

Transport Category Airplane
Head Up Display (HUD) Systems

TABLE OF CONTENTS

1. SCOPE	5
1.1 Purpose	5
2. REFERENCES	5
2.1 Applicable Documents	5
2.1.1 SAE Publications	5
2.1.2 FAA Publications	6
2.1.3 Industry Documents	7
2.2 Related Documents	7
2.2.1 SAE Publications	7
2.2.2 FAA Publications	8
2.2.3 Industry Documents	8
2.2.4 Government Documents	8
2.2.5 Foreign Government Documents	8
2.2.6 Other Publications	8
2.3 Abbreviations	9
3. DEFINITIONS	10
4. DISPLAY FUNCTION	10
4.1 General	10
4.2 Types of Applications	10
4.2.1 Supplemental Use	11
4.2.2 Alternate Use	12
4.2.3 Additional Credit Use	13
4.3 Primary Flight Reference Components	14

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2008 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

SAE ARP5288

TABLE OF CONTENTS (Continued)

5. GENERAL DESIGN CONSIDERATION	14
5.1 System Function	14
5.1.1 Intended Function	14
5.1.2 AS8055 Compliance	14
5.1.3 Dual HUD Considerations	14
5.2 Safety Assessment Guidelines	15
5.2.1 Functional Hazard Assessment Guidelines	15
5.2.2 System Safety Assessment Guidelines	22
5.2.3 Software Development Assurance	22
5.2.4 Hardware Design Assurance	22
5.3 Preflight Test Considerations	23
6. EQUIPMENT INSTALLATION	23
6.1 Location of HUD Displays and Controls	23
6.1.1 Systems Controls	23
6.1.2 Compatibility with Crew Duties	23
6.2 Field-of-View Issues	24
6.2.1 HUD Field-of-View (FOV)	24
6.2.2 External View	25
6.2.3 HUD Display Viewing Angles	25
6.2.4 HUD Visibility	25
6.2.5 HUD Eye Reference Point and Cockpit Design Eye Position	25
6.2.6 HUD Eyebox and Tolerances for Head Displacements from the DEP	26
6.2.7 HUD Alignment	27
6.3 Crew Safety	27
6.3.1 Head Clearance	27
6.3.2 Crashworthiness	27
6.3.3 Egress	27
6.3.4 Combiner Clearance to Windshield Due to Bird Strike Deflections	28
6.3.5 HUD Interface Wire Separation	28
6.3.6 HUD Hardpoint Thermal Isolation	28
6.3.7 HUD Hardpoint Mechanical Installation	28
6.3.8 Modifications to Cockpit Furnishings	28
6.3.9 Acoustic Considerations	28
7. DISPLAY VISUAL CHARACTERISTICS	29
7.1 Visual Display Characteristics	29
7.1.1 Symbol Positioning Accuracy (External)	29
7.1.2 Symbol Positioning Alignment	30
7.1.3 Dithering	30
7.1.4 Display Drift	30
7.1.5 Line Width	30

TABLE OF CONTENTS (Continued)

7.1.6	Display Jitter	30
7.1.7	Display Flicker.....	30
7.1.8	Symbol Quality	30
7.1.9	Display Binocular Parallax Errors.....	30
7.2	Photometric Characteristics	32
7.2.1	HUD Luminance	32
7.2.2	Luminance Uniformity	33
7.2.3	Display Contrast Ratio	34
7.2.4	HUD Combiner Transmissivity	34
7.2.5	HUD Combiner Real World Color Shift	34
7.2.6	Manual and Automatic Luminance Control	34
7.2.7	Combiner Performance	35
7.2.8	Color Issues	36
7.3	Other Characteristics	37
7.4	Flicker	37
7.5	Dynamics	37
7.6	Raster Display Performance (Imaging Display)	38
7.6.1	HUD Symbology and Raster Display Compatibility.....	38
7.6.2	Raster Resolution	38
7.6.3	Raster Luminance.....	38
7.6.4	Raster Contrast Variation.....	38
7.6.5	Raster Low Level Luminance.....	38
7.6.6	Raster Luminance Uniformity.....	39
7.6.7	Raster Positional Accuracy	39
7.6.8	Display Quality	39
7.6.9	Raster Display and Outside View Compatibility	39
7.6.10	Mixed Symbology and Video Operation.....	39
8.	INFORMATION DISPLAY.....	40
8.1	General	40
8.1.1	Guidelines	40
8.1.2	Factors Influencing Deviations	40
8.1.3	Previously Substantiated Deviations	41
8.2	Test Functions	41
8.3	Attitude	41
8.3.1	General Requirements.....	41
8.3.2	Bank Reference Symbols.....	41
8.4	Flight Path	42
8.5	Alphanumeric, Analog, and Combinations	42
8.6	Full-Time Versus Part Time Displays.....	43

TABLE OF CONTENTS (Continued)

9. INFORMATION SEPARATION/SYMBOLGY PRESENTATION.....	43
9.1 Standard Symbolgy.....	43
9.2 Symbol Position	44
9.2.1 Position of Message or Symbol.....	44
9.2.2 Evaluation	44
9.3 Clutter	44
9.4 Visual Attention-Getting Techniques.....	45
9.5 Head Up/Head Down Display Compatibility	46
10. SOURCES AND ANNUNCIATION	47
10.1 Power Sources.....	47
10.1.1 General Requirements	47
10.1.2 Normal Versus Abnormal Bus Transients	47
10.2 Source Selection and Annunciation	48
10.2.1 Independent Source Selection	48
10.2.2 Primary/Single Navigation Source	48
10.2.3 Multiple Navigation Sources.....	48
10.2.4 Appropriate Navigation Source Annunciation	48
10.2.5 Heading Source Reference.....	49
10.2.6 True Heading Considerations	49
10.3 Mode Annunciation	49
10.4 Alerting Issues	49
11. VERIFICATION CONSIDERATIONS	50
11.1 Human Performance Testing	50
11.1.1 Test Program Duration.....	51
11.1.2 Test Program Personnel	51
11.1.3 Previously Approved Systems	51
11.1.4 Simulation	51
11.2 Aircraft Environment Considerations.....	52
11.3 Optical Testing	52
11.4 Unusual Attitude Recovery Testing.....	52
12. GLOSSARY OF TERMS.....	53

1. SCOPE:

The material provided in this document consists of recommendations related to the design, analysis, testing, and intended functions of head up displays (HUDs) for transport category airplanes. 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.

1.1 Purpose:

This document provides recommendations for certification criteria in the design, analysis, testing, and intended functions of head up display (HUD) systems used for guidance or flight control by the pilots of transport category airplanes.

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. 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS8055	Minimum Performance Standards for Airborne Head Up Display (HUD)
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)

SAE ARP5288

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

2.1.2.1 Regulations: Compliance with many sections of Part 25 of the FAR may be related to, or dependent on, cockpit displays, even though the regulations may not explicitly state display requirements. Some applicable Sections of Part 25, as amended through Amendment 25-54, are listed below:

25.301	Loads
25.303	Factor of safety
25.305	Strength and deformation
25.307	Proof of structure
25.471	Ground loads: general
25.561	Emergency landing conditions: general
25.601	Design and construction: general
25.603	Materials
25.605	Fabrication methods
25.607	Fasteners
25.771	Pilot compartment
25.773	Pilot compartment view
25.775	Windshield and windows
25.777	Cockpit controls
25.803	Emergency evacuation
25.853	Compartment interiors
25.1301	Equipment: function and installation
25.1303	Flight and navigation instruments
25.1309	Equipment, systems, and installation
25.1321	Instruments: arrangement and visibility
25.1322	Warning, caution, and advisory lights
25.1323	Airspeed indicating systems
25.1325	Static pressure systems
25.1327	Magnetic direction indicator
25.1331	Instruments using a power supply
25.1333	Instrument systems
25.1335	Flight director systems
25.1357	Circuit protective devices
25.1381	Instrument lights
25.1431	Electronic equipment
25.1501	Operating limitations and information
25.1529	Instructions for continued airworthiness
25.1545	Airspeed indicator
25.1555	Control markings
25.1581	Airplane flight manual: general

SAE ARP5288

2.1.2.2 Advisory Circulars:

AC 25-11	Transport Category Airplane Electronic Display Systems
AC 25.773-1	Pilot Compartment View Design Considerations
AC/AMJ 25.1309	Systems Design and Analysis
AC 91-16	Category II Operations General Aviation Airplanes
AC 120-28D	Criteria for Approval of Category III Landing Weather Minima for Takeoff, Landing, and Rollout
AC 120-29	Criteria for Approving Category I and Category II Landing Minima for FAR 121 perators (Note: This document is being revised to Revision A)

2.1.3 Industry Documents:

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment (Note: DO-160 refers to the current revision of DO-160. The current revision at this writing is DO-160D)
RTCA DO-178	Software Considerations in Airborne Systems and Equipment Certification (Note: DO-178 refers to the current revision of DO-178. The current revision at this writing is DO-178B)
RTCA DO-TBD	Design Assurance Guidance for Airborne Electronic Hardware (SC-180)

2.2 Related Documents:

The following documents are referenced for background information and do not form a part of this document.

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

AIR1093	Numerical, Letter, and Symbol Dimensions for Aircraft Instrument Displays
ARP1161	Crew Station Lighting - Commercial Aircraft
ARP1874	Design Objectives for CRT Displays for Transport Aircraft
AS8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays
ARP4032A	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
ARP4102/7	Electronic Displays
ARP4102/8A	Flight Deck, Head Up Displays (HUD)
ARP4102/10A	Collision Avoidance System (Advanced TCAS)
ARP4102/11B	Airborne Windshear Systems
ARP4102/12	Airborne Landing Guidance System for Transport Aircraft
ARP4105B	Acronyms and Abbreviations for Use on the Flight Deck
ARP4754	Certification Considerations for Highly Integrated Complex Aircraft Systems

SAE ARP5288

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

DOT/FAA/RD-81/38	Aircraft Alerting Systems Standardization Study, Volume II. Aircraft Alerting System Design Guidelines
TSO-C113	Airborne Multipurpose Electronic Displays

2.2.3 Industry Documents:

2.2.4 Government Documents:

AFAMRL TR-83-95	Optical and Human Performance Evaluation of HUD Systems Design
CSERIAC SOAR-92-2	Human Factors Issues in Head Up Display Design: The Book of HUD
FSWG TR-92-01	Head Up Display Design Guide
MIL-STD-1241A	Optical Terms and Definitions
MIL-STD-1787B	Aircraft Display Symbolology
NASA TM-103947	Test Techniques for Evaluating Flight Displays

2.2.5 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

2.2.6 Other Publications:

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

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

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

2.3 Abbreviations:

ADF	Automatic Direction Finder
AFCS	Automatic Flight Control System
AFM	Airplane Flight Manual
AH	Alert Height
ALS	Automatic Landing System
ALSF	Approach Lighting Sequence Flashers
AOA	Angle of Attack
CAT I, II, III	See Section 3
cd	Candelas
CDI	Course Deviation Indicator
CHMB	Cockpit Head Motion Box
CR	Contrast Ratio
CRT	Cathode Ray Tube
DA(H)	Decision Altitude(Height)
DEP	Design Eye Position
DH	Decision Height
DME	Distance Measuring Equipment
EADI	Electronic Attitude Director Indicator
ERP	Eye Reference Point
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FHA	Functional Hazard Assessment
fL	Foot-Lamberts
FOV	Field-Of-View
GPS	Global Positioning System
HAT	Height Above Threshold
HDD	Head Down Display
HSI	Horizontal Situation Indicator
HUD	Head Up Display
IAS	Indicated Airspeed
IFOV	Instantaneous Field Of View
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
LCD	Liquid Crystal Display
MCDU	Multifunction Control Display Unit
MDA	Minimum Descent Altitude
MEL	Minimum Equipment List
MLS	Microwave Landing System
NCD	No Computed Data
PFD	Primary Flight Display
PFR	Primary Flight Reference
PLI	Pitch Limit Indicator
PSSA	Preliminary System Safety Assessment

2.3 (Continued):

RSS	Root Sum Square
SSA	System Safety Assessment
TCAS	Traffic Alert and Collision Avoidance System
UA	Unusual Attitudes
UAR	Unusual Attitude Recovery
VFR	Visual Flight Rules
V _{MO}	Maximum Operating Velocity
VOR	Very High Frequency Omnirange Station

3. DEFINITIONS:

The word "shall" is used to express an essential (mandatory) requirement. Compliance requires that there be no deviation.

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

Definitions of other words used in this document shall be as noted in Section 12, Glossary of Terms.

4. DISPLAY FUNCTION:

4.1 General:

A HUD is intended to provide the pilot with information that is useful for a particular aircraft task or operation. In most applications (see 4.2), the HUD provides an additional indication of primary flight references which allow the pilot to rapidly evaluate the aircraft attitude, energy status, and position during the phases of flight for which the HUD is designed. Many HUD installations have been quite effective for use in terminal area operations, specifically takeoff, approach, landing, and go-around. A common objective of HUD information presentation is to enhance pilot performance in such areas as the transition between instrument and visual flight in variable visibility situations, "black hole" approaches, runway slope illusions, wind shear conditions, instrument takeoffs, and missed approaches.

4.2 Types of Applications:

The following definitions of HUD applications are based on functional usage that may vary with the phase of flight. The category of HUD use, as defined in the following paragraphs, therefore may also vary with the phase of flight. For example, in many cases a HUD installation will be defined and certified as supplemental use for most flight phases but as additional credit use for a particular flight phase, such as approach and landing.

4.2.1 Supplemental Use: A HUD may be used to supplement flight deck instrumentation for use in the performance of a particular task or operation. A HUD approved for supplemental use does not replace the conventional head down flight deck information. Examples of some uses considered appropriate for supplementary approval of a HUD are:

- a. Pilot monitoring of a visual approach, airspeed, altitude, angle of attack, and autopilot performance;
- b. Display of flight path;
- c. Display of potential energy;
- d. Alerts and warning displays.

The HUD approved for supplemental use should perform its intended function throughout all segments of the flight envelope and/or flight maneuvers for which its use is approved and the information provided by the HUD should be compatible with the tasks to be performed.

An approval for supplemental use of a HUD does not eliminate or replace the requirement for standard head down instruments. The primary cockpit instruments shall continue to be utilized as the primary means for manually controlling or maneuvering the aircraft.

However, certain components of a PFR may be displayed (or repeated) on a HUD approved for supplemental use. This would allow the HUD to also be utilized as a means for manually controlling or maneuvering the aircraft. If this is the case, then, to minimize the need to transition between head up and head down information required in the controlling or maneuvering of the aircraft, all PFR components (see 4.3.1) should be provided on the HUD.

A HUD intended for supplemental use shall comply with 5.2 of this document. If the HUD displays the same information as shown on the head down display (HDD), the same functional criticality should apply to the integrity of the information on the HUD as on the HDD. The HUD should also be shown to cause no unsafe flight conditions within the flight envelope for which the HUD is approved. If the HUD could cause unsafe conditions through misuse in phases of flight other than those for which it was approved, appropriate limitations should be specified. For example, an approach and landing HUD which was not designed for cruise flight may not be operationally suitable for use at high speed or in level flight. If this possibility exists, appropriate limitations should be described to preclude its use in that situation.

NOTE: The proposal of the information to be presented and the operations to be performed using this supplemental information is determined by the HUD developer. However, if portions of the PFR defined set of components are displayed, then due to the possible preference of the pilot to remain head up when controlling the flight of the aircraft, all components of a PFR (defined for the appropriate phase of flight) will need to be displayed head up. These core requirements are introduced in the above discussion.

4.2.2 Alternate Use: A HUD may be used as an alternate source of primary information for use in the performance of a particular task or operation. This information should be presented in a manner such that the pilot can rely on the information presented by the HUD, in lieu of scanning the conventional head down instruments typically used for the task to be performed. As an example, a pilot may use a HUD approved as an alternative means to verify the performance of automatic flight control systems, without frequent reference to head down displays and instruments, during the phases of flight for which the HUD is certified. The HUD approved for alternate use should perform its intended function throughout all segments of the flight envelope and/or flight maneuvers for which its use is approved.

An approval of a HUD for use as an alternate means for satisfying a requirement would permit its use for control of an aircraft by reference to the HUD, for any phase of flight for which it is intended. During these phases of flight, the HUD is used as the primary flight reference and must meet the applicable criteria of FAR 25, Subpart F, and the complete set of PFR components for the appropriate phase of flight (see 4.3.1) must be provided on the HUD.

The need for full-time head down primary flight references to be displayed will be dependent on the characteristics of the HUD approved for alternate use (e.g., restrictions of HUD Eye Box, cross-cockpit viewing, etc.). Head down primary flight references should always be displayed with this type of application, unless they are immediately available on pilot demand and will be automatically displayed due to malfunctions or conditions when the HUD becomes unsuitable as a primary flight reference.

The safety assessment guidelines of 5.2 should be used to assess the HUD intended for alternate use. The same functional criticality should apply to the integrity of the information on the HUD as on the HDD. The necessary performance in terms of accuracy of flight, disturbance tolerance, and failure characteristics should be based on the existing criteria applicable to the function for which approval is requested. Relevant criteria for Category I/Category II precision approaches is found in the latest version of AC 120-29 and criteria for Category III landings and low-visibility takeoffs are found in the latest version of AC 120-28.

NOTE: The Alternate Use category is for an Alternate Use PFD or Alternate Use for other functions such as CAT I or CAT II approaches. An Alternate Use HUD should at least contain the PFR components associated with the flight phase during which the HUD is intended to be used. An Alternate Use PFD may be difficult to certify due to certain HUD constraints not necessarily associated with symbology (e.g., cross cockpit viewing). These requirements are reflected by the above paragraphs.

4.2.3 Additional Credit Use: A HUD may be used to provide information for use in the performance of a particular task or operation which adds to the current authorizations of a particular aircraft. For these tasks or operations, the required information will be displayed on the HUD in lieu of the head down instruments. As an example, additional credit approval of a HUD could be used to conduct operations to lower minima than currently authorized for a particular aircraft or automatic flight control system, or to conduct operations with the “pilot-in-the-active-control-loop” in situations where automated systems are otherwise used. The HUD approved for additional credit use should perform its intended function throughout all segments of the flight envelope and/or flight maneuvers for which its use is approved.

It should be noted that approval of the HUD installation does not guarantee the operational authorization. Other factors, such as the operator’s approved procedures, crew training, and maintenance program, must also be in place.

An approval of a HUD for use as an additional credit means for satisfying a requirement could permit its use for control of an aircraft by reference to the HUD, for any phase of flight for which it is intended. During these phases of flight, when the HUD is used as the primary flight reference, it shall meet the applicable criteria of FAR 25, Subpart F, and all PFR components for the appropriate phase of flight (see 4.3.1) shall be provided on the HUD. As in the case of an alternate use HUD, the need for full-time head down primary flight references to be displayed will be dependent on the characteristics of the HUD approved for additional credit use (e.g., restrictions of HUD Eye Box, cross-cockpit viewing, etc.). Head down primary flight references should always be displayed with this type of application, unless they are immediately available on pilot demand and will be automatically displayed due to malfunctions or conditions when the HUD becomes unsuitable as a primary flight reference.

The safety assessment guidelines of 5.2 should be used to assess the HUD intended for additional credit use. The same functional criticality should apply to the integrity of the information on the HUD as on the HDD. Additional credit applications with pilot-in-the-loop HUD systems may require a “proof of concept” prior to development and acceptance of specific airworthiness criteria for a particular aircraft and system type.

NOTE: Additional Credit Use implies an operation that currently cannot be performed without the HUD. The Additional Credit Use category builds on top of either a Supplemental or Alternate Use HUD, meaning that the HUD can most likely be considered a Supplemental or Alternate Use HUD with additional functions provided such as low visibility (e.g., CAT III or takeoff) guidance. If these additional credit functions involve the control or maneuvering of the aircraft, as a minimum, the components of a PFR required for the corresponding flight phases must be displayed on the HUD in addition to any symbology required (e.g., guidance cues) required to obtain an Additional Credit Use approval.

4.3 Primary Flight Reference Components:

A HUD, depending on its type of application, may be considered the primary flight reference when the pilot is flying "head up". Information should be presented to allow easy recognition by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft cockpit displays.

A Primary Flight Reference (PFR) is defined in Section 12 as a source of information sufficient to maneuver the aircraft about all three axes and accomplish a mission segment, such as takeoff or instrument approach, or terminal maneuvering. The information displayed depends on the mission segment to be performed.

The set of informational components displayed on a HUD used as a PFR should include, as a minimum, the flight references specified in FAR §25.1321. Other components required for display on a HUD are dependent on the other phases of flight and flight operations supported by the HUD. These additional components are mainly related to the display of command guidance or the display of aircraft situational information. For example, if the HUD is to be used to monitor the autopilot, the following additional information should be displayed:

- a. Situation information based on independent raw data;
- b. Autopilot operating mode if autopilot reversion is necessary;
- c. Autopilot disconnect warning.

Additional information should also be displayed if required to perform aircraft maneuvers during phases of flight which the HUD is approved. These may include:

- a. Flight path indication;
- b. Target airspeed references and speed limit indications;
- c. Target altitude references and altitude awareness (e.g., DH, MDA) indications;
- d. Heading or course references.

5. GENERAL DESIGN CONSIDERATION:

5.1 System Function:

- 5.1.1 Intended Function: All HUDs shall perform their intended function throughout the segments of the flight envelope and the flight maneuvers for which their use is approved.
- 5.1.2 AS8055 Compliance: The HUD shall be shown to comply with the requirements set forth in AS8055.
- 5.1.3 Dual HUD Considerations: In dual HUD installations, if both pilots are permitted to use their HUD simultaneously, the cockpit design shall provide for the display within the normal eye scan of the flight crew of alert, caution, and warning annunciations.

5.2 Safety Assessment Guidelines:

The use of electronic displays (including head up displays) allows designers to integrate systems to a much higher degree than was practical with previous airplane flight deck components. Failure state evaluation and the determination of criticality of display functions in highly integrated systems may become more complex. Safety Assessment determination should refer to the display function and include all causes that could affect the display of that function, not only the display equipment. "Loss of display," for example, means "loss of capability to display."

The System Safety objectives are accomplished by a process which includes the Functional Hazard Assessment (FHA), the Preliminary System Safety Assessment (PSSA), and the System Safety Assessment (SSA).

5.2.1 Functional Hazard Assessment Guidelines: The installation of HUD systems in cockpits creates complex functional interrelationships between the pilots and other display and control systems. Consequently, conducting a FHA requires a top down approach, from an airplane level perspective. Creation of a FHA for a particular installation requires careful consideration of the role the HUD plays within the cockpit in terms of integrity of function and availability of function. The FHA identifies the failure conditions for all HUD functions, analyzes the effects on the aircraft and flight crew, and assigns the corresponding criticality classification (No Safety Effect, Minor, Major, Hazardous, Catastrophic) while considering both loss of functions and malfunctions.

The FHA can be used to show compliance with some parts of FAR §25.1309. AC/AMJ 25.1309 clarifies the meaning of these requirements and also provides the accepted relationship between failure probability and the severity of the failure condition. ARP4761 provides detailed analysis of the FHA process.

Tables 1 through 4 contains FHA guidelines which specifically address HUD as Supplemental Means, HUD as Alternate Means for VFR and IFR operations to Cat I minimums, and HUD for Additional Credit for Category II, Category IIIa, and Takeoff Guidance operations. The requirements for Category I and Category II operations are contained in the latest version of AC 120-29, and the requirements for Category IIIa and (low-visibility) takeoff guidance operations are contained in the latest version of AC 120-28. As particular HUD applications differ from these classifications in their functionality or use within the overall cockpit, the FHA guidelines may require adaptation to account for these differences and may result in different hazard levels and development assurance levels. Pilot performance evaluation may be necessary in making this determination (as recommended in AC/AMJ 25.1309).

SAE ARP5288

TABLE 1 - CAT I Minimums, Functional Hazard Levels for VFR and IFR Operations
(a) Use of HUD as Supplemental Means, (b) use of HUD as Alternate Means

Note: "CO-PILOT'S PRIMARY DISPLAY" may be either head up or head down, to cover dual HUD.

	FAILURE CONDITION	EFFECTS	CLASSIFICATION OF FAILURE CONDITION
1	Loss of attitude on a HUD	Pilot reverts to HDD or standby	Minor
2	Display of misleading attitude on a HUD and the other pilot's primary display without warning	Could result in loss of aircraft control	Catastrophic
3	Display of misleading attitude on a HUD only without warning	Other pilot would detect unusual attitude	Major
4	Loss of airspeed display on a HUD	Pilot reverts to HDD or standby	Minor
5	Display of misleading airspeed on a HUD and other pilot's primary display without warning combined with loss of stall warning or overspeed warning functions	Could result in loss of aircraft control	Catastrophic
6	Display of misleading airspeed on a HUD only without warning combined with loss of stall warning or overspeed warning functions	Other pilot would detect unusual airspeed	Major
7	Loss of barometric altitude display on a HUD	Pilot reverts to HDD or standby	Minor
8	Display of misleading barometric altitude on a HUD and other pilot's primary display without warning	Could result in controlled flight into terrain – no credit is given for radio altitude display	Catastrophic
9	Display of misleading barometric altitude on a HUD only without warning	Other pilot would detect unusual altitude	Major
10	Loss of flight path vector on a HUD	Pilot must use different means to determine flight path	Minor
11	Display of misleading flight path vector on a HUD and other pilot's primary display	Pilot maintains situational awareness from other primary indications	Major
12	Display of misleading flight path vector on a HUD only without warning	Pilot maintains situational awareness from other primary instruments	Major
13	Loss of acceleration cue along flight path on a HUD	Pilot must use different means to determine acceleration	Minor
14	Display of misleading acceleration cue along flight path on a HUD and other pilot's primary display	Pilot may reduce thrust while airspeed is decreasing. Could be contributing factor during windshear occurrence	Major
15	Display of misleading acceleration cue along flight path on a HUD only	Pilot may reduce thrust while airspeed is decreasing. Could be contributing factor during windshear occurrence	Major
16	Loss of heading display on a HUD	Pilot reverts to HDD or standby	Minor
17	Display of misleading heading on a HUD and other pilot's primary display without warning	Crew should recognize condition from navigation data	Major
18	Display of misleading heading on a HUD only without warning	Other pilot would detect unusual heading	Minor
19	Loss of radio altitude display on a HUD	Pilot reverts to HDD, or loss of function	Minor

SAE ARP5288

TABLE 1 - (Continued)

	FAILURE CONDITION	EFFECTS	CLASSIFICATION OF FAILURE CONDITION
20	Display of misleading radio altitude on a HUD and other pilot's primary display without warning	Altitude minimums determined by barometric altitude	Minor
21	Display of misleading radio altitude on a HUD only without warning	Other pilot would detect unusual radio altitude	Minor
22	Loss of vertical speed on a HUD	Pilot reverts to HDD, or loss of function	Minor
23	Display of misleading vertical speed on a HUD and other pilot's primary display without warning	Aircraft could descend too rapidly on a non-precision approach	Major
24	Display of misleading vertical speed on a HUD only without warning	Other pilot may detect excessive vertical speed	Minor
25	Loss of flight director on a HUD	Pilot reverts to HDD or loss of function	Minor
26	Display of misleading flight director on a HUD and other pilot's primary display without warning	Pilots would detect excessive lateral or vertical path deviation	Major
27	Display of misleading flight director on a HUD only without warning	Pilots would detect excessive lateral or vertical path deviation	Minor
28	Loss of navigation data on a HUD	Pilot reverts to HDD or executes go around	Minor
29	Display of misleading navigation data on a HUD and other pilot's primary display without warning	May not be in a position to land at minimums	Major
30	Display of misleading navigation data on a HUD only without warning	May not be in a position to land at minimums (other pilot may detect excessive deviation)	Minor
31	Loss of slip/skid indication on a HUD when large rudder inputs are required (e.g. Engine Failure)	Pilot reverts to HDD, or loss of function	Minor
32	Display of misleading slip/skid indication on a HUD and other pilot's primary display when large rudder inputs are required (e.g. Engine Failure)	Could result in large lateral deviation due to inappropriate rudder input	Major
33	Display of misleading slip/skid indication on a HUD only when large rudder inputs are required (e.g. Engine Failure)	Other pilot would detect excessive lateral deviation	Major
34	Loss of V-speeds on a HUD	Pilot must use different means to determine V-speeds	Minor
35	Display of misleading V-speeds on a HUD and other pilot's primary display	Crew required to recognize that displayed values are different than those entered	Major
36	Display of misleading V-speeds on a HUD only	Crew required to recognize that displayed values are different than those entered	Major
37	Loss of flare cue on a HUD	Pilot must flare using visual references only	Minor
38	Display of misleading flare cue during a HUD Cat I approach	Pilot has visual contact with runway	Minor
39	Loss of display of runway information on a HUD during a Cat I approach	Pilot is required to see the runway for a Cat I approach	Minor
40	Misleading display of runway during a HUD Cat I approach	Not a primary cue	Minor

SAE ARP5288

TABLE 1 - (Continued)

	FAILURE CONDITION	EFFECTS	CLASSIFICATION OF FAILURE CONDITION
41	No resolution advisory alert on a HUD during actual TCAS alert	Pilot must rely on aural warning and resolution advisory on HDD	Minor
42	Display of incorrect TCAS resolution advisory on a HUD and HDD during actual TCAS alert situation	Pilot may fly toward other aircraft	Major
43	Display of incorrect TCAS resolution advisory on a HUD during actual TCAS alert situation	Pilot may fly toward other aircraft	Major
44	Loss of low speed awareness cue on a HUD (PLI, IAS Bug...)	Airspeed may decrease to stick shaker speed	Minor
45	Display of misleading low speed awareness cue on a HUD	Pilot has to determine aircraft stall margin via other means	Minor
46	Display of misleading low speed awareness cue on a HUD and other pilot's primary display	Pilot has to determine aircraft stall margin via other means	Minor
47	Loss of angle of attack indication on a HUD	Pilot has to determine aircraft stall margin via other means. AOA is supplemental information.	Minor
48	Display of misleading angle of attack indication on a HUD	Pilot has to determine aircraft stall margin via other means. AOA is supplemental information.	Minor
49	Display of misleading angle of attack indication on a HUD and other pilot's primary display	Pilot has to determine aircraft stall margin via other means. AOA is supplemental information.	Minor
50	Loss of crew alerting messages on a HUD	Dependent on system effect	Classification of this failure condition will be dependent on its system effect
51	Display of misleading crew alerting messages on a HUD and HDD	Pilot may perform inappropriate actions	Classification of this failure condition will be dependent on its system effect
52	Display of misleading crew alerting messages on a HUD	Pilot may perform inappropriate actions	Classification of this failure condition will be dependent on its system effect
53	Display of misleading flight crew procedures on a HUD	Pilot may perform inappropriate actions	Major
54	Display of misleading primary propulsion parameters for both or all engines	Pilot may perform inappropriate actions	Major
55	Loss of runway deceleration information	Pilot must rely on other visual cues to decelerate the aircraft	Minor
56	Display of misleading runway deceleration information without warning	Pilot must rely on other visual cues to decelerate the aircraft	Minor