.2.3 Specific requirements for whole body protective garments.

5.7.2.3.1 Breathing air supply. - Wholly independent breathing air supplies shall be preferred over devices which are designed to purify, filter or otherwise process the general external air for certain contaminants. XR-C-1

5.7.2.3.1.1 Breathing air supply limits. - The length of time that a breathing device can safely be used shall be clearly evident to the user prior to donning the device. This may be accomplished by a gauge directly calibrated in useful air remaining, an unbroken seal with suitable markings or other reliable means. XR-C-1

5.7.2.3.1.2 Warning device. - A warning device shall be incorporated in all such breathing devices to alert the user to a diminished supply in sufficient time to return to a safe environment. XR-C-1

5.7.2.3.2 Communications. - Reliable voice communication devices shall be provided when protective equipment covers all or most of the head region. XR-C-1

5.7.2.4 Clothing design criteria for temperature extremes.

5.7.2.4.1 Exposure to heat. - Human thermal comfort shall be defined as a function of air temperature and humidity as shown in figure 91. Design recommendations for normal street clothing (1 clo), seated resting individuals, and minimal air movement shall not exceed the upper limits of the evaporative regulation curve. (Webb, 21). XR-S-2

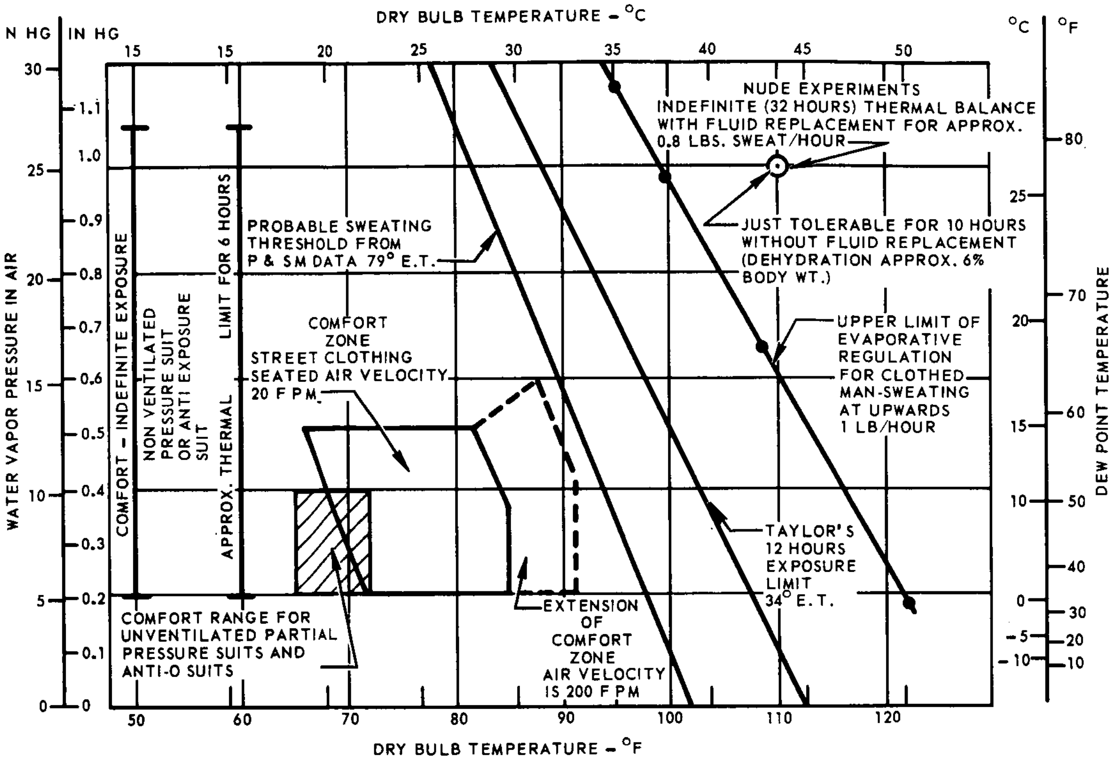
5.7.2.4.1.1 Heat exposure tolerance as a function of clothing worn. - Under conditions of slow heat pulse in which the environmental temperature is increased at the rate of 100 degrees Fahrenheit per minute until pain tolerance is reached, the clothing assemblies required for specific temperature and exposure durations shall be selected from figure 92. (Webb, 6). XR-S-2

5.7.2.4.1.2 Heat exposure tolerance as a function of clothing worn, altitude, and body storage rate. - Clothing values (for seated and untrained men) for various operative temperatures and altitudes as well as tolerance limits for each combination in relation to body storage rate, shall be determined from figure 93. (Blockley, 22). XR-S-2

5.7.2.4.1.3 Heat exposure tolerance for various areas of body as a function of clothing worn. - Maximum temperature and limits of tolerance obtained for various clothing worn over specific body parts are shown in table XXXII. This table shall be employed in the determination of clothing values for various body parts, and the maximum protection afforded (in terms of temperature limits and duration) by the clothing selected. (North American Aviation, 23). XR-S-2

5.7.2.4.2 Exposure to cold. - The amount of clothing insulation required for continuous cold environment exposure shall be considered to depend on the metabolic heat production rate that maintains body temperature. (See section 5.7.1.3.3, figure 87). (Taylor, 24). XR-S-2

5.7.2.4.2.1 Duration of exposure to cold. - Clothing values for seated and resting personnel exposed to various levels of cold temperatures, shall be determined from figure 85, section 5.7.1.3.3 as a function of exposure time. (Burton, 25). XR-S-3



NOTE:

HUMAN THERMAL COMFORT DEFINED BY AIR TEMPERATURE AND HUMIDITY IN THE AREA ENCLOSED BY THE HEAVY SOLID LINE. NOTE THE STIPULATIONS OF NORMAL STREET CLOTHING, SEATED RESTING INDIVIDUALS, AND MINIMAL AIR MOVEMENT. AN INCREASE IN AIR VELOCITY TO 200 FPM, WHICH IS A COMMON LEVEL IN HIGH PERFORMANCE AIRCRAFT, EXTENDS THE COMFORT ZONE INTO HIGHER TEMPERATURES AS SHOWN. IF IMPERMEABLE CLOTHING IS WORN, COMFORT (INDEFINITE TOLERANCE) FOR SEATED MEN MOVES TOWARD THE COLD SIDE. PARTIAL COVERAGE WITH RUBBERIZED CLOTH, AS FOUND IN ANTI-O SUITS AND PARTIAL PRESSURE SUITS, CALLS FOR DRIER, COOLER CONDITIONS AS SHOWN IN THE CROSS-HATCHED AREA. COMPLETE COVERAGE WITH IMPERMEABLE MATERIAL, AS FOUND IN ANTI-EXPOSURE SUITS AND FULL PRESSURE SUITS, CALLS FOR DEFINITELY COOL TEMPERATURES, BUT NO SPECIAL HUMIDITY SINCE EVAPORATION CANNOT TAKE PLACE. ACTIVITY IN SUCH ASSEMBLIES PRODUCES CRITICAL THERMAL LOADING, SOLVED ONLY BY FORCED CLOTHING VENTILATION TO PERMIT REMOVAL OF WATER VAPOR.

SEVERAL REFERENCE POINTS ARE SHOWN FOR WARM CONDITIONS ABOVE THE COMFORT ZONE, AGAIN FOR NORMALLY CLOTHED RESTING MEN, WHERE AIR VELOCITY IS LOW. THE SWEATING THRESHOLD FALLS AT ABOUT THE LINE LABELED AS 79°F E.T. (EFFECTIVE TEMPERATURE), AS DERIVED FROM A PREDICTION METHOD CALLED THE PREDICTED FOUR-HOUR SWEAT RATE (P4SR). EXPOSURES UP TO 12 HOURS CAN BE TOLERATED, BUT WITH THE COST OF PHYSIOLOGICAL ADAPTATION UP TO 84°F E.T. THERMAL BALANCE (AT A HIGHER-THAN-NORMAL BODY TEMPERATURE) CAN BE MAINTAINED FOR HOURS UP TO THE LINE SHOWN FITTING SOLID DOT DASH POINTS, AND CORRESPONDING TO ABOUT 92°F E.T. FINALLY, A SET OF EXPERIMENTS IS SHOWN WITH NUDE MEN AT REST AT 110°F AND 25 MM LIG VAPOR PRESSURE, WHEREIN THOSE WHO HAD FLUID REPLACEMENT MAINTAINED THERMAL BALANCE FOR 32 HOURS, AND THOSE DEPRIVED OF FLUID BECAME SEVERELY DEHYDRATED AND LOST THERMAL CONTROL IN 10 HOURS. (COMPILED BY WEBB ASSOCIATES, 1966.)

Figure 91. Thermal comfort zone

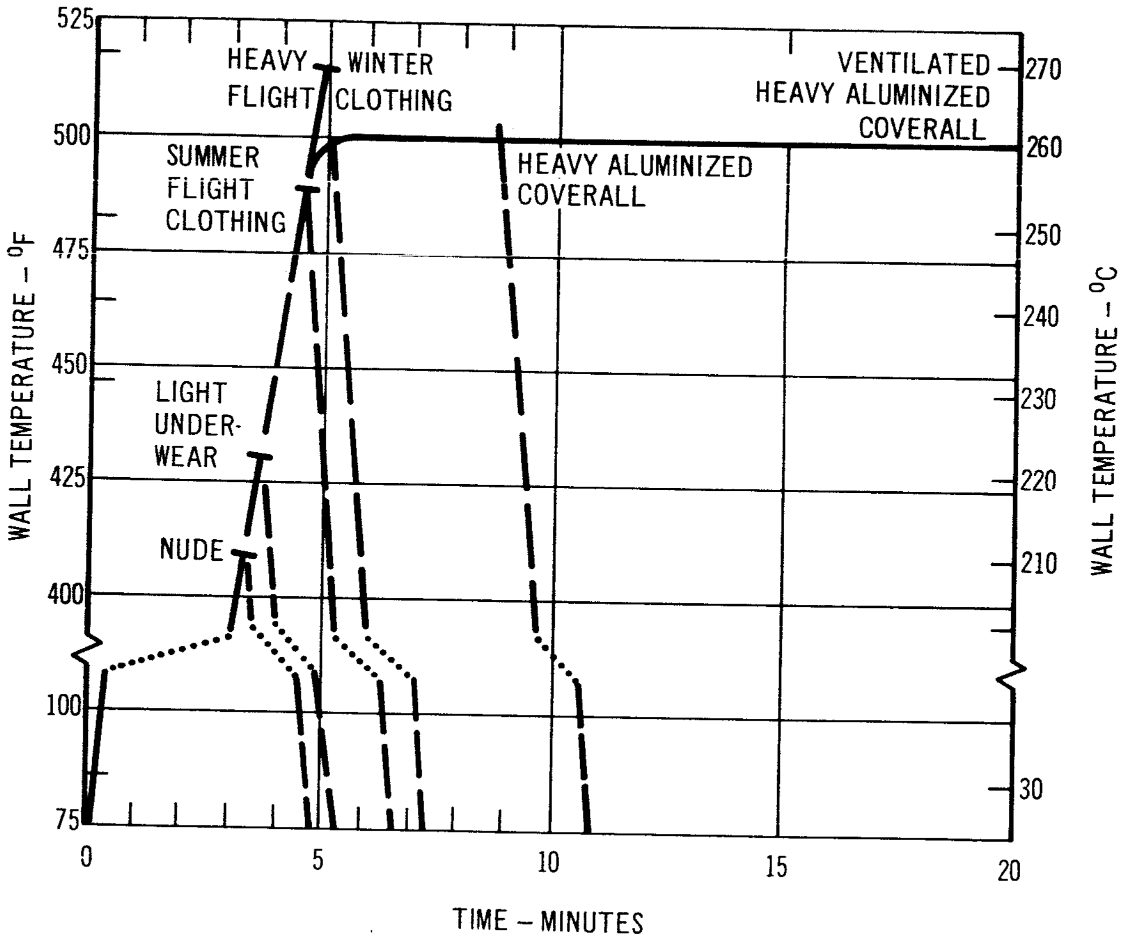
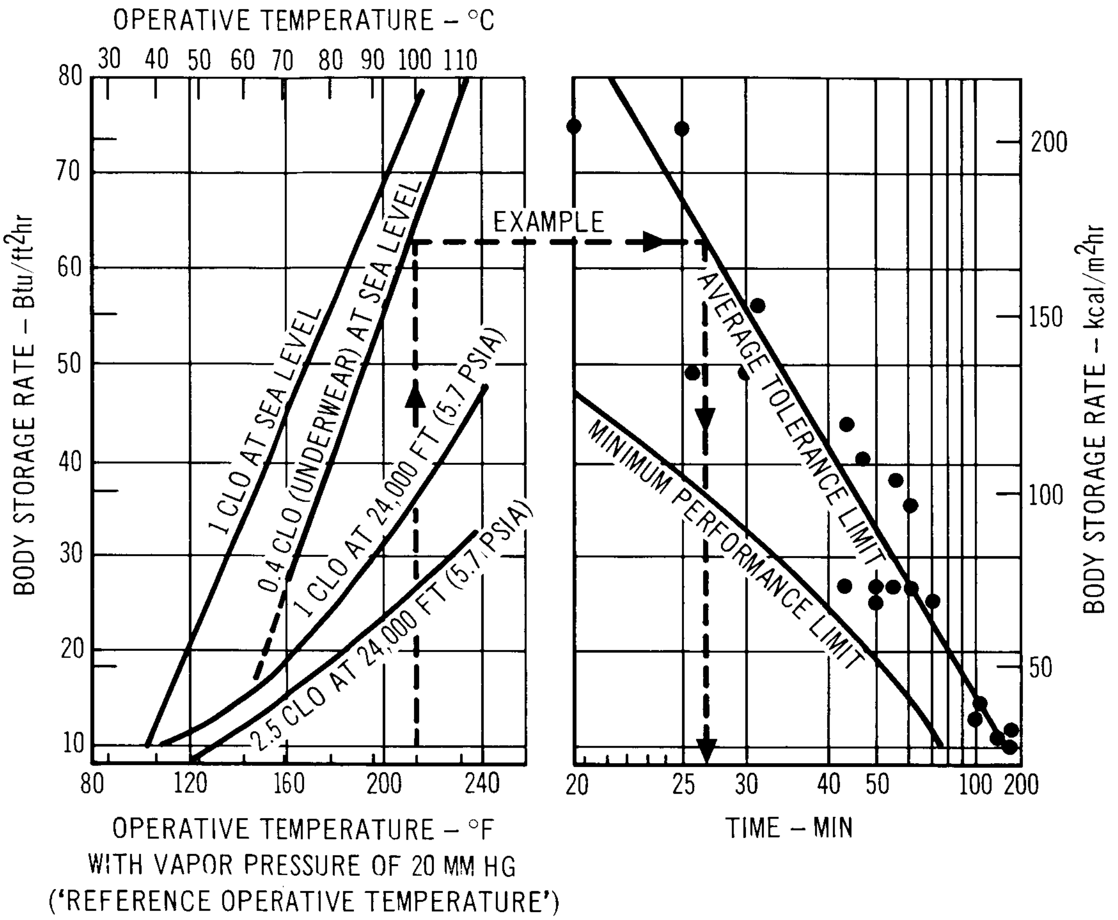


FIGURE 92 SHOWS THE INCREASE IN TOLERANCE TIMES (VOLUNTARY LIMIT WHEN SURFACE PAIN BECOMES UNBEARABLE) FOR SUBJECTS EXPOSED TO A HEAT PULSE WHERE WALL TEMPERATURE WAS INCREASED AT 100°F/MIN, AND THE SUBJECTS WORE CLOTHING AFFORDING VARIOUS DEGREES OF PROTECTION. EACH LIMIT REPRESENTS AVERAGE DATA FOR FROM 3 TO 10 SUBJECTS. WHEN AN ALUMINIZED SURFACE WAS USED WITH A HEAVY COVERALL, THE PROTECTION INCREASED AGAIN; EXPOSURES WERE CHANGED IN FORM. THE INCREASE IN WALL TEMPERATURE WAS STOPPED AT 500°F AND THAT TEMPERATURE HELD UNTIL TOLERANCE WAS REACHED. ADDING VENTILATION WITH AIR AT ABOUT 85°F ALLOWED THESE EXPOSURES TO LAST BEYOND 20 MINUTES.

Figure 92. Tolerable heat pulses



THIS CHART SHOWS THE RATE OF STORAGE OF BODY HEAT FOR SEVERAL CONDITIONS OF CLOTHING AND ALTITUDE, WHERE SEATED AND UNTRAINED MEN ARE EXPOSED TO NON-COMPENSABLE HEAT. ENTRY IS BY MEANS OF THE REFERENCE OPERATIVE TEMPERATURE, DEFINED AS THE TEMPERATURE OF AIR AND WALLS WHICH, IN COMBINATION WITH A VAPOR PRESSURE OF 20 MM HG, HAS EQUIVALENT EFFECTS TO SOME OTHER COMBINATION OF HUMIDITY AND TEMPERATURES. OPERATIVE TEMPERATURE IS THE WEIGHTED MEAN OF AIR AND WALL TEMPERATURE, WHERE THE WEIGHTING COEFFICIENTS ARE THE RESPECTIVE HEAT TRANSFER COEFFICIENTS FOR CONVECTION AND RADIATION.

SOURCE: BLOCKLEY (22)

Figure 93. Heat storage and tolerance

Table XXXII.

Pain from conductive heating

BODY AREA	CLOTHING WORN	METAL SURFACE TEMPERATURE	AVERAGE TOLERANCE TIME (SECONDS)
HAND	BARE SKIN	120	10–15
KNEECAP	BARE SKIN	117	34.0
	BARE SKIN	120	5.0
FINGERTIP	AF/B-3A LEATHER GLOVES	150	12.6
	AF/B-3A LEATHER GLOVES	160	7.3
HAND – PALM	AF/B-3A LEATHER GLOVES	150	25.2
	AF/B-3A LEATHER GLOVES	175	9.7
	AF/B-3A LEATHER GLOVES	185	8.0
FOREARM	SAC ALERT SUIT	150	20.6
	SAC ALERT SUIT	175	8.0
UPPER ARM	K-2B LIGHT AF FLIGHT COVERALL	150	7.5
	SAC ALERT SUIT	150	31.3
	ALERT SUIT PLUS BRYNJE NET STRING UNDERWEAR	300	7.2
	K-2B SUIT	150	18.1
	K-2B SUIT PLUS BRYNJE UNDERWEAR	150	61.0
BUTTOCKS	SAC ALERT SUIT	150	70.3
	ALERT SUIT PLUS BRYNJE UNDERWEAR	300	21.7
	K-2B SUIT	150	32.5
	K-2B SUIT PLUS BRYNJE UNDERWEAR	150	+90.0
MID-THIGH	SAC ALERT SUIT	150	35.6
	ALERT SUIT PLUS BRYNJE UNDERWEAR	300	13.1
	K-2B SUIT	150	13.6
	K-2B SUIT PLUS BRYNJE UNDERWEAR	150	+90.0
KNEECAP FLEXED	SAC ALERT SUIT	150	14.4
	ALERT SUIT PLUS BRYNJE UNDERWEAR	175	9.5
	K-2B SUIT	150	7.3
CALF MUSCLE	SAC ALERT SUIT	150	14.4
	ALERT SUIT PLUS BRYNJE UNDERWEAR	300	11.4
	K-2B SUIT	150	13.2
	K-2B SUIT PLUS BRYNJE UNDERWEAR	150	66.1
UPPER ARM	MD-3A WOOL-NYLON ANTI-EXPOSURE SUIT	300	12.0
	MD-3A WOOL-NYLON ANTI-EXPOSURE SUIT	400	10.2
FOREARM	MD-3A SUIT	250	15.9
PALM OF HAND	ALUMINIZED ASBESTOS GLOVE	250	13.5
BACK OF HAND	ALUMINIZED ASBESTOS GLOVE	250	5.2
PALM OF HAND	ARCTIC MITTEN	300	18.7
	ARCTIC MITTEN PLUS B-3A GLOVE	300	37.0
	ARCTIC MITTEN PLUS B-3A GLOVE	400	27.6
	PIGSKIN '800°F' HEAT GLOVE	300	30.7
	PIGSKIN '800°F' HEAT GLOVE	400	21.0
	PIGSKIN '800°F' HEAT GLOVE	500	18.5

NOTES: LIGHT TOUCH PRESSURE (LESS THAN 1 PSI) APPLIED TO HEATED METAL SURFACE. THE ELBOW AND KNEE SOMETIMES RECEIVED SECOND DEGREE BURNS WITHOUT PAIN.

SOURCE: ADAPTED FROM NORTH AMERICAN AVIATION (23).

5.7.2.4.2.2 Material of construction. - Material of construction shall consider thermal insulation, air permeability, water vapor permeability, water absorption, radiation emission and absorption, abrasion and tear resistance, and weight. XR-C-2

Insulation of clothing is expressed in "clo" units and shall be defined as:

$$1 \text{ clo} = 0.88 \frac{^{\circ}F}{Btu/ft^2hr} \quad \text{or} \quad 0.18 \frac{^{\circ}C}{KCal/m^2hr}$$

(Burton, 25). XR-S-2

5.7.2.4.2.3 Clothing and metabolic activity rate. - The insulation in clothing required for cold environments for thermal balance at various levels of activity shall be determined from figure 87, section 5.7.1.3.3. (Burton, 25). XR-S-3

5.7.2.4.2.4 Excess of 4.5 clo. - Clothing values in excess of 4.5 clo shall not be recommended for conditions of work that require more than gross bodily movements. (Webb, 21). XR-S-3

APPENDIX A
CONTRIBUTORS

SAFETY	5.7.3
Preliminary design safety factors: consider,	5.7.3.1
Identify inherent hazards	5.7.3.1.1
Design for fail safe	5.7.3.1.2
Consider safety for: space, configuration, controls & displays	5.7.3.1.3
Provide warning devices, where required	5.7.3.1.4
Identify interface safety requirements	5.7.3.1.5
Provide safety markings	5.7.3.1.6
Specific design requirements: consider,	5.7.3.2
Maintenance safety precautions: consider,	5.7.3.2.1
Provide built in lighting	5.7.3.2.1.(a)
Avoid maintenance in visually blind areas	5.7.3.2.1.(b)
Locate controls away from dangerous components	5.7.3.2.1.(c)
Protect hot or high voltage equipment from touch	5.7.3.2.1.(d)
Provide safety glass rather than breakable glass	5.7.3.2.1.(e)
Use clips or snap rings to secure glass	5.7.3.2.1.(f)
Provide finger clearances for ladders, etc.	5.7.3.2.1.(g)
Access safety precautions: consider,	5.7.3.2.2
Locate away from electrical, hot, toxic, etc.	5.7.3.2.2.(a)
Provide tool guides for high voltage	5.7.3.2.2.(b)
Provide internal lighting	5.7.3.2.2.(c)
Provide visual access in dangerous areas	5.7.3.2.2.(d)
Access openings shall be deburred & rounded	5.7.3.2.2.(e)
Use diagrams on access cover for maintenance	5.7.3.2.2.(f)
Provide locking device to keep access open, where possible	5.7.3.2.2.(g)
Provide warning labels for dangerous areas	5.7.3.2.2.(h)
Test point safety precautions: consider	5.7.3.2.3
Fan cables if test points not provided	5.7.3.2.3.(a)
Protect test points (recess, etc.)	5.7.3.2.3.(b)
Provide direct insertion & quick disconnect, where possible	5.7.3.2.3.(c)
Plugs with built-in test points: See text	5.7.3.2.3.(d)
Provide holding device for probe, where required	5.7.3.2.3.(e)

Design for one full time connect-disconnect	5.7.3.2.3.(f)
Build in high pressure test indicators	5.7.3.2.3.(g)
High pressure fluid systems: See text	5.7.3.2.3.(h)
Provide guides for interval test points	5.7.3.2.3.(i)
High voltage precautions: consider,	5.7.3.2.4
Protect personnel from dangerous components	5.7.3.2.4.(a)
Ground control shafts and bushings	5.7.3.2.4.(b)
Protect from moisture	5.7.3.2.4.(c)
Prevent accidental contact in excess of 24 volts	5.7.3.2.4.(d)
Prevent exposure to 150 or more volts. See text	5.7.3.2.4.(e)
Safety equipment and devices: consider,	5.7.3.2.5
Provide first aid kits	5.7.3.2.5.(a)
Provide eye baths & showers where toxic area	5.7.3.2.5.(b)
Provide automatic shut-off for fuel equipment	5.7.3.2.5.(c)
Provide fire extinguishers, where required	5.7.3.2.5.(d)
Design emergency doors accessible & quick opening	5.7.3.2.5.(e)
Provide for flushing of harmful materials spilled	5.7.3.2.5.(f)
Identify areas requiring special clothing, tools, etc.	5.7.3.2.5.(g)
Provide self-locking into elevating stands, etc.	5.7.3.2.5.(h)
Provide outriggers for stands with high center of gravity	5.7.3.2.5.(i)
Provide guards for moving machinery	5.7.3.2.5.(j)
Provide handrails, where required, See table XXV	5.7.3.2.5.(k)
Provide skid proof flooring, stairs and steps	5.7.3.2.5.(l)
Provide ladder cages for ladders over 20 feet	5.7.3.2.5.(m)
Design for 60 mph winds on open doors	5.7.3.2.5.(n)
Auditory warning displays: consider,	5.7.3.3
Usage: consider,	5.7.3.3.1
Use auditory warning where immediate attention required	5.7.3.3.1.(a)
When to use: See text	5.7.3.3.1.(b)
Use only standard auditory signals	5.7.3.3.1.(c)
Selection criteria: consider,	5.7.3.3.2
Check equipment designs specs for requirement	5.7.3.3.2.(a)
Consider frequency, intensity and character	5.7.3.3.2.(b)
Keep intensity level below 130 db	5.7.3.3.2.(c)

Signals: 220 to 3200 cps	5.7.3.3.2.(d)
If high ambient noise, channel thru earphones	5.7.3.3.2.(e)
Measure ambient noise	5.7.3.3.2.(f)
Intensity level: See fig. 94	5.7.3.3.2.(g)
Voice warning shall be at least 85% intelligible	5.7.3.3.2.(h)
Environment toxicity: consider,	5.7.3.4
Carbon dioxide: See text	5.7.3.4.1
Carbon monoxide: See text	5.7.3.4.2
Other contaminants: See table XXVI	5.7.3.4.3

5.7.3 Safety. - Safety shall be considered for all industrial activities. Those safety considerations which are applied during the design phase of system development are generally superior in concept and operation to those which are applied in the post-design phase. Design engineers shall incorporate all feasible methods of reducing hazards and accident rates into their designs. Where tradeoffs are unavoidable, procedures which minimize hazards will be developed as equipment is designed. XR-C-1

5.7.3.1 Preliminary design safety factors.

5.7.3.1.1 Inherent hazards. - All hazards shall be identified and associated with the function accomplished by the design; eg, cryogenics, hypergolics, and high voltage. XR-C-1

5.7.3.1.2 Fail-safe design. - Where high reliability cannot be expected and the consequences of failure will be severe, design shall be fail-safe. XR-C-1

5.7.3.1.3 Special considerations. - To assure safety during installation, checkout, maintenance and operation of the equipment, consideration shall be given to requirements of space, configuration, controls, and indicators. XR-C-2

5.7.3.1.4 Warning devices. - A warning device shall be used in the following cases:

(a) A hazard alerting device shall be provided to warn personnel of impending or existing hazards; eg, fire or presence of combustible or hazardous gas. XR-C-1

(b) Operations of switches or controls which initiate hazardous operations such as ignition and crane moving, shall require the prior operation of a related locking control. Where practicable, the critical position of the operational controls will activate a warning device in the affected area. XR-C-1

5.7.3.1.5 Interface requirements. - The interface requirements between a design and a facility or equipment (including that of other contractors) shall be checked to identify hazards or hazard potential situations. XR-C-1

5.7.3.1.6 Markings. - Conspicuous markings or labels shall be provided to warn personnel of high voltage, high gas pressure, flammable liquids, and toxic liquids or gases. These markings shall be located on or adjacent to the hazardous equipment or material. XR-C-1

5.7.3.2 Specific design requirements.

5.7.3.2.1 Maintenance safety precautions. - Attention shall be given to the following maintenance precautions:

(a) Built-in lighting for in-cabinet maintenance will be provided. In cases where this is not feasible, provision shall be made for portable lights to illuminate the work area. XR-C-2

(b) Maintenance in blind spots shall be avoided. No deviation shall be permitted where high voltage sources, hot or cold components or other dangerous equipment are present. XR-C-1

(c) Internal controls such as switches and adjusting screws shall not be located close to dangerous components or equipment. XR-C-2

(d) Components which retain heat or electrical potential when the equipment is turned off shall not be located where personnel are likely to touch them during routine maintenance. XR-C-2

(e) Safety glass or clear plastic shall be used rather than breakable glass. XR-C-2

(f) Clips, snap rings or other devices shall be used to secure glass windows. Cement shall not be used alone. XR-C-2

(g) Provision shall be made for finger clearance in the design of telescoping steps, extension ladders and in other applicable situations. XR-C-1

5.7.3.2.2 Access safety precautions. - Attention shall be given to the following access precautions: See 5.8.5.

(a) Accesses shall be located so as to prevent personnel from touching hot or extremely cold components, toxic materials, electric current, sharp edges or moving machinery. XR-C-1

(b) Tool guides shall be provided to prevent contack with high voltages. XR-C-1

(c) Internal lighting which automatically illuminates a hazard when the access door is opened shall be provided. Two bulb reliability shall be provided. XR-C-1

(d) Visual access shall be provided where maintenance operations must be performed in dangerous areas. XR-C-1

(e) Access openings shall be deburred and rounded and fiber plastic or rubber coverings shall be provided where sharp edges could injure personnel or equipment. XR-C-1

(f) Diagrams may be used on access covers to indicate adjustment or service points. XR-C-3

(g) Wherever feasible, locking devices shall be provided on access doors to prevent them from closing during maintenance operations. XR-C-3

(h) Highly visible warning labels shall be provided on all access openings to dangerous equipment. XR-C-1

5.7.3.2.3 Test point safety precautions. - Attention shall be given to the following test point precautions: See 5.8.14; 5.8.15.

(a) Cables in junction boxes shall be fanned out for checking if standard test points are not provided. XR-C-1

(b) Test points shall be physically recessed or otherwise protected from damage by moisture, personnel or stresses of noise and vibration wherever possible. XR-C-2

(c) Direct insertion or quick disconnect connectors shall be used unless high pressures demand threaded connections. XR-C-2

(d) Plugs with built-in test points shall provide access to the output of replaceable units having no built-in test points.

(e) Test points shall be provided with a holding device if a test probe or service nozzle must remain connected to a point without being held by personnel. XR-C-2

(f) No more than one full turn shall be required to connect the test equipment lead to the test point. XR-C-2

(g) High pressure test indicators shall be built in wherever possible to avoid the dangers of temporary high pressure connections. XR-C-2

(h) Test and service points on high pressure fluid systems shall be keyed to probes or nozzles so the point is not opened until the probe or nozzle is fully inserted. XR-C-1

(i) Guides for test probes shall be provided when test points are internally located or where visual access to the point is limited. XR-C-1

5.7.3.2.4 High voltage precautions. - Attention shall be given to the following high voltage precautions:

(a) Personnel shall be protected from potentially dangerous components by every reasonable method possible such as guards, locks, covers, warning labels, component grounding, special fittings which require insulated tools, and spacing between components to prevent a tool from making contact between two exposed fittings as well as insulating mats, gloves and boots. XR-C-1

(b) All control shafts and control bushings shall be grounded. XR-C-1

(c) Equipment shall be designed so that moisture cannot collect near electrically operated controls to produce dangerous shocks. XR-C-1

(d) Equipment design shall prevent accidental contact with voltages in excess of 24 volts. XR-C-1

(e) Equipment design shall prevent exposure to voltages in excess of 500 volts when cases and seals are removed for maintenance and repair. Equipment access doors or covers shall incorporate interlocks which will remove all potentials in excess of 150 volts. XR-C-1

5.7.3.2.5 Safety equipment and devices. - The following equipment and devices shall be provided where appropriate:

(a) First aid kits containing appropriate remedies and equipment shall be located at strategic points outside the hazard areas. XR-C-1

(b) Eye baths, showers and other appropriate equipment shall be readily available in areas where toxic materials are handled. XR-C-1

(c) Automatic shut-off devices shall be provided on fuel service equipment to prevent overflow and spillage. XR-C-1

(d) Portable hand-operated fire extinguishers shall be provided in areas where fire hazards exist or may be created. XR-C-1

(e) All emergency doors and exits shall be designed so that they are easily accessible, unobstructed and quick opening. They shall also be designed to open with a single motion of hand or foot. XR-C-1

(f) To insure maximum personnel protection, provision shall be made for neutralization or flushing of harmful materials spilled on equipment as well as personnel. XR-C-1

(g) Areas of operation or maintenance where special clothing, tools or equipment are necessary shall be specifically identified and appropriate action taken to ensure the availability of such items (eg, insulated shoes, non-sparking tools, gloves or suits). XR-C-1

(h) Self-locking or other foolproof devices shall be incorporated into elevating stands or work platforms to prevent accidental collapse. XR-C-1

(i) Outriggers or some form of anchor shall be incorporated into stands with high centers of gravity. XR-C-1

(j) A guard shall be provided on all moving parts of machinery and transmission equipment in which personnel may become entangled or injured. XR-C-1

(k) Handrails, safety bars or chains shall be provided on platforms, stairs, around floor openings or wherever the possibility of a fall exists. See figures 68 and 69 and table XXV, 5.5.2 Work space. XR-C-1

(l) Skid proof flooring and stair or step treads shall be provided where applicable. XR-C-1

(m) Ladder cages shall be provided for fixed ladders over 20 feet long.

(n) Hinged panels and doors that are to be used outdoors shall be designed to withstand 60 mph winds in the full open position. XR-C-2

5.7.3.3 <u>Auditory warning displays.</u>

5.7.3.3.1 <u>Usage.</u>

(a) Auditory signals shall be used where the demands upon personnel for visual attention are complex, and immediate attention must be obtained. XR-C-1

(b) Auditory warning signals (employed in addition to visual signals) shall be used to relay specialized information such as: XR-C-1

(1) Equipment malfunctions, resulting in damage to the equipment.

(2) Unsafe conditions for personnel.

(3) Alerts and emergencies.

(4) Moving equipment.

(5) Incoming communication signals.

(c) Only standard auditory signals should be used; eg, klaxon horn, bells, siren, buzzers, etc. XR-C-2

5.7.3.3.2 <u>Selection criteria.</u>

(a) Equipment design specifications shall include the events requiring warning signals, and the priorities assigned to these signals. XR-C-1

(b) When selecting an auditory warning device, consideration should be given to the frequency, intensity level, and character (ie, steady, intermittent, modulated) of the signal relative to the noise over which the signal must be heard. XR-C-2

(c) The intensity level of auditory warning signals shall be kept below 130 db., (approximately the lower limit of the pain threshold in the human ear). (Childs, 26). XR-S-2

(d) The signals of the warning devices shall be between 220 and 3200 cps. (Childs, 26). XR-S-2

(e) Auditory signals shall be channeled through earphones for personnel who are working in an environment of high ambient background noise. XR-C-2

(f) In areas where auditory warning signals are to be used, the following measurements of sound pressure level are to be made:

(1) Measurements of ambient noise.

(2) Measurement of the ambient noise plus the auditory warning signals. These measurements are to be used to assure that ambient levels do not mask the warning signal.

(g) The difference in intensity level as a function of frequency between a pure tone warning system and the ambient noise level shall not be any less than that shown for each octave band in figure 94. (Childs, 26). XR-S-2

(h) A voice warning system shall deliver a signal which will give at least 85 percent word intelligibility during the noisiest anticipated environment. XR-C-1

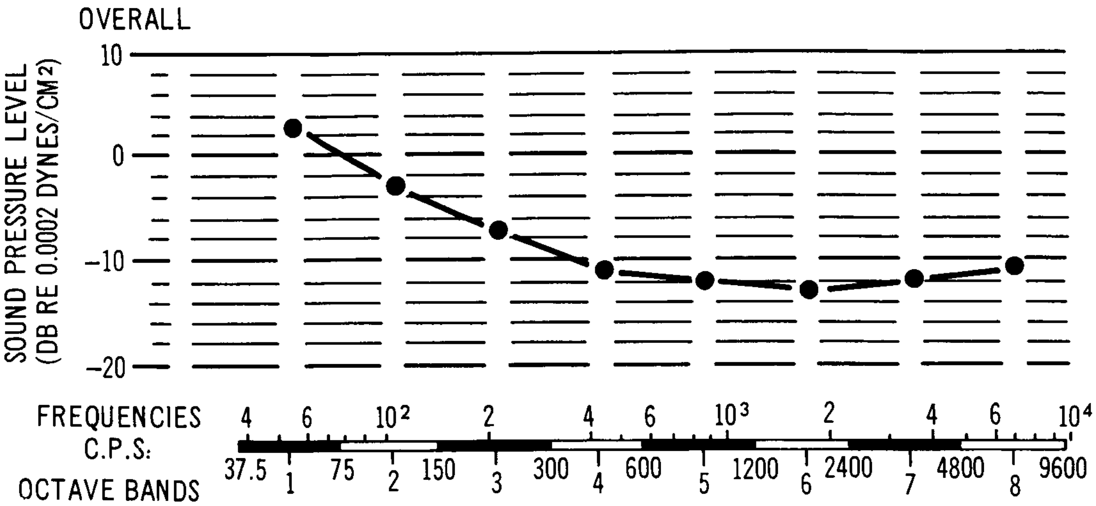


Figure 94. Minimum allowable difference in intensity level between a pure tone and ambient noise for the pure tone to be just audible SPL's vs. octave bands.

5.7.3.4 Environmental toxicity. - All atmospheric contaminants are toxic if introduced into the body in amounts greater than some threshold value, but even for amounts that might be subthreshold, contaminants are toxic if present in the body in abnormal concentrations, including substances that are normally present in the body. For this reason, it is not possible to select any particular biological parameter for relation to engineering variables. Each substance must be treated in terms of its own threshold value and its bodily effects. In all cases both concentration and time of exposure are the critical conditions. (Aero Medical Assoc., 27). XR-S-2

5.7.3.4.1 Carbon dioxide (CO_2). - Most atmospheric contaminants result from industrial or automotive processes and are subject to engineering control. An exception is carbon dioxide, which might be an industrial residue but which also is introduced into the air as a product of body metabolism. For prolonged, continuous exposure to CO_2, a maximum concentration of about 1 percent is recommended. (Aero Medical Assoc., 27). XR-S-2

5.7.3.4.2 Carbon monoxide (CO). - Carbon monoxide is odorless and cannot be detected by the human sense of smell. It is present in the atmosphere as a result of incomplete combustion almost everywhere that people are found but especially in industrialized areas. (Aero Medical Assoc., 27). XR-S-2

Major sources of CO are:

(a)	Water gas	40 perce-
(b)	Industrial blast furnaces	30 percent
(c)	Artificial illumination gas	25 percent
(d)	Gasoline--engine exhaust	7 percent
(e)	Coal gas	5 percent

5.7.3.4.3 Other contaminants. - Example of CO may be taken as representative of the action of some other chemical asphyxiants. CO_2 is a simple asphyxiant in that its effects are produced simply by displacing oxygen in inspired air. Other simple asphyxiants; eg, helium--HE, hydrogen-H_2, nitrogen-N_2, methane-CH, ethylene-C_2H_4, and nitrous oxide-NO, act in the same manner as carbon dioxide. (Aero Medical Assoc., 27). XR-S-2

A brief list of common toxic agents and their maximum allowable cc :ntrations is presented in Table XXVI. See 5.5.2.1.4

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MAINTAINABILITY 5.8

Placement of structural members shall not prevent access	5.8.4.2.4
Throwaway assemblies require no other removal	5.8.4.2.5
Protect adjacent components during maintenance	5.8.4.2.6
Mounting of units: consider,	5.8.4.3
Code interchangeable units	5.8.4.3.1
Arrange in logical order, if possible	5.8.4.3.2
Frequently used components easily accessible	5.8.4.3.3
Provide guide pins for alignment	5.8.4.3.4
Provide limit stops for racks and drawers	5.8.4.3.5
Unit removal: straight rather than at an angle	5.8.4.3.6
Extensions: design for easy removal	5.8.4.3.7
Follow standard orientation from rack to rack	5.8.4.3.8
Only interconnecting wire and struts shall be permanent	5.8.4.3.9
Location of meters: up front, if possible	5.8.4.3.10
Operating conditions: consider,	5.8.4.4
Requirement for protective garments: see 5.7.3	5.8.4.4.1
Requirement for environment factors: see 5.7.1	5.8.4.4.2
Access requirements: consider,	5.8.5
Justification: accessibility a prime maintainability problem	5.8.5.1
Application: access shall be provided to all points	5.8.5.2
Identify type, size, shape and location of access	5.8.5.3
Equipment design: consider,	5.8.5.4
Packaging: see text	5.8.5.4.1
Provide adequate visibility through access	5.8.5.4.2
Design for accessibility	5.8.5.4.3
Design for no interference in access removal covers	5.8.5.4.4
Design for ease of unit removal	5.8.5.4.5
Design for visual inspection	5.8.5.4.6
Provide edge protection	5.8.5.4.7
Consider safety precautions	5.8.5.4.8
Provide interlocks, where required	5.8.5.4.9
Provide for service equipment	5.8.5.4.10

Tanks: see text	5.8.5.4.11
Access covers shall be self-supporting	5.8.5.4.12
Provide rear accesses, when required	5.8.5.4.13
Provide instructions, where required	5.8.5.4.14
One unit shall not hinder removal of another	5.8.5.4.15
Design for one man maintenance, if possible	5.8.5.4.16
Location of accesses: consider,	5.8.6
Access criteria: consider,	5.8.6.1
Position where accessible	5.8.6.1.(a)
Permit direct access	5.8.6.1.(b)
Avoid accesses near danger zones	5.8.6.1.(c)
Design heavy units to be pulled rather than lifted	5.8.6.1.(d)
Size of accesses: consider,	5.8.6.2
General: provide adequate access	5.8.6.2.1
Number: use one large, rather than many small	5.8.6.2.2
Provide easy access to test points	5.8.6.2.3
One-hand access: see fig. 99; tables XXXIII, XXXIV, XXXV, XXXVI, XXXVII	5.8.6.2.4
Specific one-hand access: see figs. 99 and 100; table XXXVIII	5.8.6.2.5
Two-hand access: see fig. 100	5.8.6.2.6
Specific two-hand access: see figs. 100 and 101	5.8.6.2.7
Size and weight of removable units: consider,	5.8.7
Design for one man carry, if possible	5.8.7.1
Weight of unit preferred: 30 to 45 pounds	5.8.7.2
Weight of unit (heavy): see table XXXIX	5.8.7.3
Lifting height: less than 5 feet: see table XXXIX	5.8.7.4
Handles: over 45 pounds, provide handles	5.8.7.5
Removable drawers: see 5.8.7.2	5.8.7.6
Labelling: label all two man lift equipment	

Lubrication: consider,	5.8.8
Lifetime lubrication preferred	5.8.8.(a)
Provision to lube without disassembly	5.8.8.(b)
Label lubrication requirements	5.8.8.(c)
Locate oil dipsticks prominently	5.8.8.(d)
Locate replenishing points prominently	5.8.8.(e)
Locate drain points prominently	5.8.8.(f)
Position drain points so waste container can be provided	5.8.8.(g)
Fasteners: consider,	5.8.9
Standardize wherever possible	5.8.9.1
Design: see figs. 102 and 103	5.8.9.2
Specific fastener design: consider,	5.8.9.3
Provide deep slots	5.8.9.3.1
Provide wrenching clearance	5.8.9.3.2
Minimize bolt length	5.8.9.3.3
Surface mount bolts	5.8.9.3.4
Provide threaded nut plates, preferred	5.8.9.3.5
Quick-opening captive fasteners: one turn to open	5.8.9.3.6
Latch locks: spring load	5.8.9.3.7
Latch-handle: may be used	5.8.9.3.8
Quick-release clamps: for holding wires, tubing and hoses	5.8.9.3.9
Positioning of fasteners: consider,	5.8.9.4
Locate from internal corners	5.8.9.4.(a)
Space adequately	5.8.9.4.(b)
Locate to not interfere with adjoining equipment	5.8.9.4.(c)
Cover fasteners: consider,	5.8.9.5
Hinged covers preferred	5.8.9.5.1
Standardize	5.8.9.5.2
Captive fasteners may be used	5.8.9.5.3
Latches are preferred	5.8.9.5.4
Tools: consider,	5.8.10
Variety of tools: keep to a minimum	5.8.10.1
Provide non-sparking tools, where required	5.8.10.2

Provide non-conductive handles, where required	5.8.10.3
Avoid special tools, if possible	5.8.10.4
Handles: consider,	5.8.11
Handle design: see text	5.8.11.1
Type of handle: see fig. 104	5.8.11.2
Handle dimensions: see table XLI	5.8.11.3
Handle location (general): consider,	5.8.11.6
Guard against actuation of controls	5.8.11.6.(a)
Protect delicate parts of instrument face	5.8.11.6.(b)
Serve as locking device	5.8.11.6.(c)
Serve as protective support	5.8.11.6.(d)
Handle location (specific): consider,	5.8.11.7
Single handle over center of gravity	5.8.11.7.(a)
Two handles: at equal intervals	5.8.11.7.(b)
Placement: do not interfere with equipment	5.8.11.7.(c)
Clearance: 2.5 inches	5.8.11.7.(d)
Position: on front of panel to be pulled	5.8.11.7.(e)
Design for comfort	5.8.11.7.(f)
Handles will not interfere with carrier	5.8.11.7.(g)
Covers and cases: consider,	5.8.12
Orientation: shall be obvious	5.8.12.1
Case design: see fig. 105	5.8.12.2
Case size: adequate for easy clearance	5.8.12.3
Provide guides, tracks and stops	5.8.12.4
Opening procedure shall be obvious	5.8.12.5
Provide hinging, if possible	5.8.12.6
Securing required shall be obvious	5.8.12.7
Avoid sharp edges	5.8.12.8
Provide rests and stands, where required	5.8.12.9
Conductors: consider,	5.8.13
Wires shall be bound in cables	5.8.13.1
Long cables shall be secured by clamps	5.8.13.2

Cable routing: use grommets	5.8.13.3
Provide cable protection: see fig. 106	5.8.13.4
Input-output cables do not terminate at panel face	5.8.13.5
Provide receptacles for test cables	5.8.13.6
Color coding may be used	5.8.13.7
Connectors: consider,	5.8.14
Provide easy disconnect	5.8.14.1
Connector spacing: see fig. 107	5.8.14.2
Position for easy test and service	5.8.14.3
Provide self-alignment pins	5.8.14.4
Align in standardized manner	5.8.14.5
Design so interchange of connectors is not possible	5.8.14.6
Provide captive caps for protection	5.8.14.7
Provide adequate identification: see fig. 108	5.8.14.8
Use female sockets as "hot" sockets	5.8.14.9
Provide high voltage protection	5.8.14.10
Provide adequate grounding	5.8.14.11
Test points: consider,	5.8.15
Primary test points: consider,	5.8.15.1
Provide test points where not self checking	5.8.15.1.(a)
Primary test points to indicate malfunction only	5.8.15.1.(b)
Distinguish between primary and secondary test points	5.8.15.1.(c)
Sequence test points if possible	5.8.15.1.(d)
Adjustment test points shall be near display and control	5.8.15.1.(e)
Avoid test points at side of cabinets	5.8.15.1.(f)
Secondary test points: consider,	5.8.15.2
Provide input-output check, where possible	5.8.15.2.(a)
Provide sufficient test points to prevent component removal	5.8.15.2.(b)
Identify each test point	5.8.15.2.(c)
Built in test equipment: consider,	5.8.15.3
Provide adequate built in test to insure trouble shooting	5.8.15.3.(a)
Portable test box may be used. See fig. 109	5.8.15.3.(b)
Individual meters may be used but are not preferred	5.8.15.3.(c)

Labelling: consider,	5.8.16
Usage: consider,	5.8.16.1
All units and parts shall be labelled	5.8.16.1.(a)
Structural members will be labelled	5.8.16.1.(b)
Special instructions shall be provided	5.8.16.1.(c)
Information shall be consistent in instructions and manuals	5.8.16.1.(d)
Label placement: consider,	5.8.16.2
Labels shall be protected	5.8.16.2.(a)
Labels shall be similarly located	5.8.16.2.(b)
Labels shall read horizontally	5.8.16.2.(c)
Labels shall be placed where they can be seen: see fig. 110	5.8.16.2.(d)

5.8 Maintainability.

5.8.1 Maintainability definition. - The term maintainability refers to the design of equipment for ease of servicing, calibration, repair and replacement. The maintainability of equipment may be considered as a measure of the ease with which the equipment can be kept in operating condition. In the design of earth launch systems, consideration shall be given to the design for ease of maintenance. XR-C-1

5.8.2 Types of maintenance. - Design for maintainability shall consider all of the four types of maintenance likely to be used on the equipment. The analysis of the task shall be sufficient to determine the requirements for the following: XR-C-1

(a) Regularly scheduled preventive maintenance tasks

(b) Testing

(c) Trouble shooting

(d) Replacement or repair of components and units

5.8.3 Maintenance criteria.

5.8.3.1 Design for ease of maintenance. - The design of equipment shall include features to ease all of the maintenance tasks that will have to be performed. XR-C-1

5.8.3.2 Reliability of components. - The designer shall be responsible for the selection of components of high reliability. XR-C-1

5.8.3.3 Component arrangement. - Components shall be arranged in such a manner that maintenance and repair can easily be performed. XR-C-1

5.8.3.4 Early design. - Maintenance criteria shall be arranged in the earliest possible stages of the planning. To successfully design for maintainability, the engineer should obtain the following information: XR-C-1

(a) Information about operational equipment similar to the proposed equipment in design.

(1) A listing of the maintenance features used.

(2) A listing of problems in maintenance of the system.

(b) Specific function of the equipment in the system.

(c) The exact location of the equipment in the system.

(d) Structural members that may limit access or space available for the equipment. Design shall attempt to overcome this reduction in maintenance efficiency.

(e) The test equipment and tools that will be needed to maintain the equipment.

(f) The types of maintenance men who will be available to care for the equipment. The lower the skill level the maintenance crew will have, the more need for assistance from the engineer.

(g) The work and storage areas to be used for the equipment and support gear.

(h) The level of maintenance that will be done at the use location.

(i) The reliability of the components and the entire unit.

5.8.4 Specific maintainability criteria.

5.8.4.1 Unitization.

(a) Unless structurally or functionally unfeasible, all equipment shall be designed in such a manner that rapid and easy removal and replacement of malfunctioning units can be accomplished.
XR-C-1

(b) Unitization of system equipment shall be carried at least to the level of the diagnostic capability of the test equipment or operator. That is, if the capability exists to isolate a malfunction of a part, component, or assembly of the equipment in its normal operation conditions, then that component, or part of the assembly shall be packaged so as to be quickly and easily removed and replaced. Unitization to a lower level than that specified above may be desirable for purposes of bench maintenance.

(c) Units serving the same function in different applications shall be designed to be interchangeable, whenever posiible. XR-C-2

(d) Functions shall be so unitized that it is possible to adjust each unit separately, where consistent with maintenance concepts. XR-C-2

(e) Test points shall be located so that input and output of each unit may be checked separately whenever possible. XR-C-2

5.8.4.2 Location of components.

5.8.4.2.1 Orderly array. - Parts shall be mounted in an orderly array on a two-dimensional surface and not stacked one on another, ie, the lower layer not supporting the upper layer of units. See figure 95. XR-C-2

5.8.4.2.2 Large components. - Large manufactured parts which are difficult to remove shall be so mounted that they do not prevent convenient access to other parts. XR-C-2

5.8.4.2.3 Space for test equipment. - Sufficient space shall be provided so that test equipment and other required tools can be used without difficulty or hazard due to moving mechanical parts, high voltages, toxic or corrosive chemicals, or extreme temperatures. XR-C-2

5.8.4.2.4 Placement of structural members. - Structural members of the units and chassis shall not prevent access to other components. XR-C-2

5.8.4.2.5 Throwaway assemblies. - All throwaway assemblies or parts shall be accessible without removal of other components. XR-C-2

5.8.4.2.6 Adjacent components. - Adjacent components shall not be damaged while the repaired unit is being repaired or maintained. XR-C-2

5.8.4.3 Mounting of units.

5.8.4.3.1 Code interchangeable units. - All interchangeable units shall be coded (keyed) so that it is physically impossible to insert a wrong unit. XR-C-1

5.8.4.3.2 Array. - Where possible units should be laid out so that a minimum of place-to-place movement is required of the operator during checkout. XR-A-3

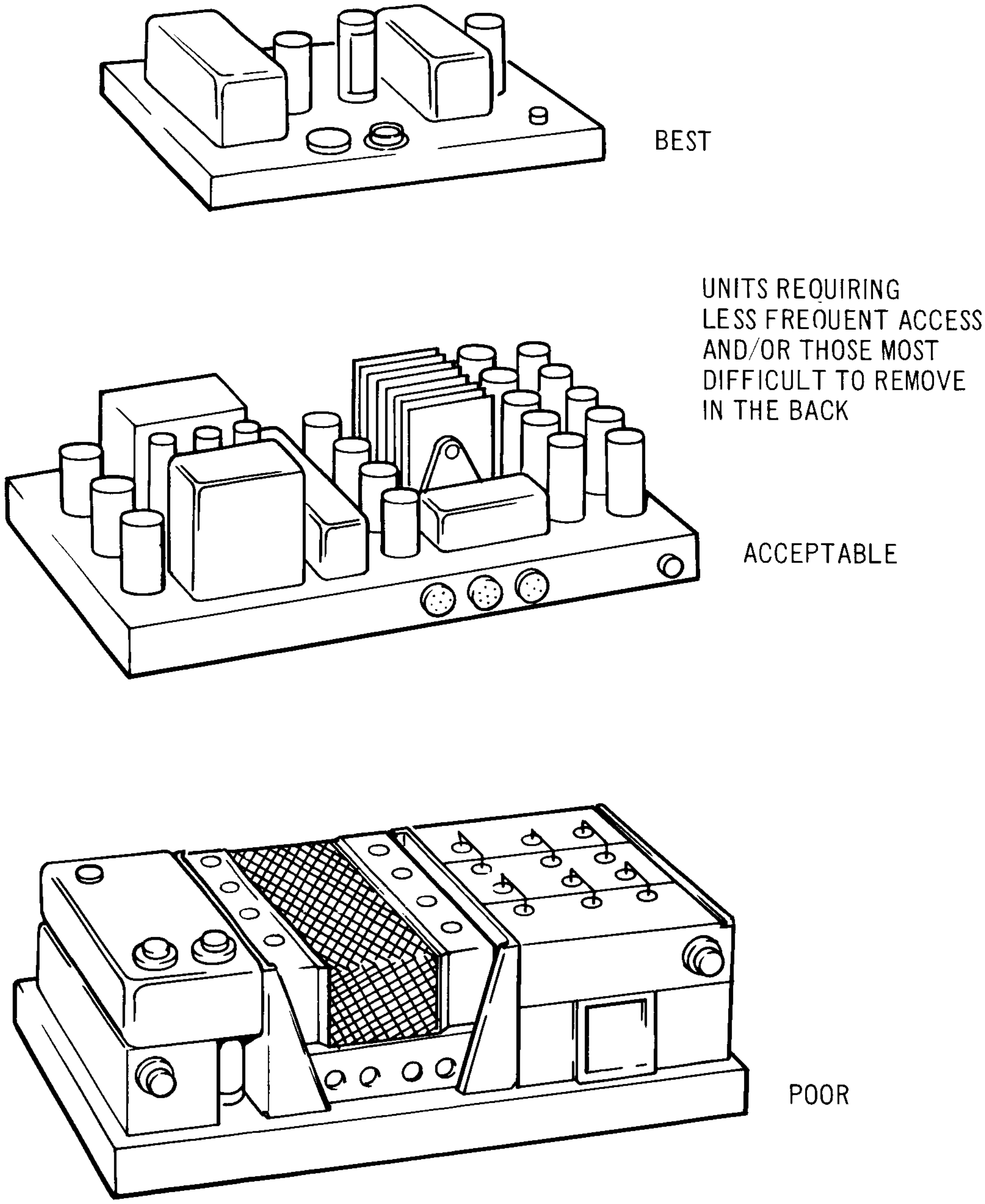


Figure 95. Mounting of units

5.8.4.3.3 Frequency. - Units which are frequently pulled out of their installed position for checking shall be mounted on roll-out racks, slides, or hinges (where weight is not critical). XR-C-2

5.8.4.3.4 Guide pins. - Guide pins or their equivalent shall be provided on units for alignment during mounting. XR-C-1

5.8.4.3.5 Limit stops. - Limit stops shall be provided on roll-out racks and drawers. Override of these limit stops shall be conveniently accomplished. XR-C-2

5.8.4.3.6 Unit removal. - Units shall be removable along a straight or slightly curved line rather than through an angle. XR-C-2

5.8.4.3.7 Extensions. - Irregular, fragile, or awkward extensions, such as cables, wave guides, hoses, etc, shall be easily removable before the unit is handled. XR-C-2

5.8.4.3.8 Standard orientation. - Components of the same or similar form, but of different functional properties (eg; vacuum tubes), shall be mounted with a standard orientation through the unit, but shall be readily identifiable, distinguishable, and not physically interchangeable. See figure 96. XR-C-1

5.8.4.3.9 Mounting. - Only interconnecting wiring and structural members shall be permanently attached to the unit chassis. All parts shall be mounted on or as subassemblies. XR-C-2

5.8.4.3.10 Location of meters. - Meters, readouts, counters and other components which are subject to periodic calibration shall be installed in such a way that they can be easily removed, preferably from the panel front. Where feasible, connection to the rest of the circuitry by crimping, soldering or other permanent means shall be avoided. XR-C-2

5.8.4.3.11 Periodically tested components. - See 5.8.15 for details.

5.8.4.4 Operating conditions. - Men and equipment are affected by their environment. The designer shall assume that the equipment will be maintained at the extremes of the possible environmental conditions, and shall provide features to facilitate maintenance under such conditions. See 5.5.1, 5.5.2, 5.7.1 and 5.7.2 for details. XR-C-1

5.8.4.4.1 Protective garments. - The requirement for protective garments shall be reflected in more generous access and work space dimensions. See 5.7.3. XR-C-2

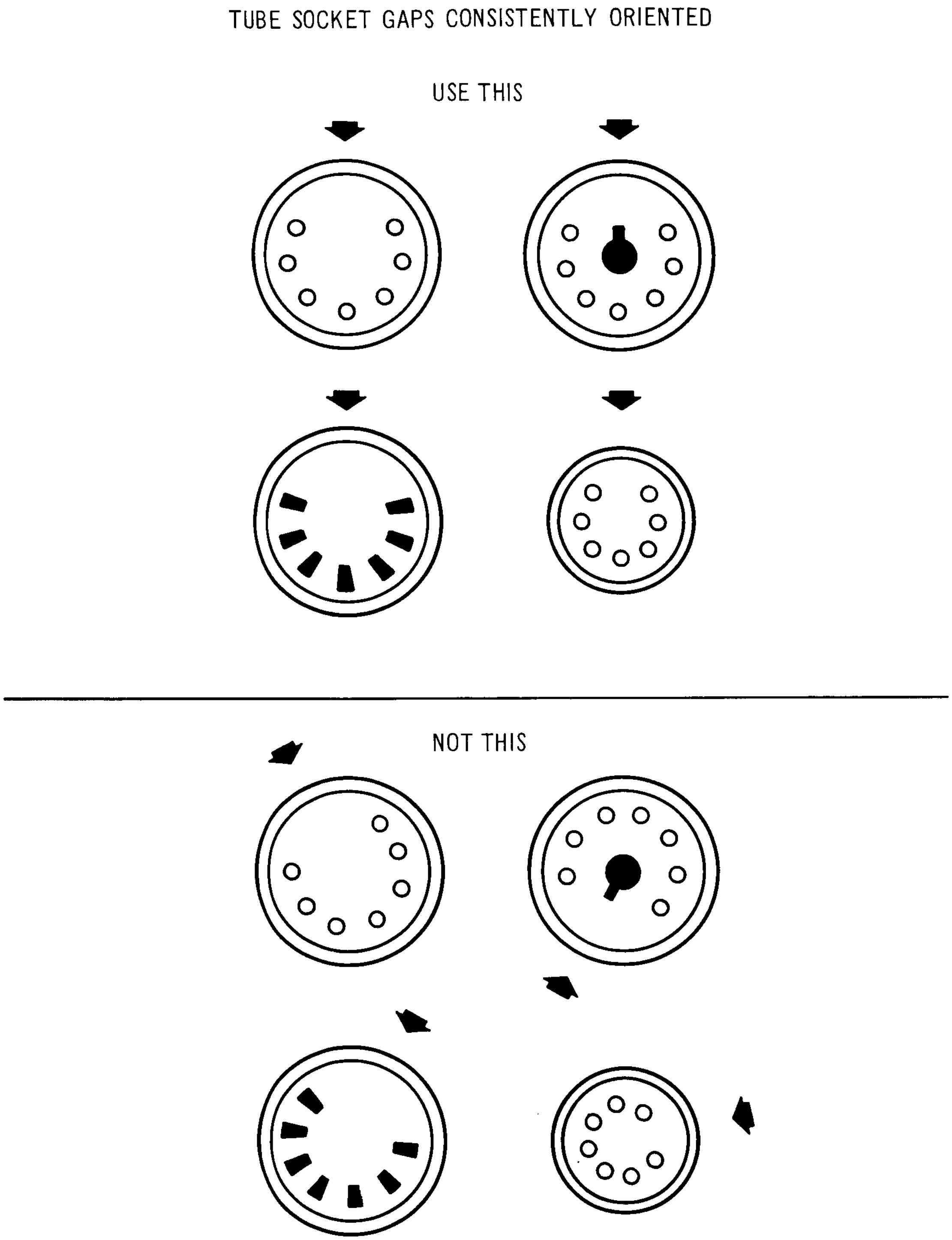


Figure 96. Standard orientation of components

5.8.4.4.2 Environmental factors. - Those environmental factors that cannot readily be controlled shall be compensated for in the design. See 5.7.1. XR-C-1

(a) Extreme cold shall require increases in access dimensions to accommodate heavy clothing. XR-C-2

(b) Humidity and heat may require larger knob and control sizes and texturing to reduce effects of perspiration. XR-C-2

(c) Variations in illumination and contrast may require supplementary sources of lighting. See 5.6.1 for details. XR-C-2

5.8.5 Access requirements.

5.8.5.1 Justification. - Accessibility shall be considered a prime maintainability problem. Ineffective maintenance is often the result of inaccessibility. Maintenance personnel will tend to delay or omit maintenance actions, to make mistakes, and to accidentally damage equipment, if they cannot adequately see, reach and manipulate the items on which they must work. XR-C-1

5.8.5.2 Application. - Access shall be provided to all points, items and components which require or may require testing, servicing, adjusting, removal, replacement or repair. XR-C-1

5.8.5.3 Design considerations. - The type, size, shape, and location of access shall be based upon a thorough understanding of the following required information:

(a) Operational location, setting and environment of the unit. XR-C-2

(b) Frequency with which the access route must be used. XR-C-2

(c) Maintenance functions to be performed through the access route. XR-C-2

(d) Time requirements for the performance of these functions. XR-C-2

(e) Types of tools and accessories required by these functions. XR-C-2

(f) Work clearances required for performance of these functions. XR-C-2

(g) Type of clothing likely to be worn by the technician. XR-C-2

(h) Distances to which maintenance personnel must reach within the access. XR-C-2

(i) Visual access requirements of personnel in performing the task. XR-C-2

(j) Packaging of items, elements and units behind the access. XR-C-2

(k) Mounting of items, units and elements behind the access. XR-C-2

(l) Hazards involved in or related to use of the access. XR-C-2

(m) Size, shape, weight and clearance requirements of logical combinations of the human body, and tools, units and other equipment that must use the access route. XR-C-1

5.8.5.4 Access requirements (specific).

5.8.5.4.1 Equipment design. - The equipment shall be designed for overall accessibility where required and where possible. XR-C-1

(a) Split-line design (convenient line disconnects) shall be provided. XR-C-2

(b) Hinged or removable chassis shall be used. See figure 97.

(c) Major units and assemblies shall be designed with removable housing to make complete inspections possible. XR-C-2

(d) Spacecraft or missile skin shall be hinged for ease of access to assemblies and accessories during major checkouts, turn-around, etc. XR-C-2

(e) The design of unit accessibility features shall be correlated with the accessibility requirements of the overall system. XR-C-2

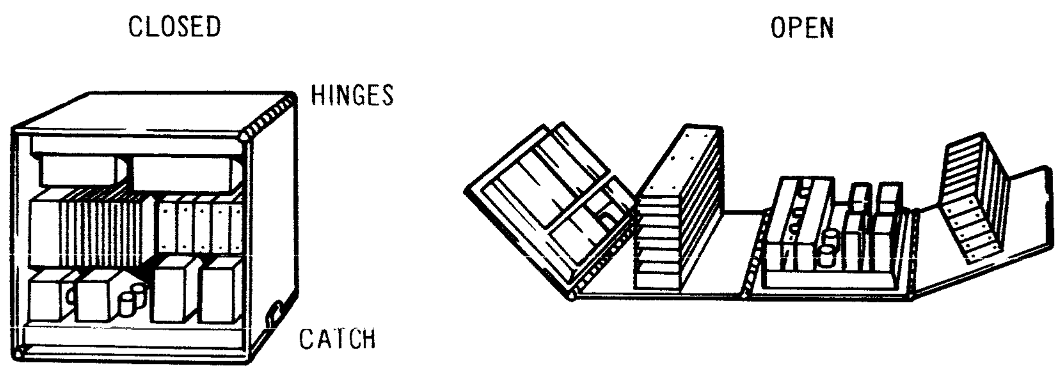


Figure 97. Fold-out construction

5.8.5.4.2 Visibility. - Check points, adjustment points, cables and connectors, and labels shall be accessible for easy observance. XR-C-1

5.8.5.4.3 Accessibility. - Accesses shall be designed, located, covered, and fastened in such a manner as to avoid the necessity for removing components, wires, etc., to reach the item requiring maintenance. XR-C-1

5.8.5.4.4 Interference. - Bulkheads, brackets, other units, etc, shall not interfere with removal or opening of covers of units within which work must be done. XR-C-2

5.8.5.4.5 Unit removal. - Design so that the removal of any replaceable unit shall require opening of only one access, unless the accesses are of the latched and hinged door type. XR-C-2

5.8.5.4.6 Visual inspection. - Items requiring only visual inspection (hydraulic reservoirs, gauges, etc) shall be located so that they can be observed without the removal of panels or other components. XR-C-1. Where a protective cover is required, the following factors shall be considered: See figure 98.

(a) An opening with no cover shall be used unless this is likely to degrade system performance. XR-C-1

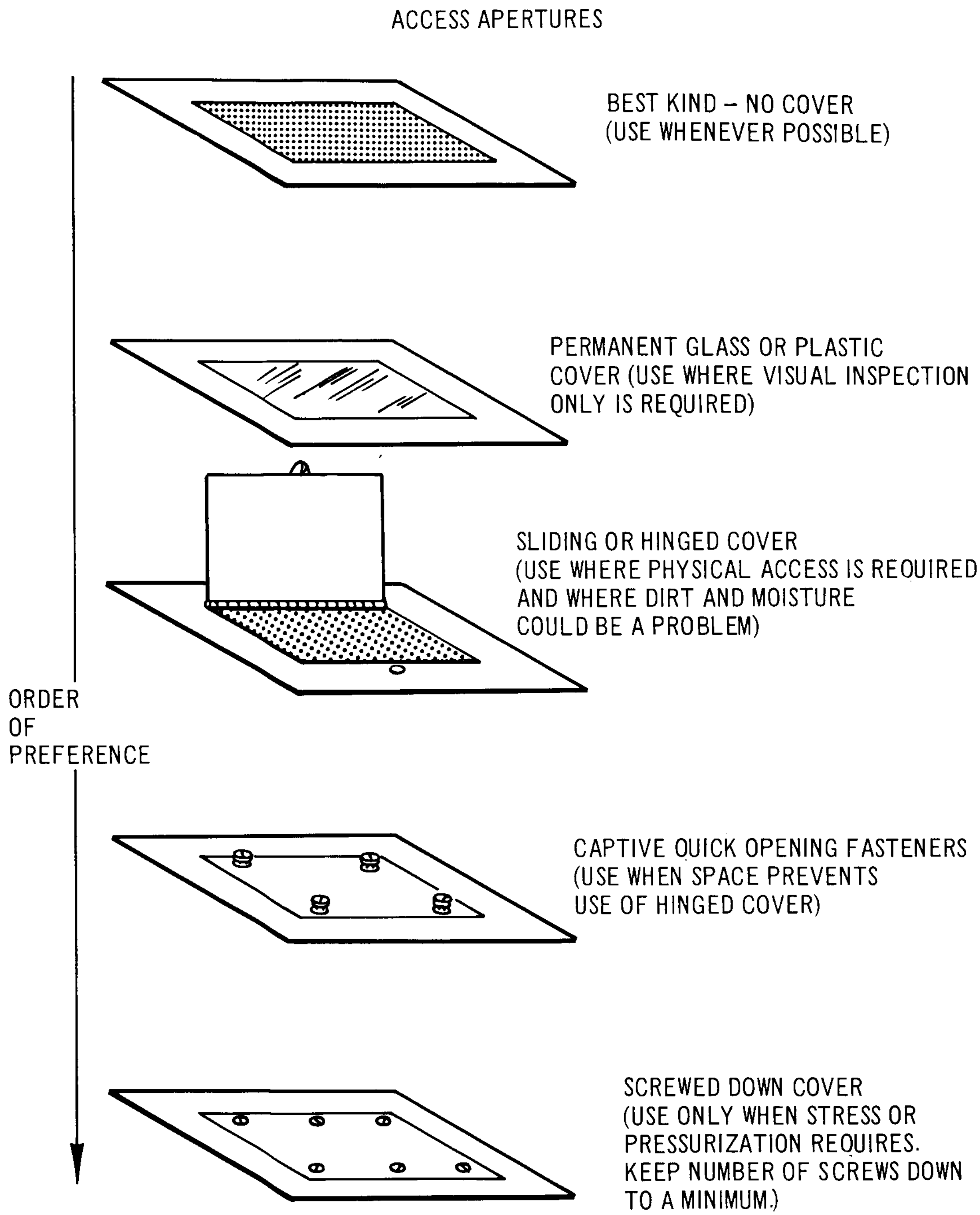


Figure 98. Access and inspection openings

(b) A plastic window shall be used if dirt, moisture, or other foreign materials are a problem. XR-C-1

(c) A break-resistant glass window shall be used if physical wear, heat or contact with solvents will cause optical deterioration of a plastic window. XR-C-1

(d) A quick-opening metal cover shall be used if glass will not meet stress or other requirements. XR-C-1

5.8.5.4.7 Edge protection. - The edges of accesses shall be lined with internal fillets or other suitable protection wherever sharp edges might otherwise injure personnel or equipment such as hoses. XR-C-2

5.8.5.4.8 Safety. - Where accesses are located over unavoidable dangerous mechanical or electrical components, design the access door so that when opened, an internal light shall illuminate. A warning label shall be provided on the door. XR-C-1

5.8.5.4.9 Interlocks. - Safety interlocks shall be incorporated on accesses leading to equipment with high voltages. If the equipment circuit must be on during maintenance, provide a cheater switch that automatically resets when the access is closed. XR-C-1

5.8.5.4.10 Service equipment. - Where access for tools, test leads, and service equipment is required, the following practices shall be observed (in order of preference): XR-C-1

(a) Use an opening with no cover unless this is likely to degrade system performance. XR-C-1

(b) Use a sliding or hinged cap if dirt, moisture, or other foreign materials are a problem. XR-C-1

(c) Use a quick-opening cover plate if a cap will not meet stress requirements. XR-C-1

5.8.5.4.11 Tanks. - Self-sealing tanks shall be provided with an access of such size and location that the entire interior of the tank is available for inspection, cleaning, or other maintenance without removal of the tank. XR-C-2

5.8.5.4.12 Access covers. - All access covers which are not completely removable shall be self-supporting in the open position. XR-C-1

5.8.5.4.13 Rear access. - Sliding, rotating, or hinged units to which rear access is required shall be free to open or rotate their full distance and remain in the open position without being supported by hand. XR-C-1

5.8.5.4.14 Instructions. - If lettered instructions relating to a covered unit are required on or adjacent to a hinged door, the lettering shall be properly oriented for reading when the door is open. XR-C-1

5.8.5.4.15 Multiple units. - Wherever possible, units shall be so located that no other equipment must be removed to gain access to or remove the unit. When necessary to place one unit behind another, the unit requiring most frequent access shall be most accessible to the user. XR-C-1

5.8.5.4.16 Two-man maintenance. - Access to units maintained by one operator shall not require removal of equipment maintained by a second operator, when such equipment is of critical nature and its maintenance requires highly specialized skill. XR-C-2

5.8.6 Location of accesses.

5.8.6.1 Access criteria. - Access openings shall be located:

(a) Only on unit faces that will be accessible in normal installation. XR-C-1

(b) To permit direct access and maximum convenience for job procedures. XR-C-1

(c) Away from extreme temperatures, high voltages, or dangerous moving parts. If not possible, adequate insulation, shielding, or guards shall be provided around such parts to prevent injury to personnel. XR-C-2

(d) So that heavy units will be pulled out rather than lifted out. XR-C-2

(e) In accordance with the work space requirements in 5.5.2. XR-C-1

5.8.6.2 Size of accesses.

5.8.6.2.1 General requirements. - Make accesses whatever size and shape is necessary to permit easy passage of the required items, body parts, tools or equipment. XR-C-1

5.8.6.2.2 Number of accesses. - One large access shall be preferable to two small ones; but where structural or other considerations require separation, visual and physical access may be provided separately. XR-C-1

5.8.6.2.3 Supplementary accesses. - Where stress doors are employed or access covers are otherwise difficult to remove, provide a smaller access to frequently used test or service points. XR-C-2

5.8.6.2.4 One-hand access. - One-handed access openings shall conform to the following criteria:

(a) Minimum space requirements for finger access shall follow the requirements listed in figure 99. (MCKendry, 1). XR-S-2

(b) Minimum space requirements for full hand to wrist access shall follow the requirements listed in tables XXXIII, XXXIV, XXXV, XXXVI, and XXXVII, and figure 99. (Altman, 2; McKendry, 1). XR-S-2

(c) Minimum space requirements for full hand beyond wrist access shall follow the requirements listed in figure 100. (Altman, 2). XR-S-2

5.8.6.2.5 Specific one-hand access.

(a) Minimum space for inserting empty hand held flat shall be 2 1/4 by 4 inches. See figure 99. (Hertzberg, 3). XR-S-2

(b) Minimum space for inserting empty hand through square hole shall be 3 1/2 by 3 1/2 inches. (Hertzberg, 3). XR-S-2

(c) Minimum space for inserting a miniature vacuum tube, held with the thumb and first two fingers, up to the center knuckle of the middle finger, shall be 2 by 2 inches. XR-C-1

Table XXXIII.

Space envelope for plug-in operations
(tubes of various sizes removed and replaced)

DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH		RIGHT WIDTH		UP		DOWN	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1 INCH	1.19	.56-2.05	1.69	1.18-2.45	1.23	.41-1.91	1.31	.41-2.66
2 INCHES	1.43	.68-2.40	2.04	1.41-2.68	1.74	.75-2.91	1.64	.83-3.33
3 INCHES	1.53	.68-2.40	2.23	1.90-2.56	2.06	1.16-3.25	1.70	.83-3.41
4 INCHES	1.59	.62-2.35	2.24	1.75-2.81	2.30	1.58-3.75	1.55	.66-3.16
5 INCHES	1.58	.56-2.30	2.16	1.37-2.87	2.46	1.50-3.91	1.30	.41-2.66
6 INCHES	1.55	.56-2.30	2.07	.87-2.75	2.56	1.80-3.91	1.08	.25-2.50

Table XXXIV.

Space envelope for grasping and turning tools
(pliers and wire cutters)

DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH		RIGHT WIDTH		UP		DOWN	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1 INCH	1.64	.50-2.65	1.67	.66-2.25	1.20	.50-1.83	1.69	.66-3.08
2 INCHES	1.96	.68-3.20	2.19	1.18-2.68	1.61	.66-2.16	2.26	1.00-3.16
3 INCHES	2.08	.81-3.50	2.44	1.50-3.12	1.72	.75-2.16	2.66	1.00-2.91
4 INCHES	1.86	.56-3.40	2.49	1.68-3.37	1.74	.83-2.41	1.88	.91-2.41
5 INCHES	1.49	.47-3.20	2.89	1.68-3.00	1.83	1.00-2.50	1.52	.83-2.08
6 INCHES	1.29	.50-2.80	2.36	1.62-2.99	1.83	1.08-2.50	1.40	.66-2.08

Table XXXV.

Space envelope required for using an average-sized socket Allen wrench to remove a knob (2 inches in length)

DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH		RIGHT WIDTH		UP		DOWN	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1 INCH	1.02	.00-1.87	2.95	2.12-4.00	3.36	2.50-4.50	1.79	.33-5.33
2 INCHES	1.12	.00-2.00	3.38	2.12-4.56	3.72	3.00-4.41	2.26	.66-5.41
3 INCHES	1.22	.00-2.13	3.38	2.12-4.35	3.59	3.00-4.08	2.54	.66-5.08
4 INCHES	1.31	.00-2.18	3.07	1.93-3.87	3.31	2.25-3.75	2.50	.66-4.16
5 INCHES	1.36	.00-2.18	2.64	1.62-3.37	2.91	1.25-3.40	2.25	.66-3.83
6 INCHES	1.42	.00-2.13	2.31	1.41-3.12	2.77	1.16-3.41	2.01	.58-3.41

Table XXXVI.

Space envelope required for using an average-sized socket wrench to turn a nut (3/8 inch base with 3-1/4 inch shaft)

DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH		RIGHT WIDTH		UP		DOWN	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1 INCH	2.09	.47-3.20	2.92	2.25-4.30	2.73	2.00-3.75	2.88	2.08-3.33
2 INCHES	2.12	.50-3.35	3.25	2.37-4.55	2.86	1.75-3.75	2.65	1.66-3.41
3 INCHES	2.04	.56-3.31	3.13	2.43-4.35	3.10	1.83-4.25	2.10	1.33-2.50
4 INCHES	1.86	.68-3.18	2.94	2.06-4.35	3.23	2.08-4.41	1.65	1.08-2.08
5 INCHES	1.54	.56-2.81	2.73	1.93-4.35	3.25	2.33-4.08	1.10	0.66-1.75
6 INCHES	1.31	.47-2.50	2.55	1.37-4.25	3.11	2.50-4.16	0.76	0.50-1.25

Table XXXVII.

Workspace for hand tool tasks

TASK	DEPTH OF REACH (Z) (INCHES FROM ACCESS TO WORK POINT)	MAXIMUM SPACE USED AT ANY DEPTH							
		UNCLOTHED ARM				ARCTIC JACKET AND LEATHER GLOVE			
		WIDTH RIGHT	(X)** LEFT	HEIGHT DOWN	(Y) UP	WIDTH RIGHT	(X) LEFT	HEIGHT DOWN	(Y) UP
TURNING BOLT WITH	6	2.0	1.2	2.2	1.7	2.3	1.9	2.3	1.9
COMMON SCREWDRIVER	12	2.3	2.0	2.3	1.7	3.4	3.1	3.1	2.4
(VERTICAL PLANE)	18	2.8	1.8	2.3	2.0	3.8	2.9	3.2	3.8
	24	3.3	1.8	2.3	2.0	3.8	2.5	4.1	2.9
TURNING BOLT WITH	6	2.4	2.2	0.3	8.3	2.8	1.6	0.7	8.6
COMMON SCREWDRIVER	12	2.9	1.4	1.9	8.3	3.2	2.3	2.3	8.4
(HORIZONTAL PLANE)	18	3.4	1.5	2.2	8.3	4.0	2.8	2.8	8.0
	24*								
TURNING BOLT WITH	6	3.8	2.5	3.8	1.1	2.8	4.6	4.4	1.1
OFFSET SCREWDRIVER	12	2.3	4.4	4.1	1.4	2.8	5.3	5.2	2.4
(VERTICAL PLANE)	18	2.7	4.3	4.4	2.9	2.9	5.3	5.4	2.5
	24	3.3	4.2	4.4	1.2	4.0	4.4	4.4	3.1
TURNING BOLT WITH	6	2.5	4.8	1.4	2.8	2.5	4.3	1.5	3.6
OFFSET SCREWDRIVER	12	3.3	4.3	2.1	3.7	3.2	5.2	2.7	3.3
(HORIZONTAL PLANE)	18	3.1	4.2	2.8	3.7	3.7	4.5	2.8	3.8
	24	3.5	4.4	3.4	4.1	3.7	5.3	4.4	3.4
CUTTING WIRE	6	2.3	1.9	1.8	2.2	2.6	2.3	2.4	2.3
(VERTICAL PLANE)	12	2.5	2.0	2.3	2.2	3.7	2.0	3.1	2.4
	18	3.0	2.1	2.3	2.3	3.5	2.9	3.4	2.8
	24	1.9	3.3	3.5	1.7	4.1	3.1	4.2	3.4
CUTTING WIRE	6	2.8	0.6	1.4	2.9	3.1	1.2	3.2	1.8
(HORIZONTAL PLANE)	12	2.7	1.0	2.3	2.1	3.2	2.1	3.2	2.7
	18	2.9	1.5	2.3	3.2	3.6	2.9	3.0	2.8
	24	3.8	1.7	3.7	1.8	4.2	2.9	4.5	2.8

ALL MEASUREMENTS ARE IN INCHES. DEPTH IS ALONG AN IMAGINARY LINE FROM THE CENTER OF THE WORK POINT TO THE CENTER OF THE EXTERNAL ACCESS. HEIGHT AND WIDTH MEASURES ARE TAKEN FROM THE SAME IMAGINARY LINE.

* SUBJECT WAS UNABLE TO REACH THE WORK POINT THROUGH THE ACCESS AT THIS DISTANCE.

** LEFT AND RIGHT DIRECTIONS ARE IN RESPECT TO SUBJECT FACING THE TASK.

ADAPTED FROM ALTMAN 2.

MINIMAL FINGER ACCESS TO FIRST JOINT:

PUSH BUTTON ACCESS:

- Bare Hand: 1.25" dia.
- Gloved Hand: 1.5" dia.

TWO FINGER TWIST ACCESS:

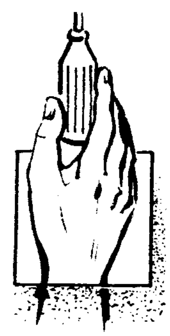
- Bare Hand: 2.0" dia. clearance around object
- Gloved Hand: 2.5" dia. clearance around object

VACCUM TUBE INSERT (tube held as at right):

- Miniature tube: 2.0" dia. clearance around object
- Large tube: 4.0" dia. clearance around object

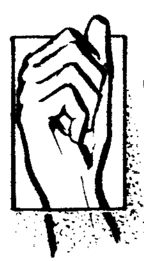
MINIMAL ONE HAND ACCESS OPENINGS:

EMPTY HAND TO WRIST:	WIDTH	HEIGHT
• Bare hand, rolled:	3.75" sq. or dia.	
• Bare hand, flat:	2.25" × 4.0" or 4.0" dia.	
• Glove or mitten:	4.0" × 6.0" or 6.0" dia.	
• Bulky Protective mitten:	5.0" × 6.5" or 6.5" dia.	



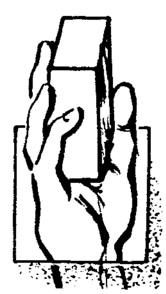
HAND PLUS 1" DIA OBJECT,
TO WRIST:

- Bare hand:
  3.75" sq. or dia.
- Glove or mitten:
  6.0" sq. or dia.
- Bulky Protective mitten:
  7.0" sq. or dia.



CLENCHED HAND TO WRIST:

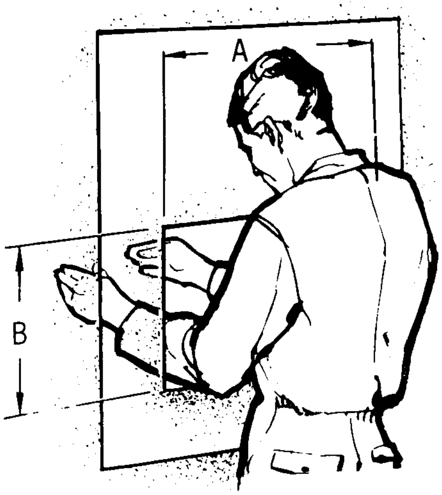
- Bare hand: 3.5" × 5.0" or 5.0" dia.
- Glove or mitten: 4.5" × 6.0" or 6.0" dia.
- Bulky Protective mitten: 7.0" × 8.5" or 8.5" dia.



HAND PLUS OBJECT OVER 1" IN DIA
TO WRIST:

- Bare hand:
  1.75" clearance around object
- Glove or mitten:
  2.5" clearance around object
- Bulky Protective mitten:
  3.5" clearance around object

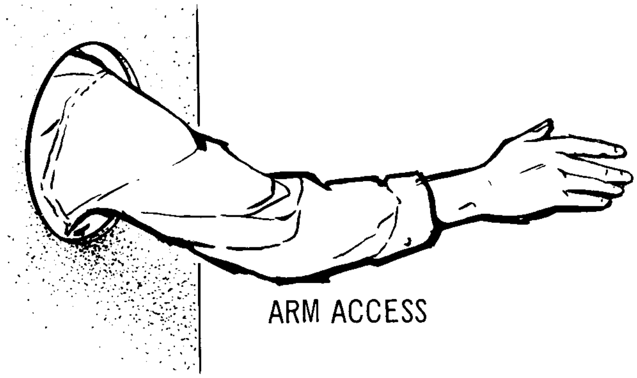
Figure 99. Hand access openings



TWO HAND REACH 6 TO 25 INCHES IN DEPTH

BLIND ACCESS

LIGHT CLOTHING	A	8" OR 75% OF REACH
	B	5"
BULKY PROTECTIVE CLOTHING	A	6" PLUS 75% OF REACH
	B	7"
VISIBLE ACCESS		
	B	22.6"



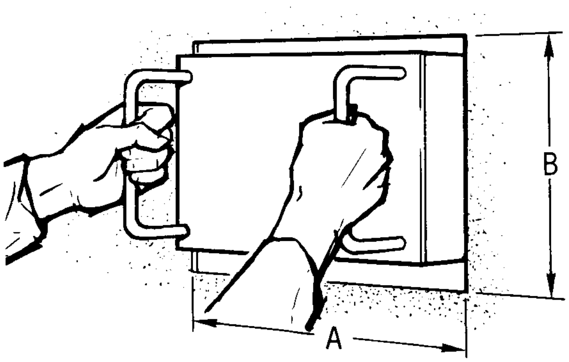
ARM ACCESS

ARM TO ELBOW

LIGHT CLOTHING	4.5" X 4.5" DIA OR 3.5" AROUND OBJECT
BULKY PROTECTIVE CLOTHING	7" X 7" DIA OR 3.5" AROUND OBJECT

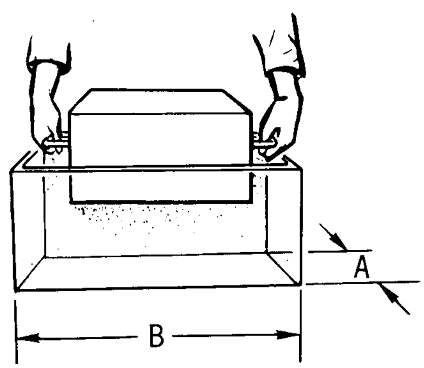
ARM TO SHOULDER

LIGHT CLOTHING	5" X 5", 5" DIA OR 3.5" AROUND OBJECT
BULKY PROTECTIVE CLOTHING	8.5" X 8.5", 8.5" DIA OR 3.5" AROUND OBJECT



INSERT OBJECT WITH HANDLES ON FACE

A	BOX PLUS 1.5"
B	8.5" OR BOX PLUS 1.5" WHICHEVER IS GREATER



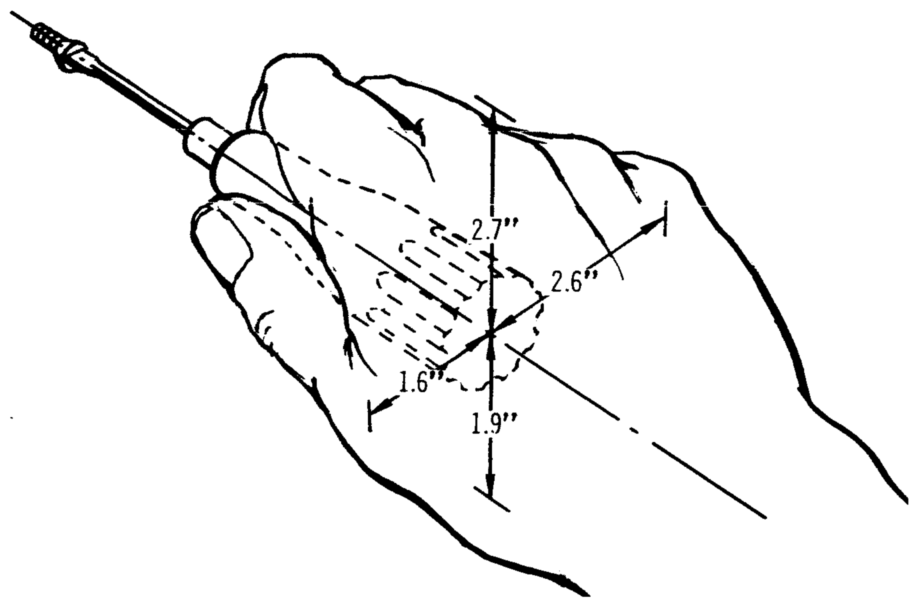
INSERT OBJECT WITH HANDS ON SIDES

A	BOX PLUS 1.5"
B	BOX PLUS 4.5" (LIGHT CLOTHING) BOX PLUS 7" (BULKY PROTECTIVE CLOTHING)

Figure 100. Work space requirements

Table XXXVIII.

Space envelope for tools which require hand rotation (screw drivers, spintites)



DISTANCE FROM END OF FINGERS	HORIZONTAL AXIS				VERTICAL AXIS			
	LEFT WIDTH MEAN RANGE		RIGHT WIDTH MEAN RANGE		UP MEAN RANGE		DOWN MEAN RANGE	
1 IN.	1.16	.68–2.00	1.90	1.37–2.50	1.51	.66–2.25	1.26	.50–2.08
2 IN.	1.45	.92–2.25	2.31	1.75–2.85	2.00	1.08–2.91	1.62	.58–2.33
3 IN.	1.49	.93–2.25	2.42	1.88–2.81	2.26	1.25–3.33	1.67	.58–2.58
4 IN.	1.45	.65–2.20	2.40	1.75–3.00	2.39	1.25–3.33	1.52	.58–2.50
5 IN.	1.41	.40–1.95	2.32	1.63–2.95	2.31	1.25–3.50	1.36	.58–2.25
6 IN.	1.31	.35–2.50	2.21	1.68–2.90	2.44	1.83–3.58	1.04	.33–1.83

NOTE:
THE POINTS ARE GIVEN IN INCHES FROM AN IMAGINARY LINE EXTENDING ALONG THE AXIS OF THE TOOL INVOLVED. WHEN ALL FOUR UNDERLINED POINTS ARE PLOTTED ON PERPENDICULAR AXES THEY DESCRIBE THE MAXIMUM AVERAGE VOLUME REQUIRED FOR THE OPERATION. A MORE GENEROUS AND COMFORTABLE ENVELOPE IS DESCRIBED BY USING THE MAXIMUM RANGE VALUES INSTEAD OF THE MAXIMUM MEAN VALUES.

(d) Minimum space for inserting a large vacuum tube (CRC 1625, base diameter 1 3/8 inches, height 4 1/2 inches, excluding pins and grid cap) shall be 4 by 4 inches. XR-C-1

(e) Minimum space for inserting and tightening an AN plug (14 pin connector-outside diameter 1 7/8 inches) shall be 4 by 4 inches. XR-C-1

(f) Minimum space for inserting a box (or electric assembly) shall be the diameter of box plus 1 3/4 inches. XR-C-1

(g) Minimum space for inserting screw drivers shall be in accordance with specifications found in table XXXVIII. (McKendry, 1). XR-S-2

5.8.6.2.6 Two-hand access. - Minimum space for two-hand accesses, reaching with both hands to a depth of 6 to 25 inches, shall conform to or exceed the following: See figure 100. (Altman, 2; McKendry, 1). XR-S-2

(a) Light clothing: 5 inches high by 8 inches or 75 percent depth of reach, whichever is greater.

(b) Bulky protection clothing: 7 inches high by 6 inches plus 75 percent of depth of reach.

(c) For visual contact, height shall be a minimum of 22.6 inches.

(d) Clearances around objects inserted into accesses shall conform to or exceed the clearances in figure 100.

5.8.6.2.7 Specific two-hand access. - The following factors shall be considered:

(a) Inserting a box (or electronic assembly) grasped by handles on front into an aperture, 1 1/2 inch clearance on each side of the box shall be provided. See figure 100. (Altman, 2). XR-S-2

(b) Reaching through aperture with both hands to a depth of 6 to 24 inches, a width of 3/4 inch depth of reach and a height of 4 inches shall be provided. See figure 101. (Altman, 2) XR-S-2

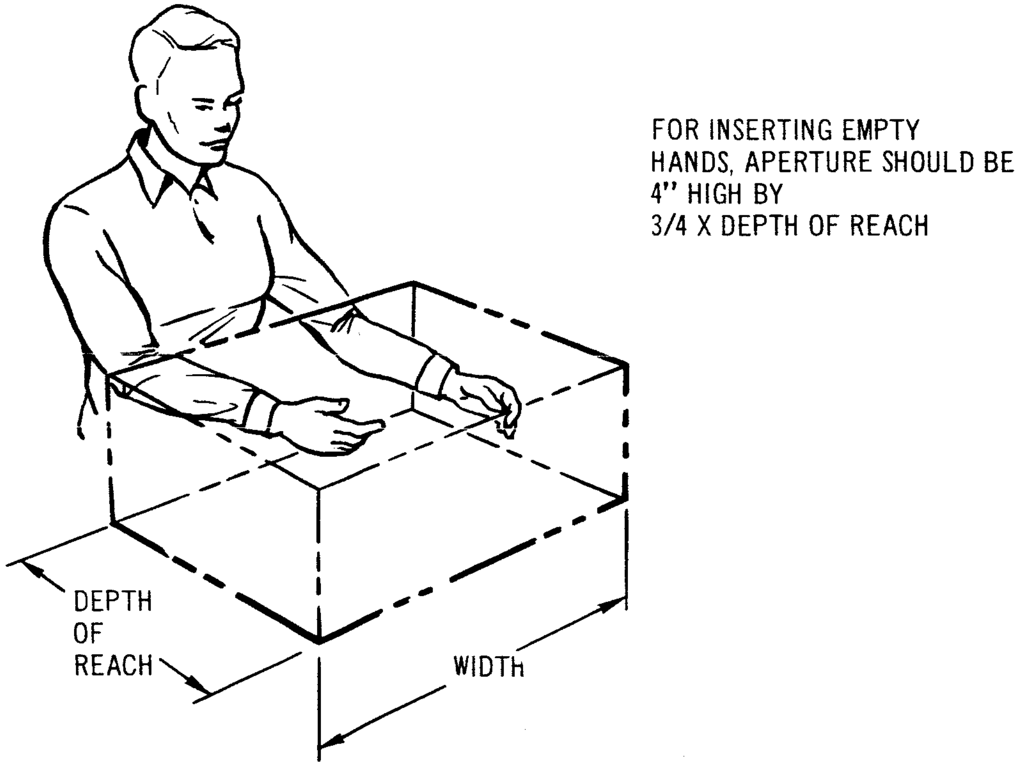


Figure 101. Arm access

(c) Reaching in full arm's length (to shoulders) straight ahead with both arms, a width of 19 1/2 inches and a height of 4 inches shall be provided. (Altman, 2). XR-S-2

5.8.7 Size and weight of removable units. - Removable units shall comply with the following weight criteria: Where exceptions have to be made, refer to standards outlined in 5.4.1.

5.8.7.1 Unit size and weight. - Units shall be small and light enough for one man to handle and carry, unless overriding design considerations exist. XR-C-2

5.8.7.2 Weight of unit: preferred. - Weight of removable units shall be held below 45 pounds for non-vehicle use. For vehicle, use 30 pounds or less. (Emanuel, 4). XR-S-2

5.8.7.3 Weight of unit: heavy. - For units weighing more than 30 (vehicle) or 45 (non-vehicle) pounds, two-man lifting capability shall be provided. See table XXXIX for preferred requirements. (McKendry, 1). XR-S-2

If these values cannot be complied with, see figure 37, section 5.4.2.1.4, for acceptable values.

Table XXXIX.

Two-man lift requirements

WEIGHT (LBS) \ HEIGHT* (IN.)	0–12	13–24	25–36	37–48	49–60	61–72
0–5						
6–10						
11–15						
16–20						X
21–25					X	X
26–30				X	X	X
31–35				X	X	+
36–40			X	X	X	+
41–45			X	X	X	+
46–90	X	X	X	X	X	+

X = USE TWO-MAN LIFT AND LABEL AS SUCH

\+ = USE MECHANICAL LIFT AND LABEL AS SUCH

5.8.7.4 Handles. - All removable units in excess of 30 (vehicle) or 45 (non-vehicle) pounds, but weighing less than 90 pounds, shall have provisions for two-man lifting. (Emanuel, 4). XR-S-2

5.8.7.5 Two-man lifting. - Two-man lifting provisions shall be provided on any removable units weighing less than 30 (vehicle) or 45 (non-vehicle) pounds if any of the following conditions apply. XR-S-2

5.8.7.6 Removable drawers. - For removable drawers of electronic test equipment, provisions for two-man lift shall be included in accordance with 5.8.7.2. XR-S-2

5.8.7.7 Labelling. - All units requiring two-man lift shall be prominently labelled with a label. All units requiring mechanical lifting shall be prominently labelled. XR-C-1

5.8.8 Lubrication. - Mechanical components requiring lubrication shall conform to the following criteria:

(a) Components shall have self-lubrication or life-time lubrication (preferred). XR-C-1

(b) Mechanical components shall have provision for lubrication without disassembly. XR-C-2

(c) When lubrication is required, the type lubricant to be used and the frequency of lubrication shall be specified by a label located at or near the lube port, or within the packaging of the item. XR-C-2

(d) Locate oil dipsticks and other such level indicators so that they may be fully withdrawn without touching other pieces of equipment. XR-C-2

(e) Fluid replenishing points shall be located so that there is little chance of spillage during servicing, and that there is no requirement for special funnels. XR-C-1

(f) Drain points shall be located so that fluid will not drain on personnel or sensitive equipment. XR-C-1

(g) Drain points shall be located to permit fluid drainage directly into a waste container without the use of adapters or piping. XR-C-2

5.8.9 Fasteners.

5.8.9.1 Standardization.

(a) When possible, standard sizes of bolt heads shall be used to reduce number of tool sizes required. XR-C-1

(b) Standardize thread size as much as possible. Bolts or screws which are located adjacent to each other shall be of the same thread type in order to minimize the chance of using the wrong screw or bolt and damaging the thread. XR-C-1

(c) The number of screw head types shall be minimized on a given piece of equipment. XR-C-2

(d) Wherever possible, assemblies and units shall be designed for removal in the field with common hand tools. XR-C-2

(e) Wherever possible, identical screw and bolt heads or other appropriate fasteners shall be used to enable various panels and components to be removed with a single tool. XR-C-2

5.8.9.2 Design considerations.

(a) If compatible with stress, load and pressurization considerations, fasteners for mounting assemblies, subassemblies, etc, shall fasten or unfasten in a maximum of 10 turns. XR-C-2

(b) Hand-operated fasteners (as shown in figure 102) are preferred; those requiring standard hand tools are acceptable; those requiring non-standard tools shall not be used. XR-C-1

(c) Fasteners requiring high torque shall be provided with external grip heads. See figure 103. XR-C-1

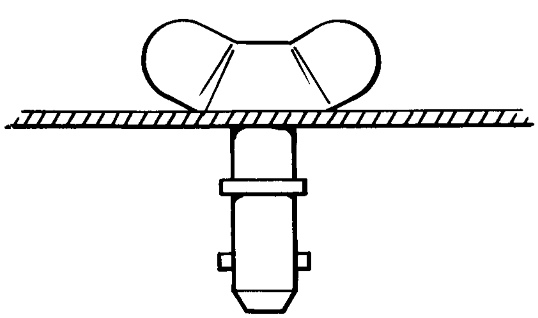
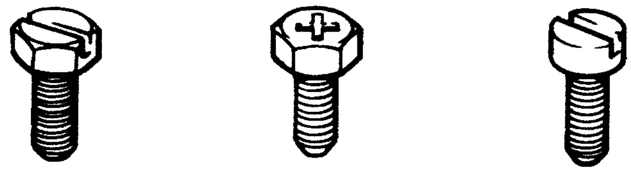


Figure 102. Hand operated fastener

EXTERNAL GRIP HEAD PERMITS USE OF WRENCH



THIS KIND HAS TO BE DRILLED OUT IF SLOT IS DAMAGED

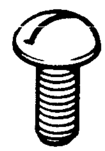


Figure 103. External grip head fasteners

(d) Captive bolts and nuts shall be used in situations where the dropping of these small items into the equipment will cause damage or create a difficult removal problem. XR-C-2

(e) Fasteners for doors and drawers shall be designed so as to preclude injury to the operator when the fastener is released. XR-C-2

(f) Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit shall have large enough holes for passage of the screw without perfect alignment. XR-C-2

5.8.9.3 Specific fastener design considerations.

5.8.9.3.1 Slot design. - Screws with deep slots on screw heads shall be used to minimize slot damage. XR-C-2

5.8.9.3.2 Wrenching clearance. - If possible, slot head bolts shall be used which can be operated with a screw driver if there is not adequate wrenching clearance. XR-C-1

5.8.9.3.3 Bolt length. - Bolts having the appropriate length for any specific task shall be selected. Unnecessary length means more work and added weight, and increases the likelihood of personnel danger and equipment damage. XR-C-2

5.8.9.3.4 Mounting. - Heads of mounting bolts should come up to the work surface. XR-C-2

5.8.9.3.5 Threaded nut plates. - Threaded nut plates shall be used when several bolts are to be fastened on one surface and where positioning and holding the nuts may be difficult. XR-C-2

5.8.9.3.6 Quick-opening captive fasteners. - Quick-opening captive fasteners shall require only a quarter turn to operate. Quarter-turn fasteners should be self-locking and spring loaded. XR-C-1

5.8.9.3.7 Latch lock. - Whenever possible, latch catches shall be spring loaded to lock on contact, rather than necessitate a positive locking device. If positive locking is necessary, provide a latch loop and locking action. XR-C-2

5.8.9.3.8 Latch-handle. - Latches or locks which perform a dual purpose may be used. For example, a lock may be designed to serve as a handle. XR-C-2

5.8.9.3.9 Quick-release clamps. - Quick-release clamps shall be used for holding wires, tubing, or hoses that must be removed frequently. Use clamps that require the technician to use only one hand to operate. XR-C-2

5.8.9.4 Positioning of fasteners.

(a) Nuts, bolts, and screws shall be located far enough away from internal corners so that they may be manipulated with ease. XR-C-1

(b) Bolts and screws shall be located far enough apart so there is adequate tool clearance. XR-C-1

(c) If a component is to be mounted near other pieces of equipment, fasteners shall be located away from the edges of the adjacent equipment. XR-C-1

5.8.9.5 Cover fasteners.

5.8.9.5.1 Hinged covers. - Hinged covers shall be used to reduce the number of fasteners required, unless precluded by space restrictions. XR-C-2

5.8.9.5.2 Standardization. - The same size and type of fasteners shall be used for all covers and cases on a given system, except where stress or other considerations demand special fasteners. XR-C-2

5.8.9.5.3 Captive fasteners. - Captive fasteners shall be used for fastening access panels and covers. XR-C-2

5.8.9.5.4 Latches. - Where stress requirements permit, latches shall be used on covers and doors as they afford more rapid access than doors secured by screws and bolts. XR-C-2

5.8.10 Tools.

5.8.10.1 Variety of tools. - The number and variety of maintenance tools shall be kept to a minimum, and the use of special tools shall be avoided. XR-C-1

5.8.10.2 Non-sparking tools. - Non-sparking tools shall be utilized in explosive areas. XR-C-1

5.8.10.3 Non-conductive handles. - Tools used in extremely cold or hot temperatures or near high voltages shall be provided with non-conductive handles. XR-C-1

5.8.10.4 Special tools. - When special tools are absolutely necessary, they shall be color coded or marked to indicate intended use. XR-C-1

5.8.11 Handles.

5.8.11.1 Handle design. - The selection of handle design shall consider the factors listed: XR-C-1

(a) Weight of the item or unit.

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

(c) Type of clothing and gloves required.

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

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

(f) Distance over which the item must be carried

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

(h) Additional uses the handle could serve.

5.8.11.2 Types of handles. - The type of handle to be selected shall comply with requirements for which the handle is to be used, ie, as determined from 5.8.11.1. Figure 104 illustrates different types of handles. XR-C-1

5.8.11.3 Curvature of handle. - The curvature of the handle shall comply with the dimensions found in table XXXX. XR-C-1

5.8.11.4 Handle dimensions. - The dimensions of the handle shall comply with the dimensions found in table XXXXI. XR-C-1

5.8.11.5 Handle location: general. - Handles shall be located so as to:

(a) Guard against inadvertent actuation of controls. XR-C-1

(b) Protect delicate parts of instrument faces. XR-C-2

(c) Serve as locking devices to secure components in place. XR-C-2

(d) Serve as protective supports or stands for components; eg, can be used as maintenance stands when handles are inverted. XR-C-2

5.8.11.6 Handle location: specific. - The location of handles shall be such that:

(a) Single handles are over the center of gravity. XR-C-1

(b) Two or four handles are at equal intervals from the center of gravity. XR-C-1

(c) Handles are placed where they do not interfere with equipment operation or maintenance. XR-C-1

(d) At least a 2.5 inch clearance between handles and obstructions is provided. XR-C-1

(e) They are placed on the front of a panel if an item must be pulled from the rack. XR-C-2

(f) They can be held comfortably. XR-C-2

(g) The carried item will ride clear of the legs of personnel. XR-C-2

Table XXXX.

Curvature of handle or edge

WEIGHT OF ITEM	RADIUS OF CURVATURE (MINIMUM)
UP TO 15 LBS:	R – 1/8 IN.
15 TO 20 LBS:	R – 1/4 IN.
OVER 20 LBS:	R – 3/8 IN. BUT 1/5 IN.
T-BAR POST:	T – 1/2 IN.

GRIPPING EFFICIENCY IS BEST IF FINGERS CAN CURL AROUND HANDLE OR EDGE TO AN ANGLE OF 120 DEGREES OR BETTER.

Table XXXXI.

Dimensions of handle

DIMENSIONS OF HANDLE	EXPECTED USER CLOTHING								
	BARE HAND			GLOVED HAND			ARCTIC MITTEN		
TYPE OF HANDLE:	X	Y	Z	X	Y	Z	X	Y	Z
ONE-HAND BAR	2.0	4.25	2.0	2.5	4.75	2.0	3.0	5.5	3.0
TWO-HAND BAR	2.0	8.5	2.0	2.5	9.5	2.0	3.0	11.0	3.0
TWO-FINGER BAR	1.25	2.5	1.5	1.5	3.0	1.5	DON'T USE		
ONE-HAND RECESS	2.0	4.25	3.5	2.5	4.75	4.0	3.0	5.5	5.0
TWO-FINGER RECESS	1.25-DIA		2.0	1.5-DIA		2.0	DON'T USE		
ONE-FINGER RECESS	1.25-DIA		2.0	1.5-DIA		2.0	DON'T USE		
FINGER-TIP RECESS	0.75-DIA		0.5	1.0-DIA		0.75	DON'T USE		
T-BAR	1.5	4.0	1.5	2.0	4.5	2.0	DON'T USE		
J-BAR	2.0	4.0	2.0	2.0	4.5	2.0	3.0	5.0	3.0

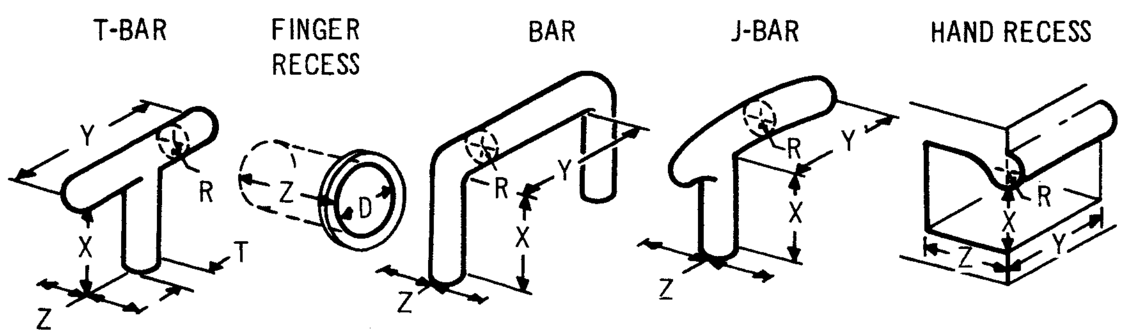


Figure 104. Types of handles

5.8.12 Covers and cases.

5.8.12.1 Orientation. - The proper orientation of a unit within its case shall be made obvious, either through the design of the case or by means of appropriate labels. XR-C-2

5.8.12.2 Case design. - Cases shall be designed to lift off units rather than the units be lifted out of cases. See figure 105. XR-C-2

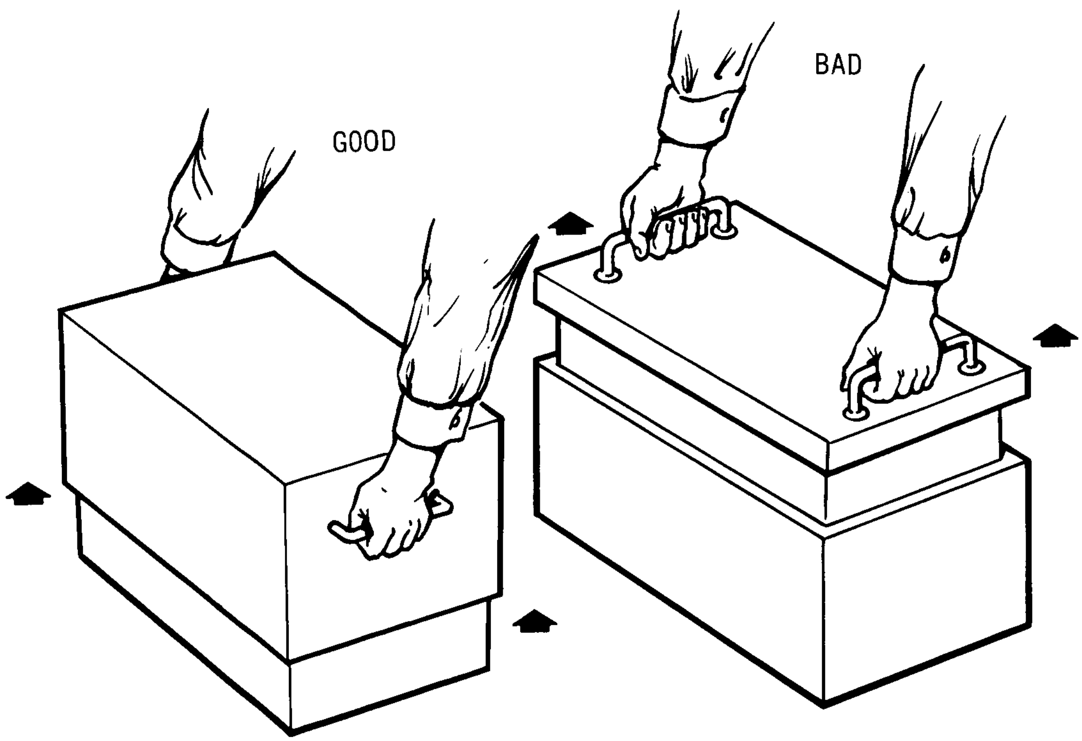


Figure 105. Cover design

5.8.12.3 Case size. - Cases shall be made sufficiently large so that wires and other delicate components are not likely to be damaged when the cases are removed or replaced. XR-C-1

5.8.12.4 Guides, tracks and stops. - Guides, tracks, and stops shall be provided to facilitate handling and to prevent damage to units and components. XR-C-1

5.8.12.5 Opening. - The method of opening a cover shall be obvious. If it is not obvious from the construction of the cover itself, an instruction plate shall be permanently attached to the outside of the cover. XR-C-2

5.8.12.6 Hinging. - Hinged covers should be used to reduce the number of fasteners required, unless precluded by space restrictions. XR-C-2

5.8.12.7 Cover placement. - When a cover is in place but not secured, it shall be obvious. XR-C-2

5.8.12.8 Corners. - Sharp edges and corners on cases and covers shall be avoided. XR-C-1

5.8.12.9 Rests and stands. - Rests and stands on which units can be placed shall be provided. Rests or stands shall incorporate provisions for test equipment, tools, manuals, and other aids. Where design requirements permit, the rests and stands shall be a part of the basic chassis. XR-C-2

5.8.13 Conductors.

5.8.13.1 Wires. - Wires shall be bound into cables and held by lacing twine or another acceptable method. XR-C-1

5.8.13.2 Long cables. - Long conductors or cables, internal to equipment, shall be secured to the chassis by cable clamps. Cables shall be long enough so that each functioning unit can be checked in a convenient place. Extension cables should be provided where this is not feasible. XR-C-2

5.8.13.3 Cable routing. - If it is necessary to route cables and wires through holes in metal partitions, the cables shall be protected from mechanical damage by grommets or other acceptable means. Routing of electrical cables below fluid lines or near high temperature sources shall be avoided. XR-C-2

5.8.13.4 Cable protection. - Cables shall be routed so that: See figure 106.

(a) They cannot be pinched by doors, lids, or components. XR-C-2

(b) They cannot be walked on or used for hand tools. XR-C-2

(c) They are accessible for inspection and repair. XR-C-2

(d) They are not sharply bent or severely twisted. XR-C-2

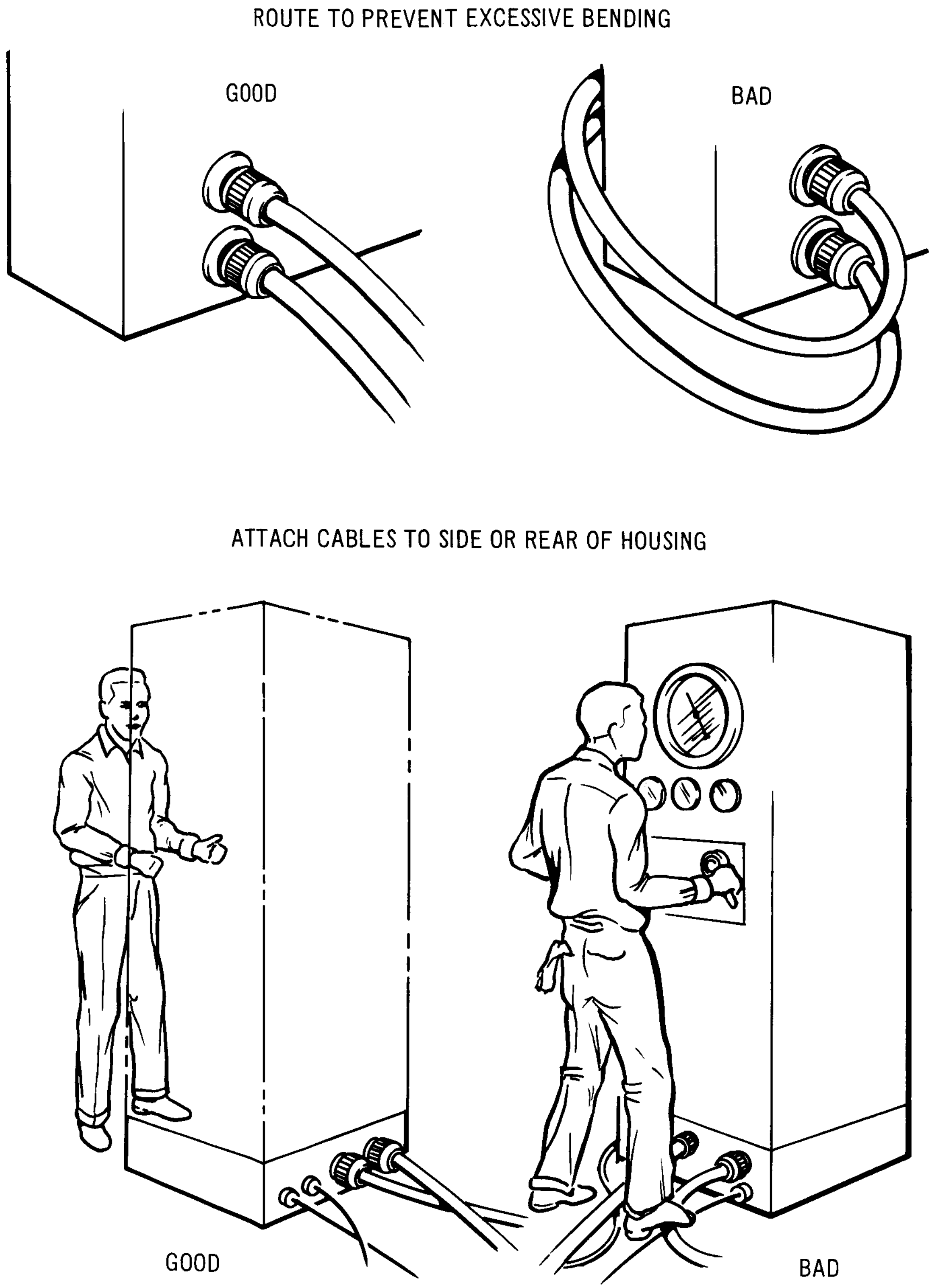


Figure 106. Cable routing

5.8.13.5 Input-output cables. - Input and output cables, with the exception of test cables or headset wires, shall not terminate on the control-display surface of cabinets, racks, or consoles. XR-C-2

5.8.13.6 Receptacles for test cables. - The receptacles for test cables or headset wires which terminate on control and display panels shall be so located so that the associated cable will not interfere with controls and displays. XR-C-2

5.8.13.7 Insulated conductors. - Cables containing individually insulated conductors within a common sheath shall be coded. XR-C-1

5.8.14 Connectors.

5.8.14.1 Disconnect. - Plugs shall require no more than one turn to disconnect or other quick disconnect design shall be provided. XR-C-2

5.8.14.2 Connector spacing. - Connectors shall be located far enough apart so that they can be grasped firmly for connection and disconnection. Space required will depend upon the size and shape of the plug. See figure 107. XR-C-2

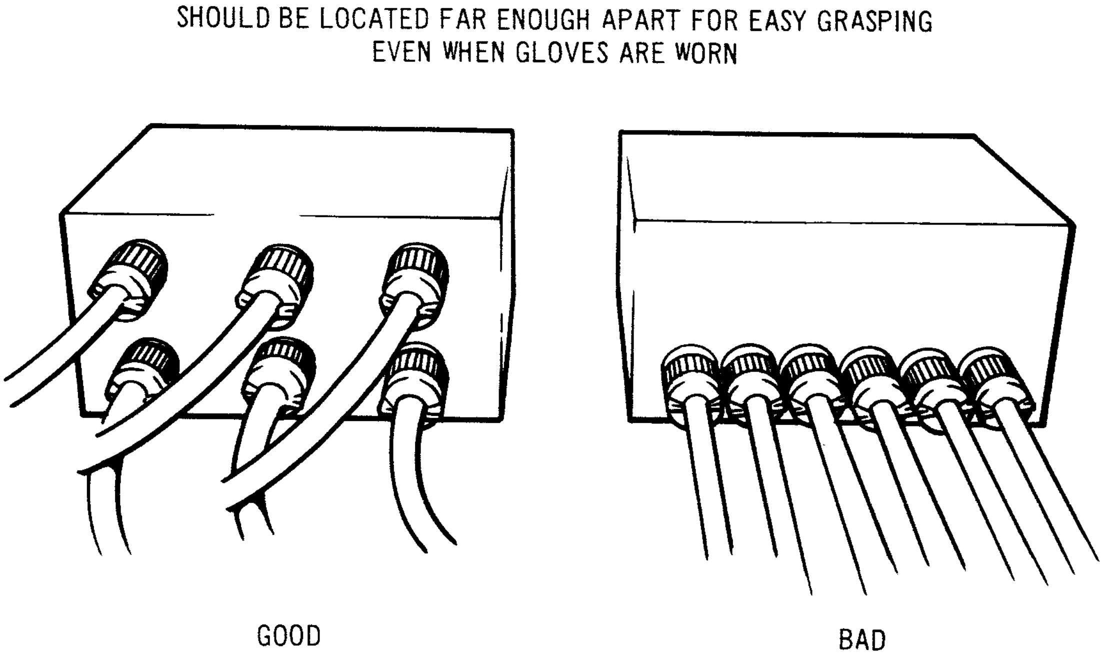


Figure 107. Connector spacing

5.8.14.3 Test and service. - The rear of plug connectors shall be accessible for test and service, except where potting, sealing or other considerations preclude this. XR-C-2

5.8.14.4 Alignment. - Plugs or receptacles shall be provided with aligning pins or other alignment devices. Aligning pins on plugs shall project beyond the electrical pins. XR-C-2

5.8.14.5 Alignment orientation. - Plugs or receptacles shall be arranged so that the alignment pins orient in the same direction throughout the system. XR-C-2

5.8.14.6 Interchange of connectors. - Where a reasonable possibility exists for unintentional interchange of connectors, plugs shall be so designed that it is impossible to insert the wrong plug into a receptacle. XR-C-2

5.8.14.7 Protection. - Plugs and receptacles on the exterior of portable unit cases shall be covered with captive caps wherever possible. XR-C-2

5.8.14.8 Identification. - Connecting plugs and receptacles shall be identified by numbers or letters. To increase reliability, an additional means such as color or shape coding may be used in exceptional cases. See figure 108. XR-C-2

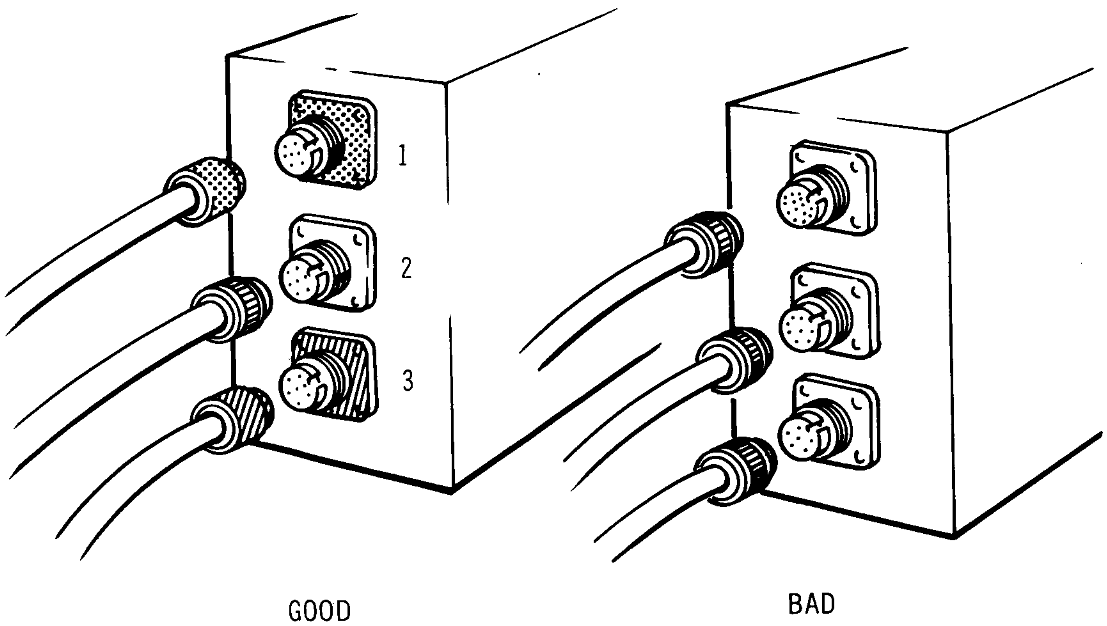


Figure 108. Connector coding

5.8.14.9 Female sockets. - The system shall be designed so that "hot" contacts are socket (female) contacts. XR-C-2

5.8.14.10 High voltage protection. - Warning labels plus recessed connectors or other applicable items shall be provided where potentials exceed 150 volts, and in all cases where potentials are hazardous to personnel. XR-C-2

5.8.14.11 Grounding. - All external metal parts shall be at ground potential. XR-C-1

5.8.15 Test points. - Test points are classified as primary (operational) and secondary (maintenance). Primary test points are used to isolate a malfunctioning detail part within a subassembly, after the subassembly has been removed from a larger or major assembly.

5.8.15.1 Primary test points. - Primary test points shall be in accordance with the following criteria:

(a) Where a unit is not completely self-checking in its operational condition, appropriate test points shall be provided. XR-C-2

(b) Only such primary test points as are necessary to determine that a unit is malfunctioning shall be provided. XR-C-2

(c) Primary test points shall be so located and coded as to be readily distinguished from secondary test points. XR-C-2

(d) Where feasible, primary test points shall be grouped in a line of matrices reflecting the sequence of tests to be made. XR-C-2

(e) Primary test points used in adjusting the unit shall be located close to the controls and displays used in the adjustment. XR-C-2

(f) Primary test points shall not be located on the sides of standard cabinets. XR-C-2

5.8.15.2 Secondary test points. - Secondary test points shall be in accordance with the following criteria:

(a) A secondary test point shall be supplied at the input and output of each part or throwaway component, where feasible, and when not in conflict with other requirements. XR-C-2

(b) Sufficient test points shall be provided so that it will not be necessary to remove subassemblies from assemblies during trouble shooting. XR-C-2

(c) Each test point shall be so marked so as to be readily identifiable. XR-C-2

5.8.15.3 Built-in test equipment. - Built-in test equipment shall conform to the following criteria, in order of preference:

(a) Adequate test equipment to handle routine testing and trouble shooting shall be built into the equipment where feasible. See figure 109. XR-C-2

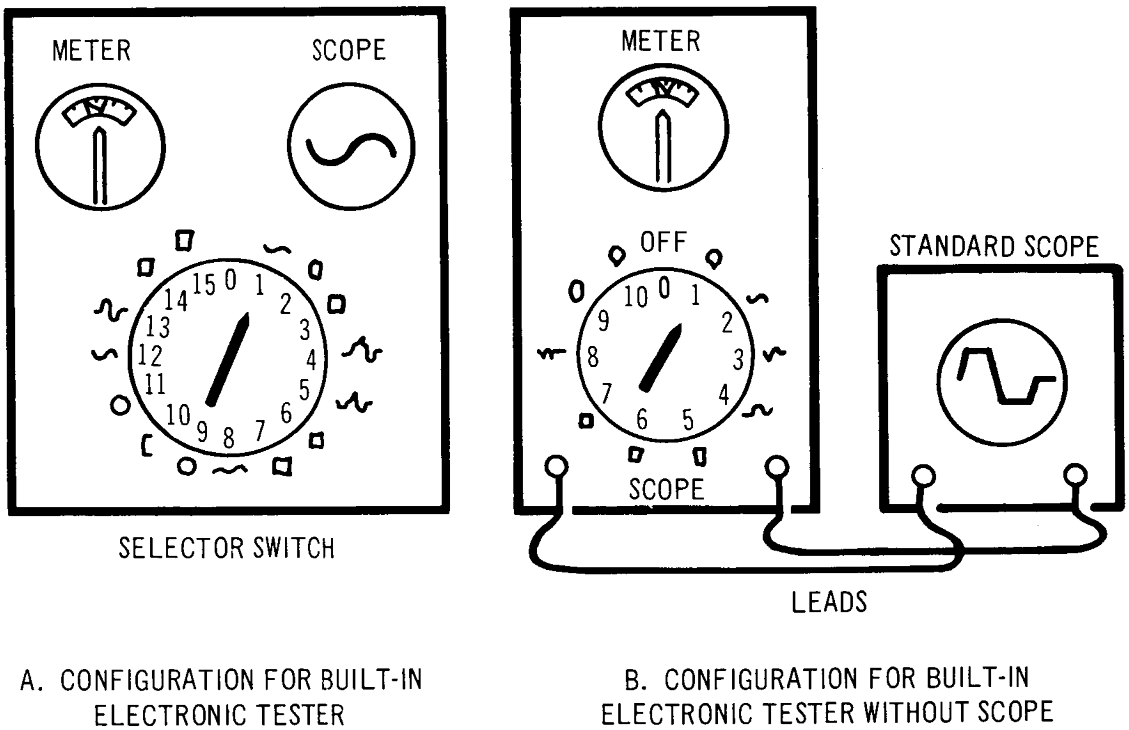


Figure 109. Configurations for electronic testers

(b) If space or weight considerations make built-in equipment impossible, a portable test box with a multiple prong connector to attach to the test panel shall be considered. See figure 109 for a recommended configuration. XR-C-2

(c) If a central test panel is not feasible for a system, a center-reading meter on each major component whose signal can be checked by a meter may be provided. Use test jacks and a selector switch to provide an outlet for signals requiring a scope. Indicate in-tolerance readings on the selector switch. See figure 109. XR-C-2

5.8.16 Labelling.

5.8.16.1 Usage.

(a) All units and parts shall be labelled with full identifying information to facilitate replacement with spares. XR-C-1

(b) Structural members will be labelled with information about their physical characteristics and structural or function limitations. XR-C-2

(c) If parts cannot be designed to be installed in only one position, they shall be labelled so that fore and aft parts are distinguishable. XR-C-1

(d) Information shall be consistent with both instruction manuals and parts catalogs. XR-C-1

5.8.16.2 Label placement. - See 5.2.4.

(a) Labels shall be located so they will not be obliterated by dirt, grease or moisture. XR-C-2

(b) Labels shall be placed on similar pieces of equipment in the same relative location. XR-C-2

(c) Labels shall read horizontally, not vertically. XR-C-2

(d) Labels shall be placed on components where they can be seen when installed. See figure 110. XR-C-2

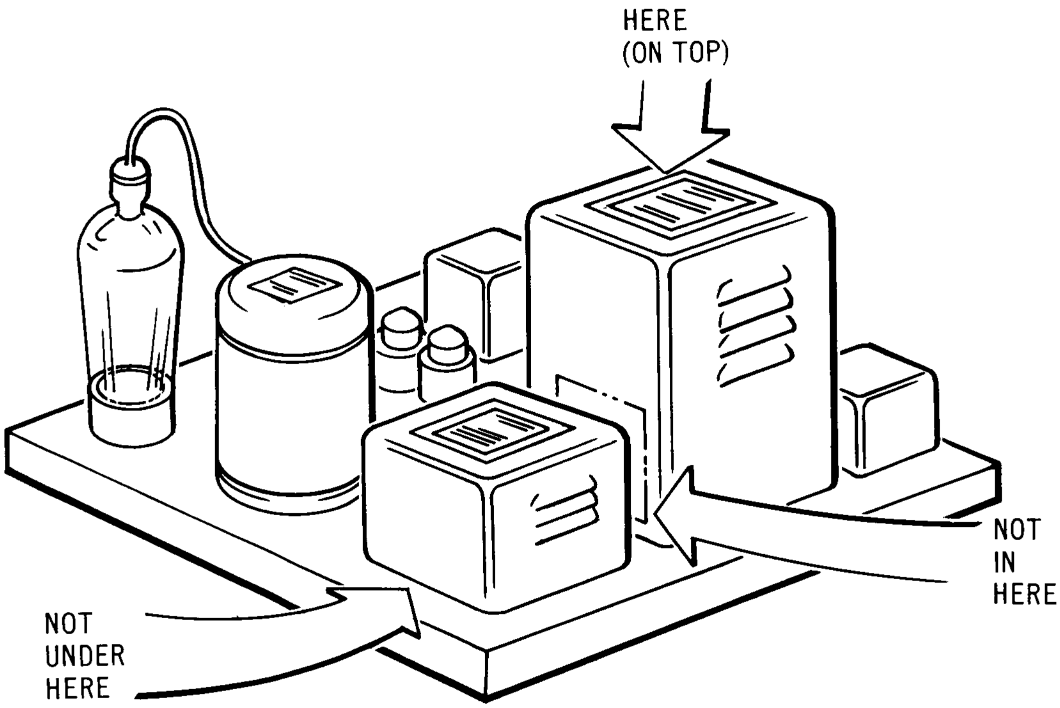


Figure 110. Label placement

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APPENDIX A

Contributors

The following list represents those individuals and their affiliated governmental agencies or industrial firms from whom information or assistance was received by direct contact during the revision of this standard.

1. J. A. Seeman
   NASA/MSFC
   R-P & VE-VSL
   Huntsville, Alabama

2. D. H. Weidig
   Brown Engineering Company/MSFC
   R-P & VE-VSL
   Huntsville, Alabama

3. Alan A Burrows, Ph.D.
   Manager
   Biotechnology Section, Advanced Systems
   Aircraft Division, Douglas Aircraft Company
   Long Beach, California

4. Stanley Lippert
   Head
   Human Factors Research
   Biotechnology Section, Advanced Systems
   Aircraft Division, Douglas Aircraft Company
   Long Beach, California

5. James W. Altman
   Director
   Institute for Performance Technology
   American Institute for Research
   410 Amberson Avenue
   Pittsburgh, Pennsylvania 15232

6. Gerald Chaikin
   Engineering Requirements Branch
   Engineering Services Division, DR&D
   Headquarters
   U. S. Army Missile Command
   Redstone Arsenal, Alabama

7. Robert F. Chaillet
Chief, Technical Specifications Office
U. S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland 21005

8. Stanley Deutsch
Chief, Man-Systems Integration
Biotechnology & Human Research
National Aeronautics and Space Administration
Washington, D. C. 20546

9. D. J. Dougherty, Ph.D.
Bell Helicopter Company
Division of Bell Aerospace Corporation
Post Office Box 482
Fort Worth, Texas 76101

10. Robert E. Ehrlich
General Electric Company
Technical Military Planning Operation
735 State Street, P. O. Drawer QQ
Santa Barbara, California 93102

11. Earl J. Ends, Ph.D.
Head, Human Factors Engineering
Life Sciences (Advanced Design)
Lockheed-California Company
Division of Lockheed Aircraft Corporation
Burbank, California 91503

12. Edward R. Jones, Manager
Engineering Psychology
McDonnell Aircraft Corporation
Lambert-Saint Louis Municipal Airport
Box 516
St. Louis, Missouri 63166

13. Donald I. Kane
Applied Science Division
Litton Systems, Inc.
2295 Walnut Street
St. Paul, Minnesota 55113

14. J. T. Keeley
Manager, Program Safety
Martin Company
Denver 1, Colorado

15. G. M. Knauf, M.D.
Deputy Director, Space Medicine
Office of Manned Space Flight
National Aeronautics and Space Administration
Washington, D. C. 20546

16. William B. Knowles, Jr.
Hughes Aircraft Company
Aerospace Group
Research & Development Division
Culver City, California

17. Robert J. Lacey, Major, USAF
Systems Effectiveness Division
Directorate of Systems Policy
DSC/Systems
Headquarters
Air Force Systems Command
United States Air Force
Andrews Air Force Base, Washington, D. C. 20331

18. J. E. Mangelsdorf
Bioastronautics
Lockheed Missiles & Space Company
Sunnyvale, California

19. Patricia Marshall
Acting Chief Librarian
Technical Information Service
American Institute of Aeronautics and Astronautics, Inc.
750 Third Avenue
New York, New York 10017

20. V. J. Michel
Chief Librarian
Technical Information Center
Autonetics
Division of North American Aviation, Inc.
P. O. Box 4173, 3370 Miraloma Avenue
Anaheim, California 92803

21. T. L. Rogers, Supervisor
S-II Data Requirements
Space and Information Systems Division
North American Aviation, Inc.
12214 Lakewood Boulevard
Downey, California 90241

22. George E. Rowland, Ph.D.
President
Rowland & Company
P. O. Box 61
Haddonfield, New Jersey

23. M. J. Sadoski
Reference Librarian
U. S. Navy Electronics Laboratory
San Diego 52, California

24. A. H. Schwichtenberg, M.D.
The Lovelace Foundation
Department of Aerospace Medicine
and Bioastronautics
4800 Gibson Boulevard, S.E.
Albuquerque, New Mexico

25. Dr. A. D. Swain
Technical Information Division
Sandia Corporation
Box 5800
Albuquerque, New Mexico 87115

26. Harold A. Voss, Ph.D.
Head, Aviation Psychology Division
U. S. Naval Training Device Center
Port Washington, New York 11050

27. Robert Y. Walker, Ph.D.
Staff Engineer, Aerospace Medicine
The Boeing Company
P. O. Box 3707
Seattle 24, Washington

28. Paul Webb, M.D.
Principal Associate
Webb Associates
Box 308
Yellow Springs, Ohio

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