AEROSPACE STANDARD

AS8055 REV. A

Issued 1999-03
Revised 2015-07

Superseding AS8055

(R) Minimum Performance Standard for
Airborne Head Up Display (HUD)

RATIONALE

This SAE Aerospace Standard provides the Minimum Performance Standard for Airborne Head-Up Display (HUD) for use by the aerospace industry and may also be used by the FAA and other regulatory agencies in a technical standard order. The original version focused on CRT-HUD technology and Revision A updates the CRT requirements and extends the requirements to cover digital HUDs. This document was developed by the SAE A-4 HUD subcommittee and supersedes AS8055.

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1. SCOPE

This SAE Aerospace Standard (AS) specifies minimum performance standards for airborne binocular Head-Up Displays (HUDs) in fixed wing (14 CFR part 23, 25) aircraft; while this document is also applicable to rotorcraft (14 CFR part 27, 29) additional performance standards may be required for rotorcraft. This aerospace standard covers basic display standards, but does not include specific application requirements. Specific applications can include flight instrumentation, navigation, engine and system status, alerting, surveillance, communication, terrain awareness, weather, enhanced vision, synthetic vision and other displays.

This document covers criteria for conformal and non-conformal HUD systems that are intended for use in the flight deck by the pilot or copilot. Display minimum performance characteristics are specified for standard and other environmental conditions for the purpose of product qualification.

This document does not address sensor imaging systems, displays worn by the pilot (goggles, helmet mounted displays) or specific symbology to be displayed.

This document is intended to be used in combination with other guidance material contained in current system specific, Technical Standard Orders (TSOs), Advisory Circulars (ACs), and other Federal Aviation Administration (FAA)-approved guidance material. This SAE Aerospace Standard can be applicable to HUDs used across multiple aircraft types.

2. REFERENCES

The documents listed in 2.1 are regulations, requirements, or recommended practices and not necessarily minimum standards or requirements. These documents are invoked by this document only to the extent specified herein. The documents listed in 2.2 are provided for information purposes only and do not form a part of the requirements of this document.

2.1 Applicable Documents

The following publications form a part of this document only to the extent specified within the requirements of this Aerospace Standard. The latest issue of all SAE publications shall apply except in cases where referring documents call out specific versions. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP5583A Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment

2.1.2 Regulatory Publications

FAA AC-( ) documents are available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, or www.faa.gov

“14 CFR” documents may be purchased from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, www.faa.gov

“TSO” documents are available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, or www.faa.gov

“JAR” documents may be purchased from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.iny/home/rg_certspecs.html

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Advisory Circular 20-136B Aircraft Electrical and Electronic System Lightning Protection

Advisory Circular 20-158 Certification of Aircraft Electrical and Electronic Systems for Operations in the High-Intensity Radiated Fields (HIRF) Environment

Advisory Circular 25-11A Transport Category Airplane Electronic Display Systems

Advisory Circular 23.1309-1D System Safety Analysis and Assessments for Part 23 Airplanes

Advisory Circular 25.1309-1A System Design Analysis

14 CFR 2X.562 Emergency Landing Dynamic Conditions
23.562(b) (5); 25.562(c) (5); 27.562(c) (5); 29.562(c) (5)

14 CFR 2X.853 Compartment Interior

14 CFR 25.869 Fire Protection: System

14 CFR 2X.1309 Equipment, Systems, and Installation
23.1309; 25.1309; 27.1309; 29.1309

2.1.3 RTCA/EUROCAE Publications

RTCA publications available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

EUROCAE publications available from EUROCAE Secretariat, 102 rue Etienne Dolet, 92240 Malakoff, France, Tel: +33 1 40 92 79 30, www.eurocae.net.

RTCA DO-160G/EUROCAE ED-14G Environmental Conditions and Test Procedures for Airborne Equipment

2.1.4 CIE (Commission Internationale de l'Eclairage) Publications

Available outside of the U.S. from CIE Central Bureau, Babenbergerstrasse 9/9A, 1010 Vienna, Austria, Tel: +43 1 714 31 87, www.cie.co.at and inside the U.S. from United States National Committee of the Commission Internationale De L'Eclairage, Radiometric Physics Division, National Bureau of Standards, Washington, DC 20234.

2.1.5 Electronic Industry Association (EIA) Publications

Available from Available from Electronic Component Association (ECA), 2500 Wilson Boulevard, Arlington, VA 22201-3834, Tel: 703-907-7500, www.eia.org.

EIA-503-A Recommended Practice for the Measurement of X-Radiation from Direct-View Television Tubes

2.2 Related Publications

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

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP1161 Crew Station Lighting – Commercial Aircraft

ARP1782 Photometric and Colorimetric Measurement Procedures for Airborne 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 Flight Deck Layout and Facili

ARP4102 Flight Deck Panels, Controls, and Displays

ARP4102/7 Electronic Displays

ARP4102/8 Flight Deck Head-Up Displays

ARP4103 Flight Deck Lighting for Commercial Transport Aircraft

ARP4105 Abbreviations, Acronyms, and Terms for Use on the Flight Deck

ARP4155 Human Interface Design Methodology for Integrated Display Symbology

ARP4256 Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft

ARP4260 Photometric and Colorimetric Measurement Procedures for Airborne Electronic Flat Panel Displays

AIR4742 Display Characteristics of FDI Head-Up-Guidance System As Approved for the B-727 Airplane

ARP5287 Optical Measurement Procedures for Airborne Head Up Display (HUD)

AS8034 Minimum Performance Standard for Airborne Multipurpose Electronic Displays

2.2.2 Regulatory Publications

FAA AC-( ) documents are available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, or www.faa.gov

“14 CFR” documents may be purchased from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, www.faa.gov

“TSO” documents are available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, Tel: 301-322-4961, or www.faa.gov

“JAR” documents may be purchased from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.iny/home/rg_certspecs.html

FAA Advisory Circular 23.1309-1D

System Safety Analysis and Assessments for Part 23 airplanes

FAA Advisory Circular 23.1311-1B Installation of Electronic Display Instrument Systems in Part 23 Airplanes

FAA Advisory Circular 25.773.1 Pilot Compartment Design Considerations

FAA Advisory Circular 29.773-1 Pilot Compartment View

FAA Advisory Circular 120-28D Criteria for Approval of Category III Weather Minima for Takeoff, Landing and Rollout

FAA Advisory Circular 120-29A Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operations

14 CFR Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

14 CFR Part 25/JAR Part 25 Airworthiness Standards: Transport Category Airplanes

14 CFR Part 27 Airworthiness Standards: Normal Category Rotorcraft

14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft

14 CFR 25.581 Lightning Protection

14 CFR 2X.773 Pilot Compartment View
23.773; 25.773; 27.773; 29.773

14 CFR 2X.1301 Function and Installation
23.1301; 25.1301; 27.1301; 29.1301

14 CFR 2X.1303 Flight and Navigation Instruments
23.1303; 25.1303; 27.1303; 29.1303

14 CFR 23.1311 Electronic Display Instrument Systems

14 CFR 25.1316 System Lightning Protection

14 CFR 2X.1321 Arrangement and Visibility
23.1321; 25.1321; 27.1321; 29.1321

14 CFR 2X.13xx High-intensity Radiated Fields (HIRF) Protection
23.1308; 25.1317; 27.1317; 29.1317

JAR-HUDS-901 Category 3 Operations with a Head Up Display

JAR-HUDS-902 Category 2 Operations with a Head Up Display

JAR-HUDS-903 Head Up Displays

TSO-C113 Airborne Multipurpose Electronic Displays

2.2.3 RTCA/EUROCAE Publications

RTCA publications available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

EUROCAE publications available from EUROCAE Secretariat, 102 rue Etienne Dolet, 92240 Malakoff, France, Tel: +33 1 40 92 79 30, www.eurocae.net.

RTCA DO-178B/EUROCAE ED-12B Software Considerations in Airborne systems and equipment Certification

2.2.4 CIE (Commission Internationale de l'Eclairage) Publications

Available outside of the U.S. from CIE Central Bureau, Babenbergerstrasse 9/9A, 1010 Vienna, Austria, Tel: +43 1 714 31 87, www.cie.co.at and inside the U.S. from United States National Committee of the Commission Internationale De L'Eclairage, Radiometric Physics Division, National Bureau of Standards, Washington, DC 20234.

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

2.2.5 U.S. Government Publications

Copies of these documents are available online at http://quicksearch.dla.mil.

MIL-HDBK-87213 Military Handbook: Electrically/Optically Generated Airborne Displays

MIL-STD-1787B Military Standard: Aircraft Display Symbology

MIL-STD-1295A Military Standard: Human Factors Engineering Design Criteria for Helicopter Cockpit Electro-Optical Display Symbology (Cancelled)

MIL-STD-810 Military Standard: Environmental Test Methods and Engineering Guidelines

2.2.6 Other Publications

Human Factors Issues in Head-Up Display Design: “The Book of HUD”; SOAR CSERIAC 92-2 May 1992

2.3 Definitions

Definitions used in this document shall be as noted in the Glossary of Terms defined in Section 7.

The word "shall" is used to express an essential requirement where compliance is mandatory.

The word "should" is used to express a recommendation. Deviation from the specified recommendation shall require justification.

The word “must” is used to express an essential (mandatory) requirement that is required by a specific regulation.

3. GENERAL REQUIREMENTS

3.1 Material

Material shall be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft instruments.

3.2 Workmanship

Workmanship shall be consistent with high quality aircraft electromechanical and electronic instrument manufacturing practices.

3.3 Components Compatibility

If a display system component is individually acceptable but requires calibration adjustments or matching to other components in the aircraft for proper operation, the component shall be identified in a manner that will ensure performance to the requirements of this document.

3.4 Interchangeability

Display system components which are identified with the same manufacturer part or model number shall be completely interchangeable.

3.5 Accessibility of Adjustments and Controls

Calibration adjustments which are not normally made in flight shall not be readily accessible to flight personnel when the equipment is installed in accordance with the equipment manufacturer's instructions.

The arrangement of the HUD operational controls shall ensure that they are visible to, identifiable and usable by the pilot from his normal seated position. The arrangement and/or type of the controls should preclude inadvertent operation.

3.6 Self-Test Capability

If the equipment contains integral arrangements to permit preflight and/or in-flight self-test checks on the operation of the equipment in combination with other aircraft subsystems, such tests shall not adversely affect any associated subsystem.

In-flight, self-test activation features which are interruptive to the system shall include a means to inform the pilot or appropriate flight crew member of this mode of operation.

3.7 Effect of Tests

The application of all prescribed in-service testing shall not produce a subsequent condition which would be detrimental to the continued performance of the equipment.

3.8 Malfunction and Failure Indications

3.8.1 Malfunction Indication

Means shall be provided to indicate HUD system malfunctions or failures to the appropriate crew member. A blank display or an “X” across a blank display are examples of acceptable means of indicating failure.

3.8.2 Power Failure Indication

Means shall be provided to indicate when electrical power (voltage and/ or current of all required phases) is not sufficient for proper operation of the equipment. A blank display is an example of acceptable means of indicating failure.

3.8.3 Fail Safe Provision

No single failure or malfunction of the HUD system shall introduce unsafe conditions to associated interconnected equipment.

- Unsafe conditions include the probability of failure of the article that could lead to an unsafe condition, based upon the design assurance level.

- A System Safety Assessment (SSA) shall be performed on the equipment being submitted for TSO authorization. The SSA shall include any probable failure conditions of the article. Depending on the hazard classification for both Hardware and Software, the results of the SSA may require that a Failure Modes and Effects Analysis (FMEA) be performed to identify, isolate, and mitigate individual failures.

- ARP4761 Table 1 shows a means of evaluating the failure condition severity as related to Probability Objectives and Assurance Levels for components and systems in aircraft.

3.9 Multiple Mode or Function Indications

When a HUD has more than one operational display mode, each mode shall be indicated by the HUD.

3.10 Identification

The following information shall be legible and permanently marked on the equipment or nameplate attached thereto:

a. Name of equipment

b. Manufacturer's part number

c. Manufacturer's serial number or date of manufacture

d. AS8055A or equivalent approval identification

e. Manufacturer's name or trademark

f. Weight to the nearest 0.05 kg (tenth of a pound)

g. Environmental categories per DO-160G/ED-14G

3.11 Display

The information being displayed should functionally conform to the applicable SAE Aerospace Recommended Practice or other standards as appropriate.

3.11.1 Discernibility

Means shall be incorporated to prevent obscuration or confusion of task essential information. Task essential information shall be identified and defined by the applicant (e.g., typically by the manufacturer or OEM).

3.11.2 Critical Information

Means shall be provided to inform the pilot if critical data normally displayed on the HUD is invalid. For display function criticality and the criticality of hazardously misleading primary flight data, refer to AC 25-11A.

3.11.3 Information Limit Indication

A means shall be provided to identify when critical information exceeds the display format functional limits.

3.11.4 Scale Indications

The display scaling, graduations, and numeration shall be appropriate for the level of reading accuracy and dynamic range required (e.g., familiar units of measure are not as significant as the values and may be a smaller font, but still must be discernible).

3.11.5 Ambiguity

Means shall be provided to prevent ambiguous indications within the operating range of the equipment.

3.12 Resistance to Dust and Moisture

Optics shall be designed to prevent contamination of internal surfaces by dust or moisture under all operating and test conditions including the low temperature and fogging tests of this document.

3.13 Mechanical Hazard System Protection

Within the environmental constraints of this document, the HUD system shall be designed such that no hazard will result from implosion, or other mechanical failures. When the HUD combiner is stowed, the combiner shall be designed such that it cannot be inadvertently deployed.

3.14 Fire Resistance

Except for small parts (e.g., fasteners, grommets, knobs, seals, small electrical parts) that would not contribute significantly to the propagation of a fire, all materials used must be self-extinguishing when tested in accordance with the requirements of 14 CFR 2X.853 and 25.869 Appendix F thereto, with the exception that materials tested may be configured in accordance with paragraph (b) of Appendix F or may be configured as used.

3.15 Supplemental Heating/Cooling

Where supplemental heating or cooling is required by the equipment to ensure conformance with this standard, it shall be the responsibility of the manufacturer to specify such requirements. If the loss of supplemental heating or cooling during normal system operation could lead to hazardously misleading information, the heating or cooling sources shall be monitored and the flight crew alerted to the failure.

3.16 Lighting

Per regulation 14 CFR 2X.1543, all instrument markings shall be clearly visible to the appropriate crewmember. All display and control labels and markings shall be clearly visible and easily readable in all flight deck lighting conditions, without requiring external lighting.

When integral lighting is provided, all indices within the required viewing envelope shall be viewable under normal flight deck lighting conditions.

3.17 Flight Guidance Performance

If the HUD displays command guidance, it shall not cause sustained nuisance oscillations, undue attitude changes or excessive control activity (resulting from configuration, power changes, or any other disturbance to be expected in normal operation), when followed by the pilot.

3.18 Visual Obstructions

The HUD should not have drive electronics or supporting structure that is so intrusive so as to block the outside view to a hazardous degree.

4. MINIMUM PERFORMANCE STANDARDS UNDER STANDARD CONDITIONS

The manufacturer shall conduct sufficient tests to prove compliance with this Aerospace Standard. The applicable standard test conditions are given in RTCA DO-160G/EUROCAE ED-14G. Applicable measurement procedures are given in ARP5287, Optical Measurement Procedures for Airborne Head Up Displays; however, they should not be considered the only acceptable methods for optical testing of airborne HUD.

4.1 Equipment Functions and Mechanical Operation

Equipment shall display information with contents as specified by the appropriate standard document. All equipment functions and mechanical devices shall perform their intended function.

4.1.1 Start-Up

Under standard ambient conditions, a display shall present statically correct and nonmisleading information within 1 minute of receiving valid data. Full dynamic and other detailed performance requirements should be met within 10 minutes.

4.1.2 Power Transient Recovery

For power interruptions up to 200 ms in duration, recovery time should not exceed 1 second. In no case shall power transients cause any erroneous display or output after the recovery time (see also section 16 of DO-160G/ED-14G).

4.1.3 Lag Time

The lag time between pilot selection of a format and display of the format should not exceed 1 second. The lag between pilot selection of primary flight data and display of the data should not exceed 0.25 seconds (reference ARP4102/7, 6.1.3).

4.1.4 Data Update

Display data shall be updated at sufficient frequency to meet symbol motion (4.2.11) requirements. In particular, for pitch and roll the update rate should be a minimum of 15 Hz.

4.2 Display Characteristics

The following requirements apply to the HUD in its installed position and as viewed under all flight deck lighting conditions from the HUD Eye Reference Point. The following subparagraphs do not include the effects of sensor errors or noise.

4.2.1 HUD Display Viewing Angles

There are four distinct field-of-view (FOV) characteristics which shall be specified to fully describe the characteristics of the angular region over which the virtual HUD display is visible. These FOV characteristics are the total FOV, the instantaneous FOV (IFOV), the binocular overlapping FOV, and the instantaneous monocular FOV. These FOV characteristics shall be specified by the HUD manufacturer and shall be consistent with the intended function of the HUD. The amount of vertical and horizontal head movement needed to see the total FOV should not cause excessive pilot workload or discomfort.

4.2.2 HUD Eyebox

The HUD Eyebox is a three-dimensional volume of a size and shape that is specified by the HUD manufacturer in which certain optical performance requirements are met. From all points within the HUD Eyebox, a minimum monocular FOV shall be visible. The minimum monocular FOV should include the center of the FOV and shall be specified by the manufacturer. The minimum size of the HUD Eyebox should be:

Lateral: 76.2 mm (3.0 inches)
Vertical: 50.8 mm (2.0 inches)
Longitudinal: 101.6 mm (4.0 inches)

The lateral and vertical dimensions represent the total movement of a monocular viewing instrument with a 6.35 mm (0.25 inch) entrance aperture (pupil). The HUD Eyebox longitudinal dimension represents the total fore-aft movement over which the requirement of this specification are met. The Eyebox size should be maximized consistent with other flight deck constraints. The Eyebox size may ultimately constrain the placement of the symbology in some applications. Whenever possible, the HUD Eye Reference Point should be coincident with the flight deck Design Eye Position. As a minimum, the HUD Eyebox shall contain the flight deck Design Eye Position. When the HUD Eye Reference Point is not coincident with the flight deck Design Eye Position, the above stated minimum Eyebox dimension may not be sufficient. Loss of binocular overlapping field of view with head motion should be minimized. The HUD Eyebox volume is not constrained to be rectangular, but shall totally contain the volume of the minimum HUD Eyebox defined in this specification. Figure 1 graphically shows an example where the minimum HUD Eyebox is wholly contained within the manufacturer's stated HUD Eyebox.

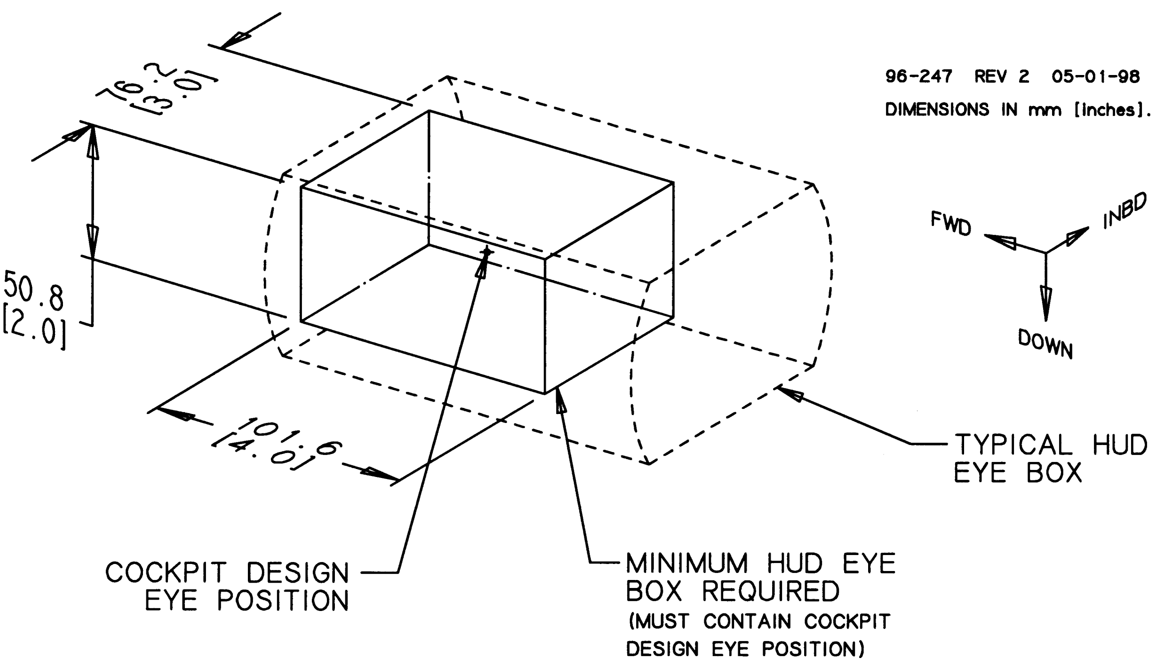

Figure 1 - Minimum HUD eyebox

4.2.3 Symbol Positioning Accuracy (External)

External Symbol Positioning Accuracy, or Display Accuracy, is a measure of the relative conformality of the HUD display with respect to the real world view seen through the combiner and windshield from any eye position within the HUD Eyebox. Display Accuracy is a monocular measurement, and, for a fixed field point, is numerically equal to the angular difference between the position of a real world feature as seen through the combiner and windshield, and the HUD projected symbology.

The total HUD system display accuracy error budget (excluding sensor and windshield errors) includes installation errors, digitization errors, electronic gain and offset errors, optical errors, combiner positioning errors, errors associated with the CRT and yoke, misalignment errors, environmental conditions (i.e., temperature and vibration), and component variations. Optical errors are both head position and field angle dependent and are comprised of three sources: uncompensated pupil and field errors originating in the optical system aberrations, image distortion errors, and manufacturing variations. The optical errors are statistically determined by sampling the HUD FOV and Eyebox. (See 4.2.10 for a discussion of field of view and Eyebox sampling.) The optical errors shall represent 95.4% (2 sigma) of all sampled points.

The display accuracy errors are characterized in both the horizontal and vertical planes. Total display accuracy shall be characterized as the root-sum square (RSS) errors of these two component errors. All display errors shall be minimized across the display field of view consistent with the intended function of the HUD. The following are the allowable display accuracy errors for a conformal HUD as measured from the HUD Eye Reference Point:

HUD Boresight	≤ 17’ 11” (5.0 mrad)
≤ 10 degree diameter	≤ 25’ 47” (7.5 mrad) (2 Sigma)
≤ 30 degree diameter	≤ 34’ 23” (10.0 mrad) (2 Sigma)
> 30 degree diameter	< 34’ 23” + kd[(FOV)(in degrees) - 30] (10 mrad + kr[(FOV)(in degrees) - 30)] (2 Sigma) kd = 0’ 43” of error per degree of FOV kr = 0.2 mrad of error per degree of FOV FOV = Field of view in degrees

The HUD manufacturer shall specify the maximum allowable installation error.

In no case shall the display accuracy error tolerances cause hazardously misleading data to be presented to the pilot viewing the HUD.

4.2.4 Symbol Positioning Alignment

Symbols which are interpreted relative to each other shall be aligned to preclude erroneous interpretation of information. Symbols which are not interpreted relative to each other may overlap but shall not cause erroneous interpretation of display data.

4.2.5 Display Drift

Dimensional and positional stability of display system presentations shall be sufficient to ensure the requirements of 4.2.3 are met. Drifts shall in no case cause an erroneous interpretation of the information presented.

4.2.6 Line Width

When viewed from any point in the HUD Eyebox, unless specifically enhanced, the symbol line width shall be less than 2 mrad when measured at the 50% intensity points with symbol luminance set at maximum. The symbol line width shall be greater than 0.5 mrad when measured at the 50% intensity points with symbol luminance set at 3.4 cd/m^2 (1 fL). Display line widths shall be of sufficient size and sharpness to display the intended information with no distracting visual effects or display ambiguities that could result in an unsafe condition. The line should appear uniform when viewed at all rotational or translational orientations.

4.2.7 Display Jitter

There should be no discernible display jitter when viewed within the viewing envelope. In no case shall the display jitter be objectionable. Display jitter amplitude shall be less than 0.6 mrad peak-to-peak when viewed from the HUD Eye Reference Point. Jitter of 0.3 mrad peak-to-peak from any point within the HUD Eye Box is a suggested upper limit, but that may not be acceptable in some instances.

4.2.8 Display Flicker

The display shall not exhibit any unacceptable level of flicker under the full range of ambient environment up to the maximum ambient illumination level specified by 4.3.1 when viewed from any position within the HUD Eyebox when viewing into the HUD Total Field of View.

For CRT based HUDs, refresh rates of 60 Hz with a P-43 phosphor and 50 Hz with P-53 phosphor should provide an acceptably low level of flicker. Other refresh rates and phosphors shall be shown to not exhibit unacceptable flicker. Refresh rates of 60 Hz have also been found to be acceptable for LCD HUDs.

4.2.9 Symbol Quality

Lines, symbols, and characters shall have no tails, squiggles, skews, or gaps, other geometric distortions (of greater than one half the local width), which cause erroneous interpretation of displayed data. Any distorted dimension should not exceed one half the local line width in the area of the distortion.

For a digital (e.g., LCD based) HUD, the display is an array (matrix) of discrete elements and, therefore, displayed information may have visible spatial anomalies, such as stair stepping, line width variation, and moire'. The display shall have no matrix anomalies which cause distraction or erroneous interpretation. This shall be assessed in both static and dynamic conditions.

Visible defects on the display (such as failed-ON or failed-OFF elements, rows, or columns, spots, etc.) should not be distracting and shall not cause an erroneous interpretation of the display.

Gray scale control, when used for anti-aliasing or to provide luminance control should be sufficient for its intended function. Its use should not cause apparent variations in line shape and quality. Deviations across the HUD field of view should be minimized to avoid misleading information.

4.2.10 Display Binocular Parallax Errors

The HUD provides a virtual image at optical infinity. Parallax errors exist when two eyes view the same information in the HUD virtual image. Thus, parallax errors exist only within the Binocular Overlapping portion of the Field of View (7.7). If the optical system is not perfect, there will be slight angular errors between what the two eyes see. These errors are known as binocular parallax errors. Parallax errors are generally specified for eyes spaced apart 63.5 mm (2.5 inches) (the interpupillary distance) which lie in a common horizontal plane. Parallax errors are subdivided into horizontal errors, which are those errors in the plane of the eyes, and vertical errors, which are those errors perpendicular to the plane of the eyes. Computing of these errors is acceptable.

The binocular parallax error for a fixed field point is equal to the angular difference in the two rays entering the eyes separated by the interpupillary distance. If the projected virtual image was perfect, the two ray angular directions would be identical, and the parallax errors would be zero. Since HUD optical systems are not perfect, there are residual uncompensated optical errors in the optical system. These uncompensated errors result in parallax errors and contribute to display accuracy errors. Display Accuracy errors are specified in 4.2.3.

Horizontal parallax is further divided into convergent errors, or optical errors causing the eyes to angle inward (i.e., objects inside of infinity), and divergent errors which cause eyes to angle outward. Vertical parallax errors, or dipvergence, represent eyes skewed differentially out of the horizontal eye plane. Thus, convergence, divergence, and dipvergence describe how two eyes are oriented with respect to each other to visually merge symbology.

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Normal eyes cannot readily compensate for divergent or dipvergent parallax errors. For this reason, these errors should be made as small as practical. Convergent parallax errors cause the apparent display depth to vary inside of optical infinity across the field-of-view. Convergent errors are easy to visually accommodate, but lead to accuracy errors.

One means to characterize parallax errors is to divide the HUD total field of view into a grid containing many field points (i.e., a grid size of about 1 degree vertically by 2 degrees horizontally). This field of view grid is sampled from many different head positions within the HUD Eyebox, resulting in thousands of parallax performance data points. The parallax errors for the HUD can then be characterized as a percentage of points meeting a performance criteria.

The computed parallax errors shall meet the following 2 sigma values:

Within the central 10 degree diameter portion of the total field of view, when viewed from the HUD Eye Reference Point:

Convergence	< 6’ 53” (2.0 mrad)
Divergence	< 3’ 26” (1.0 mrad)
Dipvergence	< 3’ 26” (1.0 mrad)

Within the total display field of view, when viewed from within the HUD Eyebox:

Convergence	< 12’ 2” (3.5 mrad)
Divergence	< 5’ 9” (1.5 mrad)
Dipvergence	< 6’ 53” (2.0 mrad)

Note that a convergence error of 12’ 2” (3.5 mrad) corresponds to a display image distance of about 18 m (59 feet). These errors apply to HUDs designed to operate with non-distorting windshields. Larger parallax errors may be unavoidable when correcting for windshields curvature.

4.2.11 Symbol Motion

The system operation should not be adversely affected by aircraft maneuvering or changes in attitude encountered in normal operation.

For those elements of the display that are normally in motion, any jitter, jerkiness, or ratcheting effect should neither be distracting nor objectionable. They should maintain luminance, contrast, line width, and symbol quality characteristics independent of the rate of motion.

Screen data update rates for analog symbols used in direct airplane or powerplant manual control tasks (such as attitude, engine parameters, etc.) should be equal to or greater than 15 Hz. Any lag introduced by the display system should be consistent with the airplane control task associated with that parameter. In particular, display system lag (including the sensor) for attitude should not exceed a first order equivalent time constant of 100 ms for airplanes with conventional control system response. Evaluation should be conducted in worst case aerodynamic conditions with appropriate stability augmentation systems off in order to determine the acceptability of display lag.

For a Digital (e.g., LCD based) HUD, the response time of pixel state changes should not be so long as to create erroneous interpretation or loss of displayed information due to artifacts such as smearing and loss of luminance.

4.2.12 Image Retention

Image retention is an undesired afterimage that persists on the display (applies to both CRT and LCD Digital based HUDs). Image retention should not be readily discernable day or night, should not be distracting, and shall not cause an erroneous interpretation of the display.

If the HUD incorporate slow rate “dithering” to reduce image retention resulting from stationary symbology, non-conformal symbology may be moved at a slow rate if the spatial relationships are not misinterpreted. Conformal symbology should not be dithered, unless it does not exceed the positioning accuracy errors defined in this section.

4.2.13 Response Time

For a Digital (e.g., LCD based) HUD, the response time of pixel state changes should not be so long as to create erroneous interpretation or loss of displayed information due to artifacts such as smearing and loss of luminance. The display response time shall meet the following requirements.

- ≤ 60 ms for total range, i.e., sum of full-off to full-on plus full-on to full-off (as measured from 10% maximum gray level of 90% maximum gray level plus 90% maximum to 10% maximum).

- ≤ 200 ms between any intermediate levels of gray with a luminance change of at least 10%.

- In addition to the above for subjective evaluation, no tunneling (i.e., dimming) or objectionable smearing of critical or essential dynamic symbology or video shall be observable.

- This level of response time performance is required after the warm-up period ends, as defined in the environment section (see Section 5).

4.3 HUD Photometric Characteristics

4.3.1 HUD Luminance

The HUD shall be capable of providing a usable display under all foreseeable ambient background conditions, including a sun-lit cloud of 34 000 cd/m^2 (10 000 feet/L) and a night approach to a sparsely lit runway (a black hole approach).

4.3.2 Luminance Uniformity

The luminance variation of displayed symbols, lines, or characters nominally of equal luminance shall meet the following requirements:

a. When measured from the center of the HUD Eyebox, the luminance variation of symbols contained in the monocular instantaneous FOV shall be less than ±30%.

b. When measured over 80% of the HUD Eyebox, the luminance variation of any particular symbol shall not vary by more than ±30%.

These requirements apply for any luminance control setting. The luminance uniformity variation shall be calculated as follows:

$$\textbf{Luminance Uniformity Variation (\%)} = \frac{\mathbf{Lmax - Lmin}}{\mathbf{[Lmax + Lmin]}} \times \mathbf{100} \qquad \text{(Eq. 1)}$$

Where Lmax and Lmin are the maximum and minimum, respectively, values of luminance measured at a minimum of five points, including one point at the display center and four points equidistant from the center.

4.3.3 Display Contrast Ratio

The HUD Contrast Ratio is a measure of the ratio of the luminance of the virtual display relative to the real world background. HUD display contrast ratio is defined as follows:

$$\mathbf{CR} = \frac{\textbf{Display Luminance} + \textbf{Background Luminance}}{\textbf{Background Luminance}} \qquad \text{(Eq. 2)}$$

Based on this definition, a contrast ratio equal to 1.0 represents no information on the display.

The HUD contrast ratio shall be greater than 1.20 when measured against a 34 000 cd/m^2 (10 000 fL) ambient background, and assuming a 100% transmissive aircraft windshield. The measurement is made at the center of the display area from the HUD Eye Reference Point. Degradation over time to a contrast ratio of 1.15 is allowable. The combiner transmissivity requirements of 4.3.4 shall be simultaneously achieved when computing Contrast Ratio.

4.3.4 HUD Combiner Transmissivity

The light transmissivity of the HUD combiner shall be greater than 70% (photopic) for all HUD viewing angles when measured from the HUD Eye Reference Point. The transmissivity can be measured against a D65 light source or computed by analysis/ measurement. The transmissivity through the combiner shall not vary by more than ±20% over the total field of view when viewed from the HUD Eye Reference Point.

4.3.5 HUD Combiner Real World Color Shift

When wavelength selective combiners are used to enhance the photometric performance of the HUD combiner, the real world color shift shall not be objectionable, and shall not cause erroneous or ambiguous interpretations of real world objects.

4.3.6 Manual and Automatic Luminance Control

The HUD system should have both manual and automatic luminance control capabilities. While the luminance control is varied, the relative luminance of all displayed symbols, characters, lines, and generated backgrounds shall generally track the control setting in a smooth and easily controllable manner without abrupt luminance changes. In no case shall any symbols or characters become invisible at the minimum luminance setting while other characters or symbols are usable. If the HUD system has both manual and automatic luminance control modes, there shall be no objectionable luminance transients while transitioning from manual to automatic mode, or from automatic to manual control mode.

NOTE: Automatic luminance control is highly recommended and may be required for low visibility operations when the pilot may not have time to manually adjust the luminance.

4.3.6.1 Manual Luminance Control

The display luminance of the HUD system shall be capable of being manually adjusted from less than 1.7 cd/m^2 (0.5 fL) to a luminance level capable of meeting the requirements of 4.3.1.

4.3.6.2 Automatic Luminance Control (If Required)

When the automatic luminance mode is selected by the crew member, the HUD shall be capable of automatically tracking the ambient luminance level such that the pre-selected HUD display contrast ratio remains approximately constant as a function of ambient light from 340 cd/m^2 (100 fL) up to the maximum HUD luminance level required by 4.3.3. The HUD luminance shall track the ambient luminance level until the maximum luminance capability of the HUD is achieved. As the ambient luminance level continues to increase, the HUD luminance shall remain constant. The ability to control HUD luminance may be evaluated during flight test in night conditions ranging from a dark background to a night approach at a runway with bright city background, an ALSF II (or equivalent) approach lighting systems, touchdown zone lights, and centerline lights with high intensity runway lights set to step 5. The manual luminance control shall not be adversely affected by failure of the automatic luminance control.

4.3.7 Combiner Performance

As far as practical, the optical performance and physical characteristics of the combiner shall be sufficient to not degrade, distort, or distract the pilot’s view of external references or of other aircraft.

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4.3.7.1 Combiner Induced Real World Distortion and Parallax Errors

The HUD combiner should not cause the angular location of real world objects, as they appear through the combiner, to deviate by more than 2.0 mrad (monocular). This deviation requirement shall apply for all head positions within the allowable HUD Eyebox and over the total field of view of the HUD. The maximum allowable radial error shall be computed as the root sum square of the azimuth and elevation component errors. When viewing through the HUD combiner, the parallax errors (binocular) of the real world view seen by the pilot should be less than 1.5 mrad.

4.3.7.2 Reflections, Secondary Reflections, and Glare

The HUD combiner should not result in any unwanted reflections or glare (from external or internal sources) that cause erroneous or ambiguous interpretations of real world objects or display information.

4.3.7.3 Secondary Display Images

When viewed from within the HUD Eyebox, the luminance of any secondary display images (ghost images) should be less than 2% of the luminance of the main display.

4.3.8 Color

Where multiple colors are used to enhance discrimination, the use of color shall result in unambiguous and no erroneous interpretation of the displayed information for all foreseeable conditions relative to the lighting environment for which the use of the HUD is intended.

In general, color should not be used as the only coding dimension. Other coding dimensions such as shape, location, bold, boxed, or highlighting should be used as redundant coding.

4.3.8.1 Color Uniformity

The color difference between any symbols of the same color located at any position within the total FOV shall be sufficient to prevent an ambiguity or an incorrect identification of an assigned color from any head position within the HUD Eyebox.

4.3.9 Color Registration

When a display element is a composite of multiple traces (such as multiple guns of a shadow mask CRT), the color line centers shall be converged. This convergence value at any point shall be within the average of the line widths of the respective traces at that point. This requirement applies over the HUD Eyebox area for all symbol intensity settings.

When a display element is comprised of two or more closely spaced traces (such as video generated symbology) the primary color line centers shall be converged. This convergence value should be within one display line width when viewed from the manufacturer's specified Eye Reference Point.

In no case shall misconvergence cause a line, symbol, character color or character form to be ambiguous.

4.3.10 Discrimination

Displayed information shall have sufficient luminance contrast and/or color difference to discriminate between the following as applicable:

a. Between symbols (including characters and/or lines) and the background (ambient or generated) on which they are overlayed.

b. Between various symbols, characters and lines. This shall also include when they overlay ambient or generated backgrounds.

c. Between the generated backgrounds and ambient backgrounds.

d. Between the generated backgrounds of various specified colors.

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In all cases the luminance contrast and/or color differences between all symbols, characters, lines, or all backgrounds shall be sufficient to preclude confusion or ambiguity as to information content of any displayed information. When operationally required, the absolute color of the information shall be identifiable.

4.4 HUD Physical Assembly

The HUD installation should be shown to be safe from physical hazards likely to be encountered during both routine operations or emergency procedures. Criteria to be considered should include physical hazards to the pilot during turbulence, hard landings, bird strikes, abrupt deceleration encountered during maximum braking, and rapid egress.

4.4.1 Combiner Stowage

The HUD combiner should be capable of being stowed when not in use.

4.4.2 Combiner Head Injury Criteria

The combiner assembly shall be designed to meet the requirements of 14 CFR 2X.562.

4.4.3 Combiner Position Alignment

The HUD system shall provide a warning to the pilot if the position of the combiner causes conformal data to become hazardously misaligned.

4.4.4 Head Clearance Measurement

Head clearance is defined as the physical spacing between any portion of a pilot's head and the closest approaching portion of the HUD system located generally above the pilot's head. For the purpose of this document, head clearance is specified with respect to a 95 percentile male head illustrated in Figure 2. The HUD manufacturer shall specify the minimum clearance between the three-dimensional outline of the head and the closest approaching HUD system structure, excluding padding. A distance of 50 mm (2 inches) has been shown to be acceptable.

4.5 Video Display Performance (Imaging Display)

When the HUD system is capable of displaying video images, the HUD shall meet all requirements contained within this section in addition to the other requirements of this document. The term "video" is not intended to limit or restrict the display technology and implies any display technology which is capable of generating a full field display containing imagery generated by any number of sensor types or data bases.

When an imaging display capability is included in the HUD, it should perform as follows:

4.5.1 HUD Symbology and Video Display Compatibility

The display of video on the HUD shall not compromise the presentation of aircraft flight information when that information is required to be displayed.

4.5.2 Video Resolution

The HUD system video resolution requirements shall be specified by the vendor to be consistent with imaging sensor angular resolution, the HUD optics and the intended function of the HUD-sensor system. The HUD and sensor system resolution should not be limited by the display capabilities of the HUD optics or electronics. The HUD system video resolution shall meet the vendor specified requirements and its intended function system requirements for all environmental test conditions in Section 5.

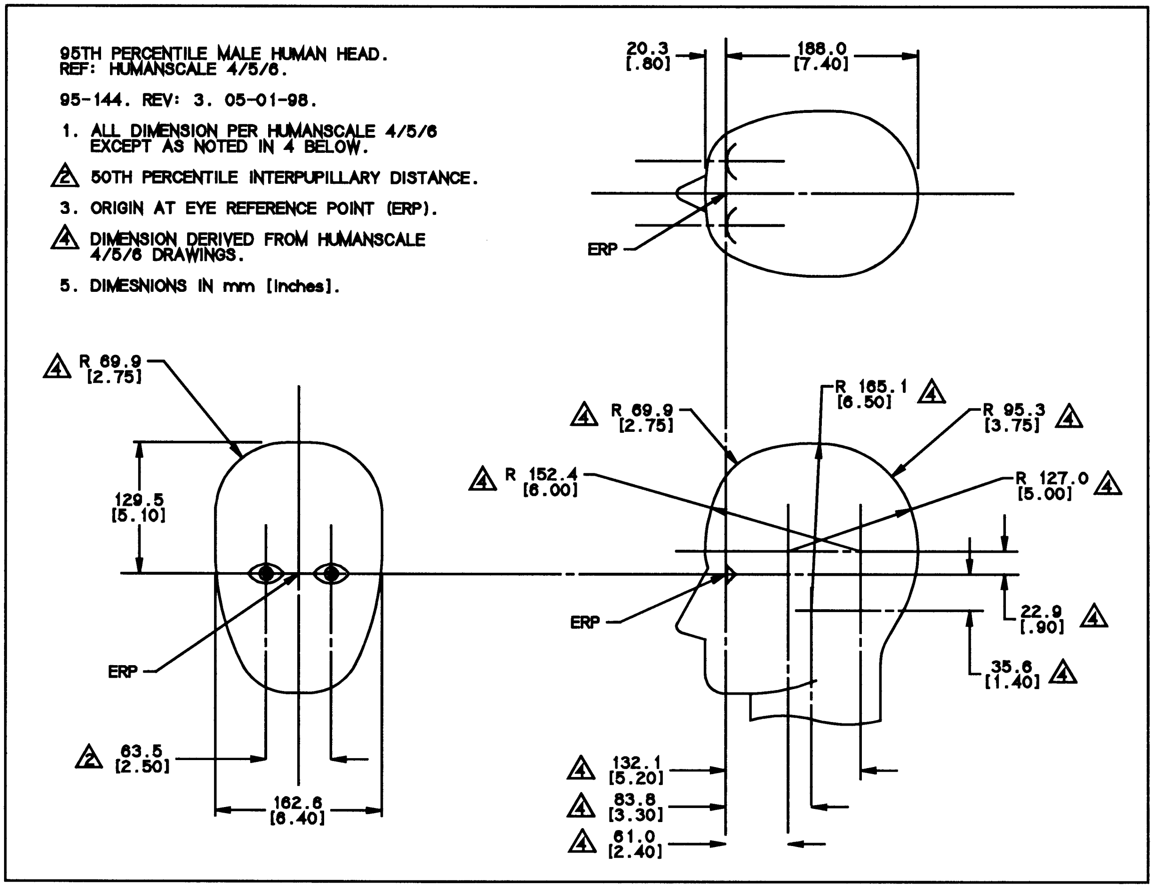

Figure 2 - Dimensions for a 95 percentile male head (all units are in inches)

4.5.3 Video Luminance

The HUD video luminance shall be adequate to display a minimum number of gray shades against a real world background luminance which is representative of the environment in which the HUD and sensor system is intended to operate. The vendor shall specify the maximum background luminance in which the HUD and sensor system is intended to operate and the minimum number of gray shades the system is to display. The system shall be capable of providing this video display luminance requirement for all environmental test conditions in Section 5.

4.5.4 Video Contrast Variation

The contrast ratio between sequential gray shades in a display of six shades of gray should be 1.4 +0.4, -0.2 with appropriate HUD settings of brightness and contrast controls, and excluding the contribution of ambient background.

4.5.5 Video Low Level Luminance

The HUD should be capable of providing a very dim, easily controllable image free of background glow in areas not displaying information in night conditions. The requirement can be considered to have been met when the following is achieved:

In a dark ambient background (less than 0.34 cd/m^2 (0.1 fL)), with symbols and peak white video adjusted to approximately 1.7 cd/m^2 (0.5 fL), a minimum of six shades of gray should be visible and the areas of the video which are blank should not be visible.

4.5.6 Video Luminance Uniformity

The variation in intensity between any two points within 10 degrees of each other or within the monocular FOV should not exceed ±35% when a flat field signal is applied.

4.5.7 Video Distortion and Linearity

No picture element should be displaced from its true position such that it can present hazardously misleading information to the pilot.

4.5.8 Video Display and Outside View Compatibility

The display of video imagery on the HUD should not compromise the effective use of outside visual reference for required pilot tasks such as takeoff and landing, obstacle avoidance, aircraft collision avoidance, or weather or visual reference assessment.

NOTE: This requirement is not intended to preclude use of imagery to provide enhanced visual cues consistent with the above requirements.

4.5.8.1 Automatic Brightness Control

Systems using automatic brightness control of symbology or symbology and video combined shall meet the applicable display luminance and contrast requirements defined in this section.

5. MINIMUM PERFORMANCE STANDARDS UNDER ENVIRONMENTAL CONDITIONS

To demonstrate compliance with this document, the tests of this section shall be conducted (where applicable). All equipment, displays, display systems, and components shall meet the applicable sections of DO-160G/ED-14G. Unless otherwise specified, the environmental measurement procedures applicable to a determination of performance under environmental conditions are set forth in RTCA DO-160G/ EUROCAE ED-14G. Performance tests which shall be made after subjection to test environments may be conducted after exposure to several environmental conditions. The order of tests shall be in accordance with paragraph 3.2, of Section 3.0 of DO-160G/ED-14G. Unless otherwise specified in this document, the environmental test procedures contained in RTCA DO-160G/ED-14G will be used to demonstrate equipment compliance.

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations. Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for the particular environmental condition. These tests are identified by the phrase "when required." If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these "when required" tests will be performed.

The environmental performance requirements identified in this section shall be met for all equipment, displays, display systems, and components. At the conclusion of all environmental tests, the requirements of Section 4 of this document shall be met.

5.1 Requirements

The following performance requirements (5.1.1 through 5.1.6) shall be met for the environmental conditions as required in 5.4 through 5.30 of this document. Compliance may be demonstrated by testing, analysis or combination thereof.

For example: Position accuracy over temperature may be determined by the combination of analysis that the optics meet its allowed budget over temperature and test measurements that the electronics meets its allowed accuracy budget over temperature.

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5.1.1 Display Characteristics

The HUD display system shall meet the display characteristics of the following paragraphs:

a. 4.2.3 Symbol Position Accuracy (External)

b. 4.2.4 Relative Symbol Position Accuracy

c. 4.2.5 Display Drift

d. 4.2.6 Display Line Width

e. 4.2.8 Display Flicker

f. 4.2.9 Symbol Quality

5.1.2 Luminance

The display luminance shall be sufficient for the display to perform its intended function.

5.1.3 Color

Where multiple colors are used, any change in color shall not cause ambiguous or erroneous information to be presented.

5.1.4 Color Registration

For multicolor displays, color misregistration shall not cause symbol color to be ambiguous or erroneous information to be presented.

5.1.5 Display Response Time

The display response time shall be sufficient for the display to perform its intended function. The display response time shall be less than 1 second.

5.1.6 Mechanical Operation

All mechanical devices shall perform their intended function in a clear and unambiguous manner.

5.2 Definition of Terms

The definition of environmental general terms, including temperature stabilization, control, and test category are given in DO-160G/ED-14G Section 2.0.

5.3 Conditions of Tests

The equipment connection, air temperature measurement, environmental test condition tolerances and test equipment requirements are given in DO-160G/ED-14G Section 3.0.

5.4 Temperature and Altitude Tests (Section 4.0, DO-160G/ED-14G)

When the display system is subjected to this test, all of the requirements of 5.1 of this document shall be met.

5.4.1 Low-Temperature Test

This test includes Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test and Operating Low Temperature Test.

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Under the environmental temperature conditions, the manufacturer shall specify the time required to meet full performance. The maximum time to meet full performance shall be equal to or less than 10 minutes. The requirement could be shorter for displays intended for more critical functions.

5.4.2 High Temperature Test

This test includes Ground Survival High Temperature Test and Short-Time Operating High Temperature Test and Operating High Temperature Test.

a. When subjected to the high short-time operating temperature, the equipment shall function both electrically and mechanically.

b. When the equipment is operated at the high operating temperature, all of the requirements of 5.1 of this document shall be met.

c. Systems which require cooling air shall meet all of the requirements of 5.1 of this document.

5.4.3 In-Flight Loss of Cooling Test

When the display system is subjected to this test, all of the requirements of 5.1 of this document shall be met.

5.4.4 Altitude, Decompression and Overpressure Tests (When Required) (Section 4.6 DO-160G/ED-14G)

5.4.4.1 Altitude Test

When subject to this test, all of the requirements of 5.1 of this document shall be met. The instrument shall be so designed as to safeguard against hazards to the aircraft and crew, and/or malfunction of the instrument due to outgassing of organic or inorganic compounds when subjected to the altitude conditions of DO-160G/ED-14G, paragraph 4.6.

5.4.4.2 Decompression Test

When installed in accordance with the equipment manufacturer's instructions, the equipment shall function properly as intended and not be adversely affected following by exposure to the decompression test conditions of DO-160G/ED-14G, paragraph 4.6.2. When subjected to the decompression test(s), all of the requirements of 5.1 of this document, along with the following shall be met.

5.4.4.3 Overpressure Test

When the equipment is subjected to the overpressure test, all of the requirements of 5.1 of this document shall be met.

5.5 Temperature Variation Test (Section 5.0, DO-160G/ED-14G)

When the equipment is subjected to this test, all of the requirements of 5.1 of this document shall be met.

5.6 Humidity Test (Section 6.0, DO-160G/ED-14G)

After being subjected to this test, the following shall apply:

a. Within 15 minutes after primary power is applied, the equipment shall operate at a level of performance which indicates no significant performance change has occurred and no significant failures of components or circuitry have occurred.

b. Within 4 hours after primary power is applied, all of the requirements of Section 4 of this document shall be met.

5.7 Operational Shocks and Crash Safety Tests (Section 7.0, DO-160G/ED-14G)

a. After being subjected to the operational shock test, all of the requirements of Section 4 of this document shall be met.

b. After being subjected to the crash safety shocks, the equipment shall remain in its mounting and no parts of the equipment or its mounting shall have become detached.

5.8 Vibration Tests (Section 8.0, DO-160G/ED-14G)

a. When subjected to this test, the display shall not distort either dimensionally or in visual characteristics to the extent that it presents misleading or erroneous information.

b. At the conclusion of vibration testing, all of the requirements of Section 4 of this document shall be met.

5.9 Explosive Atmosphere Test (When Required) (Section 9.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met.

5.10 Waterproofness Test (When Required) (Section 10.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met.

5.11 Fluids Susceptibility Test (When Required) (Section 11.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met.

5.12 Sand and Dust Test (When Required) (Section 12.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met. External glass surfaces may be covered during the sand and dust test.

5.13 Fungus Resistance Tests (When Required) (Section 13.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met.

5.14 Salt Fog Test (When Required) (Section 14.0, DO-160G/ED-14G)

After being subjected to this test, all of the requirements of Section 4 of this document shall be met.

5.15 Magnetic Effect Test (Section 15.0, DO-160G/ED-14G)

When the equipment is subjected to this test, it shall meet all of the requirements of DO-160G/ED-14G for the DO-160G/ED-14G equipment category of installations for which it is intended.

5.16 Power Input Test (Section 16.0, DO-160G/ED-14G)

The HUD shall meet the requirements of Section 16.0 of DO-160G/ED-14G for power interruptions. Note however, that the requirements for operating through power interruptions specified in Section 16 may not be sufficient for some HUD applications, specifically during critical phases of flight as defined by CFR 121.542 (c) /CFR 135.100 (c.

5.16.1 Normal Operating Conditions

When the equipment is subjected to this test, the requirements of Section 4 of this document shall be met.

5.16.2 Abnormal Operating Conditions

When the equipment is subjected to these conditions, it shall continue to operate after being turned on. Degradation of performance is tolerable providing ambiguous, erroneous, or unsafe information is not displayed and that the equipment will return to normal operating conditions when the normal power is restored.

5.17 Voltage Spike Test (Section 17.0, DO-160G/ED-14G)

5.17.1 Category A Test (When Required)

After testing to Category A test requirements all of the equipment shall meet the requirements of Section 4 of this document. After interruption of displayed information, if it occurs, the display shall return to normal operation and meet all of the requirements of section 4 of this document.

5.17.2 Category B Test (When Required)

a. Following the application of Intermittent Transients, all of the requirements of Section 4 of this document shall be met.

b. During the application of Repetitive Transients, the display may distort momentarily, however, critical data shall be readable and not hazardously misleading. After interruption of display information, if it occurs, the display shall return to normal operation and meet all of the requirements of Section 4 of this document.

5.18 Audio Frequency Conducted Susceptibility – Power Inputs (Section 18.0, DO-160G/ED-

The display shall not distort either dimensionally or in visual characteristics to the extent that it presents ambiguous or erroneous presentation of information. After momentary distortion the display shall return to normal operation and meet all of the requirements of Section 4 of this document.

5.19 Induced Signal Susceptibility Test (Section 19.0, DO-160G/ED-14G)

The display shall not distort either dimensionally or in visual characteristics to the extent that it presents ambiguous or erroneous presentation of information. After momentary distortion the display shall return to normal operation and meet all of the requirements of Section 4 of this document.

5.20 Radio Frequency Susceptibility Test (Radiated and Conducted) (Section 20.0, DO-160G/ED-14G)

After being subjected to the tests in this section, the equipment shall meet all of the requirements of Section 4 of this document. The tests levels from DO-160G/ED-14G Section 20 shall be specified by the equipment manufacturer. The levels should be consistent with those expected in the aircraft locations where the equipment and wiring will be installed. Additional guidance on selecting test levels for installations is given in ARP5583A and AC20-158. During application of the tests, the display shall not distort either dimensionally or in visual characteristics to the extent that it presents ambiguous or erroneous information. The equipment manufacturer shall define acceptable performance. After the aircraft is exposed to HIRF, each affected system that performs these functions shall automatically recover normal operation, unless this conflicts with other operational or functional requirements of that system.

NOTE: For installation related conditions, see Advisory Circular 20-158 Certification of Aircraft Electrical and Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment.

5.21 Emission of Radio Frequency Energy Test (Section 21.0, DO-160G/ED-14G)

When the equipment is subjected to this test, it shall meet requirements for the appropriate category as specified as specified in Section 21 of DO-160G/ED-14G.

5.22 Lightning Induced Transient Susceptibility (Section 22.0, DO-160G/ED-14G)

After being subjected to the tests in this section, the equipment shall meet all of the requirements of Section 4. The tests levels from DO-160G/ED-14G Section 22 shall be specified by the equipment manufacturer. The levels should be consistent with those expected in the aircraft locations where the equipment and wiring will be installed. Additional guidance on selecting test levels for installations is given in ARP5413 and AC 20-136. During application of the tests, the display shall not present ambiguous or erroneous information. The equipment manufacturer shall define acceptable performance. For example, displays should not display hazardously misleading primary flight data, and operation should be quickly recoverable after exposure.

NOTE: For installation related conditions, see Advisory Circular 20-136A Protection of Aircraft and Electrical / Electronic Systems against the Indirect Effects of Lightning.

5.23 Lightning Direct Effects (When Required) (Section 23.0, DO-160G/ED-14G)

If this section is required by DO-160G, then after being subjected to this test, the equipment shall meet all of the requirements of Section 4 of this document.

5.24 Icing (When Required) (Section 24.0, DO-160G/ED-14G)

This section is not applicable to display systems installed inside the aircraft.

5.25 Electrostatic Discharge (ESD) (Section 25, DO-160G/ED-14G)

After being subjected to this test, the equipment shall meet all of the requirements of Section 4 of this document.

5.26 X-Ray Radiation

This section only applies to display and display systems using CRTs. LCDs and other systems that do not emit X-ray radiation do not need to document compliance to this section, nor deviations to the requirements in this section. The display system should be so designed so as to safeguard against hazard to the aircraft and crew due to X-ray radiation. Radiated energy measured 5 cm (2.0 inches) from the unit surface in the direction of the design eye, in a worse case operating condition, shall not exceed 0.1 milliroentgen per hour as measured in accordance with procedures specified in EIA RS503a. X-Ray radiation analysis may be submitted in lieu of testing.

5.27 UV Radiation

This section only applies to display and display systems using CRTs. LCDs and other systems that do not emit UV radiation do not need to document compliance to this section, nor deviations to the requirements in this section. Radiation emitted by display systems shall not result in radiation on exposed skin or eyes exceeding the following values:

a. In the wavelength from 200 to 315 nm: 0.05×10^{-6} W/cm^2

b. In the wavelength from 315 to 400 nm: 0.05 x 10-^{3} W/cm^2

UV radiation shall be measured using a Radiometer positioned as close to the display unit is feasible.

5.28 Fogging (Hermetically Sealed or Desiccated Display Units Only)

The display unit, while operating, shall be exposed to the high operating ambient temperature for a minimum of 30 minutes. While at this temperature, the external face of the cover glass shall be reduced to a temperature of not more than 20 °C. No moisture or other material shall be deposited on the internal face of the cover glass or filter.

5.29 Thermal Shock (When Required)

The operating unit shall be subjected to ambient temperature extremes between the high operating temperature (see section 5.4.2 of this document and also section 4 of DO-160G) and the low operating temperature (see 5.4.1 of this document and also Section 4 of DO-160G) without evidence of damage or operating failure. The unit shall operate in a high temperature test chamber at the high operating temperature until the unit temperature stabilizes. At the end of this time period, the temperature change (e.g., moving the unit to another chamber) shall be done as rapidly as possible but per the procedures and requirements specified in Section 5 of DO-160G, a cold chamber with an internal chamber temperature at the low operating temperature.

5.30 Dielectric Test

This section is applicable to the cathode ray tube of CRT displays and planar gas discharge displays as well as any other display or display system component that has a high voltage circuit internal to the equipment.

The requirements in this section are intended to ensure that the dielectric of insulation is sufficient to keep any high voltage from causing a hazard. After completion of all other qualification tests, the display system shall meet the following dielectric test. In the performance of this test, any internal and/or external components or wires connected between the circuits and equipment case or frame shall be disconnected. The insulation resistance measured at a minimum of 200 V DC for 5 seconds shall not be less than 5 MΩ.

6. TEST PROCEDURES

6.1 Test Conditions

Where not otherwise defined by applicable 14 CFRs, display system sampling required to demonstrate compliance with the requirements of this AS shall be determined by the manufacturer. The complete system shall meet the requirements of the manufacturer's recommended test procedure before qualification testing is started.

Unless otherwise specified below, equipment meeting the requirements of this standard shall be tested under the conditions specified in Section 3 of RTCA DO-160G/ EUROCAE ED-14G and/or sections of this document. Applicable optical measurement procedures are given in ARP5287, however, they should not be considered the only acceptable methods for optical testing of airborne HUD.

6.2 Ambient Room Conditions

When tests are conducted with the atmospheric pressure or temperature values substantially different from those specified in DO-160G/ED-14G, allowance shall be made for these variations.

6.3 Power Conditions

Except as otherwise specified herein, all tests shall be conducted at the power rating (supplied voltage, frequency, etc.) recommended by the manufacturer.

7. GLOSSARY OF TERMS

7.1 Ambient Background

Background other than generated background.

7.2 Ambiguous or Erroneous Information

Information that is capable of being understood in a different sense than intended.

7.3 Combiner

Component located in the pilot's forward field of view which provides superposition of the symbology on the external field of view.

7.4 Conformal

Conformal information is that which overlays the real world element that it is meant to portray irrespective of the viewing position.

7.5 Contrast Ratio

See 4.3.3.

7.6 Design Eye Position

The design eye position is a single point designated by the airframe manufacturer that provides an optimum combination of outside visibility and instrument scan.

7.7 Display Element

The smallest addressable entity of the display. In the case of an active matrix LCD, the smallest addressable element of an individual color.

7.8 Failed-Off

A display element, row, or column which is failed permanently or sporadically in the “dark” or non-emitting state.

7.9 Failed-On

A display element, row, or column which is failed permanently or sporadically in the “bright” or emitting state.

7.10 Field of View (FOV)

7.10.1 Total FOV

The total FOV is the union of the solid angles subtended at each eye by the clear aperture of the HUD optics from positions within the Eyebox. Thus, the total FOV defines the maximum angular extent of the display than can be seen with either eye allowing head motion within the Eyebox. It is generally specified in degrees vertical and degrees horizontal. The total FOV is illustrated in Figure 3.

7.10.2 Instantaneous FOV (IFOV)

The instantaneous FOV is the union of the two solid angles subtended at each eye by the clear aperture of the HUD optics from a fixed head position within the HUD Eyebox. Thus, the instantaneous FOV is comprised of what the left eye sees plus what the right eye sees from a fixed head position within the HUD Eyebox. The instantaneous FOV is illustrated in Figure 3 as the sum of the left eye and right eye monocular FOV.

7.10.3 Binocular Overlapping FOV

The binocular overlapping FOV is the intersection of the two solid angles subtended at each eye by the clear aperture of the HUD optics from a fixed head position within the HUD Eyebox. This defines the maximum angular extent of the HUD display which is visible to both eyes simultaneously. Thus, the binocular overlapping FOV is comprised of what the left eye sees which is common to what the right eye sees from a fixed head position within the HUD Eyebox. The binocular overlapping FOV is illustrated in Figure 3.

7.10.4 Monocular FOV

The monocular FOV is the solid angle subtended at the eye by the clear aperture of the HUD optics from a fixed eye position. This defines the angular extent of the HUD display as seen by a single eye as shown in Figure 3. The size and shape of the monocular FOV is dependent on the eye position within the HUD Eyebox.

7.11 Flicker

Undesired rapid temporal variation in part or total display luminance.

7.12 Flight Deck

Flight deck refers to the pilot compartment of all types of aircraft and is the generic term for “flight deck” and “cockpit.”

7.13 Generated Background

Internally generated imagery upon which symbology may be superimposed.

7.14 HUD Computer, HUD Symbol Generator, or HUD Processor Unit

The HUD Computer contains interface circuitry, display processing and symbol generation capabilities, power supplies, and the display unit interface. The HUD Computer receives data from external sensors and systems, produces symbols as electronic signals, and transmits the symbols to the display unit(s) for display to the pilots.

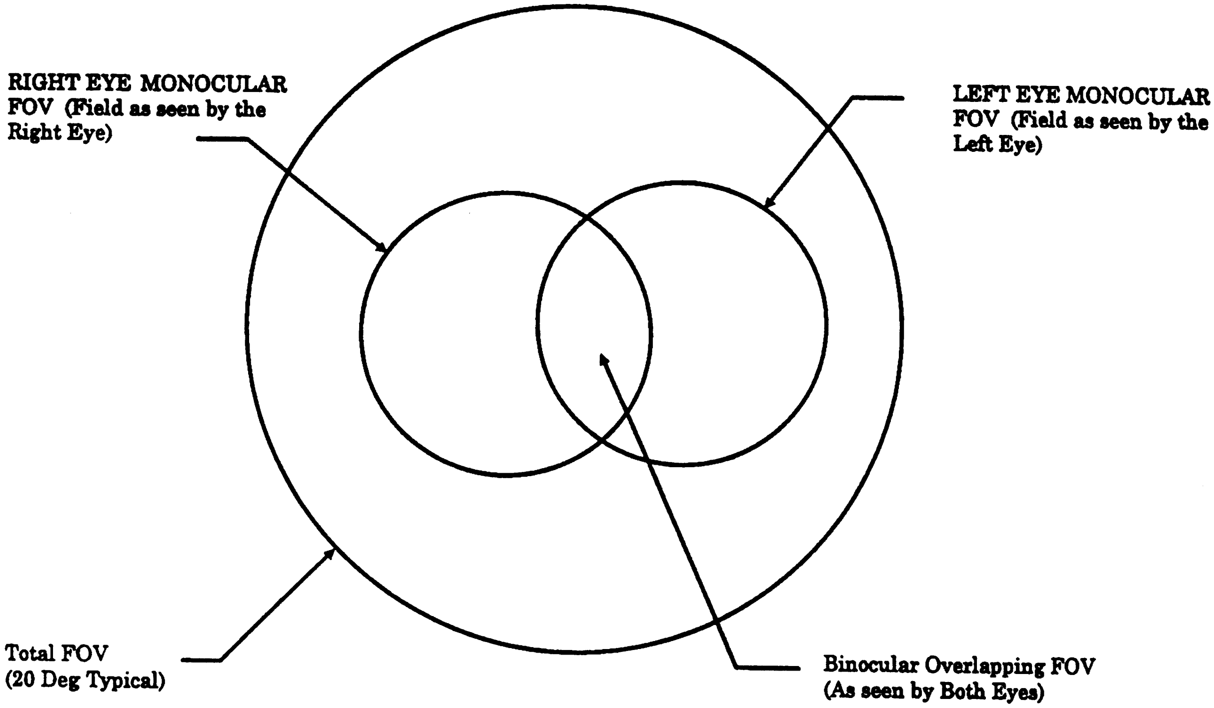

Figure 3 - HUD field of view (at optical infinity)

7.15 HUD Control Panel (HCP)

The HCP is an optional LRU providing means for manually selecting the display modes and entering reference data. The HUD luminance control may also be provided on the HCP as long as the pilot can adjust the HUD luminance without leaving the HUD Eyebox.

7.16 HUD Eye Reference Point

The spatial position of the observer's eye relative to the optical axis is designated by the manufacturer. The HUD Eye Reference Point is contained within the specified HUD Eyebox.

7.17 HUD Eyebox

See 4.2.2.

7.18 HUD System

A display system which presents flight data symbols into the pilots forward field of view. The symbols should be presented as a virtual image focused at optical infinity. In this document, a HUD system can include one or more of the following components. Other configurations are possible:

- Symbol Generator/Processor Unit (SG) containing display processing and symbol generation processing and symbol generation capability, power supplies, interface logic/buffer circuits and Display Unit interface capability. The SG receives data from external sources, produces symbols as electronic signals, and transmits the symbols to the Display Unit(s).

- Control Panel (CP) is an optional component providing the means for manually selecting display symbology options/modes, selections, settings, brightness, etc.

- Display Unit (DU)/Combiner providing the visual display of symbology.

7.19 Industry Standards

A standard which has been adopted by industry which will be useful for the design and procurement of equipment.

7.20 Jitter

Undesired, rapid movement discernible to a human eye located at the HUD Eye Reference Point.

7.21 Line Width

Width at 50% of peak luminance of the line luminance distribution.

7.22 Luminance

The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction.

7.23 Minimum Performance Standard

A standard which specifies the minimum equipment design requirements as established by the operational and environmental conditions encountered during normal flight (taxi, take off, climb, cruise, descent, landing, and taxi). It also specifies the minimum equipment performance necessary for safe operation of the aircraft during normal flight.

7.24 Nonconformal

A term used to describe HUD information which is not intended to have registration between the real world view and the displayed information.

7.25 Operating Modes

Pilot selectable or automatic variation in the intended function(s) of the HUD system.

7.26 Optical Infinity

When applied to a HUD system, optical infinity refers to a condition when the image distance to the virtual display is such that the horizontal parallax for 95% of all possible look angles and head positions within the HUD Eyebox is less than 12’ 2” (3.5 mrad). This represents an optical image distance of at least 18 m (59 feet).

7.27 Parallax Errors

Optical errors inherent in binocular HUD optical systems originating from uncorrected pupil aberrations. Parallax errors exist only when two eyes are viewing the same information on the HUD image source (i.e., field points contained within the binocular overlapping FOV). Parallax errors are generally specified for eyes spaced apart by 63.5 mm (2.5 inches) (the interpupillary distance) which lie in a common horizontal plane. Parallax errors are subdivided into horizontal errors, which are those errors in the plane of the eyes, and vertical errors, which are those errors perpendicular to the plane of the eyes.

7.27.1 Convergence

A horizontal parallax component causing the viewer's eyes to look inwards, or to converge towards a finite image distance.

7.27.2 Divergence

A horizontal parallax component causing the viewer's eyes to look outward, or to diverge.

7.27.3 Dipvergence

The vertical parallax component causing the viewer's eyes to skew differentially out of the horizontal eye plane.

7.28 Photopic

A photometric measurement where the spectral sensitivity of the measuring device matches the spectral sensitivity of the human eye adapted under daylight vision conditions.

7.29 Primary Flight Display

An electronic display which provides at least the basic “T” information as defined in AC 25-11, paragraph 7.a.

7.30 Ratcheting

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.

7.31 Video Resolution

Video resolution is a measure of the angular resolving capabilities of the HUD. Video resolution is specified independently in the vertical and horizontal display axis. As an example, a CRT HUD may be capable of providing 200 resolvable line pairs over a vertical (horizontal) display field of view of 20 degrees. This results in 10 resolvable line pairs per vertical (horizontal) degree of HUD display.

7.32 Redundancy

Multiple data paths and processing to allow a system to be failure tolerant.

7.33 Reflective or Holographic HUD

See Appendix A.

7.34 Refractive HUD

See Appendix A.

7.35 Shall Function

The equipment shall serve its intended function and not exceed the given tolerances.

7.36 Shall Not Be Adversely Affected

The equipment shall not exhibit characteristics or sustain damage which precludes proper functioning and/or use.

7.37 Transmittance of Combiner

Percentage of light from an external source passing through the combiner.

8. NOTES

8.1 A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications nor in documents that contain editorial changes only.

PREPARED BY THE SAE SUBCOMMITTEE A-4 HUD, HEAD UP DISPLAY OF
COMMITTEE A-4, AIRCRAFT INSTRUMENTS

APPENDIX A - HEAD UP DISPLAYS

A.1 HUDS THAT COLLIMATE BY REFRACTION

Refractive optics HUDs have been in use for many years in both military and commercial aircraft. Refractive optics HUDs are characterized by an optical system illustrated in Figure A1.

In this design an image source (cathode ray tube (CRT) or liquid crystal display (LCD)) is collimated (focused at optical infinity) by the exit lens of the optical system. Collimation is achieved by refractive optics. The exit lens acts as a pupil when reflected by the combiner as shown in Figure A1. The HUD image seen by the pilot appears through the pupil. This is analogous to looking through a porthole while standing several feet away. Only a portion of the total scene can be seen from a fixed head position. In a HUD, the instantaneous field of view is equal to the angle the pupil subtends at the pilot's eye. By moving his head up and down and side to side, the subtended angle changes and the pilot can see a different portion of the field of view. The limits of the subtended angle is referred to as the total field of view and is dependent on the optical design and image source size. This is illustrated in Figure A2.

To increase the field of view in a refractive HUD, either the pupil size (exit lens) aperture shall be increased, or the distance from the pilot's eye to the pupil shall be reduced. The vertical instantaneous field of view may be increased by adding a second combiner plate parallel with the first combiner but vertically displaced above it as illustrated in Figure A3.

The combiners in refractive HUDs are designed to reflect a percentage of the light coming from the CRT. Special reflective coatings can be used on the combiner to enhance the reflectance. Reflective coatings can be either wavelength insensitive or wavelength sensitive depending on the transmission and reflection characteristics desired of the combiner. If non-wavelength selective coatings are used, the sum of the combiner transmission and combiner reflection is less than or equal to one.

A.2 HUDS THAT COLLIMATE BY REFLECTION

“Reflective HUDs” are also commonly referred to as “Holographic HUDs”, or “Diffractive HUDs”. In this design approach, the collimating function, performed by the exit lens in the refractive HUD design is merged with the combiner into a single collimator-combiner element. The combiner necessarily has optical power and is often curved. The curved reflective surface within the combiner cooperates with a relay lens assembly to provide a collimated display at optical infinity.

By merging the combining and collimating functions, the porthole effect no longer restricts the field of view. The field of view is limited more by flight deck geometry and physical constraints, such as maximum combiner size and overall HUD envelope.

The combiner used in reflective HUDs often contain an embedded reflection enhancing coating, such as a holographic coating, to reflect the CRT's intermediate image to the pilot. When wavelength selective reflective coatings are used (i.e. holograms) the sum of the combiner eye- weighted (photopic) transmission and the combiner reflection can be greater than one. Figure A5 illustrates a typical overhead mounted reflective HUD optical configuration.

One significant benefit of the reflective optics is that the instantaneous field of view is larger than in refractive HUDs and approaches the total field of view of the system. The resulting advantage is that the pilot no longer has to move his head to see the total field of view. The display is visible as long as the pilot's eyes remain within the HUD eye motion box or pupil. It follows that a large eye box allows a greater range of head motion without losing the instantaneous field of view. A typical reflective HUD field of view is illustrated in Figure A4.

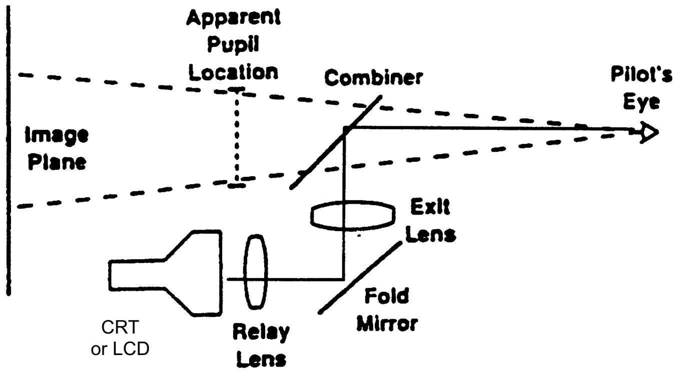

Figure A1 - Refractive optics HUD optical diagram

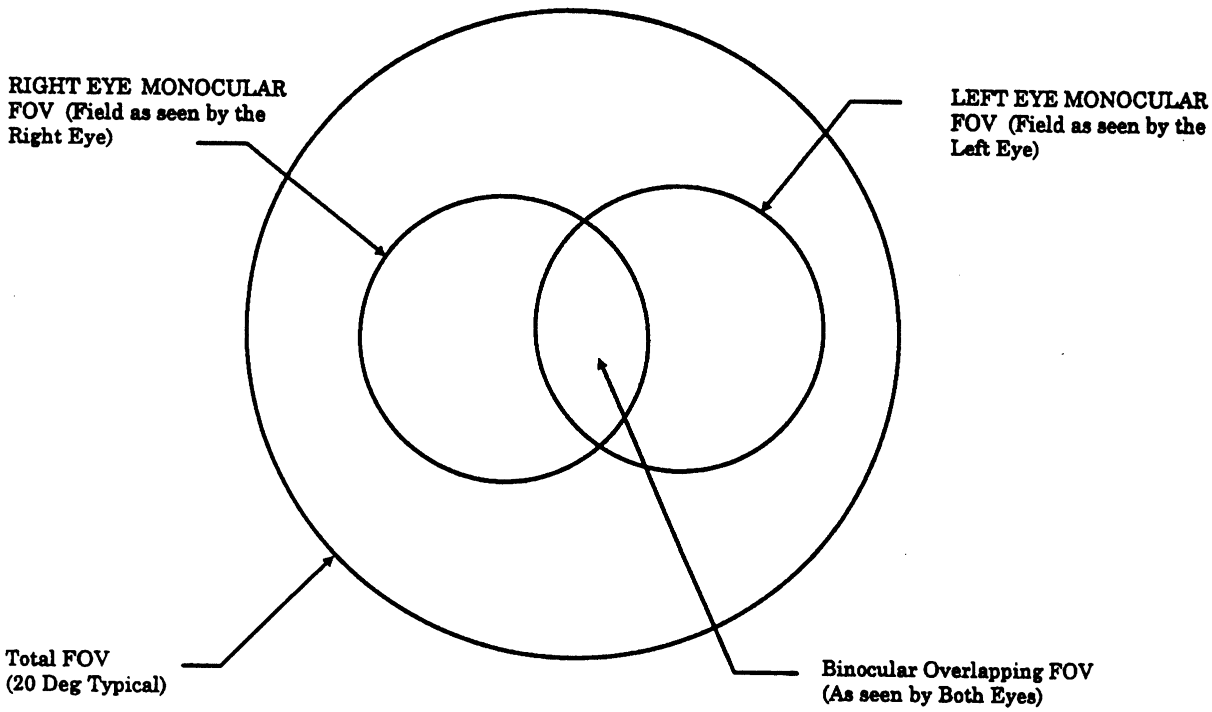

Figure A2 - HUD field of view (at optical infinity)

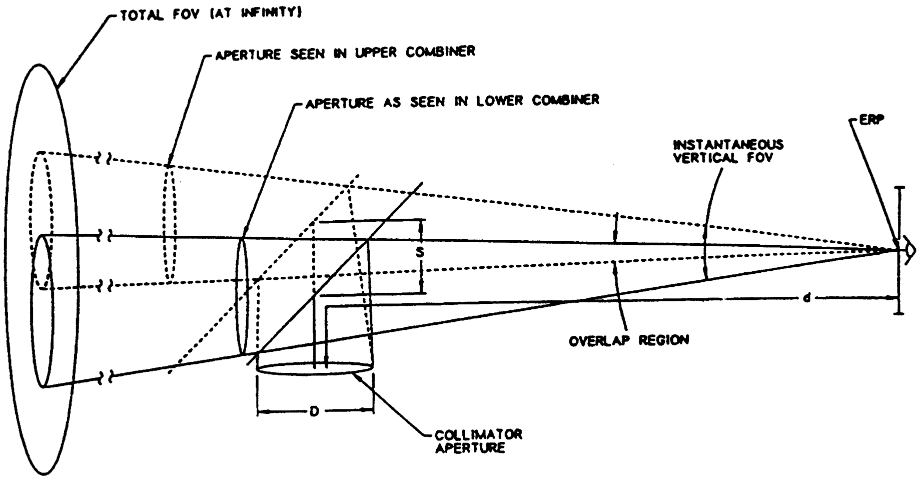

Figure A3 - HUD with second combiner

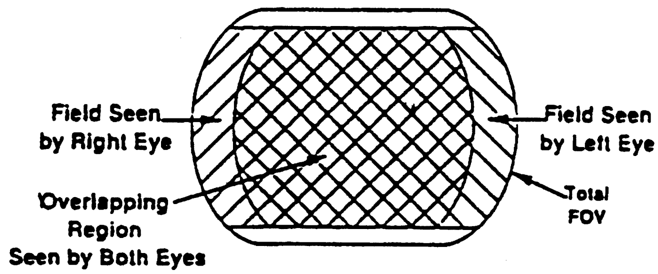

Figure A4 - Reflective HUD field of view

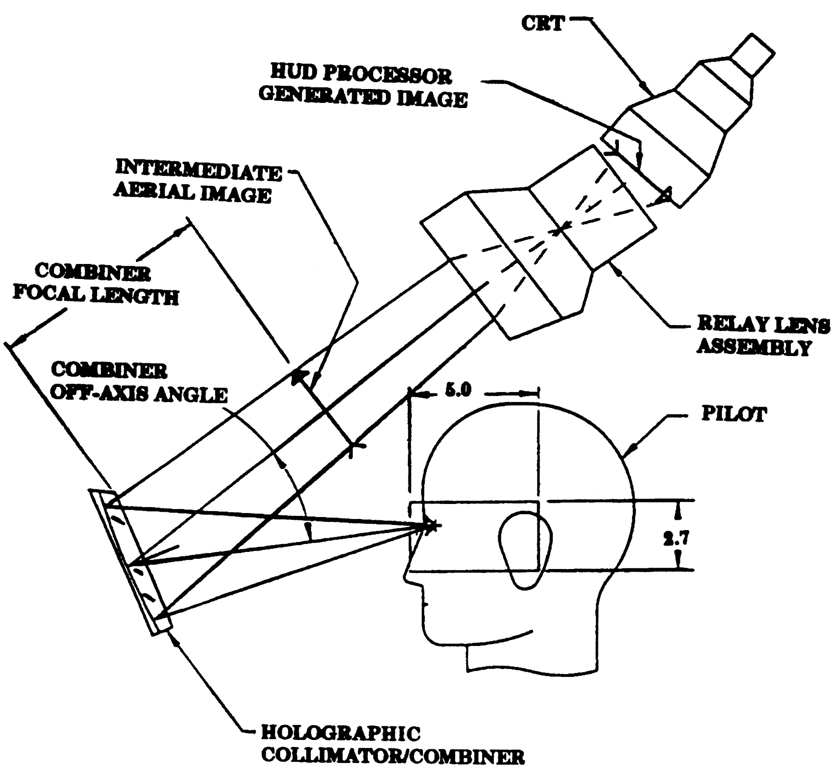

Figure A5 - Reflective HUD optical configuration