



AEROSPACE STANDARD

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Minimum Performance Standard for
Airborne Head-Worn Display (HWD)

RATIONALE

This SAE Aerospace Standard provides the Minimum Performance Standard for Airborne Head-Worn Display (HWD) for use by the aerospace industry and may also be used by the Federal Aviation Administration (FAA) and other regulatory agencies in a technical standard order. This document was developed by the SAE G-10 HWD and A-4 HUD subcommittees.

TABLE OF CONTENTS

1.	SCOPE.....	5
2.	REFERENCES.....	5
2.1	Applicable Documents	5
2.1.1	SAE Publications.....	6
2.1.2	ANSI Accredited/ISEA Publications	6
2.1.3	Regulations	6
2.1.4	Industry Documents	8
2.1.5	U.S. Army Aeromedical Research Laboratory Publications	8
2.1.6	Other Publications.....	8
2.2	Related Publications	9
2.2.1	SAE Publications.....	9
2.2.2	CIE Publications.....	9
2.2.3	Code of Federal Regulations (CFR) Publications	10
2.2.4	EASA Publications	10
2.2.5	FAA Publications	10
2.2.6	RTCA Publications	11
2.2.7	Transport Canada Publications.....	11
2.2.8	U.S. Government Publications.....	11
2.2.9	Other Publications.....	12
2.3	Definitions	12
2.4	Abbreviations and Acronyms	18
3.	GENERAL REQUIREMENTS.....	19
3.1	Material.....	19
3.2	Workmanship	19
3.3	Components Compatibility	19
3.4	Interchangeability	19
3.5	Accessibility of Adjustments and Controls	20
3.6	Self-Test Capability	20
3.7	Effects of Tests	20

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Documents

Standard, visit Sharing Hub

3.8	Malfunction and Failure Indications	20
3.8.1	Malfunction Indication	20
3.8.2	Power Failure Indication.....	20
3.8.3	Fail Safe Provision	20
3.9	Multiple Modes	20
3.10	Identification	21
3.11	Display.....	21
3.11.1	Discernibility	21
3.11.2	Critical Information	21
3.11.3	Information Limit Indication	21
3.11.4	Scale Indications	21
3.11.5	Ambiguity	21
3.12	Resistance to Dust and Moisture	21
3.13	Mechanical Hazard System Protection	22
3.14	Fire Resistance	22
3.15	Supplemental Heating/Cooling	22
3.16	Lighting.....	22
3.17	Flight Guidance Performance	22
3.18	O2 Mask Compatibility	22
3.19	Crew Hygiene.....	22
4.	MINIMUM PERFORMANCE STANDARDS UNDER STANDARD CONDITIONS	23
4.1	Equipment Functions and Mechanical Operation	23
4.1.1	Start-Up	23
4.1.2	Power Transient Recovery.....	23
4.1.3	Lag Time	23
4.1.4	Data Update	23
4.1.5	Visual Obstructions	23
4.1.6	Head/Display Tracking Latency Requirements.....	25
4.1.7	Head/Display Tracking Performance	25
4.2	HWD Mounting.....	26
4.2.1	Mass, Fit, Balance, and Pilot Comfort.....	26
4.2.2	Mounting Adjustments.....	26
4.2.3	Wired Connections	26
4.2.4	Compatibility with Other Head-Worn Equipment	26
4.2.5	Eyeglasses.....	26
4.3	Crew Safety.....	27
4.3.1	Head Injury Criteria (HIC) and Head Clearance	27
4.3.2	Retention in Donned Condition	28
4.3.3	Neck Injury Criteria.....	28
4.3.4	Special Considerations for Dual HWD Installations	29
4.3.5	Acoustic Considerations.....	29
4.4	Display Characteristics.....	29
4.4.1	Visual Display Characteristics.....	29
4.4.2	Symbol and Imagery Positioning	29
4.4.3	HWD Symbol Positioning Alignment.....	32
4.4.4	Image Retention.....	32
4.4.5	Line Width	33
4.4.6	Static Display Jitter.....	33
4.4.7	Display Flicker	33
4.4.8	Display Quality	33
4.4.9	Exit Pupil	33
4.4.10	Eye Relief and Eyeglasses Compatibility.....	34
4.4.11	Field of Vision (FOV) and Field of Regard (FOR).....	34
4.4.12	Display Configuration	34
4.4.13	HWD Use for Enhanced Vision Systems (EVS) and/or Synthetic Vision Systems (SVS) Display	36
4.4.14	Response Time	36

4.5	Photometric Characteristics	36
4.5.1	Environmental Lighting Conditions	36
4.5.2	Luminance Uniformity	37
4.5.3	Display Contrast Ratio	37
4.5.4	HWD Transmissivity	38
4.5.5	HWD Sun Visor Transmissivity	39
4.5.6	HWD Color Shift	39
4.5.7	Manual and Automatic Luminance Control	39
4.5.8	HWD Optical Performance	40
4.5.9	Use of Color	40
5.	MINIMUM PERFORMANCE STANDARDS UNDER ENVIRONMENTAL CONDITIONS	41
5.1	Requirements	41
5.1.1	Display Characteristics	41
5.1.2	Luminance	41
5.1.3	Color	42
5.1.4	Color Registration	42
5.1.5	Display Response Time	42
5.1.6	Mechanical Operation	42
5.2	Definition of Terms	42
5.3	Conditions of Tests	42
5.4	Temperature and Altitude Tests (refer to Section 4.0, RTCA DO-160/EUROCAE ED-14)	42
5.4.1	Low-Temperature Test	42
5.4.2	High-Temperature Test	42
5.4.3	In-Flight Loss of Cooling Test (if applicable)	42
5.4.4	Altitude, Decompression, and Overpressure Tests (when required) (refer to Section 4.6, RTCA DO-160/EUROCAE ED-14)	43
5.5	Temperature Variation Test (refer to Section 5.0, RTCA DO-160/EUROCAE ED-14)	43
5.6	Humidity Test (refer to Section 6.0, RTCA DO-160/EUROCAE ED-14)	43
5.7	Operational Shocks and Crash Safety Tests (refer to Section 7.0, RTCA DO-160/EUROCAE ED-14)	43
5.8	Vibration Tests (refer to Section 8.0, RTCA DO-160/EUROCAE ED-14)	43
5.9	Explosive Atmosphere Test (when required) (refer to Section 9.0, RTCA DO-160/EUROCAE ED-14)	44
5.10	Waterproofness Test (when required) (refer to Section 10.0, RTCA DO-160/EUROCAE ED-14)	44
5.11	Fluids Susceptibility Test (when required) (refer to Section 11.0, RTCA DO-160/EUROCAE ED-14)	44
5.12	Sand and Dust Test (when required) (refer to Section 12.0, RTCA DO-160/EUROCAE ED-14)	44
5.13	Fungus Resistance Tests (when required) (refer to Section 13.0, RTCA DO-160/EUROCAE ED-14)	44
5.14	Salt Fog Test (when required) (refer to Section 14.0, RTCA DO-160/EUROCAE ED-14)	44
5.15	Magnetic Effect Test (refer to Section 15.0, RTCA DO-160/EUROCAE ED-14)	44
5.16	Power Input Test (refer to Section 16.0, RTCA DO-160/EUROCAE ED-14)	44
5.16.1	Normal Operating Conditions	44
5.16.2	Abnormal Operating Conditions	44
5.17	Voltage Spike Test (refer to Section 17.0, RTCA DO-160/EUROCAE ED-14)	44
5.17.1	Category A Test (when required)	44
5.17.2	Category B Test (when required)	45
5.18	Audio Frequency Conducted Susceptibility - Power Inputs (refer to Section 18.0, RTCA DO-160/EUROCAE ED-14)	45
5.19	Induced Signal Susceptibility Test (refer to Section 19.0, RTCA DO-160/EUROCAE ED-14)	45
5.20	Radio Frequency Susceptibility Test (Radiated and Conducted) (refer to Section 20.0, RTCA DO-160/EUROCAE ED-14)	45
5.21	Emission of Radio Frequency Energy Test (refer to Section 21.0, RTCA DO-160/EUROCAE ED-14)	45
5.22	Lightning Induced Transient Susceptibility (refer to Section 22.0, RTCA DO-160/EUROCAE ED-14)	45
5.23	Lightning Direct Effects (refer to Section 23.0, RTCA DO-160/EUROCAE ED-14)	46
5.24	Icing (refer to Section 24.0, RTCA DO-160/EUROCAE ED-14)	46
5.25	Electrostatic Discharge (ESD) (refer to Section 25.0, RTCA DO-160/EUROCAE ED-14)	46
5.26	X-Ray Radiation	46
5.27	UV Radiation	46
5.28	Fogging (Hermetically Sealed or Desiccated HWD Only)	46
5.29	Thermal Shock	46
5.30	Dielectric Test	46
5.31	Shatterproofness	46

6.	TEST PROCEDURES.....	47
6.1	Test Conditions	47
6.2	Ambient Room Conditions	47
6.3	Power Conditions	47
7.	NOTES	47
7.1	Revision Indicator	47
Figure 1	HWD system scope.....	5
Figure 2	HWD field of view (at optical infinity).....	13
Figure 3	Real and virtual images.....	17
Figure 4	HWD design - no horizontal nor downward visual obstructions.....	24
Figure 5	HWD design - maximum upward visual obstructions	24
Figure 6	Frames of reference	30
Figure 7	Maximum accuracy error over FOV at LOS.....	32
Figure 8	Contributions for determining image source luminance requirements for an HWD in an aircraft cockpit	37
Table 1	Total system accuracy RSS.....	32

1. SCOPE

This SAE Aerospace Standard (AS) specifies minimum performance standards for airborne head-worn display (HWD) to be used as a head-up display (HUD) equivalent in fixed wing (14 CFR Parts 23 and 25) aircraft. While this document may be applied to rotorcraft using an HWD for piloting functions (14 CFR Parts 27 and 29), additional performance standards may be required. This AS covers basic display requirements 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 formats.

This document covers criteria for conformal HWD 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.

Figure 1 defines the HWD System Scope for use within this document.

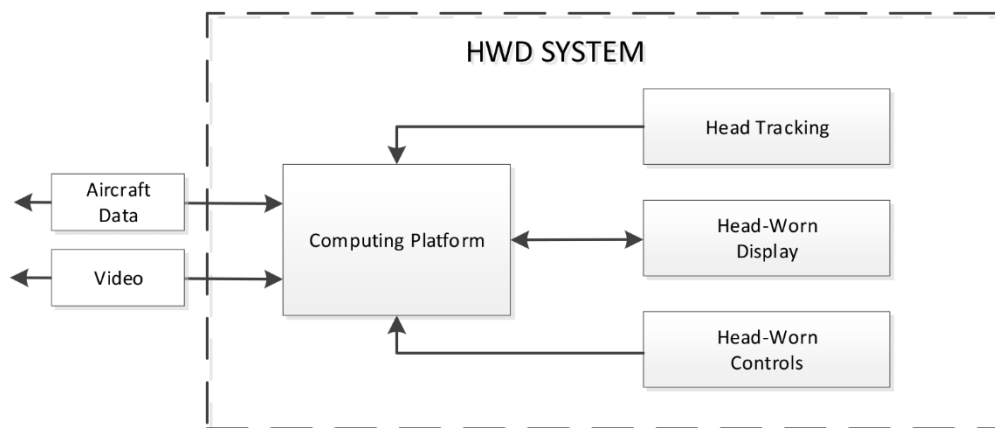


Figure 1 - HWD system scope

This document does not address sensor imaging systems, imagery, symbology, installation, or integration.

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 FAA-approved guidance material. This AS is applicable to HWDs 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 to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. 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, special condition, or Equivalent Level of Safety (ELOS) is 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.

ARP4102/7	Electronic Displays
ARP4761	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment
ARP5583A	Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment
ARP5677	Human Engineering Considerations for Airborne Implementation of Enhanced Synthetic Vision Systems
ARP6377	Human Engineering Considerations Associated with Design and Airborne Implementation of Head Worn Display (HWD) Systems
AS8034C	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
AS8049D	Performance Standard for Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft
AS8055A	Minimum Performance Standard for Airborne Head Up Display (HUD)
AS25050B	Colors, Aeronautical Lights and Lighting Equipment, General Requirements for

2.1.2 ANSI Accredited/ISEA Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

Available from International Safety Equipment Association, 1101 Wilson Boulevard, Suite 1425, Arlington, VA 2209-1762, Tel: 703-525-1695, <https://safetysiteequipment.org/>.

ANSI/ISEA Z87.1-2020	American National Standard for Occupational and Educational Personal Eye and Face Protection Devices
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2.1.3 Regulations

Regulations that affect displays, systems, and pilot-system interface are in 14 CFR Parts 23, 25, 27, and 29. Many of the rules are similar across the CFR Parts, but there are also distinct differences that reflect the differences in use of the aircraft identified in each part. The list of applicable regulations is long and comprises substantial sections of the regulations. The list regulations is too long to be reproduced here and the user of this document is encouraged to seek further expert advice on the existing regulations surrounding the installation of avionics to cover items as diverse as structural loads, emergency conditions, cockpit controls, flight and navigations systems, control markings, and others. For Part 23 references where Part 23 Amendment 23-64 (or later) is used, refer to AC 23.2010-1.

2.1.3.1 Code of Federal Regulations (CFR) Publications

Copies of these documents are available online at <https://www.ecfr.gov/>.

14 CFR Part 23	Air Worthiness Standards: Normal Category Airplanes
14 CFR Part 25	Air Worthiness Standards: Transport Category Airplanes
14 CFR § 25.561	General
14 CFR § 25.869	Fire protection: systems
14 CFR § 25.1439	Protective breathing equipment

14 CFR § 25.1447	Equipment standards for oxygen dispensing units
14 CFR Part 27	Air Worthiness Standards: Normal Category Rotorcraft
14 CFR Part 29	Air Worthiness Standards: Transport Category Rotorcraft
14 CFR § 2X.303	Factor of safety
14 CFR § 2X.337	Limit maneuvering load factors
14 CFR § 2X.341	Gust (and turbulence) loads
14 CFR § 2X.473	Ground loading/land load conditions and assumptions
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.773	Pilot compartment view
14 CFR § 2X.785	Seats, berths, (litters), safety belts, and harnesses
14 CFR § 2X.853	Compartment interior
14 CFR § 2X.1321	Arrangement and visibility
14 CFR § 2X.1523	Minimum flight crew
14 CFR § 2X.1543	Instrument markings: general
49 CFR § 571.208	Standard No. 208; Occupant crash protection
49 CFR Part 572, Subpart E	Anthropomorphic Test Devices, Subpart E - Hybrid III Test Dummy

2.1.3.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20-136B	Aircraft Electrical and Electronic System Lightning Protection
AC 20-146A	Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, and 29 Airplanes and Rotorcraft
AC 20-158A	Certification of Aircraft Electrical and Electronic Systems for Operations in the High-Intensity Radiated Fields (HIRF) Environment
AC 23.2010-1	FAA Accepted Means of Compliance Process for 14 CFR Part 23
AC 23.1311-1C	Installation of Electronic Display for Part 23 Airplanes
AC 25-11B	Transport Category Airplane Electronic Display Systems
AC 25.562-1B	Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes
AC 25.773-1	Pilot Compartment View Design Considerations
PS-AIR-25-33	Occupant Injury Considerations for Dual Pilot Head Up Display (HUD) Installations



2.1.4 Industry Documents

2.1.4.1 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

EUROCAE ED-14 Environmental conditions and test procedures for airborne equipment

(Note: EUROCAE ED-14 refers to the current revision of EUROCAE ED-14. The current revision at this writing is EUROCAE ED-14G.)

2.1.4.2 RTCA Publications

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

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

(Note: RTCA DO-160 refers to the current revision of RTCA DO-160. The current revision at this writing is RTCA DO-160G.)

RTCA DO-315B Minimum Aviation System Performance Standards for an Enhanced Flight Vision Systems, Synthetic Vision Systems, Combined Vision Systems and Enhanced Flight Vision Systems

2.1.5 U.S. Army Aeromedical Research Laboratory Publications

Copies of these documents are available online at <https://discover.dtic.mil/>.

Harding, T. and McLean, W. (2023). *Head mounted display guidelines for future vertical lift aircraft* (Report No. USAARL-TECH-TR-2023-19). U.S. Army Aeromedical Research Laboratory.

McEntire, B.J. and Shanahan, D.F. (1998). *Mass requirements for helicopter aircrew helmets* (USAARL Report No. 98-14). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

2.1.6 Other Publications

Bailey, R.E., Kramer, L.J., and Williams, S.P. (2010, April 23). *Enhanced vision for all-weather operations under NextGen* [Conference paper]. SPIE Defense, Security, and Sensing 2010, Orlando, FL, USA. <https://doi.org/10.1117/12.852667>.

Bailey, R.E., Shelton, K.J., and Arthur, J.J., III (Trey). (2011, April 25-29). *Head-worn displays for NextGen* [Conference paper]. SPIE Defense, Security, and Sensing 2011, Orlando, FL, USA. <https://ntrs.nasa.gov/citations/20110011184>.

Boff, K.R. and Lincoln, J.E. (Eds.) (1988). *Engineering data compendium: Human perception and performance* (Vol. 3). Armstrong Aerospace Medical Research Laboratory. <https://ntrs.nasa.gov/citations/19880019248>.

Cupero, F., Valimont, B., Wise, J., Best, C., and De Mers, B. *Head worn display system for equivalent visual operations* (Report No. NASA/CR-2009-215781). National Aeronautics and Space Administration.

Heavens, O.S. and Ditchburn, R.W. (1991). *Insight into optics*. Wiley.

Melzer, J.E. (2001). Head-mounted displays. In C.R. Spitzer (Ed.), *The avionics handbook*. CRC Press.

2.2 Related Publications

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

AIR1093	Numerical, Letter and Symbol Dimensions for Aircraft Instrument Displays
AIR4742	Display Characteristics of FDI Head-Up Guidance System as Approved for the B-727 Airplane
ARP1161	Crew Station Lighting - Commercial Aircraft
ARP4032	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4101/2	Flight Deck Layout and Facilities
ARP4102	Flight Deck Panels, Controls, and Displays
ARP4102/4	Flight Deck Alerting System (FAS)
ARP4102/8	Flight Deck Head-Up Displays
ARP4102/10	Traffic Display and Collision Avoidance Systems
ARP4102/11	Airborne Windshear Systems
ARP4102/12	Approach to Landing Guidance System for Transport Aircraft
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 Symbolology
ARP4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP4260	Photometric and Colorimetric Measurement Procedures for Airborne Electronic Flat Panel Displays
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP6023	Human Engineering Considerations for Implementing Enhanced Synthetic Vision Systems in Vertical Flight Capable Platforms

2.2.2 CIE Publications

Available from CIE Central Bureau, Babenbergerstrasse 9/9A, 1010 Vienna, Austria, Tel: +43 1 714 31 87, www.cie.co.at.

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

2.2.3 Code of Federal Regulations (CFR) Publications

Copies of these documents are available online at <https://www.ecfr.gov/>.

14 CFR § 23.1311 Electronic display instrument systems

14 CFR § 25.1316 Electrical and electronic system lightning protection

14 CFR § 2X.789 Retention of items of mass in passenger and crew compartments and galleys

14 CFR § 2X.803 Emergency evacuation

14 CFR § 2X.1301 Function and installation

14 CFR § 2X.1303 Flight and navigation instruments

14 CFR § 2X.1309 Equipment, systems, and installation

14 CFR § 2X.13xx High-intensity radiated fields (HIRF) protection
23.1308; 25.1317; 27.1317; 29.1317

2.2.4 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany,
Tel: +49 221 8999 000, www.easa.europa.eu.

CS-AWO Certification Specifications Certification and Acceptable Means of Compliance for All Weather Operations

2.2.5 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591,
Tel: 866-835-5322, www.faa.gov.

AC 20-167A Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment

AC 23.1309-1E System Safety Analysis and Assessments for Part 23 Airplanes

AC 25-1302-1 Installed Systems and Equipment for Use by the Flightcrew

AC 25.1309-1A System Design and Analysis

AC 25.1322-1 Flightcrew Alerting

AC 27-1B Certification of Normal Category Rotorcraft

AC 29-2C Certification of Transport Category Rotorcraft

AC 90-106A Enhanced Flight Vision Systems

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

AC 120-29A Criteria for Approval of Category I and Category II Weather Minima for Approach

AC 27 MG 19	Guidance on Electronic Display Systems (EDS) for Rotorcraft Installations
AC 29 MG 19	Guidance on Electronic Display Systems (EDS) for Rotorcraft Installations
AC/AMJ 25.1309	Systems Design and Analysis
TSO-C113B	Airborne Multipurpose Electronic Displays
TSO-C210	Airborne Head-Up Displays

2.2.6 RTCA Publications

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

RTCA DO-178C	Software Considerations in Airborne Systems and Equipment Certification
RTCA DO-254	Design Assurance Guidance for Airborne Electronic Hardware
RTCA DO-359	Minimum Aviation System Performance Standards (MASPS) for Synthetic Vision Guidance Systems
RTCA DO-371	Minimum Aviation System Performance Standards (MASPS) for Aircraft State Awareness Synthetic Vision Systems

2.2.7 Transport Canada Publications

Available from Transport Canada, Tower C, Place de Ville, 330 Sparks Street Ottawa, Ontario K1A 0N5, Tel: 1-800-305-2059, www.tc.gc.ca.

AC 603-001	Use of Night Vision Imaging Systems
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2.2.8 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

AFAMRL TR-83-095	Optical and Human Performance Evaluation of HUD Systems Design
FSWG TR-92-01	Head Up Display Design Guide
MIL-HDBK-87213	Military Handbook: Electrically/Optically Generated Airborne Displays
MIL-STD-810	Military Standard: Environmental Test Methods and Engineering Guidelines
MIL-STD-1241	Optical Terms and Definitions
MIL-STD-1787	Aircraft Display Symbolology
NASA TM-103947	Test Techniques for Evaluating Flight Displays
USAARL Rept No. 97-17	Image Quality Figures of Merit for Contrast in CRT and Flat Panel Displays

2.2.9 Other Publications

Melzer, J.E. and Moffit, K. (1997). *Head-mounted displays: Designing for the user*. McGraw-Hill.

Newman, R.L. (1995). *Head-up displays: Designing the way ahead*. Routledge.

Rash, C.E. (1999). *Helmet-mounted displays: Design issues for rotary wing aircraft*. U.S. Army Medical Research and Material Command.

Weintraub, D.J. and Ensing, M. (1992). *Human factors issues in head-up display design: the book of HUD* (Report No. CSERIAC SOAR 92-2). Crew Systems Ergonomics Information Analysis Center.

2.3 Definitions

2.3.1 AMBIENT BACKGROUND

Background other than generated background.

2.3.2 AMBIGUOUS OR ERRONEOUS INFORMATION

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

2.3.3 BRIGHTNESS

The perceived attribute of light sensation by which a light stimulus appears more or less intense (refer to Boff and Lincoln, 1988). Brightness differs from luminance in that brightness is a subjective observation while luminance is an objective measurement. See LUMINANCE.

2.3.4 COMBINER

HWD component located in front of the pilot's eye(s) which provides superposition of the symbology on the external field of view (FOV).

2.3.5 CONFORMAL

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

2.3.6 CONTRAST RATIO

The ratio of the luminance of the virtual display relative to the real-world background. HWD display contrast ratio is defined as follows:

$$CR = \frac{\text{Display Luminance} + \text{Background Luminance}}{\text{Background Luminance}}$$

2.3.7 CONVERGENCE

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

2.3.8 DESIGN EYE POSITION

The point, specified by the airframe manufacturer, from which the pilot can view cockpit instrumentation, have adequate external view, and can reach cockpit controls (refer to AC 25.773-1).

2.3.9 DIPVERGENCE

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

2.3.10 DISPLAY ELEMENT

The smallest addressable entity of the display. In the case of an active-matrix liquid crystal display (LCD), the smallest addressable element of an individual color.

2.3.11 DIVERGENCE

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

2.3.12 EXIT PUPIL

The volume of space within which a pilot's eye(s) should be in with respect to the HWD to see the full instantaneous FOV.

2.3.13 EYE BOX

A three-dimensional volume specified by a HWD manufacturer in which certain optical performance requirements are met.

2.3.14 FAILED-OFF

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

2.3.15 FAILED-ON

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

2.3.16 FIELD OF VIEW (FOV)

The angular region over which the HWD is visible. There are four distinct FOV characteristics which are described below.

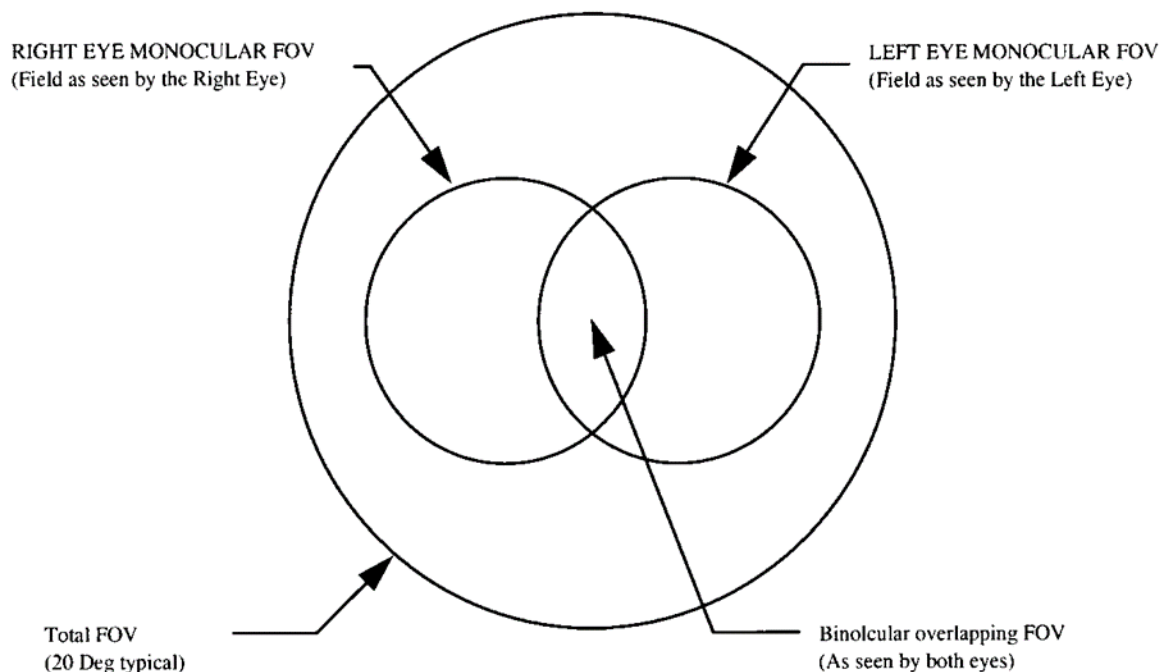


Figure 2 - HWD field of view (at optical infinity)
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2.3.16.1 TOTAL FOV

The total FOV is the union of the solid angles subtended at each eye by the clear aperture of the HWD optics from positions within the exit pupil. Thus, the total FOV defines the maximum angular extent of the display than can be seen with either eye. It is generally specified in degrees vertical and degrees horizontal. The total FOV is illustrated in Figure 2.

2.3.16.2 INSTANTANEOUS FOV (IFOV)

The IFOV is the union of the two solid angles subtended at each eye by the clear aperture of the HWD optics from the exit pupil. Thus, the IFOV is comprised of what the left eye sees plus what the right eye sees from a fixed head position within the exit pupil. The IFOV is illustrated in Figure 2 as the sum of the left eye and right eye monocular FOV.

2.3.16.3 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 HWD optics from the exit pupil. This defines the maximum angular extent of the HWD 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 exit pupil. The binocular overlapping FOV is illustrated in Figure 2.

2.3.16.4 MONOCULAR FOV

The monocular FOV is the solid angle subtended at the eye by the clear aperture of the HWD optics from the exit pupil. This defines the angular extent of the HWD as seen by a single eye as shown in Figure 2. The size and shape of the monocular FOV is dependent on the eye position within the exit pupil.

2.3.17 FIELD OF REGARD (FOR)

The field of regard is the range of line of sight, laterally and vertically that the head tracking function can fully support.

2.3.18 TOTAL FIELD OF REGARD

Total field of regard is the combination of IFOV and FOR. It represents all of the viewing angles for which the HWD can provide a satisfactory display.

2.3.19 FIELD ERRORS

With respect to a HUD or HWD, the difference between the intended and measured points in the FOV.

2.3.20 FLICKER

An undesired rapid temporal variation in display luminance of a symbol, group of symbols, or a luminous field caused by in internal display anomaly or externally by light passing through a passing or rotating system (e.g., sunlight through the rotor system).

2.3.21 FOOT-LAMBERT

A unit of luminance equal to 1 lm/ft².

2.3.22 FLIGHT DECK

Flight deck refers to the pilot compartment of all types of aircraft.

2.3.23 HEAD-UP DISPLAY (HUD)

A display that presents symbols/data into the pilot's forward field of view. The symbols should be presented as a virtual image focused at optical infinity.

2.3.24 HEAD-WORN DISPLAY (HWD)

Any device attached to or worn on the head that presents symbols/data into the pilot's field of view when part of an HWD System.

2.3.25 HUD EQUIVALENT

Requirements for a HWD to meet a "HUD-equivalent" capability are derived from FAA guidance material. For instance, under EFVS operations, these "essential features" of the HUD or equivalent display were described as follows (refer to Bailey et al., 2010):

- The display should provide the EV image and spatially referenced flight symbology so that they are aligned with and scaled to the external view (i.e., conformal rendering).
- The display should be located so the pilot is looking forward along the flight path (i.e., looking at and through the imagery to the out-of-the window view) to readily enable a transition from EFVS imagery to the out-the window view.
- The display should not require the pilot to scan up and down between a head down display of the image and the out-the-window view looking for primary flight reference information.

Refer to Bailey et al. (2011), page 4.

2.3.26 HWD CONTROL PANEL (HCP)

The HCP (if required) is an optional means for manually selecting the display modes and entering reference data. The HWD luminance control may also be provided on the HCP.

2.3.27 HWD SYSTEM

A system that is used to support a head-worn display.

2.3.28 INDUSTRY STANDARDS

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

2.3.29 JITTER

Undesired, rapid movement discernible to a human eye located at the exit pupil.

2.3.30 LIGHT SOURCE D65

D65 is a Commission International de l'Eclairage (CIE) standard colorimetry illuminant which simulates daylight represented by a 6500 K color temperature. This source can be simulated with readily available lower color temperature black-body sources (i.e., 2856 K) and appropriate filters.

2.3.31 LUMINANCE

Luminous flux reflected or transmitted by a surface per unit solid angle of projected area in a given direction. The units of measurement are the foot-lambert (fL) or candela per square meter (cd/m²).

Luminance differs from brightness in that luminance is an objective photometric measurement and brightness is a subjective perception. See BRIGHTNESS.

2.3.32 MUST

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