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# HUMAN FACTORS ENGINEERING GUIDELINES FOR OVERHEAD CRANES

September 28, 2001

SPACEPORT ENGINEERING  
AND TECHNOLOGY DIRECTORATE

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John F. Kennedy Space Center





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**September 28, 2001**

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## FOREWORD

This guideline provides standards for overhead crane cabs that can be applied to the design and modification of crane cabs to reduce the potential for human error due to design. This guideline serves as an aid during the development of a specification for purchases of cranes or for an engineering support request for crane design modification. It aids human factors engineers in evaluating existing cranes during accident investigations or safety reviews.

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Requests for improvements to this document should be directed to NASA, Spaceport Engineering and Technology Directorate (mail code: YA, Kennedy Space Center, Florida 32899), using the KSC form 21-610NS, Standardization Document Improvement Proposal, attached to the back of this document. Requests for additional copies of this document should be sent to the local KSC documentation center or Library-D, Kennedy Space Center, Florida 32899.





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## ABBREVIATIONS AND ACRONYMS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BIT	built-in test
cd/m <sup>2</sup>	candela per square meter
CIE	Commission Internationale de l'Eclairage
CMAA	Crane Manufacturer's Association of America
COTS	commercial off-the-shelf
CRT	cathode-ray tube
dB	decibel
E-stop	emergency stop
fc	footcandle
fL	footlambert
ft	feet
HFE	Human Factors Engineering
Hz	hertz
in	inch
kg	kilogram
KSC	John F. Kennedy Space Center
lb	pound
LCD	liquid crystal display
lx	lux
m	meter
mm	millimeter
mN-m	millinewton-meter
mrad	milliradian
N	newton
nm	nanometer
OSHA	Occupational Safety and Health Administration
oz	ounce
PSIL	preferred speech interference level
s	second
YA	Spaceport Engineering and Technology Directorate



## SECTION I

## GENERAL

## 1.1 SCOPE

This Human Factors Engineering guideline for overhead crane cabs provides:

- NASA John F. Kennedy Space Center (KSC) contractors and civil servants with a guideline that can be applied to the design and modification of crane cabs to reduce the potential for human error due to design
- An aid for designers, engineers, human factors personnel, and safety personnel during the development of a specification for purchase of commercial off-the-shelf (COTS) or custom-built cranes and for the development of an engineering support request for a crane design modification
- An aid for human factors engineers tasked with evaluating existing cranes during accident investigations or safety reviews

NOTE

A customer should not use this document as a reference in a procurement specification for the development of cab design by a crane manufacturer or supplier. It should be considered as an internal KSC document only and used in the development of specifications.

KSC-YA-5436, Human Factors Engineering Guidelines for Overhead Cranes, was developed for specialized conditions and requirements at KSC. This document should be used only by those companies/organizations that have the same requirements stated as follows:

- A seated operator
- An open crane cab
- A view-over the-top console design
- Operations in a clean room environment
- Precise crane movements
- Detailed hook position information
- No visibility of the crane hook

### CAUTION

This guideline specifies requirements for a seated console design that provides no visibility of the crane hook and requires the crane operator to rely solely on the radio communication. This is a KSC requirement and is not in compliance with OSHA 1910.179 paragraph (c)(1)(ii), which states: The arrangement (of the cab) shall allow the operator a full view of the load hook in all positions. Consequently, unless other companies/organizations have sought a waiver from this regulation, as KSC has done, the seated console with no-visibility of the hook should not be used.

All crane design projects will benefit from the incorporation of human factors engineering methodology and other portions of the guideline which, if applied properly, would lead to a crane design that optimizes the operator interface, minimizes human error, and improves safety in crane operations.

**1.1.1 FORMAT.** This guideline is presented in a checklist format, where each subparagraph addresses one specific item. The document can be used in its entirety or in part, as determined by the specific crane design task or modification. Line items in the document that contain the word “shall” are mandatory requirements from Occupational Safety and Health Administration (OSHA) and/or other standards authorities cited in this document and must be applied if the applicable feature is incorporated into the crane design. Line items that contain the word “should” are optional and recommended where practicable.

This document has been broken down into sections covering design guidelines, seated workspace, controls and displays, detailed guidelines for controls and displays, labeling, and maintenance. Specific requirements for seating, controls, and displays should be used to guide the purchase of acceptable COTS products. Custom-built seating, controls, or display components are not required. Standardization is a continuous process, and this guideline was developed using the latest possible revisions of the available standards. However, this document should be updated to reflect revisions of standards as they occur.

**1.1.2 GUIDELINE USE.** KSC-YA-5436 provides information about the effective design of crane cabs to optimize human performance in crane operations and maintenance with emphasis on operator reach, visibility and operation of controls, and visibility/legibility of displays.

For new crane designs or crane refurbishment projects, successful application of the principles in this guideline can be achieved when used in combination with a Human Factors Engineering (HFE) methodology. HFE should be an integral part of the design/refurbishment process to ensure the system functions and the operator tasks are defined so the appropriate type of human-machine interfaces (e.g., displays, controls) is selected. Once the interfaces are selected, this



guideline can be used to provide detailed information about the requirements for the design and placement of each interface.

For effective, safe designs, it is recommended that HFE be applied systematically through the design/refurbishment process, using this guideline and HFE methodology, including useability testing and feedback from the crane operators.

**1.1.3 HUMAN FACTORS SPECIALIST.** When this document is used as a checklist to inspect existing cranes and to determine if the current design creates a significant potential for human error and/or injury, it should be used by a qualified human factors specialist. The human factors specialist should evaluate each feature that is identified as deficient and determine its impact on human performance, the criticality of its impact, and the likelihood of the potential error. If a potential error is critical, may occur frequently, or may cause injury, modifications to the crane design should be recommended to reduce the risk of future accidents.

**1.1.4 REFERENCE DOCUMENTS.** This guideline was developed in response to Firm Fixed Price contract MR 002072(F), which tasked The Boeing Company to develop a human factors design concept and requirements for overhead cabs that optimize the human-machine interface. The contract resulted in the production of this guideline and a control-console concept for KSC Operations and Checkout Building 27-1/2-ton overhead bridge cranes. This guideline contains standards that shall be applied to the design and/or modification of indoor overhead crane cabs at KSC. This guideline was developed from the following references:

- a. ANSI A1264.1, Safety Requirements for Workplace Floor and Wall Openings, Stairs, and Railing Systems
- b. ANSI/HF 100-1998, American National Standard for Human Factors Engineering of Visual Display Terminal Workstations Human Factors Society, Inc. (1998), Human Factors Society, Inc.: Santa Monica, California
- c. ASME B30.11, Monorail Systems and Underhung Cranes
- d. ASME B30.17, Overhead and Gantry Cranes, Top Running Bridge, Single Girder, Underhung Hoist
- e. ASME B30.2, Overhead and Gantry Cranes, Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist
- f. 29 CFR 1910.147, Occupational Safety and Health Standards, Subsection 147, the Control of Hazardous (Lockout/Tagout) – Inspection Procedures and Interpretive Guidance
- g. 29 CFR 1910.179, Occupational Safety and Health Standards, Subsection 179, Overhead and Gantry Cranes

- h. CMAA Standard 70, Specification for Top Running Bridge & Gantry Type Single Girder Electric Overhead Travelling Cranes
- i. CMAA Standard 74, Specification for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Travelling Cranes
- j. FED-STD-595, Colors Used in Government Procurement
- k. ISO 2631-4, Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration -- Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems
- l. ISO 3864, Safety colors and safety signs
- m. ISO 6081, Acoustics
- n. ISO 7096, Earth-moving machinery -- Laboratory evaluation of operator seat vibration
- o. ISO 7752-1, Lifting appliances -- Controls -- Layout and characteristics -- Part 1: General principles
- p. ISO 7752-5, Lifting appliances -- Controls -- Layout and characteristics -- Part 5: Overhead travelling cranes and portal bridge cranes
- q. ISO 8566-1, Cranes -- Cabins -- Part 1: General
- r. ISO 8566-5, Cranes -- Cabins -- Part 5: Overhead travelling and portal bridge cranes
- s. ISO 11660-2, Cranes -- Access, guards, and restraints -- Part 2: Mobile cranes
- t. ISO 13200, Cranes -- Safety signs and hazards pictorials - General principles
- u. KSC-DE-512-SM, Facility, System and Equipment General Design Requirements
- v. MIL-STD-681(D)1, Identification Coding and Application of Hookup and Lead Wire
- w. MIL-STD-1472, Human Engineering Design Criteria for Systems, Equipment and Facilities
- x. NSS/GO-1740.9, NASA Safety Standard for Lifting Devices and Equipment

- y. Roebuck J, *Anthropometric Methods: Designing to Fit the Human Body* (1995), Human Factors & Ergonomics Society: Santa Monica, California
- z. Salvendy, G., *Handbook of Human Factors* (1987), John Wiley & Sons, Inc.: New York
- aa. Sanders, M., and McCormick, E. J., *Human Factors in Engineering and Design* (1987), McGraw-Hill Book Company: New York
- bb. Shneiderman, B., *Designing the User Interface: Strategies for Effective Human-Computer Interaction* (1987), Addison-Wesley: Reading, Massachusetts
- cc. Woodson, W.; Tillman, B.; and Tillman, P.; *Human Factors Design Handbook, Second Edition*, McGraw-Hill Inc.: New York, New York



## SECTION II

### REQUIREMENTS

#### 2.1 DESIGN GUIDELINES

The following design guidelines apply to open cabs (in contrast to enclosed cabins) in a clean room environment. If enclosed cabins are required or preferred, see MIL-STD-1472 for guidelines. Cab dimensions shall take into account the type of work and the length of continuous working periods of the crane operator. The cab should conform to the requirements for minimum cab dimensions presented in ISO 8566-5. Whenever feasible, free floor space of not less than 1220 millimeters (mm) [4 feet (ft)] should be provided in front of each console.

The cab should be free from projecting parts that may cause injury. Where projections are necessary, they shall be covered or guarded. The cab floor shall have a nonskid surface and be easily cleaned.

2.1.1 ILLUMINATION. The cab shall be equipped with sufficient and suitable interior lighting:

- General lighting and supplementary lighting shall be used to ensure 540 lux (lx) [50 footcandles (fc)] at the console and at the maintainer's work area.
- Broad-spectrum illumination (white light) shall be used for general illumination.
- Indirect lighting should be used where possible to provide console illumination free from glare and unwanted reflections.
- Direct light sources should be arranged so their angle of incidence to the visual work area is not the same as the operator's viewing angle.
- Polarized light, shields, hoods, lenses, diffusers, or visors shall be used over the crane console and controls (where needed) to minimize glare.
- Cab design shall ensure (by testing) that the maximum-to-average-luminance ratio does not exceed 5:1 across the viewing area. Six test readings should be taken in the work area to determine the average luminance of the use area.

2.1.2 NOISE. Personnel shall be protected from noise that could cause physical impairment (i.e., fatigue or injury). Since crane operations require direct communication, noise levels from the crane during normal working conditions and from other nearby equipment must not interfere with necessary voice, telephone, and radio communication. To accomplish this:

- The equivalent A-weighted sound pressure level, as determined in accordance with ISO 6081 shall not exceed 65 decibels (dB) at the crane operator's ear while the operator is seated at the console.
- To ensure that intelligible speech communication can occur, the preferred speech interference level (PSIL) should be less than 60 dB.

**2.1.3 WHOLE BODY VIBRATION.** The whole body vibration (the vibration transmitted through the chair to the crane operator) shall be measured in accordance with ISO 7096.

- The cab shall be adequately braced to prevent swaying or vibration but not so as to interfere with access to the cab or the vision of the operator.
- Where vibrating motions are transmitted to the human body through supporting surfaces, equipment vibrations shall not impair required manual control or visual performance.
- The crane-supporting surface shall not vibrate in a frequency range between 0.1 and 0.5 hertz (Hz).
- For an operator sitting in the crane cab for 4 to 8 hours, the whole body vibration shall not exceed 10 Hz at 0.3 meter per second squared ( $m/s^2$ ).
- Vertical sinusoidal vibration between 5 and 20 Hz with accelerations exceeding  $0.2 m/s^2$  shall be avoided.
- System resonance below 20 Hz shall be avoided.
- For additional guidelines on vibrations, refer to ISO 2631-4.

**2.1.4 VISIBILITY.** The design and arrangement of the cab shall allow the crane operator visibility of the load block in all positions. When physical arrangements obscure the operator's view, the operator shall be aided by other means such as, but not limited to, closed-circuit TV, mirrors, radio, telephone, or a signal person.

**2.1.5 INGRESS AND EGRESS.** Access to and egress from the cab shall conform to the NASA, KSC, Crane Manufacturer's Association of America (CMAA), American National Standards Institute (ANSI), American Society of Mechanical Engineers (ASME), and OSHA standards.

**2.1.6 PLATFORMS, PASSAGEWAYS, AND WALKWAYS.** Platforms, passageways, and walkways shall conform to the dimensions specified by OSHA and in ISO 11660-2.

- The width of any walkway shall be a minimum of 457.2 mm [18 inches (in)] but is preferred to be 762 mm (30 in) or greater.

- The width of any platform shall be a minimum of 609.6 mm (24 in) but is preferred to be 762 mm (30 in) or greater.
- The width of any passageway that will accommodate personnel passing from opposite directions shall be 889 mm (35 in) or greater.

2.1.7 LADDERS AND STAIRWAYS. Ladder and stairway dimensions shall conform to ISO 11660-2. This includes the following requirements:

- For access requiring a ladder, the preferred angle of ascent is between 75 and 85 degrees, and the angle of ascent shall not exceed 90 degrees.
- For access requiring stairs, the angle of ascent shall be a minimum of 20 and shall not exceed 50 degrees. The preferred angle of ascent for stairs is 30 to 35 degrees.
- All platforms, walkways, ladders, and stairs shall have a nonskid or other high-friction surface.
- Access to the cab shall not require a step over a gap of more than 152.4 mm (6 in) whether it is by stairs, a fixed ladder, or platform.
- Conductors of the open type mounted on the crane runway beams or overhead shall be so located or so guarded that persons entering or leaving the cab or crane footwalk normally could not come into contact with them.

2.1.8 HANDRAILS. Handrail, handhold, and toeboard dimensions shall conform to ISO 11660-2 and ANSI A1264.1.

- Handrails should be 1066.8 mm (42 in) high, with vertical posts no more than 1828.8 mm (6 ft) apart and have a 152.4 mm (6 in) toeboard at the bottom.
- Handrails should have an intermediate rail halfway between the top of the toeboard and the top rail.

2.1.9 ENCLOSURE OPENINGS AND DOORWAYS. Cab and maintenance access enclosure openings shall conform to ISO 11660-2. These enclosures shall accommodate the entire population and shall be equal to or exceed the 99th-percentile dimensions of that population. The primary opening shall be accessible directly from the platform, walkway, or access steps. If a door is used, the door shall:

- Be a hinged type.
- Open outward.

- Be opened without infringing on the standing position of the person opening it.
- Not require a force of more than 135 newtons (N) to open or close the door.
- Have a latching device.

2.1.9.1 Hinged-Door Dimensions (One-Person): Hinged doors that allow the passage of one person should have the following dimensions:

- The door should have a height between 2012 and 2103 mm (6.6 and 6.9 ft).
- The door should have a width between 810 and 860 mm (32 and 34 in).
- The door hinge should be between 990 and 299.7 mm (3.9 and 11.8 in) from the nearest corner.
- The door should be at least 730 mm (2.9 in) from the nearest equipment or obstruction.

2.1.9.2 Emergency Doors and Exits: Emergency doors and exits shall:

- Be clearly designated.
- Be readily accessible.
- Be unobstructed.
- Be simple to locate in the dark.
- Be quick opening in 3 seconds or less.
- Require 44 to 135 N of operating force to open.
- Permit one-person egress in 5 seconds or less.

## 2.2 SEATED WORKPLACE

The cab shall be equipped with a seat suitable for operating the crane that minimizes operator fatigue. The seat shall permit visual, reach, and communications access so the intended work tasks can be performed efficiently and without interference. The seat shall be easily adjustable and lockable (horizontally and vertically) in order to provide the operator with an optimal working position.

- The seat shall have cushioning that has a flat, firm shape with enough softness to deform.



- The seat shall have resilient material and springs to minimize vibration and absorb shocks.
- The seat shall provide an adjustable backrest that inclines and is shaped to follow the inward curve of the lower back and provide adequate support. It should support the operator's body weight, primarily around the two bony points of the pelvis.
- The seat shall provide adjustable height and adjustable elbow rests.
- The seat shall have a swivel capability.
- The seat shall incorporate perforated or ventilated materials to prevent hotness or sweating.
- The seat shall be constructed and positioned to allow easy access.

2.2.1 SEATING DIMENSIONS. Use the following to select the best commercially available seating.

- The seat height should provide 152.4 mm (6 in) of adjustment in increments of no more than 30 mm (1 in).
- The seat pan width should be 450 mm (17.7 in) to 510 mm (20 in).
- The seat pan should have a waterfall front edge.
- The seat should slope backward 0 to 7 degrees.
- The seat should provide a supporting backrest that reclines 100 to 115 degrees.
- The backrest size should be 381 to 508 mm (15 to 20 in) high and 300 to 360 mm (12 to 14 in) wide.
- The angle between the seat and the lower leg should be 60 to 100 degrees.
- The seat should have five supporting legs or should be firmly attached to the cab floor and provide adjustable positioning toward the console. Swivel chairs that have supporting legs should have a seat base of 457 mm (18 in).
- The armrests should be undercut to allow space for the hips and thighs.
- The armrests should be adjustable between 190.5 and 297 mm (7.5 and 11 in) above the compressed seat surface.
- The armrest should be at least 203 mm (8 in) in length.

2.2.2 DIMENSIONS FOR CONSOLE CONFIGURATIONS. At the time of the guideline development, KSC Crane Design Engineers preferred seated consoles and indicated that these were required at KSC. If they are not required, there are other options (for example, placement of the controls on the crane operator's chair). See figure 2-1. All overhead crane cab consoles requiring vision over the top and a seated operator shall conform to the dimensions listed in table 2-1 and depicted in figure 2-2. These dimensions provide room for safe and comfortable work.

Table 2-1. Console Configuration Dimensions

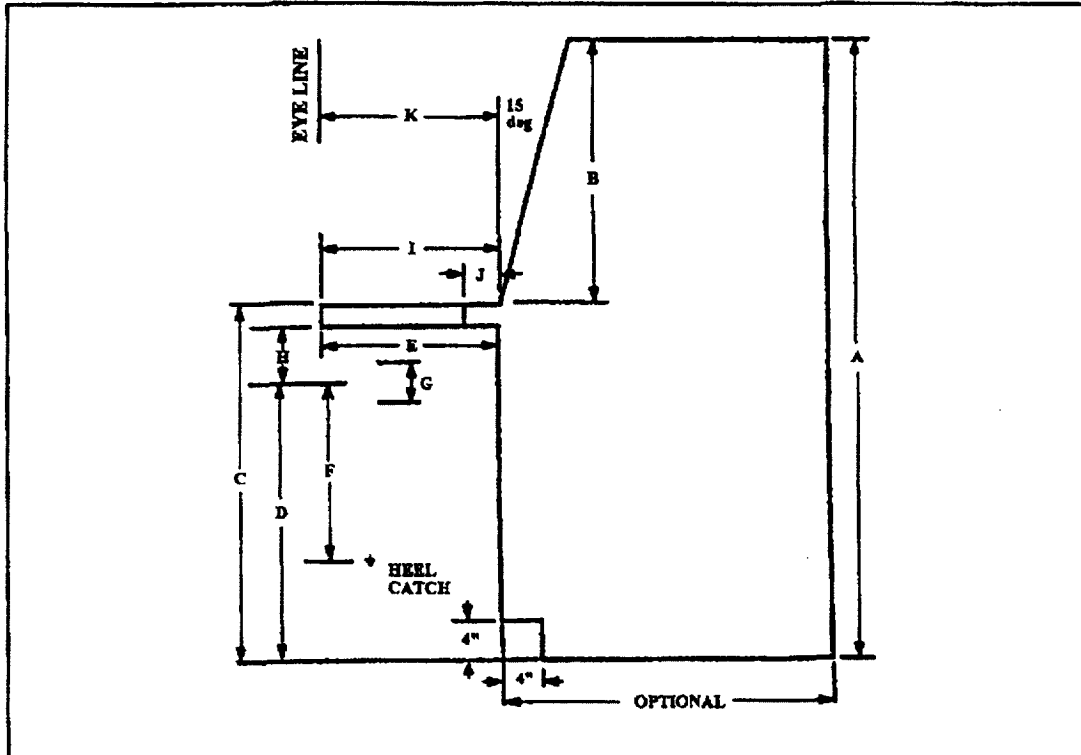
Type Console	Maximum Total Console Height From Standing Surface mm (in)	Suggested Vertical Dimension of Panel (With Sills) mm (in)	Writing Surface Shelf Height From Standing Surface mm (in)	Seat Height From Standing Surface at Midpoint of G (figure 2-2) mm (in)	Maximum Console Width (Not Shown) mm (in)
	A	B	C	D	-
Sit (With Vision Over the Top)*	1170 (46.0)	520 (20.5)	650 (25.5)	435 (17.0)	1120 (44.0)
	1335 (52.5)	520 (20.5)	810 (32.0)	595 (23.5)	1120 (44.0)
	1435 (56.5)	520 (20.5)	910 (36.0)	695 (27.5)	1120 (44.0)

\*In table 2-1, a range of maximum console heights (see column A) is provided to allow latitude in the volume of the lower part of the console (see columns C and D).

- Minimum Knee Clearance:** The minimum clearance provided for the knees shall be 460 mm (18 in). The preferred knee space be 640 mm (25 in) in height. If a footrest is used, it will increase the needed knee space. Where equipment permits, sloping under the console surface should attain knee space and associated leg space.
- Foot Support to Sitting Surfaces:** Foot support should be used if an operator cannot keep both feet flat on the floor when the chair height is properly adjusted to the work surface. When a foot support is used, it shall be 460 mm (18 in) from the sitting surface.
- Console Horizontal Surface Depth:** The console depth shall be a minimum of 406 mm (16 in) and shall not exceed 609 mm (24 in).
- Front Edge of the Console:** The front edge shall be rounded or provide cushioning so it does not create contact stress on the operator's forearms during control use.
- Eye Line-to-Console Vertical Surface Distance:** The minimum distance between the operator's seated eye reference point and the console shall be 406.4 mm (16 in).



Figure 2-1. Seated With Vision Over the Top



Key	Dimensions	mm	in
A.	Maximum total console height from standing surface	See Table 2-1	
B.	Suggested vertical dimension of panel, including sills	See Table 2-1	
C.	Writing surface: shelf height from standing surface	See Table 2-1	
D.	Seat height from standing surface at midpoint of "G"	See Table 2-1	
E.*	Minimum knee clearance	460	18.0
F.*	Foot support to sitting surface**	460	18.0
G.*	Seat adjustability	150	6.0
H.*	Minimum thigh clearance at midpoint of "G"	190	7.5
I.	Writing surface depth including shelf	400	16.0
J.	Minimum shelf depth	100	4.0
K.	Eye line-to-console front distance	400	16.0

\* Not applicable to console types 4 and 5  
 \*\* Since this dimension must not be exceeded, a heel catch must be added to the chair if "D" exceeds 460 mm (18.0 in).

Note: A shelf thickness of 25 mm (1 in) is assumed. For other shelf thicknesses, suitable adjustments should be made.

Figure 2-2. Console Dimensions

- **Viewing Angle:** The total required left-to-right viewing angle should not exceed 190 degrees (see head and eye rotation in figure 2-3). This angle should be reduced whenever possible through appropriate control-display layout.

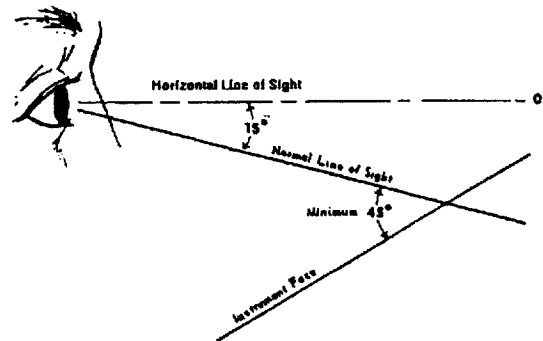


Figure 2-3. Lines of Sight

**2.2.3 WRAPAROUND CONSOLES.** When requirements for preferred panel space for a single seated operator exceed a panel width of 1120 mm (44 in), a flat-surface, wraparound console (figure 2-4) or chair with arm controls should be provided.

- The width of the central segment should be not more than 1120 mm (44 in).
- The width of the left and right segments should not exceed 610 mm (24 in).
- The left and right segments of a wraparound console should be placed at an angle, measured from the frontal plane of the central segment, so that the 5th-percentile stationary operator can reach these segments. This can be accomplished if all controls are within 596 mm (23.5 in).

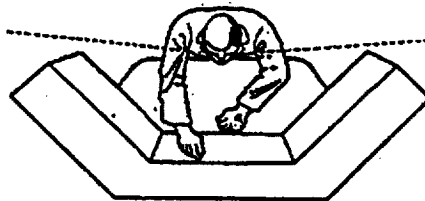


Figure 2-4. Example of Horizontal Wraparound Console

## 2.3 CONTROLS AND DISPLAYS

### 2.3.1 LAYOUT AND GROUPING OF CONTROLS AND DISPLAYS.

- The position of the controls shall be such that when the driver is intentionally engaging one control, inadvertent engagement of other controls is highly unlikely.
- If controls are located on panels separate from their associated displays, the control and display panels should be adjacent to each other.
- Related controls and displays should be located near one another and arranged in functional groups (for example, power, status, and test). The groups should be easily identifiable as related groups by enclosing them with a line marked on the panel or color-coding.

#### NOTE

For an arrangement within groups where sequential operations follow a fixed pattern, controls should be arranged to facilitate operation. If the controls and displays within a functional group are not used in any specific sequence, they should be arranged either in accordance with their importance or their frequency of use and should be located to provide for left-to-right or top-to-bottom order of use, or both.

- The arrangement of functionally similar or identical primary controls and displays should be consistent from panel to panel throughout the system, equipment, or vehicle. Mirror-image arrangements should not be used.

### 2.3.2 CONTROL LOCATION.

- Primary controls shall not exceed 304.8 mm (12 in) from the right or left of the center point of the seat or 508 mm (20 in) above the seat reference height.
- Controls mounted on the vertical surface that require precise or frequent operation or are considered emergency controls shall be located 200 to 750 mm (8 to 30 in) above the sitting surface.
- Other secondary controls shall not exceed 457 mm (18 in) right or left and 812 mm (32 in) above the seat reference. Emergency and secondary controls that require precise adjustments should be no more than 381 mm (15 in) to each side and 762 mm (32 in) above the seat.
- Controls shall not obscure the display. Similarly, the operator's hand shall not obscure the display while he or she is operating the control.

- ❑ The complexity and precision of controls should not exceed the operator's manipulative capability, including manual dexterity, coordination, and reaction time, under the dynamic conditions and environment in which his or her performance is expected to occur.

2.3.3 DISPLAY LOCATION. Display faces should be perpendicular to the maintainer's line of sight and shall be less than 45 degrees from the line of sight as illustrated in figure 2-3. Parallax should be minimized.

- ❑ Displays that must be read precisely and frequently shall be located in an area 360 to 810 mm (4 to 32 in) above the sitting surfaces, and no farther than 530 mm (21 in) laterally from the centerline. Displays shall not be located any closer than 330 mm (13 in) from the operator.
- ❑ If an operator needs to manipulate a control while observing more than one display, the display should be placed as near as possible to all of the related controls and should not exceed 64 mm (2.5 in) from the eye reference point of a seated operator.
- ❑ Important, critical, and frequently used displays should be located in the optimum visual field as illustrated in figure 2-5. Furthermore, they should occupy a privileged position in that field (for example, the top or left-most position) or they should be highlighted in some manner.
- ❑ Emergency display should be located where they can be seen quickly and easily (e.g., warning lights within a 30-degree cone of the operator's normal line of sight).

#### 2.3.4 GENERAL DISPLAY CHARACTERISTICS.

- ❑ Legibility: Displays shall be legible under all anticipated viewing conditions.
- ❑ Display Information: Information should be presented in a directly usable form (i.e., operators shall not have to transpose, compute, interpolate, or mentally translate the information displayed into other units).
- ❑ Display Font Characteristics: Where users must read quickly under adverse conditions (e.g., poor lighting), a sans serif style should be used.
- ❑ Contrast: Contrast between light characters and a dark screen background should be not less than 6:1 (10:1 preferred); contrast between dark characters and a light screen background should be not less than 1:6 (1:10 preferred).

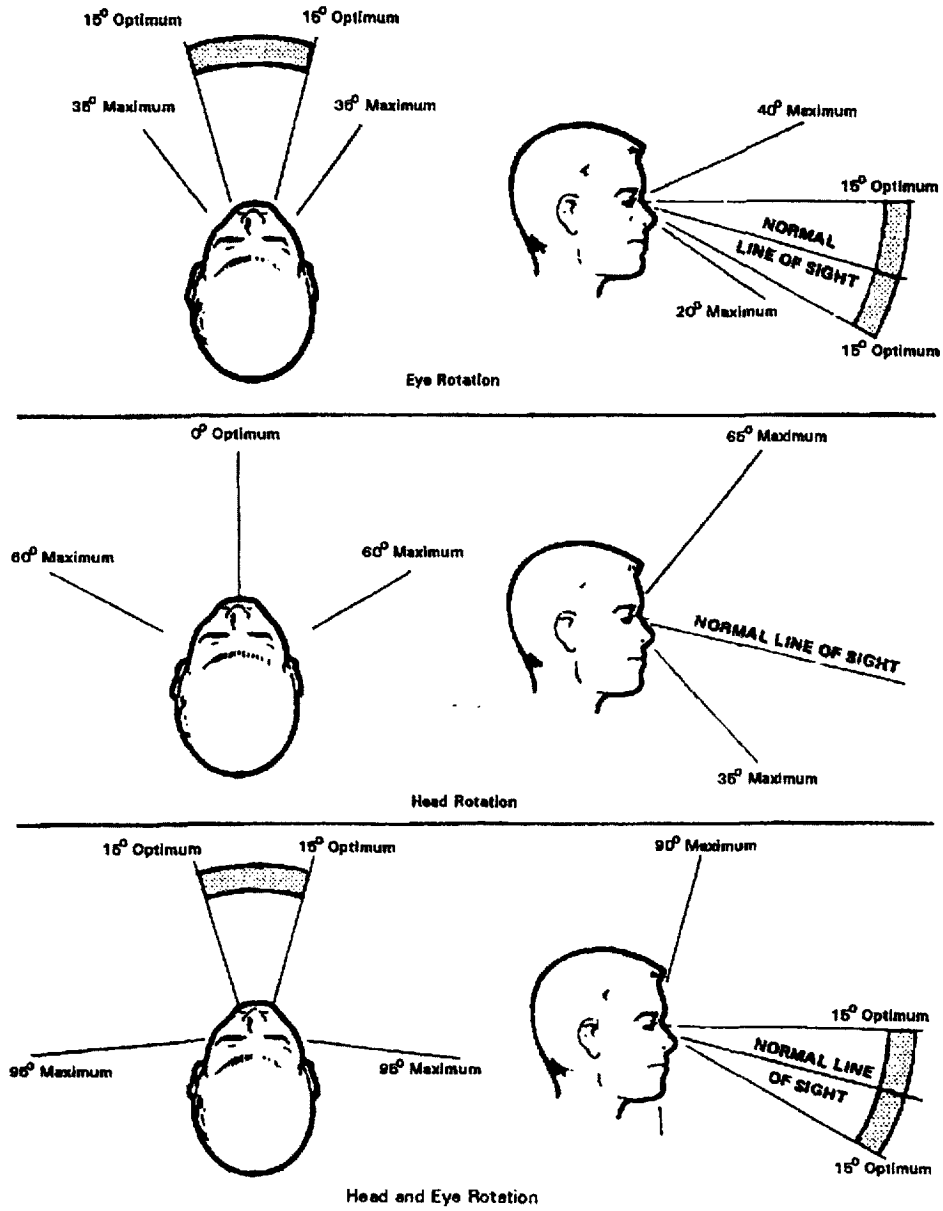


Figure 2-5. Optimum Vertical and Horizontal Visual Fields



- ❑ **Foreground/Background Colors on Displays:** The contrast between graphics, text, or symbols and the display background shall be sufficiently high to ensure visibility and readability. In general, colors for symbols and text shall differ from their background by a minimum of 100  $\Delta E$  (CIE  $Lu^*v^*$ ) distances. [The Commission Internationale de l'Eclairage (CIE) is an international organization dedicated to the measurement, specification, and standardization of color and lighting. The CIE  $Lu^*v^*$  (also called CIELUV) is a color relational system based on the 1976 Uniform Color space where L represents the black-white (luminance),  $u'$  represents the red-green, and  $v'$  represented the yellow-blue coordinates of a color on a three-dimensional color diagram called the CIE 1976 Uniform Color Scale. The  $\Delta E$  is the distance between colors on the diagram. Additional information and a copy of the diagram can be obtained from the CIE or can be found in the book Using Computer Color Effectively (L.G. Thorell/W.J. Smith, Prentice Hall: Englewood Cliffs, New Jersey). To determine the CIE chromaticity coordinates of each CRT color, a spectral scan can be made using a device such as a Minolta Croma Meter CS-100]. The following color combinations shall be avoided:
- Saturated red with saturated blue
  - Red with orange
  - Red with purple
  - Light blue with dark blue
  - Dark blue with medium blue
  - Kelly green with army green
  - Green with gray
- ❑ **Numeric Digital Displays:** Numeric digital displays should be used when precision of displayed information is important but should not be used as the only display of information when the pattern of variation is important for accurate perception or when rapid or slow digital display rates inhibit accurate perception.
- ❑ **Display Complexity:** The complexity and precision of displays should not exceed the ability of the operator/maintainer to discriminate detail.

### 2.3.5 DISPLAY RESPONSE TO CONTROL.

- ❑ **Basic Display-Control Relationships:** The relationship of a control to its associated display and a display to its associated control should be immediately apparent and unambiguous to the operator.

- ❑ **Consistency of Movement:** Direction of control movement should be consistent with any related movement of an associated display or equipment component. In general, depressing a control or moving it forward, clockwise, up, or to the right should cause a quantity to increase or cause the display or equipment component to move forward, clockwise, or up.
  - **Moving Pointer, Circular Scale:** Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right should produce a clockwise movement of circular scale pointers and an increase in the magnitude of the reading.
  - **Moving Pointer, Linear Scale:** Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right should produce a movement up of a pointer on a vertical linear scale and to the right of a pointer on a horizontal scale; in both cases, the control movement should result in an increase in the magnitude of the reading.
- ❑ **Display/Control Feedback:** A display associated with an input control device should provide feedback so rapidly that the operator perceives it to be instantaneous.

#### 2.3.6 GENERAL CONTROL CHARACTERISTICS.

- ❑ **Control Separation:** The separation between two controls shall be a minimum of 25.4 mm (1 in). Spacing should be increased as appropriate to accommodate the wearing of gloves or other protective handwear. Some controls (e.g., foot pedals, joysticks, rotary controls, etc.) have additional separation requirements, which can be found in the detailed control guidelines below.
- ❑ **Feedback:** All controls shall provide a positive indication of control activation by tactile feedback (snap feel), an audible click, or an integral light.
- ❑ **Detent Stops:** If a system or unit of equipment requires operation of a control in discrete steps, a control having detent stops should be used.
- ❑ **Limit Stops:** If a control does not have to be operated beyond indicated end positions or specified limits, it shall have stops at the beginning and end of the range of control positions.
- ❑ **Blind Operation:** Where “blind” operation is necessary and controls are not separated by 127 mm (5 in), controls should be shape-coded. Shape-coding may be used to ensure identification of control knobs or handles by “feel” where visual identification is not possible, where diversion of operator visual attention to identify the proper control would detract from mission accomplishment, or where the consequences of incorrect control selection would be severe. When shape-coding is used:
  - The coded feature should not interfere with ease of control manipulation.

- Shapes should be identifiable by hand and by eye regardless of the position and orientation of the control knob or handle.
  - Shape-coded knobs and handles should be positively and nonreversibly attached to their shafts to preclude incorrect attachment when replacement is required.
  - Shapes should be associated with or resemble the control function and not alternate functions.
- Prevent Accidental Actuation:** Controls shall be designed and located so they are not susceptible to being moved accidentally, particularly critical controls whose inadvertent operation might cause damage to equipment, injury to personnel, or degradation of system functions. If a control must be protected from accidental actuation, one or more of the following methods shall be used:
- Locate and orient the control so the operator is not likely to strike or move it accidentally in the normal sequence of control movements.
  - Recess, shield, or otherwise surround the control by physical barriers. The control should be entirely contained within the recess or barrier envelope.
  - Cover or guard the control. Safety or lock wire should not be used.
  - Interlock the control so extra movement (e.g., a side movement out of a detent position or a pull-to-engage clutch) or the prior operation of a related or locking control is required.
  - Provide the control with movement resistance (e.g., viscous or coulomb friction, spring loading, or inertia) so definite or sustained effort is required for actuation.
  - Lock the control to prevent it quickly passing through a position when strict sequential activation is necessary (i.e., the control is moved only to the next position, then delayed).
- Dead-Man Controls:** Wherever operator incapacity can produce a critical system condition, the crane shall incorporate dead-man controls that will result in system shutdown to a non-critical operating state when force or input is removed.
- Interlocks and Alarms:** Where practical, the critical position of a control that initiates hazardous operation (e.g., crane movement) should activate visible and audible warning signals in the affected work area.
- Consistency of Use:** A control used for a critical/emergency function should be dedicated to that function only.

### 2.3.7 FAILURE INDICATORS.

- Use of Failure Indicators: Failure indicators shall inform the user of an equipment malfunction. Indicators should be provided for:
  - Equipment failures
  - Equipment out-of-tolerance conditions
  - Equipment overload (even if overloaded equipment remains in operation)
  - Power failures
  - Open circuits resulting from fuse or circuit breaker operation
  - Failure of a display or display circuit
  - Loss of redundancy (display should remain on until redundant unit is restored)

## 2.4 DETAILED GUIDELINES FOR CONTROLS AND DISPLAYS

Use the following guidelines for optimal selection and placement of commercially available controls and displays. If a particular control to be used does not appear in this section, refer to MIL-STD-1472 for specific guidelines.

### 2.4.1 FOOT-OPERATED CONTROLS AND PEDALS.

- When To Use Foot-Operated Controls: Foot-operated controls should be used only if an operator can be expected to have both hands occupied when activation is required. Foot-operated controls shall be guarded to prevent accidental activation. Their use should be limited to noncritical or infrequent operations, such as press-to-talk communication. Foot-operated controls shall not be used when precise control actions or movements are required or selection from many controls is required.
- Operation of Foot Controls: Foot controls shall be located and designed so they can be operated in as natural a way as practicable. They shall be positioned for operation by the toe and ball of the foot rather than by the heel. The following should be avoided:
  - Frequent, maximum reaching.
  - Requiring the leg or foot to be held in an awkward position for extended periods of time.
  - Requiring frequent or prolonged application of maximum force.

- Requiring an operator to search for a particular foot control in order to select the proper one.
  - Placing a foot control where it might be stepped on and actuated inadvertently.
  - Using a foot pedal design that creates conditions in which the foot or clothing might be entrapped by an intervening control as an operator moves the foot from one control to another.
- Size: The foot pedal shall have a rectangular shape and be a minimum width of 88.9 mm (3.5 in) and a minimum height of 25 mm (1 in). Preferably, the height of the foot pedal should be 110 mm (4.5 in) or greater.
  - Resistance: The resistance of the pedal shall be a minimum of 45 N (10 lb) and shall not exceed 150 n (33.7 lb).
  - Displacement: The displacement of the foot pedal should be a minimum of 13 mm (0.5 in) and shall not exceed 63.5 mm (2.5 in).
  - Pedal Angle: The pedal angle should be less than 20 degrees. If required, the pedal angle can exceed 20 degrees from the horizontal floor; however, a heel rest should be provided.
  - Pedal Return: Pedals shall return to the original null position without requiring assistance from the operator.
  - Separation Between Pedals: One switch per foot is recommended. If it is necessary that more than one switch be operated by the same foot, those switches should be separated by at least 75 mm (3 in) horizontally and 200 mm (8 in) vertically.
  - Nonslip Pedal Surface: Pedals shall be provided with a nonskid surface. Similar surfaces are desirable for all pedals.

#### 2.4.2 ROTARY CONTROLS.

- When To Use Rotary Controls: If a switch must have three or more detent positions, a rotary selector switch should be used. If only two positions are needed, a rotary switch should not be used unless prompt visual identification of the switch position is of prime importance and if speed of control operation is not critical.
- Shape: Moving pointer knobs should be bar-shaped, with parallel sides and with the indicating end tapered to a point.

- ❑ **Size:** The length of the rotary control knob shall be a minimum of 25 mm (1 in) and shall not exceed 100 mm (4 in). The width shall be a minimum of 25 mm (1 in). The height of the control shall be minimum of 16 mm (0.6 in) and shall not exceed 75 mm (3 in).
- ❑ **Resistance:** The turning resistance of a rotary switch shall increase between adjacent positions so the switch will not stop between the positions but rather will "snap" into one of the positions. The resistance shall be a minimum of 115 mN-m (1 in-lb) and shall not exceed 680 mN-m (6 in-lb).
- ❑ **Displacement:** The displacement of a rotary control should a minimum of 15 degrees and shall not exceed 40 degrees.
- ❑ **Separation:** The minimum separation between controls shall be 25 mm (1 in) for a one-hand control operation and 75 mm (3 in) for a two-hand control operation. The preferred separation is 50 mm (2 in) for one-hand operation and 125 mm (5 in) for two-hand operation.

#### 2.4.3 KEY-OPERATED SWITCHES.

- ❑ **When To Use Key-Operated Switches:** Key-operated switches should be used to prevent unauthorized operation (e.g., on and off system operation).
- ❑ **Size:** The key-operated switch shall have a height of 13 to 75 mm (0.5 to 3 in).
- ❑ **Teeth on Both Edges:** The key for the switch should have teeth on both edges and should fit the lock with either side up or forward.
- ❑ **Resistance:** The key-operated switch resistance shall be a minimum of 115 mN-m (1 in-lb) and shall not exceed of 680 mN-m (6 in-lb).
- ❑ **Displacement:** The key should turn a minimum of 30 degrees and a maximum of 90 degrees.
- ❑ **Direction of Rotation:** Key-operated on-off switches shall be positioned so the key is vertical when the switch is off. The key should be turned clockwise from the vertical off position to the on position at the 90-degree clockwise position.
- ❑ **Key Removal:** Operators shall be able to remove the key from the switch only when the switch is in the off position.

#### 2.4.4 SINGLE-FINGER MOMENTARY PUSHBUTTONS.

- ❑ **When To Use Pushbuttons:** Pushbuttons should be used if a control is needed for momentary contact or to activate a locking circuit, particularly if the control will be used frequently. Pushbuttons should not be used if the status of a function must be indicated by the position of its control.

- ❑ **Shape:** All single-finger momentary pushbuttons should be square.
- ❑ **Size:** The single-finger momentary pushbutton shall be no smaller than 25.4 mm (1 in) and should have a concave surface. Large hand/fist-operated mushroom-shaped pushbuttons shall only be used as emergency stop controls.
- ❑ **Resistance:** The resistance shall be a minimum of 2.8 N [10 ounces (oz)] and shall not exceed 11 N (40 oz). The preferred resistance range is 2.8 N (10 oz) to 5.6 N (20 oz).
- ❑ **Displacement:** The displacement should be a minimum of 2 mm (0.08 in) and shall not exceed 6 mm (0.25 in). The preferred displacement is between 2 mm (0.08 in) and 3.8 mm (0.15 in).
- ❑ **Movement Direction:** The pushbutton shall be activated by pushing it down, and it should automatically return to its original position when released. Preferably, there should be an elastic resistance aided by slight sliding friction, starting slowly, building rapidly, and with a final sudden drop to indicate activation.
- ❑ **Separation:** There shall be a minimum separation of 25 mm (1 in) between pushbuttons. Where possible, the separation between pushbuttons should be 50 mm (2 in).
- ❑ **Color:** The same color should be used for all pushbuttons. The color should provide a high contrast with the console.
- ❑ **Barriers:** All pushbuttons [with the exception of the emergency stop (E-stop)] shall be surrounded by a physical barrier that prevents accidental activation. The barrier shall be a minimum width of 3 mm (0.125 in) and a minimum depth of 5 mm (0.2 in).

#### 2.4.5 ILLUMINATED LEGEND PUSHBUTTONS.

- ❑ **Shape:** All illuminated legend pushbuttons should be square or rectangular and should have a concave surface.
- ❑ **Size:** The illuminated legend pushbutton shall be no smaller than 25.4 mm (1 in). The preferred size is 38 to 50.8 mm (1.5 to 2.0 in).
- ❑ **Resistance:** The resistance shall be a minimum of 2.8 N (10 oz) and shall not exceed 11 N (40 oz) of force. The preferred resistance range is 2.8 N (10 oz) to 5.6 N (20 oz).
- ❑ **Displacement:** The displacement should be a minimum of 2 mm (0.08 in) and shall not exceed 3.8 mm (0.15 in).
- ❑ **Movement Direction:** The pushbutton shall be activated by pushing it down and it should automatically return to its original position when released. Preferably, there should be an

elastic resistance aided by slight sliding friction, starting slowly, building rapidly, and with a final sudden drop to indicate activation.

- Separation:** There shall be a minimum separation of 25 mm (1 in) between illuminated legend pushbuttons and other controls. Where possible, the separation should be 50 mm (2 in).
- Color:** All illuminated pushbuttons that provide general system status should be white opaque background. The color of letters on the pushbutton should be black or dark blue and should provide a high contrast with the background.
- Barriers:** All illuminated legend pushbuttons (with the exception of the E-stop) shall be surrounded by a physical barrier that prevents accidental activation. The barrier shall be a minimum width of 3 mm (0.125 in) and a minimum depth of 5 mm (0.2 in).

#### 2.4.6 MUSHROOM-SHAPED PUSHBUTTONS.

A RED mushroom-shaped pushbutton shall provide a manual mechanism for an immediate safe shutdown of the system, which removes all power from the crane and subsequently sets all brakes. This pushbutton shall be manually reset by pulling up. This button shall be labeled EMERGENCY STOP.

- Size:** The mushroom-shaped pushbutton shall have a diameter greater than 19 mm (1.5 in) and shall have a slightly convex surface. This button shall be designed to be operated with the palm of the hand or a fist.
- Resistance:** The mushroom-shaped pushbutton shall provide a minimum resistance of 2.8 N (10 oz) and shall not exceed 23 N (80 oz) of resistance. The preferred resistance for the mushroom-shaped E-stop button is between 10 N (36 oz) and 23 N (80 oz).
- Displacement:** The mushroom-shaped pushbutton should provide 13 mm (0.5 in) to 38 mm (1.5 in) of displacement when pressed.
- Location:** The mushroom-shaped pushbutton shall be placed on the horizontal console surface within 596 mm (23.5 in) of the operator's position.
- Separation:** The mushroom-shaped emergency stop pushbutton should be separated from all other controls and displays by a minimum of 152 mm (6 in).

#### 2.4.7 TOGGLE SWITCHES.

- When To Use Toggle Switches:** Toggle switches should be used for functions that require two discrete positions or where space limitations are severe.



- ❑ **Size:** The arm of the toggle switch shall be a minimum length of 13 mm (0.5 in) and shall not exceed a length of 50 mm (2 in). The tip of the arm shall be a minimum of 3 mm (0.13 in) and a maximum of 25 mm (1 in).
- ❑ **Resistance:** For small toggle switches, the resistance shall be a minimum of 2.8 N (10 oz) and shall not exceed 4.5 N (16 oz). If a large toggle switch is used [e.g., 50-mm (2-in) arm length] the maximum resistance is 11 N (40 oz). The resistance of a toggle switch should increase as the switch is moved toward its midpoint, then decrease as the switch "snaps" into its alternate position. The switch shall not be capable of remaining between positions without being held.
- ❑ **Displacement:** The displacement of a two-position toggle should be a minimum of 30 degrees and shall not exceed 80 degrees. The minimum displacement of a three-position toggle shall be 17 degrees and shall not exceed 40 degrees. The preferred displacement is 25 degrees.
- ❑ **Orientation:** Toggle switches shall be vertically oriented with OFF in the down position. Horizontal orientation and actuation of toggle switches should be used only for compatibility with the controlled function or equipment location.
- ❑ **Separation:** The minimum separation between toggle switches and other controls or toggles shall be at least 25.4 mm (1 in). The preferred separation is 50.8 mm (2 in).
- ❑ **Preventing Accidental Actuation:** If actuation might result in a critical or hazardous condition, the switch shall be protected. Protection should be by means of a barrier or a cover and shall not be by lock wire. When a toggle switch cover is used, the resistance to lifting a cover should not exceed 13 N (3 lb) and the cover should not interfere with the operation of the switch or of adjacent controls when it is open.

#### 2.4.8 ROCKER SWITCHES.

- ❑ **When To Use Rocker Switches:** Rocker switches should be used for functions requiring two discrete positions. They should be used rather than toggle switches if a toggle switch handle might interfere with or be interfered with by surrounding activity (e.g., operator's clothing or phone cord) or when the panel space is too limited for the labeling of toggle switch positions.
- ❑ **Operation:** Actuation of the upper portion, that is, depressing it, should turn the equipment or component ON, cause a quantity to increase, or cause movement of a unit equipment or a component clockwise, forward, up, or to the right.
- ❑ **Size:** The rocker switch shall have two distinct faces, each with a width of at least 6 mm (0.25 in) but preferably 10 mm (0.4 in). The switch should have a face length of at least 13 mm (0.5 in).

- ❑ **Resistance:** The resistance shall be a minimum force of 2.8 N (10 oz) and shall not exceed 11 N (40 oz). The preferred resistance range is between 2.8 N (10 oz) and 8 N (28.7 oz). The resistance of a rocker switch should increase as the upper portion is pressed down or in and then decrease so the switch "snaps" into position.
- ❑ **Displacement:** The displacement should be a minimum of 3 mm (1.25 in). A rocker switch should not be capable of stopping between positions.
- ❑ **Angle:** The angle between the alternate faces of the switch should be 30 degrees.
- ❑ **Labeling:** The letters and numerals should be internally illuminated on an opaque switch background. The letter/number height should be 4.8 mm (3/16 in) with a height-to-width ratio of 3:2 and a stroke width ratio of 10:7.
- ❑ **Orientation:** The rocker switch should be vertically oriented.
- ❑ **Color:** Alternate color contrast on the two faces of the rocker switch should be used to provide a conspicuous cue of switch position.
- ❑ **Preventing Accidental Actuation of Rocker Switches:** If it is imperative that a rocker switch not be operated inadvertently (for example, if actuation might result in a critical or hazardous condition), the switch shall be protected (for example, with a channel guard, barrier, cover, or an equivalent protective measure).

#### 2.4.9 SLIDE SWITCHES.

- ❑ **When To Use Slide Switches:** Slide switch controls may be used for functions that require two discrete positions or a high number of discrete positions in which the switches are arranged in a matrix to permit easy recognition of relative switch settings. Slide switches should not be used where incorrect positioning is to be avoided. Their use should be limited on crane consoles.
- ❑ **Size:** The slide switch shall have a width of at least 6 mm (0.25 in) and a maximum width of 25 mm (1.0 in). The height of the slide switch should be a minimum of 6 mm (0.25 in) for use by a bare hand and a minimum of 13 mm (0.5 in) for use by a gloved hand.
- ❑ **Resistance:** For a small switch, the resistance shall be a minimum of 2.8 N (10 oz) and shall not exceed 4.5 N (16 oz). For a large switch, the resistance shall be a minimum of 2.8 N (10 oz) and shall not exceed 11 N (40 oz).
- ❑ **Orientation:** The slide switch should be vertically oriented. Movement of the switch up or away from the operator shall turn the equipment on or cause a quantity to increase or move clockwise, up, or to the right. Horizontally oriented slide switches should be used only for compatibility with the control and the equipment.

**2.4.10 JOYSTICKS.** All cab-operated cranes shall be equipped with displacement joysticks. The joysticks should be of the continuous-effect type that will not unduly tire the operator during lengthy operations. When a displacement joystick is used for rate control, the joystick should be spring-loaded so that it returns to center when released.

- Size:** All joysticks placed on one console should be shape-coded. The joysticks that are separated by less than 12.7 mm (5 in) shall have different size shafts and/or shaped grips so that the crane operator can differentiate between joysticks by feel.

  - If a round top is used, it should have a palm grip that is a minimum of 50 mm (2 in). If a cylinder-top handgrip is used, it should have a palm grip equal to or between 25 and 32 mm (1 and 1.25 in) with 120 mm length (4.5 in).
  - The grip diameter should not exceed 50 mm (2 in).
  - The handgrip length of a hand-operated displacement joystick should be in the range of 110 to 180 mm (4.3 to 7.1 in). Clearance should be at least 100 mm (4 in) to the side and 50 mm (2 in) to the rear.
- Specific Use of Buttons on Joysticks:** When buttons are located on hand-operated joysticks, they shall be operable using a normal grip without diminishing control of the joystick. Thumb-operated buttons shall not be used. Finger-operated buttons shall be a minimum of 50 mm (2.0 in) and designed so they can be activated by two to three fingers.
- Resistance:** The joystick shall have a forward/backward resistance that is a minimum of 40 N (145 oz) and a maximum of 80 N (290 oz). Where possible, the forward/backward resistance should be 60 N (215 oz). The joystick shall have a lateral (left/right) resistance that is a minimum of 20 N (72 oz) and shall not exceed 60 N (215 oz). Where possible, the lateral resistance should be 40 N (145 oz).
- Displacement:** The displacement of the joystick should not exceed 45 degrees. A joystick that moves forward/backward shall have a displacement no greater than 360 mm (14 in). A joystick that moves from left to right shall have a displacement no greater than 965 mm (38 in).
- Movement Direction:** The direction of joystick movement will correspond to the direction of load movement north, south, east, and west. When the hoist joystick is pushed forward, it should produce a corresponding downward movement of the hook. When the hoist joystick is pulled backward, it should produce an upward movement of the hook.
- Separation Between Joysticks:** A minimum of 127 mm (5 in) shall be provided between joysticks. A minimum of 50.8 mm (2 in) clearance shall be provided between the joystick and the edge of the console.

- Location:** The joystick for the bridge and trolley travel should be located so the operator can readily face the direction of travel. The arrangement of the joysticks shall be as follows: from left to right – bridge, trolley, and hoist, conforming to CMAA specifications. The joysticks should be located on the horizontal console surface within 390 mm (15.5 in) of the seated operator.
- Response Delay:** Delay between the joystick movement and the confirming display response should be minimized and should not exceed 0.1 s.
- Preventing Accidental Actuation of Joysticks:** Joysticks should be provided with a notch or latch which in the “off” position prevents the handle from being inadvertently moved to the “on” position. An “off” detent or spring return arrangement is acceptable.

#### 2.4.11 KEYPAD AND KEYBOARD.

- Design:** Where possible, a standard Qwerty design or numeric keypad should be used.
- Keytop Size:** The minimum horizontal strike surface of each key shall be 12 mm (0.47 in). The keys may be any shape, provided spacing requirements are not violated.
- Key Resistance:** The keys shall have a minimum resistance of 0.25 N (0.9 oz) and shall not exceed a resistance of 1.5 N (5.4 oz).
- Displacement:** The preferred vertical displacement (key travel distance) is 2 to 4 mm (0.08 to 0.16 in). The keys should have a minimum displacement of 1.5 mm (0.06 in) and shall not exceed a displacement of 6 mm (0.24 in).
- Adjustable Slope:** The keypad should have an adjustable slope that provides an angle from 0 to 15 degrees.
- Key Spacing/Separation:** The horizontal centerline distances between adjacent keys should be between 18 and 19 mm (0.71 and 0.75 in). The vertical centerline distances between adjacent keys should be between 18 and 21 mm (0.71 and 0.82 in).
- Key Texture:** A 1.0 mm (0.04 in) texture or ridge should be placed on center key for tactile position indication of center key.

#### 2.4.12 INDICATOR LIGHTS.

- When to use:** Indicator lights should be used to display qualitative information that requires immediate attention or an immediate response. They may also be used occasionally, if appropriate, to display maintenance and adjustment information. Their use, however, should be minimized and reserved for displaying only that information necessary for effective operation and maintenance.

- ❑ **Size:** Indicator lights shall be a minimum of 13 mm (0.5 in) in diameter. The preferred size is 16 mm (1 in) in diameter.
- ❑ **Shape:** Indicator lights shall be round with an extended lens to increase the viewing angle.
- ❑ **Light Intensity:** The light produced shall be twice as bright as the immediate background. The light should be at a minimum 10 percent greater than the luminance of the cab and glare. The luminance should not exceed 300 percent of the cab luminance.
- ❑ **Time Lags:** Once the system detects a malfunction, the warning light should illuminate. No time lag should occur between the malfunction and the illumination.
- ❑ **Lamp Redundancy:** Where possible, the filament/bulb of the indicator light should be redundant.
- ❑ **Lamp Replacement:** Lamps should be removable and replaceable through the front of the display panel. Removal and replacement of lamps should not require the use of tools.
- ❑ **Meaning of No Illumination on Displays:** The absence or removal of the illumination of a transilluminated display shall not be used to indicate a malfunction, “no-go,” or out-of-tolerance condition. For maintenance displays, the absence of illumination should not indicate a “power off” condition. In contrast, the absence of illumination is acceptable to indicate power off for an operational display. The absence of light shall not indicate a “ready” or in-tolerance condition unless the operator can easily test the bulb.
- ❑ **Lights on Maintenance Displays:** Indicator lights used solely for maintenance and adjustment should be covered or nonvisible during normal operation of the equipment but should be readily accessible when needed.
- ❑ **Color of Indicator Lights:** When an indicator light is used to represent a specific meaning (e.g., danger, caution, go ahead), the color coding of the light shall conform with the color-coding standards of simple indicator lights presented in table 2-2. This does not preclude the use of additional colors to represent other meanings.

#### 2.4.13 ANALOG DISPLAYS.

- ❑ **Size:** The display size must allow for all numbers on a scale to be printed in 4.7-mm (0.18-in) font or larger, without crowding. It should also be large enough to allow all graduation marks to be printed on a display face without crowding.
- ❑ **Shape:** A semicircular shape is preferred over other shaped analog displays.
- ❑ **Pointer:** The pointer should be mounted close to the face of the dial to minimize parallax. It should extend to but not overlap scale graduation marks. The tip should be tapered to a 20-

degree angle on each side (total 40-degree angle) equal in width to the minor graduation marks.

- Pointer Color:** The tip to the center of the dial should be the same as the color of the marks. The tail of the pointer should be the same color as the dial face, unless the tail is used as an indicator itself or unless the pointer is used for horizontal alignment. The luminance contrast ratio between scale face and markings and pointer should be at least 3:1.

Table 2-2. Color Coding of Simple Indicator Lights

Size/Type	Red	Yellow	Green	White
13 mm (0.5 in) diameter/steady	Malfunction, action stopped, failure, stop	Delay, check, recheck, acceptable, action	Go ahead, in tolerance, ready	Functional or physical position, action in progress
25 mm (1 in) diameter or larger/steady	Master summation (system or subsystem)	Extreme caution (impending danger)	Master summation (system or subsystem)	
25 mm (1 in) diameter or larger/flashing (3 to 5 per s)	Emergency condition (impending personnel or equipment disaster)			

- Placement of Pointers:** Pointers should be located to the right of vertical scales and at the bottom of horizontal scales. For circular scales, the alignment of the pointer or fixed reference line should be in the 12 o'clock position for right-left directional information and in the 9 o'clock position for up-down information. For purely quantitative information, either position may be used on a circular scale.
- Numerical Progression:** Numerical values should increase on fixed scales in the clockwise direction on curved scales, from left to right on horizontal scales, and from bottom to top on vertical scales.
- Orientation:** All numbers and text should be oriented in an upright horizontal position.
- Location of Numbers:** Numbers on the side of graduation marks should be placed away from the pointer so the pointer does not obscure the numbers.
- Size of Graduation Marks:** The height of the largest graduation mark shall be no greater than 90 mm (3.5 in).
- Intermediate Marks:** There should be no more than nine intermediate marks between numbered scale markers.

- Scale Starting Point: Display scales should start at zero unless this is inappropriate for the information displayed.
- Coding on Display Face: Coding, for example, by pattern or color, should be used on the faces of scale indicators to convey such information as desirable, undesirable, or inefficient operating ranges; dangerous operating levels; warnings; and cautions.

#### 2.4.14 CRT/LCD

- Raster Modulation: The CRT raster modulation should be less than 20 percent.
- Adjustable Luminance: A control should be provided to vary luminance from 10 percent of minimum ambient luminance to full luminance. The highest luminance, either character or background, should be 35 candela per square meter ( $\text{cd/m}^2$ ) [10 foot lamberts (fL)] or more.
- Flicker Free: The CRT refresh rate and other parameters (such as duty cycle, brightness, contrast, color, and motion) should be adjusted to provide a flicker-free display.
- Installation: The face of the display should be flush with the surface of the panel in which it is installed.

2.4.15 HUMAN COMPUTER INTERFACE DESIGN. The software program shall be developed with the following features.

- Consistency:
  - The display of data shall remain consistent from screen to screen.
  - Similar parameters shall be displayed the same way.
  - Similar messages shall be displayed in the same way and in the same location.
  - Similar actions shall be required to produce similar results on the screen.
  - Standard abbreviations and terminology shall be used. Wording of text data shall be limited to commonly understood terms.
  - The character set, screen layouts, and color schemes shall be consistent from screen to screen.

Effective Feedback:

- Response time between control inputs and displays shall be minimized.
  - Graphical or alphanumeric displays shall be selected based on the type of data to be presented.
  - The character set shall use a minimum 7:9 width-to-height ratio for tasks that require continuous reading; minimum 5:7 ratio for general numeric and uppercase text; and 4:5 minimum for superscripts, fractions, or text not directly related on the task.
  - Use of color shall support task display, incorporating common color stereotypes for the intended user community.
  - Graphical displays shall be designed as monochrome to start, with color added later as required for enhancement.
- 
- Cautions and warnings shall have a method for being acknowledged and turned off.
  - Help screens shall have a method for choosing a subsequent action.
  - The effect of a control input shall be displayed on the screen to give the user feedback.
  - The program shall have an "Undo" function that is activated by the keypad to reverse user commands.
  - The program shall contain a feature to prevent data from being lost in the event a keypad command or pushbutton is inadvertently activated. If an erroneous command is entered, the program shall leave the system state unchanged or display a prompt on how to restore the system to its proper state.
  - Proficient users should have optional methods of controlling the display that eliminate functional steps (e.g., going from a two-function display to the third display without having to reset the entire display). This may not be appropriate for all functions.
  - Troubleshooting or built-in-test (BIT) displays shall be selectable so users will be able to examine only what is required for the particular event.
  - The program shall be written to give the user the capability to control the display so required actions can be performed easily and necessary information is readily obtained.
  - The program shall be written to reduce the number of unanticipated displays that may appear.



- ❑ The program shall be written so data required to perform an action is displayed at the time it is required.

#### 2.4.16 VISUAL WARNINGS AND SIGNALS.

- ❑ Failures that require immediate operator action to avert impending injury, equipment damage, or both should initiate an emergency alarm (visual or auditory).
- ❑ An alerting and warning system or signal should provide the operator with a greater probability of detecting the triggering condition than his or her normal observation would provide in the absence of the alerting or warning system or signal. An emergency alarm generated by a visual display shall:
  - Use a flashing red light 3 to 5 Hz, with a 50-percent duty cycle (if the flasher fails, the light should illuminate and burn steadily). If multiple flashers are visible, they should be synchronized.
  - Be clearly noticeable under all anticipated lighting conditions.
  - Be conspicuously different from general area lighting.
  - Have a specific meaning within the operational area where they are used.
  - Be singular in purpose yet comprehensive in meaning (not refer to other warnings).
  - Transmit all essential information in the first 5 seconds.
  - Be visible from all locations, including bridge and trolley topside.
- ❑ Alarm Parameter Selection: If applicable, the limits or set points that initiate an alarm or warning display should be set so the alarm gives operators adequate time to respond to the condition before it becomes more serious.
- ❑ Text Height for Visual Warnings: Text for visual warning and caution signals shall be presented using characters between 8.7 milliradians (mrad) and 17.4 mrad (30 and 60 minutes of subtended arc) as measured from the longest anticipated viewing distance, with the larger size used where conditions may be adverse. For a viewing distance of 0.5 m (20 in), this equals 4.4 mm (0.174 in) to 8.8 mm (0.349 in).
- ❑ Automatic Clearing of Alarms: The equipment or system that triggers an alarm shall clear the alarm automatically when the triggering condition no longer exists.

- Out-of-Service Alarms: If an alarm fails, the system should provide a prompt indication of the failure.
- Testing of Alarms: One or more controls should be provided to permit the testing of alarms.

#### 2.4.17 AUDIO SIGNAL DISPLAYS

- When To Use Audio Signal Displays: An audio display should be provided if any of the following conditions apply:
  - The criticality of a response to a visual signal makes supplementary or redundant alerting desirable.
  - It is desirable to warn, alert, or cue the operator for subsequent or additional responses.
  - Voice communication is necessary or desirable.
- Signal Type: When an audio presentation is required, the optimum type of signal shall be presented in accordance with table 2-3. Audio signals shall not interfere with other sound sources, including verbal communication.

#### 2.4.18 AUDIO WARNINGS AND SIGNALS.

- Relation to Visual Displays: If used in conjunction with a visual display, an audio warning device should be supplementary or supportive. The audio signal should be used to alert and direct the operator's attention to the appropriate visual displays.
- Automatic Reset: An automatic reset function for audio signals shall be provided, whether the signals are designed to terminate automatically, manually, or both. The automatic reset function should be controlled by a sensing mechanism that recycles the signal system to a specified condition as a function of time or the state of the signaling system so the warning device can sound again if the condition reappears.
- Two-Element Signals: An alerting signal of 0.5-s duration should be provided by an identifying or action signal. All essential information should be transmitted in the first 2.0 s of the identifying or action signal.
- Frequency Range: The frequency range of a warning signal shall be between 200 and 5,000 Hz. The preferred range is between 500 and 3,000 Hz.
- Audibility: Alarms should exceed the prevailing ambient noise level by at least 10 dB or any maximum sound level with a duration of 30 s by at least 5 dB, whichever is louder. The alarm shall not exceed 115 dB at the ear of the listener.

- The audio display device and circuit should be designed to preclude warning signal failure in the event of system or equipment failure and vice versa.

Table 2-3. Functional Evaluation of Audio Signals

Function	Type of Signal		
	Tones (Periodic)	Complex Sounds (Nonperiodic)	Speech
Quantitative Indication	<u>Poor</u> Maximum of 5 to 6 tones absolutely recognizable.	<u>Poor</u> Interpolation between signals inaccurate.	<u>Good</u> Minimum time and error in obtaining exact value in terms compatible with response.
Qualitative Indication	<u>Poor-to-Fair</u> Difficult to judge approximate value and direction of deviation from null setting unless presented in close temporal sequence.	<u>Poor</u> Difficult to judge approximate deviation from desired value.	<u>Good</u> Information concerning displacement, direction, and rate presented in form compatible with required response.
Status Indication	<u>Good</u> Start and stop timing. Continuous information where rate of change of input is low.	<u>Good</u> Especially suitable for irregularly occurring signals (e.g., alarm signals).	<u>Poor</u> Inefficient, more easily masked, problem of repeatability.
Tracking	<u>Fair</u> Null position easily monitored, problem of signal-response compatibility.	<u>Poor</u> Required qualitative indications difficult to provide.	<u>Good</u> Meaning intrinsic in signal.
General	Good for automatic communication of limited information. Meaning must be learned. Easily generated.	Some sounds available with common meaning (e.g., fire bell). Easily generated.	Most effective for rapid (but not automatic) communication of complex, multidimensional information. Meaning intrinsic in signal and context when standardized. Minimum of new learning required.

#### 2.4.19 SPEECH TRANSMISSION EQUIPMENT.

- Frequency Range: Microphones and associated system input devices should be designed to yield optimum response to the part of the speech spectrum most essential to intelligibility, that is, between 200 and 6,100 Hz. If the system necessitates a narrower speech transmission bandwidth, the range should be at least from 250 to 4,000 Hz.
- Dynamic Range: The dynamic range of a microphone used with a selected amplifier should be great enough to admit variations in signal input of at least 50 dB.

#### 2.5 LABELING

2.5.1 GENERAL REQUIREMENT. Each unit, assembly, subassembly, and part shall be labeled with a clearly visible, legible, and meaningful name, number, code, mark, or symbol, as applicable. This gross identifying label should be located externally in such a position that it is not obscured by adjacent items, on the flattest, most uncluttered surface available, or on a main chassis of the equipment. If appropriate, the unit should be etched or embossed into the surface for durability, rather than stamped, stenciled, or printed. In general, labels should be provided on equipment to:

- Locate and identify the equipment, controls, displays, access openings, test points, etc.
- Interpret and follow procedures.
- State warnings or cautions to avoid hazards.
- Supply critical instructions for servicing or maintenance of equipment if there is no other provision for them.
- Supply useful information, such as instructions, the weight of the equipment, or calibration information.
- Record or supply critical data to an operator if there is no other provision for them.
- Record and supply historical data, such as periodic readings or the date of servicing or replacement.
- Compass Label: All overhead cranes at KSC shall have a label indicating the primary compass points with the words "NORTH," "SOUTH," "EAST," and "WEST" (or "N," "S," "E," "W") aligned on the console in the proper direction and oriented so the text is read horizontally by the seated operator. This shall be accompanied by a north, south, east, west (or N, S, E, W) direction sign located beneath the crane in clear view of the persons on the floor handling the load.

□ Design of Labels:

- Labels shall be easily identifiable and shall be designed for accurate identification of information at the distance and illumination level at which they are intended to be used.
- Labels shall be supplemented where appropriate with other coding such as color and shape (as in warning or danger signs).
- Labels shall use boldface type to emphasize words or phrases.
- Labels shall list the steps in a series of instructions, not present them in paragraph form.
- Labels shall have consistent terminology.

- Character Height for Viewing Distance: Unless circumstances require otherwise, labels should be clearly legible at a viewing distance of 710 mm (28 in). The recommended height for letters and numerals at this distance is approximately 5 mm (0.18 in). Table 2-4 gives minimum character heights for other viewing distances.

Table 2-4. Minimum Character Heights for Other Viewing Distances

Viewing Distance	Minimum Height
Less than 0.5 m (20 in)	2.3 mm (0.1 in)
0.5 to 1.0 m (20 to 40 in)	4.7 mm (0.2 in)
1.0 to 2.0 m (40 to 80 in)	9.4 mm (0.4 in)
2.0 to 4.0 m (80 to 160 in)	18 mm (0.75 in)

- Text on Labels: The labeling specifications for the crane shall conform to the following:

- Character height in accordance with table 2-4.
- Stroke width of 1/6 to 1/7 of the height in normal illumination and 1/7 to 1/8 of the height in dim illumination.
- Width-to-height ratio of letters and numerals should be 3:5 (with the exceptions of "M" and "W," which should be 4:5; "4," which should be 4:5 of the height; and "I" and "1," which should be 1:5 of the height).
- Character Spacing: At least one stroke width.

- Word spacing: Between words, the space shall be one normal width character.
  - Line Spacing: At least ½ of character height.
  - Case of Letters: All capitals for single words, mixed case for phrases and sentences.
  - Font: San serif.
- Wording of Labels: The wording of labels shall:
- Be brief but explanatory.
  - Be familiar to operators and maintainers.
  - Use abbreviations and abstract terms only if it can be reasonably expected that all operators and maintainers will know them.
  - Be consistent with designations and terms in user documentation and parts catalogs.
- Text and Background Combinations: Text and background combinations shall provide sufficient contrast to ensure legibility. Black characters may appear on white, yellow, light gray, matte-finished brass or aluminum, or any bright-plated backgrounds; white character may appear on dark backgrounds; other acceptable combinations are blue on white and green on white.
- The design of graphic symbols for signs, safety messages, and labels shall conform to ISO 3864 and ISO 13200.
- Size Graduation Discussion: The characters identifying controls and displays should be larger than the characters identifying control positions. With the smallest characters determined by viewing conditions, the dimensions of each character should be at least approximately 25 percent larger than those of the next smaller label.
- Location of Labels:
- Labels shall be in a consistent location for all equipment, displays, and controls. Labels should be placed above the control or display they describe.
  - Labels shall be located so they are visible and readable with the equipment in the installed position.
  - The labels shall be positioned so the operator's hand, arm, or controls will not obscure them.

- The labels shall be located so they do not obscure any other needed information.
  - Labels shall be placed so opening or removing an access cover will not remove or obscure a hazard warning.
  - The labels shall be oriented so alphanumeric characters are read horizontally, not vertically.
  - Direction of movement shall be labeled on the display face.
  - Units of measurement (e.g., volts, psi, and meters) shall be labeled on the panel.
  - When a line is used to enclose a functional group, a label shall be centered at the top of the group.
  - Adjacent labels shall be sufficiently separated so they are not read as one continuous label.
- Control and Display Labels: Each control and display shall be labeled according to function. The following criteria apply:
- Similar names for different controls shall be avoided.
  - Instruments shall be labeled in terms of what is being measured or controlled, taking into account the user and purpose.
  - Control labels shall indicate the functional result of control movement (e.g., increase, ON, OFF) and may include calibration data where applicable. Such information should be visible during normal operation of the control.
  - All controls (e.g., joysticks) used to move the load shall be labeled as to function and direction of load movement.
  - When controls and displays must be used together to make adjustments, appropriate labels shall indicate their functional relationship.
- Access-Opening Labels: Each access opening shall be labeled with:
- A name, number, letter, or other symbol and referred to by that identification in maintenance instructions.
  - A conspicuous warning label advising the operator/maintainer of any hazard (if a hazard exists) and stating any necessary precautions.

- Instructions for opening the access cover if it is not obvious from the cover construction.
  - Identifiers for maintainable components accessible through the opening.
  - Information about equipment to be used in the maintenance tasks and procedural information about the tasks themselves.
- Hazard Labels on Equipment:** If any hazard exists in servicing or maintaining a unit of equipment, the equipment shall have a warning label attached that describes the hazard. All pinch hazard areas, low overhangs, and rotating equipment shall be identified and labeled.
- Labeling Heavy Units:** Weight and center-of-gravity caution placards shall be placed on any unit of equipment to be moved for maintenance if its weight exceeds 13.6 kilograms (kg) [30 pounds (lb)]. Any unit of equipment designed to be lifted or carried by more than one person should be labeled prominently with its weight and the number of people recommended to lift or carry it. Where mechanical or power lift is required, hoist and lift points should be clearly labeled.

## 2.5.2 CODING.

- Safety colors and contrast colors shall be used to denote meaning established in ISO 3864.
- Recommended Colors for Equipment:** If color coding is used, the colors shall be distinguishable by both color-normal and color-deficient persons. Colors meeting this criterion are given in FED-STD-595 and are shown in table 2-5.
- Color Coding of Wire:** Insulated wire, cables, and electrical connectors shall be color- and number-coded in accordance with industry or manufacturer standards (for example, FED-STD-595 and MIL-STD-681) acceptable to the acquisition agency. As a minimum, color coding and wire numbers shall be provided and shown on crane wiring diagram and elementary control schematics.
- Color Selection for Displays:** Unobtrusive colors should be used to display information used infrequently. Warm colors (those with longer wavelengths, such as red or orange) should be used to convey action or the requirement for a response. Cool colors (those with shorter wavelengths, such as blue or green) should be used to convey status of background information. To avoid mismatch of color and color associations that can slow recognition time and increase errors, each color should represent only one category of displayed data. To maximize discriminability, colors having the following dominant wavelengths (or others as widely spaced along the visible color spectrum) shall be used:
- Red [700 nanometers (nm)]
  - Orange (600 nm)



- Yellow (570 nm)
- Yellow-green (535 nm)
  - Green (500 nm)
  - Blue-green (493 nm)
  - Blue (470 nm)

Table 2-5. Recommended Colors

Color	Specification Number*
Red	1110
Orange	1210
Yellow	1310
Blue	10B 7/6
Purple	2715
Gray	1625
Buff	1745
White	1755
Black	1770
* Specifications from FED-STD-595, with the exception of blue, which is adopted from the Munsell Color Notation System. (For more information contact the CIE or review the book <u>Using Computer Color Effectively</u> , L.G. Thorell/W.J. Smith, Prentice Hall: Englewood Cliffs, New Jersey.)	

- Color-Coding for Controls: Colors may be used only to supplement other control coding methods. Not more than five colors should be used. Controls should be black (17038, 27038, or 37038) or gray (26231 or 36231). If color coding is required, only the following colors identified in FED-STD-595 should be selected for control coding:

- Red: 11105, 21105, 31105
- Green: 14187
- Orange-Yellow: 13538, 23538, 33538

- White: 17875, 27875, 37875

## 2.6 MAINTENANCE

This section contains human factors criteria and guidelines intended to make crane maintenance safe, fast, and easy. It is important to include these human engineering criteria early in the design phase to ensure equipment is designed for maintenance.

### 2.6.1 GENERAL DESIGN GUIDANCE.

- Design Simplicity: Systems and equipment should be designed to be as simple as possible to minimize the complexity and frequency of maintenance.
- Parts Standardization: Standard parts should be used whenever practicable and should meet the human engineering criteria in MIL-STD-1472.
- Use Common Test Equipment and Tools: Whenever possible, systems and units of equipment should be designed so maintenance can be accomplished with common test equipment and tools.
- Modular Design: Equipment should be designed, where possible, into modules that are independent, interchangeable, and easily replaced.
- Noninterchangeability of Items: Units of equipment that are similar in size and shape to other items but different from them in functional properties should be easily identifiable and distinguishable. In addition, they should not be physically interchangeable. Equipment should include physical features that prevent improper mounting.
- Lubrication:
  - Equipment should be configured to permit checking of lubricant reservoir levels without disassembly.
  - Lubrication points should be accessible, clearly labeled, and where applicable, provided with captive caps or covers.
  - Access points for adding or changing lubrication should be placed so any commodity spill will be contained.
- Separating Maintenance and Operational Displays: If a module contains both maintenance and operational displays, the maintenance displays should be separated from the operational displays.

- ❑ **Control Limits:** Calibration or adjustment controls intended to have a limited degree of motion should have mechanical stops sufficiently strong to prevent damage by a force or torque 100 times greater than the resistance to movement within the range of adjustment.
- ❑ **Designing for Safety of Maintainers:** Equipment shall not present hazardous conditions to maintainers as they perform maintenance procedures. A positive means (for example, disconnects or lockouts, emergency shutdown devices, electrical cutout switches, warning signs, or guards) should be designed into equipment and used to control hazardous conditions and facilitate safety as outlined in 29 CFR 1910.147. Equipment shall be designed to eliminate pinch hazards or provide barriers to guard personnel.
- ❑ **Critical or Sensitive Adjustments:** Critical or sensitive adjustments shall incorporate features such as locking devices to prevent inadvertent or accidental adjustment. If a locking device is used, operation of the locking device should not change the adjustment setting.
- ❑ **Safety Switch:** On cab-operated cranes a switch or circuit breaker of the enclosed type, with provision for locking in the open position, shall be provided in the leads from the runway conductors. A means of opening this switch or circuit breaker should be located within easy reach of the operator.
- ❑ **Malfunction Identification:** Use built-in testing, diagnostics, and fault localization capabilities to simplify troubleshooting and to facilitate rapid and positive fault detection and isolation of defective items.
- ❑ **Fault Detection Without Disassembly:** Equipment should permit fault detection and isolation without removing components, through the use of built-in test, integrated diagnostics, or standard test equipment. Fault detection and isolation should identify without ambiguity which component has failed.
- ❑ **Latches and Catches:** Latches and catches should give a clear visual indication that they are engaged. The spring action or snap-down force should not be so strong that it could injure the maintainer. Latches and catches should be located and positioned to avoid inadvertent operation.
- ❑ **Cable Clamps:** Unless wiring ducts or conduits are used, mechanically (not adhesive) mounted cable clamps should be provided to:
  - Ensure correct routing of electrical cables within and between equipment items.
  - Ensure cables do not hinder or obstruct equipment maintenance.
  - Facilitate the mating of cables with their associated equipment items.
  - Prevent chafing caused by contact with adjacent structure.

- Ensure clamps are visible when equipment is installed.

**2.6.2 DESIGNING EQUIPMENT FOR HANDLING.** The purpose in designing equipment for handling is to increase the efficiency of the maintainer and to reduce the likelihood of injury to the maintainer or damage to the equipment.

- Avoidance of Damage From Handling:** Parts that are susceptible to damage during maintenance activities should be located or shielded so they will not be damaged during these activities.
- When Handles Are Needed:** Units of equipment intended to be carried shall have handles or grasp areas. Items requiring handles should be provided with not less than two handles or one handle and one grasp area. A handle is a permanent part of a unit of equipment that is designed to be grasped by the hand. Handles may extend out from the unit so the fingers wrap around them, or they may be recessed areas so the fingers fit inside an opening. Extended handles may be rigid or folding. The size, number, and location of handles depend upon the following:
  - The weight and center of gravity of the unit.
  - The number of people lifting or carrying the unit.
  - The type of clothing worn and whether or not gloves are worn.
  - The position of the unit before handling and its final position.
  - The frequency with which the unit is handled.
  - Any additional uses the handles may serve.
- Units of equipment weighing less than 4.5 kg (10 lb) should have handles if they would otherwise be difficult to grasp, remove, or carry.
- Units of equipment weighing between 4.5 kg (10 lb) and 18 kg (40 lb) should have one or more handles that permit easy handling of the unit by one person. If the unit is bulky or if its weight is unevenly distributed, the handles should permit easy handling by two people.
- Units of equipment weighing between 18 kg (40 lb) and 68 kg (150 lb) should have handles that provide easy handling of the unit by two or more people. If the unit is very large, it shall have a means of mechanical lifting.
- Handle Characteristics/Handle Comfort:** Handles should be comfortable and easy to grasp; they should not cut into the hand or cause undue pressure on the fingers.

- ❑ **Handle Location:** Handles should be located so their use does not expose a maintainer to thermal or electrical hazards. The location of handles with respect to the center of gravity of the unit of equipment determines the tendency of the unit to tip or sway when it is lifted or carried. Placing the handles above the center of gravity and placing pairs of handles on opposite sides of the unit on a line passing through the center of gravity horizontally ensure the stability of the unit. However, other considerations may outweigh these “balance” considerations. For example, if a unit is intended to be pulled out of a rack, its handles will probably be located on the front of the unit.
  - **Single Handle:** A single handle should be located directly above the center of gravity of a unit of equipment.
  - **Pairs of Handles:** The two handles or a pair of handles should be located on opposite sides of the unit of equipment on or above a line passing horizontally through the unit’s center of gravity.
- ❑ **Handle Attachment:** Handles should be permanently attached to the unit of equipment.
- ❑ **Recessed, Hinged, and Folding Handles:** Recessed, hinged, or folding handles may be used to conserve space or to achieve a smooth surface. When they are used, they should be accessible without the use of tools, and they should remain securely folded when not in use.
- ❑ **Stops for Hinged or Folding Handles:** Hinged or folding handles should have a stop that holds them perpendicular to the surface on which they are mounted when they are moved into carrying position. It should require only one hand to move them into this position.
- ❑ **Handle Dimensions:** The diameter of the handle should be 25.4 mm (1 in) or greater. The handle should be designed to minimum handle dimensions stated in MIL STD-1472.
- ❑ **Handle Surface:** The surface of handles should be sufficiently hard that grit and grime do not become embedded during normal use.
- ❑ **Handle Conductivity:** The handle material that comes into contact with a maintainer’s hand should not conduct heat or electricity.
- ❑ **Structural Clearance Around Handles:** Handles should be located to provide a clearance of at least 50 mm (2 in) between the handle and any obstruction when the equipment is in its installed position or maintenance position. The location of handles should not interfere with installing, removing, operating, or maintaining the equipment.

### 2.6.3 ALIGNMENT AIDS.

- Prevention of Improper Mounting: Equipment shall be designed so it is physically impossible to mount it incorrectly. To accomplish this, units of equipment should include physical features (such as supports, guides, or alignment pins) that prevent improper mounting.
- Limit Stops: Limit stops should be provided on all drawer-, slide-, or hinge-mounted equipment that must be moved from its operating position to a maintenance position. Rollout tracks and drawers should be self-locking in the retracted and extended positions.

### 2.6.4 EQUIPMENT ACCESSIBILITY.

- Complete Visual and Physical Access: Equipment should be positioned so the maintainer has complete visual and physical access to all parts of the equipment on which maintenance is performed; this include maintenance displays, access openings, adjustment points, test points, cables, connectors, labels, and mounting fasteners.
  - Equipment shall be designed to eliminate or minimize the need for maintenance or repair tasks that require technicians to be located on the bridge or trolley during crane movement.
  - Equipment shall be designed so that all maintenance can be performed with fall prevention or access to fall protection (harness tie points). This shall include access to limit switches.
  - Where there is minimal space between the facility support structure and the crane, and when personnel are required to be on the bridge or trolley to perform maintenance activities, installation of a false ceiling should be considered to abate overhead impact and pinch hazards.
  - Access points for maintenance, inspection, calibration, and adjustment should be from above or outside equipment where possible, as opposed to underneath or inside.
  - Equipment should be arranged so items with a higher failure rate (or more frequent history of replacement) are accessible for replacement without having to move nonfailed items.
- Visual Access for Inspection: Units of equipment that require frequent visual inspection should be positioned so the components to be inspected (such as displays, test points, and labels) can be seen easily without the removal of any other equipment.
- Working Space for Tool Use: Units of equipment should be positioned so there is sufficient space around them for the use of any tools and test equipment required for their maintenance.
- Access Room To Open Covers: Units of equipment should be positioned with sufficient clearance from other equipment and structures to permit unhindered opening of any covers that are opened during maintenance tasks.

- ❑ **Removal Path:** Units of equipment intended to be replaceable by maintainers should be positioned so they can be removed along a straight or moderately curved path, not along a sharply bent path.

#### 2.6.5 ACCESS OPENINGS.

- ❑ **Access for Near Related Displays, Controls, and Connectors:** Access openings should be located within easy view and reach of any test points, displays, controls, or connectors that require access in performing a particular maintenance task.
- ❑ **Access Openings Away From Hazards:** Access openings should be located at a safe distance or shielded from any hazards, such as high voltages or dangerous moving parts to which the maintainer might be exposed.
- ❑ **Openings To Prevent Injury or Damage:** The edge of access openings should be either (1) sufficiently rounded and smoothly finished or (2) covered or coated sufficiently to prevent injury to the maintainer's person, clothing, and equipment. Exposed surfaces and corners should be rounded to a radius not less than 0.75 mm (0.3 in). Where edges can present a personnel safety hazard, edges should be suitably protected or rounded to a radius not less than 3.3 cm (0.5 in).
- ❑ **Access for Maintenance:** The crane should be designed to allow effective maintenance by providing sufficient space for maintenance personnel to access the equipment and components. This space should permit the 95th-percentile male to have sufficient access and space to perform the maintenance tasks and to use the tools necessary for the tasks. Reach limits should permit the 5th-percentile female to perform the tasks with the appropriate tools.
- ❑ **Dimensions for One-Hand or -Arm Access:** Dimensions for openings intended to allow access by one hand or one arm should equal or exceed those given in figures 2-6 and 2-7.

#### 2.6.6 CONNECTORS.

- ❑ **Safety:** Connectors should be selected or designed to ensure the safety of maintainers and equipment from pressures, contents, or voltages during the release of connectors.
- ❑ **Removal and Replacement With One Hand or Tool:** Nuts and bolts that are removed and replaced frequently or that are relatively inaccessible should be mounted so they can be removed and replaced with one hand or one tool. A recess should be provided to hold either the bolt or the nut.
- ❑ **Distinctive Connectors:** Connectors for lines serving different functions (for example, fluid lines or electrical power lines) shall be distinctively different and physically incompatible.

- ❑ Preventing Mismatching and Misalignment of Connectors: Electrical plugs and connectors shall be selected or designed so it is physically impossible to insert them incorrectly. To prevent connection to an incorrect receptacle, the connectors and receptacles for different functions should have different pin configurations.
- ❑ Connector Alignment Before Contact: Each connector shall have an aligning device that makes it physically impossible to insert it into a receptacle the wrong way. The alignment device (connector, plug, receptacle, etc.) shall ensure correct alignment is achieved before electrical contact is made.
- ❑ Connector Alignment Coding: The connector shall be marked or coded in a durable manner to show the position of the alignment device. Methods for marking or coding include painted stripes and arrows.
- ❑ Alignment of Drawer Connectors: If a module or unit of equipment is mounted in a drawer with a connector at the back that mates with a connector in the rack, guide pins or other alignment devices should be provided to ensure proper mating.






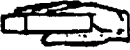


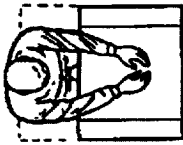
	Height mm (in)	Width mm (in)	Diameter mm (in)
<b>Empty hand, to wrist</b>			
	Bare hand, flat 55 (2.25)	100 (4.0)	100 (4.0)
	Bare hand, rolled 95 (3.75)	95 (3.75)	95 (3.75)
<b>Clenched hand, to wrist</b>			
	Bare hand 5 (3.75)	125 (5.0)	125 (5.0)
<b>Hand plus 25 mm object, to wrist</b>			
	Bare hand 95 (3.75)	95 (3.75)	95 (3.75)
<b>Hand plus X mm object, to wrist</b>			
	Bare hand	X + 45 (1.75) clearance around object	
<b>Arm to elbow</b>			
	Light clothing 100 (4.0)	115 (4.5)	115 (4.5)
<b>Arm to shoulder</b>			
	Light clothing 125 (5.0)	125 (5.0)	125 (5.0)

Figure 2-6. Minimum Dimensions of Openings Designed for Access by One Hand Without Visual Access

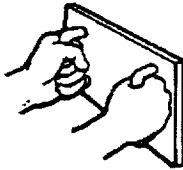


Reaching with both hands to depth of 150 to 500 mm (6 to 20 in):

Light clothing:    Width:    200 mm (8 in) or depth of reach\*  
                         Height:    125 mm (5 in)

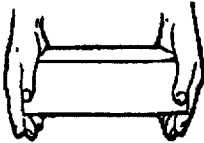
Reaching full arm's length (to shoulders) with both arms:

                         Width:    500 mm (20 in)  
                         Height:    125 mm (5 in)



Inserting box grasped by handles on front:

13 mm (0.5 in) clearance around box, assuming adequate clearance around handles



Inserting box with hands on the sides:

Light clothing:    Width:    Box plus 115 mm (4.5 in)  
                         Height:    125 mm (5 in) or 13 mm (0.5 in) around box

Figure 2-7. Minimum Dimensions of Openings Designed for Access by Two Hands Without Visual Access

# STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

## INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

**NOTE:** This form may not be used to request copies of documents, nor to request waivers or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document or to amend contractual requirements.

<b>I RECOMMEND A CHANGE:</b>	1. DOCUMENT NUMBER KSC-YA-5436	2. DOCUMENT DATE September 28, 2001
3. DOCUMENT TITLE Human Factors Engineering Guidelines for Overhead Cranes		
4. NATURE OF CHANGE <i>(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)</i>		
5. REASON FOR RECOMMENDATION		
<b>6. SUBMITTER</b>		
a. NAME <i>(Last, First, Middle Initial)</i>	b. ORGANIZATION	
c. ADDRESS <i>(Include Zip Code)</i>	d. TELEPHONE <i>(Include Area Code)</i>	7. DATE SUBMITTED
<b>8. PREPARING ACTIVITY</b>		
a. NAME Director of Spaceport Engineering and Technology	d. TELEPHONE <i>(Include Area Code)</i> (321) 867-7770	
c. ADDRESS <i>(Include Zip Code)</i> National Aeronautics and Space Administration - Mail Code: YA Kennedy Space Center, FL 32899		

