SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4256

Issued 1996-12

Submitted for recognition as an American National Standard

DESIGN OBJECTIVES FOR LIQUID CRYSTAL DISPLAYS FOR PART 25 (TRANSPORT) AIRCRAFT

FOREWORD

This SAE Aerospace Recommended Practice (ARP) is intended as a guide toward standard practice and is subject to change to keep pace with experience and technical advances. This document provides additional information pertinent to AS8034.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1. SCOPE:

This document covers monochrome and color LCDs (transmissive, transflective, and reflective), both matrixed and segmented in format, and is applicable to the following types of displays:

a. Flight and navigation displays
b. Engine, systems, and warning devices
c. Control displays

In this document the terms “LCD”, “LCD Display”, “Display”, and “Instrument” are synonymous and encompass the display system (e.g., LCD device, drivers, backlight, display processor, etc.), not just the device.

1.1 Purpose:

This document recommends design and performance criteria for liquid crystal displays (LCDs) on the flight deck of aircraft subject to Part 25 certification. It is intended as guidance for the certifying authority. A secondary purpose is to share information about the unique characteristics of LCDs and how they relate to the flight deck.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP450D	Flight Deck Visual, Audible and Tactile Signal
ARP571C	Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
ARP1068B	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
AIR1093	Numeral, Letter and Symbol Dimensions for Aircraft Instrument Displays
ARP4102	Core Document, Flight Deck Panels, Controls and Displays
ARP4102/7	Electronic Displays
ARP4103	Flight Deck Lighting and Visual Interface
ARP4105	Nomenclature and Abbreviations for Use on the Flight Deck
AS8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
AMS 2521B	Reflection Reducing Coatings for Instrument Glasses

2.1.2 FAA Publications: Available from the Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591.

FAR Part 25/JAR 25
TSO-C113 Airborne Multipurpose Electronic Displays

2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Recommended Practice.

2.2.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP1161 Crew Station Lighting - Commercial Aircraft
ARP1782 Photometric and Colorimetric Measurement Procedures for Direct View CRT Displays
ARP1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP4032 Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4101 Core Document, Flight Deck Layout and Facilities
ARP4260 Photometric and Colorimetric Measurement Procedures for Airborne Direct View Flat Panel Displays (When Approved)
ARP4067 Design Objectives for CRT Displays for Part 23 Aircraft

2.2.2 FAA Publications: Available from the Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591.

Advisory Circular 25-11Transport Category Airplane Electronic Display Systems

2.2.3 U.S. Military Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

AFGS-87213B (USAF)Displays, Airborne, Electronically/Optically Generated

2.2.4 CIE Publications: Available outside of the U.S. from Bureau Centrale De La CIE, 52, Boulevard Malesherbes, 75008 Paris, France and inside the U.S. from United States National Committee of the Commission Internationale De L'Eclairage, c/o Thomas Lemons, TLA-Lighting Consultants, Inc., 7 Pond Street, Salem, MA 01970-4893.

Supplement No. 2 to CIE Publication No. 15 Recommendations on Uniform Color Spaces Color Difference Equations - Psychometric Color Terms

2.2.5 RTCA/EUROCAE Publications: Available from RTCA, Inc., 1140 Connecticut Avenue, Suite 1020, Washington, DC 20036.

RTCA DO-160C/EUROCAE ED-14C	Environmental Conditions and Test Procedures for Airborne Equipment
RTCA DO-178B/EUROCAE ED-12B	Software Considerations in Airborne Systems and Equipment Certification

2.3 Definitions:

Definitions used in this document shall be as noted in the Glossary of Terms defined in Section 5.

The word "shall" is used to express an essential (mandatory) requirement. Conformance requires that there be no deviation. The word "should" is used to express a recommended requirement. Deviation from the specified recommendation may require justification.

3. GENERAL REQUIREMENTS:

3.1 Equipment Functions:

The design objectives for flight deck displays as set forth in ARP4102/7 are applicable to LCD displays unless they are superseded by or conflict with the recommendations of this document.

3.2 Environmental Conditions:

Except as detailed in appropriate sections of this document, the performance requirements specified in Section 4 apply over the applicable environmental conditions and test procedures set forward in RTCA document DO-160C and over the useful life of the equipment. In no case shall performance be degraded so as to lead to erroneous interpretation or loss of displayed data.

3.3 Smoke and Toxicity:

No material used shall liberate gases or fumes that are detrimental to performance of the aircraft or to performance or to health of personnel.

3.4 Malfunction Indication:

Means must be provided to indicate malfunctions or failures to the appropriate crew member in a positive manner (reference ARP4102, 6.2). It is not practical to use built-in-self-test procedures to monitor the functionality of all the addressable elements in liquid crystal display devices. One manual means to detect addressable element malfunctions is to provide a “push-to-test” procedure which activates all display elements in “on” and “off” states. Displayed fonts, symbols, indicia, etc. should be designed to be tolerant of addressable element defects and failures whenever practical.

Particular emphasis should be given to precluding or mitigating failures which could result in hazardously misleading information. Inconspicuous and undetected loss of information could contribute to hazardously misleading information. Consideration should be given to drive and addressing techniques to avoid the loss of information resulting from the failure of rows, columns, and/or elements.

3.5 Glass Breakage:

Front glass strength shall be sufficient to withstand normal impacts that can be expected in the flight deck environment without cracking, breaking, or loss of LCD edge seal.

4. DETAIL REQUIREMENTS:

4.1 Display Visual Characteristics:

4.1.1 Viewing Characteristics: All indicating means displayed (indicia, pointers, symbols, etc.) shall be completely visible from any eye position within the viewing envelope(s) as specified by the equipment manufacturer. Each installation shall be examined to verify that the design eye position(s) and allowable head motion envelope(s) (reference 2.2.1, 4.1.1.1, and 6.1.5 of ARP4102) are within each viewing envelope.

Cross-cockpit viewing to the other pilot’s displays should be provided to achieve the capability recommended by ARP4102. The cross-cockpit viewing angle is installation dependent and is usually a compound angle.

NOTE: The cockpit viewing angle requirements may far exceed 45 degrees.

4.1.2 Symbol Alignment: Symbols which are interpreted relative to each other (i.e., cursors on scales, command bars against reference points, etc.) shall be aligned to preclude misinterpretation of information.

4.1.3 Matrix Anomalies: Since the display is an array of discrete elements, displayed information may have visible spatial and color anomalies. Stair stepping, line width variation, and moire are examples of spatial anomalies; color banding and color fringing are examples of color anomalies. Anomalies are especially visible in dynamic images and may not be visible in static images. The extent of the anomaly is dependent on many factors including the size, shape, and arrangement of the display elements, construction of the symbol, rate, direction, and increment of motion and luminance control of the elements. The display shall have no matrix anomalies which cause distraction or erroneous interpretation. This shall be assessed with both static and dynamic formats.

4.1.4 Crosstalk: Crosstalk should not be readily apparent or distracting.

4.1.5 Jitter: There should be no discernible display jitter when viewed within the viewing envelope. Jitter of 0.3 mrad peak-to-peak from any point within the viewing envelope is a suggested upper limit, but that may not be acceptable in some instances.

4.1.6 Line Width Uniformity: When viewed from the design eye position (DEP), lines of a specified color and luminance should appear uniform in width at all rotational or translational orientations of the line. Line width variation should not be readily apparent or cause distracting visual effects. Lines with a minimum line width less than 70% of the maximum line width may produce an undesirable visual "roping" effect.

4.1.7 Symbol Quality: Symbols should not have distracting gaps or geometric distortions. Symbol quality characteristics shall not cause erroneous interpretations; any distorted dimension should not exceed one half the local line width.

4.1.8 Flicker: Flicker should not be readily discernible or distracting under day, twilight, or night conditions, considering both foveal and full peripheral vision, and using an operational format most susceptible to producing flicker. This is intended to include stroboscopic flicker induced by vibration and/or pilot motion.

4.1.9 Symbol Motion: Display symbology that is in motion (translation and/or rotation) should not have distracting jitter, jerkiness, or ratcheting effects. Dynamic symbols should maintain luminance (per 4.1.10), contrast, color, line width, and symbol quality characteristics independent of their rate of motion. Pointers and bar graphs should be designed with built in hysteresis or smoothing of the displayed value such that when a constant or near constant value of a parameter is to be displayed, objectionable motion is eliminated.

4.1.10 Response Time: Response time limitation shall not produce undesirable artifacts which could lead to the erroneous interpretation or loss of displayed information. Such artifacts include smearing of moving images and loss of luminance. These effects may be temperature dependent and shall be evaluated over the operating temperature range. For either increasing or decreasing commanded luminance, the ratio of integrated luminance change (luminance perceived by the eye) to commanded steady state luminance should be greater than a suggested value of 70%. Mathematically, this is described as:

$$\text{Perceived Luminance Change ("ON")} = \frac{\int_{t_o}^{t_u} L(t)dt}{t_u(L_c - L_{t_o})} \geq 0.7 \qquad \text{(Eq.1)}$$

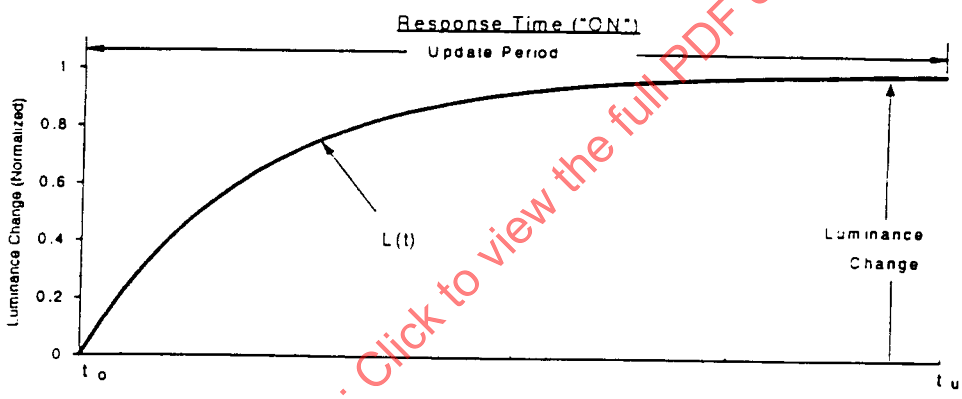

FIGURE 1

$$\text{Perceived Luminance Change ("OFF")} = 1 - \frac{\int_{t_o}^{t_u} L(t)dt}{t_u(L_c - L_{t_o})} \geq 0.7 \qquad \text{(Eq.2)}$$

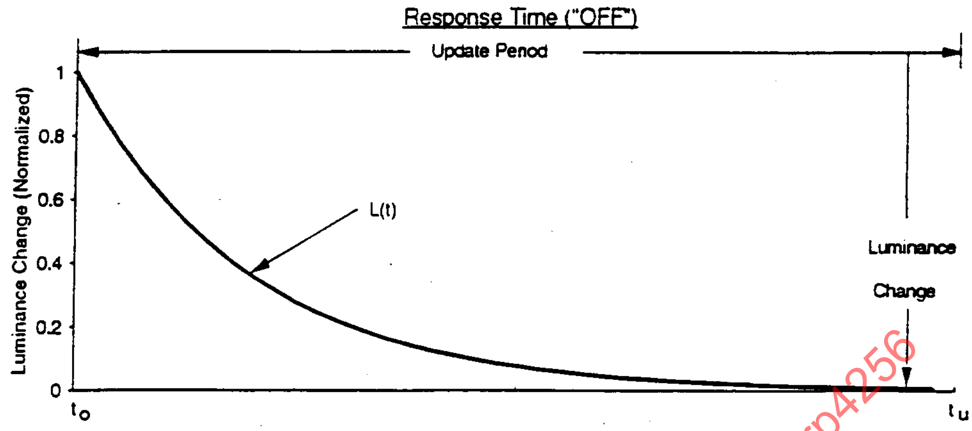

FIGURE 2

4.1.10 (Continued):

where:

L(t) = Function luminance change with respect to time
L_c = Commanded steady state luminance
L_{t_o} = Initial steady state luminance
t_u = Data update period (reference 4.3.3)
t_o = Start of the update period (time = zero)

NOTE: The data update period is here assumed to be longer than the refresh cycle.

For displays with slowly changing symbol positions, t_u shall be equal to the data update period or the minimum time required for symbol line widths to move to new pixel positions, whichever is greater. In no case should response time cause the maximum perceived luminance of dynamic symbology to fall below 70% of the average white luminance recommended in 4.2.2.1.

4.1.11 Image Retention: Image retention should not be readily discernible day or night, should not be distracting, and shall not cause an erroneous interpretation of the display. Image retention is an undesired afterimage that persists on the display.

4.1.12 Defects: Visible defects on the display surface (such as failed-ON or failed-OFF elements, rows, or columns, spots, discolored areas, etc.) should not be distracting and shall not cause an erroneous interpretation of the display. Defects which are not visible with any operational format from the minimum viewing distance are acceptable.

4.1.12.1 Failed-ON Row/Columns (Matrix Display): No failed-ON row/columns shall be allowed on the display.

4.1.12.2 Failed-OFF Row/Columns (Matrix Display): Depending on resolution, mode, color, and format, there may be failed-OFF row/column defects which are neither distracting nor cause erroneous interpretation. In no case shall a failed-OFF row/column cause any erroneous interpretation. If a failed-OFF row/column is in an unused area (format dependent) or is orthogonal to symbol lines, it may never be detected.

4.1.12.3 Element Failures: Beyond the requirements of 4.1.12.1 and 4.1.12.2, the number of acceptable element failures is an aesthetic issue. Failed-OFF and failed-ON blue elements are much less objectionable than failed-ON red, green, or white elements. Clusters of failed elements are more objectionable than those widely separated. The number of acceptable defects is dependent on the format. Any segment failure on a segmented display shall constitute an unacceptable display (unless there are redundant segments).

4.1.12.4 Defect Service Limits: Defects should not constitute a service limit unless they are distracting or could cause an erroneous interpretation. Even though failed-ON row/columns are not acceptable at acceptance testing, they might be tolerated in service for a time if safe flight is not threatened by distraction or erroneous interpretation. Dispatch capability can and should be enhanced by designing the display hardware/software system to be as tolerant of failures as practical; an example is designing symbols with displayed lines that are at least three elements wide so that no single failed row/column can cause an erroneous interpretation.

4.1.13 Multiple Images: When illuminated with light not normal to the display surface, for example sun shafting illumination, transflective or reflective liquid crystal displays can produce multiple images of displayed information. The multiple images formed should not be distracting and shall not cause erroneous interpretation of displayed data.

4.2 Photo-Colorimetric Characteristics:

4.2.1 General: The display symbology shall be clearly readable throughout the viewing envelope under all ambient illumination levels ranging from 1.1 lux (0.1 fc) to sun-shafting illumination of 86 100 lux (8000 fc) incidence on the face of the display.

4.2.2 Luminance: The display luminance shall be sufficient to provide a comfortable level of viewing under all conditions of cockpit ambient illumination and provide rapid eye adaptation for transitions from forward field-of-view (FOV) luminance levels of up to 34 300 cd/m^2 (10 000 fL).

The luminance uniformity values stated in 4.2.2.3 and 4.2.2.4 shall be used for LCDs instead of the values stated in AS8034, 4.3.2.2.

4.2.2.1 Maximum Luminance, Transmissive Displays: With manual and automatic luminance controls at maximum, the average white symbol luminance across the usable display surface should be at least 257 cd/m^2 (75 fL) when measured from the design eye position in a dark ambient. The maximum white symbol luminance should be at least 171 cd/m^2 (50 fL) anywhere on the usable display surface under static or dynamic conditions. This luminance requirement is based on a 0.6 mrad line width. Larger line widths and filled areas will require less luminance to provide the same apparent brightness. Conversely, smaller line widths will require more luminance for the same apparent brightness. Based on matching brightness of parallel lines on a dark surround with luminances of 1 to 8 fL at a 33 inch viewing distance, the following brightness-to-luminance relationship has been developed.

The relationship between luminance and relative brightness shown below is normalized for a 0.6 mrad line width (0.5 mm or 0.02 in at a 33 in viewing distance). For line widths from 0.15 to 1.5 mrad, luminance times the normalizing factor, K_n, yields equal apparent brightness:

$$\text{Apparent Brightness} = K_n \times \text{Luminance} \quad \text{(Eq.3)}$$

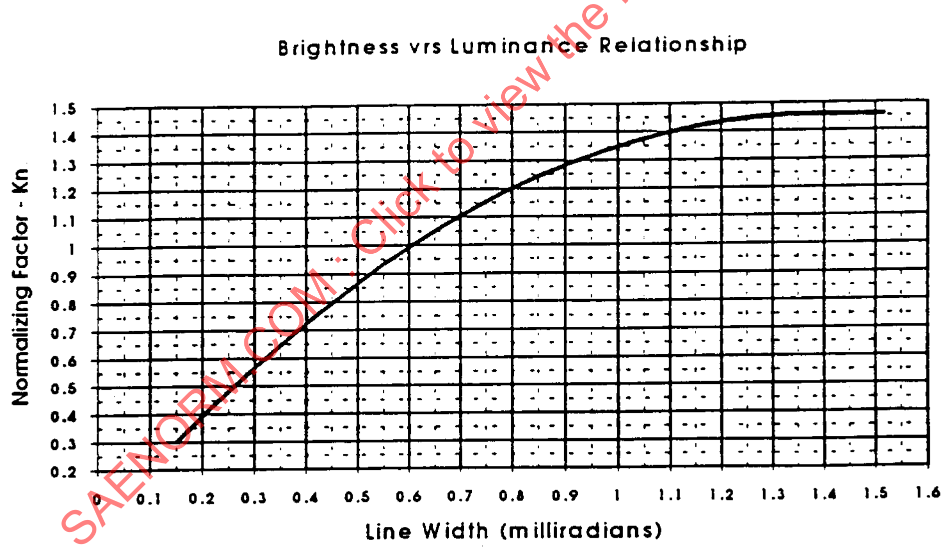

FIGURE 3

4.2.2.1 (Continued):

Other symbol colors typically have a luminance level significantly lower than white. The actual level of the luminance disparity between white and other colors is dependent on several factors including pixel configuration, backlight phosphor mix, and color filters employed. Other colors, especially red and blue hues have greater perceived brightness than white which partially compensates for this luminance disparity. The use of larger line widths, symbol area fills, and white outlining of dimmer symbol colors should be used to further compensate for lower symbol color luminance values.

Maximum luminance required is also a function of the display flight deck location. The above luminance requirement is based on requirements for primary instrumentation centrally located under the glare shield and are minimum performance requirements. Glare shield mounted displays subject to the immediate proximity of the forward-field-of-view ambient luminance will require greater luminance levels for equal readability.

4.2.2.1.1 Maximum Luminance, Transflective/Reflective Segmented Displays: Transflective or reflective segmented liquid crystal displays should have the following maximum total white segment luminance (self-luminance plus reflected illumination with any integral lighting or gray scale controls set to maximum luminance) when measured from the design eye position. These luminance requirements are based on a 1.2 mrad line width (reference normalizing factor, K_n in 4.2.2.1) and are minimum performance requirements.

TABLE 2

Cockpit Location	Luminance Level	Diffuse Source Cockpit Illumination
Glare shield	≥70 fL	= 2160 lux (200 fc)
Front Panel and Side Console	≥50 fL	= 1620 lux (150 fc)
Aisle Stand and Overhead Panel	≥35 fL	= 1080 lux (100 fc)

NOTE: The total luminance requirements stated above have been deemed sufficient by pilot evaluations. The cockpit ambient illumination levels which contribute to these total luminance values, however, are installation dependent and depend on cockpit configuration.

4.2.2.2 Minimum Luminance: Under night lighting, with the display brightness set at the lowest usable level for flight with normal symbology, all flags and annunciators shall be adequately visible. To achieve acceptable viewing in dark conditions, the minimum white symbol luminance when measured in a dark ambient should be no greater than 0.343 cd/m^2 (0.1 fL) for 0.6 mrad wide lines. A narrower line could have higher luminance (reference normalizing factor, K_n in 4.2.2.1). A luminance of 0.171 cd/m^2 (0.05 fL) will be desired by a small percentage of users.

4.2.2.2 (Continued):

NOTE: These minimum luminance values have been established for dark-adapted flight conditions. The values may be increased for applications where the flight deck ambient lighting design precludes a high degree of night vision adaptation.

4.2.2.3 Design Eye Position Luminance Uniformity: Display areas of a specified color (excluding the dark or OFF state) and luminance should have a luminance uniformity of less than 0.5 across the utilized display surface when measured from the DEP. In no case should luminance nonuniformity cause the maximum white symbol luminance anywhere on the usable display surface to go below the 171 cd/m^2 (50 fL) value specified in 4.2.2.1.

Where: $\text{Luminance Uniformity} = \frac{L_{max} - L_{min}}{L_{mean}}$

And: L_{max} = Maximum luminance measured anywhere on the utilized display surface from the DEP
L_{min} = Minimum luminance measured anywhere on the utilized display surface from the DEP
L_{mean} = Mean luminance of the utilized display surface as measured from the DEP

NOTE: The measurement technique used to determine L_{mean} should produce a value as close as possible to that given by:

$$\frac{L\,dA}{A} \qquad \text{(Eq.4)}$$

where A is the utilized display surface area. Care should be taken to sufficiently sample luminance over the utilized display surface to produce this result.

The size of the display, its format, and the gradient of the nonuniformity affect overall acceptability. Higher values of the luminance uniformity metric could be comfortably acceptable. The rate of change of luminance within any small area should be minimized to eliminate distracting visual effects and could require a smaller value of the luminance uniformity metric. Of particular concern are effects caused by the instrument's integral lighting.

4.2.2.4 Viewing Envelope(s) Luminance Uniformity: Display area luminance should not vary more than 0.5 when measured from any eye position within each viewing envelope as specified by the equipment manufacturer and with the display set to its maximum gray scale (full-on).

Where: $$\text{FOV Luminance Uniformity} = \frac{L_{max} - L_{min}}{L_{mean}}$$

And: L_{max} = Maximum area luminance of a specified area measured from any eye position within each viewing envelope
L_{min} = Minimum area luminance of a specified area measured from any eye position within each viewing envelope
L_{mean} = Mean area luminance within each viewing envelope

4.2.2.5 Background (Black) Uniformity: The total difference in the color, 1976 CIE ΔE^* (CIELUV), at any two locations commanded to their dark state, within the usable display surface, should not exceed 12. These limits apply for any fixed eye position within the design viewing envelope with the display integral lighting set to full intensity and measured in a dark ambient illumination environment.

Where: $$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2}}$$

And: ΔL^* = Difference between background color CIE 1976 L* values
Δu^* = Difference between background color CIE 1976 u* values
Δv^* = Difference between background color CIE 1976 v* values

Where: $$L^* = 116\sqrt[3]{\frac{\text{Measured Luminance}}{100\text{ fL}}} - 16$$

for Measured Luminance > 1 fL
L^* = 9.03 x Measured Luminance
for Measured Luminance < 1 fL
$u^* = 13L^*(u' - 0.1978)$
$v^* = 13L^*(v' - 0.4684)$

NOTE: Reference 5.2.

The size of the display, the amount of black in the format, and the gradient of the nonuniformity affect overall acceptability. Higher values of ΔE^* could be comfortably acceptable. The rate of change of ΔE^* within any small area should be minimized to eliminate distracting visual effects and could require a smaller value of the ΔE^* metric.

4.2.2.6 Background (Black) Chroma: The average Background CIE 1976 Chroma, C^*_{back}, measured across the utilized display surface should be less than or equal to 26 anywhere within the display's design viewing envelope when measured in a dark ambient illumination environment with the display integral lighting set to full intensity.

Where: $C^*_{back} = 13\, L^*_{back} \sqrt{(u'_{back} - 0.1978)^2 + (v'_{back} - 0.4684)^2}$

And:

u'_{back} = CIE 1976 u' of background

v'_{back} = CIE 1976 v' of background

$L^*_{back} = 116 \sqrt[3]{\frac{\text{Measured Luminance}}{100 \text{ fL}}} - 16$

for Background Luminance > 1 fL

L^*_{back} = 9.03 x Measured Luminance

for Background Luminance < 1 fL

D_{6500} (u'=0.1978, v'=0.4684) is recommended as the reference to insure uniformity from flight deck to flight deck. Another reference could be used to insure uniformity across a given flight deck providing the color is not objectionable.

4.2.3 Contrast Ratio (CR): The contrast ratio (total foreground luminance/total background luminance) shall be sufficient to provide a promptly discernible, easy to read image under all conditions of cockpit illumination and under all conditions of eye adaptation to the external visual scene. Image brightness, the subjective perception of luminance, is heavily dependent on image size or line width. Smaller line widths than those referenced in the following paragraphs will require higher contrast ratios for comparable readability.

The following contrast ratio requirements apply only to skeletal-graphics or text display formats. Formats which present image video information or make extensive use of shading to code information may require higher contrast ratios.

4.2.3.1 Dark Ambient Contrast Ratio: The average white contrast ratio over the usable display surface should be a minimum of 20:1 at the design eye position and 10:1 for any eye position within the viewing envelope. This requirement shall apply to self-luminous displays in a dark ambient or to transflective/reflective displays subjected to a cockpit illumination of dark ambient to 100 fc. This requirement is based on a 0.6 mrad line width. For line widths of 1.2 mrad or greater, the average white contrast ratio at the design eye position should be a minimum of 15:1.

4.2.3.2 High Ambient Contrast Ratio: The average white contrast ratio over the usable display surface should be a minimum of 3:1 for 0.6 mrad line widths and 2:1 for 1.2 mrad line widths when viewed from any eye location within the viewing envelope. This requirement shall apply to self-luminous or transflective/reflective displays when subjected to point source illumination levels up to 86 100 lux (8000 fc). This requirement does not apply to specular reflections from point source illuminations.

4.2.4 Color: Displayed symbology shall be distinguished from its background and from the other symbols by means of luminance differences and/or chromaticity differences in all ambient conditions defined in 4.2.1.

The most credible color difference system is CIELUV which is described in Supplement 2 to CIE Publication No. 15; but it does not consider symbol size and does not offer criteria for perception. Except in cases where an absolute chromaticity is desired (e.g., Cyan for sky shading), colors should be selected which maximize color differences. Results should be analyzed using the CIELUV system since this system perceptually weights both luminance and chromaticity components in determining color difference. Although there is no adequate basis for specifying a minimum acceptable difference at this time, chroma difference tolerances are recommended to prevent generic color confusion when observing several LCD displays on the same flight deck. The chroma difference tolerances shown below are partitioned into three separate categories:

a. Chroma difference between colors across the utilized display surface (4.2.4.1)
b. Chroma difference between specified colors and colors measured at the DEP (4.2.4.2)
c. Chroma difference between DEP colors and colors anywhere in the viewing envelope (4.2.4.3)

In no case shall the tolerances specified in the subparagraphs listed above act additively to prevent discrimination or proper interpretation of symbols of different colors. A display not meeting these limits could be acceptable if analysis/testing of operational formats determine the distinguishability of the symbols.

4.2.4.1 Chroma Uniformity: A symbol of a specified color set to any intensity within the specified dimming range (backlight and/or gray scale) shall have a chroma which is uniform across the utilized display area when viewed from the design eye position. The chroma difference (ΔC^*_{fixed}) between any two points on the screen of the same color when viewed from a fixed point should not exceed 24.

Where: $\Delta C^*_{fixed} = \sqrt{\Delta u^{*2} + \Delta v^{*2}}$

And:

Δu^* = Difference between measured CIE 1976 u* values
Δv^* = Difference between measured CIE 1976 v* values
u^* = $13L^*(u'-0.1978)$
v^* = $13L^*(v'-0.4684)$

$L^* = 116 \sqrt[3]{\frac{\text{Measured Luminance}}{100\text{ fL}}} - 16$

for Measured Luminance > 1 fL

L^* = 9.03 x Measured Luminance
for Measured Luminance < 1 fL

4.2.4.2 Design Eye Position Chroma Tolerance: When displayed image colors, set to any intensity within the specified backlight dimming range are measured in a dark ambient illumination environment the chroma difference (ΔC^*_{dep}) between the specified color and measured color should be no greater than 24 when measured from the design eye position.

Where: $\Delta C^*_{dep} = 13\, L^*_{measured} \sqrt{\Delta u'^2 + \Delta v'^2}$

And: $\Delta u'$ = Difference between specified u' values and u' measured at the display center

$\Delta v'$ = Difference between specified v' values and v' measured at the display center

$$L^*_{measured} = 116 \sqrt[3]{\frac{\text{Measured Design Eye Luminance}}{100\ \text{fL}}} - 16$$

for Measured Design Eye Luminance > 1 fL

$L^*_{measured}$ = 9.03 x Measured Design Eye Luminance

for Measured Design Eye Luminance < 1 fL

4.2.4.3 Viewing Envelope(s) Chroma Tolerance: Within each viewing envelope, the intended colors should be identifiable in the presence or absence of other colors and distinguishable from each other. All displayed image colors measured at the display center from any point within each viewing envelope should have a chroma difference (ΔC^*_{fov}) no greater than 26 when compared to the same color as measured at the design eye position. This measurement shall be performed in a dark ambient illumination environment with the display set to the selected color's maximum luminance and gray scale level.

Where: $\Delta C^*_{fov} = 13\, L^*_{measured} \sqrt{\Delta u'^2 + \Delta v'^2}$

And: $\Delta u'$ = Difference between u' measured at any point in each viewing envelope and u' measured at the design eye position

$\Delta v'$ = Difference between v' measured at any point in each viewing envelope and v' measured at the design eye position

$$L^*_{measured} = 116 \sqrt[3]{\frac{\text{Measured Design Eye Luminance}}{100\ \text{fL}}} - 16$$

for Measured Design Eye Luminance > 1 fL

$L^*_{measured}$ = 9.03 x Measured Design Eye Luminance

for Measured Design Eye Luminance < 1 fL

Some displays which do not meet this recommendation have been found acceptable. Such displays will require evaluation/analysis to determine acceptability.

4.2.5 Gray Scale: Gray scale control may be required to match chromaticity requirements, remove stair stepping, render video images, or provide luminance control. The degree of control needed depends on the purpose. When gray scale is used for anti-aliasing, deviations in luminance levels can lead to variations in line shape and legibility. When gray scale is used for color selection, deviations in primary color gray scale luminance levels can lead to variations in chromaticity. Gray scale luminance level deviations throughout the viewing envelope should be minimized to preclude misleading information or distraction.

4.2.6 Specular Reflections: The specular reflectivity of all surfaces in the optical path should be minimized to preclude distracting image reflections (e.g., pilot's white shirt reflections). The display front surface and any other surfaces in the optical path which are not optically coupled to minimize dissimilarities in their index of refraction should have a reflection reducing coating with performance characteristics conforming to AMS 2521. Electrode patterns and other nonemitting areas should have low reflectivity coatings to minimize internal reflections. In no case shall the level of reflectivity and resulting loss of contrast be sufficient to cause distracting or erroneous interpretation.

The total photopic specular reflectivity (in %) of LCD displays installed where direct solar or "white shirt" specular reflections are within the instrument's viewing envelope should be equal to or less than the LCD display maximum white luminance times the line width normalizing factor, K_n (reference 4.2.2.1), divided by 100:

$$\text{Specular Reflectivity (\%)} \leq \frac{K_n \times L_{max}}{100} \qquad \text{(Eq.5)}$$

For viewing angles of 30° or less from the display normal, and L_{max} in fL

4.2.7 Inactivated Segments: In segmented displays, when segments are not electrically activated, there shall be no obtrusive difference between the normal background luminance, color, or texture and the inactivated segments or the area surrounding them. Contrast ratios (between inactivated segments and the background) in excess of 1 to 1.15 measured at the design eye position under a point source ambient illumination of up to 86,100 lux (8000 fc) result in visibility of the inactive segments and should be avoided. In no case where the contrast ratio exceeds 1 to 1.15 shall the data be misleading.

4.3 Operating Time:

4.3.1 Warm-Up: Under ambient room conditions, a display should present statically correct and nonmisleading information within 1 min of the initial turn-on. Full dynamic and other detailed performance requirements should be met within 10 min.

4.3.1.1 Power Transient Recovery: For power interruptions up to 200 ms in duration, recovery time should not exceed 500 ms. Power interruptions between 200 ms and 1 s in duration may cause disruptions of system operation for up to 2 s after completion of the transient. Recovery from power interruptions up to 10 s duration should not cause any unsafe condition in system operation. In no case shall power transients cause any steady erroneous display or output.