TECHNICAL SPECIFICATION

# ISO/TS 21957

First edition
2023-07

# Road vehicles — Visibility — Specifications and test procedures for head-up displays (HUD)

*Véhicules routiers — Visibilité — Spécifications et procédures d'essai pour les affichages tête haute (HUD)*



Reference number
ISO/TS 21957:2023(E)

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# Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 35, *Lighting and visibility*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

This document outlines ergonomic specifications, evaluations and test methods for the design and laboratory assessment measurement of head-up display (HUD) image qualities like virtual image distance (X), aspect ratio (Y and Z), luminance, contrast and image height adjustment ranges. This document also outlines procedures for measuring HUD images for the purpose of laboratory assessments, as measured from observation areas defined by an eyebox, and provides the definition of the eyebox from the locating the driver's eyellipse (see ISO 4513).

This document also provides a standard measurement practice of HUD virtual images for HUD bench testing, static and dynamic laboratory test, as well as methods for documenting HUD virtual image attributes such as size, luminance, contrast, field of view, image location adjustment ranges and HUD eyebox attributes using image readability standards from SAE J1757-1, SAE J1757-2, ISO 15008 or other applicable standards where required.



# Road vehicles — Visibility — Specifications and test procedures for head-up displays (HUD)

## 1 Scope

This document provides a common framework of definitions and measurement methods for the design, and ergonomics testing of automotive head-up displays (HUDs) independent of technologies except where noted. Applications in both passenger cars (including sport utility vehicles and light trucks) and commercial vehicles (including heavy trucks and buses) are covered. This document does not include helmet-mounted HUDs or other head carried gear such as glasses.

Areas covered in this document include:

— guidance on how to establish reference points and representative viewing conditions based on vehicle coordinates and ranges of driver's/passenger's eye points;

— descriptions of the HUD image geometry and optical properties measurements;

— definitions of the HUD virtual image and driver vision measurements;

— static and dynamic laboratory tests, and dynamic field operational assessments that include suggested vehicle setup procedures in order to measure HUD image attributes.



## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4130, *Road vehicles — Three-dimensional reference system and fiducial marks — Definitions*

ISO 4513, *Road vehicles — Visibility — Method for establishment of eyellipses for driver's eye location*

ISO 16750-2:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 2: Electrical loads*

ISO 16750-3:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 3: Mechanical loads*

ISO 16750-4:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 4: Climatic loads*

ISO 16750-5:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 5: Chemical loads*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

## 3.1 Terms related to vehicles

**3.1.1**
**vehicular coordinate system**
three-dimensional reference coordinate system showing the supporting surface of the vehicle as the zero Z plane (horizontal zero plane), the zero Y plane (vertical longitudinal zero plane), and the zero X plane (vertical transverse zero plane) at non-operational conditions

Note 1 to entry: It is defined on a right-handed coordinate system having the x-axis positive pointing opposite of the forward movement direction, z-axis positive being orthogonal to the ground plane and pointing upwards, and the y-axis positive pointing to the right seen in forward movement direction. (See also 3.1.2 for reference grid under operational condition.)

**3.1.2**
**three-dimensional reference grid**
longitudinal plane X-Z, a horizontal plane X-Y and a vertical transverse plane Y-Z which are used to determine the dimensional relationships between the positions of design points on drawings and their positions on the actual vehicle when the vehicle coordinates is in operational condition

Note 1 to entry: There can be national regulation applicable which specifies the vehicle operation condition affecting the three-dimensional reference grid which is used in the evaluation procedure of this document. For example, in countries adopting Reference [22], the operation condition determining the three-dimension reference grid is given in the Reference [22], 2.3 (see also 3.1.1).

**3.1.3**
**V point**
vision point positions in the passenger compartment determined as a function of vertical longitudinal planes passing through the centres of the outermost designated seating positions on the front seat and in relation to the "R" point and the design angle of the seat-back, and are used for verifying compliance with driver's fields of view requirements

[SOURCE: Reference [22], 2.8]

**3.1.4**
**H point**
pivot centre of the torso and thigh of the 3-D H machine installed in the vehicle seat, and located in the centre of the centre line of the device which is between the ‘H’ point sight buttons on either side of the 3-D H machine

Note 1 to entry: The H point is detailed in ISO 6549 and it is used to determine the location of the *eyellipse* (3.2.1). The "H point" corresponds theoretically to the "R" point.

**3.1.5**
**SgRP**
seating reference point
R point
design point defined by the vehicle manufacturer for each seating position and established with respect to the three-dimensional reference system

Note 1 to entry: The R point is detailed in ISO 6549 and it is used to determine the location of the *eyellipse* (3.2.1).

**3.1.6**
**windscreen datum point**
point situated at the intersection with the *windscreen* (3.3.13) of lines radiating forward from the *V points* (3.1.3) to the outer surface of the windscreen

[SOURCE: Reference [22], 2.11]



**3.1.7**
**P point**
point about which the driver's head rotates when driver views objects on a horizontal plane at eye level

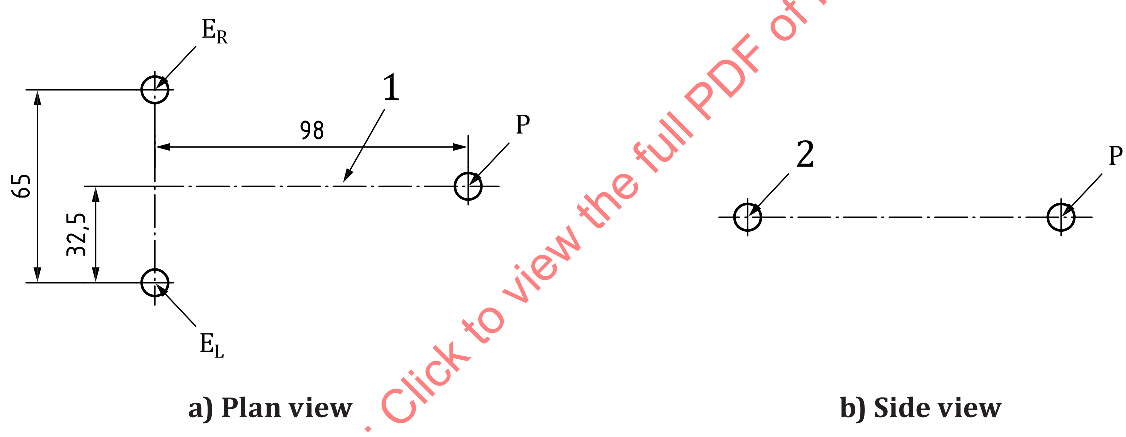
Note 1 to entry: *Head-up display* (*HUD*) (3.3.1) images are presented to the driver intended to be observed with the head oriented in a forward direction (for P3 and P4, see Figure 7). Nevertheless, small head rotation may occur while accessing device for indirect vision with some minor residual head turn around this point (for P1 and P2, see Figure 7).

[SOURCE: Reference [22], 2.14, modified —Note 1 to entry was added.]

**3.1.8**
**E point**
point representing the centre of the driver's eyes and used to assess the extent to which "A" pillars obscure the field of vision

Note 1 to entry: The E points' definition is adopted from UN Regulation 125 when observing the direction of "A" pillar while the driver's ocular reference point (ORP) defined in 3.3.17 is the centre at forward-facing driver head orientation. See Figure 1 for the correlation of E point to with *P point* (3.1.7).

Dimensions in millimetres




**Key**

$E_L$ left eye
$E_R$ right eye
P neck pivot point
1 driver head centre line
2 line, viewed end on, between $E_L$ and $E_R$

**Figure 1 — Neck pivot point and associated eye points**

**3.1.9**
**seat-back angle**
angle measured between a vertical line through the *H point* (3.1.4) and the torso line using the back-angle quadrant on the 3-D H machine

[SOURCE: Reference [22], Annex 3, 2.6, modified — The term was originally "actual torso angle", and supplemental information were removed from the definition.]

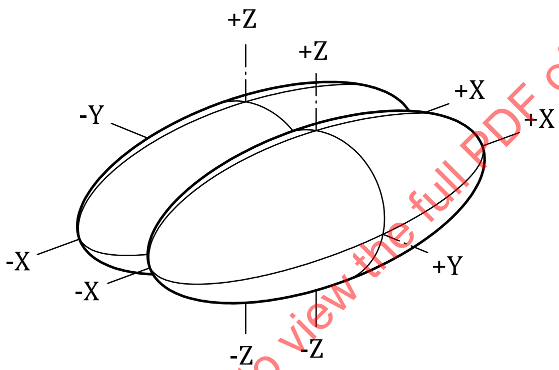
**3.1.10**
**A pillar**
roof support forward of the vertical transverse plane located 68 mm in front of the *V points* (3.1.3) and includes non-transparent items such as *windscreen* (3.3.13) mouldings and door frames, attached or contiguous to such a support

[SOURCE: Reference [22], 2.16]

## 3.2 Terms related to the eyellipse and eyebox

**3.2.1**
**eyellipse**
statistical distribution of eye locations in three-dimensional space located relative to defined vehicle interior reference points

Note 1 to entry: Eyellipse is a term derived as a contraction of the words “eye” and “ellipse” and it is defined in ISO 4513. Unless otherwise specified, the eyellipse space in this document refers to the specific eyellipse representing the distribution of the 95$^{th}$ percentile of driver population as seated in the drive seat. Figure 2 shows an eyellipse model which would be located as shown in Figure 3.

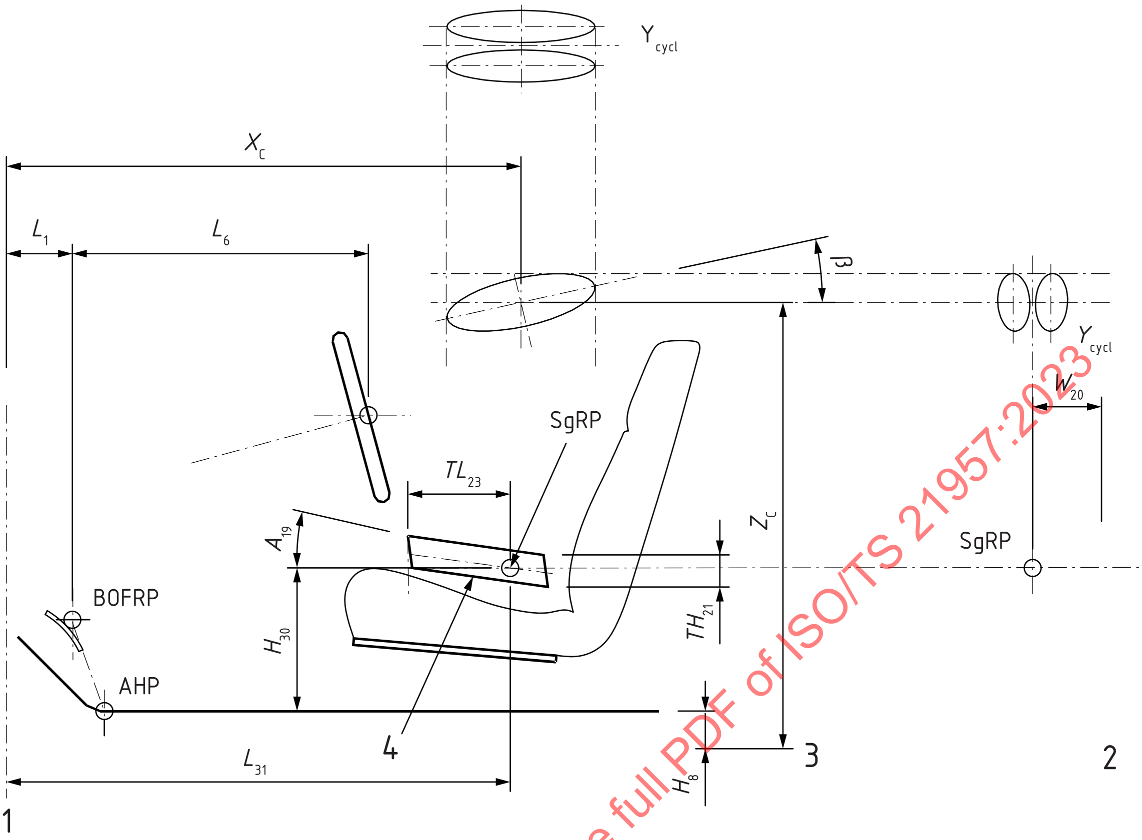



**Key**
X, Y, Z ellipse axes

**Figure 2 — Eyellipse**






**Key**

| | |
|---|---|
| $A_{19}$ | seat track rise |
| AHP | accelerator heel point |
| BOFRP | ball of foot reference point |
| $H_8$ | z-coordinate of the AHP |
| $H_{30}$ | z distance of the *SgRP* (3.1.5) from the AHP |
| $L_1$ | x-coordinate of the BOFRP |
| $L_6$ | x distance from the steering wheel centre to BOFRP |
| $L_{31}$ | x-coordinate of the SgRP |
| SgRP | seating reference point |
| $TH_{21}$ | H-point vertical adjustment |
| $TL_{23}$ | seat track travel |
| $W_{20}$ | y-coordinate of the SgRP |
| $X_c$ | x-coordinate of the eyellipse centroid location |
| $Y_{cycl}$ | mid-eye y-coordinate |
| $Z_c$ | z-coordinate of the eyellipse centroid location |
| $\beta$ | side view angle |
| 1 | zero X grid |
| 2 | zero Y grid |
| 3 | zero Z grid |
| 4 | H-point travel path |

**Figure 3 — Location of the eyellipse relative to driver packaging dimensions**

[SOURCE: ISO 4513:2022, 3.1, modified — Explanation on "contraction of the words “eye” and “ellipse” used to describe" has been deleted, Figure 3 was added and Note 1 to entry has been replaced.]

**3.2.2**
**eyebox**
simplified two-dimensional rectangular box model providing the representative distribution range of the driver's eye reference point for evaluation, encapsulation and having its frame line tangential to the *eyellipse* (3.2.1)

Note 1 to entry: The eyebox is an area covering the entire range of driver with different physical characteristics and a *device under test* (*DUT*) (3.3.25) may not necessarily be capable of conveying visual information within the entire eyebox range without personal adjustment. See also *adjusted viewable HUD window* (3.2.3). It is rather a rectangular vertical plane defined at the centre of the eyellipse and actually it is not a three-dimensional box.

**3.2.3**
**adjusted viewable HUD window**
observation eyebox window at adjusted condition
range designed to convey the visual information to the viewer at adjusted condition, within which the image generated by the *device under test* (*DUT*) (3.3.25) satisfies the required image quality condition

Note 1 to entry: The driver's eye position is expected to come somewhere within the *eyellipse* (3.2.1) range. A *head-up display* (*HUD*) (3.3.1) system is often composed of a reflective device transferring image from the imaging device towards the driver's eye, and its visibility is affected by the observation point. To satisfy needs of drivers with different genders or anthropometric characteristics, a system may provide adjustability to satisfy those different needs. A DUT adjusted to a specific eye position shall provide satisfactory image within an expect range of driver head movement.

Note 2 to entry: An HUD system is a system expected to be capable of providing a uniform image quality to the entire eyellipse range without deterioration of the image quality, and this implies to cover a certain acceptable range of eye movement coverage while in operation that may not cause a drastical degradation on the perceived image quality by the driver normal head movements within this specified window. The DUT shall be capable of properly conveying the visual information to at least a defined range characterized according to this constrained window once adjusted by each driver. This auxiliary observation *eyebox* (3.2.2) range is defined as complementary range for image quality evaluation.

Note 3 to entry: If the quality of the image conveyed to the viewer drastically varies within this range, it may induce discomfort. On the other hand, if the quality of the image gradually degrades with the driver head displacement going beyond this adjusted viewable HUD window position, the degradation of the image caused by the displacement of head position will motivate the driver to return his head position to within this window, therefore, to enable such design strategy which may motivate the driver to return his head position within the adjusted viewable HUD window, but it does not prevent to cause degradation when the driver may move his/her eyes beyond this range as a mean to motivate the driver to maintain their head to a certain limited range to be able to access to the visual information conveyed by the HUD. the image quality beyond this range does not necessarily need to fulfil the same image quality as required with driver eye at nominal position.

**3.2.4**
**eye position tracker**
equipment to localize the dynamic positioning of the driver's eye

Note 1 to entry: The detected position of the eye serves to dynamically control and generate augmented reality images of intended information according to geometrical positional configuration of the driver's eye point of observation. Other adaptations or adjustments according to detected driver's eye position may apply.

## 3.3 Terms related to an HUD system

**3.3.1**
**HUD**
head-up display
information display system that enables the driver to access visual information within a driver's direct field of view without requiring drivers to move their gaze orientation toward the traditional information cluster panel display

Note 1 to entry: The nomenclature of head-up display (HUD) came from the use of this term to describe a type of display system used in military avionics application, where information to the pilot was provided in a form not requiring any deliberated head down movement to access the dynamic displayed information.

Note 2 to entry: The use of this term for automotive applications includes a variety of display systems that display information such that drivers do not need to look down at traditional cluster displays.

**3.3.2**
**HUD engine**
PGU
picture generation unit
assembly which composes part of a *head-up display* (*HUD*) (3.3.1) system incorporating an image generating device and optical components to guide the generated image onto the display *combiner* (3.3.3)

Note 1 to entry: The visual information generated by the HUD engine is reflected by the combiner which directs visual information to the observer.

Note 2 to entry: HUD systems may have compensation optics unit to extend the visual accommodation distance of generated images by using a combination of transmissive and reflective optical elements.

Note 3 to entry: Many aftermarket HUDs often use a simple combiner with limited capability to project the virtual image at a specified distance, which results in higher accommodation efforts when images are viewed by the observer.

**3.3.3**
**combiner**
element or subcomponent of a *head-up display* (*HUD*) (3.3.1) system in which images generated on by the *HUD engine* (3.3.2) are reflected to reach the observers eyes (retina)

Note 1 to entry: There are several types of HUD, and the use of combiners may differ according to the construction design or technology adopted to create the HUD system. HUD systems using the front *windscreen* (3.3.13) itself to act as combiner have their surface treated to properly reflect the image generated by the HUD engine.

Note 2 to entry: The HUD type using a separate transparent optical combiner to reflect the image generated by the HUD engine is differentiated from an HUD in which the windscreen itself acts as combiner. These HUDs have a separate physical combiner, so they are often called "combiner HUDs" to distinguish them from a windscreen-type HUD. A benefit of combiner HUDs is their capability to apply different optical design curvature on the combiner surface when compared the windscreen type which has its reflective surface restricted to the curvatures of the vehicle windscreen design. Separate physical combiner components in a combiner type HUD imposes bordering frames to the viewer.

Note 3 to entry: A combiner in HUD systems is a component that helps the system to combine and superimpose the generated image on top of the actual driving scene image when an observer watches a roadway scene through the combiner. A combiner does not be necessarily need to be a physically reflective element. Holographic diffractive elements are an example of an element that is not reflective but still capable to deliver images as combiner.

**3.3.4**
**AR HUD**
augmented reality head-up display
genre of *head-up display* (*HUD*) (3.3.1) where images displayed to the viewer are presented in driver normal front gaze orientation requiring minimum movement of viewer gaze orientation to access to the displayed information

Note 1 to entry: Presentation of the information in augment reality in many applications is intended to provide the presented information superimposed on image of the real-world view scene, virtually creating, and displaying symbols and signs as they might exist in the real world, but in a virtual visual manner.

**3.3.5**
**C-HUD**
**combiner head-up display**
genre of *head-up display* (*HUD*) (3.3.1) where image displayed to the viewer are reflected by a separate *combiner* (3.3.3) which is located in between driver's eye and the *windscreen* (3.3.13)

**3.3.6**
**W-HUD**
windscreen head-up display
windshield head-up display
genre of *head-up display* (*HUD*) (3.3.1) where images displayed to the viewer are reflected by the *windscreen* (3.3.13) itself and the windscreen acts as an integrated *combiner* (3.3.3)

**3.3.7**
**2D HUD**
two-dimensional head-up display
traditional *head-up display* (*HUD*) (3.3.1) that displays information on a flat focal plane at a virtual distance from the observer

Note 1 to entry: This term is sometimes used to differentiate the traditional 2D HUD from the genre of HUDs that have added functionality to display information with depth perceptibility (e.g. *3D HUD* (3.3.8)). See Figure B.1.

**3.3.8**
**3D HUD**
three-dimensional head-up display
genre of *head-up display* (*HUD*) (3.3.1) where images are presented to the viewer with stereoscopy aspects providing observers a sense of virtual depth

Note 1 to entry: While a classical *augmented reality head-up display* (*AR HUD*) (3.3.4) provides visual information to the viewer image at the same gaze orientation to where the information is expected to be shown in three-dimensional real-world space, the 3D HUD also provides the visual information by means of stereoscopy giving the viewer an additional sense of depth perception. Figure B.1

Note 2 to entry: The three-dimensional sense of perception is achieved by different means and there exist multiple techniques to achieve it. One technique is that the image viewer captures images for each eye with perspective.

**3.3.9**
**HUD effective display area**
active area in which the generated virtual image is effectively observable within the direct field of view of the driver/observer

**3.3.10**
**HUD absolute maximum luminance level**
maximum luminance functional capability to display a virtual image by the *device under test* (*DUT*) (3.3.25) regardless of ambient light condition

Note 1 to entry: The luminance level under night ambient condition may impose gaze disturbing the driver's vision. A DUT may have an embedded function to adjust the maximum brightness level up to this maximum limit, whether manually or automatically. Conditional maximum brightness level is defined in 3.3.11.

**3.3.11**
**HUD conditional maximum brightness level**
maximum luminance adjusted under detected ambient light condition in operation

Note 1 to entry: The *head-up display* (*HUD*) (3.3.1) illumination setting is typically automatically controlled according to the detected external environment condition and avoids excessive bright display in night drive environment as a use case example. Figure 4 is an example of linear gradation test image with brightest and *HUD ON darkest level* (3.3.12).


**Key**

1 brightest display level (100 % signal level)

2 HUD ON darkest level (0 % signal level)

**Figure 4 — Example of neutral colour luminance gradation test image**



**3.3.12**
**HUD ON darkest level**
darkest luminance level when the *head-up display* (*HUD*) (3.3.1) is in operation, displaying a "numerically absolute black signal" and capable to achieve when displayed as a virtual image by the *device under test* (*DUT*) (3.3.25)

Note 1 to entry: Depending on the technology used, the darkest level achieved when a "numerically black signal" does not reach an absolute zero. When pixel uses light-emitting devices, 0 level is likely to be achieved while back-lit LCD or LCOS type devices have some extent of leak light even when displaying a "numerically black signal" when the device is in operation mode.

**3.3.13**
**windscreen**
windshield
W/S
transparent structural component of a vehicle used to protect the vehicle's occupant from the wind and alien objects reaching the occupant while traveling and at the same time providing necessary direct frontal vision to the driver (in front of the driver through which the driver views the road ahead) to access the visual scene to convey a safe driving manoeuvre task

Note 1 to entry: It is a protective laminar composite component often made as an assembly of at least two laminar glass sheets with an intermediate plastic material which holds together when shattered, for improved safety.

Note 2 to entry: The windscreen has at least two reflective surfaces (outer/inner) and it is likely to have an anisotropic curved surface relative to the driver seating positioning. In a W-HUD, its surface(s) acts as *combiner* (3.3.3) element reflecting the projected image from the *HUD engine* (3.3.2) toward the driver's eye.

Note 3 to entry: Windscreen or windshield are common term largely used to refer to the safety "glazing" component or material as defined under UN Regulation No. 43 or FMVSS SS571.205

**3.3.14**
**depth of field**
axial depth of the space on both sides of the image within which the image appears acceptably sharp, while the positions (distance) of the object plane and of the objective of the camera are maintained

Note 1 to entry: In some publications, the term “depth of focus” is used to refer to object space. It is recommended that, when the distinction is important, the full terms “depth of field (in object space)” and “depth of focus (in image space)” be used.

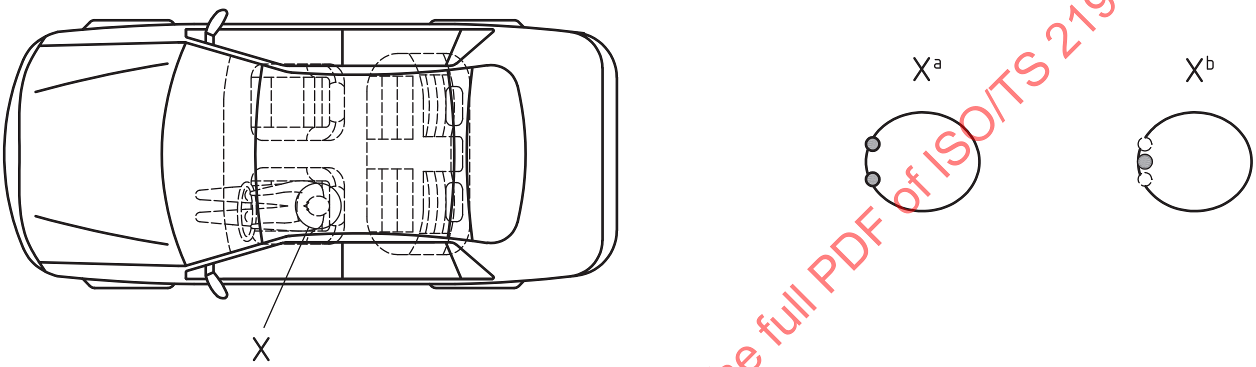
Note 2 to entry: It is the range of observed distance of objects nearest and furthest from observer which are in focus.

[SOURCE: ISO 10934:2020, 3.1.37, modified — The term was originally "depth of field", Notes 2 and 3 to entry have been added.]

**3.3.15**
**forward infinity-oriented setup**
orientation of the evaluation equipment toward the vehicular forward infinity movement having as its infinity the horizontal line on a straight road

**3.3.16**
**driver's field of vision**
horizontal and vertical field of vision provided through the *windscreen* (3.3.13) and extendable beyond the *A pillar* (3.1.10) of a vehicle

**3.3.17**
**driver's ORP**
**driver's ocular reference point**
cyclopean eye
middle point between the two ocular points of the driver




**Key**

Xa driver's binocular point

Xb driver's ocular reference point

Unless otherwise indicated, the measurement is to be performed based on the driver's ocular reference point. Specific needs for stereoscopy measurement may require evaluation on each right and left eye with typical average pupillary distance of 65 mm.

**Figure 5 — Driver's ocular reference point**

Note 1 to entry: See Figure 5 for the difference of driver's binocular point and driver's reference ocular point. In the case of *3D HUD* (3.3.8), the perceptual depth is achieved by the stereoscopic perception and the eye position is tracked to generate an image to be displayed on the *device under test* (*DUT*) (3.3.25) according to the detected eye point.

Note 2 to entry: *E point* (3.1.8) is the term used to specifically refer to the eye point when the driver accesses the area around an *A pillar* (3.1.10) as defined under ISO 4513 (see Note 1 to entry in 3.1.8).

[SOURCE: ISO 16505:2019, 3.1.4, modified — Notes 1 and 2 to entry and the admitted term "cyclopean eye" have been added.]

**3.3.18**
**transparent area**
area of a vehicle *windscreen* (3.3.13) or other glazed surface whose light transmittance measured at right angles to the surface is not less than 70 %, used by a driver to access the frontal field of vision while performing the driving task

[SOURCE: Reference [22], 2.13, modified — Information about armoured vehicles removed and "used by a driver to access the frontal field of vision while performing the driving task" added.]



**3.3.19**
**transparency of HUD display combiner area**
light transmittance measured at natural observation angle of the driver forward vision at a *combiner* (3.3.3) area on a *windscreen* (3.3.13), given in comparison to light transmittance on an area other the combiner dedicated area

Note 1 to entry: In case the combiner area of *head-up display* (*HUD*) (3.3.1) is a dedicated area which influences the transmittance of frontal vision of the driver, the dedicated area shall be additionally evaluated to verify the reduced transparency at the area dedicated as combiner. This applies specially when a separate combiner is adopted as a mean to generate the HUD image, (a *combiner head-up display* (*C-HUD*) (3.3.5) usually adopts an optical combiner element between the driver's eye and windscreen).

**3.3.20**
**optical accommodation distance**
optical distance of the projected virtual image from the driver's eye point where the best focus is achieved

Note 1 to entry: In the absence of any astigmia aberration, the horizontal and vertical focusing distances are same.

Note 2 to entry: The system may exhibit an astigmatism effect resulting in difference in optical accommodation distance regarding horizontal resolution and vertical resolution. It is suggested to measure each accommodation individually to better characterize the *device under test* (*DUT*) (3.3.25) properties.

**3.3.21**
**binocular depth perception**
brain perception of distance from image capture by the left and right eye of the observer and processed in the brain

Note 1 to entry: In a stereoscopic *3D HUD* (3.3.8), images with disparity are artificially created and displayed by the *head-up display* (*HUD*) (3.3.1) unit to the left and right eye respectively, thus giving a sense of information being superimposed on 3D real space at an intended depth (distance from observer).

**3.3.22**
**luminance contrast ratio**
ratio of displayed image luminance relative to the defined reference background scene

Note 1 to entry: The luminance contrast ratio is affected by multiple factors other than the background scene and displayed image itself, and effects like haze and scene.

**3.3.23**
**look down angle**
LDA
amount of gaze down angle required to observe the centre of the virtual display image area, relative to frontal infinity orientation

Note 1 to entry: See 6.2.2.1 and Figure 16.

**3.3.24**
**look over angle**
LOA
amount of the lateral gaze angle required to observe the centre of the virtual display image area, relative to the vertical plane which contains the frontal infinity orientation from the ocular reference point (ORP)

Note 1 to entry: See 6.2.2.2 and Figure 16.

**3.3.25**
**DUT**
**device under test**
single component or combination of multiple components that performs a function of the *head-up display* (*HUD*) (3.3.1) as defined to be tested

## 4 Abbreviated terms

LDA look down angle

LOA look over angle

SgRP seating reference point

## 5 Specification, verification, and reference point definition for HUD image evaluation

### 5.1 General

The images generated by the HUD engine unit are targeted to be observed by the driver. The driver's eye positioning is one of the essential attributes determining the image performance as observed by the driver. Therefore, this clause details on the procedure to determine these eyes positioning related attributes which will be used during the following measurement procedure to access the HUD image and the related quality evaluation. Annex A provides additional information for allocating the eyebox.

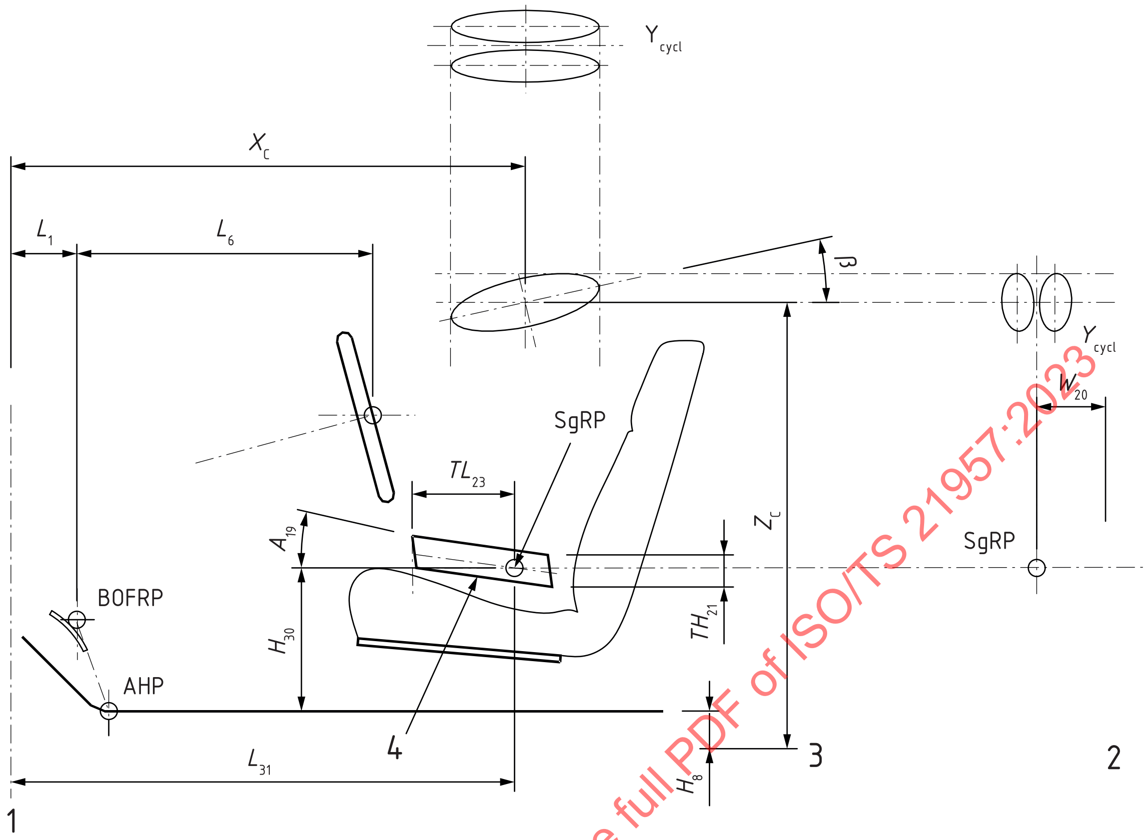
The windscreen datum point (3.1.6) is the intersecting point from V point (3.1.3) or the driver's ocular reference point (3.3.17) when the driver's gaze is towards forward infinity, according to forward infinity-oriented setup (3.3.15). For evaluation procedures with the vehicle in operation condition, the driver forward infinity gaze line will be intersecting the windscreen datum point (3.1.6), and intersecting also the point indicated by key "I" in Figure 8.

The H point (3.1.4) and seat-back angle (3.1.9) are factors that influence the driver's eye point but based on several findings in the development of ISO 4513, they are directly factored into the calculation of the eyellipse (see ISO 4513:2022, Clause F.2).

### 5.2 Eyellipse and the eye centroid location

The eyellipse is the three-dimensional statistical distribution space where the driver's eye location could come while driving. The eyellipse location within the vehicle is defined in ISO 4513. It establishes the location of drivers' eyes inside a vehicle. The quality of image conveyed by the HUD to the driver is evaluated as visual information observed within this space. This document adopts the eyellipse covering the 95$^{th}$ percentile driver population.

The precise location shall be derived according to the definition in ISO 4513.




**Key**

| | |
|---|---|
| $A_{19}$ | seat track rise |
| AHP | accelerator heel point |
| BOFRP | ball of foot reference point |
| $H_8$ | z-coordinate of the AHP |
| $H_{30}$ | z distance of the SgRP from the AHP |
| $L_1$ | x-coordinate of the BOFRP |
| $L_6$ | x distance from the steering wheel centre to BOFRP |
| $L_{31}$ | x-coordinate of the SgRP |
| SgRP | seating reference point |
| $TH_{21}$ | H-point vertical adjustment |
| $TL_{23}$ | seat track travel |
| $W_{20}$ | y-coordinate of the SgRP |
| $X_c$ | x-coordinate of the eyellipse centroid location |
| $Y_{cycl}$ | mid-eye y-coordinate |
| $Z_c$ | z-coordinate of the eyellipse centroid location |
| $\beta$ | side view angle |
| 1 | zero X grid |
| 2 | zero Y grid |
| 3 | zero Z grid |
| 4 | H-point travel path |

**Figure 6 — Location of the eyellipse relative to driver packaging dimensions**



## 5.3 Eyebox location

The eyebox is used as a measuring position for most of the image quality evaluation within this document as a practical position point of evaluation and located over the driver seat as described in Figure 6.

Due to the difficulty of working directly with the eyellipse using the complex three-dimensional space to perform measurements, a solid rectangular box model is adopted as a representative point to determine the measuring point. This eyebox is used to determine the measuring points throughout the evaluation, thus it simplifies the measurement procedure, without a need to access the curved three-dimensional space of an eyellipse.

This clause provides the procedure to translate the eyellipse coordinate information to the eyebox.

As the image quality observed by the driver may depend on the observation point within the eyellipse, test procedures described in the following clause will adopt a specific representative point on this eyebox to perform the evaluation.

Figure 7 shows the driver eyellipse plan view (at the top) and side view (at the bottom) as described in ISO 4513, and the bold line illustrate the eyebox Y and Z dimensions positioned centred and vertical at the mid-eye centroid. The vehicular X axis touching the outermost surface of the eyellipse at this vertical plane is in fact a planar range defined by a plane orthogonal.

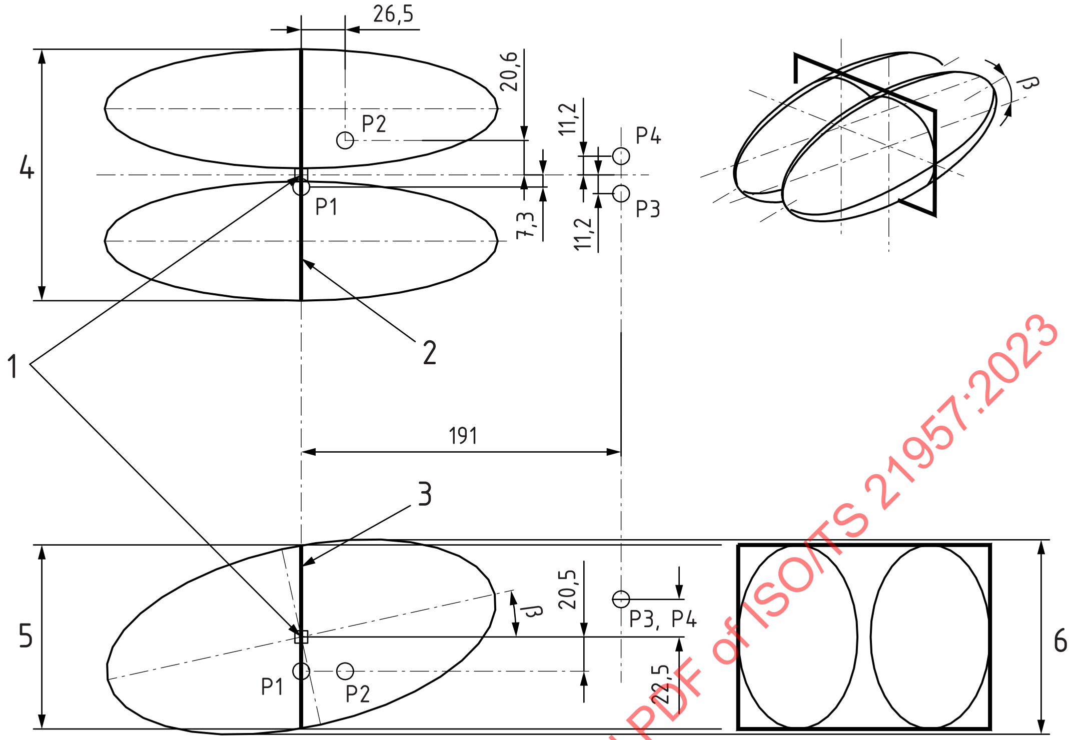
The vertical size of the eyebox adopts the dimension indicated by Figure 7, key 5, for practical reasons. A small deviation exists compared to the outermost range of the eyellipse indicated by Figure 7, key 6 but the difference is negligible.

The test procedure described in this document considers a baseline to cover 95$^{th}$ percentile of the driver and therefore, the evaluation shall consider determining the eyellipse that covers the 95$^{th}$ percentile of the driver population. Therefore, values to establish the eyellipse for this 95$^{th}$ coverage shall be used determine the respective eyebox. ISO 4513 provides details to derive the neck pivot points, or simply P points selected according to the driver task. Multiple P points are defined in ISO 4513 but points P1 and P2 are specific points where drivers change their head position to access visual information around the A pillar (3.1.10) area and therefore they are not applicable when observing information provided by an HUD towards a forward viewing task to the road ahead.



Dimensions in millimetres




**Key**

1 driver 's ORP (mid-eye centroid)
2 eyebox horizontal frame (bold line)
3 eyebox vertical frame (bold line)
4 eyebox lateral y dimension
5 eyebox vertical z dimension
6 widest Z dimension of the tilted eyellipse (reference)

β side view angle
P1 neck pivot points used to position eye points(reference)
P2 neck pivot points used to position eye points(reference)
P3 neck pivot points used to position eye points
P4 neck pivot points used to position eye points

NOTE The outermost vertical dimension given in key 6 is not used.

**Figure 7 — Eyebox versus eyellipse and P point location**

NOTE Eyellipse are shown for reference purposes to determine the eyebox frame location.

# 6 Evaluation, test and measurement

## 6.1 General

Evaluation, test procedures are described in the following subclauses.

### 6.1.1 Measurement setup

#### 6.1.1.1 General care

When performing evaluation of an HUD system, its optical components like the HUD engine, the windscreen or the combiner shall be positioned and aligned according to the installation packaging design, operation, and vehicle load condition. For details on operation condition, see also 7.2.

The vehicle load condition can affect the vehicle pitch. The measurement shall be performed following the nominal positioning and orientation under this condition. National bodies can have information on instructions to set the vehicle under such predefined operation condition.

For setup in a laboratory environment, components including windscreen and peripheral components affecting the virtual image shall be positioned to mimic the in-vehicle installation packaging condition of the HUD under test.

Vehicles fitted with suspension enabling their ground clearance to be adjusted shall be tested under the normal conditions of use specified by the vehicle manufacturer.

Gloss of surrounding components might influence the viewing performance due to parasitic incident alien light. Stray light that may hit onto the effective viewing area of the HUD displayed image may decrease the image quality formed by the HUD. Note that that incident alien stray light can be reflected by some of the HUD components themselves but also as secondary reflection.

#### 6.1.1.2 Darkroom environment

To avoid the alien external light affecting the evaluation result, care should be taken to secure that incident light other than that aimed for evaluation is properly excluded from the surrounding environment.

The dark room condition required for measurement may depend on the type of evaluation to be performed/executed. If the evaluation targets measuring the luminance characteristic of the DUT, any alien stray light that may disturb the measurement result shall be minimized.

On the other hand, in evaluation of physical properties like LDA, LOA and distortion measurement, the incident alien illumination does not get severely affected. In most cases, a moderate dark condition is enough to enable to perform these measurements. However, for evaluation of visual properties like resolution, contrast and ghost measurement, an exaggerated influence of alien incident illumination may potentially affect the results. Therefore, appropriate counter measures shall be taken to remove the effect of such alien light. Typically, an environment under 0,05 lx can be enough.

Unless otherwise indicated, the foreground shall be covered by a black dark material or black light trap. Removing lights from the foreground (at dark) enables evaluation purely generated by the HUD. However, this is not a realistic use case because the situation is similar to evaluating in complete darkness, i.e. without switching any headlight ON.

An example of an environment setup can be found in SAE J1757-1.

#### 6.1.1.3 Laboratory setup

Figure 8 shows an example of setup and necessary equipment positioning. A movable vertically standing panel parallel to the vehicular y-z plane and capable to be moved along the vehicle longitudinal axis x-axis of the vehicle coordinate shall be place in front of the DUT. The coordinates shall follow ISO 4130. The positioning of the panel with a physical grid shall be well aligned to evaluate the location of the virtual image created by the DUT, and adjustable to bring the panel position at an accommodation distance of best focusing distance generated as virtual image when observed from the driver's eye point.

The movement range of the movable standing panel shall be capable to cover the virtual image focus accommodation distance. When evaluating a DUT with its accommodation distance shorter than the frontmost point of the vehicle under evaluation, the lower frame of the movable standing panel may physically intervene with the body of the vehicle. In such case, the lower parts movable standing panel shall be arcaded over the vehicle's body frontal structure and be capable to move up to the windscreen. For combiner-type HUD (C-HUD) with short accommodation distance, the measurement of the accommodation distance may be performed without the windscreen as the windscreen does not affect the accommodation distance.



A linear rail guided movement is suggested to reduce the needs for alignment when adjusting the distance.

A grid screen is placed on the panel facing towards the observer side. The grid lines shall be designed with lines widths which are well observable, and line spacing pitch precision capable of differentiating the virtual image position on the order of at least 1/10$^{th}$ of its maximum virtual image display size.

All components shall be aligned according to the designed installation position and orientation in the target vehicle to enable an appropriate evaluation where the optical path plays an important role in the quality of the generated virtual image by the DUT.

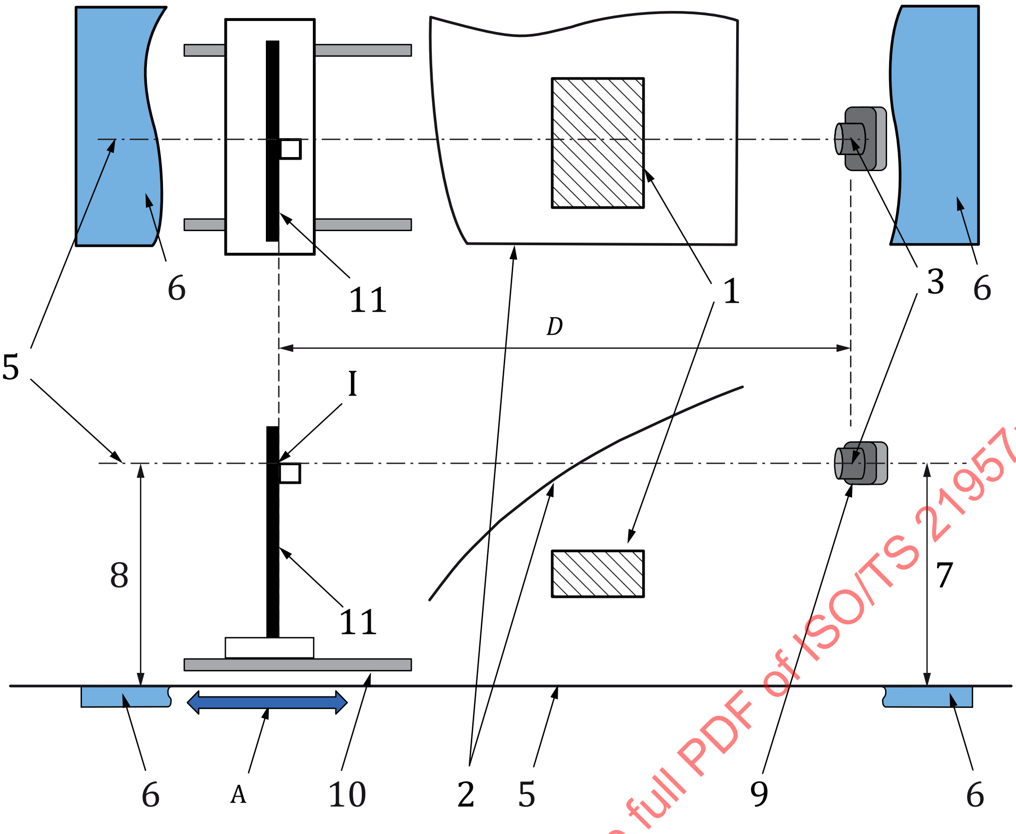
A planar grid screen is used to evaluate the system performance. The grid screen shall be placed in front of the windscreen, with its horizontal axis parallel to the ground-surface infinity horizon line. The rotation angle in respect to the grid chart normal axis serves as the reference of rotation of the virtual image created by the HUD engine. (See 6.1.1.5.)

If the system of the DUT incorporates any semi-automated or automated level adjustment function which adjusts the vertical image position such that the intended image infinity is adjusted to the driver's view of the physical infinity horizon line, the measurement shall be performed under the adjusted condition.

For an evaluation using equipment in forward infinity orientation, the evaluation equipment is placed and fixed at the defined measurement point in the eyebox space with its orientation toward the negative x-axis to mimic the driver gaze orientation toward the frontal horizon. The forward infinity gaze orientation corresponds to the forward infinity-oriented setup to which the evaluation equipment should be set up (3.3.15), equivalent to 0° look down angle and 0° look over angle. Under this condition, the centre of the image, i.e. the chart zero reference point for the test, is displayed in the infinity point when the vehicle moves forward. This specific chart with forward infinity-orientation setup applies to the evaluation of "look down angle", "look over angle" and "HUD FoV" coordinates measurement. Unless otherwise specified, the centre of the eyellipse corresponding to the centre eyebox is taken to be the driver's ORP point, and the angular measurement is measured in reference to this ORP point.

For an evaluation considering the HUD virtual image observation, photometric equipment orientation shall be aligned and oriented according to the expected gazing orientation. The evaluation for the image quality like luminance, contrasts and distortion measurement applies. Unless the specific region on the measurement is specified, the measurement equipment shall target to evaluate at the central reference datum position.

The vehicle test condition affects the positioning and alignment in reference to the vehicle supporting road surface plane, or the vehicular coordinate system (3.1.1). Unless otherwise specified, the standard measuring condition is set to follow driving conditions which consider the vehicle carrying a passenger, luggage and fuel under nominal condition. Nominal conditions can be determined by individual regulations of the national body regarding the vehicle operation condition as described by three-dimensional reference grid (3.1.2). See also 7.2.




**Key**

| | | | |
|---|---|---|---|
| I | infinity gaze orientation cross point with grid screen | 9 | evaluation equipment (camera) |
| 1 | picture generating unit | 10 | parallel motion guide rail for the grid screen |
| 2 | windscreen | 11 | grid screen |
| 3 | driver's ORP | 12 | reserved |
| 4 | reserved | 13 | reserved |
| 5 | zero z-grid (road surface of ground) | 14 | reserved |
| 6 | ground | 15 | driver's forward view infinity orientation line |
| 7 | height of driver's ORP from ground | *D* | distance from ORP to grid screen |
| 8 | I point height on the grid screen | *A* | adjustment to bring screen to focus point |

**Figure 8 — Plan top view and side view of HUD measurement setup**



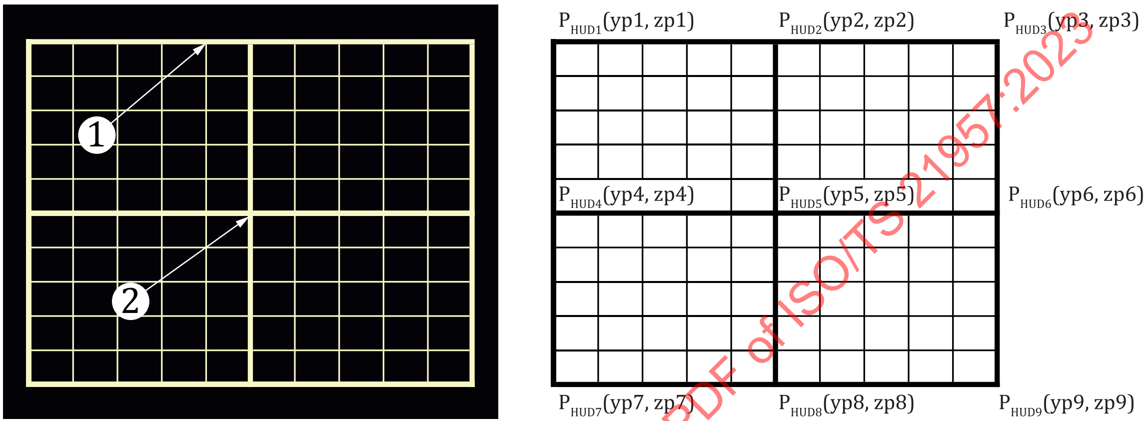
The size of the movable screen panel and the grid chart shall be large enough to enclose the HUD virtual image and be adjustable to cover the measurement point.

NOTE Laser pointer or an equivalent can be used for verification of the grid orientation and position alignment. The beam size of the light beam affects the measuring accuracy. A light beam leaving the source and reaching a flat mirror from the normal orientation returns its incoming beam right to the source. Therefore, when the light leaving the laser pointer is oriented from the driver's eye toward the forward infinity, the light beam hits the "I" infinity point on the standing panel, and if a planar mirror is placed parallel to the standing panel, the mirror returns the incident light beam back to the light source. A deviation to the returned light is observed in case the movable target screen/mirror setting is not precisely orthogonal to the light beam oriented to the vehicle infinity.

#### 6.1.1.4 Virtual image frame

For the verification of an image generated by the HUD, a dummy frame image shall be generated and displayed in the HUD. To verify the corner positioning and centre position, the dummy testing frame shall be composed at least by a frame with a line surrounding the area covered by the HUD function, and a centre cross marker, which serves as reference datum. Figure 9 is an example of the frame image to be used for the verification of measuring items given in 6.2.

The figure on the right side represents the illustrative image of a generated image observed from the ORP of an image ideally projected with no distortion, where $P_{HUD1}$, $P_{HUD3}$, $P_{HUD7}$ and $P_{HUD9}$ represent the left top, right top, left bottom and right bottom corner; $P_{HUD2}$ and $P_{HUD8}$ are the middle point top and bottom outer frame; and $P_{HUD4}$ and $P_{HUD6}$ are the middle point of left and right outer frame. The cartesian coordinate given in parenthesis at the right side of each point is defined based on a measurement with an image projected on best focus accommodation distance. The datum point of this cartesian coordinate shall be the point I when observed from the ORP (see Figure 12).




**Key**

1 framing lines covering the HUD display range

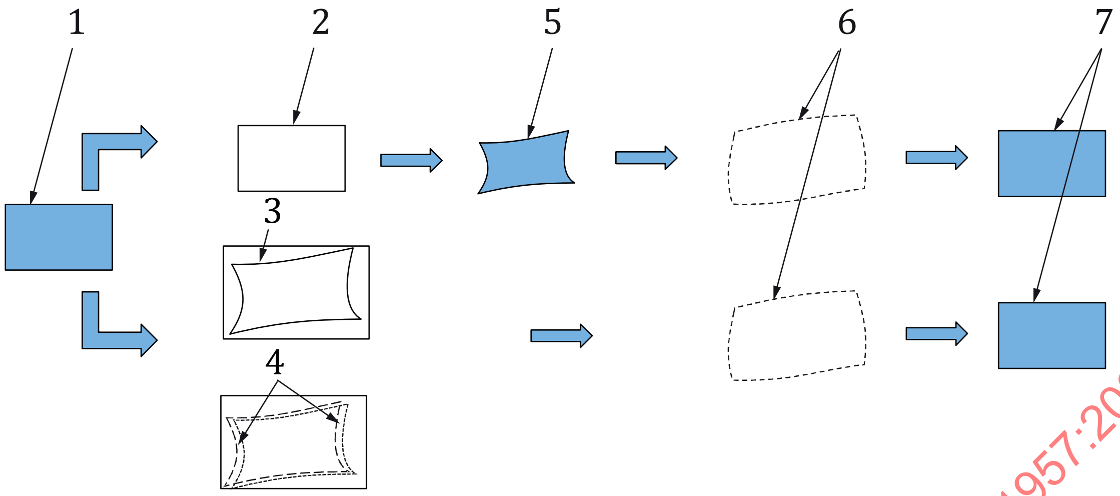
2 reference centre cross marker (centre datum reference position)

**Figure 9 — Frame and centre cross marker**

Figure 9 shows an example of a test image containing an outer frame and intermediate grid lines to be displayed as bright lines. The right-side figure shows the nine representative projected points $P_{HUD1}$ to $P_{HUD9}$ with their cartesian address origin (0,0) defined at the I point.

The DUT may apply different technologies to compensate for the optical deformation when the windscreen is used as combiner. This may occur because the windscreen composing an HUD system is generally not symmetric from the driver's eye point when the HUD system uses the windscreen as a combiner. The artificially generated image can be classified as "unprocessed original frame image" and "compensated virtual image". Figure 10 shows a conceptual image showing differences in these two different technologies depending on how the compensation is applied to correct the deformation. The technologies used to compensate the image distortion caused by the windscreen curvature can be achieved by using a compensation optical element, or a displacement compensation by computational/numerical readdressing of the generated image by the display device. Unless otherwise stated, the HUD intended image refers to the original image data to be displayed.

Some types of HUD may not have the capability to display a full area of information as illustrated by the outer framing line in Figure 9, key 1. The display area may be limited by a restricted effective area of display capability. In such a case, the HUD effective display area (3.3.9) shall be visually reported relative to the framing mesh grid line. This will serve as a guide for the content creator to avoid any information to be displayed out of the HUD effective display area (3.3.9).




**Key**

1 intended content of display digitized at image generator ECU

2 generated image on the display device (e.g. LCD) without geometric correction

3 generated image on the display device (e.g. LCD) with geometric correction

4 generated image on the display device (e.g. LCD) with 3D stereoscopy compensation

5 illustrative optical element used for image deformation corrective purpose

6 illustrative stage of image deformation caused by the windscreen

7 virtual image observed from the driver's ORP

NOTE 1 The display capability does not necessarily require to be a complete rectangle range and therefore, the example given in this figure is for an ideal case.

NOTE 2 A "compensated virtual image" is applicable when evaluating the display performance of the whole HUD system, while a non-compensated virtual image might serve for analyses' purpose of partial evaluation of intermediate component. (For example, obtain compensation factor to create the numerically compensation map parameter.)

**Figure 10 — Illustrative explanation of different distortion compensation**

#### 6.1.1.5 Physical grid screen for evaluation

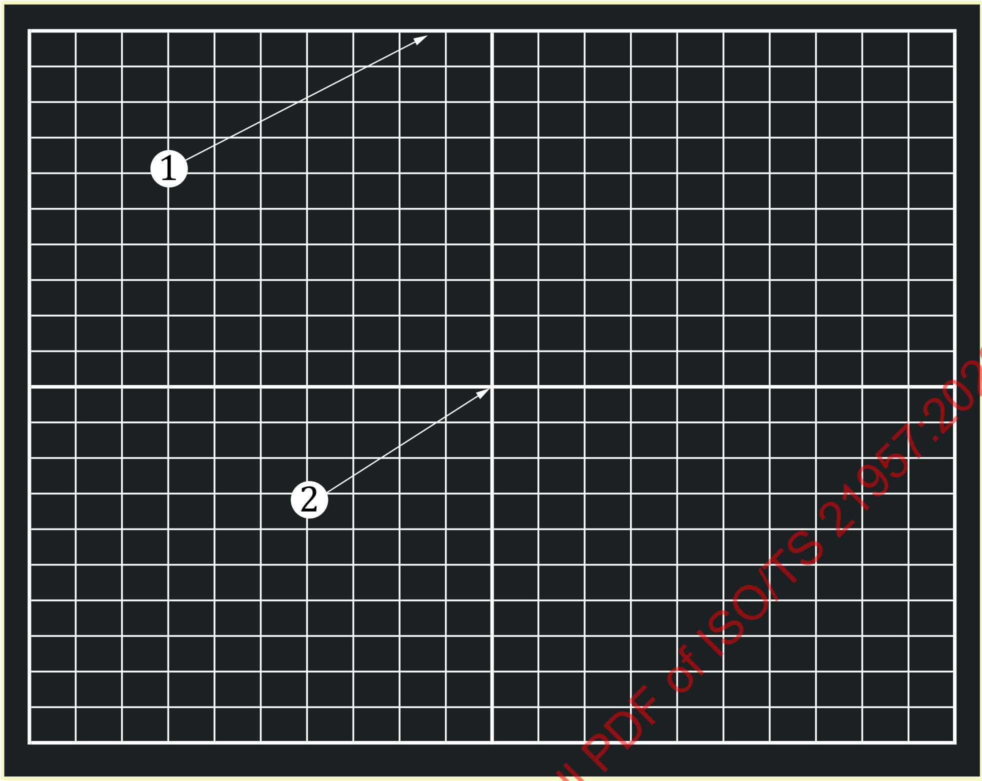
A physical grid/lattice chart is used to find the location of a virtual image in the real-world coordinate space. This grid chart is to be placed and set on the surface of the movable vertically standing panel. The grid shall enable the verification of the position of the virtual image as projected in the real-world space coordinate.

The whole size of the grid chart shall cover at least the entire range where the virtual image is observable from the observer's eyebox outermost point. The scale of the grid helps to identify the offset deviation of the virtual image projected into the real-world coordinate space, with its grid scale providing solid and reliable addresses.

If the stands sporting a mechanical frame of the grid screen provide an appropriate mechanism to precisely adjust the vertical and lateral positioning, the reference origin point may be aligned and positioned to the cross point to the driver's ORP forward infinity gaze orientation cross point. If such adjustment is possible, the cross-reference centre marker on the grid chart directly provides the positioning address of the virtual image address. However, the adjustment mechanism may not be necessarily available if the grid screen s rigidly fixed in the supporting stand frame. In such case, find the intersecting cross point to the driver's ORP forward infinity gaze orientation and it is indicated as point "I" in Figure 12 or 16.






**Key**

1 outmost frame of grid/lattice used to evaluate the virtual image relative positioning

2 cross reference centre marker

NOTE 1 The horizon line does not necessarily come to the infinity horizon line and the centre marker indicated by the key 2 point does not necessarily appear on the driver's ORP infinity line, i.e. it is equivalent to the observer's eye height from the road ground-surface.

NOTE 2 A white grid line over a black background provides better observation of the target image under test. Nevertheless, an alternatively black print on a white background can also be used for a practical and ink-saving economical reason.

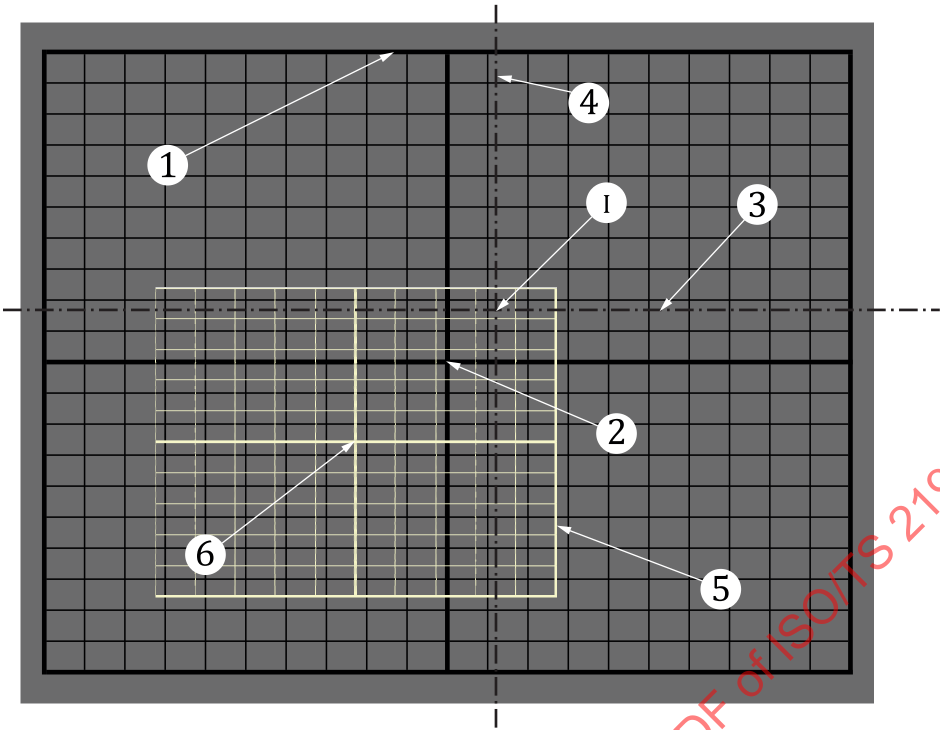
**Figure 11 — Reference grid/lattice chart for positioning measurement on real space**



The example of a grid/lattice chart given in Figure 11 shows the frame and scale printed in bright tone lines on a dark background material. As printing and creating such grid pattern may consume excessive ink, white paper printed with dark scales may also be adopted. However, the inverted bright background lowers the visual image contrast during the virtual image verification. Therefore, whenever evaluation is done on an inverse contrast bright grid/lattice chart, place a dark light-absorbing material to enable the appropriate observation of the virtual image by obscuring the reflection from the grid chart bright reflection momentarily.

NOTE Finding and adjusting the cross point to the driver's ORP forward infinity gaze orientation cross point on the grid chart can be difficult in some cases. Optionally, a laser pointer beam place at the driver's ORP with the orientation from the driver's ORP toward infinity gaze orientation can help to guide find the point. First, place a target point in front of the vehicle where the driver's ORP is expected to pass, at the same height (z-axis) and same lateral positioning (y-axis) of the driver's ORP, and adjust the laser beam orientation without the screen. A planar mirror placed parallel to the grid screen surface will return the beam back to the laser pointer beam source whenever the screen is correctly adjusted orthogonal to the vehicle forward motion.

Figure 12 is an example of virtual image projected over a bright grid/lattice background grid screen.




**Key**

1 outermost frame of the grid screen place at the background
2 cross reference centre marker of the grid screen
3 horizon line viewed from driver's eye level, passing point I
4 cross line of chart and the x-z plane passing driver reference eye point or ORP, passing point I
5 virtual image outermost frame
6 virtual image cross reference centre point, $P_{HUD5}$
I cross point between horizon line given in key 3 and line given in key 4

**Figure 12 — Example of the observed overlaid image on bright background grid chart**

### 6.1.1.6 Eye reference measuring points

The eye reference point used for the measurement is the driver's ORP, unless otherwise indicated. Note that E point may apply if the target DUT is designed to provide virtual images specifically around A pillar which may require head turns.

The virtual image generated and displayed by the DUT is viewed from the driver's eyes. And the driver's eyes position is distributed within the eyellipse, which is the three-dimensional space defining the space where the generated virtual image shall be visible and legible to the driver.

To facilitate the evaluation of the performance of the DUT, the eyebox is adopted as being a more practical way to define the measuring position, as representative location of the driver's eyes. The following positions are defined as basic positions from where the virtual image shall be evaluated.

Clause 5 specifies the eyebox as representative points from where the HUD virtual image shall be evaluated from. The measurement equipment to capture the virtual image shall be placed on defined locations of this eyebox.

a) centre position (single measuring points defined by the eyebox centre point)

b) side middle points of the rectangular line of the eyebox;



c) corner points of the eyebox.

The corner points go beyond the eyellipse range, and the evaluation result can serve as indicator of the extended performance rather than a required performance range of operation (see Clause 5).

Degradation limits in general may occur beyond the defined eyebox space. The visibility of the virtual image in an HUD may occur by a physical blinker limiting the visual range, or the visual degradation of the virtual image. A physical blinker may discretely mask the virtual image to null. When the degradation limit is required, the visual degradation limit range is verified as the angle providing at least 35 % of luminance observed at centre orientation.

For a DUT with a discrete obstruction limit, the angular limit shall be evaluated. The first lateral limit point of degradation is defined as the viewing angle where the outer eye observation angle provides a virtual image luminance decreasing to 35 % of the luminance observed at centre or a decrease in the observed resolution by half. The second lateral limit point of degradation is the angle where the inner eye exhibits the equivalent degradation indication that the driver is no longer able to access the image provided by the DUT.

NOTE 1 An HUD system can have the capability to adjust the formation of the generated image to best fit to the driver head/eye position, some by manual adjustment or some by automatic self-adjustment by self-detecting the driver's head/face/eye position. In such a case, the evaluation is performed after adjusting these settings.

NOTE 2 For specific needs there is an option to use the effective right or left eye position as the measurement reference eye point. An example is an evaluation considering natural monovision or a driver adopting monovision treatment.

NOTE 3 For the evaluation of a 3D HUD using autostereoscopic technology, the viewing performance strongly depends on the eye positioning because different images will be presented to the observer according to the eye position. Details of the adjustment capability specific to a 3D HUD where the self-adjustment capability has a high influence on the perceived image quality by the eye positioning are described in Annex B. More information particular to 3D HUD is found in Annex B.

#### 6.1.1.7 Target measuring orientation

Table 1 and Figure 13 describe the measuring orientations from ORP to points *j* = 1, 2, 3, 4, 5, 6, 7, 8, 9) for virtual image uniformity measurement. The numbers presented in the Table 1 column “Point *j*” stand for the positioning from the outermost bordering corner at the top left corner of the virtual image region defined on the DUT. The differentiation of definition for a measuring point located at $P_{HUD1}$ to $P_{HUD9}$ points on the outer frame (see Figure 9) and the intermediate space given in Table 1 is that most of the geometric aspects are measured based on the frame reference as given in Figure 9, while optical characteristics like luminance, contrast, and resolution adopt the orientation given in Table 1. Table 1 is provided in the percentage referenced to the left top corner considering an ideal projection of a full frame rectangle without any distortion. The table is provided in reference to the left top corner point but if asymmetry is observed, the centre point *j* = 5 could be adopted as reference to determine other points and the modified reference to point *J* = 5 as reference shall be reported accordingly.

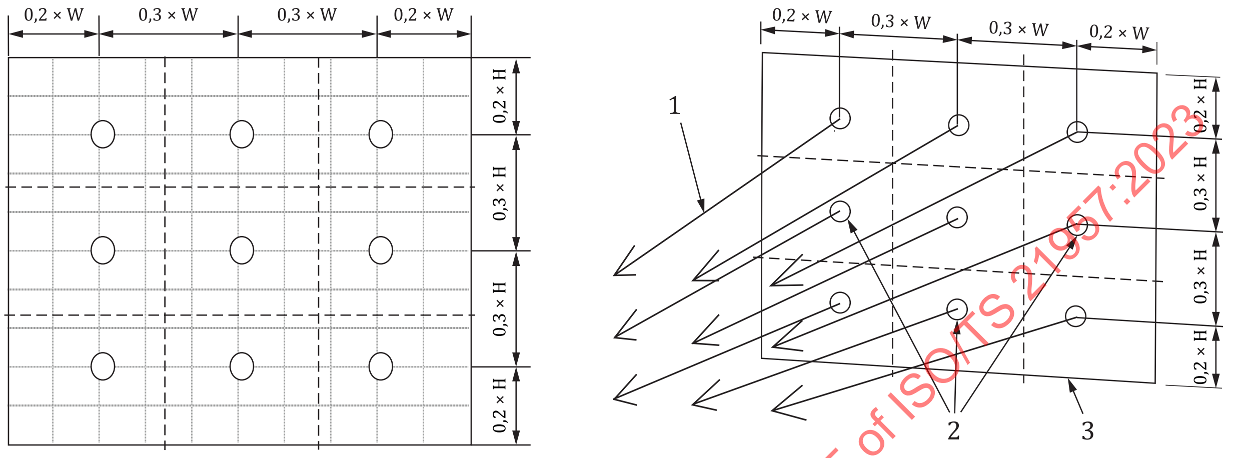


**Table 1 — Measurement points for the uniformity evaluation**

| Point *j* | Percentage of from left corner | Percentage from top left corner |
|---|---|---|
| 1 | 20 | 20 |
| 2 | 50 | 20 |
| 3 | 80 | 20 |
| 4 | 20 | 50 |
| 5 | 50 | 50 |
| 6 | 80 | 50 |
| 7 | 20 | 80 |
| 8 | 50 | 80 |

**Table 1** *(continued)*

| Point *j* | Percentage of from left corner | Percentage from top left corner |
|---|---|---|
| 9 | 80 | 80 |




a) Evaluation points (orientations)

b) Measurement orientation

**Key**

1 viewing orientation from ORP within the defined point in the eyebox space

2 measuring spot opening angle (<0,2°)

3 HUD virtual image frame outermost line (see Figure 12)

**Figure 13 — Measurement viewed from ORP**

## 6.2 Characterization of the HUD spatial and orientational aspects

### 6.2.1 Optical accommodation distance

This test procedure evaluates the accommodation distance $D_{acc}$ (i.e. the driver's eye point to focus point on the virtual image) in which the virtual image is optically created in the free space within the observer's field of view. The virtual image is observable from the intended design driver's eye point. It requires an optical evaluation equipment to measure the accommodation distance. A virtual image positioned at the accommodation distance forms the "virtual image plane".

NOTE 1 The evaluation does not consider the deviation of accommodation distance due to eye disorders, like myope (near-sightedness).

A camera system with an objective with shallow depth of field can be used to estimate the accommodation distance of the image generated by the HUD in the object space. The depth of field of a camera is affected by the aperture, which is described by the F number. The longer its focal length and larger the aperture (which corresponds to a smaller F number), the shallower the observed depth of field becomes.

When using a conventional consumer camera to find the accommodation distance, a reference edge chart in the object space shall be adopted as reference. With the camera objective adjustment capturing the virtual image in the best focus centre position, the physical reference grid chart is moved back and forth along the axis of the camera, or the driver's eye orientation (eye's gaze orientation towards frontal infinity as given in Figure 8). The centre of the best focus point is adopted as the estimated virtual image accommodation distance of the virtual image generated by the HUD system.



If any astigmatism remains observable in the system design, the best focusing accommodation distance may depend on a different orientation of the image presented in the virtual image generated by the HUD system. In this case, the priority focusing orientation is the observable detail along the horizontal line, to perceive edges of lines in vertical orientation, (like dense forest of bamboo). The measurement equipment shall detect the vertical line edges as the primary accommodation distance.

The following are the measuring steps to evaluate the optical accommodation distance.

a) Generate an artificial electronically framing image of the area to be displayed by the DUT. The image shall contain bright frames on dark background so that the frame edges are visually observed through the DUT as described in 6.1.1.1.

b) Observe the displayed frame image on HUD using the equipment (camera) for evaluation at the defined eye position.

c) Adjust the focusing of the equipment for evaluation and search for the equipment focusing distance to bring the chart lines to best the objective focusing distance. Record the numerical distance value if the adjustment is performed by the equipment for evaluation to find the best focusing distance automatically and if the detected distance can be numerically provided. Otherwise, if the focusing distance is adjusted by manual adjustment of the focal distance, move back and forth the focusing point and maintain the best focus position locked to the be the best focusing distance. See conceptual image in Figure 14.

   In case the background grid/lattice chart disturbs the focusing procedure, the background area can be temporally replaced by a black matte material to reduce the disturbing reflection from the ambient light.

d) Once the focusing of the equipment is achieved on the virtual image, fix it to the best focusing of the virtual image, then move the background grid/lattice chart and bring it to the best focusing point along the x axis.

e) To find the peak and best focusing distance, move back and forth the grid/lattice chart. The position of the grid/lattice chart which gives the same best focusing adjustment to the focusing position obtained for step c) for the frame image generated by step a), is taken as the accommodation distance of the virtual image generated by the DUT. Figure 15 shows a conceptual image where both the image of the frame generated by the HUD as well as the foreground grid/lattice chart is in focus.

NOTE 2 The depth of field of a camera system is determined by the objective lens used in the evaluation.

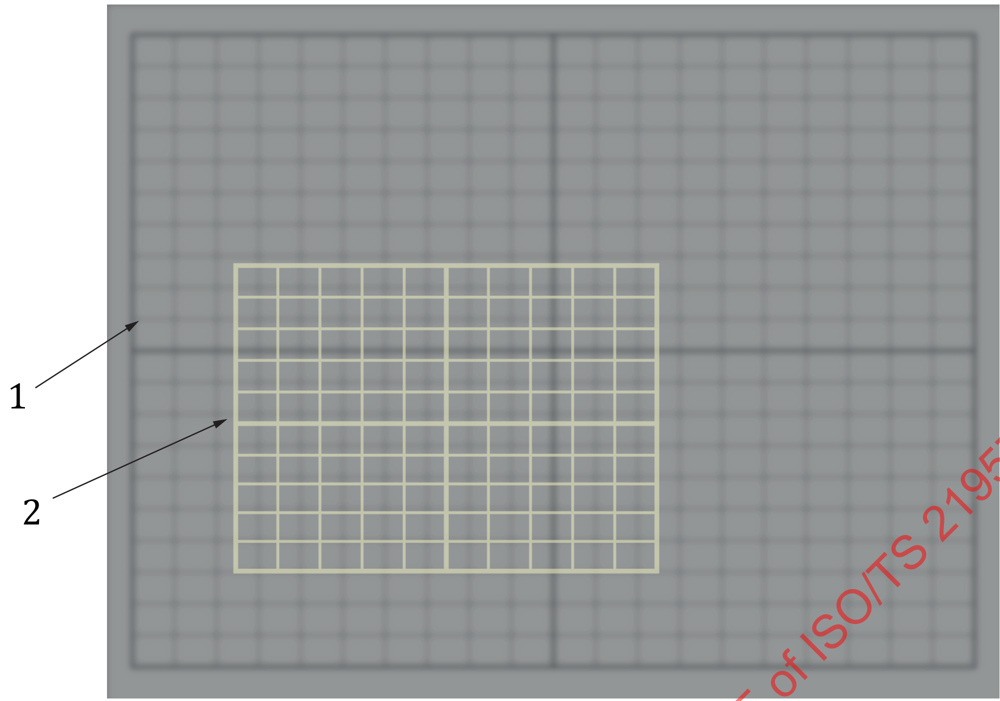
For an evaluation of a combiner HUD having the accommodation distance too close and which causes the measurement reference grid chart to physically interfere with the windscreen, the measurement can be performed without the presence of windscreen. In such a case, the modified testing setup configuration shall be clearly reported together with the results to avoid any misinterpretation of the results.

If the optical system of the HUD exhibits any astigmatism, the focusing adjustment given in step c) in this subclause can exhibit different focusing distances on its horizontal and vertical orientation (sagittal and meridional orientation). In the presence of exaggerated occurrences of astigmatism, the difference of accommodation distance shall be reported separately. The primary focusing orientation is to obtain the best focusing distance for the display of vertical lines.

NOTE 3 This measurement is based on an assumption that does not consider the actual accommodation distance characterized by individual with corrective needs, but instead considers the optical distance in an ideal case on an individual with no needs of corrective optics.



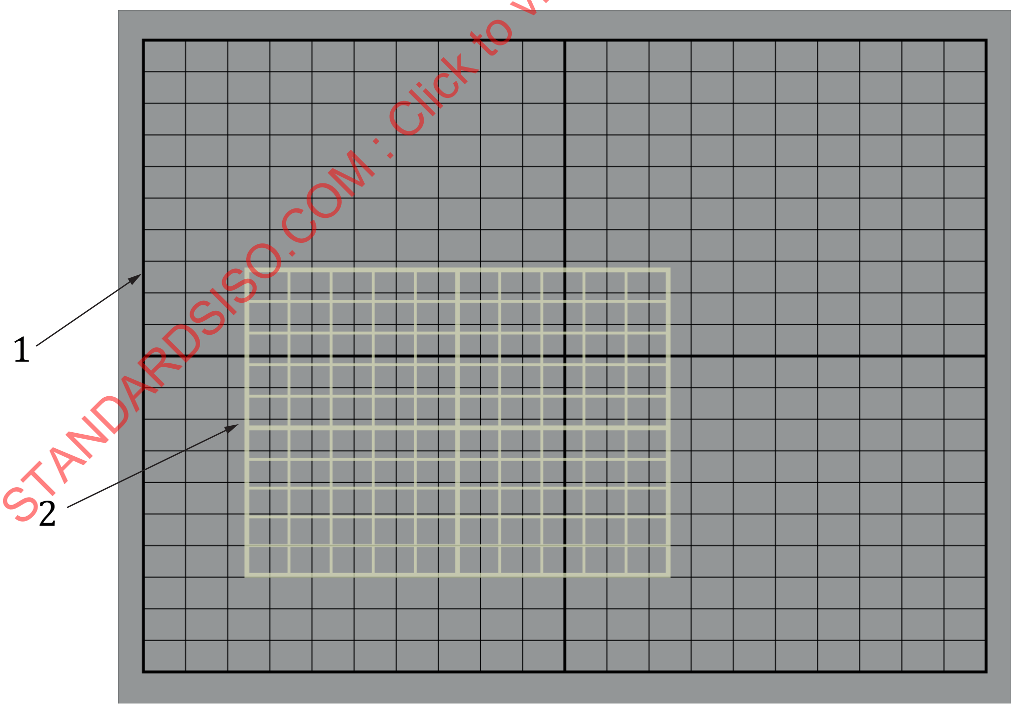



**Key**

1 camera-captured image with a grid screen chart located at a distance out of the best focus

2 evaluation camera adjusted to an HUD overlaid image in best focus

**Figure 14 — Conceptual image of an in-focus HUD frame and out-of-focus grid screen chart**




**Key**

1 camera-captured image with a grid screen chart adjusted to an HUD virtual image distance

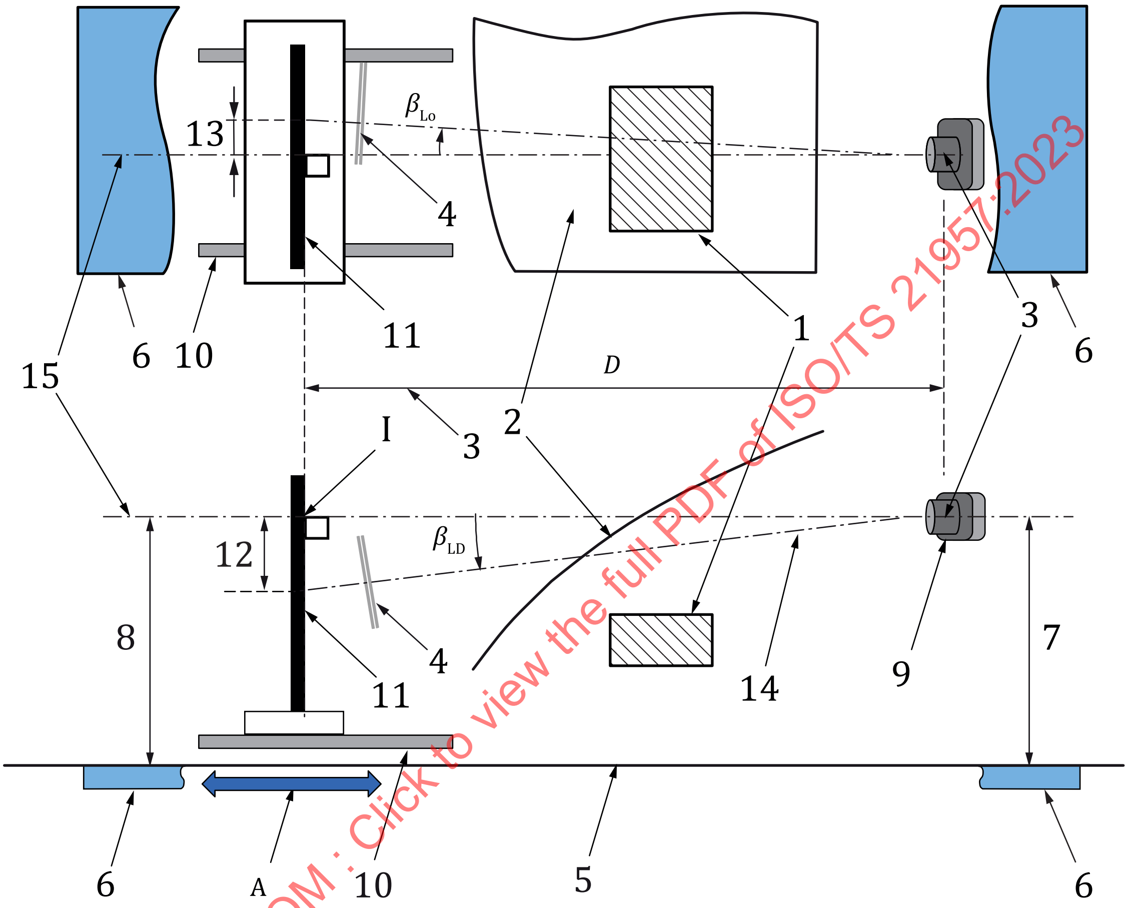
2 evaluation camera adjusted to an HUD overlaid image in best focus

**Figure 15 — Conceptual image of in-focus HUD frame and in-focus grid screen chart**

### 6.2.2 Look down angle (LDA), look over angle (LOA) and image orientation coordinates

The image generated by the DUT is likely to be displayed out of the main driver's frontal direct vision area. The centre of the displayed image frame $P_{HUD5}$ described in 6.1.1.4 is measured as an angular deviation of the driver's frontal viewing orientation toward infinity.

Figure 16 provides an illustrative sketch of which angular dimension shall be measured.





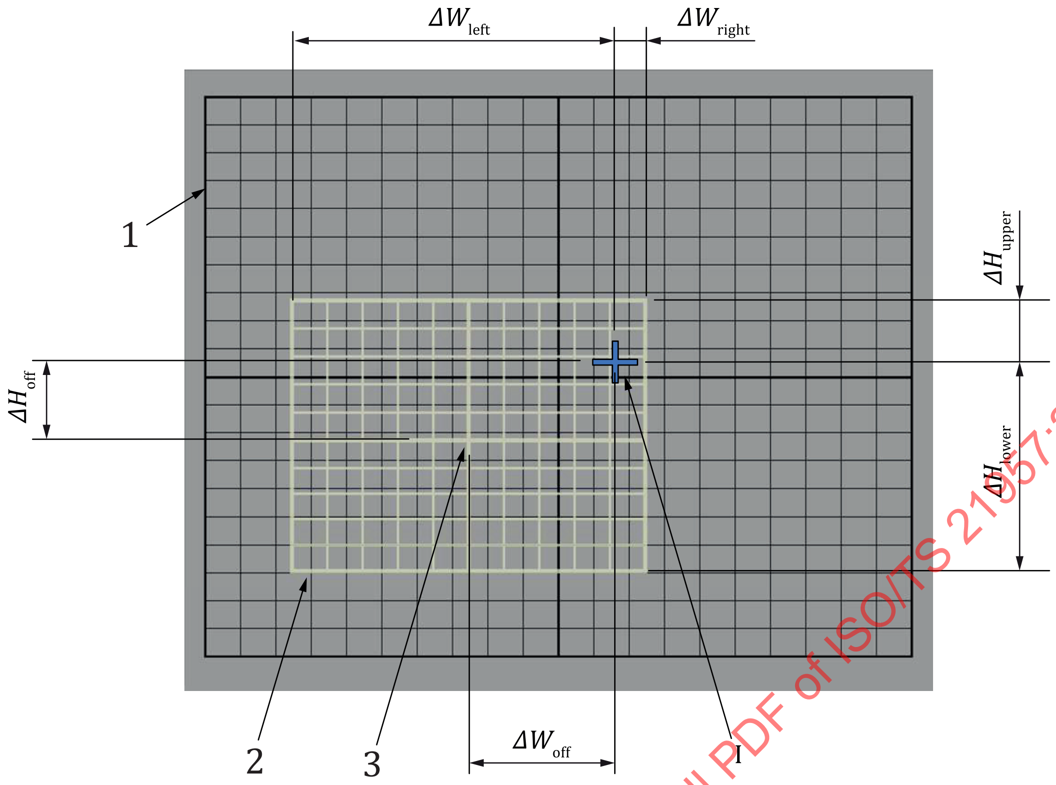

**Key**

| | | | |
|---|---|---|---|
| I | infinity orientation cross point with grid screen | 10 | parallel motion guide rail for the grid screen |
| 1 | picture generating unit | 11 | evaluation grid screen |
| 2 | windscreen | 12 | vertical off set of $P_{HUD5}$ from I ($\Delta H_{off}$) |
| 3 | driver's ORP | 13 | horizontal (Lateral) off set of $P_{HUD5}$ from I ($\Delta W_{off}$) |
| 4 | virtual image plane | 14 | driver's viewing orientation towards $P_{HUD5}$ |
| 5 | zero z-grid (road surface of ground) | 15 | driver's forward view infinity orientation line |
| 6 | ground | $\beta_{LD}$ | look down angle (LDA) |
| 7 | height of driver's ORP from ground | $\beta_{Lo}$ | look over angle (LOA) |
| 8 | I point height on the grid screen | *D* | distance from ORP to grid screen |
| 9 | evaluation equipment (camera) | *A* | adjustment to bring screen to focus point |

NOTE The height of keys 7 and 8 becomes equal to *Zc* when the vehicle is set at an operation condition as described in 7.2.

**Figure 16 — Look down and look over angle measurement configuration**

To measure these angular dimensions, the vertical and horizontal distance of the virtual image centre point $P_{HUD5}$ is measured in reference to the infinity cross point I, which is the cross point of the driver's frontal infinity orientation from the ORP on the evaluation grid screen plane (see Figure 17).




**Key**

I infinity orientation cross point with grid screen

1 background grid screen

2 virtual image generated by DUT

3 image centre cross reference point of virtual image $P_{HUD5}$

**Figure 17 — Display field of view and positioning**



### 6.2.2.1 Look down angle (LDA)

The look down angle is the amount of gaze down angle required to observe the centre of the virtual display image area, relative to the frontal infinity orientation. It is measured by observing the virtually generated image by the DUT. By definition, the downward angle polarity is taken as the positive polarity (see Figure 16).

The following are the measuring steps to evaluate the look down angle.

a) Set the DUT according to the setup instruction given in 6.2.1.

b) Place the movable screen panel at the HUD accommodation distance, (this is complementary) and record the accommodation distance $D$=$D_{acc}$.

c) Mark the point I on the grid/lattice chart, indicating the cross point of the gaze line of the driver's eye toward the frontal infinity. This will be the zero look down angle for the evaluation reference.

d) Display the frame and centre guide virtual image as defined in 6.1.1.4.

e) Measure the vertical offset distance $\Delta H_{off}$ of the virtual image centre $P_{HUD5}$ of the display image along the z-axis (see Figure 17).

f) First, the look down angle shall satisfy the following relation:

$$\tan(\beta_{LD}) = \frac{\Delta H_{off}}{D} \tag{1}$$

where

$\beta_{LD}$ is the look down angle;

$\Delta H_{off}$ is the offset deviation distance from infinity cross point I;

$D$ is the horizontal longitudinal distance from the driver's ORP to the projected image plane.

Thus, the look down angle is calculated using Formula (2):

$$\beta_{LD} = \tan^{-1}\left(\frac{\Delta H_{off}}{D}\right) \tag{2}$$

The lower image in Figure 16 shows the side view where key $\beta_{LD}$ indicates the LDA.

#### 6.2.2.2 Look over angle (LOA)

The look over angle is the amount of the lateral gaze angle required to observe the centre of the virtual display image area, relative to the vertical plane which contains the frontal infinity orientation from the ORP. It is measured by observing the virtually generated image by the DUT. The right-side orientation is taken as the positive polarity.

The measuring steps to evaluate the look over angle are a continuation of the steps after d) described in 6.2.2.1.

a) Measure the horizontal (lateral) offset distance $\Delta W_{off}$ of the virtual image centre $P_{HUD5}$ of the display image along the y-axis (see Figure 17).

b) First, the look over angle shall satisfy the following relation:

$$\tan(\beta_{Lo}) = \frac{\Delta W_{off}}{D} \tag{3}$$

where

$\beta_{Lo}$ is the look over angle;

$\Delta W_{off}$ is the horizontal offset deviation distance from infinity cross point I;

$D$ is the horizontal longitudinal distance from the driver's ORP to the projected image plane.

Thus, the look over angle is calculated using Formula (4):

$$\beta_{Lo} = \tan^{-1}\left(\frac{\Delta W_{off}}{D}\right) \tag{4}$$

The upper image in Figure 16 shows the plan view where key $\beta_{Lo}$ indicates the LOA.

#### 6.2.2.3 Image orientation coordinate/virtual image coordinate

The virtual HUD image centre coordinate is measured on the y-z plane respective to the driver's infinity viewing orientation in the cartesian coordinates. The coordinate address is measured on the screen positioned at a distance where the HUD forms the virtual image at the ideal virtual image accommodation distance (see 6.2.1).

The image orientation coordinates are complementary values to the LDA and LOA defined in 6.2.2.1 and 6.2.2.2. Nevertheless, the cartesian coordinate may provide a direct understanding of the image available by HUD virtual image.

In other words, the infinity point I in Figure 18 is the (0,0) address on the cartesian coordinate. Figure 18 shows an example of image with the centre point $P_{HUD5}$ located $|\Delta W_{off}|$ left and $|\Delta H_{off}|$ below the I point (0, 0) resulting in the coordinate address (yp5, zp5) = ( $-|\Delta W_{off}|$, $-|\Delta H_{off}|$).

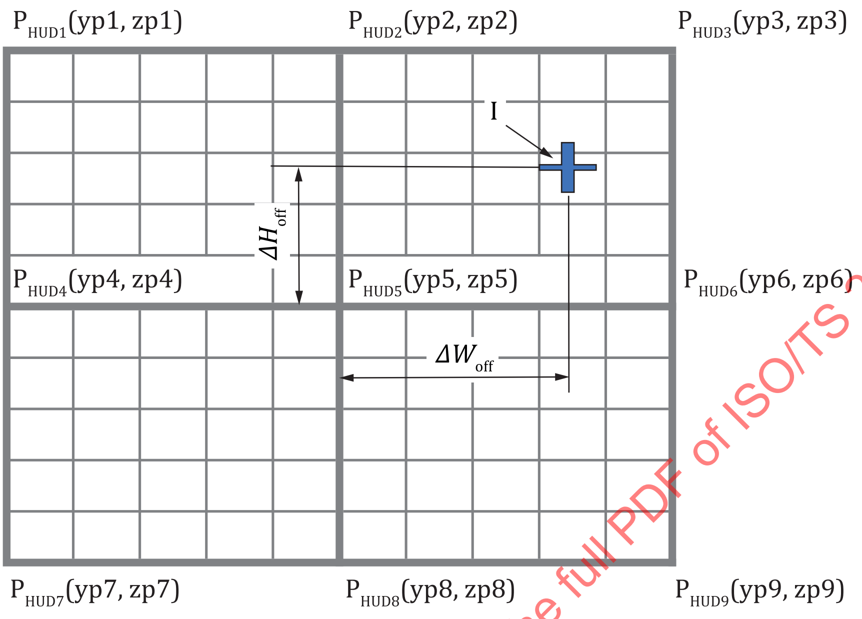



**Figure 18 — Image outer frame coordinate and datum**



### 6.2.3 Display field of view (DFoV)

The display field of view is the virtual image given in the angular range in which the maximum intended image of the HUD is derived from the same setup for evaluating the LDA and LOA in 6.2.2.2 and 6.2.2.3.

For this evaluation, the frame of the DUT displayed image is used to derive the display field of view. To avoid the complexity of the measurement and calculation, the projected frame image of the DUT is projected on the planar surface at the ideal virtual image accommodation distance (see 6.2.2) with minimum distortion.

The following are the steps to obtain the display field of view:

a) With the setup of the DUT according to the procedure given in 6.2.2, obtain the coordinate value of the image outer frame line centre $P_{HUD4}$ and $P_{HUD6}$ for horizontal measurement and $P_{HUD2}$ and $P_{HUD8}$ for the vertical measurement.

b) Perform an equivalent procedure to calculate the LDA and LOA to obtain the angular viewing orientation of the points.

c) For the horizontal field of view, subtract the left centre point angular deviation from the right centre point angular deviation, taking into consideration that if image of the DUT strides over the viewing infinity orientation, the left centre point might be a negative value.

d) For the vertical field of view, subtract the lower centre point angular deviation from the upper centre point, with the same process described in step c).

$$\alpha_{FoV\_hor} = \tan^{-1}\left(\frac{\Delta W_{left}}{D}\right) + \tan^{-1}\left(\frac{\Delta W_{right}}{D}\right) \quad (5)$$

where

| | |
|---|---|
| $\alpha_{FoV\_hor}$ | is the horizontal display field of view; |
| $\Delta W_{left}$ (=yp4) | is the left-side offset deviation of the outermost line generated by the DUT from the I point; |
| $\Delta W_{right}$ (=yp6) | is the right-side offset deviation of the outermost line generated by the DUT from the I point; |
| $D$ | is the horizontal longitudinal distance from the driver's ORP to the projected image plane. |

$$\alpha_{FoV\_ver} = \tan^{-1}\left(\frac{\Delta H_{upper}}{D}\right) + \tan^{-1}\left(\frac{\Delta H_{lower}}{D}\right) \quad (6)$$

where

| | |
|---|---|
| $\alpha_{FoV\_ver}$ | is the vertical display field of view; |
| $\Delta W_{upper}$ (=zp2) | is the upper side offset deviation of the outermost line generated by the DUT from the I point; |
| $\Delta W_{lower}$ (=zp8) | is the lower side offset deviation of the outermost line generated by the DUT from the I point; |
| $D$ | is the horizontal longitudinal distance from the driver's ORP to the projected image plane. |

## 6.3 Luminance/brightness and contrast

The luminance/brightness, non-uniformity and contrast characteristics of the virtual image generated by the DUT are evaluated. For the evaluation of the luminance characteristic, the orientation of the evaluation camera is adjusted to the intended gaze orientation along line indicated by Figure 19, key 14.

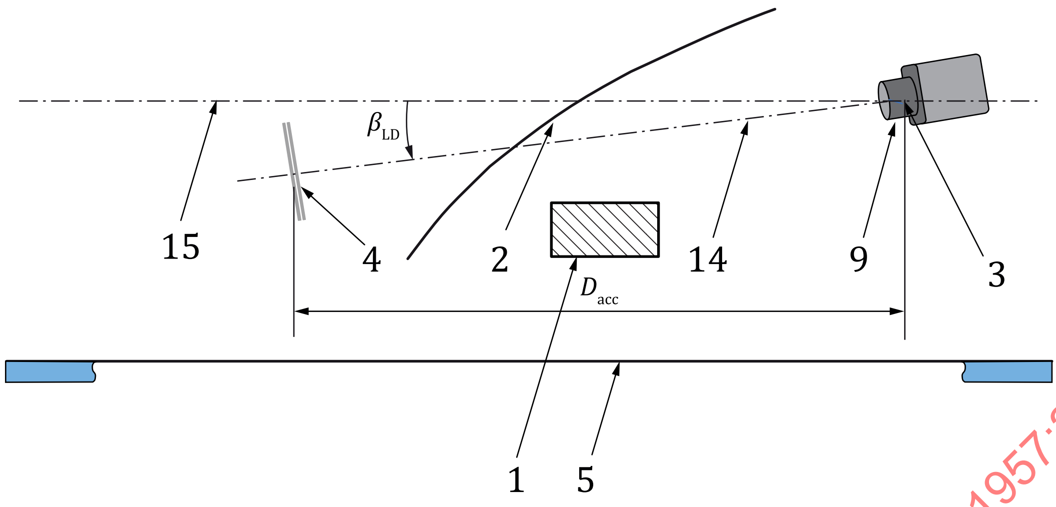
### 6.3.1 Luminance and luminance non-uniformity measurement

The luminance of the virtual image generated by the DUT is evaluated.

The viewing characteristics of an image generated by HUD are strongly influenced by the viewing orientation and viewing position. Therefore, the critical characteristics are measured considering both the viewer position defined by the eyebox and an image range over its field of view. Additionally, the evaluation equipment shall be oriented toward the intended orientation as represented in the Figure 19.






**Key**

1 picture generating unit
2 windscreen
3 driver's ORP
4 virtual image plane at accommodation distance
5 zero z-grid (road surface of ground)
9 evaluation(camera) equipment
14 driver viewing orientation towards $P_{HUD5}$
15 driver's forward infinity gaze orientation line
$\beta_{LD}$ look down angle
$D_{ACC}$ eye focus accommodation distance

**Figure 19 — Conceptual image for the luminance/contrast evaluation**



The following are the steps to evaluate luminance.

a) Set up the HUD system according to the basic configuration for measurement as defined in 6.1.1.7.

b) Bring the setup to a darkroom environment condition as defined in 6.1.1.2.

c) Position the luminance meter at the specified eye point measuring position.

The centre of eyebox is the location to place the evaluation photometric equipment.

For systems with high dependency on viewing orientation, an additional measuring position can be defined to be evaluated and reported. Typically, measuring at the eyebox frame centre point may provide a good estimation of the system performance.

d) Set a dummy artificial white image generated by and displayed on the DUT. In a system where the DUT is not designed to generate a white image, generate the expected uniform flat field image.

e) Display the image at the brightest level within the effective area.

f) Target the photometric equipment toward each of the nine orientations as defined in 6.1.1.7, with the measuring spot circle capable of measuring with an accuracy of less than 0,2 .

g) The luminance non-uniformity ($L_{NU}$) is calculated using Formula (7).

$$L_{NU} = \frac{L_{max} - L_{min}}{L_{max}} \times 100\,\% \tag{7}$$

where

$L_{max}$ is the maximum luminance value observed among L1 to L9;

$L_{min}$ is the minimum luminance value observed among L1 to L9.

If the luminance/brightness of the display image is self-adjusted to the environmental external condition by detecting the ambient light, the measurement shall be performed at its capability at maximum environmental brightness condition.

The definition of "non-uniformity" shall not be confused with "Uniformity". A uniformity of 90 % corresponds to 10 % non-uniformity.

NOTE Consideration of adjustment/dimming capability in accordance with environmental conditions is given in 6.5, for example, direct sunlight condition, diffused daylight condition, night condition.

### 6.3.2 Chromaticity measurement

The colour is an important factor to convey information over the DUT. The chromaticity of the image generated by DUT is measured to verify that the intended colour is appropriately viewable from the ORP. The display image is evaluated according to colour space as specified in CIE 1931 xy chromaticity diagram.

The following are the steps to evaluate the chromaticity.

a) Set up the HUD system to the basic positions for measurement as defined in 6.1.1.7.

b) Create the darkroom environment condition as defined in 6.1.1.2.

c) Position the luminance meter at the specified eye point.

d) The measurement positions shall be the nine positions (orientation) on the virtual image as defined in 6.1.1.7.

e) Set to the maximum brightness.

f) Generate and display images of each specific predefined colour of red, green, blue, and white according to the design specification of the DUT in the effective area.

g) Measure the chromaticity coordinate (x, y) of the image for each measuring orientation. The spot size of the circle to measure the chromaticity of the image should not exceed an angular size larger than 0,2°.

### 6.3.3 Contrast ratio

The visual information conveyed by an HUD is a superimposed additive luminance cast over the forward scene luminance. The DUT shall be capable of providing enough luminance contrast signal so that the visual information becomes perceivable and/or legible by the observer. The luminance contrast ratio 3.3.22 is measured to verify the performance of the DUT.

The following are the steps to evaluate the contrast ratio.

a) Set up the HUD system according to the basic configuration for measurement as defined in 6.1.1.7.

b) Set up the HUD system in a darkroom environment as described in 6.1.1.2.

c) Place the luminance meter at each of the specified eye points "$j$" $j$=1 to 9, with tools which have the capability to adjust the orientation toward the nine target points as defined in Table 1.

d) Set to the maximum brightness on the DUT to reach the HUD conditional maximum brightness level (3.3.11).

   NOTE 1 For contrast measurement under bright environmental conditions as detailed in 7.4.1, it is possible that the DUT needs to adjust the brightness to reach its maximum capability defined as HUD absolute maximum luminance level (3.3.10).

e) Measure the average brightness of the virtually displayed image in a viewing spot circle of 0,2 for each of the orientation.

f) Set to the brightness on the DUT to the lowest/minimum signal level equivalent to HUD ON darkest level (3.3.12) under the same conditions and measure the average brightness of the virtual dark image in the same manner as step e).

NOTE 2 The procedure described is a sequential measurement but alternatively, the bright and dark can be measured with a pattern as given in Figure 4, as an example of neutral colour luminance gradation test image with the darkest and brightest pattern.

g) The luminance contrast ratio can be calculated following Formula (8):

$$C_j = \frac{L_{white\_j}}{L_{black\_j}} \quad (8)$$

where

$C_j$ is the observed luminance contrast toward observation point described in 6.1.1.3;

$L_{white\_j}$ is the luminance value observed at white patch area;

$L_{black\_j}$ is the luminance value observed at dark patch area.

NOTE 3 The dark level is determined by the sum of leak luminance especially in a system using LCD with backlight illumination and surrounding alien light source that can disturb the image formed by the DUT system. In a system using technology like OLED with absolute zero illumination at dark level operation, alien light source reflecting on the emitter surface or other can be the factor determining the dark level.

NOTE Incident light onto the HUD optical component inducing haze can generate some bias dark level decreasing the contrast. Due to the difficulties of considering every possibility and integrating them into a standard evaluation procedure, it is advised to report separately in cases where any significant effect can be predicted to occur from a design point of view.

## 6.4 Spatial characteristics

### 6.4.1 Resolution

The resolution is the metric to describe the capability to convey spatial image detail to the viewer. It is measured using a test pattern and given in a unit of numbers of line pairs distinguishable per viewing angle. The test is used to verify whether the system is capable of displaying an intended resolution.

The limit resolution is determined as the maximum capability of the system to convey higher spatial (angular) frequency of the system and defined as the frequency where the brightness modulation transfer capability drops to 10 % compared to a flat reference bright level and dark level reproduced to the driver's view by the DUT.

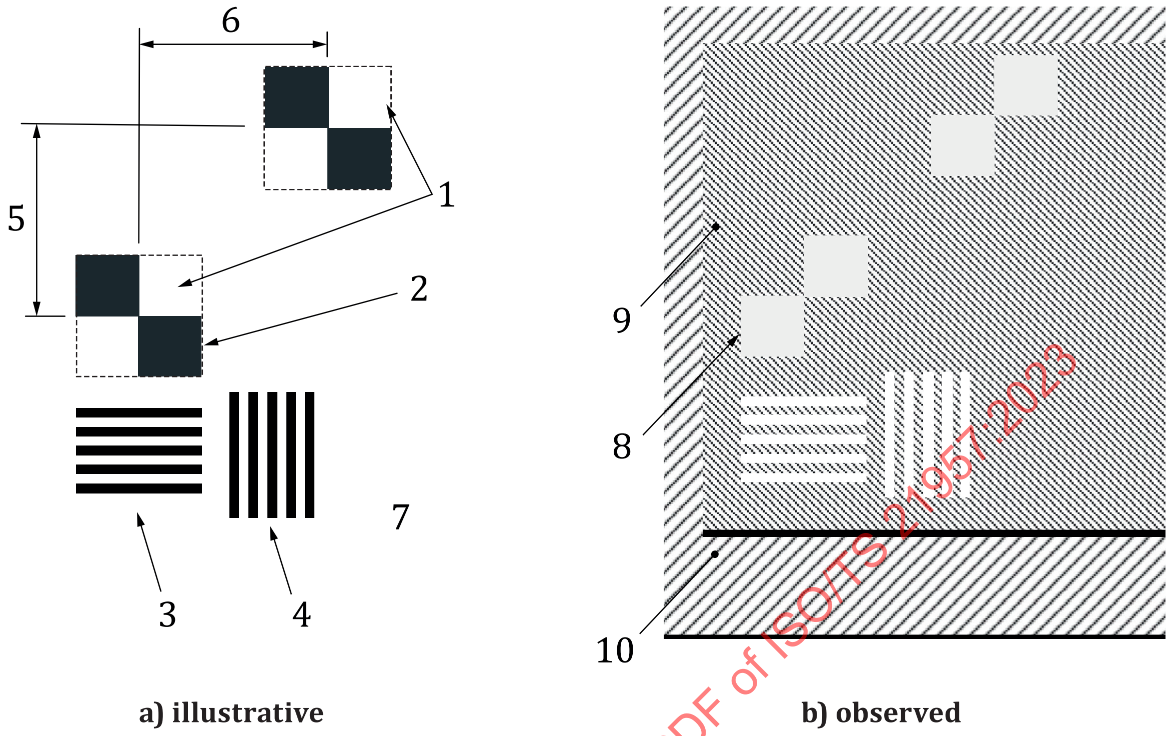
The resolution may exhibit orientational dependency. To verify the horizontal and vertical resolution, the test is performed for each orthogonal orientation.

An illustrative test pattern with at least five black and white line pairs as shown in Figure 20 a) shall be generated, fed to the DUT, and made available to the driver's field of vision. Then, the displayed image is captured using an evaluation camera positioned at the ORP and optionally to the respective measuring point if it is specified. The test pattern shall also contain an additional area of black and white large enough to be taken as reference. A minimum five lines width area is adopted to avoid any influence from the peripheral area.

The evaluation shall be performed in the darkroom environment as specified in 6.1.1.2.






**Key**

1 cross pattern bright patch
2 illustrative unlit "dark" patch
3 line set for vertical resolution verification
4 line set for horizontal resolution verification
5 reference verticals inter marker width
6 reference horizontals inter marker width
7 not lit periphery
8 generated image from bright patch
9 dark level derived from "dark area"
10 foreground outside the HUD effective frame

**Figure 20 — HUD Resolution evaluation pattern**

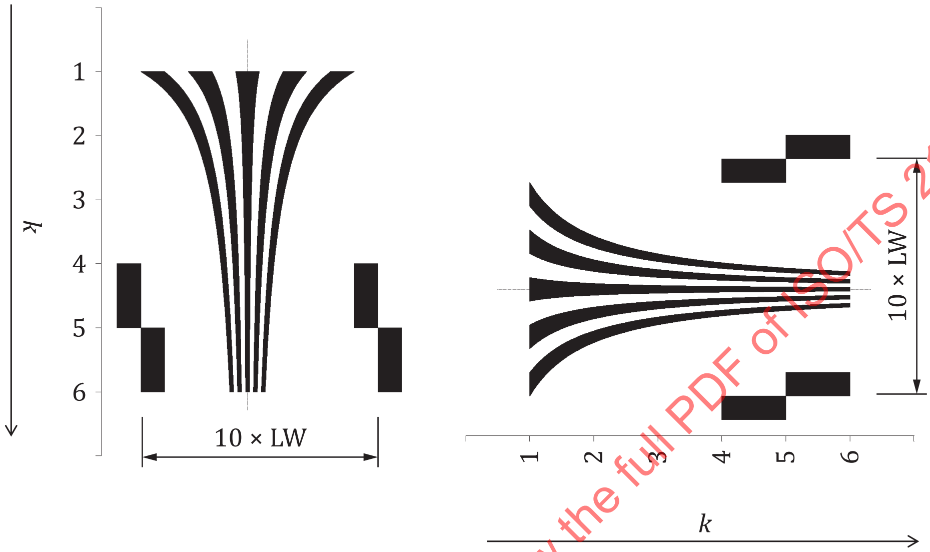
The test pattern as described in Figure 20 is used to evaluate the resolution. It consists of a line set of horizontal lines to evaluate the vertical resolution and a line set of vertical lines to evaluate the horizontal resolution. Two cross check patterns are used as reference points to obtain the width to derive the actual number of lines per viewing angle.

Gradually reduce the size of the pattern image generated by the HUD engine in a time sequential manner, verify the modulation of the image captured by an evaluation camera positioned at the measuring eyebox centre. The limit resolution is obtained when the observed captured image line modulation amplitude of the test pattern (see Figure 20, key 3 and 4) drops to 10 % compared to the full modulation obtained from the reference bright patch and "dark" patch. See Figure 20, key 1 and 2.

Alternatively, a single hyperbolic test pattern can be used to verify the limit resolution. Instead of gradually reducing the width of the test pattern in a time-sequential manner until the limit resolution condition is achieved, the test pattern of a variable spatial frequency pattern is provided within a single shot image. See Figure 21.

A hyperbolic chart pattern is generated and displayed over the DUT. This pattern is used to find the limit resolution of the system. The image of the chart is fed to be displayed and captured by an evaluation camera positioned at the ORP. It is analysed to find the first point where the reproduced hyperbolic chart loses its correct periodicity, or where the modulation drops under 10 % of the reference black and white level, whichever occurs first.

Display the test pattern over the DUT and determine the point where the modulation does not drop under 10 % of the reference black and white level. The resolution shall be verified at least on the nine orientations as described in 6.1.1.7. The number given in the test pattern provides the reciprocal of the width of the pattern line at point 1. For example, "2" represents that the line width is a 1/2 of point "1" and the resolution is twice (= x 2). Note that the black and white pattern shown in this figure is just an illustrative representation while an actual test pattern follows the same instructions as mentioned above. Note that Figures 20 and 21 contain the surrounding area given in bright, but this representation is valid for the document printing (ink saving) purpose only. The actual HUD can only generate the bright pattern, while the dark level is the natural background dark. In other words, the image provided in the illustration is a negative pattern.




**Key**

*k* frequency scale (= multiplication factor) in reference to point *k*=1

LW the reference line width at *k*=1, LW=*lw* (*k*=1)

**Figure 21 — Hyperbolic chart to evaluate the resolution**

The resolution performance of a system is not only determined by the number of pixels count of image generating device. Optical elements may cause asymmetric effects like a notable occurrence of astigmatism which results in different accommodation distance for edges of different orientation (e.g. horizontal versus vertical). Note 1 provides a guide to evaluate the astigmatism effect.

NOTE 1 Astigmatism can be verified by evaluating the accommodation focusing distance of the horizontal and vertical line edges using the same test pattern. Astigmatism is the difference in the accommodation focusing distance of the horizontal and vertical edges. If the horizontal accommodation distance and vertical accommodation distance differs, it can cause viewing discomfort to the driver as the observed image can blur depending on the orientation of the image pattern/edge orientation. To evaluate the astigmatism of the DUT, the resolution measurement procedure can be adopted and compared to the resulting resolution degradation in the horizontal and vertical orientation. If both horizontal and vertical edge exhibit same accommodation distance, the DUT is free of astigmatism effect. The level of image degradation caused by astigmatism can be characterized as the amount of resolution drop in the orthogonal edge resolution (i.e. horizontal line edge resolution drop compared to vertical line resolution fixed at accommodation distance).

NOTE 2 The actual test pattern is projected as a negative test pattern of the image shown in Figure 21. The black area is just the foreground non-illuminated scene ahead. Therefore, it is the dark lines of the Figure 21 that will be represented as bright image when projected by the DUT. See Figure 20 b).



NOTE 3 A parallel line and space pattern contains at least five line and space pairs which have a constant width along the extended direction. On the other hand, in a hyperbolic test pattern, the line width $lw(k)$ of the line and space is made reciprocal to distance $k$, or $lw(k)=1/k$, along the extended direction $k$. This means that the spatial frequency created by the line and space increases linearly to $k$. It is drawn from a reference point at $k$=1 and it can be extended with an appropriate scale and distance that meets the purpose of use. By adding a reference scale marker 1, 2, 3, 4, 5, 6 indicating where width becomes 1/2, 1/3, 1/4, 1/5, 1/6 it helps localizing readout value. Additionally, a reference dimension indicator equalling to a width of 10 times wider to the unit width at $k$=1, given by 10 × LW in the Figure 21 helps to minimize reading errors when determining the reference single line width at $k$=1.

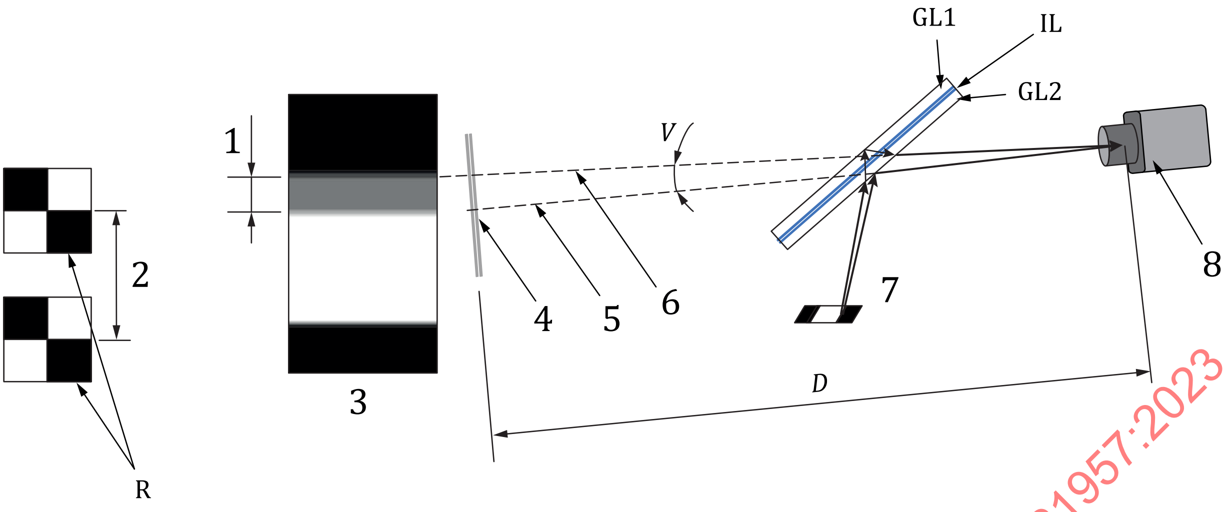
### 6.4.2 Ghost image

In an HUD system that uses the vehicle glazing windscreen material itself to reflect the image generated by the HUD engine, the combiner function is achieved by the specular reflection of the generated image at the frontal and rear surface of the windscreen. These may cause the light ray path to deviate from each other.

Due to the different path of the light ray when it is reflected by the frontal and rear surface of glazing material, a mismatch in the ray path may occur when redirecting the image ray toward the observer's eye point. This mismatch may cause a duplicated ghost image, which may deteriorate the image quality as well as reduce the legibility of the displayed information. Due to the large tilting angle of the windscreen orientation along the vehicle's Y axis in conventional passenger vehicles (Category M in UNECE definition) for aerodynamical reasons, this deviation on the image light path occurs most prominently in the vertical z-direction. Countermeasures to mitigate such ghost images may not be necessarily perfect to combine these different light paths. This clause provides a measurement method to evaluate the amount of the residual ghost image caused by this multiple reflection at the windscreen surface.

The difference in the reflection index of glass to open air causes an optical reflection at the surface. The reflection index is determined by multiple factors, but this document measures the resulting observable amount of visible ghost image in terms of contrast degradation and angular offset to the driver's view.

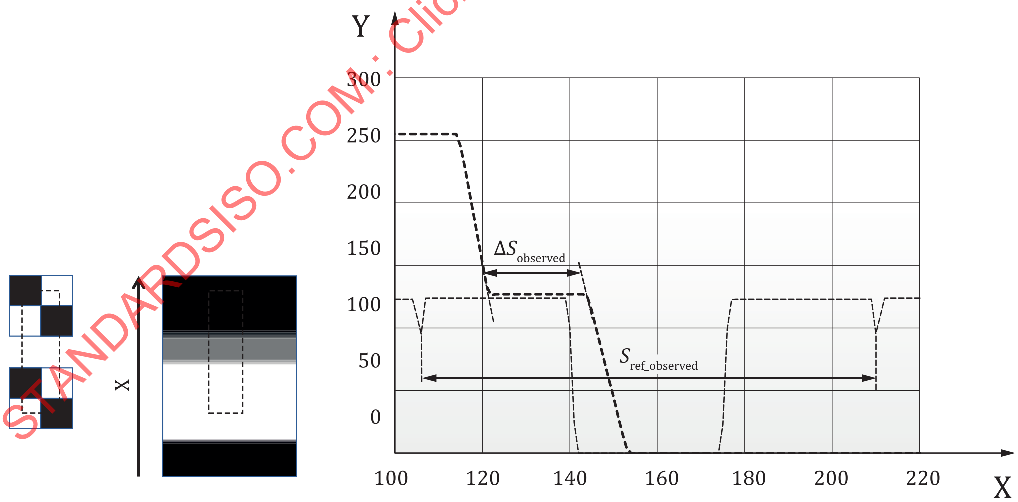
The test procedure described here is based in the above consideration and therefore, if an image generated by an HUD differs by design, the measurement shall be adapted to the combiner inclination angle.




**Key**

1 disparity of ghost image: $\Delta S_{observed}$
2 inter marker separation width $S_{ref}$
R physical reference marker to determine $S_{ref}$
3 example virtual image width ghost
4 virtual image plane
5 virtual line sight representing boundary caused by windscreen frontal reflection
6 virtual line sight representing boundary caused by windscreen rear reflection
*V* disparity angle of ghost image
7 incident image ray boundary to the windscreen
8 evaluation camera oriented towards measuring point
GL1 outer glass of laminated windscreen
IL interlayer lamination plastic material (e.g. PVB)
GL2 inner glass of laminated windscreen
*D* distance from eye observation point to chart plate

**Figure 22 — Conceptual cross-sectional view to measure ghost width**




**Key**

X scan along orthogonal orientation [a.u.]
Y detected luminance profile along X [a.u.]
$\Delta S_{observed}$ observed disparity of ghost image
$S_{ref\_observed}$ observed reference inter marker width

**Figure 23 — Plot of observed image edge from ORP along orthogonal orientation**

The image generated by the HUD engine is displayed as a luminance additive procedure over the real-world scene. In the process of this information projection, a bright image projected on the windscreen is reflected by its frontal surface as well as the rear surface, where the light is partially refracted penetrating into the windscreen glass and then reflected back from the frontal reflection with a possible deviation in the light path compared to the frontal reflection. This deviation of the path may create a secondary image boundary which is referred to ghost image of the HUD. The darker region is partially eroded by this ghost causing the formation of double edge of bright region, which decreases the edge acutance affecting the perceptual image quality of the displayed information. Occurrences of ghost images may degrade the perceptual image quality of the DUT.

The following are the steps to evaluate the ghost image due to the dual refection by the windscreen in which the angle of displacement of secondary image is measured.

a) Set up the HUD system to the basic positions for measurement as defined in 6.1.1.3.

b) Create the darkroom environment condition as defined in 6.1.1.2.

c) Generate and project an image of a sharp-edged white box containing a horizontal white (orthogonal to the windscreen inclination) bordering edge, with the white area positioned at the centre of the HUD image designed area (unless otherwise specified to measure specific point on display area other than centre).

d) Using an image-capturing device, obtain an image of the observed white box's edge boundary, but also containing the markers to be used as reference.

e) From the captured image, determine the boundary of the image created as the dual reflection which is formed as the brightest border and the secondary brightest border. As Figure 22 shows, the brightness of the brightest area is the sum of both frontal and rear reflection while the second brightest area is created from the frontal reflection alone. The reference dimension scale chart set shall be captured in the same image or under the same distance and the known separation distance will be used as reference.

f) Obtain the offset width $\Delta s$ of the uppermost white box bordering image to inner box bordering image along the orthogonal direction (see Figure 22, key 1). The known distance of the marker separation distance $S_{ref}$ is used as a reference to convert the observed $\Delta S_{observed}$ in the captured image. If the reference width is observed to be $S_{ref\_observed}$ on the captured image, the ghost image in real space is equivalent to $\Delta s = S_{ref} \times (\Delta s_{observed}/S_{ref\_observed})$. The image capture using the evaluation camera at the ORP can be used to a precise ratio of $\Delta s_{observed}/S_{ref\_observed}$. For an exemplar plot see Figure 23.

g) Calculate the disparity visual ghost angular size $V$ using Formula (9):

$$V = \tan^{-1}\left(\frac{\Delta s}{D}\right) \tag{9}$$

where

$V$ is the visual ghost angular size;

$\Delta s$ is the orthogonal offset of the white box bordering edge;

$D$ is the distance from the ORP to measuring plane.

NOTE 1 When the reflection of the outer surface does not permit to distinguish the intermediate white to grey bordering line, partially coating half, or part of the frontal surface (left or right half) with light absorbing liquid/gel material with diffraction index near equivalent with the glass material can help to reduce the reflection from its surface.

NOTE 2 Ghost images considered under this test procedure are based on the HUD type which uses the reflection from outer and inner surface of a windscreen as an intrinsic combiner. It does not consider other types of technology used to create the HUD image, e.g. holographic diffraction.

NOTE 3 In an HUD system which uses light selective technologies that significantly reduce the occurrence of observable ghost from rear surface reflection, is it possible that the measurement provided in this clause is of no value or even hard to perform because the rear side shallow reflection signal can become occluded under the measurement capability limitation.

NOTE 4 The profile of the image edge can optionally be obtained by plotting the image intensity of the captured image by the camera along the orthogonal orientation to the displayed virtual image.

NOTE 5 In a 3D HUD using stereoscopy, two separate images corresponding to the image to be observed by the left and right eye are generated by the HUD engine but if there is inappropriate tracking of the dynamic eye movement or mismatch to actual eye position it can cause these independent images to contaminate each other's view.

### 6.4.3 Distortion and rotation

In most HUD systems, a matrix arrayed display device is used to generate images to be displayed to the observer. The image is made observable from the observer's eye point as a virtual image, by enabling the light leaving the matrix display to reach the observer's eye point, guided by an optical component which is finally reflected by the windscreen or a separate combiner component. The asymmetrical physical structure of these reflectors may cause the reflected image from the matrix image to become distorted in an asymmetric manner. The distortion measurement is a procedure to evaluate and quantify the amount of visual displacement of the virtual image, relative to its reference point, namely the positional reference datum point and its expected geometry of the virtual image.

The size and coverage of an HUD display area are design dependent. Therefore, in case an entire full rectangular size is reproducible by the DUT, a rectangular target frame with a middle line shall be artificially generated by the DUT engine. Its resulting viewable image is captured by a camera from the representative observer's(driver) eye point from the ORP. The generated rectangular artificial frame image shall be the intended content of the display digitized at the image generator ECU and displayed on the panel as illustrated in Figure 4, key 2.

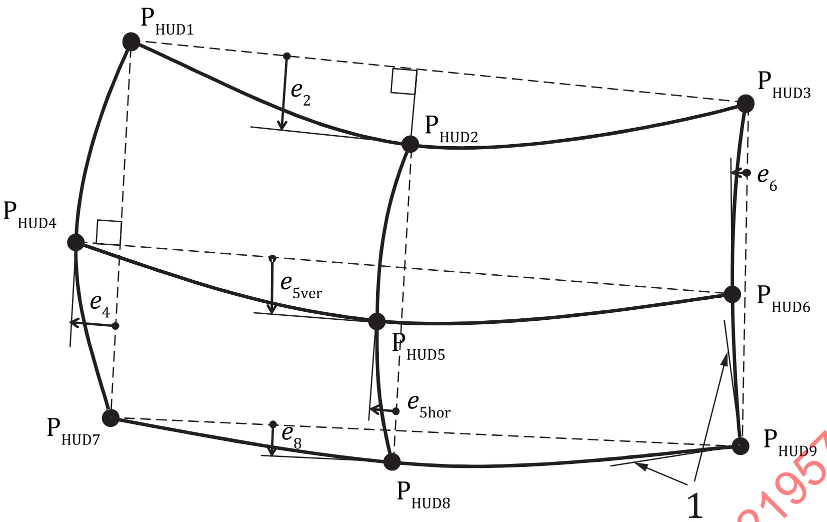
Some types of HUDs may generate an image on the display panel matrix compensating for the optical distortion caused by the intermediating elements like the mirror of a combiner aspheric surface, thus enabling the removal of the optical corrective element.

Because of the asymmetrical layout when a windscreen is used as a combiner to convey the image to the driver's ORP, a complex distortion could be induced in the projected image generated by the DUT. This clause provides some representative measurements to characterize the observed distortion of the image conveyed over the HUD and some of the following evaluation tests might be too exhaustive or too exaggerated.

Figure 24 shows an example of a measurement adopted to determine the amount of vertical bending of the outermost frame line at point $P_{HUD2}$ in respect to the ideal straight line connecting $P_{HUD1}$ and $P_{HUD3}$; similarly, the amount of horizontal bending of the outermost frame line at point $P_{HUD4}$ in respect to the ideal straight line connecting $P_{HUD1}$ and $P_{HUD7}$. An inward bended deviation like shown in $P_{HUD2}$ is represented in a negative value, while an outward bended deviation like shown in $P_{HUD4}$ is represented in a positive value by definition. As $P_{HUD5}$ is defined to be the datum, the deviation of $P_{HUD5}$ is measured in respect to a straight line connecting $P_{HUD2}$ and $P_{HUD8}$ for horizontal measurement and a line connecting $P_{HUD4}$ and $P_{HUD6}$ for vertical deviation measurement. The distortion causing a bending of the central line connecting $P_{HUD2}$ and $P_{HUD8}$ is defined as negative when it is shaped like “(” and positive when it is shaped as “)”. And the distortion causing the lines connecting $P_{HUD4}$ and $P_{HUD6}$ is defined to be negative when it shaped as “U” and positive in opposite case. As an example, the illustrated in Figure 24 represents horizontal centre point distortion to be $-|e_{5hor}|$ and the vertical centre point distortion to be $-|e_{5ver}|$ because it is “(” shaped and “U” shaped respectively. Figure 25 is an example of frame image displayed by and HUD and captured to evaluate the distortion and rotation.






**Key**

$P_{HUD5}$ datum point at the centre of display area

$e_2$ vertical deviation of $P_{HUD2}$

$e_4$ horizontal deviation of $P_{HUD4}$

$e_{5ver}$ vertical deviation of centre $P_{HUD5}$

$e_{5hor}$ horizontal deviation of centre $P_{HUD5}$

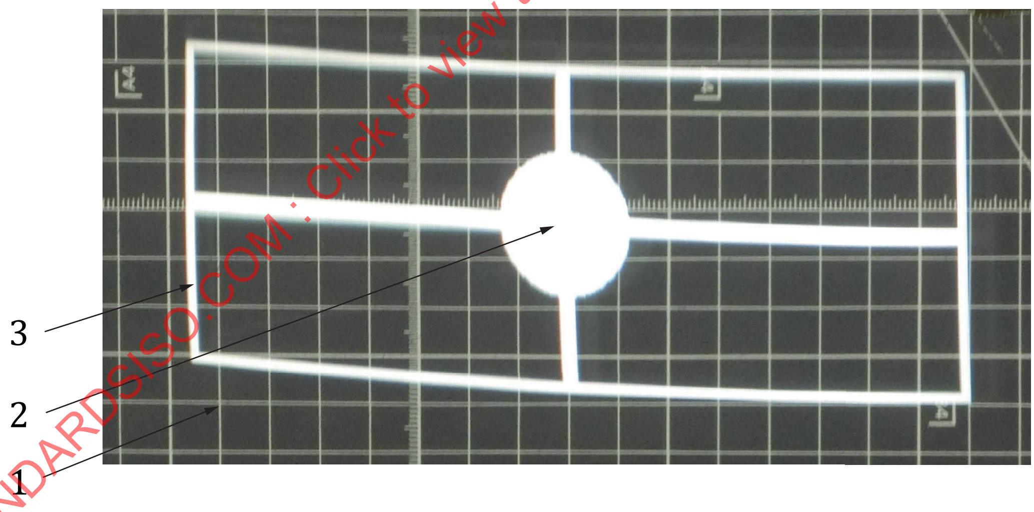
$e_6$ horizontal deviation of $P_{HUD6}$

$e_8$ vertical deviation of $P_{HUD8}$

1 example of corner angle at $P_{HUD9}$

**Figure 24 — Distortion measuring reference points**






**Key**

1 grid screen (aligned to ground surface)

2 datum point at the centre of display area

3 virtual image outermost frame

**Figure 25 — Distortion measuring points**

### 6.4.3.1 Characterizing trapezoid like or diamond shape

Each of the relative four corners angle is obtained for $P_{HUD1}$, $P_{HUD3}$, $P_{HUD7}$, $P_{HUD9}$ in the adjacent corner points. Figure 26 shows an example for the corner point $P_{HUD7,}$ evaluated in respect to the adjacent corners. The corner angle described by Figure 24, key 1 provides the detail of each corner distortion, while this item provides a bigger picture of the deformation of the image as a whole image. Describing the deformation of corner points by the following procedure to the four corners may provide a better picture of the type of distortion exhibited by the DUT.

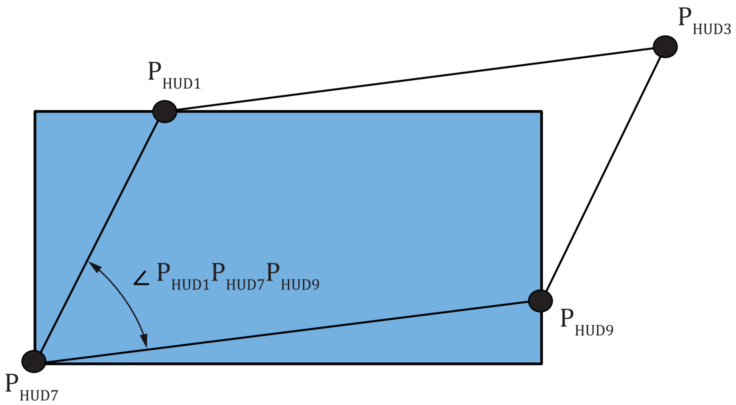



**Figure 26 — Distortion measuring points**

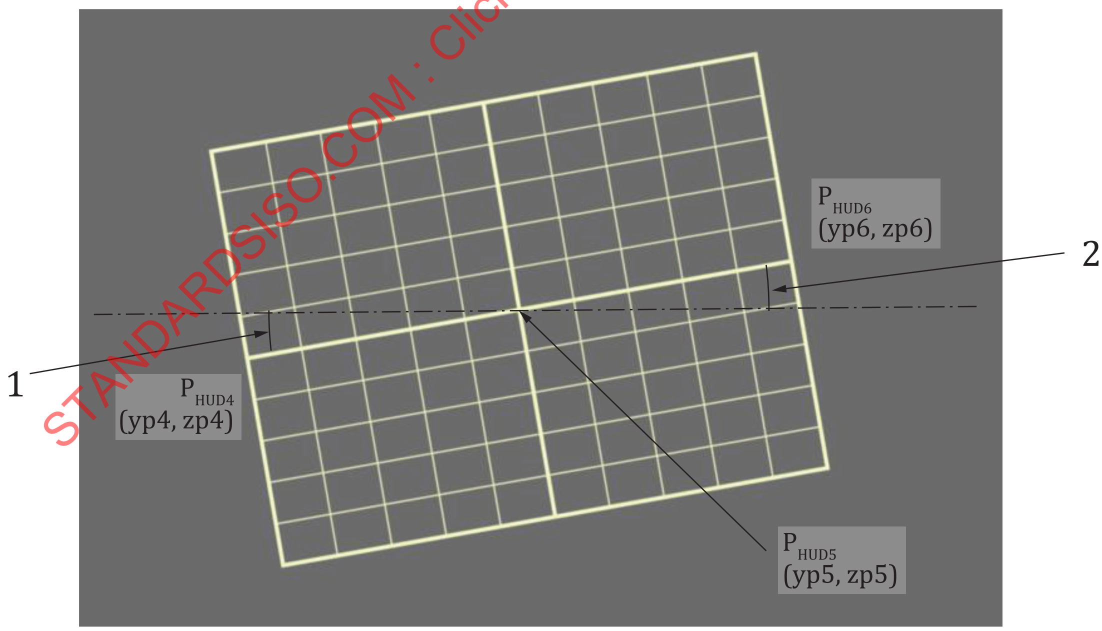
$$C_{\mathrm{dist}}\left(\mathrm{P}_{\mathrm{HUD7}}\right)=\angle \mathrm{P}_{\mathrm{HUD1}}\mathrm{P}_{\mathrm{HUD7}}\mathrm{P}_{\mathrm{HUD9}}-90^{\circ} \quad (10)$$

where

| | |
|---|---|
| $C_{\mathrm{dist}}(\mathrm{P}_{\mathrm{HUD7}})$ | is a representation of corner angular distortion at corner $\mathrm{P}_{\mathrm{HUD7}}$; |
| $\angle \mathrm{P}_{\mathrm{HUD1}}\mathrm{P}_{\mathrm{HUD7}}\mathrm{P}_{\mathrm{HUD9}}$ | is the angle between lines encompassing $\mathrm{P}_{\mathrm{HUD7}}$ and passing $\mathrm{P}_{\mathrm{HUD1}}$ and $\mathrm{P}_{\mathrm{HUD9}}$. |

NOTE The corner angular distortion at $\mathrm{P}_{\mathrm{HUD7}}$ is negative when corner $\mathrm{P}_{\mathrm{HUD7}}$ is viewed as an acute angle and positive if viewed as an obtuse angle.

### 6.4.3.2 Rotation




**Key**

1 rotation of $\mathrm{P}_{\mathrm{HUD4}}$

2 rotation of $\mathrm{P}_{\mathrm{HUD6}}$

**Figure 27 — Measurement angle for rotation**

The rotation of the displayed image $\varphi_{di}$ is calculated for the rotation observed on the image expected to be given as horizontal line to the observer. For an HUD image exhibiting large distortion, the left side and right side to centre $P_{HUD5}$ at (yp5, zp5) datum point may not be equal. See Figure 27 for the measurement angle for rotation. The representative rotation is calculated as the average given by Formula (11).

$$\varphi_{di} = \frac{1}{2} \times \left\{ \tan^{-1}\left( \frac{z_{p6} - z_{p5}}{y_{p6} - y_{p5}} \right) + \tan^{-1}\left( \frac{z_{p5} - z_{p4}}{y_{p5} - y_{p4}} \right) \right\} \tag{11}$$

where $\varphi_{di}$ is the rotation of the displayed image.

### 6.4.4 Deviation ratio of aspect ratio

Ideally, a generated image shall be viewed by the driver in the same horizontal and vertical aspect ratio. An image generated with an aspect ratio $W_{original}$: $H_{original}$ displayed over the DUT having the image width equal to $\Delta W_{left}+\Delta W_{right}$ and the image height equal to $\Delta H_{upper}+\Delta H_{lower}$ will generate an image having the ratio $R_{ar}$.

$$\left(\Delta W_{left} + \Delta W_{right}\right) : \left(\Delta H_{upper} + \Delta H_{lower}\right) = R_{ar} \times : \left(W_{original} : H_{original}\right) \tag{12}$$

where $R_{ar}$ is the deviation ratio of the aspect ratio when image is displayed by the DUT.

NOTE $R_{ar}$ is equal to 1 when no deviation occurs. If $R_{ar}$ is over a unit (i.e. $R_{ar} > 1$) the image gets widened horizontally and if $R_{ar}$ is under unit (i.e. $R_{ar} < z$) the image gets slimed horizontally. $R_{ar}$ can be interpreted to be the horizontal scale factor of the observed image generated by the HUD.

## 6.5 Others

### 6.5.1 General

There are additional aspects that may affect the performance of the information displayed by an HUD system. This clause provides useful information to be further considered, if it is applicable to the DUT.

### 6.5.2 Care and considerations

When performing an evaluation of an HUD system, its optical components like the HUD engine, the windscreen or the combiner shall be positioned and aligned according to the installation packaging design, with the vehicle operation under nominal load condition.

The vehicle load condition can affect the vehicle pitch and consequently the orientation of the driver gaze orientation towards the horizon infinity height. The measurement shall be performed following the nominal positioning and orientation under the vehicle operational load condition while driving. Please be aware that individual regulations from the national body regarding the vehicle operation can have their own pre-defined condition.

### 6.5.3 Capability of geometric adjustability to the driver head position

Some HUDs can have manual, semi-automatic or automatic adjustment capabilities in which the image displayed by the DUT is adjusted according to factors like driver's eye position. In case such adjustment function is provided by the DUT, such like eye position tracker (3.2.4), the operation manual shall provide appropriate instruction on the procedure for the adjustment. Inappropriate adjustment can cause visual discomfort not only to perceive the information provided by the DUT but it may also decrease the driver's attention to the road ahead.

The basic performance of the DUT shall be tested under the representative position and vehicle load and operation condition.



On manually adjustable device, the evaluation of the system shall be performed at the extreme left and right sides as well as top and bottom limit points of the eyebox and the range of adjustability shall be reported in mm (millimetre) unit.

NOTE 1 Some adjustment hysteresis can be adopted in the system to mitigate the motion sickness that can occur if continuously adjusted.

NOTE 2 The DUT may adopt external face detection or eye tracker to precisely locate the driver's eye position using an eye position tracker (3.2.4). For such DUT, it is necessary that the face detector or eye tracker is capable of properly detecting and adjusting the DUT properly. Inaccuracy of eye position detection, latency of the dynamic adjustment and continuous adjustment with latency can lead to discomfort, such as motion sickness. It is not the target of this document to provide a detailed measurement procedure to evaluate these dynamic properties.

NOTE 3 For 3D AR HUD, refer to Annex B where more detail is given on considerations required for driver gaze position. Some systems can require the use of an eye position tracker (3.2.4) to generate an image according to the driver's actual dynamic positioning.

When there is a driver with physical characteristics that lead to an eye position exceeding the eyellipse encapsulated within the 95th percentile of the driver population, and the adjustment range is not capable of bringing the display image, the information should be provided in the operation manual such that the driver is not forced to use the HUD with discomfort.

### 6.5.4 Display visual performance adjustability

The HUD display can be endowed with adjustment capabilities for bringing the output image quality to match the viewer's characteristic. This adjustment function could be available as manual, semi-automated or automated depending on the adopted design. The perceived image by the driver is affected by the driver's eye/head/face position, external light conditions, and other factors. The following items need an evaluation of the adjustability coverage:

1) display image brightness adjustment in accordance with external/environmental light conditions (e.g. day/night dimming),

2) colour of the message to external light condition,

3) size of visual information conveyed by the system,

4) adjustability according to the position of driver's head/eye/face.

For the evaluation of performance of automatic adjustment, see 6.5.5.

The performance of the DUT shall be tested under the representative position.

### 6.5.5 Automatic adjustment accuracy and latency

For a DUT with automatic adjustment, the adjustment operation accuracy and the latency of the adjustment shall be evaluated. The following are some examples of possible function(s) a DUT can provide.

1) Geometrical adjustment to best fit the driver's eye/eyellipse/face position. The adjustment can be provided in different stages of use:

   a) once per identified driver,

   b) once boarded,

   c) dynamic adjustment,

   d) this function is available for HUD adopting on request re-adjustment.

2) External environment luminance adjustment:

   a) daylight once per identified driver,



b) night

c) night with headlamp light on windscreen,

d) foggy environment,

e) sunset.

In an AR HUD (3.3.4) further superimposing the virtual image in the three-dimensional space, the virtual image is reproduced using stereoscopy technology (see Annex B). It requires precise adjustment of the eye position to avoid driver discomfort when accessing the visual information provided by the DUT. Therefore, the device adopted to track the driver's eye position shall be separately evaluated in synchronization with the 3D generated image displayed to the viewer.

i. Capture the head movement of the driver using an equipment with known detection latency.

ii. Capture the tracking data log of the results with eye position tracker (3.2.4).

iii. Capture the resulting generated image by the DUT.

iv. Verify the latency between the actual eye position movement and the generated image by the DUT. The total systematic delay caused due to eye position detection, transfer of data and processing time delay to generate the readjusted stereoscopy image is reported. Maintaining certain unsensitive eye/head movement detection zone and lag may avoid the discomfort, like control hunting.

# 7 Laboratory assessment on vehicle setup and eyellipse location (procedure for measurement of HUD virtual image)

## 7.1 General

Field evaluation in a real world would be ideal to verify the HUD's performance on actual use case conditions. However, this implies poor reproducibility of achieving equal conditions among different situations because generating natural testing conditions across different testing sites and testing instances is mostly impossible in view of everchanging natural conditions. Therefore, the present clause introduces a set of test conditions intended to reproduce specific real road-testing conditions, with several controlled preconditions.

Sunlight incident height, cloud, atmospheric condition, snow and rain are just a few examples of many attributes that affect the evaluation. The predefined conditions enable a comparative and analytical evaluation of the HUD's performance as installed in a vehicle evaluation across different labs. The following subclause provides representative predefined test conditions applicable in common for the HUD system evaluation to mimic a field operational testing condition.

## 7.2 Vehicle setup

The information provided by DUT is conveyed to the driver's field of vision while the vehicle is in running condition as described in 3.1.2. As the vehicle pitch and/or seat height from the road surface can change according to the load, a nominal position shall be achieved according to the vehicle condition as described by local regulation. The vehicle shall be levelled with suspension blocked-out and placed on jack-stands (or equivalent methods) in preparation for dimensional and orientational measurement. Benchmarking processes require establishing repeatable fiducial points for levelling, so common vehicle fiducial points should be used and recorded when establishing vehicle levelling.

The image observable by the driver is dependent on the eye position relative to the HUD engine as well as the windscreen or the combiner used to reflect the image, whichever is applicable. Therefore, it is necessary to determine the driver seating reference point (SgRP) for the driver's seats in vehicles (see ISO 20176 and ISO 4513 to determine the eyebox).

NOTE Please be aware of any individual regulations of the national body defining a vehicle in running condition. [For example, in Reference [22], the vehicle in running condition would refer to a vehicle in running order plus one front-seat passenger, the mass of the passenger being 75 kg with tolerance of ±1 %, where the mass of a vehicle in running order includes the mass of the vehicle and its body with cooling fluid, lubricants, fuel, 100 %of other liquids, tools, spare wheel and driver. The mass of the driver is evaluated at 75 kg (distributed as follows: 68 kg for the mass of the occupant and 7 kg for the mass of luggage, in accordance with ISO 2416). The tank contains 90 % and the other liquid-containing appliances (other than those intended for waste water) 100 % of the capacity declared by the manufacturer.]

## 7.3 Mannequin/visual reference eye point installation

In case a mannequin is used to determine the physical location of the observer's eye for the measurement, it is recommended to keep records of both relative humidity, room temperature and the total time the vehicle is kept in these conditions as part of the testing environment condition. This is especially important if the vehicle is new because the driver's seat compressed contours may not have reached design intent cushion compression through use. Keeping record of the mannequin head reference point relative to vehicle coordinate may help in confirming that the mannequin has come to the expected positioning within the seat.

## 7.4 External environmental condition

Unless specified to evaluate the DUT in some specific external climatic condition, the evaluation shall be performed under environmental conditions that include a clear sky and good visibility.

NOTE Rain, snow, sandstorm, or fog are just some examples of environmental conditions that can affect the image quality of the information generated by an HUD.

### 7.4.1 External light environment

The environmental light condition may largely vary upon time of the day, weather conditions and time of the year. The external lighting may further be influenced by artificial public road illumination, surrounding vehicle illumination and other types of illumination introduced in public space.

Table 2 describes some of the representative external light conditions that shall be evaluated. Daylight, cloudy sky, sunset, sunrise, night, with and without counter vehicle headlamp high beam switched on are some of basic conditions to which an HUD may be exposed in field use. The evaluation shall be performed with external light conditions given within the condition range provided in Table 2. The actual external light condition is recorded at windscreen position and at the foreground position. The former light condition is intended to verify the effect to external light adjustments or side effects to the optical patch of projected image, and later light condition is intended to characterize the road scene illumination condition, if applicable.

**Table 2 — Representative environmental light conditions to be evaluated**

| Environmental condition | Illuminance on road | Applicability of test |
|---|---|---|
| Clear sky | 100 000 to 120 000 [lx] | Applicable |
| Cloudy sky<br>(diffused light from top) | 10 000 to 30 000 [lx] | Applicable |
| Twilight | 500 to 1 000 [lx] | Applicable |
| Night with head light | 50 to 20 000 [lx] | Applicable |
| There are several adverse light conditions where it is hard to access the visual information conveyed by the HUD. Unless the system is designed to specifically be operationally capable to overcome such harsh conditions, the following items are not applicable. | | |
| Sunset contre-jour/backlight | | Currently N/A[a] |
| Exposed to direct high beam head lamp | | Currently N/A[a] |
| High beam + under fog | | Currently N/A[a] |
| Heavy rain | | Currently N/A[a] |

[a] In current technology decremental performance of visible information conveyed by the HUD may occur when exposed to the presence of harsh disturbing external light. Contre-jour sunset or headlamp high beam reflected on wet road are some other examples that makes it difficult the access visual information by an HUD. However, these harsh conditions are not typical to occur in real use case. An HUD is not a replacement equipment to a conventional instrumental panel where safety relevant symbol(s) or other HMIs shall be given to the driver because under some harsh conditions the information given by HUD may likely to be deteriorated.

**Warning — In case there is risk of causing driver visual distraction under harsh weather conditions it might be appropriate to provide recommendations for care in the user's operation manual.**

### 7.4.2 Road surface ahead

The images formed on the windscreen are overlayed luminance images projected on top of the foreground visual scene as observed by the driver while driving on various actual road scenes. The conditions described herein are some examples of predefined road scenes, as representative conditions to enable comparative and stable evaluation in laboratory test to mimic a real-world use condition. The luminance of this foreground scene on various road conditions is to be calculated with Formula (13):

$$L_{\mathrm{road}} = \rho \times E_{\mathrm{v}} \tag{13}$$

where

$L_{\mathrm{road}}$ is the illumination reaching from the road ahead;

$\rho$ is the reflection rate of the road;

$E_{\mathrm{v}}$ is the illuminance cast over the road.

Table 3 provides some typical representative road surface conditions to be considered but may not necessarily be a representative condition of all actual road conditions.

**Table 3 — Typical reflection/albedo rate from multiple source**

| Type of foreground road | Reflection rate | Typical albedo | Albedo |
|---|---|---|---|
| Concrete | 0,05 | 0,55<br>(new concrete) | 0,10 – 0,35 |
| Asphalted | 0,03 | 0,04 (fresh) | 0,05 – 0,20 |
| Worn asphalt | | 0,12 | |
| Tar and gravel | | | 0,08 – 0,20 |
| Snow road white | 0,1 | 0,80 (fresh) | |
| Desert sand | | 0,40 | |
| Green grass<br>(on road periphery) | | 0,25 | |

Information conveying safety relevant information like Request to Intervene (RTI) on critical conditions shall not be provided solely by the HUD system because in adverse conditions the safety relevant information can become hard to recognize through the HUD alone. For example, redundant HMI symbols on I/P along audible warnings are highly recommended to minimize any risk of these warning messages to be missed.

There are some specific ambient and/or road conditions where the information legibility conveyed by an HUD may be deteriorated. The operation manual shall provide warning information for conditions not suitable for an HUD to convey safety critical status information. Sunset contre-jour or headlamp of incoming vehicle under wet road surface at night are just examples where a driver may be unable to access the information conveyed by a traditional HUD.



## 8 Environmental test

### 8.1 General

The built-in type HUD is an equipment that is partially embedded into the instrumental panel within the passenger compartment space. It is exposed to environmental conditions, it is partially under the passenger compartment classification, but it is less severely affected. On the other hand, a stand-alone type of HUD set on a dashboard comes under the passenger compartment classification. Therefore, test conditions can differ according to the design of the intended DUT, and this document provides some recommendations according to the different types of HUD. The details of the test conditions are given in Annex C and Annex D.

#### 8.1.1 Measurement setup

ISO 16750-2 (electric test), ISO 16750-3 (mechanical test), ISO 16750-4 (climate test) and ISO 16750-5 (chemical test) provide a set of environmental conditions and testing for electrical and electronic equipment. An HUD device having its main electronic functional parts assembled into a single unit is typically embedded into the dashboard space located in front of the steering position, the DUTs are exposed to moderate environmental conditions but still exposed to direct sunlight through the windscreen.

The DUT shall be evaluated following the procedure for electrical loads test given in ISO 16750-2, according to pre-conditions as specified by the manufacturer of the DUT. See Table C.1.

The DUT shall be tested with a mechanical loads test as described in ISO 16750-3. The DUT is an equipment with an installation within the dashboard assembly in the passenger compartment with exposure to direct solar radiation. These conditions require to test using code E within the ISO 16750-3:2023, Table B.1. See Annex C, Table C.2.

The device is likely to be protected within the dashboard, having part of its optical path exposed to the reach of the user. It is recommended to perform the test described in ISO 16750-3:2023, 4.1, 4.2, and 4.3, but items described in ISO 16750-3:2023, 4.4, and 4.5 may not be relevant.

The DUT shall be tested with a climatic-loads test as described in ISO 16750-4. The operating temperature range code H and the climatic requirement code G could be applied as it is located in the passenger compartment and partially exposed to direct radiation. (See ISO 16750-4:2023, Table A.1.)

When the DUT's optical window is directly accessible to the user, it may become exposed to chemical substances in the passenger compartment. ISO 16750-5:2023, Table 1 provides a set of chemical loads applicable for testing electronic equipment with its mounting location in the passenger compartment with classification code "B". It shall be tested according to pre-condition as specified by the manufactured of the DUT. See Annexes C, D.

### 8.1.2 Measurement procedure

Many real-world environmental conditions are difficult to be precisely replicated within a laboratory environment or may require an exaggerated amount of resources to achieve a similar condition. Therefore, this document provides a baseline guideline to assess the DUT by defining a set of minimum required evaluations.

A vehicle with a passenger on board prepared for driving is expected to reach a moderate temperature range. Therefore, the DUT in operation with a passenger on board may bring the respective equipment within the compartment to operate at a moderate temperature range.

If the equipment is exposed to some specific identified condition, for example, a specific resonance vibration occurring due to the vehicle design, that additional condition shall be evaluated following instructions of use and it shall be verified that the DUT is not affected. Vibration may deteriorate the visual performance of a displayed image.

### 8.1.3 Protection of HUD unit against foreign objects, liquids

The HUD's opto-electrical unit of the HUD engine is typically protected in an enclosure and the unit assembled into the dashboard space of the vehicle. The intrusion of dust particles, liquids and/or gas causing optical surface contamination can affect the image quality during its life cycle. Therefore, the DUT shall be subjected to environmental tests to verify the durability resistance to the required test conditions. It shall follow the test procedure as specified by ISO 20653 and meet the protection level IP code requirement as specified under the designed conditions of use.

NOTE Cumulative contamination by outgas from the internal component within the HUD engine enclosure can also affect the optical performance of the DUT. If that happens, it is advised to take appropriate countermeasure and evaluate the influence to image quality.

## 9 Consideration when using HUD

This document does not prescribe any specific care for use as it may depend on display technologies used or a particular packaging design into the vehicle cabin. Instead, it provides some considerations which may serve as guidance, and they are given in Annex E and Annex F to bring awareness and to avoid misuse. The user of this document shall consider the adopted technology and analysis the needs for additional care.

# Annex A
(informative)

# Eyellipse versus eyebox

## A.1 General

The 3D space defined as an eyellipse is easy to handle in a virtual computed theoretical space (see Figure A.1). However, handling and positioning equipment for actual measurement of HUD characteristics according to the theoretical point in the eyellipse space is not practical and efficient. It is extremely challenging from a practical point of view.

To facilitate and to provide a practical way to perform the evaluation test, a representative point characterizing the eyellipse limit range is adopted, defined as "eyebox", which provides the relevant measurement reference point. The eyebox concept is introduced to simplify the measuring point in the 3D space when performing image quality related evaluations.

This annex is intended to provide information to generate and define the respective eyebox from the eyellipse. The term "eyebox" used in this document refers to the space generated from the eyellipse, correlating to the respective driver population coverage estimated and defined in ISO 4513.

In this document, the eyebox is defined by the specific eyellipse covering the 95 % of the driver population unless otherwise specified. For equipment designed to support extended driver population coverage beyond the 95 % of the driver population, refer to ISO 4513 to generate the enlarged eyebox and eyebox range.

The system is expected to cover the 95 % of the driver population with anthropometric characteristics described in ISO 4513, whether by manually adjusting the equipment or having an automatic or semi-automatic adjustment. The DUT is not required to provide a satisfactory image over the entire eyellipse or eyebox range in a single adjustment setting but requires to be adjustable to meet the needs of different driver characteristics, having anthropometric characteristics within the 95 % of the driver population, used to define the eyellipse space.

The location of the eyellipse uses the H point and R point as described in ISO 6549.

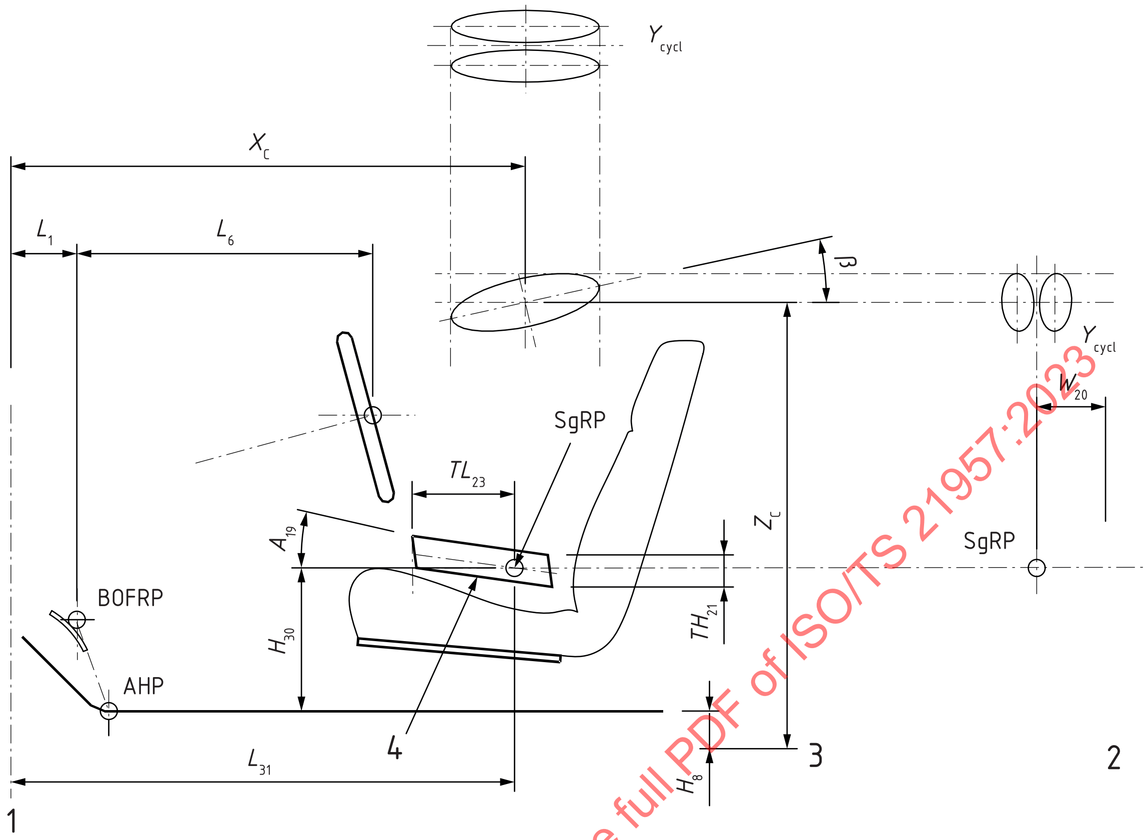
Note that once adjusted to a particular driver, the DUT shall be capable of conveying the visual information to the driver within a reasonable range of driver head movement, whose range is defined as the adjusted viewable HUD window in 3.2.3.

The eyellipse is a three-dimensional statistical distribution space where the driver's eye location could come while driving. The eyellipse location within the vehicle is defined in ISO 4513. It establishes the location of drivers' eyes inside a vehicle. The quality of the image conveyed by the HUD to the driver is evaluated as visual information observed within this space. This document adopts the eyellipse covering the 95$^{th}$ percentile driver population. The seat-back angle (3.1.9), or torso angle is one of the elements that affects the eye positioning itself, but it does not apply for the calculation of eyellipse location.

The precise location of the eyellipse shall be derived according to definition as described in ISO 4513 as centroid location parameter $X_c$, $Y_{cycl}$, and $Z_c$. The volumetric parameter determines the size of the eyellipse of 95$^{th}$ percentile driver population, and the angles $\beta$ given in ISO 4513:2022, 4.2 and 4.3.2 are used to determine the eyebox.






**Key**

| | |
|---|---|
| $A_{19}$ | seat track rise |
| AHP | accelerator heel point |
| BOFRP | ball of foot reference point |
| $H_8$ | z-coordinate of the AHP |
| $H_{30}$ | z distance of the SgRP from the AHP |
| $L_1$ | x-coordinate of the BOFRP |
| $L_6$ | x distance from the steering wheel centre to BOFRP |
| $L_{31}$ | x-coordinate of the SgRP |
| SgRP | seating reference point |
| $TH_{21}$ | H-point vertical adjustment |
| $TL_{23}$ | seat track travel |
| $W_{20}$ | y-coordinate of the SgRP |
| $X_c$ | x-coordinate of the eyellipse centroid location |
| $Y_{cycl}$ | mid-eye y-coordinate |
| $Z_c$ | z-coordinate of the eyellipse centroid location |
| $\beta$ | side view angle |
| 1 | zero X grid |
| 2 | zero Y grid |
| 3 | zero Z grid |
| 4 | H-point travel path |

**Figure A.1 — Location of the eyellipse relative to driver packaging dimensions**



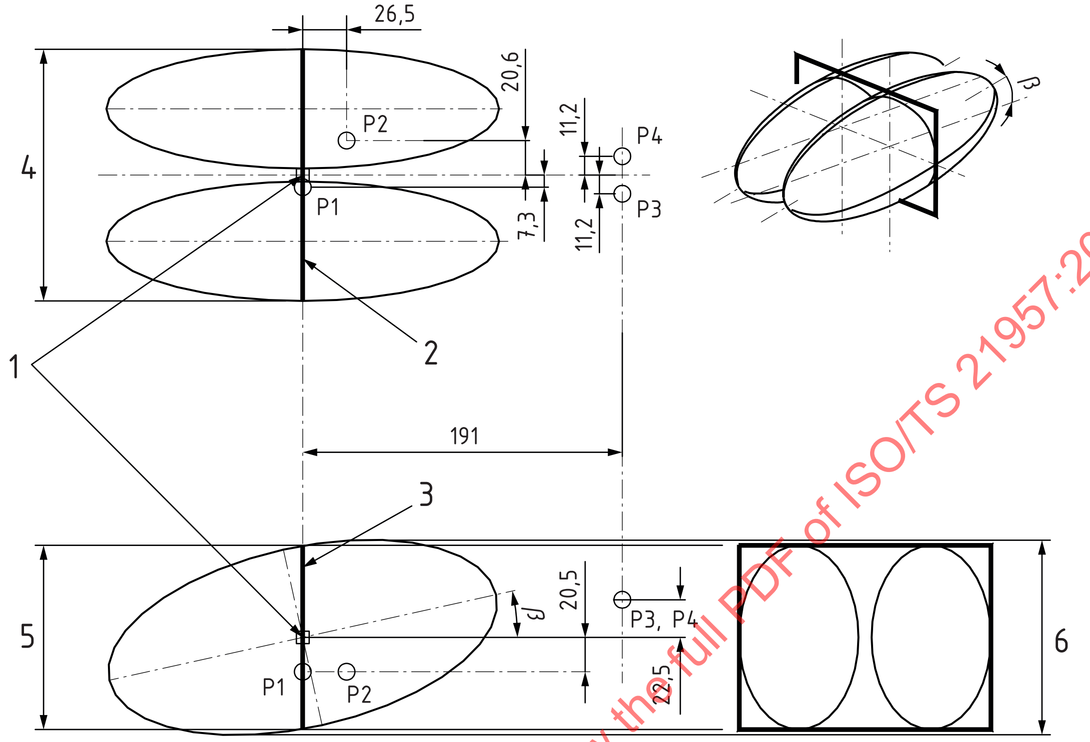
## A.2 Conversion of eyellipse to eyebox coordinate

The eyebox is a simplified two-dimensional rectangular box model providing the representative distribution range of the driver's eye reference point for evaluation, encapsulating and having its frame line tangential to the eyellipse; but for simplification, a slightly inner point is used to derive the eyebox frame as described in Figure A.2.

Unlike the theoretical 3D space of the eyellipse, the eyebox enables defining the physical measuring point along the edge or line of this eyebox rectangular cube without compromising the needs of the evaluation.

The eyebox is defined in the vertical y-z plane at the centre of the eyellipse plane. The upper frame of the eyebox is determined by the uppermost point of the crossline of the eyellipse to the defined y-z plane and lower frame determined by the lowermost point of the crossline of the eyellipse to the defined y-z plane. The lateral frame of the eyebox is determined by the outermost right and left surface of the eyellipse. For more detail see the projection view of the 95 % eyellipse as shown in the Figure A.2, side and plan view respectively.

Dimensions in millimetres




**Key**

1 driver 's ORP (mid-eye centroid)

2 eyebox horizontal frame (bold line)

3 eyebox vertical frame (bold line)

4 eyebox lateral y dimension

5 eyebox vertical z dimension

6 widest Z dimension of the tilted eyellipse (reference)

P1 neck pivot points used to position eye points(reference)

P2 neck pivot points used to position eye points(reference)

P3 neck pivot points used to position eye points

P4 neck pivot points used to position eye points

**Figure A.2 — Eyebox versus eyellipse and P point location**

For an evaluation of an HUD system intended to have an extended driver population coverage with different anthropometry characteristics, evaluate the system on the basis of the expanded eyebox that would cover those driver population needs under seat adjusted condition whenever applicable.



# Annex B
(informative)

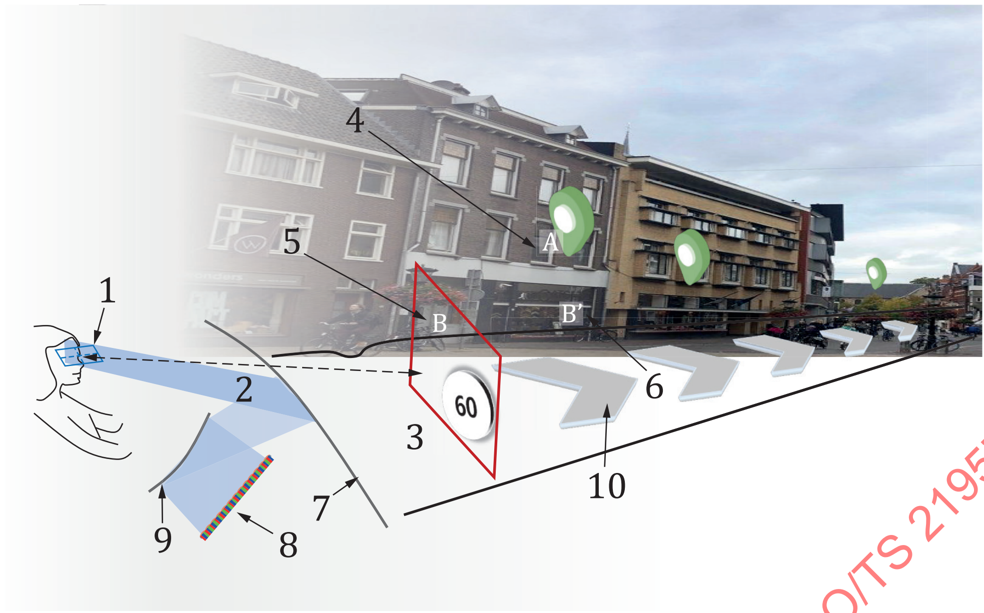
# Subjective evaluation for a 3D HUD

## B.1 General

This annex provides a report on an evaluation regarding perceptual characteristics observed on a stereoscopy-based 3D HUD where the visual information is provided with a perceptual depth onto the real-world scene. This annex is not a comprehensive study, but it may still provide some useful information on aspects to consider when adopting a 3D HUD in practice. This annex covers the aspect related to comfort when using stereoscopy type of HUD. Information conveyed by the HUD onto the driver direct field of view may conflict with the driver demand to access the real-world road ahead and human factor aspect like the attention allocation among other(s) are expected to be visited and explored as a continuation of this document.

A traditional 2D HUD displays an image at a defined depth (distance from observer) while a 3D HUD may display information on variable depth depending on the artificially created disparity. It enables image to be perceived at different depth by the driver. The image displayed at different perceptual depth has advantages when providing visual information to the driver like travel path guidance according to the real road path ahead or the positional information according to the actual position in real world. It may require less effort by the viewer to access the visual information provided at adaptive depth.

Figure B.1 is an illustrative example of a scene describing different situation of image conveyed by 2D HUD and 3D HUD. The item indicated by key 3 is the virtual plane (screen) where the virtual image is provided by the HUD and the driver needs to adjust their eyes accommodation distance to that particular distance to properly access the information displayed on a 2D HUD. This requires the driver to reallocate their viewing condition from a scene far away to a proximity plane of the HUD image. On the other hand, a 3D HUD with variable depth perception capability can generate virtual images at variable depth on different targeted depths. The items given by symbols "B" and "B'" are an illustrative representation for virtual image displayed on a 2D HUD and 3D HUD, respectively. When using a 3D HUD, the symbol "B'" is projected to be perceived by the driver at a depth to indicate an information corresponding to geographical point, in this example near the item "A" (see Figure B.1). Another example of 3D-HUD usage is the display of symbols with continuous variable depth like the path arrow marker on the road (e.g. Figure B.1, key 10).




**Key**

1 driver's ORP within the eyebox
2 virtual image distance
3 virtual image plane, or also referred as "virtual image screen"
4 the real building (A) on the street
5 the 2D virtual symbol (B) indicating the real building (A)
6 the 3D virtual symbol (B') indicating the real building (A)
7 windscreen
8 display device within the HUD engine
9 convex mirror
10 path arrow marker

**Figure B.1 — B symbol on the virtual image screen of a 2D HUD versus the stereo B' symbol with depth information indicating the real building A on the street**

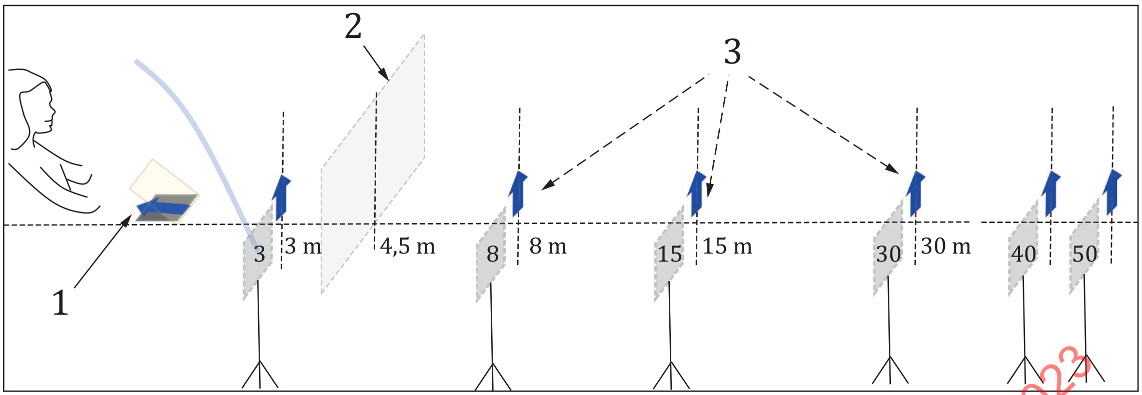


There are various monocular and binocular cues contributing to our depth perception. Cutting and Vishton introduced the depth cues that vary in their effectiveness at different distances except two types of monocular cues of occlusion and relative size[13]. The binocular disparity is the main cue applied to create stereo contents in 3D displays. The binocular disparity is defined according to Reference [14] as follows: "when both eyes focus on an object, the different position of the eyes produces a disparity of visual angle, and a slightly different image is received by each retina". The two images are automatically compared and, if sufficiently similar, are fused, providing an important cue to depth perception. This is also called retinal disparity[14].

## B.2 3D depth perception

It is preferable for a driver that a navigation symbol is reproduced at the same distance where the next turn is placed. The 3D HUD should therefore display the corresponding 3D virtual content such as an arrow at the same depth as the augmented real turning location (see Figure B.1, key 10 for an example of marker symbol). This clause introduces the assessment methodology for the depth perceived by a subject observer in augmented surroundings.

This clause provides the evaluation study on 3D depth perception by varying the inter-pupillary distance variation or in other words what determines the binocular depth perception (3.3.21).




**Key**

1 3D HUD unit (PGU)
2 virtual image screen
3 3D virtual objects

**Figure B.2 — Example of measurement configuration for the perceived-depth and visual-comfort evaluations**



The following are the assessment procedures.

a) Selection of the evaluation target distances to be assessed:

— it is recommended that the target distances are chosen from both the front and the rear positions of the virtual image screen for the 3D HUD to be evaluated (see the measuring configuration in Figure B.2);

— for instance, one front position of 3 m and five rear positions of (8, 15, 30, 40, 50) m can be chosen if the virtual image screen is displayed at 4,5 m from the user.

The distance of the virtual image screen, i.e. the virtual image plane, is determined by the optical design in a 3D HUD and shall be provided as design data by the 3D HUD manufacturer. Otherwise, this can be measured using calibrated cameras. See 6.2.1 for the procedure to verify the virtual image optical accommodation distance (3.3.20).

b) Siting the real objects at the target distances:

— the real objects are located at the selected target distances;

— for instance, the square panels with numbers (3, 8, 15, 30, 40 and 50) representing the target distances are placed at respective positions.

c) Preparation of the virtual object for the subjective evaluation:

— the inter-pupillary distance of each observer is measured;

— preparation of the respective virtual-object image (see arrows in Figure B.2) by considering the inter-pupillary distance of each observer.

The observers see different depths against one virtual object presented at a certain distance due to their inter-pupillary distance variation, in other words what determines the binocular depth perception. The nominal inter-pupillary distance or the distance between $E_L$ and $E_R$ is 65 mm as given in 3.1.8 but for an accurate evaluation, the actual value is measured and used. If the binocular disparity is applied for depth reproduction in the 3D HUD to be evaluated, the virtual-object test image should be generated by reflecting the individual inter-pupillary distance (see Figure B.3).

d) Set up the HUD system according to the experimental configuration shown in Figure B.2:

— the observer seating position is suggested depending on the distance of the virtual image screen for the 3D HUD to be evaluated;

— for instance, the observer is asked to sit at a 0,7 m distance from the combiner or the windscreen where the virtual image screen is displayed 4,5 m away from the observer.

e) Assessment of the perceived depth:

— the observer is asked to adjust the depth of the virtual object to the position of the real square panel;

— for instance, the observer is asked firstly to manipulate left/right arrow keys on the keyboard in order that the positions between the virtual object and the square panel with number 3 are perceived to have the same depth, and secondly to push enter key on the keyboard for saving the depth position of the virtual object;

— these manipulations and saving processes are repeated for all target distances.

NOTE An input equipment that uses a keyboard where the left/right key input can adjust the generated virtual image disparity gradually is adopted to perform the experiment where the observer's task is to adjust the subjective perceived depth to each requested target square panel, and the results are recorded for the correlation evaluation.

f) Analysis of the depth evaluation results:

— it is recommended that the observers' perceived depth results are compared in the binocular angle (see Figure B.3) or in the diopter (distance in meter$^{-1}$) dimension;

— for instance, the perceived depth results can be shown in meter, diopter and binocular angle dimensions in Figure B.4 a)-c) and Figure B.5 a)-c) for 38 younger adults (mean age 34,9 years old) and 19 elderly adults (mean age 60,6 years old) respectively;

— the virtual-objects are perceived by younger observers to be placed at (3,5, 8,6, 15,7, 26,4, 33,8 and 41,1) m [in median values in Figure B.4 a)] that are slightly further from the observer in comparison with the actual target-object locations at (3, 8 and 15) m but are closer from the observer at 30, 40, and 50 m;

— the virtual objects are perceived by older observers to be placed at (3,5, 9,8, 16,6, 31, 40,6 and 50,2) m (in median values in Figure B.5 a)) this is slightly further from the observer in comparison with the actual target-object locations at (3, 8 and 15) m but are similar to (30, 40, and 50) m;

— for younger observers, the 25$^{th}$ to 75$^{th}$ percentile ranges in the perceived depth at (3 – 50) m actual target distance falls into similar size in diopter and binocular angle dimensions in Figure B.4 b) and c);

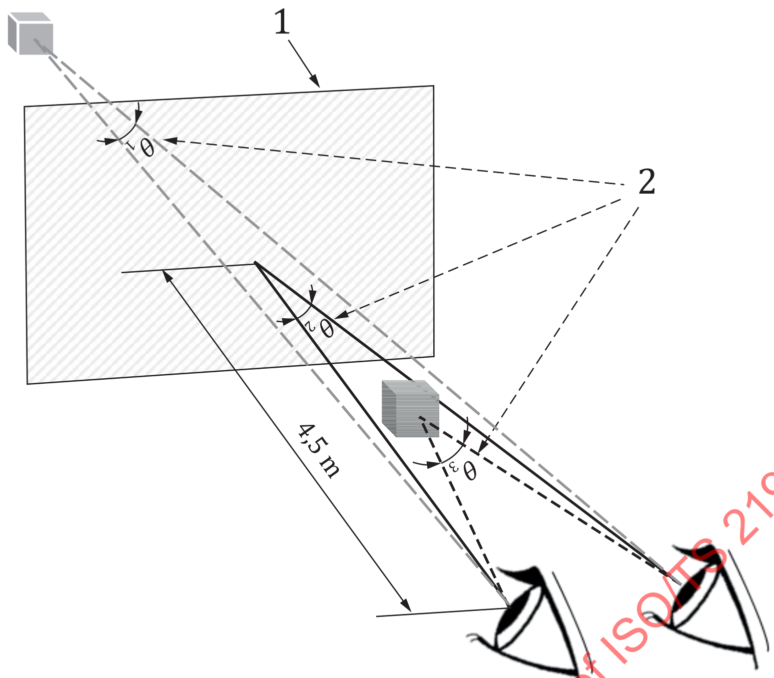
— for older observers, the 25$^{th}$ to 75$^{th}$ percentile ranges in the perceived depth at (3 – 50) m actual target distance falls into similar size in diopter and binocular angle dimensions in Figure B.5 b) and c);

— these indicate for both younger and older observers that recognition degree against 3D virtual objects is similar in the distance range of (3 – 50) m with comparable 25$^{th}$ to 75$^{th}$ percentile diopter sizes.

NOTE The determinable deviation is not the same in the actual distance. This phenomenon is well described as follows: distance or depth errors are apt to occur in distant portion of the visual field because depth cues are attenuated or are below threshold and therefore are unable to support the perception of depth between distant objects at different positions[15]. The sensitivity in differentiation of the distances of two objects is less in further distances. As an object moves away from the observer, the distance in meter becomes larger while the binocular angle or diopter values become smaller. Considering this fact, the perceived observation in different distances is more accurately compared in the binocular or diopter domain.



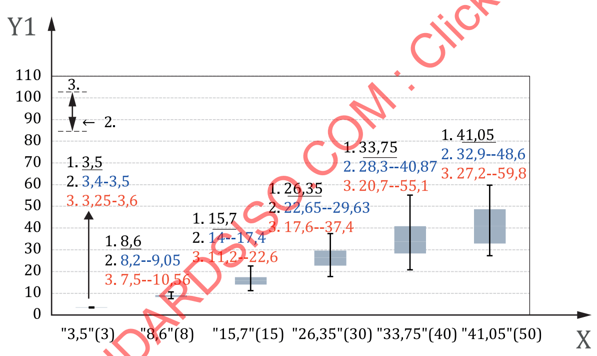



**Key**

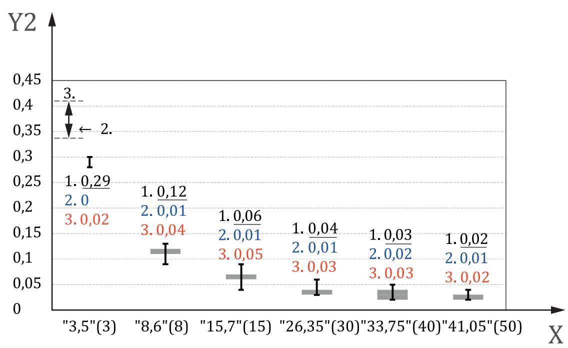
1 virtual image screen

2 binocular angles of $\theta_1$ for the rear object of, $\theta_2$ for the object on, and $\theta_3$ for the front object of the virtual image screen

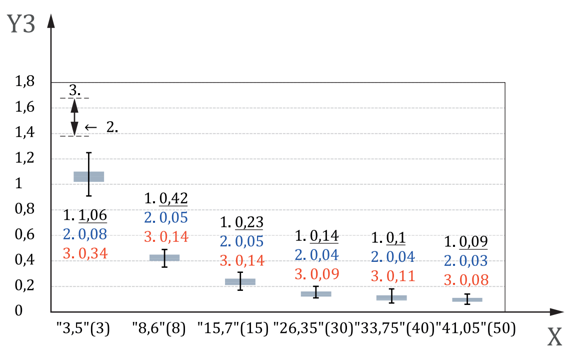
**Figure B.3 — Illustration of the binocular angles ($\theta_1 < \theta_2 < \theta_3$) for the virtual objects located at different depth in 3D HUD with the virtual image screen designed at 4,5 m**




**a) in physical meter dimension**




**b) in diopter dimension**




**c) in binocular dimension**

**Key**

X location of "perceived" and (real) object (m)

$Y_1$ perceived physical depth in meter

$Y_2$ perceived distance in diopter

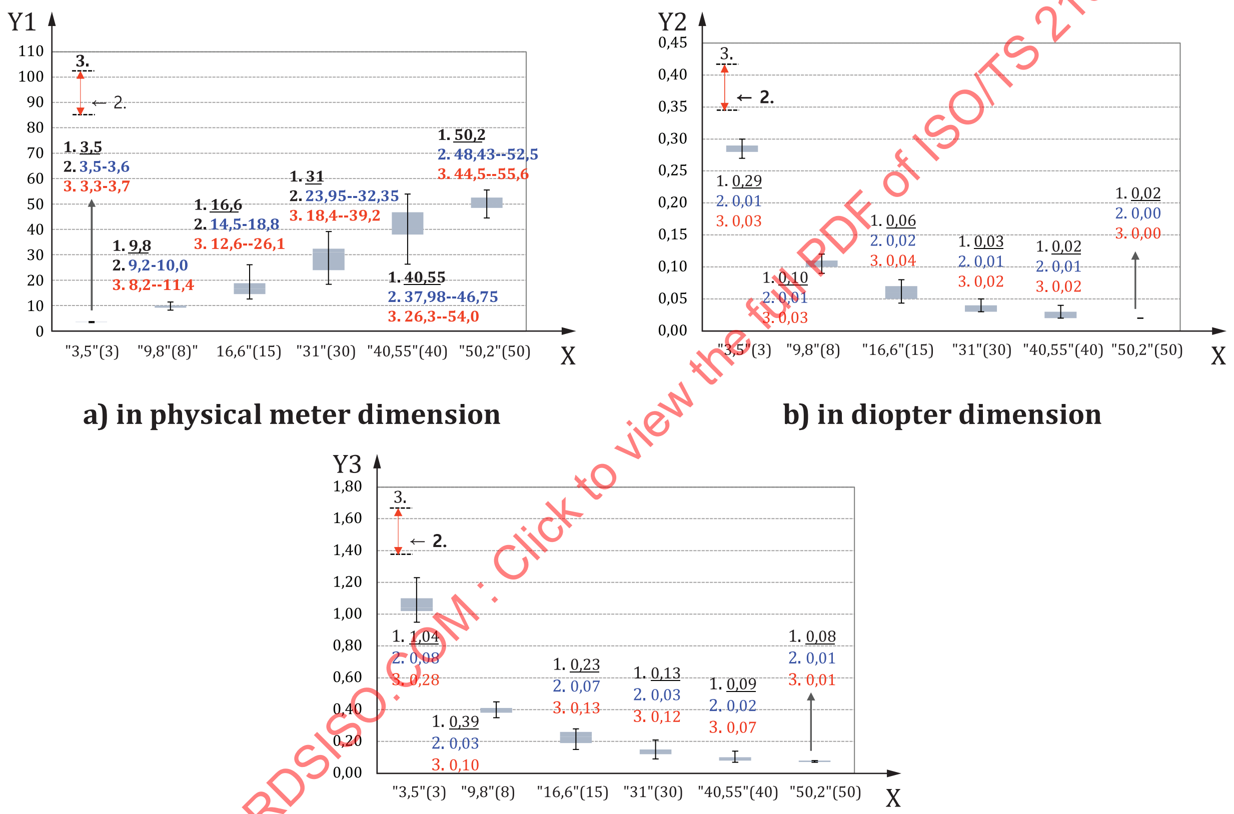
$Y_3$ perceived distance in binocular angle

1 median value

2 75th percentile value – 25th percentile value

3 maximum value – min value

**Figure B.4 — Example of the perceived depth results at the real target distances of (3, 8, 15, 30, 40, 50) m in the 3D HUD with the distance of the virtual image screen (4,5 m) for 38 younger adults (mean age 34,9 years old)**




a) in physical meter dimension

b) in diopter dimension

c) in binocular dimension

**Key**

X location of "perceived" and (real) object (m)

$Y_1$ perceived physical depth in meter

$Y_2$ perceived distance in diopter

$Y_3$ perceived distance in binocular angle

1 median value

2 75th percentile value – 25th percentile value

3 maximum value – min value

**Figure B.5 — Example of the perceived depth results at the real target distances of (3, 8, 15, 30, 40, 50) m in the 3D HUD with the distance of the virtual image screen (4,5 m) for 19 elderly adults (mean age 60,6 years old)**

## B.3 3D visual comfort

The provision of visual comfort 3D content is an important issue particularly for safe driving in automotive applications. It is known in the field of conventional stereoscopic 3D displays that viewing the 3D content with excessive parallaxes can evoke visual discomfort because of the difficulty in fusion and an increased disagreement of accommodation and convergence[16][17][18]. The viewing condition however differs between 3D TV and see-through 3D HUD. The investigation of visual comfort range is required for images projected by an 3D HUD in the front/rear at different distances of the virtual image plane (also referred to as visual image screen) designed to have an accommodation distance at 4,5 m, on which there is no parallax (zero disparity) i.e. the reference 2D virtual screen. The assessment methodology is introduced to find out the parallax range in which users view comfortably the 3D virtual content.

The following are the assessment procedures where a) to d) subprocedures are the same as in Clause B.2 for 3D depth perception:

a) selection of the evaluation target distances to be assessed;

b) siting the real objects at the target distances;

c) preparation of the virtual object for the subjective evaluation;

d) setup of the HUD system to the experimental configuration shown in Figure B.2;

e) assessment of the visual comfort level:

— the observer is asked to stare at the virtual object (at least for one second) whose position is adjusted beforehand to the depth of the real square panel;

— the observer is then asked to rate his/her symptom on a 6-point Likert scale where 0 indicates no discomfort at all and 5 indicates severe discomfort [for the scale, see Figure B.6 d)]:

  — 0 for comfort;

  — 1 for perceivable discomfort (just recognizable);

  — 2 for acceptable discomfort (a little bit uncomfortable but tolerable);

  — 3 for mildly discomfort (slightly uncomfortable);

  — 4 for moderately discomfort (to be interrupted for driving);

  — 5 for severely discomfort (difficult to driving).

f) repetition of these processes for all target distances;

g) analysis of the visual comfort evaluation results:

— it is recommended that the observers' rating values are compared in the parallax-angle or delta-dioptre dimension;

— the parallax angle is calculated by subtracting the binocular angle at the target virtual-object distance from the binocular angle at the virtual image screen (see Figure B.3);

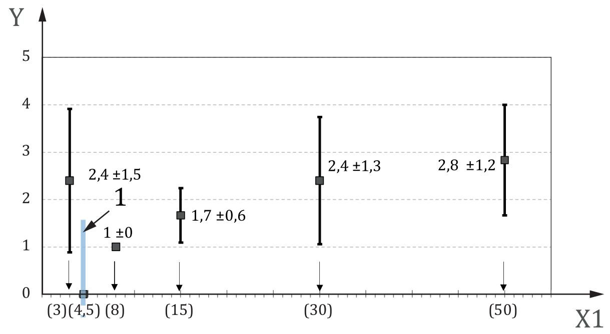
— the delta dioptre is calculated by subtracting the dioptre at the target virtual-object distance from the dioptre at the virtual image screen;

— for instance, the observation results are shown in the meter, delta-diopter and parallax-angle dimensions in Figures B.6 a)-c) where the target virtual-object distances are (3, 8, 15, 30, and 50) m;

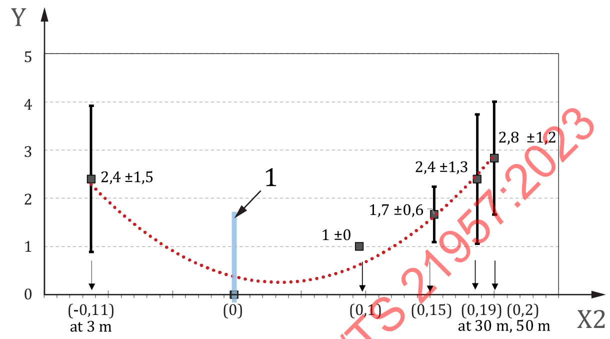
— in the delta-dioptre [Figure B.6 b)] and parallax-angle [Figure B.6 c)] dimensions, observers tend to recognize more discomfort as the delta-dioptre or parallax-angle value becomes deviated from zero at the virtual image screen in both negative (the front) and positive (the rear of the virtual image screen) directions;

— this trend is not seen in the meter dimension [Figure B.6 c)] indicating that the plot of visual discomfort values against deltadioptre or parallax angle provides more intuitive results;

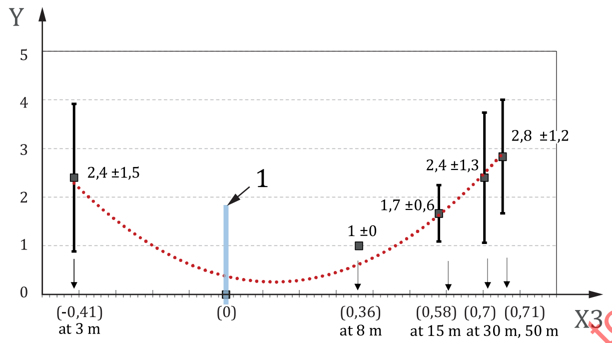
— the comfort zone can be estimated from the observation results shown in Figure B.6 b) and c).




**a) plotted against physical distance**




**b) plotted against delta diopter**




**c) plotted against parallax angle**

| Y axis Discomfort rating scale | |
|---|---|
| 0 | None |
| 1 | Perceivable |
| 2 | Acceptable |
| 3 | Mildly |
| 4 | Moderately |
| 5 | Severely |

**d) discomfort rating scale**

**Key**

$X_1$ virtual object location from user in physical meter

$X_2$ virtual object location from user converted as delta-diopter, given in upper parenthesis

$X_3$ virtual object location from user converted as parallax angle, given in upper parenthesis

Y discomfort rating scale, detailed in d)

1 at the distance of virtual image screen at 4,5 m from the user

**Figure B.6 — Example of the visual-discomfort rating results at the target virtual-object distances of (3, 8, 15, 30, 50) m in the 3D HUD with the virtual image screen designed at 4,5 m**

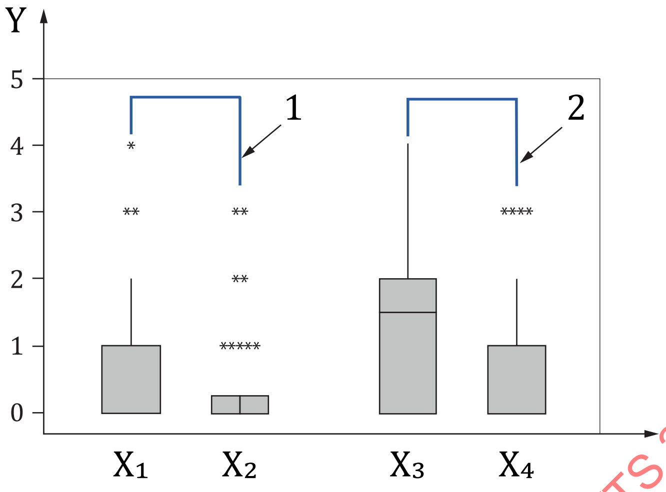


NOTE Considering more severe experimental conditions (at least staring at virtual object for one second) compared to the real situation, it can be said that users are perceived to be comfortable with 3D virtual objects up to 30 m (scale 3, ‘slightly uncomfortable’). It is unlikely to experience discomfort up to 30 m. To find out the visual comfort zone, more experiments including dynamic situation are required.

The visual comfort is also compared in Figure B.7 between 2D HUD viewing (virtual objects on the virtual image screen at 4,5 m versus their corresponding real objects at 8 m and 15 m) and 3D HUD viewing (both 3D virtual and their corresponding real objects at 8 m and 15 m) cases. The statistical analysis based on Mann-Whitney test results show that observers experience a more comfortable viewing for a 3D HUD than for a 2D HUD: p value = 0,062 (< 0,1) in the 90 % confidence level between the 2D (the real object at 8 m and the virtual object at 4,5 m) and the 3D (both real and virtual objects at 8 m) HUD viewing case, and p value = 0,008 (< 0,05) in the 95 % confidence level between the 2D (the real object at 15 m and the virtual object at 4,5 m) and the 3D (both real and virtual objects at 15 m)

HUD viewing case. This finding supports that the 3D HUD can provide a safer viewing experience to drivers than the 2D HUD.




**Key**

$X_1$ 2D HUD viewing condition 1 (real object at 8 m versus virtual object at 4,5 m)

$X_2$ 3D HUD viewing condition 1 (real object at 8 m versus virtual object at 8 m)

$X_3$ 2D HUD viewing condition 2 (real object at 15 m versus virtual object at 4,5 m)

$X_4$ 3D HUD viewing condition 2 (real object at 15 m versus virtual object at 15 m)

Y visual discomfort

1 visual discomfort comparison between 2D HUD viewing case (observers look at the real object placed at 8 m and the virtual object placed at 4,5 m) and 3D HUD viewing case (observers look at the real and the virtual objects placed at 8 m)

2 visual discomfort comparison between 2D HUD viewing case (observers look at the real object placed at 15 m and the virtual object placed at 4,5 m) and 3D HUD viewing case (observers look at the real and the virtual objects placed at 15 m)

**Figure B.7 — Example of the comparison of visual-discomfort rating results between 2D and 3D HUD viewing cases**



## B.4 3D integrated vision

There exists a range of distances that are visually perceived both at the same perceptual distance (i.e. a range of disparities that yield binocular singleness), even if the real object on the road associated with the 3D virtual symbol is located at a different distance. This phenomenon is due to the Panum's fusional area in our eyes. When we look at an object with two eyes, we perceive it as singular, like we do other parts of the visual scene stimulating points on our retina that share a common visual direction. These points are termed "retinal corresponding points" and fall on an area called the "horopter". Points outside the horopter fall on slightly different positions and do not have the identical visual direction and lead to "retinal disparity", the basis of our depth discrimination. The region in the visual space over which we perceive single vision is known as "Panum's fusional area", with objects in front and behind this area being in physiological diplopia (i.e. double vision). Panum's fusional area is characterized by a narrow range of (6-10) arcminute in the fovea and a widening range of (30 to 40) arcminute in the periphery of our eyes. More details of the horopter and Panum's fusional area can be found in References [19] and [20].

One of the 3D HUD functions is to display the 3D virtual symbol or letter in order to point to the actual building or object location on the road. An "integrated vision test" is introduced to assess how far away the 3D HUD's virtual image is to be recognized by the user at the same time, compared to the target building and object. Its result will then be compared with the Panum's fusional area.