[INCH-POUND]
A-A-58055
January 1, 1996

COMMERCIAL ITEM DESCRIPTION

INDICATOR, ATTITUDE, THREE INCH, SOLID STATE, SELF-CONTAINED

The General Services Administration has authorized the use of this commercial item description, for all federal agencies

1 SCOPE This commercial item description covers a 3-inch, solid state, self-contained attitude indicator intended to provide a standby attitude display for transport aircraft

2 SALIENT CHARACTERISTICS.

2 1 Performance

2 1 1 Accuracy

2 1 1 1 Static Accuracy The indicator, when connected and operating at standard "bench" conditions, shall provide pitch and roll accuracies of ±0 5°

2 1 1 2 Dynamic Accuracy The indicator shall provide pitch and roll accuracies of ±0 5° when the aircraft is in steady state, unaccelerated, non-maneuvering flight The pitch and roll error shall not exceed ±3 0° during all anticipated normal and emergency flight operations for a transport aircraft that is within the envelope of safe or recoverable flight The supplier shall perform the tests and analysis necessary to verify that the indicator meets these accuracy requirements Flight profiles that can be used in the analysis to verify the dynamic accuracy requirements are given in Appendix 2

2 1 2 Response Time The indicator shall achieve the required accuracy of ±0 5° within five minutes after power is applied when operating within the full environmental range specified in section 2 6 The indicator shall achieve ±0 5° accuracy after one minute of unaccelerated flight following a turn or acceleration

2 1 3 Dynamic Range The instrument shall operate and display attitude through full 360° rotations in pitch and roll There shall be not reduction in accuracy for all displayed angles

2 1 4 Dynamic Rate The instrument shall operate when the aircraft dynamic rates are within the following limits

Roll	100° per second
Pitch	75° per second
Yaw	100° per second

2 2 Controls

2 2 1 Reset A control shall be provided to reset the instrument to 0° pitch and 0° roll

2 3 Display The display shall meet the requirements of Appendix 1

Beneficial comments, recommendations, additions, deletions, clarifications etc and any data which may improve this document should be sent to SA-ALC/TILDD, 485 Quentin Roosevelt Rd , Kelly AFB TX 78241-6425

FSC 6610

2 3 1 Display Area The minimum active display area shall be [illegible] by [illegible] inches

2 3 2 Viewing Envelope The display shall meet the requirements of Appendix 1 paragraphs 4 2 2 4 for luminance uniformity and 4 2 4 3 for chroma (perceived color) uniformity for the design eye positions and allowable head motion envelopes as given in Appendix 3

2 3 3 Display Quality The display shall exhibit viewing characteristics, line-width uniformity, symbol alignment, and symbol uniformity compatible with Appendix 1 paragraphs 4 1 1 4 1 2 4 1 6 and 4 1 7 The display shall exhibit no matrix anomalies, crosstalk, jitter, flicker, or symbol motion jerkiness as described in Appendix 1 paragraphs 4 1 3 to 4 1 9

2 3 4 Display Resolution The display shall contain a minimum pixel density of 80 pixels (color groups) elements per inch for matrix displays to avoid visual aliasing effects

2 3 5 Display Maximum and Minimum Luminance The display should be capable of providing the maximum and minimum luminance levels under the conditions specified in paragraph 4 2 2 of Appendix 1

2 3 6 Display Contrast The display should meet the contrast ratio requirements defined in Appendix 1 paragraph 4 2 3 in both dark and high ambient conditions

2 3 7 Display Temporal Response Time and Image Retention The display shall meet the response time characteristics defined in Appendix 1 paragraph 4 1 10 of a 70% perceived luminance to commanded luminance ratio over an update time period of 1/30 sec Furthermore the display shall exhibit no discernible after-image that could cause erroneous display interpretation as outlined in paragraph 4 1 11

2 3 8 Display Defects The display shall meet the defect requirements outlined in Appendix 1 paragraph 4 1 12 No failed ON Row/Columns on the display, no allowable failed OFF Row Columns within regions of significant displayed information Design guidelines should follow techniques outlined in paragraph 4 1 12 4 in order to minimize effects of failed elements

Allowable failed sub-pixel elements will follow the recommended practices of Wright Lab WL-TR-93-1177 "Draft Standard for Color Active Matrix Liquid Crystal Displays (AMLCDS) in U S Military Aircraft" paragraph 4 2 2 3 13 1 No more than 0 01% of the sub-pixels on the display shall be defective For a 240 x 240 pixel display with 2x2 sub-pixels per pixel, this corresponds to no more than 23 pixels No more than two of these allowable sub-pixel defects in the Failed-ON condition will be white pixels Furthermore, adjacent failed sub-pixels, known as a cluster defect, will be limited in number to less than 2 Failed-ON clusters and 4 Failed-OFF clusters A cluster defect in an area of critical information display is unacceptable and will result in the rejection of the display

2 3 9 Display Sunlight Readability The display shall meet the symbology readability requirements of Appendix 1 paragraph 4 2 1 for ambient illumination levels incident on the display face ranging from 1 1 lux (0 1 foot-candles) to a sun-shafting level of 86,100 lux (8000 foot-candles)

2 3 10 Display Multiple Images The display shall exhibit no multiple images due to off-normal incidence illumination that could cause erroneous interpretation of the displayed data Baffling and anti-reflection filtering of glass surfaces should be employed to minimize the occurrence

The specular reflectivity of the display face shall be < 1% per WL-TR-93-1177 paragraph 4 2 2 3 10

2 3 11 Brightness Control The indicator shall automatically control brightness as a function of sensed cockpit lighting level and pilot selected dimming level in order to provide minimum and maximum brightness levels specified in 2 3 5 The pilot selected dimming level should cause the display to match as closely as practical the brightness levels of nearby instruments that are being controlled by the same signal The pilot selected dimming level is provided as a 0 to 5 7 volt ac signal

2 3 12 Night Vision Goggle Compatibility The display will meet the requirements of NVIS[3] compatibility as specified in MIL-L-85762A, Military Specification Lighting, Aircraft Interior Night Vision Imaging System (NVIS) Compatible, 26 August 1988

2 4 Mechanical and Electrical Interface Requirements

2 4 1 Case The case shall be 3 ATI in accordance with ARINC Specification 408A, and 9 inches long maximum measured from the back of the bezel to the back of the case and excluding connector The weight, excluding cables, should not exceed 5 0 pounds The case and the bezel shall be painted in a lusterless black, Color No 37038 or equivalent The finish shall diffuse light sufficiently to avoid highlights when illuminated with external or internal light sources

2 4 2 Signal Interface The indicator shall provide serial digital interfaces in accordance with ARINC Specification 429 Output data to be provided through this interface shall include, as a minimum, roll and pitch angles and instrument fault status Acceleration, angular rate, any other sensor data such as temperature, and indicator status should be included with the output data An ARINC 429 data bus input shall be provided This input bus is used to command instrument testing and diagnostics

2 4 3 Installation Orientation The indicator shall provide program pins in the connector to specify the panel mounting angle The range of angle shall be 0° to 20° with a resolution of 1 0° The panel mounting angle will be elected by providing the proper jumper wires from a common pin to the appropriate program pins An additional pin shall be provided for parity check If the proper parity is not detected the indicator shall not display attitude and provide a message that indicates the reason for the lack of attitude display

2 4 4 Electrical Power The primary electrical power shall be 27 5 volts DC in accordance MIL-STD-704 The indicator shall operate properly over a range of 18 0 to 30 0 volts DC The total power consumption shall not exceed 20 watts operating in normal flight operation or 36 watts during warm-up Power consumption may be greater when the digital output bus is being used

2 4 5 Connector The connector shall be located at the rear of the indicator The connector shall mate with connectors in accordance with MIL-C-26482 Connector and mate shall lie within area defined by figure in Appendix 4

2 5 Supportability Requirements

2 5 1 Built-In-Test The indicator shall have built-in-test (BIT) functions for fault detection and fault identification The system BIT shall consist of power-up BIT and continuous BIT Any detected faults shall result in the message "ATTITUDE FAIL" being displayed if the display is still functional If the display is not functional, the display should be blanked A failure modes and effects analysis shall be performed to identify failure modes, define the probability and effects of these failures, and determine which are covered by BIT

2 5 1 1 Power-up BIT The indicator shall automatically perform power-up BIT every time power is applied provided that power has been removed for more than one minute The power-up BIT shall test all instrument components that can be practically tested with built in test equipment

2 5 1 2 Continuous BIT The indicator shall perform BIT continuously during operation and remove the attitude display if any failure is detected that would prevent the indicator from displaying attitude within the required accuracy

2 5 2 Reliability The indicator, including display light source, shall have a minimum mean-time-between-failure (MTBF) of 12,000 hours minimum A reliability analysis shall be performed using MIL-HDBK-217 (or equivalent) methods to support MTBF predictions A failure modes and effects analysis (FEMA) is also required to support the system safety hazard analysis

2 5 3 Maintainability The following general maintainability requirements shall be considered in the design of the indicator

a) No calibrations, adjustment, or inspections required in the field

b) Minimization of complexity of maintenance tasks (i e , calibration, adjustment, inspection, etc) by maximum use of standardized equipment or commercial items

c) Rapid and positive recognition of equipment malfunction or marginal performance on the aircraft

d) Rapid and positive identification of the replaceable defective part, assembly, or component

e) Minimum number and types of tools and test equipment (special and standard) needed to perform maintenance

f) Optimum accessibility of all components requiring maintenance, inspection, removal, or replacement

2 5 4 Elapsed Time Indication The instrument shall provide a means for determining the total time of operation This may be provided by a conventional time totalizing meter on the back of the instrument or electronically using non-volatile memory to retain the time as long as there is a means of easily reading out the information without requiring support equipment

2 6 Environment The indicator shall meet the requirements of RTCA DO-160C for operation in the cockpit of a transport aircraft The environmental categories to apply to the instrument are identified as A2XBABXWXDFSZABAZWZA3E3XX The identification of each of these items is given in the following list

Section	Test		Category
4 0	Temperature and Altitude Test		A2
	Operating Temp	-15°C to 70°C	
	Ground Survival Temp	-55°C to 85°C	
	Altitude	15,000 feet	
	Decompression	45,000 feet	
	Overpressure	-15,000 feet	
4 5 4	In-Flight Loss of Cooling Test		X
	Operation without cooling	180 minutes	
5 0	Temperature Variation Test		B
	Temperature Change Rate	5°C per minute	
6 0	Humidity Test		A
	Standard Humidity Environment		
7 0	Shock and Crash Safety		
	Operational Shock each axis	6 g	
	Crash Safety		
	Up	2 7 g	
	Down	6 0 g	
	Forward	12 0 g	
	Aft	2 0 g	
	Sideways	2 0 g	
8 0	Vibration Test		B
	Instrument Panel for Turbojet Aircraft		
9 0	Explosion Proofness Test		X
	Not Required		
10 0	Waterproofness Test		W
	Exposure to condensation		
11 0	Fluids Susceptibility Test		X
	Not Required		
12 0	Sand and Dust Test		D

	Blowing Sand and Dust Environment	
13 0	Fungus Resistance Test Fungus Environment	I
14 0	Salt Spray Test Salt Environment	S
15 0	Magnetic Effect Test Magnetic Effect Limited to < 0 3 meters	Z
16 0	Power Input Test Constant Freq ac Input to T/R Units with battery floating on bus	A
17 0	Voltage Spike Test More Sever Test for Backup Instrument	B
18 0	Audio Frequency Conducted Susceptibility Test Constant Freq ac Input to T/R Units with battery floating on bus	A
19 0	Induced Signal Susceptibility Test Interference Free Operation Required	Z
20 0	Radio Frequency Susceptibility Test Moderate to Severe Environment	W
21 0	Emission of Radio Frequency Energy Test Interference Free Operation Required	Z
22 0	Lightning Induced Transient Susceptibility Test Lightning Test Level	A3E3
23 0	Lightning Direct Effect Test Not Required	X
24 0	Icing Test Not Required	X

3 REGULATORY REQUIREMENTS

3 1 Certification The instrument shall be certified in accordance with Federal Aviation Regulations The certification shall include those defined by Part 37—Technical Standard Order Authorizations (37 114) TSO–C4c and also those required for electronic displays and software quality

4 QUALITY ASSURANCE PROVISIONS

4 1 Contractor Certification The contractor shall certify and maintain substantiating evidence that the product offered meets the salient characteristics of this Commercial Item Description, and that the product conforms to the producer's own drawings, specifications, standards, quality assurance practices, and is the same as the product offered for sale in the commercial marketplace The Government reserves the right to require proof of such conformance prior to first delivery and thereafter as may be otherwise provided for under the provisions of the contract

4 2 Inspection Requirements. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection, examination, and test requirements specified herein Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the inspection requirements specified herein, unless disapproved by the Government The Government reserves the right to perform any of the inspections, examinations, or tests set forth in this description where such inspection, examination, and tests are deemed necessary to assure supplies and services conform to prescribed requirements

5 PACKAGING

5 1 Packaging Preservation packing, and marking shall be as specified in the contract or order

6 NOTES

6 1 CID Preparation This CID was prepared with the assistance of The Charles Stark Draper Laboratory Technical contact person is

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6 2 Source of Documents

6 2 1 SAE Standards are available from the Society of Automotive Engineers, 400 Commonwealth Dr , Warrendale, PA 15096-0001

6 2 2 ARINC specifications are available from Aeronautical Radio Incorporated, 2551 Riva Road, Annapolis, MD 21401

6 2 3 Military Documents are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094

6 2 4 Wright Laboratory document can be obtained from the National Technical Information Service (NTIS) or from Wright Laboratory, Cockpit Avionics Office, WL/AAA-2 BLDG 146, 2210 Eighth St STE 1, Wright Patterson AFB, OH 45433-7511

MILITARY INTERESTS

Custodians:
Air Force - 99

Preparing Activity
Air Force -82

Agent
Air Force - 99

Project 6610-0447

APPENDIX 1 Design objectives for liquid crystal displays

NOTE This appendix was extracted from SAE Aerospace Recommended Practice ARP4256 "Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft," Draft "B"

1 SCOPE

This appendix 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 appendix 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 appendix 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 appendix 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 appendix

3 2 Environmental Conditions

Except as detailed in appropriate sections of this appendix, 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 which 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 paragraph 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

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

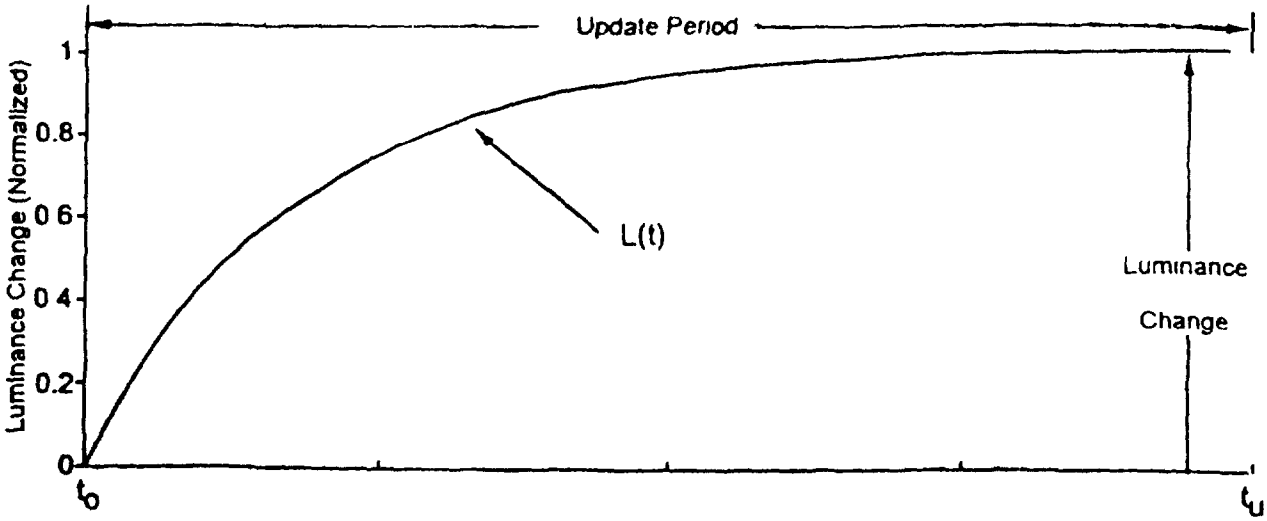

FIGURE 1 Response time ("on")

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

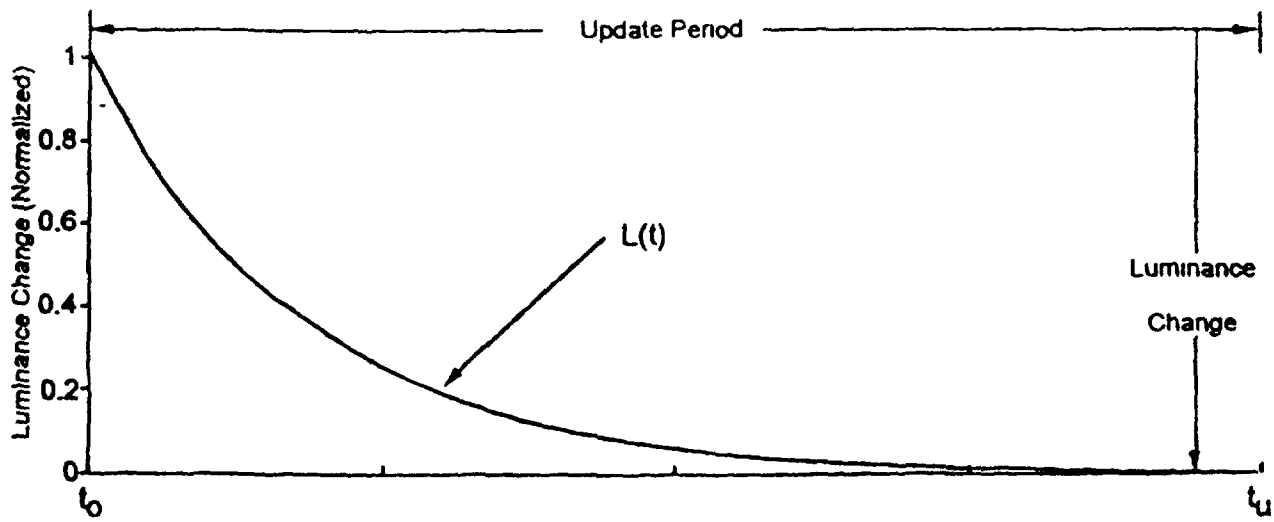

FIGURE 2 Response time ("off")

4 1 10 (Continued)

where

$L(t)$ = Function luminance change with respect to time
L_c = Commanded steady state luminance

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

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

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

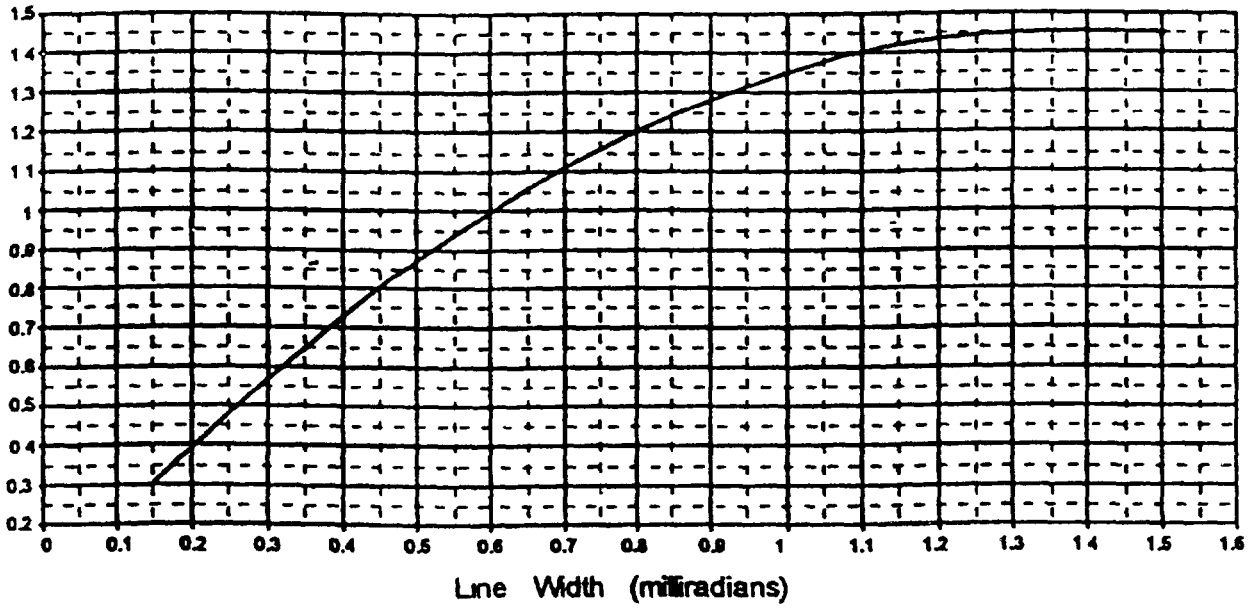

FIGURE 3 Brightness vs Luminance Relationship

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

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 Luminance Uniformity $= \dfrac{L_{max} - L_{min}}{L_{mean}}$

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

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

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 FOV Luminance Uniformity $= \dfrac{L_{max} - L_{min}}{L_{mean}}$

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

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

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

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

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

4 3 2 Lag Time The lag time between pilot selection of a format and display of the format should not exceed 1 s The lag between pilot selection of primary flight data and display of the data should not exceed 0 25 s (reference ARP4102/7, 6 1 3)

4 3 3 Data Update Display data shall be updated at sufficient frequency to meet symbol motion (4 1 9) requirements In particular, experience has shown the following to be acceptable

TABLE 3

Parameter	Minimum Rate
Pitch	15 Hz
Roll	15 Hz

5 GLOSSARY OF TERMS

5 1 CHROMATICITY A measure of the hue and purity of a color, it is defined as x,y (CIE 1931), or u',v' (CIE 1976) coordinates (reference ARP4260)

5 2 CHROMA The psychometric correlate, C*, of the concept of perceived chroma which depends significantly on the viewing conditions such as the nature of the surround (Y_n, u'_n, v'_n)

Where $C^* = \sqrt{u^{*2} + v^{*2}}$

And $u^* = 13L^*(u'-u'_n)$

$v^* = 13L^*(v'-v'_n)$

$$L^* = 116\sqrt[3]{\frac{\text{Luminanace}}{Y_n}} - 16 \text{ for Luminance} > 1 \text{ fL}$$

$$L^* = 903 \times \frac{\text{Luminance}}{Yn} \quad \text{for Luminance} < 1 \text{ fL}$$

Where the surround or object-color stimulus is specified as

Y_n = 100 fL
u'_n = 0 1978 (D_{65})
v'_n = 0 4684 (D_{65})

5 3 COLOR BANDING (MATRIX) Nonuniform distribution of color within a line or symbol (see Figure 4)

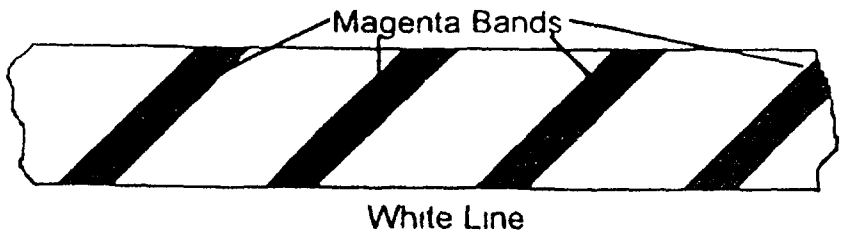

FIGURE 4

5 4 COLOR FRINGING (MATRIX) Color distortion along the edge of a line or symbol due to the interaction of line or symbol orientation with pixel pattern geometry (see Figure 5)

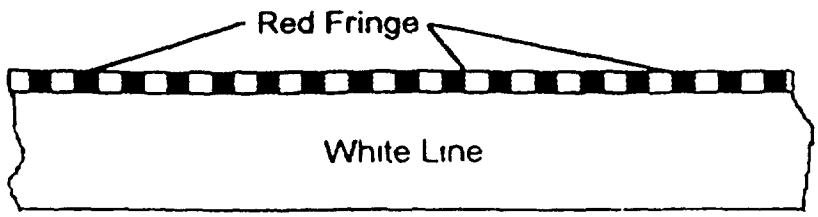

FIGURE 5

5 5 CONTRAST RATIO (CR) $CR = \frac{L_t}{L_b}$

L_t is the total luminance of the symbol or image, including any transmitted and reflected light as measured in the specified lighting conditions L_b is the luminance of the background, or dimmer area, including any transmitted and reflected light and any stray display emissions measured in the specified lighting conditions See ARP1782 for a full discussion on this and related definitions

5 6 CROSSTALK Unwanted luminance modulation in display elements which is caused by the cross coupling of electrical signals addressed to other elements or rows, columns, or blocks of other elements

5 7 DESIGN EYE POSITION (DEP) A point fixed in relation to the aircraft structure (neutral seat reference point) at which the midpoint of the pilot's eyes should be located when seated at the normal position The DEP is the principal dimensional reference point for the location of flight deck panels, controls, displays, and external vision (reference Figure 1 of ARP4101)

5 8 DISPLAY ELEMENT The smallest addressable entity of the display In the case of an active matrix LCD, the smallest addressable shutter of an individual color In the case of a segmented display, any of the shapes, or symbols made up of only one individual addressable entity

NOTE Other commonly used terms are "dot" in matrixed displays and "segment" in segmented displays

5 9 FAILED-ON A display element, row, or column which is failed permanently or sporadically in the bright" or emitting state

5 10 FAILED-OFF A display element, row, or column which is failed permanently or sporadically in the dark" or nonemitting state

5 11 FLICKER Flicker is an undesired rapid temporal variation in display luminance of a symbol, or a group of symbols, or a luminous field Flicker can cause fatigue and reduced crew efficiency

5 12 GRAY SCALE The incremental levels of display element light transmission which exist between fully off (dark) and fully on (bright)

5 13 IMAGE RETENTION Image retention is an undesired afterimage (residual pattern) that persists on the display

5 14 INSTRUMENT The word "instrument" shall be considered to mean the specific unit or complete system for which this appendix is written

5 15 JITTER Unintended rapid movement discernible to a human eye located at the design eye position

5 16 LINE WIDTH Width at 50% of peak luminance of the line luminance distribution when measured from the DEP

5 17 LUMINANCE A measure of luminous intensity per unit area, units are candela per square meter (cd/m^2) or foot-lamberts (fL) (reference ARP4260)

5 18 MILLIRADIAN (mrad) An angular measurement equal to 0 0573 degrees defined as one thousandth of an arc whose length equals the circle radius Table 1 converts milliradians to linear dimensions (inches and millimeters) for a viewing distance of 762 mm (30 in)

5 19 MOIRE A pattern seen when two out of phase spatially periodic patterns are superimposed

5 20 PIXEL In a matrix display, the smallest group of display elements which provides the color capability of the display

NOTE Be careful with the word "pixel", it is sometimes erroneously used to refer to a single "display element" on a color matrix display (see 5 8)

5 21 RACHETING Discontinuous (jerky) movement or rotation of a dynamic display feature caused by excessively large quantization steps in the translation or rotation of the particular feature

5 22 ROPING Periodic luminance modulation along a line producing a "rope-like" appearance

5 23 SEGMENTED DISPLAY A display in which the individual addressable display elements (segments) are of varying shape and/or orientation such that they are dedicated to the display of a specific type or specific types of symbolic or pictorial information

5 24 SERVICE LIMITS An end of life condition under which the unit must be removed from the aircraft

5 25 SPECULAR REFLECTIONS Reflections from a finite, resolvable area of a surface which continuously, over that area, follow the law of reflection (angle of light incidence equals angle of light reflection) Such reflections are exemplified by those from an ideal mirror and involve no diffusion or scattering of light

5 26 STAIR STEPPING Discrete steps occurring along edges of a line or symbol caused by quantization phenomena

5 27 STROBOSCOPIC FLICKER An electronic display image can appear to flicker or jump when the image has a short rise and fall time and there is relative motion between the observer and the display Because of the relative motion, the pulsing image is focused upon different areas of the retina This gives the observer the impression that the image is flickering or breaking up

5 28 VIEWING ENVELOPE The volume in space defined by, as a minimum, the total viewing angles in both the horizontal and vertical planes measured normal to the plane of the display surface, and the minimum distance from the center of display surface for which the instrument complies with this appendix

PREPARED BY SAE SUBCOMMITTEE A-4ED, ELECTRONIC DISPLAY
OF COMMITTEE A-4, AIRCRAFT INSTRUMENTS
TABLE 1

angle (α) mrad	angle (α) deg	h in	h mm	angle (α) mrad	angle (α) deg	h in	h mm
0 10	0 3'	0 0030	0 08	5 5	18 9'	0 165	4 29
0 15	0 5'	0 0045	0 11	6 0	20 6'	0 180	4 57
0 20	0 7'	0 0060	0 15	6 5	22 3'	0 195	4 95
0 25	0 9'	0 0075	0 19	7 0	24 1'	0 210	5 33
0 30	1 0'	0 0090	0 23	7 5	25 8'	0 225	5 72
0 35	1 2'	0 0105	0 27	8 0	27 5'	0 240	6 10
0 40	1 4'	0 0120	0 30	8 5	29 2'	0 255	6 48
0 45	1 5'	0 0135	0 34	9 0	30 9	0 270	6 86
0 50	1 7'	0 0150	0 38	9 5	32 7'	0 285	7 24
0 55	1 9'	0 0165	0 42	10	34 4	0 30	7 60
0 60	2 1'	0 0180	0 46	15	51 6'	0 45	11 4
0 65	2 2'	0 0195	0 50	20	1°9'	0 60	15 2
0 70	2 4'	0 0210	0 53	25	1°26'	0 75	19 1
0 75	2 6	0 0225	0 57	30	1°43'	0 90	22 9
0 80	2 8'	0 0240	0 61	35	2°1'	1 05	26 7
0 85	2 9	0 0255	0 65	40	2°17'	1 20	30 5
0 90	3 1'	0 0270	0 69	45	2°35'	1 35	34 3
0 95	3 3'	0 0285	0 72	50	2°52'	1 50	38 1
1 0	3 4'	0 0300	0 76	55	2°9'	1 65	41 9
1 5	5 2'	0 0450	1 14	60	3°26'	1 80	45 7
2 0	6 9'	0 0600	1 52	65	3°43'	1 95	49 5
2 5	8 6'	0 0750	1 91	70	4°1'	2 10	53 3
3 0	10 3'	0 0900	2 29	75	4°18'	2 25	57 2
3 5	12 0	0 1059	2 67	80	4°35'	2 40	61 0
4 0	13 8'	0 1200	3 05	85	4°52'	2 55	64 8
4 5	15 5'	0 1350	3 43	90	5°10'	2 70	68 6
5 0	17 2'	0 1500	3 81	100	5°44'	3 00	76 0

NOTES

1 Milliradians and degrees (α) to inches and millimeters (h) at the display surface for a viewing distance (d) of 762 mm (30 in) which is a typical viewing distance for a design eye position

2 $h = \alpha \times d$

where

h = Character or symbol height
α = Angle subtended (radians)
d = Viewing distance

3 This conversion table is for an assumed viewing distance of 762 mm (30 in) and may not satisfy performance criteria

APPENDIX 2 Typical C-5 flight profiles to be used for determining SAI accuracy.

1 Refueling training

- Racetrack pattern with 180° turns at 15° bank and a minimum of 5 min straight and level between turns

2 Takeoff and landing training

- Takeoff, climbing 180° turn to downwind starting at 500 feet and climbing to 1200 feet above ground, 180° turn to final approach and touchdown keeping whole pattern within 1 n m of runway, repeat pattern

3 Combat Air Tactics (CAT)

- Takeoff, begin 45° bank at 200 feet, climb in a continuous turn at 15° nose up or less as required to maintain Vmco + 10 knots until reaching 5000 feet,
- Approach and landing, begin 45° bank at 5000 feet, descend in a continuous turn 15° nose down or less as required to maintain less than maximum flap speed (approx 217 KCAS)

(maneuver used to keep aircraft over airfield to minimize exposure to ground fire)

APPENDIX 3 Design eye points relative to the normal of the display surface for C-5 to be used for display characteristics requirements.

Primary design eye point (pilot) Eye position 21 inches to left, 31 inches in front of, and 6 inches above the display

Secondary design eye point (copilot) Eye position 31 inches to right, 31 inches in front of, and 6 inches above the display

The eye box of both primary and secondary eye point is 4 inches wide, 4 inches high and 7 inches long

APPENDIX 4 Physical constraints on rear connector