

Human Engineering Considerations Associated with Design and Airborne Implementation of Head Worn Display (HWD) Systems

RATIONALE

Head worn displays (HWD) are being used as tools to improve pilot awareness of aircraft performance, and as a primary flight guidance display. They offer unique and powerful capabilities that extend beyond the standard panel mounted displays, and they can present a wide variety of information on the flight deck/cockpit from dynamic terrain imagery to checklists. Their unique and novel capabilities especially when combined with head tracking and sensor imagery can create unexpected human factors issues. The correct implementation of these types of display systems is essential and critical to safe flight-specific operations.

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1. SCOPE

Head worn displays (HWD) can display a variety of information ranging from a full complement of primary flight information (PFI), including enhanced, synthetic, or combined vision system imagery to simple representations of airspeed, altitude, or heading to operationally specific information that may not be related aircraft performance or control. The display functions discussed in this ARP are limited to intended functions related to aircraft control and management and the presentation of PFI.

The material provided in this document consists of recommendations related to the design, analysis, testing, and intended functions of head worn displays (HWDs) for normal, utility, acrobatic, commuter, and transport category aircraft and special classes of aircraft. The content is targeted to HWDs that provide navigation, control and primary flight guidance information including terrain and obstacle avoidance. The content of the document is limited to statements of general design and installation considerations, including display function criticality and compliance considerations; symbology, coding, clutter, dimensionality, and attention getting requirements; equipment installation; display visual characteristics; failure modes; information display and formatting; specific integrated display and mode; and system verification. This document addresses both the installation of a single HWD, as well as special considerations related to dual HWDs, one for each pilot, or configurations incorporating a HWD and a HUD.

The guidance may also apply to HWDs that are intended to be used as a supplemental display in which the HWD contains the minimum information immediately required for other intended functions. These types of HWDs may not have a head tracking function if they are not displaying earth- or aircraft-referenced symbols or information (e.g., attitude, flight path guidance, imagery, etc.).

A HWD may also be used to display enhanced and synthetic vision video images. While this document does include guidance for the display of a video image on a HWD, the scope of this document does not address the requirements for the systems that provide those images.

Due to their impact on operational and performance characteristics, this document relies heavily on HWD human engineering considerations. This document attempts to be independent of candidate technologies; however, where the performance characteristics of specific technologies are relevant, they will be identified, and where performance criteria are relevant to specific intended functions/use they will be identified.

1.1 Purpose

This document provides recommendations for certification criteria in the intended function, design, analysis, testing, and implementation of head worn display (HWD) systems used for the portrayal of guidance, navigation, or flight control information and imagery by the pilots of normal, utility, acrobatic, commuter, and transport category aircraft and special classes of aircraft.

2. REFERENCES

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 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.

AIR1093A Numeral, Letter, and Symbol Dimensions for Aircraft Instrument Displays

ARP1161A Crew Station Lighting - Commercial Aircraft

ARP1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft

ARP4032B	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4101	Flight Deck Layout and Facilities
ARP4101/2	Pilot Visibility from the Flight Deck
ARP4102	Flight Deck Panels, Controls, and Displays
ARP4102/4	Flight Deck Alerting System (FAS)
ARP4102/7	Electronic Displays
ARP4102/8A	Flight Deck Head Up Displays (HUD)
ARP4102/10A	Collision Avoidance System (Advanced TCAS)
ARP4102/11B	Airborne Windshear Systems
ARP4102/12A	Airborne Landing Guidance System for Transport Aircraft
ARP4105C	Abbreviations, Acronyms and Terms for Use on the Flight Deck
ARP4754A	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment on Civil Airborne Systems and Equipment
ARP5287	Optical Measurement Procedures for Airborne Head Up Display (HUD)
ARP5288	Transport Category Airplane Head Up Display (HUD) Systems
ARP5677	Human Engineering Considerations for Airborne Implementation of Enhanced Synthetic Vision Systems
ARP6023	Human Engineering Considerations for Implementing Enhanced Synthetic Vision Systems in Vertical Flight Capable Platforms
AS8034C	Minimum Performance Standards for Airborne Multipurpose Electronic Displays
AS8055A	Minimum Performance Standards for Airborne Head Up Display (HUD)
AS25050B	General Requirements for Colors, Aeronautical Lights and Lighting Equipment

2.1.2 FAA Publications

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

2.1.2.1 Regulations

Regulations that affect displays, systems, and pilot-system interface are in 14 CFR Parts 23, 25, 27, 29. Many of the rules are similar across the CFR Parts but there are also distinct differences that reflect the differences in the design and use of the aircraft identified in each part. The list of applicable regulations is long and comprises substantial sections of the regulations. The list of 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 64 is used, refer to AC 23.2010-1 FAA Accepted Means of Compliance Process for 14 CFR Part 23.

2.1.2.2 Advisory Circulars

AC 20-167A	Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment
AC 20-175	Controls for Flightdeck Systems
AC 23-1311-1C	Installation of Electronic Display in in Part 23 Airplanes
AC 23.2010-1	FAA Accepted Means of Compliance Process for 14 CFR Part 23
AC 25-11B	Electronic Display Systems
AC 25.773-1	Pilot Compartment View Design Considerations
AC 25-1302-1	Installed Systems and Equipment for Use by the Flightcrew
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 603-001	Transport Canada Advisory Circular: Use of Night Vision Imaging Systems AC 603-001AC/AMJ 25.1309 Systems Design and Analysis

2.1.3 Industry Documents

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
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(Note: DO-160 refers to the current revision of DO-160. The current revision at this writing is DO-160G.)

RTCA DO-178	Software Considerations in Airborne Systems and Equipment Certification
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(Note: DO-178 refers to the current revision of DO-178. The current revision at this writing is DO-178C.)

RTCA DO-254	Design Assurance Guidance for Airborne Electronic Hardware
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RTCA DO-315B	Minimum Aviation System Performance Standards for an Enhanced Flight Vision Systems, Synthetic Vision Systems, Combined Visions Systems and Enhanced Flight Vision Systems
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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 FAA Publications

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

DOT/FAA/RD-81/38	Aircraft Alerting Systems Standardization Study, Volume II. Aircraft Alerting System Design Guidelines
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TSO-C113b Airborne Multipurpose Electronic Displays

TSO-C210 Airborne Head Up Displays

2.2.2 Government Documents

CSERIAC SOAR-92-2 Human Factors Issues in Head Up Display Design: The Book of HUD

FAMRL TR-83-95 Optical and Human Performance Evaluation of HUD Systems Design

FSWG TR-92-01 Head Up Display Design Guide

MIL-STD-1241A Optical Terms and Definitions

MIL-STD-1787C 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

2.2.3 Foreign Government Documents

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

2.2.4 Other Publications

Bailey, R.E., Shelton, K.J., and Arthur, J.J., III (Trey), Head-Worn Displays for NextGen, NASA Langley Research Center, Hampton, VA.

Boff, K.R., and Lincoln, J.E. (eds.), Engineering Data Compendium. Human Perception and Performance, Armstrong Aerospace Medical Research Laboratory, 1988.

Heavens, O.S., and Ditchburn, R.W., Insight into Optics, New York: Wiley, 1991.

Newman, R.L., Head Up Displays: Designing the Way Ahead, Aldershot England: Avebury Technical Publications, 1995.

Melzer, J. E., and Moffit, K., Head Mounted Displays Designing for the User, McGraw-Hill, New York, 1997.

Rash, C.E., Helmet-Mounted Displays: Design Issues for Rotary Wing Aircraft, U.S. Army Medical Research and Material Command, Fort Detrick, MD, 1999.

2.3 Abbreviations and Acronyms

ADF Automatic Direction Finder

ADI Attitude Director Indicator

AFCS Automatic Flight Control System

AFM Aircraft Flight Manual

AH Alert Height

ALS Automatic Landing System

ALS	Approach Lighting System
ALSF	Approach Lighting Sequence Flashers
ANSUR II:	Anthropometric Survey II
AOA	Angle of Attack
CAESAR	Civilian American and European Surface Anthropometry Resource
CAT I, II, III	See 2.7
cd	Candelas
CDI	Course Deviation Indicator
CFR	Code of Federal Regulations
CHMB	Cockpit Head Motion Box
CR	Contrast Ratio
CRT	Cathode Ray Tube
CVS	Combined Vision System
DA(H)	Decision Altitude (Height)
DEB	Design Eye Box
DEP	Design Eye Position
DH	Decision Height
DME	Distance Measuring Equipment
EADI	Electronic Attitude Director Indicator
EASA	European Aviation Safety Agency
ERP	Eye Reference Point
EFT	Effective Translational Lift
EV	Enhanced Vision
EFVS	Enhanced Flight Vision System
EGT	Exhaust Gas Temperature
ESVS	Enhanced Synthetic Vision System
EUROCAE	European Aviation Standards Group
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FDR	Flight Data Recorder

FHA	Functional Hazard Assessment
fL	Foot-Lamberts
FOR	Field of Regard
FOV	Field of View
GPS	Global Positioning System
HAT	Height Above Touchdown
HDD	Head Down Display
HOCAS	Hands on Collective and Stick
HOCAC	Hands on Cyclic and Collective
HOTAC	Hands on Throttle and Controls
HOTAS	Hands on Throttle and Stick
HSI	Horizontal Situation Indicator
HTF	Head Tracking Function
HUD	Head Up Display
HWD	Head Worn Display
IAS	Indicated Airspeed
IFOV	Instantaneous Field of View
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
IPD	Interpupillary Distance
LCD	Liquid Crystal Display
LOS	Line of Sight
MCDU	Multifunction Control Display Unit
MDA	Minimum Descent Altitude
MEL	Minimum Equipment List
MLS	Microwave Landing System
NVD	Night Vision Device
NVG	Night Vision Goggle
NVIS	Night Vision Imaging System

NCD	No Computed Data
PF	Pilot Flying
PFD	Primary Flight Display
PFI	Primary Flight Information
PFOV	Primary Field of View
PFR	Primary Flight Reference
PIO	Pilot Induced Oscillation
PLI	Pitch Limit Indicator
PNF	Pilot Not Flying
PSSA	Preliminary System Safety Assessment
RPM	Revolutions Per Minute
RSS	Root Sum Square
SSA	System Safety Assessment
RTCA	Radio Technical Commission for Aeronautics
TCAS	Traffic Alert and Collision Avoidance System
TQ	Torque
UA	Unusual Attitude
UAR	Unusual Attitude Recovery
VFR	Visual Flight Rules
Vmini	Instrument Flight Minimum Speed
VMO	Maximum Operating Velocity
VOR	Very High Frequency Omnidirectional Range Station

2.4 Glossary of Terms

BASIC FLIGHT INSTRUMENT LAYOUT/INSTALLATION (BASIC T): The conventional flight instrument arrangement (airspeed on the left, attitude in the center, altitude on the right and heading on the bottom) as described in 14 CFR §25.1321.

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

CAT I, CAT II, CAT III: Standing for Category I, II, and III, these are landing weather minima which are generally defined in terms of a decision height above terrain and a runway visual range. CAT III is further defined in three subset categories, CAT IIIa, CAT IIIb, and CAT IIIc.

CAT I (Category I): A precision instrument approach and landing with a decision height not lower than 60 m (200 feet) and with either a visibility not less than 800 m (2400 feet), or a runway visual range not less than 550 m (1800 feet).

CAT II (Category II): A precision instrument approach and landing with a decision height lower than 60 m (200 feet) but not lower than 30 m (100 feet) and a runway visual range not less than 350 m (1200 feet).

CAT IIIa (Category IIIa): A precision instrument approach and landing with a decision height lower than 30 m (100 feet), or no decision height and a runway visual range not less than 200 m (700 feet).

CAT IIIb (Category IIIb): A precision instrument approach and landing with a decision height lower than 15 m (50 feet), or no decision height and a runway visual range less than 200 m (700 feet) but not less than 50 m (150 feet).

CAT IIIc (Category IIIc): A precision instrument approach and landing with no decision height and no runway visual range limitations.

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:

$$CR = \frac{\text{Display Luminance} + \text{Background Luminance}}{\text{Background Luminance}} \quad (\text{Eq. 1})$$

NOTE: Background Luminance is defined in Section 7 of this document.

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

DESIGN EYE POSITION (DEP): 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).

EXIT PUPIL: The volume of space within which a pilot's eye(s) should be in with respect to the HWD display to see the full instantaneous FOV (see 7.1.12).

EYEBOX: A three dimensional volume specified by a HUD manufacturer in which certain optical performance requirements are met.

FAIL-OPERATIONAL: A system capable of completing the specified phases of an operation following the failure of any single system component after passing a point designated by the applicable safety analysis (e.g., Alert Height) (refer to AC 120-28D).

FAIL-PASSIVE: A system which, in the event of a failure, causes no significant deviation of aircraft flight path or attitude (refer to AC 120-28D).

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

FIELD OF VIEW (FOV): The angular region over which the virtual HWD display is visible. There are four distinct field of view (FOV) characteristics which are described below.

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 that can be seen with either eye. It is generally specified in degrees vertical and degrees horizontal. The total FOV is illustrated in Figure 1.

INSTANTANEOUS FOV (IFOV): The instantaneous FOV 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 instantaneous FOV is comprised of what the left eye sees plus what the right eye sees from the Exit Pupil. The instantaneous FOV is illustrated in Figure 1 as the sum of the left eye and right eye monocular FOV.

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 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 the Exit Pupil. The binocular overlapping FOV is illustrated in Figure 1.

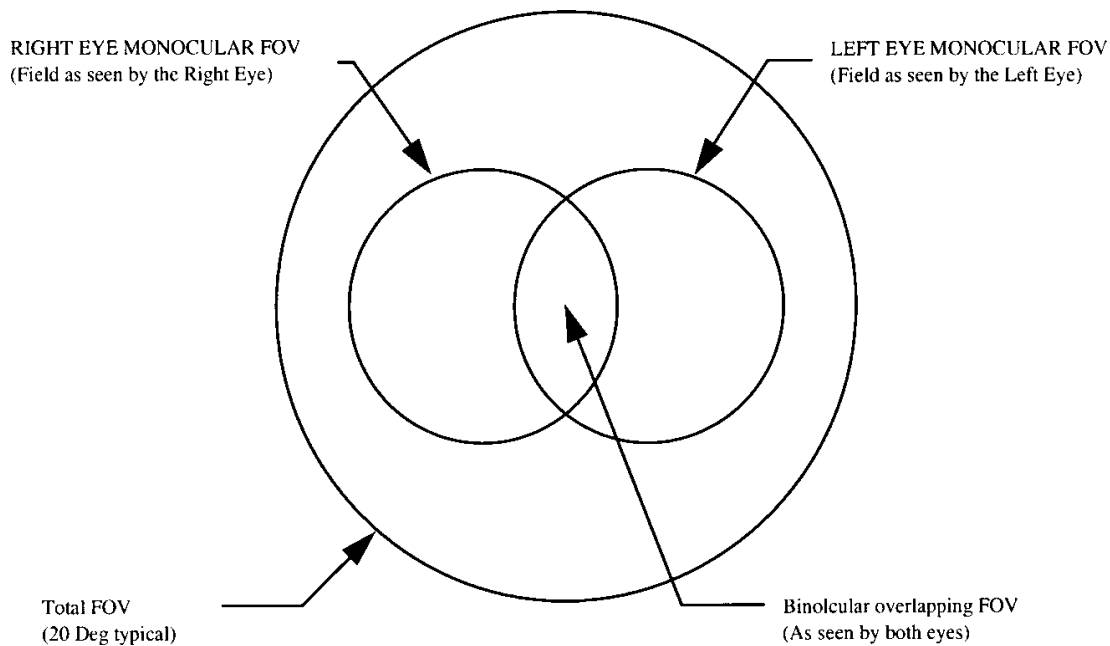


Figure 1 - HWD field of view (at optical infinity)

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 HUD display as seen by a single eye as shown in Figure 1. The size and shape of the monocular FOV is dependent on the eye position within the Exit Pupil.

FIELD OF REGARD: The angular extent of the external world that can be conformally represented on the Head Worn Display.

FLIGHT PATH DERIVATION:

INERTIAL: Data derived from an inertial sensor system or GPS.

AIR MASS: Data derived from a pitot/static system.

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

FOOT-LAMBERT: A unit of luminance equal to one lumen per square foot.

HEAD DOWN DISPLAY (HDD): A display or set of displays that provide control, performance, and navigational information, presented to the pilot on conventional head down instrumentation or panel mounted display.

HEAD UP DISPLAY (HUD): A display which presents flight control symbols into the pilot's forward field of view. The symbols should be presented as a virtual image focused at optical infinity.

HEAD WORN DISPLAY (HWD): Any device attached to or worn on the head used to display critical flight information.

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 (Bailey, Kramer, and Williams, 2009):

- 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.
<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011184.pdf>; page 4

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.

JITTER: Undesired, rapid movement discernible to a human eye.

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 cd/m^2 . One fL = 3.43 cd/m^2 . Luminance differs from brightness in that luminance is an objective photometric measurement and brightness is a subjective perception. See Brightness.

MODE: The operational state of the display: A selected group of display formats, input selections, and processing algorithms.

OPTICAL ABERRATIONS: Imperfections in the optical system that result in failure of light to converge into the intended point after transmission through the optics. Typical examples are, defocus, coma, astigmatism, spherical, and distortion.

OPTICAL INFINITY: Located at such a distance that rays of light appear parallel.

PRIMARY FIELD-OF-VIEW: Primary FOV is based on the vertical and horizontal visual fields from pilot's head reference point that can be accommodated with eye rotation only. For HWD, the primary field of view is established based on the pilot's head reference instead of the traditional aircraft reference. The values for the vertical and horizontal (relative to normal line-of-sight forward of the pilot's head) is a 30 degree diameter cone. This area is normally reserved for primary flight information and high priority alerts.

PRIMARY FLIGHT DISPLAY (PFD): A display or suite of displays which provides the information used by the pilot as the primary flight reference.

PRIMARY FLIGHT REFERENCE: A source the pilot looks at first to obtain information regarding an aircraft control or status parameter. For example, if the pilot looks at the HWD presentation of attitude instead of the panel mounted ADI, the HWD indicator is the primary attitude reference. The same holds for airspeed, altitude, or other aircraft parameter indications. The information displayed depends on the mission segment to be performed. As a guide, airspeed, pitch attitude, altitude, and heading (or their substitutes) should be displayed in a primary flight reference. Other data which is critical for immediate use, such as lateral deviation and glideslope deviation during a precision instrument approach, should be included for those mission segments where it is required.

PUPIL ERRORS: With respect to a HUD, variations in the field as the eye moves through the Eye Box are Pupil Errors. For HWD, the term Eye Box is generally replaced with Exit Pupil, field variations measured as the eye moves through the Exit Pupil are Pupil Errors.

REAL IMAGE: An image formed when the rays from an external object meet at an image point. A real image may be recorded by placing a photographic film at this point. (Heavens and Ditchburn, 1991) Real images are formed on the opposite side of the lens from the objects they represent. Figure 2 shows the geometry of real and virtual images. See Virtual Image.

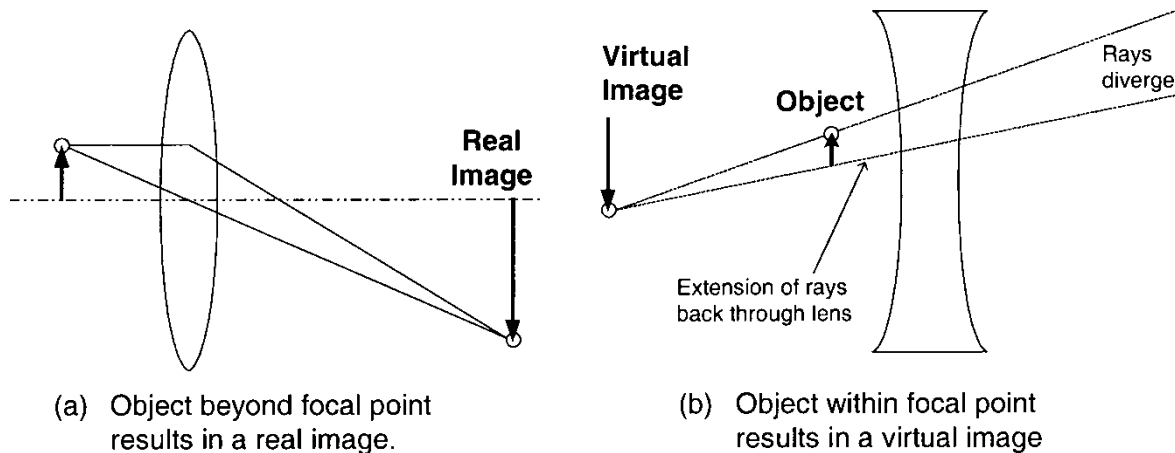


Figure 2 - Real and virtual images

REFRESH RATE: The rate at which the displayed image is redrawn.

STATUS INFORMATION: Current condition information about the aircraft systems.

UNCOMPENSATED FIELD AND PUPIL ERRORS: A cost/complexity trade-off typical in classic HUDs is to allow for some distortion aberrations in the design. This can be easily corrected for as seen from the ERP by applying the inverse distortion to the image on the display source (CRT, LCD, etc.). As the display user moves within the Eye Box, the distortion across the field of view will change. Since the distortion correction is only done from one position in the Eye Box the error associated with head movement is therefore uncompensated. The goal of the optical design is to minimize these errors within acceptable limits.

UNUSUAL ATTITUDE (UA): An aircraft in flight unintentionally exceeding the attitudes normally experienced in line operations or training.

UPDATE RATE: The rate at which the values of the displayed data are processed.

UPSET: An event that unintentionally exceeds the parameters normally experienced in flight.

VERGENCE: The angle between light rays; the angle between the eyes of an observer. When referring to the angle of the observer's eyes, the convention measures the angle looking from the observer toward the source of the light rays.

VIRTUAL IMAGE: An image which can be seen by an observer but is not a real image. A virtual image is formed when the projection of the rays (from an external object) cross, although the rays themselves do not (Heavens and Ditchburn, 1991). Virtual images are formed on the same side of the lens as the objects they represent. Figure 1 shows the geometry of real and virtual images. See Real Image.

3. DEFINITIONS

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 requires justification.

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

Definitions of other words used in this document shall be as noted in 2.4, Glossary of Terms.

4. DISPLAY FUNCTION

Design and implementation of a head worn display system will be dependent on the specified intended function.

4.1 Definition and Characteristics

A Head Worn Display (HWD) can display information such as aircraft performance and attitude, navigation information, flight guidance symbology (flight director), appropriate crew alerts, traffic, and other information that enable the pilot to monitor, control and maneuver the aircraft. Depending on the intended function of the HWD, what information and the format in which it is displayed may be a function of where the pilot's head is positioned. The intent is to enhance pilot performance in the transition between instrument and visual flight in variable visibility situations, e.g., "black hole" approaches, runway slope illusions, wind shear conditions, instrument takeoffs, missed approaches, off airport unimproved area operations, vertical flight CAT A operations, and normal and non-normal operations including engine failure management.

While this document includes guidance for the display of a video image on an HWD, the scope of this document does not include specific guidance for vision systems that provide those video images. Refer to ARP5677 for guidance. When the intent is for manual visual maneuvering, the imagery shall contain content such as terrain slope information topographical information, detected obstacles, point of intended landing, etc., all accurately registered and spatially correct in the database and display, that permits the pilot to safely maneuver the aircraft during all phases of flight and surface operations. See the latest revision of AC 20-167 for guidance. Conformal imagery shall be aligned and registered with the outside view.

4.1.1 Definition of HWD

An HWD is a display system worn on the pilot's head that projects information in alphanumeric and/or symbolic form and/or imagery to one or both pilot's eyes on a transparent screen (i.e., visor, glasses) that is oriented along the pilot's dynamically changing line of sight.

An HWD that is to be used as either as a HUD equivalent or full-axis flight display includes a head tracking function (HTF) to monitor the pilot's head location and line of sight so that the display can adjust in real time with head movements and enable the effective display of information over a wide field of regard.

4.1.2 Characteristics of HWD

Unlike the HUD, which is mounted in a fixed position with respect to the aircraft directly between the pilot and the windscreen in front of the pilot, the HWD moves with the pilot's head and maintains the display alignment with the pilot's head and eyes. The information and imagery displayed in the HWD should account for variation of the pilot's head position, orientation, and line of sight in addition to changes in aircraft position and attitude. Additionally, the HWD display is always in the pilots' field of view and the only ways for pilots to visually escape the display is to take the HWD off, turn it off, or, if able, deselect displayed information.

Another difference between the HUD and HWD implementations is the HWD device may slip or move on the pilot's head. Depending on the technology of the HWD, the headtracking system and the coordinate reference frame of the symbology, the position of the symbology with respect to the world (i.e., its conformality) may shift and present erroneous information.

4.1.2.1 Frames of Reference

The information displayed in the HWD and its relative alignment with the outside scene on the display will depend not only on the aircraft position and attitude, but also on the pilot's head position, orientation, and line of sight with respect to the aircraft frame of reference and flight path.

Figure 3 shows the reference frames relevant to a discussion of symbology displayed on an HWD. Reference frames are denoted by a capital F with a subscript. For each reference frame F_i , translational coordinates are given by the first three terms and orientation angles are in general given by the rotation about each axis contained in the next three terms e.g., $(x_i, y_i, z_i, \Psi_i, \theta_i, \Phi_i)$. The two dimensional display screen coordinates are in the display reference frame F_D and given by (x_D, y_D) . The head reference frame F_H is fixed to the head and centered on the head with coordinates and angles represented by $(x_H, y_H, z_H, \Psi_H, \theta_H, \Phi_H)$. The aircraft reference frame is fixed to the aircraft FAC with coordinates $(x_{AC}, y_{AC}, z_{AC}, \Psi_{AC}, \theta_{AC}, \Phi_{AC})$. The earth referenced frame F_E is any arbitrary coordinate reference frame fixed to the center of the earth. One example is a North East Down earth fixed reference frame with coordinates of $(X_{North\ Latitude}, Y_{East\ Longitude\ and\ Z_{Altitude}})$.

In general, the display reference frame is assumed to have a fixed translational and rotational offset from the pilot's head. The head tracker measures the pilot's head position and orientation relative to the aircraft reference frame, and the aircraft navigation system measures the aircraft position relative to earth.

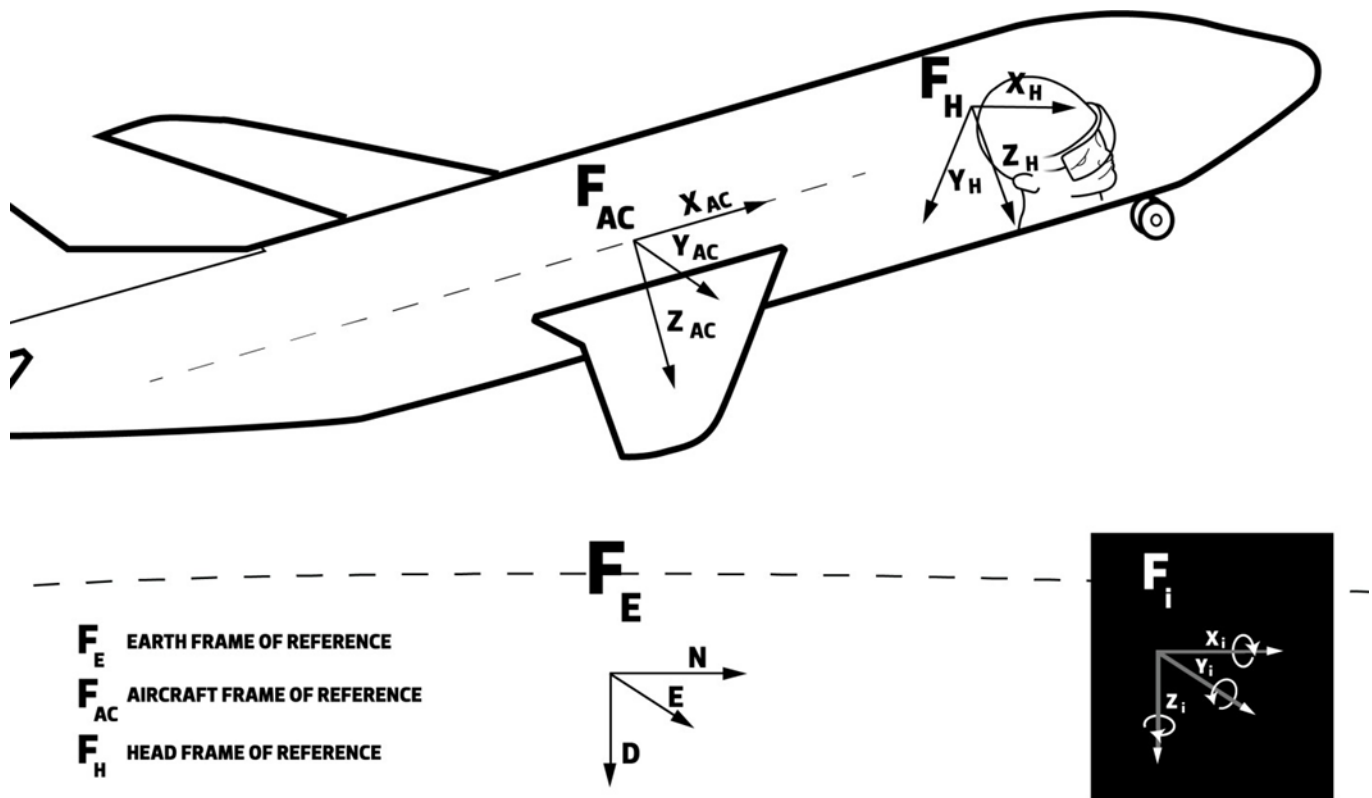


Figure 3 - Frames of reference

Head Frame: The terms head frame and display reference frame are often used interchangeably. Information that is in the head frame has a fixed position in the display screen coordinates (x_D , y_D) and its position is dynamically unaffected by aircraft position, attitude or HWD line-of-sight (LOS). For example, textual flight guidance mode annunciations and certain alerts might be fixed in position (e.g., upper left corner) on the display. In this respect, no matter where the pilot's head is pointed or where the aircraft moves, the information is displayed in the same place (e.g., upper left corner) on the HWD screen.

Aircraft Frame: Information that is in the Aircraft reference frame is fixed with respect to the aircraft coordinate system. It always appears to be in the same location with respect to the aircraft (i.e., it is pinned to the aircraft structure). An example of this is the Aircraft Reference Symbol (i.e., boresight or waterline symbol). Such information will be instantaneously positioned on the HWD according to the relative orientation and position of the HWD within the aircraft. In other words, the symbol is conformal to the aircraft. Aircraft motions, however, do not affect the instantaneous position of this information in the HWD. For example, as the pilot's head rotates left within the cockpit, the Aircraft Reference Symbol would rotate an equal angle to the right in the HWD. The boresight symbol could even disappear from the instantaneous HWD field of view as the pilot's head (LOS) turns away from it.

Earth Frame: Information that is in the Earth reference frame is fixed by position or angular orientation with respect to the Earth's coordinate system (i.e., it is pinned to a location on the earth). This information is otherwise known as "conformal" to the earth. Conformal information should be instantaneously positioned on the HWD/HUD according to the location and attitude of the aircraft as well as the position and line of sight of the HWD/HUD within the aircraft. One example of an earth referenced symbol could be a runway outline displayed on the HWD that overlays the actual runway. The position of the symbol on the HWD screen will vary as the aircraft moves or as the pilot turns their head.

Display Frame: Information that is in the Display reference frame is a two dimensional representation of the Head Frame.