direction générale
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Draft methodological guide for the human factors evaluation of head-up displays

HUD

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Août 2005

SYSTEMS CONTROL
AND FLIGHT DYNAMICS DEPARTMENT

Technical Report

Draft methodological guide for the human factors evaluation of head-up displays (HUD)

P. LE BLAYE (DCSD),
C. VALOT, A.-L. MARCHAND (IMASSA)

TR 3/ 07410 DCSD - September, 2005

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SYSTEMS CONTROL AND FLIGHT DYNAMICS

DEPARTMENT

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DCSD-S n° 185/2005

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IDENTIFICATION SHEET of ONERA document # TR 3/ 07410 DCSD

<table>
<tr><td rowspan="2">Issuing department:

Systems Control

and Flight Dynamics</td><td>Contracting party:

DGAC/SFACT</td><td>Contract references:

Marché 99 50 074 avenant n°2</td></tr>
<tr><td>Program record # :
330</td><td>Date:
September, 2005</td></tr>
<tr><td colspan="3">Title: Draft methodological guide for the human factors evaluation of head-up displays (HUD)</td></tr>
<tr><td colspan="3">Authors: P. Le Blaye (DCSD),
C. Valot, A.-L. Marchand (IMASSA)</td></tr>
</table>

PROTECTION Level:		PROTECTION Release:	
Title	: Not Protected	Title	: not applicable
Sheet	: Not Protected	Sheet	: not applicable
Document	: Not Protected	Document	: not applicable

Author abstract

This report is a draft methodological guide for the human factors evaluation of head-up displays (HUD), issued as a result of a pre-normative study conducted for the French civil aviation authorities (DGAC/SFACT), in close collaboration between ONERA (Office National d'Etudes Aérospatiales) and IMASSA (Institut de Médecine Aéronautique du Service de Santé des Armées).

This draft methodological guide was developed with the participation of HUD certification experts and based on the experience of a design and certification project in progress by Airbus.

Keywords

certification - civil aviation - regulation - human factors - symbology - head up display - HUD

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Scope : Certification and HF evaluation

This document is designed to serve as a guide for the Human Factor based evaluation of symbols used in Head Up Displays. It is meant to be used by authorities and experts in charge of certification, as well as by the designers of such devices, since it is best to involve the certification process as early as possible during the design phase.

This document is drafted as part of a research project, and should, under no circumstances, be considered -as it stands today- as a piece of regulation.

This paper addresses HUD evaluations. The generic term HUD (Head Up Display) corresponds to the flight instrument displaying head up information, superimposed over what is seen outside the cockpit. This information is displayed either in a digital format (alphanumerical items) or as analogue symbols (2D geometrical shapes). The HUD has two fundamental characteristics: the image is collimated towards infinity (or at such a distance that eyesight accommodates to infinity), and the image complies with the external world (except for some flight phases or some special manoeuvres -high angle of attack, strong side wind, unusual flight attitudes- where these symbols could be outside the field of vision: the solution then used is often the caging of symbols, or scale compression). HUDs are designed for civilian transportation aircraft, in all conditions of use (taxiing, take-off, en-route flight, controlled approach, IFR/VFR, rollout...). The HUD is an Electronic Flight Instrument System (EFIS) with specific characteristics.

These guidelines aim at making a *human factor-centred evaluation*. It does not address the technical aspects of certification, such as display reliability, or HUD technical installation procedures. It only broaches upon HUD specifics, such as sensor-captured imaging (EVS).

This guide has notes and hypertext links to make it as user-friendly as possible.

Background of Human Factors (HF) evaluation in the HUD certification process

HUD evaluation has historically been paradoxical, because older HUDs were developed and certified according to regulations which were totally out-of-phase with the state-of-the-art of the time. Most of the technological innovations involved in HUDs were invented and developed before any base-line regulatory framework was ever drafted. Since then, the body of regulations has evolved and become more comprehensive. HUD evaluations remain the order of the day, since HUDs are planned to be more extensively used, in different contexts, on more aircraft, and in interaction with other systems.

With hindsight, an operational specificity of HUDs must be outlined: very similar regulatory environments have led to different systems of symbols being used. The diversity of operational contexts, of types of machines, and of flying styles inevitably lead to a great diversity in the symbols designed and used. This is the result of history, culture and technological developments. The main question now is to check how these different philosophies in terms of symbols can bear being confronted with all foreseeable innovations in different conditions of use.

Demand for HUDs and their innovations is here to stay; this will require more complex analyses during certification. This complexity is due to various factors:

- suppliers and operators tend to constantly explore borderline contexts, making the most of "regulatory margins".
- HUDs interact with other on-board functions (TCAS, GPWS, infra-red vision systems...)
- emergence of non-linear approach flight paths

In these cases, the HUD is more than a mere information media used during a limited flight phase. Its use is becoming more extensive, more diverse, and the need to have HF certification furthers the scope of evaluation.

The purpose of this guide is to offer a checklist to scan all specific items required for a HF-centred specification, making sure no area is left aside. Legislation on both sides of the Atlantic regarding HF certification generally agrees on the approach required:

> *"Human Factors. Humans are very adaptable, but unfortunately for the display evaluation process they adapt at varying rates with varying degrees of effectiveness and mental processing compensation. Thus, what some pilots might find acceptable and approvable, others would reject as being unusable and unsafe. Airplane displays must be effective when used by pilots who cover the entire spectrum of variability. Relying on a requirement of "train to proficiency" may be unenforceable, economically impractical, or unachievable by some pilots without excessive mental workload as compensation." (AC/AMC 25-11, 4b.1).*

The HF approach is both necessary and complex because of adaptability, of the diversity in behaviours, of the difficulty in assessing what is the right investment to make in this area, and finally, because of the many elements involved in the matter.

This position is supplemented by the a new paragraph FAR/CS 25.1302 and its AC/AMC on HF certification, which are currently in the approbation process:

> *25.1302 (d) To the extent practicable, installed equipment must enable the flightcrew to manage errors resulting from the kinds of flightcrew interactions with the equipment that can be reasonably expected in service, assuming the flightcrew is acting in good faith.*
> *AC/AMC 25.1302: 7.6 Flight Crew Error Management (…)*
> *To comply with CS 25.1302(d) the design should:*
> *a. Enable the flight crew to detect, and/or recover from the errors; or*
> *b. Ensure that effects of flight crew errors on the airplane functions or capabilities are evident to the flight crew and continued safe flight and landing is possible; or*
> *c. Discourage flight crew errors by using switch guards, interlocks, confirmation actions, or similar means, or preclude the effects of errors through system logic, redundant, robust, or fault tolerant system design.*

These regulatory and advisory materials are explicit. Error is part of human nature, but interfaces must not contribute to error, errors must be detectable, and possibly recovered from. A model of human error is described in these materials, as well as methods to obtain compliance.

The SAE ARP 5288 text sheds some interesting light on evaluation (very similar to what is written in AC/AMC 25-11). Special attention is given to the test program, which must include a sufficient number of flight tests and simulator tests with a representative sample of pilots to ensure the following:

- *Reasonable training times and learning curves;*
- *Usability in an operational environment;*
- *Acceptable interpretation error rates equivalent to or less than conventional displays;*
- *Proper integration with other equipment that uses electronic display functions;*
- *Acceptability of all failure modes not shown to be Extremely Improbable; and*
- *Compatibility with other displays and controls.*

Here is another example illustrating the need to test the system with humans: performance demonstration expected out of the JAR HUD 901 for category III operations is based on achieving 1,000 simulated landings and 100 real-life landings. These landings must be performed by at least 10 pilots, with different experience levels, with an up-to-date license, and having received the same HUD training as airline pilots.

Indications provided in present regulations on evaluation methodology are limited. As of now, certifiers do not have any specific texts dealing with HUDs and explicitly describing the method to be used and the evaluation steps. The latest texts dealing with Human Factors evaluation have not yet been customised to HUDs.

In a first step, we shall address regulations on HUDs (chapter 1), then mention the evaluation techniques available (chapter 2). We will then split the approach in two: first how to assess compliance with regulations through static confrontation (chapter 3), and second, evaluations made by staging dynamic tests (chapter 4). In these two cases, we shall identify all possible points of suspicion.

1. HUD reference documents and regulations

1.1. Certification rules

The basic certification rules are now common to EASA and FAA:

CS/FAR-25 Large aeroplanes : especially the following paragraphs:

25.773 Pilot compartment view
25.777 Cockpit controls
25.1301 Function and installation
25.1303 Flight and navigation instruments.
25.1309 Equipment, systems and installations
25.1321 Arrangement and visibility
25.1323 Airspeed indicating system
25.1329 Automatic pilot system
25.1333 Instrument systems
25.1381 Instruments lights
25.1523 Minimum flight crew.

JAR OPS 1 sub part E : All weather operations, including use of hybrid[1] HUDs

JAR OPS 4 sub part 3 : All weather operations with HUD guidance, including hybrid HUDs

HUD specific rules:

JAR HUDS 901 & ACJ Category 3 operations with a head up display (non hybrid, nor dual)

JAR HUDS 902 & ACJ Category 2 operations with a head up display (non hybrid, nor dual)

JAR HUDS 903 & GM Head up displays (all types).

1.2. Acceptable means of compliance and advisory circulars

AMC 25.11 EFIS (EASA, CS 25 book 2, equivalent to FAA AC 25-11)

FAA AC 120-28D Category III operations

FAA AC 120-29A Category I and category II operations

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1 Fail-operational hybrid landing system : A system which consists of a primary fail-passive automatic landing system and a secondary independent guidance system enabling the pilot to complete a landing manually after failure of the primary system. Note: A typical secondary independent guidance system consists of a monitored head-up display providing guidance which normally takes the form of command information but it may alternatively be situation (or deviation) information.

These texts may be completed by other texts related to specific issues, such as the FAA *memorandum policies*:

FAA Memorandum Policy: Airspeed Displays for Electronic Flight Instrument Systems (EFIS), Feb. 25, 1992.

FAA Memorandum Policy: Low and High Speed Awareness Cues for Linear Tape Airspeed Displays. Sept. 12, 1996.

The JAA Certification Review Items (CRI) and FAA Issue Papers (IP) define the means of compliance to be used within each certification programme.

Among these, some Special Conditions complement the existing regulations, as needed for particular certification cases involving a novel or unusual element (e.g. : dual HUD).

FAA Special Conditions: Lockheed Martin Aerospace Corp. Model L382J Airplane. May 9, 1997.

FAA Special Conditions: McDonnell Douglas Corporation (MDC) Model MD-17 Series Airplanes. Dec. 30, 1999.

1.3. SAE documents

SAE ARP 4101 Pilot visibility from the flight deck

SAE ARP 4102/8 Flight Deck, Head-Up Displays, 1998.

Recommendations for HUD design.

SAE ARP 5287 Optical Measurement Procedures for Airborne Head-Up Display (HUD), March 1999

SAE ARP 5288 Transport Category Airplane Head Up Display (HUD) Systems, 2000.

An exhaustive design guide, specific to the HUD.

SAE AS 8055 Minimum performance standard for airborne head up display, 1999.

Technological indications for HUD design.

1.4. Regulation organisation

The above referenced texts may be categorised according to:

- their destination and status,
- which type of instrument they are applicable to,
- which concept of use they address (Appendix 1),
- which operation category and flight phase they are applicable to (Appendix 2).

These factors are discussed below.

The destination and the status of the text

The texts may be destinated for use either by the designer, by the certification team, or by the aircraft operator. They may have various status (requirement, acceptable means of compliance, advisory circular, temporary guidance,…). Anyway these distinctions should be used with care, as for instance the design, certification and operation stages are now hopefully closely inter related.

The type of instrument

A HUD is definitely a particular type of flight instrument. As such, a hierarchy of regulatory texts may be applicable:

- CS-25 , as a flight instrument ;
- AMC 25-11, as an electronic flight instrument ;
- JAR HUDS 903, 902 & 903, depending on the proposed operation category, which are specific to the HUD.

It has to be noted that some requirements generally applicable to flight instruments are not directly applicable to a HUD; such as, for instance, colour requirements for warning indications. This is a reason why specific HUD texts have been published; these texts provide supplementary requirements in order to compensate for the HUD specific characteristics. For instance they may require that flashing should be used instead of red colour.

The concept of use

Some requirements are applicable whatever is the concept of use; some are only applicable to one concept.

So, the EASA/JAA texts:

- for the monitoring and hybrid HUD concepts : JAR HUDS 903, CS-AWO, JAR OPS 1
- for the manual HUD concept, with guidance: JAR HUDS 901, 902, 903, JAR OPS 4.

The FAA text (AC 120-28D and 120-29A) are common to all three concepts, with special paragraphs for the hybrid HUD concept.

The operation category

The applicable regulation obviously depends on the operation category for which certification is to be obtained:

- CS-25, JAR HUDS 903 are applicable to all operation categories ;
- supplementary regulation is applicable to low visibility operations :
  - FAA AC 120-29A, JAR HUDS 902 or CS-AWO subpart 2 for category II ;
  - FAA AC 120-28D, JAR HUDS 901 or CS-AWO subpart 3 for category III.

The phase of flight

The following flight phases or situations are usually addressed because of their particular requirements for the use of a HUD: rollout, take-off, cruise, unusual attitudes, approach, flare and go-around…

1.5. Regulation synthesis

A synthesis of the current regulation inventory is provided in Appendix 3.

A general conclusion is that a linear lecture of the regulations is usually not easy nor relevant, due to the complexity of the existing regulation. Expertise and text interpretation are required from the designer as from the certification expert.

A more detailed comparative analysis of the European versus the American regulation has been conducted in a first part of this study.

The analysis of the **general rules**, not HUD specific, shows only some minor differences between the European and the American regulation.

These texts and especially the EFIS regulation already provide some relatively detailed specifications concerning the constitution of the basic flight and navigation symbology.

The texts **specific to the HUDs** contain some adaptations taking into account the specificities of this kind of instruments; their comparison reveals larger differences, depending on the intended type of operation and on the intended concept of use.

Nevertheless, this comparison also indicates a consensus about some fundamental HUD characteristics:

- Monochromatic (also multi coloured HUD are now appearing), collimated at optical infinity and conformal to the external vision;
- Necessary consistency with the head down displays and the cockpit environment ;
- The information to display first depends on the category of operation and on the concept of use (manual control or monitoring).

The European and the American texts address the issue of HUD symbology in a very similar way. They do not show a deep difference between their views of the role of a HUD, and they are all based on implicit requirements concerning the information which should be displayed, rather than on how this information should be displayed. For instance, the shape, size, location, digital or numerical format of the symbols are seldom described, except for the most essential basic T information.

Two main points can be drawn from the comparison of the HUD specific regulation:

- The JAR HUDS appear clearer and better organised than the FAA AC 120-29a and 120-28d; they address the functional issues, rather than the physical aspects of the equipment, which seems to be a better adapted rationale ;
- The FAA regulation provides several supplementary requirements regarding the use of hybrid HUD, including a required proof of concept for category III operations.

Last, an effort is carried out by FAA to compensate for the lack of a general HUD document. Two draft texts are worth considering in an attempt to harmonise the HUD regulation: the new SAE ARP 5288 and the FAA working paper on certification criteria.

As a conclusion, the differences between the American and the European regulation remain minor; more significant differences among the approaches of HUD issues may be rather found in their **interpretation** by the experts.

As a conclusion, beyond the existing regulation, the constitution of a symbology results of a compromise between the different needs of:

- the designer : concept of use, commercial image and benefits, cost of the certification;
- the regulation authority : guarantee some minimum standards;
- the certification team : insure a global performance and safety level within the intended use;
- the airline : economically measurable operational benefits;
- the aircrew: insure an efficient strategy given his instruction, background and experience ; safety and comfort of the passengers.

1.6. Regulation related to HF evaluation

1.6.1. Early references

An effort has been carried out for several years by the civil aviation authorities in order to build a regulation with the aim to better formalise how the human factors should be taken into account during the certification process.

For instance, the FAA issued two policy statements:

FAA Policy memo ANM-99-2. Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks. September 29, 1999.

Provides a comprehensive review and practical methods to insure that the certification plan addresses human factors.

FAA Policy memo ANM-01-03. Factors to Consider When Reviewing an Applicant's Proposed Human Factors Methods of Compliance for Flight Deck Certification, Feb 14, 2001.

A revised and augmented version of ANM-99-2.

The JAA issued a special condition, describing their HF interim policy :

JAA Project of interim policy. Human Factors Aspects of Flight Deck Design, Issue 2, 15-03-2001.

This Special Condition addresses the 'human factors' aspects of the novel items, especially in the flight deck, which are not adequately addressed by JAR 25 existing requirements.

This interim policy is no more applicable in Europe, since the transfer of authority from JAA to EASA. It will be replaced by the draft paragraph FAR/CS 25.1302 and its corresponding AC/AMC, which has been prepared by the HF harmonisation group and which is further discussed below.

1.6.2. A new reference paragraph

FAR/CS & AC/AMC 25.1302 Installed Systems and Equipment for Use by the Flight Crew. EASA NPA n°15/2004.

This rule and its AC/AMC addresses the design and approval of installed equipment intended for the flight crewmembers' use from their normally seated positions on the flight deck. The guidance is not mandatory and does not constitute a regulation ; it *describes acceptable approaches to compliance. It also provides recommendations for the design and evaluation of controls, displays, system behaviour, and system integration, as well as design guidance for error management.*

Analysis of the rule and of its explanatory notes: application to the HUD (chap 7.1)

Explanatory notes accompany the rule. Its text is reproduced below, with some explanations for the case of the HUD:

This section applies to installed equipment intended for the flight crewmembers' use in the operation of the airplane from their normally seated position on the flight deck.

As such, the rule is applicable to the HUD intended to be used by a crewmember from his/her normally seated position.

This installed equipment must be shown, individually and in combination with other such equipment,…

The certification must considered the HUD individually and in combination with other equipment. More especially, the HUD must not display information conflicting with other equipment.

…to be designed such that qualified flight crewmembers trained in its use ..

The HUD evaluation must consider aircrews with adequate qualification and level of training. Moreover, the specific needs in terms of qualification or training which may be require to use the HUD must be identified during the certification process.

…can safely perform their tasks associated with the intended function by meeting the following requirements:

The HUD equipment must be shown to be adequate to perform the intended tasks, in normal and non-normal conditions, within the required time and precision, with the expected level of safety and without interfering with the other necessary concurrent tasks.

(a) Flight deck controls must be installed and information necessary to accomplish these tasks must be provided,

The HUD must provide the information as required to perform the task…

(b) The flight deck controls and information intended for the flight crew use must:

(1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task, and

…in a clear –understandable in the context of use- and unambiguous –especially regarding the actions required to perform the task- form, at resolution and precision appropriate to the task. In particular, for instance and if this corresponds to the intended function, the HUD should allow large amplitude manoeuvres (e.g. trajectory interception) and fine piloting tasks (attitude control). Default of precision may result in a poor trajectory tracking, and on the opposite, an excess of precision may induce a useless workload to perform the task. The absence of ambiguity may not be obvious, for instance when an interpretation of the direction of a corrective action is required (e.g.: to compensate a speed deviation).

(2) Be accessible and usable by the flight crew in a manner consistent with the urgency, frequency, and duration of their tasks, and

The use of the HUD must be consistent with the urgency, frequency, and duration of the task for which it is intended. In particular, its use must not induce an excessive fatigue considering the duration of the task.

(3) Enable flight crew awareness, if awareness is required for safe operation, of the effects on the aircraft or systems resulting from flight crew actions.

According to this rule, the HUD must enable flight crew awareness, if required for safe operation, of the effects on the aircraft or systems resulting from flight crew actions. This relates especially to modes of operation, monitoring and alerts awareness.

(c) Operationally-relevant behavior of the installed equipment must be:

(1) Predictable and unambiguous and

(2) Designed to enable the flight crew to intervene in a manner appropriate to the task.

More specifically, automated changes of mode or of display format must be predictable and unambiguous.

(d) To the extent practicable, the installed equipment must enable the flight crew to manage errors resulting from flight crew interaction with the equipment that can be reasonably expected in service, assuming flight crews acting in good faith. This subparagraph does not apply to skill-related errors associated with manual control of the airplane.

This paragraph assumes that even well qualified and trained flight crew will make errors in their normal interactions with the equipment. In particular, data entry errors have to be considered (mode of operation, reference glide slope, runway length or altitude,…).

Methodological approach to certification compliance (chap. 6)

The recommended approach consists of three steps:

1st step : Identify systems, components and features in terms of degree of novelty, complexity, and integration.

2nd step : Identify how the requirements apply to the selected systems, components, and features and which aspects of the design require substantiation.

3rd step : Select appropriate means of compliance.

Design approval objectives (chap. 7)

This chapter is intended to help the applicant to identify what should be shown to demonstrate compliance. The objectives are associated with several topics, the following being more specifically applicable to the case of a HUD:

- Intended function and associated tasks (7.2): A formal task analysis is not required; some questions are provided to help evaluate whether the statement of intended function and associated task is sufficiently specific and detailed. The precision, resolution, integrity, reliability, timeliness and update rate of the information are mentioned as compliance criteria.
- Presentation of information (7.4): qualitative and quantitative display formats, consistency within the flight deck, standardisation, symbol position and priority, clutter and system response to control input are discussed among other issues.
- System behaviour (7.5): Acceptable workload, fatigue, task sharing and distribution of tasks during normal and non-normal operations, shared awareness, understanding and anticipating of mode selections and transitions are to be considered for showing compliance.
- Flight crew error management (7.6): This chapter addresses error detection, recovery and effects, assuming that flight crew errors cannot be entirely prevented and that no validated method exist to reliably predict either their probability or all the sequences of events with which they may be associated.
- Integration (7.7): this section addresses the installation and integration of the equipment into the flight deck, including consistency with the other flight deck instruments and the associated possible trade-offs, flight deck environment (ambient light and readability issue), as well as integration related workload and errors (presenting the same information in two different formats and presenting conflicting information are given as two examples that may impact error or workload).

Means of compliance (chap. 8)

A list of questions is proposed to help selecting an appropriate means of demonstrating compliance, among six general means that are found acceptable to demonstrate compliance of flight deck equipment:

1. Statement of Similarity
2. Design Descriptions
3. Calculation and Engineering Analysis
4. Evaluations (by the applicant)
5. Demonstrations
6. Tests (with the certification authorities present)

Conclusion on this new paragraph

Among the regulatory texts dedicated to human factors evaluation, the new paragraph 25.1302 and its AC/AMC represents a considerable achievement compared to the previous ones which were difficult to apply (interim policy); it is also remarkable in that it should first come into force on the European side.

The application of the proposed recommendations and methodologies from this paragraph to the case of the HUD evaluation is further discussed next in this draft guide.

2. Ergonomic techniques available for HF HUD certification

The HF evaluation carried out for certification draws extensively from methods used in ergonomics. On the one hand, this makes things easier: there is a set of well-tested and shared methods. On the other hand, it raises a difficulty: to what extent are methods used in ergonomics compatible with the objectives of certification?

Even though HF certification and ergonomics both deal with human beings and their characteristics, they have different purposes and the relationship between the two disciplines is often paradoxical.

The purpose of certification is to ensure that:

- the material certified has reached the safety level required by enforceable legislation;
- the material has no shortcomings that may jeopardise safety or escape the control of users and operators, based on the available operational knowledge.

Compliance with regulations and absence of recognised shortcomings are obtained and verified throughout the material's life span, from design to final commissioning. In this framework, certification is equal to defining a "minimum acceptable standard".

HUD evaluation for HF certification has two phases:

- The first step of the acceptance is done in reference to the regulations short-listed to this end.
- The second step supplements the first one, by putting the equipment to test, and having it also checked by the certifiers. At this stage of the process, there is a close interaction between regulations, equipment characteristics, and test feedback.

The ergonomic approach is of different nature. It occurs in the context of "good practices" to improve working conditions. The point here is to use the knowledge acquired on human performance to develop models predicting this behaviour, or predicting the performance obtained in given conditions of interaction with technical devices whose characteristics are known. Working conditions can be more accurately fine-tuned once interactions are better known.

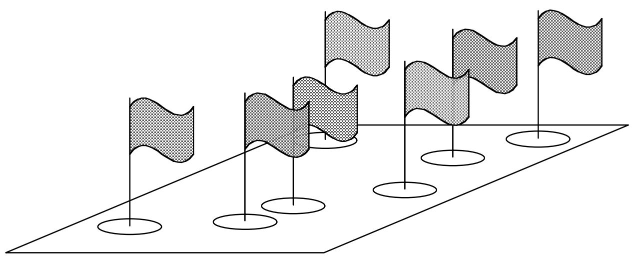
However, this situation leads to a paradox between ergonomics and certification. Methods in ergonomics seem best suited to HF certification requirements, even though they aim at results that go beyond present HF certification needs.

Nevertheless, human factors involved in certification are more or less in line with the general methods used in ergonomics. Great strides have lately been made in certification, with the human dimension being increasingly taken on-board in cockpit design. Ergonomics methods have suddenly near-invaded certification, which before tended to only be concerned with technique. This new approach, where ergonomics are to be factored in, is perfectly illustrated by the existence of a "Human Factors" component in certification. Certification requirements are changing, as designers and certifiers increasingly master these methods.

2.1. Points of suspicion

The key HF evaluation question in a certification process is to know what you are looking for. There are many possible analyses, there are many different contexts of use, the potential failures that need to be identified could be manifold. Because of this great combination of factors, and of the extensive field of investigation, certification teams usually decide to focus on points of suspicion.

A point of suspicion is a case where the interaction between equipment features, context, and actions to be performed may be problematic. Experience tells us that it is usually necessary to go and check how the manufacturer of a specific equipment actually dealt with all parameters involved in the interaction: "what symbology is to be used in case of a go around?", "How is this new symbol displayed ?".



Points of suspicion eventually make up a sort of grid covering the entire area of investigation.

The list of all points of suspicion requiring further investigation is drawn from the experience obtained by certifiers in this area, and from innovations created by the designer, which now need to be evaluated.

The strategy deployed when using points of suspicion is also useful, because it can serve as a reference when drafting investigations and staging in-situ tests. These targeted in-situ tests are expected to help better observe how the system of symbols works in general conditions, and how it reacts to specific conditions of use. Consequently, initial points of suspicion can be further investigated or diversified, depending on the results obtained during the initial investigation. Other more specialised investigation techniques come as a supplement.

This strategy using points of suspicion has been earmarked here as the general HF evaluation framework.

2.2. Difference between preliminary evaluation / in-situ evaluation

The HF evaluation of a HUD can be separated into two different phases:

- The first phase aims at assessing how well the equipment complies with the diverse characteristics of human operation. This can be obtained by comparing the data produced by any in-situ test. This comparison can be later supplemented, in situ, by the use of measurement tools during the staged test.

- The second phase aims at assessing the flight performance that may be obtained with this system. The performance may be quantified by staging an in-situ test, either in a simulator, or in flight, in a real aircraft. The flight profiles, the pilots and the scenarios used to produce these staged tests may then be diversified.

2.3. Methods for preliminary evaluation

2.3.1. Theory

These methods share a common principle, which is to compare reference data with available data on the device provided by the designer. However, the diversity of possible confrontations is great, because HF parameters cover an extensive domain, from physiological aspects (legibility, font size, light, colour characteristics...) to cognitive dimensions (compatibility of symbols between head up displays and other displays, ...).

The preliminary assessment, per se, is carried out in two stages. When the HUD is ready for in-flight tests, it has already been extensively investigated and assessed. Anthropometric and geometrical aspects have been covered by the designer during early certification stages. Know-how and rules are already established. The manufacturer's skill allows for their integration without requiring extra-work for HF certification. These elements are globally and indirectly assessed during in-situ tests, which will help perceive the correct match between all parameters chosen by the manufacturer. Points of suspicion of this nature will be short-listed at the beginning of the preliminary evaluation.

The second stage of the preliminary evaluation is devoted to equipment specificities (symbology, failures,...). Points of suspicion make it possible to review all relevant confrontations.

The chart found below shows the main steps involved in our approach:

- Describing the point of suspicion;
- Reference documents the evaluation can be based on;
- Comparisons to be made;
- Data obtained from comparisons;
- Interpretation of results obtained.

Each point of suspicion will be detailed according to this chart.

2.3.2. Practice

The chart found below shows the reference grid used for each point of suspicion short-listed in the preliminary evaluation:

Point of suspicion regarding compliance
Description of the point of suspicion
Comparison to be made

Reference texts and data	
Comparison data	
Interpretation of results	

Note :

Reference texts and data provided in the charts are only excerpts of the literature available at the time this guide was drafted. They do not aim at being comprehensive. Additional information can be found in original documentation, but was left out to save space. It is signalled by (...). In any case, please refer to the documentation in force.

2.4. In-situ evaluation methods

Task analysis, modelling, analysis of verbalisations, use of questionnaires can be carried out with very different tools. Ergonomics has a wealth of different methodologies, going from the simplest to the most sophisticated, using more or less detailed data and different levels in the depth of interpretations.

A Human Factors evaluation can be done with fairly simple methods, even if it requires using sophisticated techniques (simulators). For this reason, we shall describe a set of techniques adapted to today's certification framework.

In ergonomics as well as in certification, procedural steps for in-situ observation are similar, since the staging of human behaviours must be clearly focused:

1. Defining expected and non-expected behaviours, in relation to existing models of human operation (known models of such operation).
2. Setting up provisions adapted to observing these behaviours (task analysis, scenarios, and subjects).
3. Collecting behavioural data.
4. Interpreting results.

Given the speed with which new methods are being mastered and with which new simple and user-friendly tools are disseminated, we will try and indicate all new possibilities regarding further developments in certification methodology.

2.4.1. Definition of expected behaviour – Modelling

Models provide a generic knowledge of how human beings function. A model is a predictive and descriptive instrument. This means it can be used, ex-ante, to anticipate and predict possible behaviours, and ex-post, to describe and explain behaviours observed.

Models are derived from the generic and academic knowledge of how human beings function, and from the hands-on experience of practitioners such as pilots or HF specialists, who are also proficient in analysing human activities in situ.

Models can have various degrees of accuracy. The minimum required for any model is to factor in general HF concepts regarding the way humans function regarding errors, perception and communication modalities inside the cockpit. This makes it possible to predict what types of errors are likely to occur, which perception conflicts between Head Up and Head Down may exist, and what difficulties lie in sharing available data.

Modelling provides source information on the expected and non-expected behaviours of user pilots. A correctly designed system should not allow for anyone to be confused when using it. However a pilot may, for some reason, suddenly mix-up two symbols. Being mixed-up is not an expected behaviour, but it may happen. The expected result now becomes the fact that one or another of the pilots has cleared up the mix-up and has not allowed for the propagation of any negative consequence of this mix-up.

Available knowledge on human operation in-situ can be put into perspective, through the model, with the action framework produced by task analyses and the real-life situation scenarios developed for purposes of validation. This is why these two methodological steps, i.e.: modelling and task analysis, supplement each other and can be carried out simultaneously.

2.4.2. Provisions required to observe behaviours

Task Analysis

The purpose of task analysis is to define contexts, interactions, status of systems, and actions of each crewmember, in line with recognised practice and enforceable regulations. Task analysis results in a formal set-up including all actions and behaviours of people and systems.

A definition is offered by AC/AMC 25.1302: "*A formal analytical method used to describe the nature and relationships of complex tasks involving a human operator".*

Task analyses can have different formats:

At the simplest level, it is a mere formal description of tasks to be carried out in a given environment. It is a checklist of actions, states, with a time line and decision-making elements, aimed at obtaining well-identified results.

More sophisticated task analyses focus on risks potentially associated with the completion of actions (APR, AMDEC,...).

Task analysis is key to help identify in which context the different elements of the chosen operational model will help predict errors, difficulties in perception or in decision-making.

Staging in-situ scenarios

Combining modelling and task analysis produced a list of critical activities and contexts. The scenario operationally stages a number of sequences, aimed at checking the behaviours pilots might have in a specific situation. In other words, a scenario has two sides: a staging context where the crew performs in a nominal fashion, and a set of "traps" into which pilot and crew are not expected to fall or to come out of easily.

HUD certification requires using scenarios staging as many situations as possible, with respect to points of suspicion and their corresponding traps.

Scenarios are either **local**: they are then dedicated to one operational aspect of the HUD in a given context, or **global**: in such case, they implement all aspects of flying, including the HUD.

Local and global scenarios include the staging of normal and incident-prone situations and can be derived:

- from the preliminary model and its assumptions regarding pilot behaviour;
- from the knowledge of types of system failures (the point here is to use data directly linked to HUD operational safety).

A key point in evaluation is to make sure the situations simulated in the scenarios match realistic uses of HUDs. The scenario must involve the entire crew, even if HUD use is limited to the PF, because interactions play a major role. Whenever staging lacks coherence or realism, it will merely be "performed" by pilot and crew, with little investment or personal involvement.

Selecting the subjects: number, profile, skills

Evaluations entailing situation staging can be done with two types of pilots: airline pilots, and test pilots, be they under state contract or under private contract with aerospace companies.

By trade and experience, test pilots pay more attention to possible consequences of new devices. They are trained to observe, and are keen on detecting all possibilities entailed by the new device.

Airline pilots view innovation from a different angle: they have an extensive experience of flight routine, and of contexts of use. They will look at the device in a pro and con approach (pro: time saving, con: time required for training, change in habits required).

Any new HUD has to be tested on both kinds of pilots. According to JAA and FAA (JAR HUS 9001, FAA AC120-28D), the initial certification of a HUD for category III approaches on new aircraft requires at least 1,000 simulated landings and 100 real-life landings, with at least 10 different pilots of various levels of experience.

FSB reports also provide useful indications on the number of subjects to be used when evaluating a new device.

Several test phases must be planned for a steady sample of pilots, with time set aside between sessions for assimilation. This time helps take into account the adaptation strategies implemented after discovering the device. Subjects can then be controlled at different points in time (longitudinal study) along their HUD learning curve, and the evaluation can factor in behaviour variability, thanks to the amount of subjects tested.

In practice, it is best to have, on the one hand, a steady sample for validation, and on the other hand, as large a set as possible of "one-shot" testers.

Whatever their profiles and follow-up opportunities, pilots must be observed both individually and collectively, in order to collect data factoring in the variability of strategies according to crew make up and competence. The reason for this is that installing a HUD will not just modify the pilot's strategy, but that of the entire crew.

Collecting behavioural data

Two kinds of data families are traditionally encountered in scientific literature: objective data, made up of technical and physiological measures, collected during the activity, and subjective data, involving the operator's point of view on the activity carried out. These data are collected before or after having placed the operator in situation.

Most frequently encountered objective technical data are:

- difference with prescribed flight parameters: flight path, altitude, speed, ...
- time needed to carry out a manoeuvre, to detect a critical element, to identify a failure.
- number of times the task fails to be carried out properly, number of identification errors.

Objective physiological data are mentioned for information purposes only, because collecting them requires specialised and high-level skills. They deal with recordings of eye, heart, muscle or brain activity.

Subjective data can result from:

- questionnaires
- semi-directed interviews
- activity characterisation scale-setting, aiming at assessing how aware the operator is of the situation (ex: SA-SWORD), or of the workload (ex: Cooper-Harper, NASA-TLX...).

These data are usually supplemented by additional techniques:

- Videos recording the sequence of operations and pilot actions;
- Observation criteria, depending on expected behaviours;
- Elicited or spontaneous verbalisations;
- Structure and plans of tasks performed by pilot and crew;
- Systematically questioning the pilot after a task is performed, to outline the pilot's logic and strategy.

There are a great number of data to be selected and combined according to the analysis carried out, and to the possibilities offered by the evaluation device. Associating the two categories of data is best, but each type of data has its own implementation difficulties when aiming at certification.

Objective technical data are always directly linked to the technical possibilities offered by the simulator, which is not always pre-designed to collect this kind of data. It is not always easy to obtain and collect data for a statistical analysis. Another type of problem is encountered with this type of data: the number of pilots being tested is not always sufficient to allow for statistical analyses. Subjective data remain the main solution for evaluation purposes.

Interpretation of results

The interpretation of results is key to any HF validation. However, interpretation is not an easy task. In HF, simple success/failure criteria are seldom found. Conversely, noting that a pilot made an error cannot be a sufficient reason to reject a device.

Elements of AMC 25.1302 (d) shed useful light on results to be interpreted.

As regards human error, devices should not contribute to it, and should allow for its detection and/or recovery from it. If no recovery occurs, the consequences of the non-recovered error must be neither hazardous, nor catastrophic.

In the case of HUDs, the interpretation of results must be put in perspective with the use made of the HUD.

A HUD is not a dialogue interface associated to parameter insertions. It either helps control an automatic pilot process, or provides reference information used to fly the aircraft directly.

- The first case addresses the control of a process, which means that the pilot must always maintain an adequate and updated representation, to take over the stick if automatic systems suddenly fail.
- In the second case, the HUD is a direct flight system, providing information the pilot will use in real-time to adjust the flight path.

2.4.3. Practice

The four steps mentioned above will be carried out according to the typical chart found below, and used for each situation staging a point of suspicion:

Point of suspicion	
Description of the point, as produced by practice and feed-back	
Expected or unexpected behaviours	
Available models help specify what behaviours are considered as expected or unexpected.	
Reference texts and data	
Elements required for observation	
Collection of behavioural data	
Interpretation of results	

3. Points of suspicion compatible with a preliminary evaluation

This all-encompassing checklist highlights the major characteristics identifying a generic HUD. Reviewing these items makes up a sort of "ID" in the initial stage of HF certification, since each of the point will have a specific value for a given HUD.

The three first points of suspicion are reckoned to have been mastered during early design. They only require a general validation during the staging of situations, by verifying that characteristics used by the manufacturer are adequate:

1. Collimation
2. Field of vision and eyebox
3. General characteristics of the symbology

On the contrary, the following points of suspicion must be assessed "on paper", before actual tests.

4. Consistency of sources
5. Display of failures
6. Pilot position
7. Brightness adjustment

3.1. Collimation

Point of suspicion regarding compliance	
The collimation is the optical effect produced by the HUD combiner: the symbols are focused so that they appear at optical infinity, which considerably reduces the need for the eyes to accommodate when successively viewing the external world and the symbology. This characteristic is now accepted as a necessary feature of a HUD. The recent introduction of collimated head down displays has to be noticed. The collimation favours the physiology of human vision; however, it doesn't guarantee an ecological integration of the HUD symbols within the 3D outside view. As a matter of fact, the perception of depth –and the proper interpretation of a scene- is naturally based on some properties of the scene elements that the symbols do not provide: light and shade, location in the vision plan, perspective, relative size, texture gradient, lost of colour saturation with distance, etc. This concurrence between physiologic and cognitive vision cues may result in the fact that HUD symbols are perceived by the pilot as predominant over the outside scene.	
Comparison to be made	
Reference texts and data	SAE AS 8055 : *When applied to a HUD system, optical infinity refers to a condition when the image distance to the virtual display is such that the horizontal parallax for 95% of all possible look angles and head position within the HUD eye box is less than 3.5 mrad. This represent an optical image distance of at least 18 m.* SAE ARP 5288 : 11.15 : *The symbols should be presented as a virtual image focused at optical infinity, i.e. located at such a distance that rays of light appear parallel.*
Comparison data	Verify that the data provided by the applicant are compatible with the reference data regarding the optical properties of the display. The user's behavioural aspects are not addressed at this stage.
Interpretation of results	The interpretation of the results is processed in two steps: 1) A key is the methodology used to collect the relevant data. The methodology should aim at determining the level of validity of these data before any attempt of interpretation. The precision of the data as supplied by the optics manufacturer is a valuable input. 2) Their level of validity being estimated, the interpretation of the data focuses on the level of adequation of the applicant system with the reference texts. The reference texts specifies that collimation is to be understood as optical infinity, i.e. an optical image distance of at least 18 meters. The HUD is not the only possible cause of pilot's vision distortion; the windshield may also alter the natural vision, so that the collimation has to be considered through the HUD and the windshield. The windshield manufacturer may provide the required information on the optical characteristics of the windshield. A resulting collimation between 18 and 30 meters will be considered as acceptable.

3.2. Field of vision and eyebox

Point of suspicion regarding compliance	
The field of vision is the angular field of view provided by the HUD. It is generally specified in degrees vertical and degrees horizontal. Two types of field of view are usually considered : • The total field of view (FOV) defines the maximum angular extent of the display that can be seen with either eye allowing head motion within the eyebox. • The instantaneous FOV (IFOV) is comprised of what the left eye sees plus what the right eye sees from a fixed head position within the HUD eyebox (the normal head position when using the HUD). The eye box is a three dimensional volume specified by the HUD manufacturer in which certain optical performance requirements are met, typically from which all critical symbology elements should be visible. Its dimensions should be sufficient for normal use of the HUD without causing excessive pilot workload or discomfort. The eyebox actually fixes the head position and so the possible accesses to the cockpit while using the HUD. The installation should be compatible with the variety of morphologies, especially pilots' size (refer also to "pilot position").	
Comparison to be made	
Reference texts and data	CS 25.1321(a) : *Requires that each flight instrument for use by any pilot be plainly visible at that pilot's station, with minimum practicable deviation from the normal position and forward line of vision.* SAE AS 8055, SAE ARP 5288 5.2 : *The design of the HUD installation should provide adequate display fields-of-view in order for the HUD to function correctly in all anticipated flight attitudes, aircraft configurations, or environmental conditions such as crosswinds for which it is approved. Limitations should be clearly specified in the AFM if the HUD can not be used throughout the full aircraft flight envelope.* *The FOV characteristics shall be specified by the HUD manufacturer and shall be consistent with the intended function of the HUD. The amount of vertical and horizontal head movement needed to see the total FOV should not cause excessive pilot workload or discomfort.* *The HUD Eye Box shall wholly contain a Cockpit Head Motion Box, defined as a three dimensional spatial volume, geometrically centered at the cockpit Design Eye Point, which minimum size is as follows :* *Lateral: 76.2 mm (3.0 in.)* *Vertical: 50.8 mm (2.0 in.)* *Longitudinal: 101.6 mm (4.0 in.)* SAE ARP 5288 7.1.1 : *To support effective information transfer, the "present values" of attitude, airspeed/mach, barometric altitude, and heading should be located within the pilot's central vision when looking through the HUD. For the purposes of this document, this is a circular region with a 15° radius cone about the HUD field of view established by the manufacturer.* *In keeping with the HUD visibility criteria detailed in 5.2.6, critical information for each HUD application and phase of flight must be viewable from any point within the Cockpit Head Motion Box.*
Comparison data	Verify that the data provided by the applicant are compatible with the reference data regarding the optical properties of the display (dimensions of the eyebox) and the visibility of the symbols.
Interpretation of results	The reference texts encompass the issues to be addressed: - Minimum dimensions of the eyebox. - Symbol visibility in the various formats of the display. The actual

	visibility from the eyebox has to be explored given the possible extent of the symbol dynamics (cross wind, unusual attitudes,…). The head movements possibly required to view the peripheral zone of the display must be also assessed. A “map of visibility” from the eyebox could help to identify the possibly missing information likely to impact the usability of the HUD by the pilot in-situ.

3.3. General characteristics of the symbology

Point of suspicion regarding compliance
Modern HUD symbologies are built around a set of analogue and conformal symbols complemented by the display of altitude and speed values in a digital format, which provide the necessary information for primary flight control. The basic symbology has been extensively studied, and their format is now almost stabilised. The composition of a symbology essentially depends on its intended concept of use and of the proposed types of operations. The Appendix 4 provides a description of the main HUD symbols found on most current HUD products. The symbols **conformity** relates to the presentation of certain information conformal to the outside scene, so that: • The horizon reference actually appears superimposed over the actual horizon (taking into account the deviation due to the aircraft altitude); • One degree of a conformal heading scale actually corresponds to a viewing angle of one degree; • An inertially driven velocity vector provides an instantaneous indication of where the aircraft is going; • A conformal synthetic runway symbol is actually superimposed over the actual runway (given the accuracy of navigation data, runway databases and pilot's data entry). The conformity of its main symbols is widely acknowledged as a specificity and a strong benefit of a HUD in most usual situations. The principle of conformity may not be applied to encompass various particular situations: • Strong cross wind or flight at high angles of attack: the displacement of some usually conformal symbols may then exceed the HUD field of view. Their displacement may be limited to the limits of the field of view (caging) providing this limitation in the displacement is clearly noticeable by the pilot (for instance the symbol may be "ghosted", meaning it is displayed as dashed lines rather than solid lines); • High pitch angle (at take off or during a go around): the pitch scale may be compressed, and so no longer conformal, in order to keep the horizon reference within the HUD field of view. • Unusual attitudes: the recognition of and the recovery from such a situation may be facilitated by automatically displaying a specific symbology; this symbology may include a compressed non-conformal pitch scale. The **redundancy** of symbol characteristics: systematic use of redundant coding parameters is recommended for the symbols that need separation because of the criticality of their information content. In the case of a monochrome HUD, in order to compensate for the lack of colours, the shape, size and location may be used as possible redundant parameters; other solutions have also been developed (flashing, dashed or boxed symbols,..). The adequacy of the solutions used to **present 3D information** (e.g.: ILS deviation indications, speed error tape,…) on the two dimensions HUD also have to be considered. By

the way, the "natural and intuitive" characteristics of a symbol may not be obvious for the whole user population. **The standardisation of the symbology** is usually encouraged. In particular, the texts published by the SAE actively contribute to the standardisation effort: they constitute a state of the art, aiming for "recognition as an American National Standard". However, excessive standardisation may hinder some potentially beneficial innovations.	
Comparison to be made	
Reference texts and data	CS/AMC 25.1302 (a) : *… information necessary to accomplish the tasks associated with the intended function must be provided…* CS 25.1302 7.7.2 : *(…) promote consistency rather than rigid standardisation.* CS 25.1303 Flight and navigation instruments. *(b) The following flight and navigation instruments must be installed at each pilot station:* *(1) An airspeed indicator. If airspeed limitations vary with altitude, the indicator must have a maximum allowable airspeed indicator showing the variation of VMO with altitude.* *(2) An altimeter (sensitive).* *(3) A rate-of-climb indicator (vertical speed).* *(4) A gyroscopic rate of turn indicator combined with an integral slip-skid indicator (turn-and-bank indicator) except that only a slipskid indicator is required on aeroplanes with a third attitude instrument system usable through flight attitudes of 360º of pitch and roll, (…)* AMC 25.1303(b)(5) Attitude displays *1.1 For turbo-jet aeroplanes each display should be usable over the full range of 360° in pitch and in roll. For propeller-driven aeroplanes the pitch range may be reduced to ± 75° provided that no misleading indication is given when the limiting attitude is exceeded.* *(…)* *1.3 The display should take the form of an artificial horizon line, which moves relative to a fixed reference aeroplane symbol so as to indicate the position of the true horizon.* *NOTES:* *1 It is acceptable for the fixed reference aeroplane symbol to be positioned so that it is aligned with the horizon line during cruising flight.* *2 If a variable index is provided in addition to the fixed aeroplane symbol it should be so designed that it will not introduce any risk of misinterpretation of the display.* *1.4 There should be no means accessible to the flight crew of adjusting the relationship between the horizon line and the reference aeroplane symbol.* *1.5 The artificial horizon line should move in roll so as to remain parallel to the true horizon, i.e. when the aeroplane rolls through an angle of 30° the artificial horizon line should also rotate through 30° relative to the fixed index.* *1.6 The artificial horizon line should remain in view over a range of pitch attitudes sufficient to cover all normal operation of the aeroplane plus a margin of not less than 2° in either direction. Additional 'ghost' horizon lines should be provided parallel to the main horizon line so that beyond this range at least one such line is in view at an attitude with the range of the display.* *1.7 The pitch attitude scale should be sensibly linear while the main horizontal line is in view, but may become non-linear beyond this range.* *All the attitude displays in the aeroplane should have a similar presentation so as to prevent any risk of confusion in transferring attention from one display to another.* *1.9 Sufficient pitch and bank angle graduations and markings should be provided to allow an acceptably accurate reading of attitude and to minimise the possibility of confusion at extreme attitudes.* *1.10 A bank angle index and scale should be provided. The index may be on the fixed or moving part of the display.* *1.11 The 'earth' and 'sky' areas of the display should be of contrasting colours or shades. The distinction should not be lost at any pitch or roll angle.* *1.12 Any additional information (e.g. flight director commands) displayed on an attitude display should not obscure or significantly degrade the attitude information.* *1.13 The display should be clearly visible under all conditions of daylight and artificial lighting.*

	1.14 Words that may be ambiguous (e.g. 'climb', 'dive', 'push', 'pull') should not be used. *(…)* CS 25.1321 Arrangement and visibility *(b) The flight instruments required by CS 25.1303 must be grouped on the instrument panel and centred as nearly as practicable about the vertical plane of the pilot's forward vision. In addition –* *(1) The instrument that most effectively indicates attitude must be on the panel in the top centre position;* *(2) The instrument that most effectively indicates airspeed must be adjacent to and directly to the left of the instrument in the top centre position;* *(3) The instrument that most effectively indicates altitude must be adjacent to and directly to the right of the instrument in the top centre position; and* *(4) The instrument that most effectively indicates direction of flight must be adjacent to and directly below the instrument in the top centre position.* AMC 25-11 5b : Colour Perception vs. Workload *(…) Each symbol that needs separation because of the criticality of its information content should be identified by at least two distinctive coding parameters (size, shape, colour, location, etc.).* 7a : basic T, 7d : PFD, 7e : attitude, 7f : digital, analogue and combinations. SAE ARP 5288 3.3 (PFD) *The set of informational components displayed on a HUD <u>used as a PFD</u> should include, as a minimum, the flight references specified in FAR/CS §25.1321. Other components required for display on a HUD are dependent on the other phases of flight and flight operations supported by the HUD. These additional components are mainly related to the display of command guidance or the display of aircraft situational information. For example, if the HUD is to be used to monitor the autopilot, the following additional information should be displayed:* *a) Situation information based on independent raw data;* *b) Autopilot operating mode if autopilot reversion is necessary;* *c) Autopilot disconnect warning.* *Additional information should also be displayed if required to perform aircraft maneuvers during phases of flight which the HUD is approved. These may include:* *a) Flight path indication;* *b) Target airspeed references and speed limit indications;* *c) Target altitude references and altitude awareness (e.g., DH, MDA) indications;* *d) Heading or course references.*
Comparison data	The comparison should allow to evaluate to what extent the applicant system satisfies the reference texts. The comparison should address the characteristics of all symbols individually (conformity, coding redundancy,…) as well as being an element of the symbology (relevance, standardisation,…).
Interpretation of results	Interpretation there is quite easy as it mainly concern the physical characteristics and behaviour of the symbols displayed. The confrontation of each symbol characteristics with the specifications provided in the reference texts should be of valuable help. A symbol may be either inspired from a proven concept or it may be new and then should be easily differentiated from the other symbology elements.

3.4. Consistency of sources

Point of suspicion regarding compliance	
The consistency of the information sources needed by the HUD is a potentially weak point for its reliability and safe use: Two aspects may have to be addressed depending on the intended use: - The internal consistency of the sources used by one HUD. Modern HUD systems actually have their own monitoring algorithms. - The independency of the sources used for monitoring by the aircrew, whether using the HUD and a HDD or a second HUD (dual HUD concept). The use of non-independent sources should be annunciated to the flightcrew. The adequacy of the value of the threshold used to check the consistency of independent sources also has to be evaluated.	
Comparison to be made	
Reference texts and data	CS 25.1333 Instrument systems (a) *(a) For systems that operate the instruments required by CS 25.1303 (b), which are located at each pilot's station, means must be provided to connect the required instruments at the first pilot's station to operating systems, which are independent of the operating systems at other flight crew stations, or other equipment.* AMC 25-11 8.c (following SAE ARP 5288 9.2) : *(1) Independent attitude, heading, and air data sources are required for the pilot and co-pilot primary displays. (…). If sources to the electronic displays can be switched in such a fashion that the flight crew becomes vulnerable to hazardously misleading information on both sides of the cockpit as a result of a common failure, then this switching configuration should be accomplished by a cautionary alert in clear view of both pilots.* *(3) If a crew member can select from multiple, similar, navigation sources, such as multiple VORs or multiple, long-range navigation systems, then the display of the selected source data into a CDI type presentation should be annunciated (i.e. VOR 1, INS 2, etc.). The annunciation should be implemented in such a fashion that a non-normal source selection is immediately apparent. In addition, when both crewmembers have selected the same navigation source, this condition should be annunciated; for example, the co-pilot has offside VOR selected, with VOR 1 annunciated in amber/yellow in the co-pilot's electronic display. Exceptions to this non-normal annunciation requirement can be constructed. If the similar navigation sources are two navigation computers that ensure position and stored route identically through a cross-talk channel, electronic display of normal or non-normal source annunciation would not be required provided a system disparity was annunciated. In the case where source annunciations are not provided on the electronic displays, such source annunciations should be readily obvious to the crew.* *(4) The increased flexibility offered by modern avionics systems may cause flight crews to be more susceptible to selecting an inappropriate navigation source during certain phases of flight, such as approach. Since electronic displays may incorporate more complex switching, compensating means should be provided to ensure that the proper navigation source has been selected. In order to reduce the potential for the pilot selecting a non approach qualified navigation source for an instrument approach, unambiguous annunciation of the selected navigation source shall be provided. (…)* SAE ARP 5288 8.5 : *The HUD and HDD formats and data sources need to be compatible to ensure that the same information presented on both displays have the same intended meaning. (…)* *f) Information source should be consistent.*
Comparison data	The comparison of the data provided by the applicant and the reference text comes under the initial technical step of the certification process.
Interpretation of results	The reference texts are explicit and detailed regarding this issue; they lead to establish an organigram of the data, of their sources,

	processing and destination. This organigram will be used to identify the possible combinations where the crosscheck by the flightcrew may be hindered.

3.5. Display of failures

Point of suspicion regarding compliance	
A distinction has to be made between the display of an aircraft system failure and the display of a HUD internal failure. The display philosophy depends on the failure criticality and on the flight phase. The display of an aircraft system failure on the HUD may be required by the regulation, depending on its intended use (namely, primary flight display or not). The associated risk of an excessive visual or informative load is to be considered, together with the risk of non-detection if the display format is not adequate ("information getting techniques"). The possible HUD failures are subject to specific recommendations (see SAE ARP 5288): the resulting invalid indications have to be removed, abnormal operations should be annunciated,… The possible display of fixed information resulting from a failure of a source system is known as particularly insidious. Specific solutions in the case of a monochrome HUD have to be used to compensate for the lack of colour and to differentiate the type of alert.	
Comparison to be made	
Reference texts and data	CS 25.1309 *(c) Information concerning unsafe system operating conditions must be provided to the crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimize crew errors, which could create additional hazards.* AMC 25-11 8d : *In the case of a detected failure of any parameter, the associated invalid indications should be removed and only the flag should be displayed. It is recommended that differentiation be made between the failure of a parameter and a 'no computed data' parameter, e.g. non-reception of radio navigation data.* AMC 25-11 10 : integrated warning, caution and advisory displays *a. A 'warning' should be generated when immediate recognition and corrective or compensatory action is required; the associated colour is red. A 'caution' should be generated when immediate crew awareness is required and subsequent crew action will be required; the associated colour is amber/yellow. An 'advisory' should be generated when crew awareness is required and subsequent crew action may be required; the associated colour should be unique, preferably not amber/yellow. (…)* *b. Caution and warning displays are necessarily related to aural alerts and master caution and warning attention-getting devices. . (…)* SAE ARP 5288 9.4 : HUD alerting issues *HUDs, when used as PFDs, should provide the equivalent alerting functionality as current HDD PFDs. Warnings that require continued crew attention on the PFD, should be presented on the HUD, e.g., TCAS, Windshear, and Ground Proximity Warning annunciations. If master alerting indications are not provided within the peripheral field of view of the pilot while using the HUD, the HUD shall provide annunciations that inform the pilot of caution and/or warning conditions.* *To the extent that current HUDs are single color devices, cautions and warnings should be emphasized with the appropriate use of attention-getting properties such as flashing, outline boxes, brightness, size, and/or location.* CS/AMC 25.1302 7.5.5 : 5 : Displays for Automated Systems *The applicant should consider the following aspects of automated system design: (…)* *b. If the automated system nears its operational authority or is operating abnormally for the conditions, or is unable to perform at the selected level, it will inform the flight crew, as appropriate for the task;*
Comparison data	The comparison here consist in verifying what are the solutions

	proposed by the applicant in order to efficiently convey the information relative to the various types of alerts and failures, and to the resulting limitations of the systems. It must be noticed that the issue of failure is wide, as it encompasses : - the failures of aircraft systems, - the limitations of use of automated systems, - the possibly dangerous context of flight, - the adequate coding of information on the HUD, - the possible interaction of the display of failures on the HUD with its visual or auditive annunciation elsewhere in the cockpit.
Interpretation of results	At this stage of preliminary “paper” comparison of the applicant’s proposals with the reference requirements or recommendations, the interpretation concern the proposed solutions as described by the applicant. These solutions will be further validated during the in-situ evaluation.

3.6. Pilot position

Point of suspicion	
The use of the HUD requires the proper positioning of the pilot's head within the eyebox, the processing of the visible symbology elements, the ease of access to aircraft controls and other displays as required by the circumstances. The analysis of this point may be achieved using two complementary views: - The alignment markers, the possible seat adjustments should be adequate given the variability of pilots' morphologies (anthropometry). The position must not generate excessive workload or discomfort. A preliminary verification concerns the adequation of the proposed system with the reference documents. - This point will be also evaluated in-situ, by checking that the use of the HUD do not result in excessive fatigue or discomfort. The range of use time is large, as the HUD might be used for a short duration such as in an approach phase, as well as for several hours if the HUD is intended for use in cruise.	
Comparison to be made	
Reference texts and data	CS 25.1302 : *(b) The flight deck controls and information intended for the flight crew use must: (..)* *(2) Be accessible and usable by the flight crew in a manner consistent with the urgency, frequency, and duration of their tasks, and..* CS 25.1321 (a) *(a) Each flight, navigation, and powerplant instrument for use by any pilot must be plainly visible to him from his station with the minimum practicable deviation from his normal position and line of vision when he is looking forward along the flight path.* SAE ARP 5288 (referring to CS 25) : *5.2.4 : §25.773 (d) requires that fixed markers or other guides must be installed at each pilot station to enable the pilots to position themselves in their seats [at the Design Eye Position (DEP)] for an optimum combination of outside visibility and instrument scan. The HUD installation is not required to provide any additional markers or guides.* *§25.777 requires that cockpits must accommodate pilots from 158 cm to 191 cm tall, seated with seat belts fastened and positioned at the DEP. The requirements of §25.1321, 25.773 and 25.777 apply to the HUD installation, and the HUD installation should not diminish or impair compliance of the cockpit to these requirements.* *The visibility of the critical flight information displayed on the HUD is paramount to the HUD's intended function. The HUD installation must provide continuous visibility of this critical information from the cockpit DEP.* *5.2.6 : The field of view performance of the HUD and its installation in the cockpit needs to be tolerant of a certain amount of natural, involuntary displacements of the pilot's head from the DEP, to maintain continuous visibility of the critical flight information. Therefore, the critical flight information displayed on the HUD must be visible from any point within the Cockpit Head Motion Box.* *The design and installation of the HUD should not place physiologically burdensome fatigue, visual stress, or limitations on head position.*
Comparison data	The comparison must address the eyebox position and dimensions, the visibility of the outside scene and the seat position, taking into account the statistical range of size and morphology of the targeted population of users. The evaluation must also address the accessibility of the aircraft controls by this population, as necessary while using the HUD. It is formalised as a gaussian curve of the sizes and morphologies compatible with the system under evaluation.

	The maximum aircraft attitudes that are likely to limit the visibility of the outside world from the eyebox through the HUD will also be determined depending on the intended use and on the possible seat and position adjustments.
Interpretation of results	A spatial map of the HUD cockpit accessibility may result from the evaluation. This map materialises the possible access and use of the aircraft controls as required while simultaneously using the HUD, for a population of pilots with representative morphologies.

3.7. Brightness adjustment

Point of suspicion	
The possible adjustment of the brightness level of the HUD symbology has to be verified for all the foreseeable circumstances of use: daylight with various lighting conditions, sunlight in the pilot's eye, dark night,… In particular, the minimum brightness level needs to be small enough to avoid a possible masking of outside scene elements in dark conditions. The current technical norms provide sufficient data to define the acceptable range of brightness level in the case of a traditional monochrome green-phosphor symbology. They are not well established for polychrome symbologies making use of diversely efficient phosphors and/or techniques (LCD).	
Comparison to be made	
Reference texts and data	AMC 25.1302 7.7.4 Flight Deck Environment *It should also be recognized that the flight deck system is influenced by the physical characteristics of the aircraft into which a system is integrated, as well as the environmental characteristics. Thus, the system is subject to influences in and on the flight deck such as turbulence, noise, ambient light, smoke, and vibrations (such as those that may be due to ice or fan blade loss). Design of the system should recognize how such influences may affect usability, workload, and crew task performance. Turbulence and ambient light, for example, may affect the readability of a display. (…)* CS 25.1381 Instrument lights *(b) Unless undimmed instrument lights are satisfactory under each expected flight condition, there must be a means to control the intensity of illumination.* AMC 25-11 *6.b Chromaticity and Luminance* *(1) Readability of the displays should be satisfactory in all operating and environmental lighting conditions expected in service. Four lighting conditions known to be critical for testing are –* *(i) Direct sunlight on the display through a side cockpit window (usually short term with conventional window arrangements).* *(ii) Sunlight through a front window illuminating white shirts, which are reflected in the CRT (a function for the CRT front plate filter).* *(iii) Sun above the forward horizon and above a cloud deck in the pilot's eyes (usually a prolonged situation and the most critical of these four).* *(iv) Night and/or dark environment. Brightness should be controllable to a dim enough setting such that outside vision is not impaired while maintaining an acceptable presentation.* *(2) When displays are evaluated in these critical lighting situations, the display should be adjusted to a brightness level representative of that expected at the end of the CRT's normal useful life (5000 to 20000 hours), or adjusted to a brightness level selected by the manufacturer as the minimum acceptable output and measurable by some readily accomplished maintenance tests. If the former method is used, adequate evaluations should be performed to ensure that the expected end of life brightness levels are met. Some manufacturers have found, and the Agency has accepted, that 50% of original brightness level is a realistic end of life value. If the latter method is used, procedures should be established to require periodic inspections, and these limits should then become part of the service life limits of the aeroplane system. (…)* *(4) Electronic display systems should meet the luminance (photometric brightness) levels of SAE Document ARP 1874. A system designed to meet these standards should be readily visible in all the lighting conditions listed in paragraphs 6.b. (1) and 6.b. (2), and should not require specific flight testing for luminance if the system has been previously installed in another aeroplane with similar cockpit window arrangements. If the display evaluation team feels that some attributes are marginal under extreme lighting conditions, the following guidelines may be used:*

	(i) The symbols that convey quick-glance attitude and flight path control information (e.g., horizon line, pitch scale, fixed aeroplane symbol and/or flight path symbol, sky pointer and bank indices, flight director bars) should each have adequate brightness contrast with its respective background to allow it to be easily and clearly discernible. *(ii) The combination of colour and brightness of any subset of these symbols, which may, due to relative motion of a dynamic display, move adjacent to each other and use colour as an aid for symbol separation (e.g. flight director bars and fixed aeroplane symbol), should render each symbol distinctly identifiable in the worst case juxtaposition.* *(iii) Flags and annunciations that may relate to events of a time critical nature (including warnings and cautions defined in paragraph 10. of this AMC as well as flight control system annunciations of mode reversions) should have a sufficient contrast with their background and immediate environment to achieve an adequate level of attensity (attention getting properties). (…)* *(iv) Analogue scale displays (heading, air data, engine data, CDIs, or course lines) should each have adequate brightness with its respective background to allow it to be easily and clearly discernible. (…). Symbols used as targets and present value pointers in juxtaposition to a scale should remain distinct. If colour is required to convey the meaning of similar shaped targets or indices, the colour should remain easily discernible.* *(v) Flags and annunciations should still be visible at low display brightness when the display is adjusted to the lowest usable level for flight with normal symbology (day or night).* *(vi) Raster fields conveying information such as weather radar displays should allow the raster to be independently adjustable in luminance from overlaid stroke symbology. The range of luminance control should allow detection of colour difference between adjacent small raster areas no larger than 5 milliradians in principal dimension; while at this setting, overlying map symbology, if present, should be discernible.* *(5) Automatic brightness adjustment systems can be employed to decrease pilot workload and increase tube lifetime. Operation of these systems should be satisfactory over a wide range of ambient light conditions including the extreme cases of a forward low sun and a quartering rearward sun shining directly on the display. A measure of manual adjustment should be retained to provide for normal and abnormal operating differences. In the past it has been found that sensor location and field of view may as significant as the tube brightness dynamics. Glareshield geometry and window location should be considered in the evaluation.* See also SAE ARP 5288 6.2 and SAE ARP 8055 4.3 for more details.
Comparison data	The HUD brightness adjustment has to be evaluated from dark night flight conditions to day flight at high altitude involving very high level of ambient light, including direct sunlight. Between these two extreme conditions of use, two characteristics determine the possible usability of the display: - The HUD chromatic quality should be maintained to allow a correct interpretation of the symbology information coding. - The contrast level between the symbology and the background must be sufficient to insure an appropriate legibility under extreme lighting conditions. Another difficulty may be encountered during a low visibility approach where the brightness level is initially adjusted to a low level in order to avoid a blinding effect when the runway lights appear. It may be necessary then to rapidly adjust the brightness level to maintain the visibility of the symbology. An easy access of the brightness adjustment is critical in this case. Automatic brightness adjustment systems are not always appropriate, as they make use of a measure of the ambient light rather than a measure of the brightness of the HUD symbology background.

Interpretation of results	The interpretation results in two diagrams expressing the following characteristics as functions of the ambient light conditions: • The chromatic (wave length) stability of the symbology in low, medium, high and very high levels of light conditions. • The contrast values under the same levels of light conditions.

4. Points of suspicion requiring an evaluation in situation

The use of a HUD is questioning by many aspects, which may be addressed during the certification. Beyond the general methodological frame discussed in chapter 2, the previous certification experiences and the scientific literature highlight several points, which have to be analysed. These points are hereafter called ‘Points of suspicion’.

The Points of suspicion discussed below are classified from the most physical/physiologic to the most cognitive:

1. Symbol interpretation
2. Head-down display compatibility
3. Mode logic and annunciation, mode confusion
4. Clutter
5. Piloting performance using the HUD
6. Use in dynamic manoeuvres
7. Use in transition manoeuvres
8. Use at unusual attitudes and pilot’s spatial representation
9. Workload induced by the HUD
10. Information sharing among the flightcrew, interaction in a HUD equipped cockpit
11. Operational integration of the HUD
12. Imaging HUD (EVS)
13. Dual HUD

The two last points are related to emerging new concepts for which the available experience and the evaluation methodology are still to be established. They are addressed with fewer details than the others, because it was not possible to conduct a detailed analysis with the users and with the certification experts, as it was done during the first part of this study for the other points.

4.1. Symbol interpretation

Point of suspicion

The recommendation for correct interpretation of the symbol elements is the following:

> *"Display elements and symbology (…) should be natural, intuitive, and not dependent on training or adaptation for correct interpretation." (AC/AMC 25-11, 7.)*

This recommendation constitutes an ideal, since one has to be conscious of the fact that HUD symbols may be natural and intuitive only for pilots sufficiently used to electronic symbologies. By the way, the SAE ARP 5288 poses the ease of becoming familiar in the use of the HUD as the first criteria to be checked (reasonable training times and learning curves).

The problem is particularly noticeable with 2D representations in the vertical plan of the HUD of information of different natures: ILS bars, speed bugs,.. These representations are subject to interpretation in a sense opposite to the expected one. The problem is particularly critical in case of unusual attitude recovery.

Together with coloured representations, the avionics industry now proposes several symbolic displays including pseudo 3D representations (3D volume presented in perspective on a 2D plan, often known as 2D and a half or 2,5D, based on the work carried out for military applications in the 80's or 90's) of approach trajectories or taxi paths for instance. These new types of 3D representations have to be considered together with the existing symbols.

Expected or unexpected behaviour

The quality of the pilots' interpretation of the symbology elements may be evaluated through two distinct indicators :

- Expected behaviours: appropriate use of the displayed information, timely reaction to the information, consistent use during dynamic situations. In other words, the use of the information in situation must be easy, fast (result of an easy learning and acquisition transfer from other system) and stable (maintained in time despite a relatively seldom use of some modes).
- Unexpected behaviours: many general phenomena may indicate a specific difficulty of use: confusion, delays, approximate interpretation, inter-individual variations in practice…

Texts and references	CS 25.1302 : *(b) The flight deck controls and information intended for the flight crew use must:* *(1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task, and (…)* AMC 25.1302 7.4.2 : clear and unambiguous presentation of information : *a) Qualitative and quantitative display formats* *b) Consistency* *c) Characters, fonts, lines and scale markings* *d) Colour* *e) Symbology, text and auditory messages* AMC 25.1303(b)(5) Attitude displays AMC 25-11 5.b : Colour perception vs workload *(…) Each symbol that needs separation because of the criticality of its information content should be identified by at least two distinctive coding parameters (size, shape, colour, location, etc.).* AMC 25-11 7.e : Attitude *An accurate, easy, quick-glance interpretation of attitude should be possible for all expected unusual attitude situations and command guidance display configurations. The pitch attitude display scaling should be such that during normal maneuvers (such as take-off at high thrust-to-*

<table>
<tr><td></td><td>weight ratios) the horizon remains visible in the display with at least 2° pitch margin available. * In addition, extreme attitude symbology and automatically decluttering the EADI at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal maneuvering). Surprise, unusual attitudes should be conducted in the aeroplane to confirm the quick-glance interpretation of attitude. The attitude display should be examined in 360° of roll and ± 90° of pitch. This can usually be accomplished by rotating the attitude source through the required gyrations with the aeroplane powered on the ground. When the aeroplane hardware does not allow this type of evaluation, accurate laboratory simulations must be used.
SAE ARP 5288
7. Information display
Display elements and symbology used in airplane control should be natural, intuitive, and not unduly dependent on training or adaptation for correct interpretation. (…)
7.1 General
7.3 Attitude
8.1 Standard symbology
(..) To the degree possible symbology should use self-explanatory shapes and movements rather than abstract representations of the information to be conveyed.
8.2 Symbol position
(..)The position of a message or symbol within a display conveys meaning to the pilot. Without the consistent or repeatable location of a symbol in a specific area of the HUD, interpretation errors and response times may in-crease. (..)
8.3 Clutter,…</td></tr>
<tr><td>Elements required for observation</td><td>Several conditions have to be matched in order to efficiently evaluate the ease of interpretation of a HUD symbology :
- The symbology has to be used in a realistic context (credibility of the scenario in situation) ;
- The level of knowledge and understanding of the equipment functioning by the subjects involved in the evaluation ;
- Tasks producing results and behaviours allowing to objectivate the possible deficiencies in the information interpretation (lags, incorrect actions, confusion,…).

Ground simulators are the more appropriate tools in order to produce a controlled context of use of the various symbologies that are to be evaluated.

A succinct task analysis may help specify the circumstances in which a difficulty in the symbology interpretation may be suspected.

The scenario materialises the creation of contexts allowing the observation of the subject pilots. The scenario must also produce observable data revealing the possible difficulties of the subjects.
The level of familiarity of the pilots with the symbologies is a key point when analysing the results :
• If the aim is to evaluate the spontaneity of interpretation by pilots non-familiar with the symbology, then they should be naive and will only make use of their previously existing knowledge.
• If the aim is to evaluate the ease of interpretation by the flight crew in a routinary situation, then the crew has to become familiar and is</td></tr>
</table>

	level of familiarity has to be checked against an expected level of performance.
Collection of behavioural data	The collected data are directly related to the exact objective of the evaluation performed: one symbol or a set of symbols, in a simple or complex situation, either static or dynamic, with familiar or non-familiar pilots,… Two types of methods allow to structure the collection of data : • **Observation in situation**: hesitations, errors or reaction delays may indicate a wrong interpretation of the role and usage of symbols by the subject population. • **Post observation interviews**: they are very useful to complement the observations by providing numerous indices regarding the strategies and the nature of the difficulties faced by the pilots and flight crews. An interview may be complemented by a **questionnaire** (opinions and ratings) centred on the level of familiarity with the available symbols and modes. The subjects are then oriented by the questions, which may prove beneficial for the homogeneity of the results but which may also prevent to capture some difficulties under specific circumstances.
Interpretation of results	Although the symbols should be intuitive enough to allow a precise, immediate interpretation under any circumstances of the intended use, the level of familiarity with the symbology is a key condition. Any wrong reading by a subject, resulting in a strong reaction opposed to the actions that should be performed, is highly significant of a deficiency in the pilot-symbology interaction. This shouldn't be seen in the subjects' behaviour. If such a reaction is observed, it must be detected, recovered or limited in a time delay compatible with the aircraft situation. The pilot only can not be charged with the responsibility of the deficiency: his/her level of training, the information available and the nature of the symbols to be used also have to be questioned. The complementary data collected through the interviews are the only sources that may help understand the mechanisms behind the deficiency.

4.2. Head-down display compatibility

<table>
<tr><th colspan="2">Point of suspicion</th></tr>
<tr><td colspan="2">According to the regulation, the symbols shown on the HUD must be compatible with the symbols of the head-down displays (HDD). More precisely, it is not allowed to use the same symbol to represent different information contents, and it is preferable not to present the same information with different formats. Yet, this recommendation, if poorly understood, may result to build the HUD symbology as a direct copy of the head down displays (e.g. HSI). different formats may be suitable depending on the design and the pilot's task, if there is no ambiguity with other symbols.
Historically, it has to be noticed that some transfer in the design of symbologies have happened from the HUD to the HDD. For instance, a symbol showing the velocity vector has been added to some recent head down flight instruments symbologies (PFD).
The transition between the head-up and head-down displays must not pose any difficulty whatever the flight phase with intended use of the HUD.
Beyond the choice of symbol format, compatibility must encompass the flight deck concept of use: the HUD has to be integrated within the cockpit environment in a manner consistent with its design philosophy.</td></tr>
<tr><td>Reference texts and data</td><td>AMC 25.1302
7.4.2 Clear and unambiguous presentation of information
Where similar information is presented in multiple locations or modes (e.g., visual, auditory), consistent presentation of information is desirable. Consistency within the system in information presentation tends to minimize flight crew error. If information presentation cannot be made consistent within the flight deck it should be shown that differences do not increase error rate or tasks times leading to significant safety, flight crewmember confusion, or flight crew workload implications.
7.7 Integration, incl. integration related workload and error
AMC 25.1303(b)(5) :
1.7 (..) All the attitude displays in the aeroplane should have a similar presentation so as to prevent any risk of confusion in transferring attention from one display to another.
AMC 25-11
8.c Source switching and annunciation
(7) Mode and source select annunciations on electronic displays should be compatible (this does not mean that the labels have to be identical, but that they are unambiguous in being able to identify them as the same function) with labels on source and mode select switches and buttons located elsewhere in the cockpit.
SAE ARP 5288
8.5 Head Up/Head Down Display Compatibility
The HUD and HDD formats and data sources need to be compatible to ensure that the same information presented on both displays have the same intended meaning. HUD and HDD display parameters should be consistent to avoid misinterpretation of similar information, but the display presentations need not be identical. (…)</td></tr>
<tr><td>Elements required for observation</td><td>The task analysis is a preliminary step aiming to identify in which circumstances the compatibility with the information presented on the head down display may be a key element to keep control of a situation and so to insure the flight safety.
Two dimensions must be addressed through this task analysis:
- The general homogeneity between the HUD and HDD symbologies;
- The critical case of a transition between head-up and head-down</td></tr>
</table>

	(whatever the direction) where the compatibility is necessary to avoid any delay or misinterpretation of information. The evaluation scenario in the ground simulator must allow to put the subjects in a situation where uses of HUD and HDD information are required, either simultaneously, if consistent with the concept of use, or with transitions, due for instance to a failure of one of the displays or a change of flight phase or control mode. The pilots' or flightcrews' proficiency regarding the use of the symbologies, their possible experience with other aircraft or symbologies have to be identified and taken into account to insure a reliable interpretation of the collected data.
Collection of behavioural data	The **observable data** collected during the simulated flights may be the following: slowness of identification, confusion of symbols, inappropriate reaction during a transition, different interpretation when using head-up and head-down information. They express an incompatibility between symbols or possible different dynamics in the displays. **Questionnaires and interviews** may qualitatively complement the data collected during the simulated flights.
Interpretation of results	Any observation of behaviour leading to strong and fast but erroneous reactions during a transition shows a failure of the symbology-pilot couple. If such a failure is observed, it must be identified, recovered or contained within a time compatible with the situation of the aircraft. The compatibility between the head-up and head-down symbologies is at the same time a necessity and a fragile reality in a period of familiarisation of the pilots with the symbologies. Confusions can result from former practices, from actual incompatibilities (same symbol for two different meanings), or from a poor assimilation of the symbols and displays, either head-up or head-down. These points must, as much as possible, be clarified in order to obtain a useful interpretation. The interviews and questionnaires are necessary to raise the doubts and to help the interpretation.

4.3. Mode logic and annunciation, mode confusion

Point of suspicion	
The annunciation of the autopilot modes (typically a vertical mode and an horizontal mode) has to be distinguished from the display of the modes specific to the HUD. As far as possible, these various modes should present a same logic to keep the consistency and to avoid overloads resulting in possible confusion. The use of analogue symbols specific to a mode can allow avoiding the additional display of alphanumeric symbols (for instance: ILS box). The logic of the modes specific to the HUD, in particular when the changes of mode are done automatically, is a critical point to be evaluated as it is for any automated system (AC/AMC 25.1302). The HUD is more than a simple display: the modern HUDs provide several guidance modes (DV, FLARE, ATHR,..) which laws are usually different from the autopilot laws. Their performance and the actual possibility to monitor that they are working properly using the head-down display –if this is consistent with the concept of use- are to be addressed. The problem of **mode confusion** is an aspect of the wide issue of the human-machine coupling and understanding of the machine behaviour by its human operator.	
Expected or unexpected behaviour	
The various autopilot and HUD modes have to be annunciated by appropriate abbreviations and adequate symbologies to avoid possible confusions, in accordance with the regulation. Human error mechanisms help to specify the range of expected or unexpected behaviours. No absence of detection of a change of mode or of its annunciation, nor a misinterpretation of a change of mode must be seen.	
Reference texts and data	CS 25.1302 : *(c) Operationally-relevant behaviour of the installed equipment must be:* *(1) Predictable and unambiguous, and* *(2) Designed to enable the flightcrew to intervene in a manner appropriate to the task.* AMC 25.1302 : *7.5.1 (…) the system behavior needs to be such that a qualified flight crew can know what the system is doing and why. “Predictable and unambiguous” means that a crew can retain enough information about what the system will do under foreseeable circumstances as a result of crew action or a changing situation so that they can operate the system safely.* *(…) if flight crew intervention is part of the intended function of the system the crewmember may need to take some action, or change an input to the system, and therefore the system must be designed accordingly.* *Improved technologies, which have increased safety and performance, have also introduced the need to ensure proper cooperation between the flight crew and the integrated, complex information and control systems. If system behavior is not understood or expected by the flight crew, confusion may result. As system behavior depends on the functions allocated to it and the allocation of such functions also directly affects flight crew tasks, both should be considered in close combination. (…)* *7.5.5 Displays for Automated Systems* *Automated systems can perform various tasks with minimal crew interventions, but under the supervision of the flight crew. To ensure effective supervision and maintain crew awareness on system state and system “intention” (future states) the displays should provide salient feedback on:* *a. Entries made by the crew into the system so that the crew can detect and correct errors.* *b. Present state of the automated system or mode of operation. (What is it trying to do?)* *c. Actions taken by the system to achieve or maintain a desired state. (What is it doing?)*

	d. Future states scheduled by the automation. (What is it doing next?) *e. Transitions between system states. (What is it going to do?)* *The applicant should consider the following aspects of automated system design:* *a. Indications of commanded and actual values enable the flight crew to determine whether the automated systems will perform in accordance with their expectations;* *b. If the automated system nears its operational authority or is operating abnormally for the conditions, or is unable to perform at the selected level, it will inform the flight crew, as appropriate for the task;* *c. Support of crew coordination and cooperation by ensuring shared awareness of system status and crew inputs to the system; and* *d. Enabling the flight crew to review and confirm the accuracy of commands constructed before being activated. This is particularly important for automated systems as they can require complex input tasks.* CS 25.1309 *(a) The aeroplane equipment and systems must be designed and installed so that:* *(1) Those required for type certification or by operating rules, or whose improper functioning would reduce safety, perform as intended under the aeroplane operating and environmental conditions.* *(…)* *(c) Information concerning unsafe system operating conditions must be provided to the crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimise crew errors, which could create additional hazards.* AMC 25-11 8.c Source Switching and Annunciation *When the type or source of information presented on the primary flight instruments can change meaning with manual or automatic mode or source selection, then this mode or source must be inherently unambiguous from the format of the display or from appropriate annunciation. (…)* *(7) Mode and source select annunciations on electronic displays should be compatible (this does not mean that the labels have to be identical, but that they are unambiguous in being able to identify them as the same function) with labels on source and mode select switches and buttons located elsewhere in the cockpit.* *(8) If annunciation of automatic navigation system or flight control system mode switching is provided by the electronic display, selected modes should be clearly annunciated with some inherent attention-getting feature, such as a temporary box around the annunciation. Examples include vertical or lateral mode capture, release of capture, and autopilot or autothrottle mode change.* SAE ARP 5288 5.1.1 : Systems Controls *(..) Certain HUD system controls and mode annunciations may also need to be visible to and accessible by other crew members. (..)* *If a control function is required for HUD mode control or data entry, the control function data entry panel shall be located such that either pilot can easily view and perform all mode control selections from his seated position. HUD mode controls shall be implemented to minimize pilot workload for data selection or data entry.* *Some HUD systems may utilize Multifunction Control Display Units (MCDU), or similar data entry panels, for control and display purposes. For HUDs that provide “Additional Credit” data or guidance information (low visibility take-off guidance, or manual CAT IIIa guidance, are examples), the HUD control information should be immediately available for viewing without further pilot action.* SAE ARP 5288 8.4 : Visual Attention-Getting Techniques *Some HUD functions are intended to notify the pilot of important events. Examples include navigation sensor status changes (e.g. VOR flag), computed data status changes (e.g. flight director flag), and flight control system normal mode changes (e.g. annunciation changes from “armed” to “engaged”).* *Effective visual attention-getting techniques are needed to create an easily noticeable change and yet not be unduly distracting, so as to increase pilot workload. Effective visual techniques include symbol shape/size changes (e.g. temporarily placing a box around freshly changed modes), flashing symbols, and color changes. A legend change by itself is inadequate to positively annunciate automatic or uncommanded mode changes.*

	The use of flashing symbology as a visual attention-getting technique should be applied carefully. While flashing can be extremely effective, it should be used sparingly, (e.g. when immediate pilot intervention may be necessary). Short term flashing of symbols (e.g. approximately 10 seconds or flash until acknowledge) is easily noticable, but a permanent or long term flashing symbol that is non-cancelable can be a significant distraction and should not be used. In addition to its potential for distraction, the excessive use of flashing, whether too often or lasting too long, can reduce its effectiveness. It becomes too commonplace. (…) Test pilots and human factors specialists should carefully evaluate the use of flashing symbology. *To enhance the quick recognition and interpretation of an event (e.g. failure conditions, absence of required data) effective visual attention-getting techniques should be applied with a consistent, codified set of rules. For example, when a technique like dashes is used to indicate no computed data available (NCD) for one category of data, dashes should also be used to indicate NCD for other similar display parameters. When a strike-through line is used to indicate failure of one display parameter or mode (e.g., "ILS," "LNAV"), a strike-through line should be used for all similar failure conditions. Inconsistent use of such techniques can be misleading, with potential safety degradation. For example, the use of strike-through to indicate a non-conformal symbol in one case, and also to indicate a sensor failure would be confusing to the pilot.* *Consistent use of techniques to indicate failure and NCD events within the HUD itself is a prime consideration. Of even greater importance, however, is the requirement for the failure/NCD indications used on the HUD to be consistent with the corresponding failure/NCD indications used on the head down displays. However, use of color coding alone for color capable HUDs would be an inadequate indication of failure/NCD conditions. Outside view background lighting and color can cause color shifts even in monochrome HUDs.* SAE ARP 5288 9.3 : Mode Annunciation : *If annunciation of automatic navigation system or flight control system mode switching is provided by the HUD, selected modes should be clearly annunciated with some inherent attention getting feature, such as a temporary box around the annunciation. Examples include vertical or lateral mode capture, re-lease of capture, and autopilot or autothrottle mode change.*
Elements required for observation	The **task analysis** must focus on the circumstances in which automated aircraft control and HUD mode changes may occur (e.g., related to a transition to a specific flight phase or situation: go around, windshear,..). The **scenarios** to be used must put the flightcrews or pilots in relevant situations, containing for instance the following events: automated changes of symbologies, including possible disappearance of some symbols, whether in normal or non normal situations, important event during approach with associated warning and change of mode, use of special modes (HUD auto test),…
Collection of behavioural data	The behaviours and reactions induced by the events inserted in the evaluation scenario are observed and collected. When inappropriate, they may be related to interpretation difficulty of the display logic, or of an unexpected change of control and/or display mode. An interview possibly complemented by a questionnaire may follow the simulated flight in order to capture qualitative elements providing explicitation of the difficulties actually faced by the pilot.
Interpretation of results	No strong reaction related to an erroneous interpretation or to a default in mode awareness must be seen in these cases of mode changes. If such reaction is observed, it should be identified, recovered or contained within a time delay compatible with the actual aircraft situation.

4.4. Clutter

Point of suspicion
Several recurrent problems while using a HUD (difficulty to detect a non normal slow change of the symbology, absence of perception of an element of the external scene behind the symbology, poorly adapted symbology,..) are related to the mechanisms of human attention. The attention difficulties in the use of the HUD are generally related to the notion of **clutter**. The clutter designates a saturation of the field of view, as may happen when the display uses an excessive number and/or variety of symbols. The clutter may increase the time required to extract the useful information from the display. In the specific case of a HUD, the clutter may also produce a masking of essential elements in the external scene (e.g. traffic, runway obstacles,..). Two ways are suggested to avoid the clutter: use of simple symbol elements and limitation of the number of symbols to those which are actually required to perform the task. Two types of clutter must be distinguished : • The **physical clutter** is directly linked to the number and size of the symbols, or in other words to the filed of view covered by the symbols. The solutions used to avoid this type of clutter consist in simplifying the symbology by removing some symbols (secondary information) or by changing the symbol format (e.g. numerical value instead of a scale). The symbols may also be ranked using a hierarchy/priority order, to avoid the physical masking of an essential information by a secondary one. In operation, the **decluttering** may be automatic as a function of the flight phase (e.g. at touch down) or of the active mode (e.g. cat. III approach mode), or manual depending on the pilot's choice by use of a 'declutter' mode (AMC 25-11, 5e). • The **cognitive clutter** is more difficult to quantify and insidious: it is linked to the difficulty to interpret a large number of symbols, i.e. to the limitation of the amount of information the pilot can perceive, to the design of the symbols elements versus the nature of the information they should convey, or to the focalisation effects on a limited number of the symbols displayed. The trap of an excessive focalisation on the symbology to the detriment of other external and/or internal information elements is a recurrent subject of research. It is hopefully well known of the HUD users, and usually addressed during their instruction. The effect of a cognitive masking of a runway obstacle for instance may happen whatever is the level of physical clutter; this effect can be reproduced with a very simple symbology in laboratory experiments. This effect is actually not specific to a given symbology but to a conflict in the allocation of the attention between the displayed information and the other visible elements. The research literature shows that the symbol conformity is an aiding factor to favour a simultaneous perception of the symbology with the external world, and to limit the cognitive clutter. Parades to this type of clutter must be established within the operational procedures and training, to help the pilot to reconsider his/her priorities and use of the information available. An adequate tuning of the level of symbology luminance is also one of the key parameters.
Expected or unexpected behaviour
The behavioural responses to a cluttered display or cognitive overload are similar to those of information extraction from a large set of data or to the interpretation of a situation

<table>
<tr><td colspan="2">from both a set of displayed data and the current events.
Typical indicators include a default in the detection of a change in the situation, a difficulty to extract the relevant information, a selection of wrong symbols (due to time pressure preventing to find the adequate information source), focalisation on some elements of the symbology, "cognitive" blindness about the context or one of the symbols, incapacity to use the HUD resulting in a transition to a more rudimentary control mode.</td></tr>
<tr><td>Reference texts and data</td><td>AMC 25-11 5. e (identical to SAE ARP 5288 8.3) :
A cluttered display is one, which uses an excessive number and/or variety of symbols, colours, or small spatial relationships. This causes increased processing time for display interpretation.
One of the goals of display format design is to convey information in a simple fashion in order to reduce display interpretation time. A related issue is the amount of information presented to the pilot. As this increases, tasks become more difficult as secondary information may detract from the interpretation of information necessary for the primary task.
A second goal of display format design is to determine what information the pilot actually requires in order to perform the task at hand. This will serve to limit the amount of information that needs to be presented at any point in time.
Addition of information by pilot selection may be desirable, particularly in the case of navigational displays, as long as the basic display modes remain uncluttered after pilot de-selection of secondary data. Automatic de-selection of data has been allowed in the past to enhance the pilot's performance in certain emergency conditions (de-selection of AFCS engaged mode annunciation and flight director in extreme attitudes).
AMC 25-11 7.h : Full-Time vs. Part-Time Displays
CS/AMC 25.1302 7.4.3 b. Clutter :
Clutter is the presentation of information that is distracting from the flight crewmember's primary task. Visual or auditory clutter is undesirable. Information should be presented simply and in a well-ordered way in order to reduce interpretation time. It should be shown that an information presentation (whether visual or auditory) presents the information the flight crewmember actually requires in order to perform the task at hand.
(…) Automatic de-selection of data to enhance the flight crewmember's performance in certain emergency conditions should be shown to provide the information that the flight crewmember requires, because automatically de-cluttering display options can hide needed information from the flight crewmember. Use of part-time displays depends not only on information de-clutter goals but also on display availability and criticality. Therefore, when designing such features, AC/AMC25-11 should be followed.
(…) Information should be prioritised in accordance with the criticality of task; lower priority information should not mask higher priority information and higher priority information should be available, easily discernible, and usable. This does not imply that the display format needs to change based on phase of flight.</td></tr>
<tr><td>Elements required for observation</td><td>The progress of a flight including numerous control actions, use of outside information, transitions between the available information sources and a busy activity of the flight crew has to be considered when building the evaluation scenarios. This requires to address situations involving simultaneously the piloting activity, the management of systems, the communication with the ATC and decision making processes.</td></tr>
<tr><td>Collection of behavioural data</td><td>The behavioural data to be collected from the simulated flight are those mentioned in the unexpected behaviours above.
Interviews or questionnaires are necessary to complement the collected data for a correct Interpretation of results.</td></tr>
<tr><td>Interpretation of results</td><td>Any loss of control of a complex situation which consequences affect the conduct of the flight shall be considered as critical.
The interpretation shall then point out that the HUD symbology is not</td></tr>
</table>

	compatible with the cognitive contraints encountered in a complex flight situation.

4.5. Piloting performance using the HUD

Point of suspicion	
The performances obtained while piloting the aircraft using the HUD -in accordance with the intended use of the HUD to be evaluated- are essential, for large amplitude manoeuvres (e.g.: ILS capture) as for fine tracking task (e.g.: ILS tracking). Their evaluation must take into account the situations in which some symbols may reach the limits of the HUD field of view (strong cross wind, low speeds,…). The level of realism of the simulator is critical for the quality of such an evaluation.	
Expected or unexpected behaviour	
It is awaited of the pilot and of the crew to be able to carry out their piloting task with a level of quality comparable to that obtained with the traditional instruments. Some flight phases are particularly indicating of this level of quality: the final approach, the capture of the ILS beam... It is under such conditions that the quality of piloting or the limits will be examined, especially the imprecision or delay resulting from the use of the HUD and from the characteristics of its symbology.	
Reference texts and data	*CS 25.1302 Installed Systems and Equipment for Use by the Flight Crew* *This section applies to installed equipment intended for the flight crewmembers' use in the operation of the airplane from their normally seated positions on the flight deck. This installed equipment must be shown, individually and in combination with other such equipment, to be designed so that qualified flight crewmembers trained in its use can safely perform their tasks associated with its intended function by meeting the following requirements: (…)* *(b) Flight deck controls and information intended for flightcrew use must:* *(1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task.* *(2) Be accessible and usable by the flightcrew in a manner consistent with the urgency, frequency, and duration of their tasks, (..)* *AMC 25-11 :* *7.d. Primary Flight Displays* *(..)* *(2) Scale Markings* *(i) Air data displays have a requirement similar to attitude in that they must be able to convey to the pilot a quick-glance sense of the present speed or altitude. Conventional round-dial moving pointer displays inherently give some of this sense that may be difficult to duplicate on moving scales. Scale length is one attribute related to this quick-glance capability. The minimum visible airspeed scale length found acceptable for moving scales on jet transports has been 80 knots; since this minimum is dependent on other scale attributes and aeroplane operational speed range, variations from this should be verified for acceptability. Altimeters present special design problems in that –* *(A) The ratio of total usable range to required resolution is a factor of 10 greater than for airspeed or attitude, and* *(B) The consequences of losing sense of context of altitude can be catastrophic.* *The combination of altimeter scale length and markings, therefore, should be adequate to allow sufficient resolution for precise manual altitude tracking in level flight, as well as enough scale length and markings to reinforce the pilot's sense of altitude and to allow sufficient look-ahead room to adequately predict and accomplish level-off. Addition of radio altimeter information on the scale so that it is visually related to ground position may be helpful in giving low altitude awareness. Airspeed scale markings that remain relatively fixed (such as stall warning, VMO/MMO), or that are configuration dependent (such as flap limits), are desirable in that they offer the pilot a quick-glance sense of speed.* *The markings should be predominant enough to confer the quick-glance sense information, but not so predominant as to be distracting when operating normally near those speeds (e.g.*

	stabilised approach operating between stall warning and flap limit speeds). *(ii) Airspeed reference marks (bugs) on conventional airspeed indicators perform a useful function, and the implementation of them on electronic airspeed displays is encouraged. Computed airspeed/angle-of-attack reference marks (bugs) such as Vstall, Vstall warning, V1, VR, V2, flap limit speeds, etc., displayed on the airspeed scale will be evaluated for accuracy. Provision should be incorporated for a reference mark that will reflect the current target airspeed of the flight guidance system. This has been required in the past for some systems that have complex speed selection algorithms, in order to give the pilot adequate information required by CS 25.1309(c) for system monitoring.* *(iii) If any scale reference marks would not be available when equipment included on the MEL is inoperative, then the display should be evaluated for acceptability both with and without these reference marks.* *(iv) Digital present value readouts or present value indices should not totally obscure the scale markings or graduations as they pass the present value index.* *(v) Adjacent scale markings that have potential for interfering with each other (such as V1, VR, V2 in close proximity) must be presented so that the intended reference values remain distinct and unambiguous.* *(vi) At the present time, scale units marking for air data displays incorporated into PFDs are not required ('knots', 'airspeed' for airspeed, 'feet', 'altitude' for altimeters) as long as the content of the readout remains unambiguous. (..)* *(vii) Airspeed scale graduations found to be acceptable have been in 5-knot increments with graduations labelled at 20-knot intervals. If trend or acceleration cues are used, or a digital present value readout is incorporated, scale markings at 10-knot intervals have been found acceptable. Minimum altimeter graduations should be in 30 m (100-foot) increments with a present value readout, or 15 m (50-foot) increments with a present value index only. (…)* *(3) Vertically oriented moving scale airspeed indication is acceptable with higher numbers at the top or bottom if no airspeed trend or acceleration cues are associated with the speed scale. Such cues should be oriented so that increasing energy or speed results in upward motion of the cue. To be consistent with this convention, airspeed scales with these cues should have the high-speed numbers at the top. Speed, altitude, or vertical rate trend indicators should have appropriate hysteresis and damping to be useful and non-distracting. Evaluation should include turbulence expected in service.* *(4) The integration of many parameters into one upper display makes necessary an evaluation of the effect of failure (either misleading or total loss) of a display at the most critical time for the pilot. The sudden loss of multiple parameters can greatly impact the ability of the pilot to cope with immediate aeroplane control tasks in certain flight regimes such as during take-off rotation. If such failures are probable during the critical exposure time, the system must be evaluated for acceptability of data lost to the pilot. Automatic sensing and switching may have to be incorporated to preserve a display of attitude in one of the primary displays on the side with the failure.* *7.e Attitude* *(1) (…). The pitch attitude display scaling should be such that during normal manoeuvres (such as take-off at high thrust-to-weight ratios) the horizon remains visible in the display with at least 2° pitch margin available.* *SAE ARP 5288* *7.4 Flight Path* *An indication of the aircraft's velocity vector, or flight path, is considered essential to most HUD applications. When inertially derived, flight path display information provides an instantaneous indication of where the aircraft is actually going. During an approach this information can be used to indicate the aircraft's impact or touchdown point on the runway. Therefore, the flight path information can be used to set a precise climb or dive angle relative to the conformal outside scene or relative to the HUD's flight path (pitch) reference scale and horizon displays. The lateral orientation of the flight path display should indicate the aircraft's track, or drift, displayed relative to the aircraft's longitudinal axis (boresight).* *Air mass derived flight path may be displayed as an alternative. In this case the lateral orientation of the flight path display represents the aircraft's sideslip while the vertical position relative to the reference symbol represents the aircraft's angle of attack. Therefore, a strong headwind "deflects" the air mass derived flight path downward from its reference compared to a no-*

	headwind approach, while lateral offsets of the flight path from its reference may indicate sideslip due to out-of-trim conditions possibly caused by and engine failure. *The type of flight path information displayed (inertial, air mass, GPS, or other) may be dependent on the operational characteristics of a particular aircraft and the phase of flight during which the flight path is to be displayed.*
Elements required for observation	The task analysis and the flight experience of the flights make it possible to identify the phases of flight and the contexts for which the degree of the piloting performance must be high. Approaches with strong crosswind, ILS beam tracking or flying with high turbulence levels are examples of contexts to be integrated in the scenarios.
Collection of behavioural data	The piloting performance with the HUD will be appreciated in a same manner that for "traditional" piloting: the precision of control of the key flight parameters occupies an essential place. Speed, deviations from the target values, reaction to their evolutions, and global control of the situation constitute the observable data to collect.
Interpretation of results	As for traditional piloting, some expectations and tolerances are associated to the control of the deviations of the flight parameters. They will be used in a similar way to evaluate the handling quality using the HUD.

4.6. Use in dynamic manoeuvres

Point of suspicion	
Some manoeuvres (flare, go-around,..) may induce difficulties with the use of the HUD because of the possible inertia in symbol displacement or because of an inadequate symbology update rate. It is necessary to check the usability of the HUD for these dynamic manoeuvres. The symbology **update rate** determines phenomena that may be particularly disturbing in the case of a HUD, such as flicker or symbology lags during fast manoeuvres. The symbology **latency** and its possible **compensation** (quickening) have also to be considered. The **size and shape** of some symbols have also be found susceptible to affect their use for controlling dynamics manoeuvres (e.g. pitch scale for use in go-around).	
Expected or unexpected behaviour	
This Point of suspicion is related to an interaction between the technological characteristics of the HUD and its use for manual control of the aircraft. The expected behaviour is that the pilot shouldn't feel any difficulty induced by the limitations of the dynamics of some symbology elements when using the HUD in manoeuvres requiring rapid changes of the aircraft attitude or trajectory.	
Reference texts and data	AMC 25-11 *6.e. Dynamics* *For those elements of the display that are normally in motion, any jitter, jerkiness, or ratcheting effect should neither be distracting nor objectionable. Screen data update rates for analogue symbols used in direct aeroplane or powerplant manual control tasks (such as attitude, engine parameters, etc.) should be equal to or greater than 15 Hz. Any lag introduced by the display system should be consistent with the aeroplane control task associated with that parameter. In particular, display system lag (including the sensor) for attitude should not exceed a first order equivalent time constant of 100 milliseconds for aeroplanes with conventional control system response. Evaluation should be conducted in worst-case aerodynamic conditions with appropriate stability augmentation systems off in order to determine the acceptability of display lag.* *Note: An update rate of 10 Hz for some engine parameters has been found acceptable on some aeroplanes.* *SAE ARP 5288 :* *6.5 (similar to AMC 25-11 6.e)* *10.1.4 Simulation* *Simulation is an invaluable tool for display evaluation. Acceptable simulation ranges from a rudimentary bench test set up, where the display elements are viewed statically, to full flight training simulation with motion, external visual scene, and entire airplane systems representation. For minor or simple changes to previously approved displays, one of these levels of simulation may be deemed adequate for display evaluation. For evaluation of display elements that relate directly to airplane control (that is, air data, attitude, thrust set parameters, etc.), simulation should not be relied upon entirely. The dynamics of airplane motion, coupled with the many added distractions and sensory demands made upon the pilot that are attendant to actual airplane flight, have a profound effect on the pilot's perception and usability of displays. Display designers, as well as FAA test pilots, should be aware that display formats previously approved in simulation may well turn out to be unacceptable in actual flight.*
Elements required for observation	The scenarios must permit to reproduce situations inducing a high symbol dynamics (flight with high turbulence levels, strong cross wind, flare and go around, unusual attitude recovery,…) and to collect the possible effects of their limitations.

Collection of behavioural data	Interviews and questionnaires, combined with handling qualities rating scales, are well adapted to collect the pilots' opinion about their difficulties to perform the piloting task using the HUD symbology. The consequences on flight parameters will probably be too small for being observed by objective means.
Interpretation of results	The level of severity of the encountered difficulties and the context of their occurrence will constitute the key elements to interpret the results. A minor difficulty in a non-dangerous context will be interpreted differently than a difficulty appearing in a critical context. The level of realism of the ground simulator and more especially of its dynamics will have to be taken into account for extrapolating the results; in flight evaluation may be required at least to validate the results.

4.7. Use in transition manoeuvres

Point of suspicion	
The use of the HUD in transition piloting tasks (take off rotation, go-around, flare) has been identified as a possible issue. The comparative analysis of the existing symbologies reveals different solutions adopted by the HUD suppliers in order to compensate for the possible limitations of the HUD for use in these transition-piloting tasks. These task impose a change in the way the pilots proceed (e.g. using a manual control mode and then an automatic mode, or vice versa) or in the control cues they use (e.g. using flight path information and then pitch attitude information to perform a go-around manoeuvre).	
Expected or unexpected behaviour	
The behaviour expected to reflect an easy use of the HUD should show a fluid aircraft control and continuity in the use of the HUD during the transition manoeuvre. On the opposite, a difficulty encountered to understand and to make use of some symbology elements may reveal a potential weakness of the HUD for performing a transition manoeuvre.	
Reference texts and data	CS 25.1302 : *(b) Flight deck controls and information intended for flightcrew use must:* *(1) Be presented in a clear and unambiguous form, at resolution and precision appropriate to the task.* *(2) Be accessible and usable by the flightcrew in a manner consistent with the urgency, frequency, and duration of their tasks, and (..)* CS 25.1335 Flight director systems *Means must be provided to indicate to the flight crew the current mode of operation and any modes armed by the pilot. Selector switch position is not acceptable as a means of indication.* AMC 25-11 : 5.b, 6.e. e. Dynamics *For those elements of the display that are normally in motion, any jitter, jerkiness, or ratcheting effect should neither be distracting nor objectionable. Screen data update rates for analogue symbols used in direct aeroplane or powerplant manual control tasks (such as attitude, engine parameters, etc.) should be equal to or greater than 15 Hz. Any lag introduced by the display system should be consistent with the aeroplane control task associated with that parameter. In particular, display system lag (including the sensor) for attitude should not exceed a first order equivalent time constant of 100 milliseconds for aeroplanes with conventional control system response. Evaluation should be conducted in worst-case aerodynamic conditions with appropriate stability augmentation systems off in order to determine the acceptability of display lag.* SAE ARP 5288 7.1 : *(..) all deviations [to the basic guidelines] must be harmonised with both the HUD and HDD(s) to minimise impacts on scan, information transfer, workload, visual transitions, training, or pilot performance. Deviations from the relative left side/right side arrangement of airspeed/mach and barometric altitude information have a great potential to induce pilot error, and should not normally be accepted. Test pilots, designers, and human factors specialists should carefully evaluate proposed formats and data elements which deviate from guidelines or cockpit convention for such impacts* SAE ARP 5288 *8.1 Standard Symbology* *Since the standardization of HUD symbology can minimize pilot error and shorten training and transition times, the application of commonly used symbology is recommended. (…)*
Elements required	Any flight situation requiring a rapid change of the piloting context and

for observation	associated control parameters or of the symbology should be retained to constitute the scenarios for evaluation of the HUD adequacy for piloting the transition manoeuvres. A task analysis will help identify these situations.
Collection of behavioural data	The data to collect concern the consequences of a difficulty encountered to insure the continuous control of the transition situation using the HUD. The indicators may include an unexpected use of head down information, a delay in the control of a parameter or an erroneous reaction when the transition should occur. Objective data will be complemented by interviews or questionnaires about the performance in the transition and the quality of the control.
Interpretation of results	The severity of the consequence of a reaction delay during the transition or of a poor quality of the control will guide the Interpretation of results. Any unexpected strong reaction opposite to an appropriate control of the situation is significant of the difficulty to perform the transition-piloting task.

4.8. Use at unusual attitudes and pilot's spatial representation

Point of suspicion

Historically, the HUD appeared in the years 1950 on military aircraft as sights for gun firing, and not as flight instruments. For this application, the HUD had significant advantages on its fixed mechanical predecessors: presentation of up to date information according to the shooting conditions, position in conformity with the external world and benefits of flying head up to follow the target. At that time, the symbology was not necessarily conformal; compressed pitch scales were supposed to help the pitch control at high attitudes.

A good spatial representation is required especially for the transition manoeuvres (go around, flare,…) and for unusual attitudes recovery when no external reference cues are available (bad weather conditions).

The modern HUDs are proposed for use in many different flight phases and piloting contexts. They may be used in good visibility conditions, where the optical conformity will constitute a major help for the pilot to build an appropriate spatial representation, or in bad weather conditions, where the HUD will provide the only available information to build the spatial representation.

This issue is addressed as a primary requirement in the current regulation:

> "*EFIS displays must be able to convey to the pilot a quick-glance sense of the present speed, attitude and altitude." (AC/AMC 25-11, 7d.2i.)*

The capacity of the HUD to help perform the recovery manoeuvre from unusual attitudes (typically a pitch attitude above –20/+30 degrees or a roll angle above +/-60 degrees) is an important aspect addressed during the certification. Several types of solutions may be used by the HUD supplier, including a dedicated symbology using a compressed pitch scale and a decluttered symbology format. A transition to the head down PFD may also be required if the HUD is not designed for such a manoeuvre.

Expected or unexpected behaviour

The symbology must be able to convey the pilot a correct representation of the aircraft attitude, and especially at high attitudes. The expected behaviour consists of an efficient recovery manoeuvre from this unusual situation using the HUD or transitioning to the HDD in accordance with the concept of use. The spatial representation must be acquired and maintained throughout the manoeuvre. The recovery of an attitude within the usual limits must be fast and effective ; any delay or erroneous reaction may reveal a deficiency in the HUD usage for such a manoeuvre.

Reference texts and data	CS 25.1303 Flight and navigation instruments *(b) The following flight and navigation instruments must be installed at each pilot station: (..)* *(5) A bank and pitch indicator (gyroscopically stabilised). (See AMC 25.1303 (b)(5).)* *(6) A direction indicator (gyroscopically stabilised, magnetic or non-magnetic).* AMC 25.1303(b)(5) Attitude Displays *1 Attitude Displays* *1.1 For turbo-jet aeroplanes each display should be usable over the full range of 360° in pitch and in roll. For propeller-driven aeroplanes the pitch range may be reduced to ± 75° provided that no misleading indication is given when the limiting attitude is exceeded.* *1.6 The artificial horizon line should remain in view over a range of pitch attitudes sufficient to cover all normal operation of the aeroplane plus a margin of not less than 2° in either direction. Additional 'ghost' horizon lines should be provided parallel to the main horizon line so that beyond*

	this range at least one such line is in view at an attitude with the range of the display. *1.7 The pitch attitude scale should be sensibly linear while the main horizontal line is in view, but may become non-linear beyond this range. (..)* *1.11 The 'earth' and 'sky' areas of the display should be of contrasting colours or shades. The distinction should not be lost at any pitch or roll angle.* *2 Attitude Display Systems (Acceptable Means of Compliance)* *2.3 The definition of dangerously incorrect information depends to some extent on the characteristics of the aeroplane, but in general an error greater than 5° in pitch or 10° in roll will be considered to be dangerous.* AMC 25-11 7.e. Attitude *(1) An accurate, easy, quick-glance interpretation of attitude should be possible for all expected unusual attitude situations and command guidance display configurations. The pitch attitude display scaling should be such that during normal manoeuvres (such as take-off at high thrust-to-weight ratios) the horizon remains visible in the display with at least 2° pitch margin available. * In addition, extreme attitude symbology and automatically decluttering the EADI at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal manoeuvring). Surprise, unusual attitudes should be conducted in the aeroplane to confirm the quick-glance interpretation of attitude. The attitude display should be examined in 360° of roll and ± 90° of pitch. This can usually be accomplished by rotating the attitude source through the required gyrations with the aeroplane powered on the ground. When the aeroplane hardware does not allow this type of evaluation, accurate laboratory simulations must be used.* ** See AMC 25.1303 (b)(5) paragraph 1.6* SAE ARP 5288 : 7.3 Attitude : similar to AMC 25-11 7.e. 7.4 : Flight Path *An indication of the aircraft's velocity vector, or flight path, is considered essential to most HUD applications. When inertially derived, flight path display information provides an instantaneous indication of where the aircraft is actually going. (…). Air mass derived flight path may be displayed as an alternative.(…)* 10.4 : Unusual Attitude Recovery Testing *When the HUD can be used as a primary flight reference, effective aircraft attitude symbology must be provided to facilitate unusual attitude recovery (UAR). (…)* *See the reference document for more details…*
Elements required for observation	The typical possible unusual attitudes will be reviewed and listed. The various possible dynamics in the installation of the situation have to be addressed, whether slow or fast. The evaluation should then focus as much on the situation assessment as on its recovery. The possible addition of causes or contexts accompanying the installation of the unusual situation will also have to be considered in the scenario.
Collection of behavioural data	The collection should focus on the data revealing a loss of situation control, whether during its assessment or during the recovery.
Interpretation of results	The interpretation is based on the observed strength and magnitude of the reactions associated to the recovery manoeuvre from the unusual attitudes.

4.9. Workload induced by the HUD

Point of suspicion	
The use of the HUD modifies the flight crew tasks; as such, it may have some consequences on its workload. Some additional tasks related to the use of the HUD (pre-flight testing, data entry,..) may also induce an extra workload. The absence of significant increase of workload is an essential criterion for a HUD certification. The workload comprises two dimensions : • The possible penibility of the use because of an inadequacy of the equipment to its context of use (luminance, position, high required level of practice,…) • The compatibility between the amount of actions associated to the task and the time available to perform this task; a large gap induces a conflict and results in an increase of the workload.	
Expected or unexpected behaviour	
The use of the HUD mustn't be source of work penibility for the duration of the task nor of a conflict in the activity regarding the time available. The difficulty to evaluate the workload, possibly associated to the use of a HUD, comes from the fact that workload is a resultant. A high level of workload is experienced when the attention required to perform a task is not fully compatible with the attentional resources during the time available. One of the main consequences of a high level of workload is an incapacity for the pilot to take all the information available into account; some inputs are ignored and some necessary actions may be omitted. The impossibility to correctly perform the task within the time produces several effects: changes in the way to proceed, omission of some steps of the task, reduction of the number of checking actions, delay of planification. These necessary adaptations result in an imprecision in the control of the activity and also in a feeling of frustration for the individual in charge of performing the task. Any task element, associated to the use of the HUD and requiring some resources from the user to the detriment of another activity, is likely to induce an increase in the workload. In that way, workload actually results from various dimensions; an increase in the workload may result e.g. from an inadequate symbology for the intended task, or from necessary momentary transitions to the HDD in order to gather some information.	
Reference texts and data	AMC 25.1302 7.5.2 System Function Allocation (…) *As a design approval objective the applicant should show that functions were allocated in such a way that:* *a. The flight crew can be expected to complete their allocated tasks successfully in both normal and non-normal operational conditions, within the bounds of acceptable workload and without inducing undue concentration and fatigue (see CS 25.1523 for workload evaluation);* *(…)* 7.7.2 Consistency *Consistency needs to be considered within a given system and across the flight deck. Inconsistencies may result in vulnerabilities, such as increased workload and errors, especially during stressful situations. (…)* 7.7.3 Consistency Trade-Offs *It is recognized that it is neither always possible nor desirable to provide a consistent pilot interface. It is possible to negatively impact workload, despite conformance with the flight deck design philosophy, principles of consistency, etc. (…)*

	7.7.5 Integration Related Workload and Error *When integrating functions and/or equipment, designers should be aware of the potential effects, both positive and negative, that integration can have on crew workload and its subsequent impact on error management. Systems must be designed and evaluated both in isolation and in combination with other flight deck systems to ensure that the flight crew is able to detect, reverse, or recover from errors. This may be more challenging when integrating systems that employ higher levels of automation or that have a high degree of interaction and dependency on other flight deck systems.* *Applicants should show that the integrated design does not adversely impact workload or errors given the context of the entire flight regime (e.g., increased time to interpret a function, make a decision, and/or take appropriate actions).* JAR HUDS 903 4.a *The use of the HUD must not unduly fatigue the pilot (e.g., due to eye strain, maintaining a rigid head position, or excessive mental concentration). The workload associated with the use of the HUD must be considered in showing compliance with CS 25.1523 app D.* AMC 25-11 5.b. Colour Perception vs. Workload *(1) When colour displays are used, colours should be selected to minimise display interpretation workload. Symbol colouring should be related to the task or crew operation function. Improper colour coding increases response times for display item recognition and selection, and increases the likelihood of errors in situations where response rate demands exceed response accuracy demands.* *Colour assignments that differ from other displays in use, either electromechanical or electronic, or that differ from common usage (such as red, yellow, and green for stoplights), can potentially lead to confusion and information transferral problems.* *(2) When symbology is configured such that symbol characterisation is not based on colour contrast alone, but on shape as well, then the colour information is seen to add a desirable degree of redundancy to the displayed information. There are conditions in which pilots whose vision is colour deficient can obtain waivers for medical qualifications under crew licence regulations. In addition, normal ageing of the eye can reduce the ability to sharply focus on red objects, or discriminate blue/green. For pilots with such deficiency, display interpretation workload may be unacceptably increased unless symbology is coded in more dimensions than colour alone. Each symbol that needs separation because of the criticality of its information content should be identified by at least two distinctive coding parameters (size, shape, colour, location, etc.). (…)* 7.f . Digital, Analogue and Combinations *The Agency has a long-standing policy of not accepting digital only displays of control parameters. The reason was the belief that only analogue data in the form of a pointer/scale relationship provided necessary rate, trend, and displacement information to the pilot. However, the Agency will evaluate new electronic display formats, which include digital-only or combinations of digital and analogue displays of air data, engine instruments, or navigation data. Digital information displays will be evaluated on the basis that they can be used to provide the same or better level of performance and pilot workload as analogue displays of the same parameters. Simulator studies can be valuable in providing experience with new display formats, but care must be taken to ensure that the simulator provides all the environmental cues germane to the parameter being evaluated.* SAE ARP 5288 5.2.3 HUD Display Viewing Angles *(…) The amount of vertical and horizontal head movement needed to see the total FOV should not cause excessive pilot workload or discomfort.* 6.2.6 Manual and Automatic Luminance Control *The HUD system should have both manual and automatic luminance control capabilities. While the luminance control is varied, the relative luminance of all displayed symbols, characters, lines, and generated backgrounds shall generally track the control setting in a smooth and easily controllable manner without abrupt luminance changes. In no case shall any symbols or characters become invisible at the minimum luminance setting while other characters or symbols are usable. If the HUD system has both manual and automatic luminance control modes, there*

	shall be no objectionable luminance transients while transitioning from manual to automatic mode, or from automatic to manual control mode. *Note: Automatic luminance control is highly recommended and may be required for CAT II and CAT III operations when the pilot may not have time to manually adjust the luminance.* 7.1 General. *To maximize compatibility with head down display configurations, the principles of instrument arrangement specified in FAR §25.1321 (also known as the "Basic T") should be applied as design guidance for the HUD. Deviations from that arrangement, while possible, should only be adopted based upon substantiated human factors research or flight experience obtained from commercial, military, foreign, or other sources. An Equivalent Level of Safety Finding would normally be required. (…)* *HUD design objectives related to the HUD's intended use, display of sensor data, field-of-view, clutter, compatibility with head down instruments (see 8.5), differences in center reference points or symbology, and so on, may justify the need for some deviation to the basic guidelines.* *However, all deviations must be harmonized with both the HUD and HDD(s) to minimize impacts on scan, information transfer, workload, visual transitions, training, or pilot performance.* 8.4 Visual Attention-Getting Techniques *Some HUD functions are intended to notify the pilot of important events. Examples include navigation sensor status changes (e.g. VOR flag), computed data status changes (e.g. flight director flag), and flight control system normal mode changes (e.g. annunciation changes from "armed" to "engaged").* *Effective visual attention-getting techniques are needed to create an easily noticeable change and yet not be unduly distracting, so as to increase pilot workload.*
Elements required for observation	The evaluation test must feature the whole set of cockpit equipments. A test of the HUD in a different context would only allow a partial and unreliable evaluation; the evaluation should actually be performed within a representative situation, i.e. with a high level of fidelity of the flight deck environment, of the aircraft behaviour and of the task context.
Collection of behavioural data	The notion of workload is defined in the regulation. The appendix D of CS 25.1523 describes its different dimensions, but it doesn't provide any specific evaluation methodology. The collection of data won't focus on the specific evaluation of the workload, but on its usual cognitive consequences: error, lack of attention, absence of detection of an important information, focalisation on a routine aspect of the situation. Quite generally, the observer easily notices these types of behaviour, although they are not conscious for the subject user experiencing a heavy workload. The lack of attentional resources actually explains the impossibility for the subject to correctly insure the control of his/her activity. As a consequence, the interview will permit to pinpoint the feeling of work penibility, but probably not its associated effects on the task performance.
Interpretation of results	The interpretation must address the identifiable causes of the workload increase rather than its consequences. As a matter of fact, the cognitive economy measures resulting from the high level of workload may affect any of the piloting actions including some of the most fundamental, because of its non-conscious nature.

4.10. Information sharing among the flightcrew, interaction in a HUD equipped cockpit

Point of suspicion

The HUD symbology presents the particularity that it is visible only from the cockpit position where it is installed; this raises a specific issue in terms of information sharing within the flight crew. This issue appears at two stages: during the certification programme, within the certification team (flight test engineer and pilot) and for its operational use: specific procedures are required to insure efficient cross checks within the aircrew.

The various concepts of use determine as many different ways to share the tasks and the information data within the crew. For instance, the HUD may be used as a flight instrument for manual control or as a monitoring instrument, depending whether the chief pilot is flying or not. In both cases, the nature and the precision of the information displayed on the HUD and on the HDD do not correspond exactly, as most HUDs use their own animation laws and information sources.

Generally, the HUD modifies the information and task sharing within the cockpit and as such it requires a regular practice.

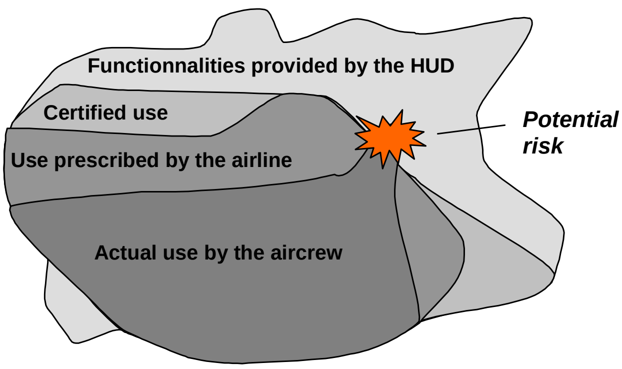
Expected or unexpected behaviour

The generic task sharing associated with the use of the applicant HUD (which may differ from the task sharing recommended by its future operator) mustn't leave room for deficiencies in the control of the situation by the aircrew, whatever the circumstances.

Reference texts and data	AMC 25.1302 7.5.2 System Function Allocation *As system behavior depends on the functions allocated to it and allocation of such functions also directly affects the flight crew tasks, both should be considered in close combination. The result of a system functional allocation is a description of system functions and flight crew tasks allocated to either the system, the human, or a combination thereof. It is recommended that functional allocation be documented as part of the design development activities, and that the allocation be applied in a manner that is consistent with the relevant flight deck design philosophy.* *As a design approval objective the applicant should show that functions were allocated in such a way that:* *a. The flight crew can be expected to complete their allocated tasks successfully in both normal and non-normal operational conditions, within the bounds of acceptable workload and without inducing undue concentration and fatigue (see CS 25.1523 for workload evaluation);* *b. Flight crew interaction with the system enables them to understand the situation as assumed per the design assumptions, and enables timely detection of failures and crew intervention if applicable;* *c. Task sharing and the distribution of tasks between the flight crew members during normal and non-normal operations is considered.* AMC 25-11 5.d Symbol Position *(3) Pilot and co-pilot displays may have minor differences in format, but all such differences should be evaluated specifically to ensure that no potential for interpretation error exists when pilots make cross-side display comparisons.* SAE ARP 5288 3.2 Types of Applications *3.2.1 Supplemental Use: A HUD may be used to supplement flight deck instrumentation for use in the performance of a particular task or operation. A HUD approved for supplemental use does not replace the conventional head down flight deck information. (…)* *The primary cockpit instruments shall continue to be utilized as the primary means for manually controlling or maneuvering the aircraft.*

	However, certain components of a PFR may be displayed (or repeated) on a HUD approved for supplemental use. This would allow the HUD to also be utilized as a means for manually controlling or maneuvering the aircraft. If this is the case, then, to minimize the need to transition between head up and head down information required in the controlling or maneuvering of the aircraft, all PFR components (see section 3.3.1 below) should be provided on the HUD. *3.2.2 Alternate Use: A HUD may be used as an alternate source of primary information for use in the performance of a particular task or operation. This information should be presented in a manner such that the pilot can rely on the information presented by the HUD, in lieu of scanning the conventional head down instruments typically used for the task to be performed.* *(…). An Alternate Use PFD may be difficult to certify due to certain HUD constraints not necessarily associated with symbology (e.g. cross cockpit viewing).* 9.4 Alerting issues *Single HUD installations can take credit for the copilot monitoring of head down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays.*
Elements required for observation	The circumstances where the use of the HUD affects the task sharing and the crosschecks within the crew are to be identified using a task analysis. The use of the HUD modifies the flight crew interactions, as only one member has access to the HUD specific information. These circumstances have to be included in scenarios likely to highlight the possible deficiencies in the situation control associated with the use of the HUD. The operational procedures developed by the airlines are supposed to encompass this issue. The test scenarios may be derived from these procedures established from previous experience, in order not to base the evaluation on scenarios or context of use far from an operational reality.
Collection of behavioural data	The observation of behaviours linked to the task sharing within the crew requires a precise analysis of the activity, as the task sharing and the crosschecks may be highly dynamic. Video recording is useful for a detailed post analysis as required. Beyond these objective data, an interview makes it possible to better understand the flightcrew's strategies and difficulties to perform their tasks.
Interpretation of results	The interpretation will address the lacks of consistency possibly observed in the task sharing or in the crosschecks. Their nature and the severity of their consequences are to be considered, whether they are likely to induce a loss of situation awareness or control.

4.11. Operational integration of the HUD

Point of suspicion	
Beyond the issue of the integration of the HUD within the cockpit systems, the HUD integration for its use in airline operations requires the definition of specific cockpit interaction procedures, because of the changes induced in the information and task sharing and in the possible cross checks. The gaps possibly existing between the technical documentation of the HUD and the certification objective have also to be considered. Some pilot guides provided by the HUD supplier usually describe all the available modes and intended uses, some of which are not among the proposed certification objectives. These gaps are progressively reduced, as the certification is usually progressively extended to all the HUD functionalities. This issue is noticeable with modern HUD designed for use with many possible modes in all flight phases while the certification focuses on poor visibility approaches. Some other restrictions of use may be also formulated by the airline itself, as a result of the experience collected and the difficulties observed on line. These gaps between the available functionalities of the equipment, the use prescribed by the airline and the actual use of a HUD are schematised on **Figure 1**. They constitute some possible weaknesses, which require special attention and which should be addressed at the instruction level and controlled based on the operational experience. Another way of action is to limit the possible functionalities to be offered by such a system.  **Figure 1** : The possible gaps between the available, the prescribed and the actual uses.	
Expected or unexpected behaviour	
The operational use of the HUD is likely to exceed the proposed functionalities as certified or prescribed by the airline. A likely behaviour with sophisticated equipment such as the modern HUDs is an exploration by the flight crew outside of the intended and (currently) certified use, because of their numerous available functionalities or modes of use in all flight phases. An extrapolation of the observed possible traps may help anticipate the possible difficulties for the integration of the HUD within the airline operations.	
Reference texts and data	CS/AMC 25.1302 7.7.2 Consistency *Consistency needs to be considered within a given system and across the flight deck. Inconsistencies may result in vulnerabilities, such as increased workload and errors, especially during stressful situations. (…)* *While it is noted that trade-offs exist, as discussed in the next section, the following are areas to consider with respect to consistency within and across systems:*

	a. Symbology, data entry conventions, formatting, color philosophy, terminology, and labeling. *b. Function and logic, e.g., where two or more systems are active and performing the same function then they should operate consistently and use the same style interface.* *c. Information presented with other information of the same type that is used in the flight deck (…)* *d. The operational environment, e.g., where a flight management system is consistent with the operational environment so that the order of the steps required to enter a clearance into the system is consistent with the order in which they are given by air traffic management.* *Adherence to a flight deck design philosophy is one means of achieving consistency within a given system as well as within the overall flight deck. Another means of achieving consistency is to standardize aspects of the design. (…)* CS 25.1585 Operating procedures *(a) Operating procedures must be furnished for* *(1) Normal procedures peculiar to the particular type or model encountered in connection with routine operations;* *(2) Non-normal procedures for malfunction cases and failure conditions involving the use of special systems or the alternative use of regular systems; and* *(3) Emergency procedures for foreseeable but unusual situations in which immediate and precise action by the crew may be expected to substantially reduce the risk of catastrophe.* SAE ARP 5288 3.2 Types of Applications *The following definitions of HUD applications are based on functional usage that may vary with the phase of flight. The category of HUD use, as defined in the following paragraphs, therefore may also vary with the phase of flight. For example, in many cases a HUD installation will be defined and certified as supplemental use for most flight phases but as additional credit use for a particular flight phase, such as approach and landing.* *3.2.1 Supplemental Use* *(…) If the HUD could cause unsafe conditions through misuse in phases of flight other than those for which it was approved, appropriate limitations should be specified. For example, an approach and landing HUD which was not designed for cruise flight may not be operationally suitable for use at high speed or in level flight. If this possibility exists, appropriate limitations should be described to preclude its use in that situation.* *3.2.3 Additional Credit Use* *(…) It should be noted that approval of the HUD installation does not guarantee the operational authorization. Other factors, such as the operator's approved procedures, crew training, and maintenance program, must also be in place.*
Elements required for observation	Although the exact definition of the operational procedures is not an objective of the certification, information and task sharing is actually an issue in the case of the HUD, as discussed in the previous Point of suspicion. The necessary extrapolation from the evaluation conducted during the certification to the operational world may help formulate recommendations for the HUD integration. The flight hours spent in line by the test pilots provide them an up to date representation of the operational activities and of the actual uses which can be imagined in a routine situation: the conditions to reproduce in a simulated scenario will be based on the experience gained on line by the pilots.
Collection of behavioural data	The data to be sought in order to evaluate the HUD integration within the airline operations consist of the possible deviations from the intended use of the HUD. These deviations may appear during the daily use in operation, but they may result from the available functionalities offered by the system. They may be previously identified by a comparison between the phases of use and the functionalities proposed for certification, and those actually available with the

	candidate HUD system. Two type of subjects may be involved in the evaluation trial: test pilots because of their wide experience and detailed knowledge of the system functions and limitations, and airline pilots because of their knowledge of the actual practices, needs and constraints.
Interpretation of results	The interpretation will address the nature of the deviations observed or the foreseeable gaps between the functionalities proposed for certification, the prescribed use by the aircraft operator and the possible daily use. Conflicting or suspicious interactions will be evaluated in accordance with their potential consequences on the control of the flight.

4.12. Imaging HUD (EVS)

Point of suspicion	
The use of a HUD system capable of displaying raster images raises several new issues, whatever the sensor used. A specific issue appears with the image interpretation, when using images generated at frequencies outside the range of natural vision. The reduction of the operational minima by using a vision through sensors in bad visibility conditions is also currently under investigation. A new FAA rule makes it possible to use the 'enhanced flight vision' to continue an approach below the 'normal' decision height, down to a lower decision height where the runway must be actually visible and identifiable. This concept designated as 'double decision' has not been validated by the JAA teams, waiting for more experience in the use of such HUDs with the current minima.	
Expected or unexpected behaviour	
The behaviour expected during a flight with natural vision cues may be used as a reference for the use of an imaging HUD. The imagery provided by the sensors reinforces : - the role of the artificial image depth resulting from the combination of several information sources, rather than a true perceptual depth ; - the role of symbols with colours and shapes belonging more to a virtual vision of the external world than to a realistic natural vision (conservation of the principles of perception through natural vision). The unexpected behaviours are directly linked to the possible difficulties to interpret and to exploit the image and the symbols displayed.	
Reference texts and data	AMC 25-11 *6.b Chromaticity and Luminance* *(1) Readability of the displays should be satisfactory in all operating and environmental lighting conditions expected in service. (…)* *(4) (…)the following guidelines may be used: (…)* *(vi) Raster fields conveying information such as weather radar displays should allow the raster to be independently adjustable in luminance from overlaid stroke symbology. The range of luminance control should allow detection of colour difference between adjacent small raster areas no larger than 5 milliradians in principal dimension; while at this setting, overlying map symbology, if present, should be discernible.* *6.d d. Flicker* *Flicker is an undesired rapid temporal variation in display luminance of a symbol, group of symbols, or a luminous field. Flicker can cause mild fatigue and reduced crew efficiency. (…) Frequencies above 55 Hz for stroke symbology or non-interlaced raster and 30/60 Hz for interlaced raster are generally satisfactory.* SAE ARP 5288 *5.2.2 External View: The HUD should not significantly degrade the necessary visual field of view of the outside world for normal, abnormal, or emergency flight maneuvers during any phase of flight for a pilot seated at the DEP. The HUD should be evaluated to ensure that it does not significantly affect the ability of any crewmember to spot other traffic, distinctly see approach lights, runways, signs, markings, or other aspects of the external visual scene.* *6.6 Raster Display Performance (Imaging Display)* *When the HUD system is capable of displaying raster images, the HUD shall meet all requirements contained within this section in addition to the other display visual requirements of Section 6:* *6.6.1 HUD Symbology and Raster Display Compatibility*

	When a combination of HUD stroke-written and raster symbology is used, that combination shall be sufficiently aligned and synchronized to avoid misleading information and to minimize pilot workload. *When the HUD has capability to switch between stroke-only and combined stroke/raster displays, the effects on display qualities during the transition shall be evaluated.* *6.6.2 Raster Resolution: The HUD system raster resolution requirements shall be specified by the vendor to be consistent with imaging sensor angular resolution, the HUD optics and the intended function of the HUD-sensor system.* *6.6.3 Raster Luminance: The HUD raster luminance shall be adequate to display a minimum number of gray shades against a real world background luminance which is representative of the environment in which the HUD and sensor system is intended to operate. The vendor shall specify the maximum background luminance in which the HUD and sensor system is intended to operate and the minimum number of gray shades the system is to display.* *6.6.4 Raster Contrast Variation: The contrast ratio between sequential gray shades should be 1.4 +0.4, -0.2 with appropriate HUD settings of brightness and contrast controls, and excluding the contribution of ambient background.* *6.6.5 Raster Low Level Luminance: The HUD should be capable of providing a very dim, easily controllable image free of background glow in areas not displaying information in night conditions. The requirement can be considered to have been met when the following is achieved; In a dark ambient background (less than 0.34 cd/m2 (0.1 fL)), with symbols and peak white video adjusted to approximately 1.7 cd/m2 (0.5 fL), a minimum number of shades of gray specified by the manufacturer should be visible and the areas of the raster which are blank should not be visible.* *6.6.6 Raster Luminance Uniformity: The variation in intensity between any two points within 10 degrees of each other or within the monocular FOV should not exceed plus or minus 35 percent when a flat field signal is applied.* *The Luminance Uniformity shall be calculated as shown in section 6.2.2.* *6.6.7 Raster Positional Accuracy: The HUD shall be capable of displaying Video with the positional accuracies specified in section 6.1.1, excluding any video sensor and sensor installation errors.* *6.6.8 Display Quality: During normal operation, the HUD shall not exhibit any objectionable flicker (defined as brightness variations at frequencies above 0.25 Hz) or jitter, (defined as positional oscillations at frequencies of greater than 0.25 Hz and amplitude greater than 0.6 mrad). There shall be no noticeable display noise, local disturbances or artifacts that detract from the use of the system.* *6.6.9 Raster Display and Outside View Compatibility: The display of raster imagery on the HUD should not compromise the effective use of outside visual reference for required pilot tasks such as takeoff and landing, obstacle avoidance, aircraft collision avoidance, or weather or visual reference assessment.* *Note: This requirement is not intended to preclude use of imagery to provide enhanced visual cues consistent with the above requirements.* *6.6.9.1 Display Blooming from Bright Sources: Certain light sources, such as those used for airport and runway lighting, may result in unusually bright raster images or sudden increases in raster brightness (display blooming). These brightness characteristics shall not impair the pilot's ability to recognize information required for the intended function of the HUD, and shall not distract the pilot while viewing through the HUD.* *6.6.9.2 Automatic Brightness Control: Systems using automatic brightness control of raster or stroke and raster combined shall meet the applicable display luminance and contrast requirements defined in this section.* *6.6.10 Mixed Symbology and Video Operation: When the HUD system incorporates a mode where stroke symbology is overlaid on a raster display, the pilot should be provided with controls to permit the independent adjustment of the video brightness. Video contrast (the difference between the black level and peak white) adjustment should be provided, through either automatic or manual means, from an imperceptible level to the maximum stated by the manufacturer. The Pilot shall be provided with a control to permit the independent adjustment of the brightness of the symbols overlaid on the raster from an imperceptible level to the maximum specified by the manufacturer.* See also the FAA Enhanced Flight Vision Systems; Final Rule, Jan 9, 2004.
Elements required	The aim of the proposed enhanced vision system is essentially to

for observation	substitute a sensor vision to the natural vision impaired by the bad weather or light conditions. The context of use for the scenarios consist of take-off, taxiing or approach operations with bad visibility (dark night, fog, rain or snow,..). The scenarios will be built upon the generic tasks performed during these operations as references for the task analysis.
Collection of behavioural data	An evaluation in situation is essential to collect relevant behavioural data. The ground simulator is an ideal tool if able to reproduce the correct flight and display dynamics and a synthetic imagery actually representative of the sensor vision. An interview will be a necessary complement given the complexity of the pilot-system interaction to be evaluated. The addition of a raster image to the HUD symbology is a novel feature for most pilots. Although many research studies have been conducted on the subjects of the image-symbology integration and interaction, this feature is just emerging for civil aviation applications. As a consequence, the training and familiarisation of the subject test pilots will be essential.
Interpretation of results	The complexity of the interpretation is high, given the level of novelty of this type of application and the required adaptation of the operational procedures for its use. The efficiency, reliability and safety levels achieved through these procedures will have to be precisely addressed.

4.13. Dual HUD

Point of suspicion	
The availability of two HUDs, one for each of the cockpit positions, noticeably modifies the possible interactions within the flight crew and the cockpit environment. This may benefit to flight safety in accordance with the principles of crosschecking, providing the HUDs use independent information sources. This may also result in an increase of complexity of the aircrew's work, which has to be addressed during the certification of such a concept, especially if the HUDs are intended for use as primary flight instruments.	
Expected or unexpected behaviour	
Mutual crosschecking is an essential component of the aircrew activity. The simultaneous use of two HUDs affects the interactions between the two crewmembers, together with the information and task sharing. In particular, the crosschecks of the flight parameters and the monitoring of possible alerts are central in the crew tasks. The expected behaviours are related to an appropriate task and information sharing within the aircrew.	
Reference texts and data	SAE ARP 5288 4.1.3 Dual HUD Considerations *In dual HUD installations, if both pilots are permitted to use their HUD simultaneously, the cockpit design shall provide for the display within the normal eye scan of the flight crew of alert, caution, and warning annunciations.* 9.4 Alerting Issues *Dual HUD installations require special consideration for alerting systems. It must be assumed that both pilots will be head up simultaneously, full or part time, especially for alternate means and additional credit HUDs. If master alerting indications are not provided within the peripheral field of view of each pilot while using the HUD, then each HUD shall provide annunciations that direct the pilot's attention to head down alerting displays. Aural alerts by themselves are not always adequate to direct the pilot's attention head down. The types of information that shall trigger the HUD master alerting display are any cautions or warnings not already duplicated on the HUD from head down primary displays, as well as any caution level or warning level engine indications or system alerts.* *Note: Do not want to redirect attention of the pilot flying to other display when an immediate maneuver is required (resolution advisory, windshear).*
Elements required for observation	The task analysis focus essentially on the crosscheck procedures and to the use of HUDs versus HDD. The scenario must provide situations involving these types of activity.
Collection of behavioural data	The data to be collected concern the crew performance regarding the control of the flight, the information crosschecks, the possible use of HUDs and head down information and their compatibility. These data will be collected through direct observation of the crew activity in simulated flights and from interviews following the flights.
Interpretation of results	Any deficiency in the flight management (information crosschecks, alert management, crew co-ordination…) may express a possible limitation in the use of the two HUDs. The evaluation of the dual HUDs is closely connected to the definition of the rules and procedures to be used by the airline. The familiarisation of the evaluation pilots must include an instruction about these specific procedures.

Conclusion

The points of suspicion approach provided in these draft guidelines matches the approach recommended by the draft AMC 25.1302 text on the human factors assessment of cockpit elements during certification.

Even if each of the point represents an object to be studied in itself, there is no reason to zoom into each point with the same level of detail. Points must be ranked by importance, through the global analysis of the characteristics and functions of the device to be assessed, taking on-board previous certification feedback.

The points can be sorted out in a preliminary phase: the first 5 points are linked to questions which were normally dealt with before per-se certification, when accepting the equipment, or during early design phases.

Among the different points of suspicion occurring in situation, various categories can be defined:

- points of suspicion linked to dynamic situations and to HUD use,
- points of suspicion more specifically linked to HUD design logic.

It is possible to envisage evaluations combining various points, as long as sufficiently comprehensive scenarios are developed. The strong point of this approach is that it generates more realistic scenarios, enhanced with a wealth of details, and closer to real flight situations.

Interpretations of the forms mentioned above share a common point: any evidence proving loss of control or consequences entailing damages amounts to a criterion of non-acceptance.

In this respect, statistics do not provide the strongest evidence. Just having one non-desired occurrence is enough evidence of a difficulty. The question is then the answer to be given to the difficulty encountered. This answer fundamentally depends on the failure mechanisms at play, which will require further analysis, if not additional tests.

This draft methodological guide still needs to be confronted with real life certification experiences; it also needs to be constantly updated to meet the rapid development of technologies, which might severely change flying habits, through the development of new concepts for HUD systems.

Abbreviations

AC	Advisory Circular (FAA)
ACJ	Advisory Circular, Joint (JAA)
AMC	Acceptable Means of Compliance (EASA)
ARP	Aerospace Recommended Practice (SAE)
AS	Aerospace Standard (SAE)
ATC	Air Traffic Control
AWO	All Weather Operations
CRI	Certification Review Item (JAA)
CS	Certification Specifications (EASA)
DCSD	Département Commande des Systèmes et Dynamique du vol
DGAC	Direction Générale de l'Aviation Civile
DEP	Design Eye Position
DH	Decision Height
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
EFIS	Electronic Flight Instrument System
ETSO	European Technical Standard Order (EASA)
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations (FAA)
FMS	Flight Management System
FSB	Flight Safety Board
GM	Guidance Material
HDD	Head Down Display
HQRS	Handling Qualities Rating Scale
HSI	Horizontal Situation Indicator
HUD	Head Up Display
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMASSA	Institut de Médecine Aérospatiale du Service de Santé des Armées
IMC	Instrument Meteorological Conditions
IP	Issue Paper (FAA)
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements (JAA)
LVP	Low Visibility Procedure
LVTO	Low Visibility Take Off
NPA	Notice of Proposed Amendment (EASA)
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
POC	Proof of Concept
RVR	Runway Visual Range
SAE	Society of Automotive Engineers
SFACT	Service de la Formation Aéronautique et du Contrôle Technique

SOP	Standard Operation Procedure
SVS	Synthetic Vision System
TCAS	Traffic Collision Avoidance System
TSO	Technical Standard Orders
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

Appendix 1: Type of applications, reliability and availability, concept of use

These notions have to be well understood, as they are central to the certification process.

The **types of HUD applications** relate to the functional usage that may vary with the phase of flight (SAE ARP 5288)[2]. The regulation distinguishes the following types of applications:

- **Supplemental use:** A HUD may be used to supplement flight deck instrumentation for use in the performance of a particular task or operation. A HUD approved for supplemental use does not replace the conventional head down flight deck information. Example of use: Pilot monitoring of a visual approach, airspeed, altitude, angle of attack, and autopilot performance.
- **Alternate use:** A HUD may be used as an alternate source of primary information for use in the performance of a particular task or operation. This information should be presented in a manner such that the pilot can rely on the information presented by the HUD, in lieu of scanning the conventional head down instruments typically used for the task to be performed. As an example, a pilot may use a HUD approved as an alternative means to verify the performance of automatic flight control systems, without frequent reference to head down displays and instruments, during the phases of flight for which the HUD is certified.
- **Additional credit use:** A HUD may be used to provide information for use in the performance of a particular task or operation which adds to the current authorisations of a particular aircraft. For these tasks or operations, the required information will be displayed on the HUD in lieu of the head down instruments. As an example, additional credit approval of a HUD could be used to conduct operations to lower minima than currently authorized for a particular aircraft or automatic flight control system, or to conduct operations with the “pilot-in-the-active-control-loop” in situations where automated systems are otherwise used.

The HUD as any flight instrument must be designed to perform its intended function throughout all segments of the flight envelope and/or flight maneuvers for which its use is approved.

The HUD **reliability** (failure condition and probability) and **availability** (behaviour in case of failure) are two essential properties evaluated during the certification, and closely dependant on the proposed type of HUD application.

In terms of **reliability**, the regulation uses the relationship between between a failure severity and its probability of occurrence to define the notion of function criticality.

The paragraph CS/FAR 25.1309 requires that any system, considered separately and in relation to other systems, must be designed so that:

[2] JAR HUDS 903 also distinguishes between supplemental and primary use.

- any catastrophic failure condition (which would result in multiple fatalities, usually with the loss of the aeroplane) is extremely improbable (average probability per flight hour of the order of 10^{-9} or less) and does not result from a single failure;
- any hazardous failure condition (which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions, involving either a large reduction in safety margins or functional capabilities, physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or serious or fatal injury to a relatively small number of the occupants other than the flight crew) is extremely remote (probability of the order of 10^{-9} to 10^{-7});
- any major failure condition (which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions with, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to the flight crew, or physical distress to passengers or cabin crew, possibly including injuries) is remote (probability of the order of 10^{-7} to 10^{-5});

The regulation (AC/AMC 25-11) provides more detailed criteria for the case of flight data display:

Criticality of flight and navigation data displayed should be evaluated in accordance with the requirements in CS 25.1309 and 25.1333. AMC 25.1309-1 clarifies the meaning of these requirements and the types of analyses that are appropriate to show that systems meet them. AMC 25.1309-1 also provides criteria to correlate the depth of analyses required with the type of function the system performs (non-essential, essential or critical). However, a system may normally be performing non-essential or essential functions from the standpoint of required availability and have potential failure modes that could be more critical. In this case, a higher level of criticality applies. Pilot evaluation may be a necessary input in making the determination of criticality for electronic displays. AMC 25.1309-1 recommends that the flight-test pilot:

(i) Determines the detectability of a failure condition,

(ii) Determines the required subsequent pilot actions, and

(iii) Determines if the necessary actions can be satisfactorily accomplished in a timely manner without exceptional pilot skill or strength.

In terms of **availability**, the regulation defines two types of systems according to the level of safety offered in the event of a failure (see for example FAA AC 120-28D):

- a fail passive system is a system which in the event of a failure does not cause a significant deviation of the trajectory or attitude of the plane;
- a fail operational system is a system which after failure of any single component, is capable of completing an approach, flare and touch down, or approach, flare, touch down and rollout by using the remaining operating elements.

Three different **concepts of use** have been identified following a review of the existing HUD products, during the previous phase of the study resulting in this guide.

- The "**manual**" concept: the manual control of the aircraft is performed using the HUD as the primary flight reference. In low visibility conditions, this type of HUD typically features a flight director with independent guidance laws.

- The "**monitoring**" concept: the HUD is used to monitor the autopilot performance. In low visibility conditions, this type of HUD typically provides raw ILS information and the maximum allowed deviations, without any guidance information. The use of this type of HUD is usually left to the crew's choice, as the aircraft is certified for the same operations with or without the HUD.
- The "**hybrid**" concept: an extension of the monitoring concept allowing an improvement of the aircraft operational capacity. This concept is economically justified for example on a basic airplane authorised for category IIIa approaches in order to carry out category IIIb approaches automatically with HUD monitoring. The HUD is used to monitor the autopilot during the approach and for manual control of the aircraft in case of an autopilot deficiency.

The concept of use is a key factor in the design of a HUD symbology: the manual concept is usually associated with a full flight symbology while the other concepts use a simplified symbology with the essential flight parameters. However, the modern HUDs are intended for use for most flight phases and operational conditions, they may be used for manual control in one phase and for monitoring in another.

Appendix 2: Operation categories

The low visibility operations are defined in JAR OPS 1E for instance:

The Low Visibility Procedures (LVP) are defined as the procedures applied at an aerodrome for the purpose of ensuring safe operations during Category II and III approaches and Low Visibility Take-offs.

The operations are categorized as:

(a) Low Visibility Take-Off (LVTO). A take-off where the Runway Visual Range (RVR) is less than 400 m.

(b) Non-Precision approach

(c) Precision approach, with three main categories:

- Category I operations: A Category I operation is a precision instrument approach and landing using ILS, MLS or PAR with a decision height not lower than 200 ft and with a runway visual range not less than 550 m.

- Category II operations: A Category II operation is a precision instrument approach and landing using ILS or MLS with:
  (i) A decision height below 200 ft but not lower than 100 ft; and
  (ii) A runway visual range of not less than 300 m.

- Category III operations: Category III operations are subdivided as follows:
  (i) Category III A operations. A precision instrument approach and landing using ILS or MLS with:
  (A) A decision height lower than 100 ft; and
  (B) A runway visual range not less than 200 m.
  (ii) Category III B operations. A precision instrument approach and landing using ILS or MLS with:
  (A) A decision height lower than 50 ft, or no decision height; and
  (B) A runway visual range lower than 200 m but not less than 75 m

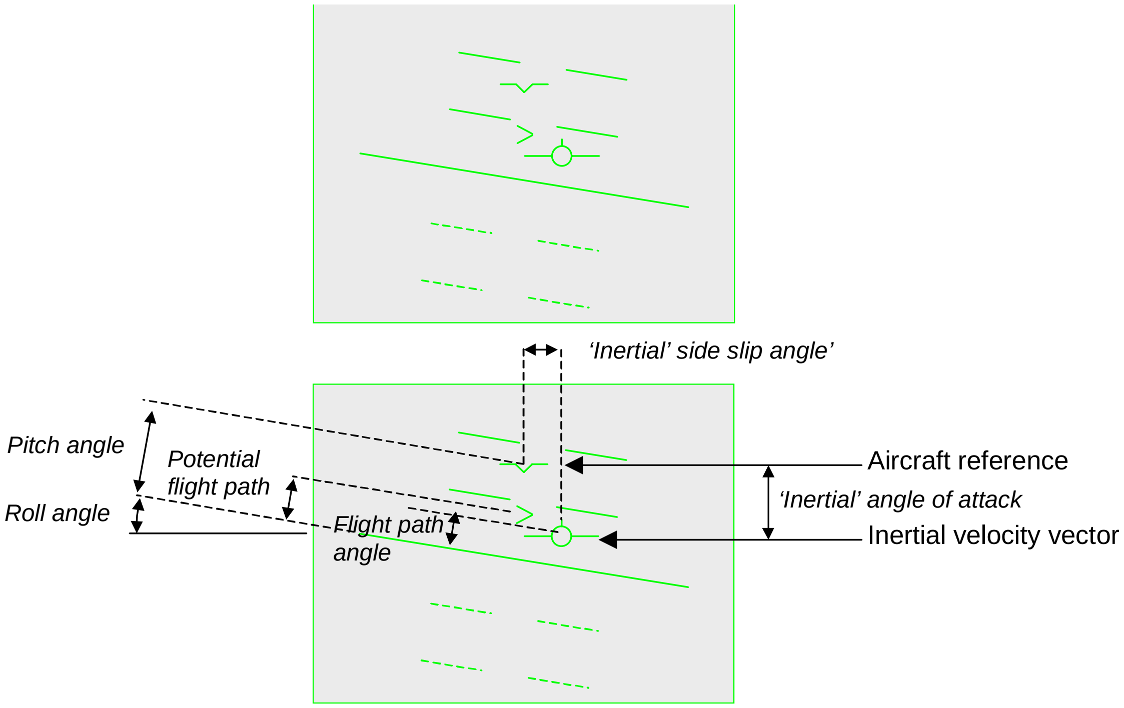
Appendix 3: Synthesis of the existing regulations

	Origin			Status				Purpose			Instrument			Operation				Concept	
Regulation	EASA/JAA	FAA	SAE	Applicable requirement	Means of compliance	Certification issue	Draft regulation	Conception	Certification	Operations	All instruments	EFIS	HUD	All operations	Category I	Category II	Category III	Manual	Monitoring & Hybrid
CS-25	x			x				x	x		x			x					
JAR HUDS 903	x			x				x	x				x	x				x	x
JAR HUDS 902	x			x				x	x				x			x		x	x
JAR HUDS 901	x			x				x	x				x				x	x	
CS-AWO	x			x				x	x				x			x	x		x
JAR OPS 1/E	x			x						x	x					x	x		x
JAR OPS 4/3	x			x						x			x			x	x	x	x
AMC 25-11	x				x				x			x		x					
CRI	x					x			x		-	-	-	-	-	-	-	-	-
FAR 25		x		x				x			x			x					
AC 25-11		x			x			x				x		x					
AC 120-29a		x			x				x	x			x		x	x		x	x
AC 120-28d		x			x				x	x			x				x	x	x
Memorandum		x			x				x		-	-	-	-	-	-	-	-	-
IP		x				x			x		-	-	-	-	-	-	-	-	-
SAE ARP 4102/8			x	x				x					x	x				-	-
SAE ARP 5288			x				x	x					x	x				x	x

NB: a dash indicates a possibility, depending on the text considered in particular.

Appendix 4 : Description of the main HUD symbols

The symbologies of the modern HUD systems are built around a basic analogue and conformal symbol set, which, once completed with the digital values of altitude and airspeed, provide all necessary information for the pilot to control the aircraft.
This basic symbol set is already shared by all the manufacturers: this appendix presents this typical symbol set and briefly reminds the signification of the main symbols.



Aircraft reference symbol :

This symbol commonly referred to as the bore sight symbol represents the projected centreline of the aircraft. It is positioned at a fixed position on the display, unlike all other symbols that are placed around it.

Horizon line and pitch scale :

The horizon line represents the local horizontal plane. It is displayed relative to the aircraft reference symbol: the distance between the a/c reference symbol and the horizon line is equal to the pitch angle: the aircraft reference symbol is on the horizon when the pitch angle is equal to zero, and the inclination of the horizon is equal to the a/c roll angle.
The pitch scale is fixed to the horizon line. It is usually scaled in five degrees increments.
The horizon line and the pitch scale provide the pitch and roll attitude required as elements of the basic T.

Inertial velocity vector :

This symbol is a key feature of the head up display, as it directly represents the direction point of the aircraft. It provides an immediate indication of where the aircraft is going. The pilot can manoeuvre the aircraft and fly the flight path to the desired point, for instance, to the

runway touch down point. If the velocity vector is above the horizon line, the aircraft is climbing.
The symbol is inertial derived, so the wind effects are included.
The angular distance between the aircraft reference symbol and the velocity vector provides an indication of the angle of attack and of sideslip angle (plus wind effects).
NB: This symbol is now reproduced on the head down displays of some recent aircraft.

Potential flight path :

This symbol is another key feature of the modern HUD symbology, originated from French flight test engineers (MM. Klopfstein, Wanner,…).
The value of the potential flight path is significant of the instantaneous flight path acceleration.
It is derived from the aircraft total energy:

$$E = mgz + \frac{1}{2} mV^2$$

By analogy, the total aircraft height is defined as:

$$H = z + \frac{V^2}{2g}$$

The derivation is the total vertical speed:

$$W = \frac{dH}{dt} = Vz + \frac{V}{g}\frac{dV}{dt}$$

Using $Vz = V \sin \gamma$, the potential flight path angle can be defined by analogy by:

$$\sin \gamma t = \sin \gamma + \frac{1}{g}\frac{dV}{dt}$$

If the calculated sinus value is more than one, this means that the current thrust is enough to allow a continuous acceleration on a vertical flight path (the case with powerful fighters).

The potential flight path chevron is conformally presented as a chevron positioned relative to the velocity vector.
If the chevron is above the velocity vector, the aircraft is accelerating.
If the chevron is positioned on the pitch scale at for instance, a 10° flight path angle, the aircraft is able to climb at a 10° flight path angle at the current speed.

The potential flight path can be used very effectively to control speed or flight path angle.
It is for instance a precious piloting aid to stabilise the approach, to pilot the aircraft on the back side of the polar, to climb over clouds or obstacles, e.g. in case of go-around or engine failure.

Other common symbols and digital values

Airspeed and ground speed

Their values are usually displayed, as they are useful for the pilot to know respectively the current aircraft handling qualities and its current total energy (for instance in case of windshear).

Barometric altitude and radio height

Their knowledge is also essential, either for aircraft piloting and navigation.
The radio height is usually only displayed at low altitude (typically below 1500 feet), depending on the performance of the radio height sensor.

Vertical speed

The magnitude of the vertical speed can be estimated from the flight path angle combined with the ground speed, so it is not strictly necessary to display its digital value.
However, the exact knowledge of the vertical speed is often useful to follow the air traffic control instructions and some pilots are used to it: so the digital value is generally displayed in feet per minutes.

Speed deviation

The speed deviation from the current selected speed is often displayed as a speed error tape positioned on the ‘wing’ of the velocity vector. Its knowledge is especially useful, combined with the potential flight path chevron, to monitor the aircraft autothrottle and/or autopilot.

Appendix 5: Subjective evaluation tools

Observations

Observers must first agree on data collection methods, and collected parameters, using a common grid. These parameters will have to be selected in relation to the HUD's specific points of suspicion. To this end, a first draft grid must be developed jointly. It can then be refined, using data (notably video data) collected during exploratory observations. This common grid makes it possible for each observer to be consistent with the others. If only one observer can occupy the area (simulator or cockpit) for reasons of lack of room, the fact that the parameters to be collected were pre-defined will guarantee recurrence of the data collected by the group.

Observations through tools or instruments must lead to modelling the activity. They must be on-going during the sequences where the pilot is getting familiar with the HUD, as well as during simulation sequences. They can be supplemented by similar observations made in previous cases or with similar devices. These observations must be as transparent as possible when testing in real-life situations, since interrupting the task might jeopardise the flight. They can be more intrusive during simulation.

It is strongly recommended to supplement the figures and parameters to be collected for a specific point of suspicion with verbalisations.

Interviews

Interviews or self-confrontations (using video/audio/digital recordings of simulations) can supplement simulation procedures. Analysing verbal production is very important for the validity of evaluation results. It provides data on the way the pilot evaluates his/her own activity, and helps flesh out the observations made during simulation with additional explanations. Verbalisation often provides a different access to action rules and mechanisms (problem solving domains).

Verbalisations collected during an interview aimed at getting explanations can be triggered about the task, during the task to be carried out (beware of interferences with the task itself), and after the task have been completed (beware of faulty memories). Five principles are key when staging an interview:

- Providing a very accurate specification of situations and events (i.e.: "the person does this/ says this, when, why...)
- Placing verbalised events back in their context
- Triggering a mental representation of the situation
- Using questions and non-imperative descriptive prompts
- Guiding the examination very closely.

NB: it is imperative for the interviewer to be fully proficient in operative jargon.

Flying as an activity calls on several types of behaviour, which cannot be studied as a whole. Regarding skills based on automatisms, verbalisation techniques cannot apply (the operator is not aware of the action performed). It is however possible to observe the spontaneous behaviour and to analyse response time or visual exploration for skill-based behaviours. Regarding rules-based behaviours, verbalisations produced in situ can be used.

In our case, verbalisations must be studied either as produced in the situation or during a self-confrontation, to understand the activity from the angle of skill- or rule-based competencies. Automatism-based competencies must be studied using a different method.

During interviews, the interviewer plays a crucial role. The interviewer must elicit speech from the interviewed party, without speaking too much. This is not a questionnaire, unless a questionnaire is used as backing during the interview, because questionnaires do not prompt verbalisation. The interviewer must:

- ask few questions
- redirect the interview if the subject loooses track of the main topic;
- accept any parallel discourse if it is interesting;
- accept silences without necessarily trying to avoid them, since silences are moments when the interviewed party can recollect memories or try to refocus;
- abstain from getting involved in the substance of the interview;
- remain quiet and still;
- create a confident atmosphere.

Prompting is key during interviews. Using a simple "why? " usually only leads to "because". A number of well-known prompts can prove to be very useful:

- If I understand you correctly, you mean...?
- Yes?
- You were saying that... Can you give me details?
- When you say that... what did you mean exactly?
- When you say that... how do you do it? can you show me?
- You mentioned two aspects, and expounded on the first one. What about the second one?

There are several kinds of interviews:

- exploratory interview: fairly open questions
- semi-directive or semi-directed interview: developing a rough draft, a sequence of leading questions (open questions). This is the most widely used type of interview.
- focused interview: list of specific points relating to the topic at hand, to analyse the impact of a specific event on the party present or involved when it occurred.

Interview analysis

Not all analysis methods are equal, and they do not all generate the same results. To chose the method providing the most reliable results, the objectives of the research and the field studied must be factored in.

Overall, analysing the content of an interview is done by breaking the rough protocol into logical units, by grouping together knowledge units verbalised as production rules "IF - condition, THEN - action".

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