## 2.0 Unique safety considerations

### 2.1 Aeroplane and systems safety

2.1.1 Systems

Installing HUD systems in flight decks may introduce complex functional interrelationships among the flight crew members and other display and control systems. Consequently, a functional hazard assessment which requires a top-down approach from an aeroplane-level perspective should be developed in accordance with CS 25.1309. Developing a functional hazard assessment for a particular installation requires careful consideration of the role that the HUD plays within the flight deck in terms of integrity and availability of function, as well as the operational concept of the installation to be certified (e.g. dual-HUD versus single-HUD installation, and the type and amount of information displayed). Chapter 4 of this AMC provides material that may be useful in preparing the functional hazard assessment.

2.1.2 Aeroplane Flight Manual (AFM) procedures

All alleviating flight crew actions that are considered in the HUD safety analysis need to be validated for incorporation into the AFM procedures section or for inclusion in type-specific training.

2.1.3 Availability of primary flight information

Requirements for the availability of primary flight information are provided in CS 25.1333.

### 2.2 Crew safety

2.2.1 Prevention of head injury

HUD equipment introduces potential hazards that are not traditionally associated with head-down electronic flight deck displays. The HUD system must be designed and installed to prevent the possibility of pilot injury in the event of an accident or any other foreseeable circumstance such as turbulence, hard landing, or bird strike. An HUD combiner with a swing-arm deployment mechanism should be designed to avoid false detents and false latch indications between the fully stowed and deployed positions. A misstowed combiner could swing inadvertently into the path of the pilot's head and cause injury. Additionally, the HUD installation, including the overhead unit and combiner, must comply with the occupant injury requirements of CS 25.785(d) and (k) and the retention requirements of CS 25.789(a).

2.2.2 Special considerations for dual-HUD installations

For dual-HUD installations, the applicant should address single events that could simultaneously incapacitate both pilots and, therefore, become safety-of-flight issues. Examples of such single events are flight or gust loads, a hard landing, or an emergency landing. The Agency may need to issue a Certification Review Item providing project-specific means of compliance if the installation geometry indicates that such events may produce occupant contact with the HUD installation.

2.2.3 Non-interference with emergency equipment

CS 25.803, CS 25.1411, and CS 25.1447 require that the HUD installation must not interfere with, or restrict the use of, other installed equipment such as emergency oxygen masks, headsets, or microphones. The installation of the HUD should not adversely affect the emergency egress provisions for the flight crew, or significantly interfere with flight crew access. The system should not hinder the flight crew's movement while conducting any flight procedures.

## 3.0 Design

### 3.1 Intended function of HUDs

The applicant is responsible for identifying the intended function of the HUD. The description of the intended function should include the operational phases of flight and the concept of operation, including how, when, and for what purpose(s) the HUD is to be used. For example, the HUD may display situational information and/or guidance information, be a supplemental display of primary flight information in all phases of flight, display command guidance for manually flown approaches and/or for monitoring autopilot-coupled instrument approaches, display guidance for low-visibility take-off, and/or display enhanced vision imagery and synthetic vision video. See paragraph 11.c of this AMC for additional guidance.

3.1.1 General

In most applications, HUDs provide an 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. HUDs are usually designed to present information to enhance pilot performance in such phases of flight as during the transition between instrument and visual flight conditions with variable outside visibility conditions. While HUDs may be designed to display enhanced and synthetic visual imagery, particular means-of-compliance guidance for this purpose is not found in this Appendix but will be addressed by associated CRIs until new CSs and AMCs are issued.

3.1.2 Display of primary flight information

3.1.2.1 HUD as de facto primary flight display

If an HUD displays primary flight information, it is considered a de facto primary flight display while the pilot is using it, even if it is not the pilot's sole display of this information. The pilot should be able to easily recognise the primary flight information — it should not be ambiguous or confusing when taking into account information displayed on other flight deck displays.

3.1.2.2 Applicable instrument requirements for HUD

Primary flight information displayed on the HUD should comply with all the requirements associated with such information in CS-25 (e.g. CS 25.1303(b) for flight and navigation instruments that must be visible from each pilot station, and CS 25.1333(b) for the operational requirements of those systems). CS 25.1321(b) specifies the requirements for arranging primary flight information. For specific guidance regarding the display of primary flight information, see the main body and Appendix 1 of this AMC.

3.1.3 Display of other flight information

Additional information may be related to the display of command guidance or specific flight parameter information needed for operating the aeroplane by reference to the HUD.

3.1.3.1 Command guidance

When the HUD is used to monitor the autopilot, it should display the following information:

— situation information based on independent raw data;

— autopilot operating mode;

— autopilot engage status; and

— autopilot disconnect warning (visual).

3.1.3.2 Flight parameter information

The HUD should also display additional flight parameter information, if required, to enable the pilot to operate the aeroplane during phases of flight for which the HUD is approved. This additional information may include:

— flight path indication;

— target airspeed references and speed limit indications;

— target altitude references and altitude awareness (e.g. decision height and minimum descent altitude) indications; or

— heading or course references.

**3.2 HUD controls**

3.2.1 Control placement

For compliance with CS 25.777, the flight crew must be able to see, identify, and reach the means of controlling the HUD, including its configuration and display modes, from the normal seated position. To comply with CS 25.777 and CS 25.1301, the position and movement of the HUD controls must not lead to inadvertent operation.

3.2.2 Control illumination

To comply with CS 25.1381, the HUD controls must be adequately illuminated for all normal ambient lighting conditions and must not create any objectionable reflections on the HUD or other flight instruments. Unless a fixed level of illumination is satisfactory under all lighting conditions, there should be a means to control its intensity.

3.2.3 Control integration

To the greatest extent practicable, HUD controls should be integrated with other associated flight deck controls to minimise the flight crew workload and error associated with HUD operation and to enhance flight crew awareness of HUD modes.

3.2.4 Ease of use

HUD controls, including the controls to change or select HUD modes, should be implemented to minimise flight crew workload for data selection or data entry, and allow the pilot to easily view and perform all mode control selections from the seated position.

## 3.3 Visibility and Field-of-View (FOV)

3.3.1 Field-of-View

The design of the HUD installation should provide adequate display FOV in order for the HUD to function as intended in all anticipated flight attitudes, aircraft configurations, and environmental conditions, such as crosswinds, for which it is approved. The AFM should specify all airworthiness and operational limitations related to these factors.

3.3.2 Impact on pilot compartment view

3.3.2.1 Interior view

Whether or not the combiner is deployed and the HUD is in use, it must not create additional significant obstructions to either pilot's compartment view as required by CS 25.773. The HUD must also not restrict the view of any flight deck controls, indicators, or other flight instruments as required by CS 25.777 and CS 25.1321.

3.3.2.2 External view

The HUD should not significantly obscure the necessary pilot compartment view of the outside world for normal, non-normal, or emergency flight manoeuvres during any phase of flight for a pilot seated at the Design Eye Position (DEP). The HUD should not significantly affect the ability of any flight crew member to spot traffic, distinctly see approach lights, runways, signs, markings, or other aspects of the external visual scene. The combination of the windshield and the HUD must meet the requirements of CS 25.773(a)(1).

3.3.2.3 HUD optical performance

As far as practicable, the optical performance of the HUD should not cause distortions that degrade or detract from the flight crew's view of external references or of other aircraft. The optical performance should not degrade or detract from the flight crew's ability to safely perform any manoeuvres within the operating limits of the aeroplane, as required by CS 25.773. Where the windshield optically modifies the pilot's view of the outside world, the motions and positions of conformal HUD symbols should be optically consistent (i.e. aligned and scaled) with the perceived outside view. To avoid distortions, the optical qualities of the HUD should be uniform across the entire FOV. When the pilot views the HUD with both eyes from any off-centre position within the design eyebox, optical non-uniformities should not produce perceivable differences in the binocular view. SAE ARP 5288, Transport Category Aeroplane Head Up Display (HUD) Systems, provides additional guidance.

3.3.3 Conformal symbols with limited HUD Field-of-View

The range of motion of conformal symbology can present certain challenges in rapidly changing and high-crosswind conditions. In certain cases, the motion of the guidance and the primary reference cue may be limited by the FOV. It should be shown that, in such cases, the guidance remains usable and that there is a positive indication that it is no longer conformal with the outside scene. It should also be shown that there is no interference between the indications of primary flight information and the flight guidance cues.

## 4.0 HUD design eyebox criteria

### 4.1 Design eye position

The FAA AC 25.773-1, Pilot Compartment View Design Considerations, defines DEP as a single point that meets the requirements of CS 25.773 and CS 25.777. For certification purposes, the DEP is the pilot's normal seated position. Fixed markers or some other means should be provided at each pilot station to enable the pilots to position themselves in their seats at the DEP for an optimum combination of outside visibility and instrument scan. The HUD installation must comply with CS 25.773 and CS 25.1321. The HUD should be able to accommodate pilots, from 1 575 to 1 905 mm (5 ft 2 in to 6 ft 3 in) tall, while they are seated at the DEP with their shoulder harnesses and seat belts fastened, to comply with CS 25.777. The DEP should be centred within the minimum design eyebox dimensions found in paragraph 4.2.3 of this Appendix. Actual HUD eyeboxes are larger than these minimum dimensions and, if not centred around the DEP, they need only be large enough so that this minimum sub-volume is centred around the DEP.

### 4.2 Design eyebox

4.2.1 Display visibility requirements

The fundamental requirements for instrument arrangement and visibility in CS 25.773, CS 25.777, CS 25.1301, and CS 25.1321 apply to HUDs. Each flight instrument, including the flight information displayed on the HUD, must be plainly visible to the pilot at that pilot's station with minimum practicable deviation from the normal position and forward line of vision. While seated at the DEP, the pilot must be able to see the flight information displayed on the HUD. The optical characteristics of the HUD, particularly the limits of its design eyebox, cause the pilot's ability to fully view essential flight information to be more sensitive to the pilot's eye position, as compared to HDDs. The HUD design eyebox is a three-dimensional volume, specified by the manufacturer, within which display visibility requirements are met. Thus, whenever the pilot's eyes are within the design eyebox, the required flight information must be visible on the HUD. The size of the design eyebox and the layout of flight information on the HUD should be designed so that visibility of the displayed symbols is not unduly sensitive to pilot head movements in all expected flight conditions. In the event that the pilot's view of displayed information is totally lost as a result of a head movement, the pilot should be able to regain the view of the display rapidly and without difficulty. The minimum monocular FOV required to display this required flight information should include the centre of the FOV and should be specified by the manufacturer. The HUD FOV should be designed by considering the intended operational environment and potential aeroplane configurations.

4.2.2 Design eyebox position

The HUD design eyebox should be laterally and vertically positioned around the respective pilot's DEP. It should be large enough so that the required flight information is visible to the pilot at the minimum displacements from the DEP specified in paragraph 4.2.3 of this Appendix. The symbols should be laid out and positioned such that excessive eye movements are not required to scan elements of the display. The displayed symbols which are necessary to perform the required tasks should be visible to the pilot from the DEP. The DEP used for the evaluation of the eyebox location should be the same as that used for the basic flight deck in accordance with the FAA AC 25.773-1.

4.2.3 Design eyebox dimensions

The lateral and vertical dimensions of the design eyebox represent the total movement of a monocular viewing instrument with a 6.35 mm (0.25 in) entrance aperture (pupil). The longitudinal dimension of the design eyebox represents the total fore–aft movement over which the requirement of this specification is met (refer to SAE AS 8055). When the HUD is a primary flight display, when airworthiness approval is predicated on the use of the HUD, or when the pilot can be reasonably expected to operate primarily by reference to the HUD, dimensions larger than the minimums shown below may be necessary.

4.2.3.1 Lateral: 38.1 mm (1.5 in) left and right from the DEP (76.2 mm (3.0 in) wide).

4.2.3.2 Vertical: 25.4 mm (1.0 in) up and down from the DEP (50.8 mm (2.0 in) high).

4.2.3.3 Longitudinal: 50.8 mm (2.0 in) fore and aft from the DEP (101.6 mm (4.0 in) deep).

**4.3 Conformal display accuracy**

4.3.1 Symbol positioning

The accuracy of symbol positioning relative to the external references, or display accuracy, is a measure of the relative conformality of the HUD display with respect to the pilot's view of the real world through the combiner and windshield from any eye position within the HUD design eyebox. The display accuracy is a monocular measurement. For a fixed field point, the display accuracy is numerically equal to the angular difference between the position of a real-world feature (as seen through the combiner and windshield) and the HUD projected symbology.

4.3.2 Error budget

The total error budget for the display accuracy of the HUD system (excluding sensor and windshield errors) includes installation errors, digitisation errors, electronic gain and offset errors, optical errors, combiner positioning errors, errors associated with the CRT and yoke (if applicable), misalignment errors, environmental conditions (e.g. temperature and vibration), and component variations.

4.3.2.1 Error sources

Optical errors are dependent upon both the head position and the field angle. Optical errors comprise three sources: uncompensated pupil and field

errors originating in the optical system aberrations, image distortion errors, and manufacturing variations. Optical errors are statistically determined by sampling the HUD FOV and the design eyebox (see 4.2.10 of SAE AS8055 for a discussion of FOV and design eyebox sampling).

4.3.2.2 Total accuracy

The optical errors should represent at least 95.4 % (2 sigma) of all sampled points. The display accuracy errors are characterised in both the horizontal and vertical planes. The total display accuracy should be characterised as the root-sum square errors of these two component errors.

4.3.2.3 Allowable margin for display errors

All display errors should be minimised across the display FOV consistent with the intended function of the HUD. Table A6-1 shows the allowable display accuracy errors for a conformal HUD as measured from the HUD eye reference point:

***Table A6-1 — Allowable display accuracy errors***

| Location on the HUD combiner | Error tolerance in milliradians (mrad) |
|---|---|
| At HUD bore sight | ≤ 5.0 mrad |
| ≤ 10° diameter | ≤ 7.5 mrad (2 sigma) |
| ≤ 30° diameter | ≤ 10.0 mrad (2 sigma) |
| > 30° diameter | < 10 mrad + kr [(FOV)(in degrees) – 30)] (2 sigma) where kr = 0.2 mrad of error per degree of FOV |

4.3.2.4 Maximum error

The HUD manufacturer should specify the maximum allowable installation error. In no case should the display accuracy error tolerances cause hazardously misleading data to be presented to the pilot viewing the HUD.

## 4.4 Symbol positioning alignment

The symbols intended for use in combination with other symbols and scales to convey meaning should be aligned and positioned precisely enough not to be misleading to the pilot.

## 4.5 Overlapping symbols

Symbols that share space with other symbols should not partially obscure or interfere with the appearance of other symbols in a way that misleads the pilot.

## 4.6 Alignment

4.6.1 Outside view

The HUD combiner should be properly aligned so that display elements such as attitude scales and flight path vector symbology are conformal (i.e. the position and motion are aligned and scaled). Proper combiner alignment is needed to match conformal display parameters as close as possible to the outside real world, depending on the intended function of those parameters.

4.6.2 Combiner

If the HUD combiner is stowable, means should be provided to ensure that it is in its fully deployed and aligned position before using the symbology for aircraft

control. The HUD should alert the pilot if the position of the combiner causes normally conformal data to become misaligned in a manner that may result in the display of misleading information.

## 4.7 Visual display characteristics

The following paragraphs highlight some areas related to performance aspects that are specific to the HUD. SAE ARP5288, Transport Category Aeroplane Head Up Display (HUD) Systems and SAE AS8055, Minimum Performance Standard for Airborne Head Up Display (HUD), provide performance guidelines for an HUD. As stated in Chapter 3 of this AMC, the applicant should notify the Agency if any visual display characteristics do not meet the guidelines in SAE ARP5288 and AS8055.

### 4.7.1 Luminance

#### 4.7.1.1 Background light conditions

The display luminance (brightness) should be satisfactory in the presence of dynamically changing background (ambient) lighting conditions (5 to 10 000 foot-Lambert (fL), as specified in SAE AS8055), so that the HUD data are visible.

#### 4.7.1.2 Luminance control

The HUD should have adequate means to control luminance so that displayed data is always visible to the pilot. The HUD may have both manual and automatic luminance control capabilities. It is recommended that automatic control is provided in addition to the manual control. Manual control of the HUD brightness level should be available to the flight crew to set a reference level for automatic brightness control. If the HUD does not provide automatic control, a single manual setting should be satisfactory for the range of lighting conditions encountered during all foreseeable operational conditions and against expected external scenes. Readability of the displays should be satisfactory in all foreseeable operating and ambient lighting conditions. SAE ARP5288 and SAE AS8055 provide guidelines for contrast and luminance control.

### 4.7.2 Reflections

The HUD must be free of glare and reflections that could interfere with the normal duties of the minimum flight crew, as required by CS 25.773 and CS 25.1523.

### 4.7.3 Ghost images

A ghost image is an undesired image appearing at the image plane of an optical system. Reflected light may form an image near the plane of the primary image. This reflection may result in a false image of the object or an out-of-focus image of a bright source of light in the field of the optical system. The visibility of ghost images within the HUD of external surfaces should be minimised so as not to impair the flight crews ability to use the display.

### 4.7.4 Accuracy and stability

#### 4.7.4.1 Sensitivity to aircraft manoeuvring

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

4.7.4.2 Motion of symbols

The accuracy of positioning of symbols should be commensurate with their intended use. Motion of non-conformal symbols should be smooth, not sluggish or jerky, and consistent with aircraft control response. Symbols should be stable with no discernible flicker or jitter.

## 5.0 Guidelines for presenting information

### 5.1 HUD and HDD compatibility

5.1.1 General

If the content, arrangement, or format of the HUD is dissimilar to the HDD, it can lead to flight crew confusion, misinterpretation, and excessive cognitive workload. During transitions between the HUD and HDDs (whether required by navigation duties, failure conditions, unusual aeroplane attitudes, or other reasons), dissimilarities could make it more difficult for the flight crew to manually control the aeroplane or to monitor the automatic flight control system. Dissimilarities could also delay the accomplishment of time-critical tasks. Some differences may be unavoidable, such as the use of colour on the HDD and a single colour (i.e. monochrome) on the HUD. The guidelines listed below are intended to minimise the potential for confusion, undue workload, and delays in flight crew task performance.

5.1.2 Exceptions

Deviation from the guidelines below may be unavoidable due to conflict with other information display characteristics or requirements unique to HUDs. These deviations may relate to the minimisation of display clutter, minimisation of excessive symbol flashing, and the presentation of certain information conformal to the outside scene. Deviations from these guidelines require additional pilot evaluation.

5.1.3 Guidelines for HUD–HDD compatibility

5.1.3.1 Consistent displays and format

The content, arrangement, symbology, and format of the information on the HUD should be sufficiently compatible with the HDDs to preclude pilot confusion, misinterpretation, increased cognitive workload, or flight crew error (see paragraphs 31.b and 31.c(3) of this AMC). The layout and arrangement of HUD and HDD formats of the same information need to convey the same intended meanings (see paragraph 36.b of this AMC). For example, the relative locations of barometric altitude, airspeed, and attitude should be similar. Likewise, the acronyms and relative locations of flight guidance mode annunciations for thrust and lateral and vertical flight path should be similar.

5.1.3.2 Symbols

Table A6-2 provides the guidelines for symbols.

***Table A6-2 — Symbol guidelines for HUD–HDD compatibility***

| Symbol characteristics | Guidelines |
|---|---|
| Shape and appearance | HUD symbols that have similar shape and appearance as HDD symbols should have the same meaning. It is not acceptable to use similar symbols for different meanings. Symbols that have the same meaning should have the same shape and appearance on the HUD and HDDs. |
| Special symbolic features | Special display features or changes may be used to convey particular conditions, such as an overlaid 'X' to mean failure of a parameter, a box around a parameter to convey that its value changed, a solid line/shape changing to a dashed line/shape to convey that its motion is limited, and so on. To the extent that it is practical and meaningful, the same display features should be used on the HUD as on the HDDs. |
| Relative location | Information that relates to the symbols should appear in the same general location relative to other information. |

5.1.3.3 Alphanumeric information

Alphanumeric (i.e. textual) information should have the same resolution, units, and labelling. For example, the command reference indication for vertical speed should be displayed in the same foot-per-minute increments and labelled with the same characters as on the HDDs. Likewise, the same terminology should be used for labels, modes, and alert messages on the HUD as on the HDDs. If the design has exceptions to this principle, then they should be justified by necessity or impracticality, and shown not to increase workload or the potential for flight crew confusion or flight crew error.

5.1.3.4 Analog scales or dials

Analog scales or dials should have the same range and dynamic operation. For example, a glideslope deviation scale displayed head-up should have the same displayed range as when it is displayed head-down, and the direction of movement should be consistent.

5.1.3.5 Flight guidance systems

Modes of flight guidance systems (e.g. autopilot, flight director, and autothrust) and state transitions (e.g. land 2 to land 3) should be displayed on the HUD. Except for the use of colour, the modes should be displayed using consistent methods (e.g. the method used head-down to indicate a flight director mode transitioning from armed to captured should also be used head-up).

5.1.3.6 Command information

When command information (e.g. flight director commands) is displayed on the HUD in addition to the HDDs, the HUD guidance cue and path deviation scaling (i.e. dots of lateral and vertical deviation) need to be consistent with that used on the HDDs. There may be cases when the other pilot is using the HDD of guidance and path deviations to monitor the flying pilot's