ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

FAKULTA DOPRAVNÍ

Yegor Spitsyn

USE OF MODERN IMAGING METHODS IN TRANSPORT AIRCRAFT COCKPITS

Bakalářská práce

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ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

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Jméno a příjmení studenta (včetně titulů):

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Kód studijního programu a studijní obor studenta:

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Zásady pro vypracování

Při zpracování bakalářské práce se řiďte osnovou uvedenou v následujících bodech:

- Popis systémů HUD (Head-up display), SVS (Synthetic Vision System), EVS (Enhanced Vision System)
- Popis existujících produktů
- Předpisové aspekty použití těchto systémů
- Metodika práce letové posádky s těmito systémy
- Zhodnocení možnosti rozšíření používání těchto systémů v obchodní letecké dopravě

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EASA: Proposed Special Condition on Enhanced Flight Vision System (EFVS) with Ops Credit Applicable to Falcon F7X

EASA: Rockwell Collins Model 6605 Head-up Display (HUD) & Enhanced Vision System (EVS)

Vedoucí bakalářské práce: **RNDr. Martin Vecko, CSc.**

Datum zadání bakalářské práce: **20. října 2017**
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BACHELOR'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

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Guides for elaboration

During the elaboration of the bachelor's thesis follow the outline below:

- Description of HUD (Head-up Display), SVS (Synthetic Vision System), EVS (Enhanced Vision System)
- Description of existing products
- Regulatory aspects of HUD, EVS and SVS operation
- Operational procedures and flight crew training for HUD, EVS and SVS
- Evaluation of the possibility of using HUD, SVS and EVS in commercial air transportation

Graphical work range: according to the bachelor's thesis superviser directions

Accompanying report length: minimum of 35 pages (including images, graphs and tables, which are a part of the accomanying report)

Bibliography: FAA Advisory Circular 90-106A

EASA: Proposed Special Condition of Enhanced Flight Vision System (EFVS) with Ops credit applicable to Falcon F7X

EASA: ROCKWELL COLLINS MODEL 6605 HEAD-UP DISPLAY (HUD) & ENHANCED VISION (EVS) SYSTEM

Bachelor's thesis supervisor: **RNDr. Martin Vecko, CSc.**

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(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

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a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule

b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

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I confirm assumption of bachelor's thesis assignment.

Yegor Spitsyn
Student's name and signature

Prague ....August 28, 2018

Poděkování

Chtěl bych chtěl poděkovat mým rodičům a mé přítelkyni za všestrannou podporu během celého studia. Poté bych chtěl poděkovat svému vedoucímu bakalářské práce RNDr. Martinu Veckovi, CSc. za cenné odborné rady a informace pro vytvoření této práce.

Prohlášení

Předkládám tímto k posouzení a obhajobě tuto bakalářskou práci, zpracovanou na závěr studia na ČVUT v Praze Fakultě dopravní.

Prohlašuji, že jsem předloženou práci vykonal samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských prací.

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V Praze dne 30. listopadu 2018

podpis

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
Fakulta dopravní

USE OF MODERN IMAGING METHODS IN TRANSPORT AIRCRAFT COCKPITS

bakalářská práce

listopad 2018

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Abstrakt

Cílem této bakalářské práce je seznámení čtenáře s moderními zobrazovacími technologiemi založenými na projekci letových parametrů a zvýšené vizuální informace na průhledových displejích v kabinách dopravních letadel. Dále je cílem odůvodnit další rozšiřování těchto technologii v letecké dopravě.

Abstract

The goal of this bachelor's thesis is to familiarize the reader with technologies based of the projection of flight parameters and enhanced visual information on head-up displays in transport aircraft cockpits. Next goal is to justify the further spreading of such technologies in transport aviation.

Klíčová slova

Průhledový displej, HUD, EVS, SVS, moderní avionika

Key words

Head-up display, HUD, EVS, SVS, modern avionics

TABLE OF CONTENTS

ABBREVIATIONS

AT	Above Threshold
CAT	Category
CFIT	Controlled Flight into Terrain
CRT	Cathode Ray Tube
CVS	Combined Vision System
DA	Decision Altitude
DH	Decision Height
D-HUDS	Digital Head-up guidance System
EASA	European Aviation Safety Agency
EFVS	Enhanced Flight Vision System
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FLIR	Forward Looking Infrared camera
FPA	Flight Path Angle
FPV	Flight Path Vector
GNSS	Global Navigation Satellite System
HAT	Height Above Threshold
HDD	Head-down Display
HGS	Head-up Guidance System
HITS	Highway in The Sky
HUD	Head-up Display
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRS	Inertial Reference System
LCD	Liquid Crystal Display
LOC	Localizer

LVP	Low Visibility Procedures
LVTO	Low Visibility Take Off
MDA	Minimum Descent Altitude
MTOW	Maximum Take Off Weight
NASA	National Aeronautics and Space Administration
PFD	Primary Flight Display
PM	Pilot Monitoring
PMMW	Passive Millimeter Wave imaging
RA	Resolution Advisory
RVR	Runway Visual Range
RWY	Runway
SGS	Surface Guidance System
SID	Standard Instrument Departure
SVS	Synthetic Vision System
TCAS	Traffic Collision Avoidance System
TO/GA	Take-off/Go around
VFR	Visual Flight Rules

1 Introduction

The aviation industry, as one of the most modern and most advanced industries of the twentieth century, has created a wide variety of unique technical solutions and machines. These machines and solutions have not existed before in any shape or form, mostly due to the fact, that when the humanity started to roam the skies, it has encountered a lot of completely unique problems and challenges. Many technical solutions were borrowed from other technical branches. For example, a big share of navigation methods in aviation are based on nautical navigation methods used on the sea, hence the name aeronautical. Another example would be aircraft powerplants: on the first airplanes, aircraft powerplants were almost no different to those used in automobiles, and even now most general aviation aircraft use piston engines. However, a significant share of technologies applied in aviation had no ancestry from other industries, but aviation required such new technologies for its further development.

Every take-off and every landing flown under Instrument Flight Rules must be always carried out with the pilot having positive visual contact with outside referential points. Especially so during an instrument approach. One of the main parameters, by which a pilot decides, after reaching minimums of an instrument approach, whether to continue and land the airplane, or to perform a go-around is gaining and maintaining outside visual reference with the runway or approach lighting system. There are exceptions to this rule during low visibility procedures (LVP), specifically CATIII B and C approaches, but these operations require a number of conditions to be met in order to be performed. If the visual contact is not gained or lost, the pilot performs a missed approach procedure, and then either goes for another approach, or diverts to an alternate aerodrome, which makes the flight more expensive for the operator. In the worst-case scenario, if the pilot chooses to violate the rules and continue the descend without visual reference, such decision can lead to an air disaster, and unfortunately aviation history knows many examples. Assisting imaging technology based on a Head-up Display (HUD) is able to provide continuous visual information of exceptional quality. Their usage adds to the overall improvement of situational awareness of the flight crew and can eventually prevent an accident related to Controlled Flight into Terrain (CFIT). [1]

This work will be about some of these technologies. Projection of basic flight parameters on a see-through head-up display, combined with additional EVS and SVS systems, has its roots in the military aviation of the Second World War [2]. With the development of electronics, and the reduction of costs, more and more civil transport airplanes are equipped with such technology. My goal in this work is to introduce the reader to this, still quite exotic airplane equipment and try to justify its further spreading in civil aviation. In this thesis, the reader will find a general description of every system, as well as specific examples of commercially available products. Next, legislation aspects of systems requirements and operation will be described, based on FAA and EASA documents. Some of the regulatory details will be commented for an easier understanding of the problematics. All comments found in this work will be written in *this font.* Finally, the reader will learn about how flight crews are trained to operate the HUD and the systems associated with it.

2 HUD

A Head-up Display or HUD is an instrument, used to project flight and navigational information in a pilot's field of view, which means projecting this information between the pilot's eyes and the windshield. The purpose of this instrument is to eliminate the need for the pilot to look down on the instrument panel and back up to look outside during operations which require outside visual reference. [3]

2.1 Historical background:

Even though it might be surprising, a head-up display is a relatively old technology. It has its origins in Great Britain at the beginning of Second World War. After the invention of radar, fighter pilots received voice commands from the ground radar operators about the position of enemy aircraft relative to the pilots. Such a method, though still used in a modern air battle scenario as a backup, is quite inconvenient due to the lack of continuous visual information about the enemy aircraft for the pilot. Because of that, the radar returns were displayed on a separate monitor located on the instrument panel. However, this method had a big disadvantage: the pilot had to move his view inside the cockpit on an illuminated monitor, and then back outside the airplane, which lowered his night vision abilities and establishing visual contact with the target during a night battle.

This problem was solved by projecting the radar return images on a flat surface of a cockpit windshield. Simultaneously, the pilot received aiming information through a gyro gunsight – an instrument that allowed to keep aim on a moving target. After further development, the projection of the target from the radar returns has been moved to the display of a gyro gunsight.

After that, the head-up displays have been improved even further by allowing the projection of many different flight and navigational parameters. The projections of the artificial horizon, airspeed and altitude, current airplane heading, and autopilot modes have been gradually added to the head-up displays over time.

During the 1960s a French test pilot Gilbert Kopfstein has developed the first design of a modern head-up display with a standard instrument projection layout and marking. This standard was created in a way so that pilots won't have difficulties with transitioning to different airplanes, as the head-up display layout would be relatively similar in every airplane. This standardization is one of the reasons why head-up displays started to spread across aviation.

Figure 1: A HUD on a MiG-29 fighter aircraft

At first, head-up displays were available exclusively for military aircraft such as fighters and some helicopters. In the 1970s, first head-up displays have been installed in civil transport airplanes, however there were very few such aircraft, and such equipment was rather exotic and did not become a trend until later. In 1994, FAA has certified a HUD for an ILS category IIIA approach in a Boeing 737 aircraft. In 1995 Morris Air, a low-cost airline, became the first operator to start flights with airplanes equipped with a HUD [4]

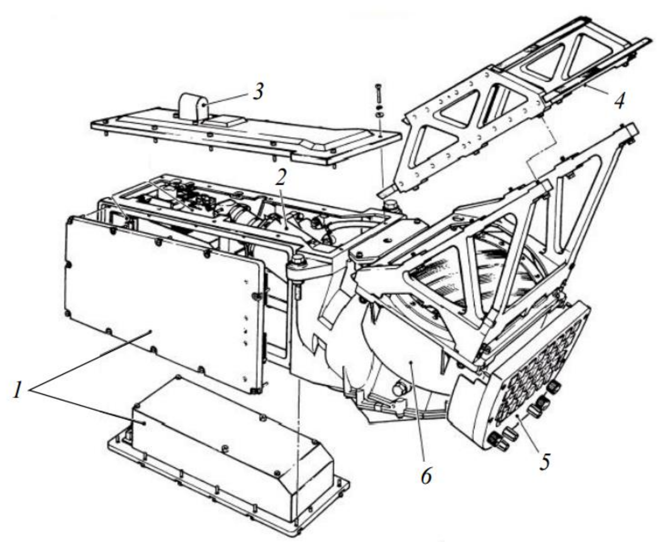
In modern days head-up displays are installed in aircraft either as a part of a standard equipment set, or as an extra option at a customer's request. Examples of aircraft with optional HUDs are Boeing 737 NG, Dash 8, Embraer 190 or Saab 2000. In Boeing 787 and Airbus 350 a head-up display is installed as a part of default equipment. Airbus 380, the world's largest airliner, is among the airplanes where a HUD is an optional equipment at a customer's request.

2.2 Basic design:

The system of a head-up display consists of two main blocks:

- The HUD itself
- Symbols generator

A symbols generator is an electronic component, which collects and processes information inputs from the flight instruments and other aircraft systems, that are meant to be projected on a HUD, and creates appropriate graphical images of such parameters in a way they are meant to look like on a head-up display



A head-up display is a separate device, generally it consists of the following parts:

1 Electronic modules
2 CRT
3 Light intensity sensor
4 Combiner
5 Multifunctional control panel
6 Optical system

Figure 2: Basic HUD design

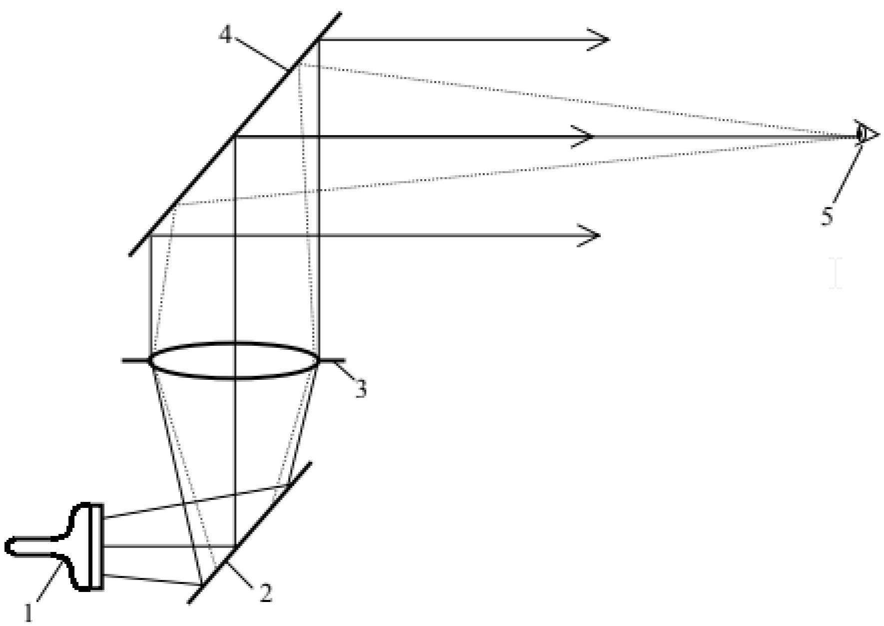
CRT (Cathode Ray Tube) is the source of the image for the head-up display. A CRT is the main reason for HUD's relatively large size (500-650 mm).

Light intensity sensor automatically regulates the brightness of images displayed on a HUD. In high intensity lighting conditions, for example when flying facing the Sun, a high enough level of display brightness is required for the pilot to be able to read the information projected on a HUD. On the other hand, when flying at night, the display brightness must be dimmed in such a way so that the pilot's natural night vision ability is not degraded. The light intensity sensor reacts to changes in lighting conditions and adjusts the display's brightness. The brightness can also be manually regulated through the control panel.

Combiner is a see-through display, which allows light from the outside to pass through, and simultaneously reflects light rays from the cathode ray tube, which are being projected on it from the other side. The name “combiner” comes from the fact that this display combines the image of the outside world with the image generated by the CRT and displayed on the glass surface.

Control panel: in military aircraft it is not possible to place the head-up display hardware above the pilot’s head, because in case of an ejection there cannot be any obstacles that prevent the ejection seat from shooting up and out. Because of that, the hardware is placed in front of the pilot’s head on the top of the instrument panel. This placement takes up precious space on the instrument panel, and so in order to save some space, the control panel is placed directly on the HUD’s hardware blocks. This panel enables the pilot to regulate parameters of the HUD itself, as well as some other parameters like weapons or navigation.

The optical system ensures the projection of the image from the CRT to the combiner’s surface, as well as the collimation of light rays that are directed to the pilot’s eyes. [5]



1. CRT
2. Mirror
3. Lens
4. Combiner
5. Estimated point of view

Figure 3: Refractory HUD basic design

2.3 Optical collimation

When a pilot is looking outside the aircraft through a head-up display, he must be able to see the data displayed on the HUD and the outside world. However, if he had to refocus his eyes every time from the distance to the instrument panel to the distance to from the outside objects, it would be a serious load for the pilot's eyes. In this case the head-up display would lose its purpose. For the pilot to simultaneously focus on the HUD image and on the image from the outside world, the HUD image must be optically located at an infinite distance. This is achieved by an optical process known as collimation. A collimator scheme is illustrated on figure 3.

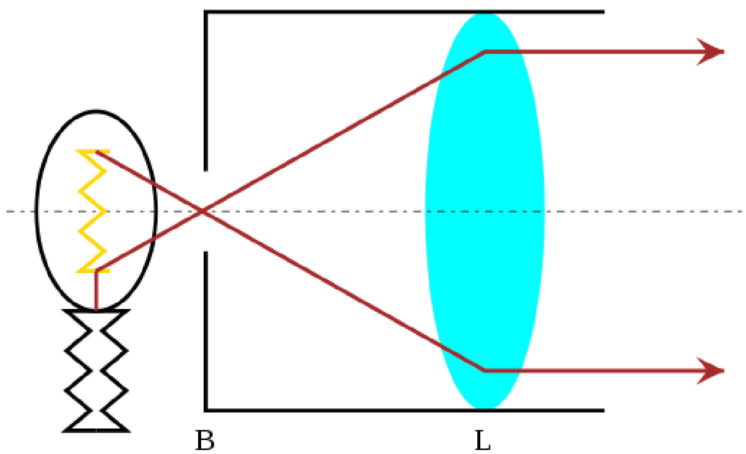


Figure 4: A simplified collimator scheme

As illustrated on figure 3, a collimator is an optical device which uses a lens or a series of lenses to move the focal length theoretically to an infinite distance. By doing that, the light rays are becoming parallel to each other. A human eye perceives the distance as infinite after about 10 meters or more away. So, a distance of more than about 10 meters away from the outside object is enough for the pilot to clearly see it and the HUD image. That distance is completely enough for aircraft operations, where distances to the object from the airplanes are mostly measured in miles, a situation where the pilot would have to refocus his eyes to see the object or HUD will never occur. [6]

2.4 Basic displayed parameters

Typical elements displayed on a head-up display are shown on a following figure

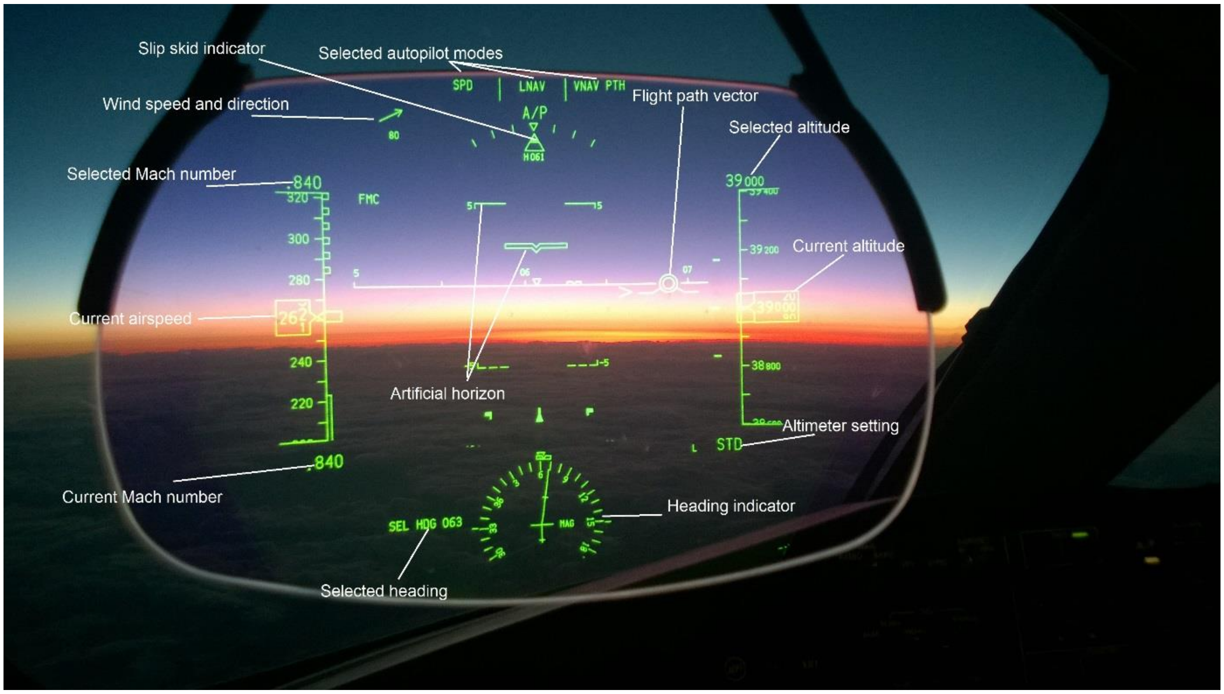


Figure 5: Displayed parameters on a HUD

In general, all head-up displays look very similar to the one shown on the figure above. As seen on the image, all displayed flight and navigational instruments look very similar to the layout of the instruments on a glass cockpit instrument panel, more precisely on a Primary Flight Display (PFD). With its center in the middle and spanning through the whole width of the display is the projection of an artificial horizon. To the left of it, an indicated airspeed tape is displayed together with a current Mach number setting. To the right of the display is the tape, indicating the current and set barometric altitude, as well as an altimeter setting. On the bottom of the display in this case a heading indicator is displayed, as well as some additional information, in this case the selected heading.

Flight Path Vector (FPV) – the vector of a flight trajectory is a specialized additional indication, on certain avionics products is even displayed on a regular primary flight display (PFD), but is primarily used when displayed on a head-up display. It provides the pilot with an estimation of where the aircraft is flying and where it would “strike”, if the current flight parameters such as acceleration, attitude and power settings will be kept constant. As shown on figure 4, the FPV is to the right of the airplane symbol lying flat on the artificial horizon. That means, that the airplane is neither climbing nor descending, and the wind pushes the aircraft to the right of the set heading. That is also confirmed by the indication of the wind speed and direction located in the top left part of the HUD.

2.5 HUD modes in different phases of the flight

During different phases of the flight, a pilot requires information from different instruments. In order to avoid overstressing the pilot's attention and to avoid confusion, a de-cluttering principle is used in the design of a head-up display. De-cluttering, as the name suggests, is a process of clearing out the information, that is currently unnecessary, or adjusting the display layout in a way, so that the displayed parameters do not cover each other and are clear and comfortable to read.

Below, as an example, is a HUD produced by the company Thales, which is installed as a part of optional equipment at a customer's request in all Airbus airplanes. This exact product has a number of basic display modes, which are switched between automatically, depending on the phase of the flight.

2.5.1 Taxi mode

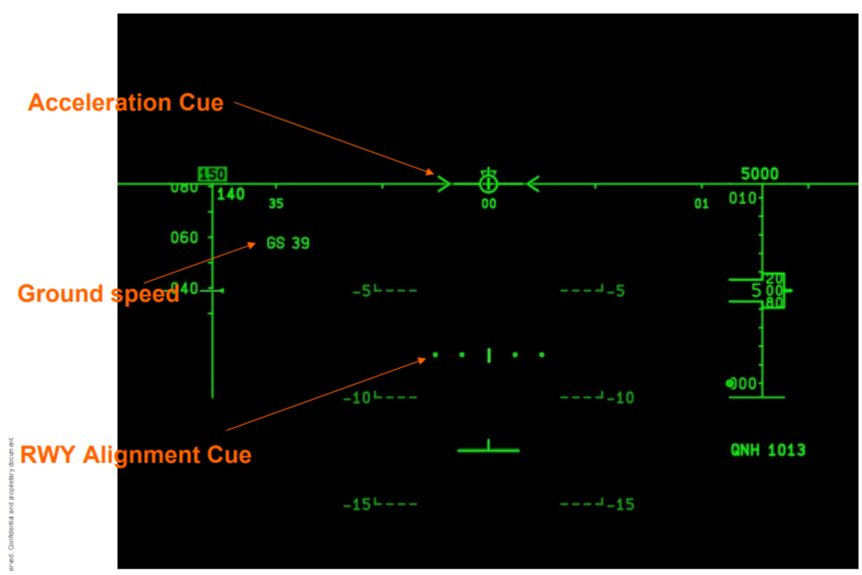


Figure 6: HUD – taxi mode

Acceleration cue – an indication of acceleration. When the arrows are above the airplane symbol, the airplane symbol, the airplane is accelerating, if they are below, that indicates a deceleration of the aircraft. An acceleration cue can help the pilot monitor a normal acceleration or deceleration during takeoff or landing rolls, and an unusual value of either one can give the pilot a clue of a possible error or malfunction.

Ground speed indication – informs the pilot about the aircraft's speed relative to the ground.

RWY alignment cue – informs the pilot about the aircraft position relative to the runway centerline. On figure 5 it is deactivated.

2.5.2 Takeoff mode

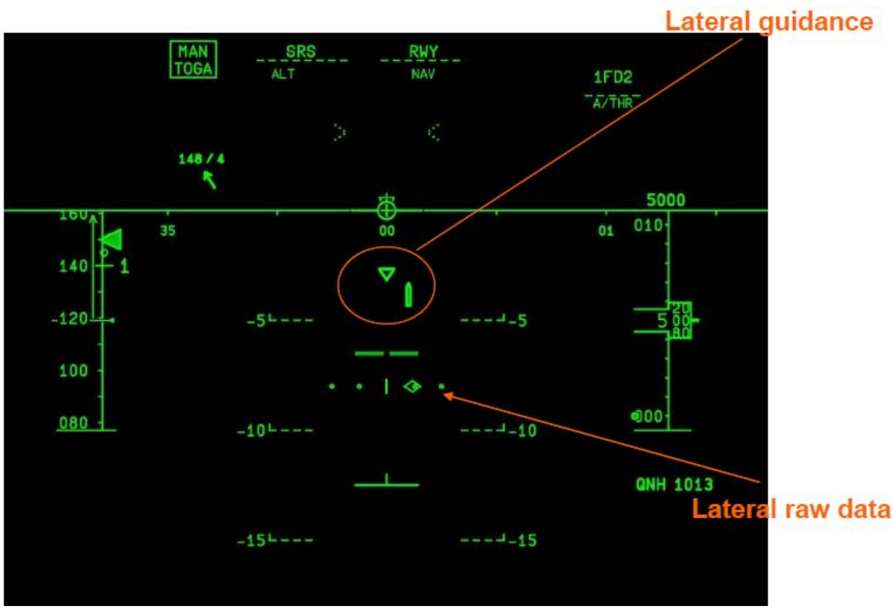


Figure 7: HUD – takeoff mode

These two indications (lateral guidance and lateral raw data) provide the pilot with the information about the position relative to the runway centerline during the takeoff roll, a helpful tool during a low visibility takeoff (LVTO).

A bottom indication provides raw data acquired from the localizer antenna, the top indication tells the pilot, how much to turn to get back on the centerline.

2.5.3 Landing mode

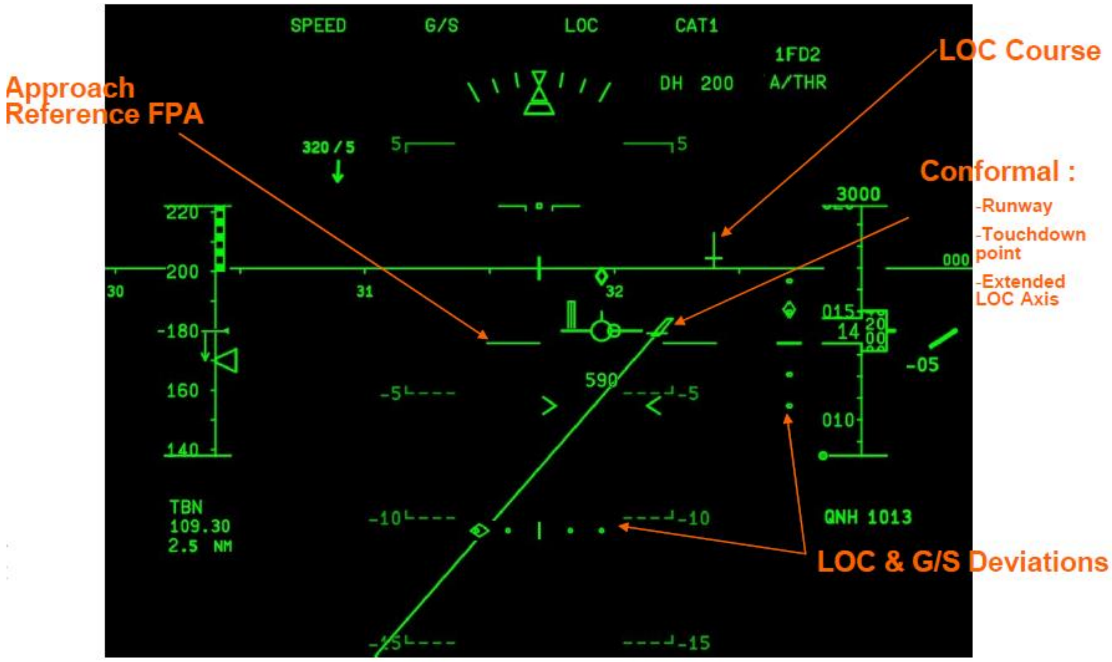


Figure 8: HUD – landing mode

A computer-generated synthetic image of the runway with its prolonged centerline is displayed on the HUD. A touchdown zone is displayed on the runway image.

During a precision instrument approach, or an instrument approach with vertical guidance, course and glideslope deviations are displayed in the same way as they would on a PFD.

An approach reference Flight Path Angle (FPA) will appear inside the artificial horizon indication. Its goal is to help the pilot maintain a correct pitch to achieve a correct descent. That is similar to a Flight Director system, except that it only works for pitch, and it is based on the flight path vector.

2.6 HUD de-clutter in strong crosswind conditions

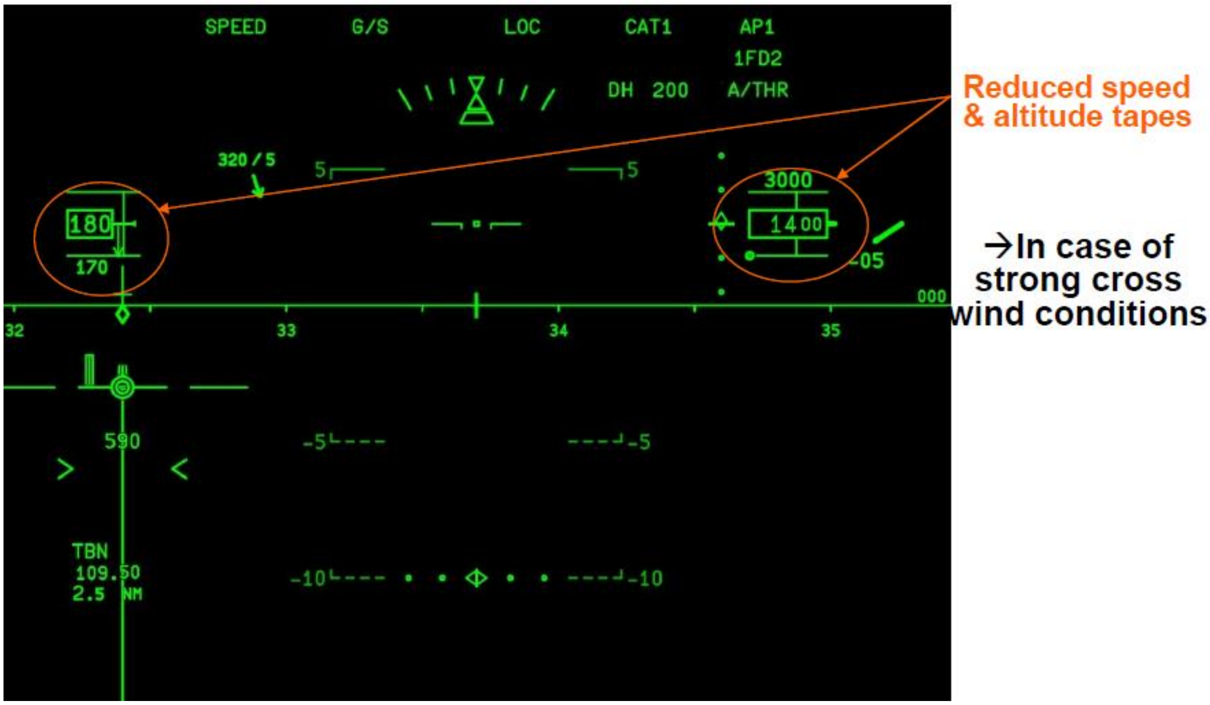


Figure 9: HUD image during a crosswind

In case of a strong crosswind, especially during landing, the aircraft's longitudinal axis is at an angle to the runway axis. For the runway and its synthetic image not to be covered by other HUD indications when the nose is slightly turned to the side, airspeed and altitude tapes are minimized in size so that only current values and trends are displayed. Display de-cluttering prevents crucial images to be covered by other ones but keeps all the displayed information on the HUD. On figure 9, the image of the airplane's FPV and the runway synthetic image is on the left, which indicates a crosswind from the right.

3 Enhanced Vision System (EVS)

According to Eurocontrol definition, an Enhanced Vision System is a technology, which incorporates information from the aircraft's on-board sensors to maintain outside visual reference in low visibility conditions [7]. In American literature and documentation, most of the time, a name Enhanced Flight Vision System (EFVS) is used. This is because the FAA decided to separate the systems' definitions by their operational capabilities such as a permission to use EVS imagery instead of natural vision for an instrument approach, which could only be done with an EVS displayed oh a HUD, not on a head-down display (HDD). So, the fully certified system is called an EFVS, and any other systems not certified for an EVS approach are called an EVS. Practically, EVS and EFVS are the same system, and to avoid confusion, from now on in this thesis, the term EVS will be used.

An Enhanced Vision System is a relatively newly developed imaging system, which enables the flight crew to see outside the aircraft cockpit better than a naked human eye is able naturally. Such a technology enhances the overall flight safety, but is also carries specific operational advantages, which will be covered later in this work. Different technical designs of this system, as well as specific examples of different products available on the avionics market and already used in operations, will be covered in this chapter.

The first technical solutions, allowing humans to see in the dark, were developed and used during the Second World War. They were firstly used by snipers in their gunsights, so that an enemy could be seen even in complete darkness. Later on, military pilots started to use night vision equipment. Firstly, they were mainly helicopter pilots, who almost always fly visually.
A first civil aircraft to be equipped and certified for EVS operations was a Gulfstream V with a Kollsman infrared camera. In 2003 EVS becomes a part of standard equipment for Gulfstream G550 aircraft, and later on G450 and G650. An EVS is available for installation as a part of optional equipment in Boeing 787 aircraft.

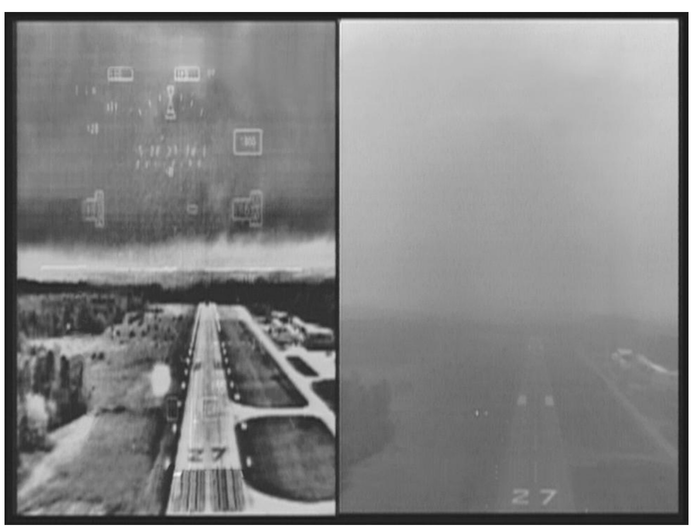


Figure 10: EVS image displayed on a HUD (left) compared to a naked eye view

3.1Technical design

3.1.1 FLIR

Forward Looking Infrared Camera (FLIR) is a piece of hardware on airplanes and helicopters that is able to capture infrared radiation with the help of a thermographic camera. This infrared light is then displayed on a display as a video recording. The main difference between a thermal camera and a regular one is that a thermal camera captures and displays light from the infrared spectrum (0,75-100 μm) instead of the light from the visible spectrum (370-750 nm). The infrared spectrum is not visible to the human eye [8]. Infrared radiation is emitted by any source of heat: buildings, vehicles, public lighting etc. Approach lighting systems and runway lights are a source of this radiation as well. An infrared camera image is displayed to the pilot, mostly through a head-up display. That image enables the pilot to "see through" most types of precipitation and clouds during the day as well as at night. The pilot sees the aerodrome or surrounding inhabited areas.

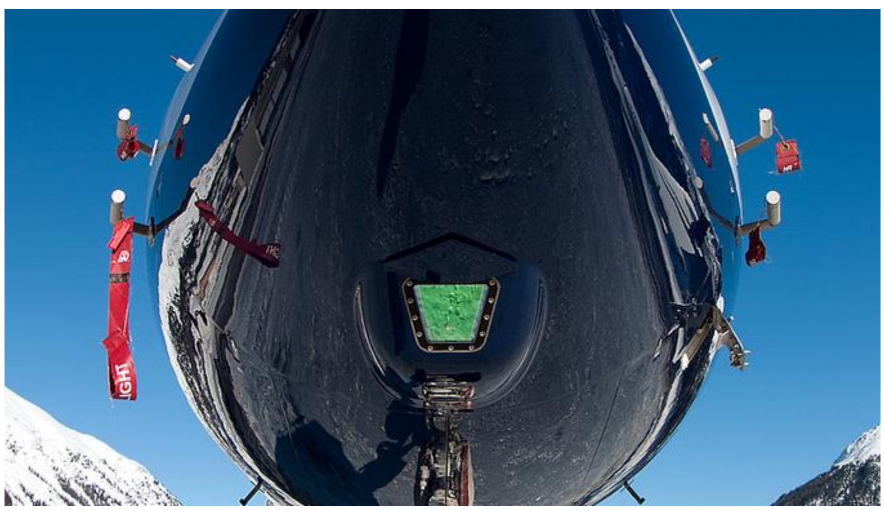


Figure 11: Placement of EVS sensor on a Gulfstream G550 aircraft

3.1.2 Camera based on Passive Millimeter Wave imaging (PMMW)

Certain types of fog, clouds and precipitation, which contain large amounts of water, can lower the resolution characteristics of an infrared camera [9]. A possible solution to this problem could be the utilization of a radar operating in a millimeter wave frequency band (70-250 GHz). The output of such radar, just like any other radar, are ranges and azimuths. This data is then converted into an optical image. This image has a lower graphical quality compared to an image from a thermal camera, but it still provides the pilot with an increased situational awareness during the approach.

So far, no EVS commercially available on the market utilizes the PMMW technology, however, some manufacturers are planning on implementation of this technology in the future models. Years ago, NASA launched researches aimed at combining images from a thermal camera and a millimeter radar into one integrated image. The purpose of these researches was to get the best information from every sensor and combine them to achieve maximum image details and quality. By combining multiple sensors, an even tougher system can be designed, that is more resistant towards atmospheric conditions, but at the same time, a high image quality is maintained. Furthermore, test flight prototypes of such systems already exist and are being tested, one can assume that it is a question of a couple of years before these products will be commercially available on the market [10].

3.2 EVS advantages:

- In case that the cloud base in the final approach segment of an instrument approach does not have a consistent height, or if there is a thin fog layer very close to the ground, EVS can prevent a brief loss of visual contact with the ground or approach lights
- The pilot is quickly informed about potential threats in the line of the aircraft's path, which are not clearly visible with a naked eye. Examples of such threats are vehicles, terrain, other aircraft, obstacles on the runway or on the other maneuvering areas at an airport
- The use of EVS enables the operator to reduce the DA/MDA up to 100 ft. AT, which increases the chance of gaining visual contact with the RWY by means of natural vision and perform a landing

3.3 EVS limitations:

- A high purchasing price
- Necessity to perform modifications in the airplane structure for the installation of optical and thermal sensors
- EVS that implements the usage of a FLIR camera is not reliably capable of detecting infrared radiation through certain types of clouds and precipitation

4 Synthetic Vision System (SVS)

The history of a Synthetic Vision System begins between 1970s and 1980s in USA, when NASA, in cooperation with major avionics manufacturers, was designing, developing and testing SVS prototypes. Test pilots who flew the aircraft that was testing those prototypes have given very good feedback about the system already then.

Figure 12: An example of SVS designed by Honeywell displayed on a PFD

The SVS is another imaging system, that assists the flight crew with visual orientation in the space in the aircraft’s flight path in any meteorological conditions during day and night. SVS improves pilots’ situational awareness, thus increasing the level of flight safety. The concept of an SVS system is computer simulation of virtual reality, displaying real outside objects. The images of these objects are not based on inputs of sensors measuring any real physical parameters like it is in case of an EVS. The image output of an SVS is completely autonomous, and is provided from an on-board database. Objects stored in the database are overlaid with the aircraft’s current position and spatial orientation using navigation systems based on GNSS or IRS

The types of databases used in SVS include terrain, geopolitical, topographical databases as well as airport infrastructure databases. Together, they create a three-dimensional image of the surrounding world, which is displayed either on a separate display, on a PFD or on a HUD. Although the displayed imagery would be identical in any of the three ways, SVS displayed on a HUD carries the most value compared to the other two. The reason is that an SVS image overlaid on the outside world image provides the best situational awareness enhancement to the pilot. However, displaying an SVS on a head-up display is much more technologically complex, as it requires a certain level of integration of the two systems. During the head-up operations, an SVS enable the pilots to “see” the surrounding terrain and any other obstacles

Figure 13: SVS HUD projection in Dassault Falcon aircraft (Falcon Eye system)

as he would in good visibility conditions, all that while looking forward outside the aircraft window, which is most natural. In modern days, a whole range of products that possess the ability to project synthetic vision exist. Those products don’t necessarily have to be expensive. A very popular mobile application gives the customer the synthetic vision capability for just $200 per year. Such products include mobile applications one can install on a tablet computer or eve on a mobile phone, and among other things, these applications have the synthetic vision function. The same principle applies: a terrain database and any other databases are stored in a device’s memory, accelerometers in the device help to determine the device’s spatial orientation, and a GNSS module provides the geographical location information. All those sensors are standard in any consumer electronics such as smartphones or tablets. Of course, these systems are not certified in any way to be used operationally in an aircraft, and they are not an official certified part of avionics equipment. However, synthetic vision on a mobile device can be a great tool, for example, for a VFR pilot, who flew into IMC conditions, or got lost at night in the vicinity of high terrain.

Another unique feature of the synthetic vision system is a so-called Highway in The Sky (HITS), or Path in The Sky. It is a projection of the flight route as a sequence of frames, usually rectangular, which the aircraft must "fly through" to remain on a prescribed track. This projection method provides the flight crew with a high-quality overview about their position relative to the path the aircraft is supposed to fly and is a good assisting tool to help remain on the track.

Figure 14 Left: SVS in Garmin G3X installed in a FM 250 Vampire II ultralight aircraft. HITS displayed on the flight route. Right: Synthetic vision in ForeFlight mobile application

It is necessary to mention that synthetic vision does not provide any operational advantages compared to a flight without any sort of visual assisting system. All SVS does is it increases the pilot's situational awareness. Aviation regulations do not allow the use of SVS projection in place of real-world visual contact with the runway during a low visibility instrument approach. SVS, being a certified part of an aircraft's equipment, is only an assisting informative tool. [11]

4.1 SVS advantages:

- Highly detailed terrain, notable obstacles and aviation infrastructure projection during the flight in any meteorological conditions
- Due to the projection images being generated by a computer without the utilization of on-board sensors, the highest image quality is ensured
- Low purchasing costs make it available for installation in light general aviation aircraft
- Unlike EVS, the system doesn't require an installation of any special equipment for the outside world projection

4.2 SVS limitations:

- SVS will only display the objects that are available in its inner database. Due to that, the database must be regularly updated
- If a system malfunction would happen, and the SVS will provide the crew with a false indication, a risk of loss of situational awareness exists
- SVS cannot be used as a supplement for an outside visual reference on a final approach segment [12]

5 CVS – Combined Vision System

Combined Vision System, or CVS, introduces a hybrid combination of the EVS and SVS systems in a single projection. Basically, a CVS is not an entirely new concept of a system, but an integration of the CVS and SVS into one combined real-time projection onto a single display. The system automatically selects the projection appropriate for the phase of the flight. For example, during an instrument approach, in an initial approach segment, an SVS would be utilized as a primary source of projection. As the aircraft would get closer to the runway, the image would gradually change from a synthetic one to an EVS imagery. This is done both for the validation of the SVS images, as well as for the projection of the runway environment [13].

5.1 Types of CVS

There are two general concepts of the projection of a Combined Vision image. The first one projects the SVS imagery in the background and EVS imagery in the foreground, meaning that the terrain further away would be projected via the database-driven imagery, while the area closer to the aircraft will be projected from the infrared sensors input. The second type of CVS combines the two images, both SVS and EVS, into one image on the whole area of the display, overlaying each other.

6 Overview of existing products

6.1 Thales D-HUDS

A French-based company Thales is a major aviation electronics manufacturer for civilian aircraft and military aircraft. This company is offering a so-called D-HUDS – Digital Head-up Display System. This system is compatible with both civilian and military aircraft and is primarily designed for the Airbus aircraft. In the civil air transport aircraft segment, it is installed in A380, A340, A350 and A320 family aircraft. Business jet installations include A318 Elite and A319CJ. In the military aircraft, D-HUDS in installed for example in the Airbus A400M.

Figure 15: Thales HUD

D-HUDS enables the integration of the SVS, EVS and SGS systems. SGS is a taxi assistance system which will be discussed later. A single display, as well as a dual HUD installation is optional. The angular display field of view coverage is 35º×26º.

D-HUDS utilizes liquid crystal displays (LCD) technology. These displays are also manufactured by Thales. The use of LCDs instead of a cathode ray tube design has the following advantages:

- Lower mass (23 kg), volume and electric power consumption (160 W)
- Lower operating costs compared to HUDs with a conventional CRT
- An image of a higher brightness
- Additional options such as the line thickness manual adjustment [14]

6.2 Rockwell Collins Head-up Guidance System 3500 (HGS™)

The following product was developed by an American company Rockwell Collins. It incorporates the head-up display system itself as well as EVS and SVS support, if the customer wishes to order these optional functions. The most interesting features of this particular product are all the different modes and elements displayed on a HUD. These modes and elements are great assisting tools helping the flight crew in all phases of the flight from taxiing and take-off roll to an approach, landing and rollout. The highly intuitive symbology used in this product reduces the pilot's mental workload and increases his situational awareness.

Figure 16: Operational situations display on a HGS. TCAS RA instruction (left), tailstrike alert and correctional instruction (right)

Another technological novelty, which Rockwell Collins in cooperation with Flight Dynamics company is a Surface Guidance System (SGS) – a taxiing assisting system based on a database-driven projection of airport infrastructure such as taxiways and runways, all displayed on a HUD [15]. Essentially, the same principle is used here as in an SVS, but precision requirements for this system are much higher due to a very small margin of error a taxiing aircraft can afford.

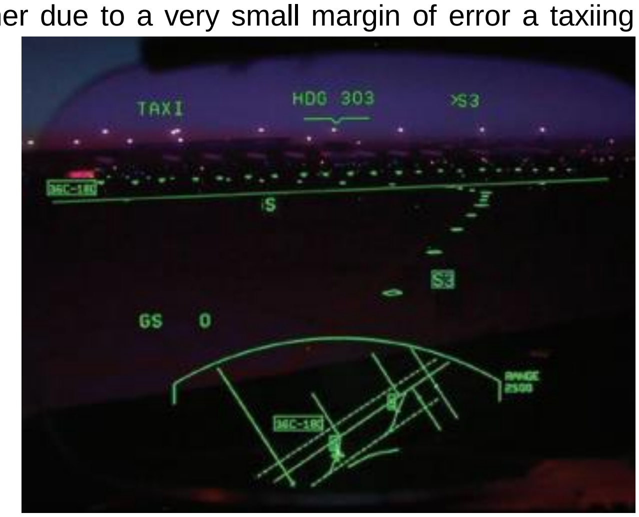


Figure 17: A taxi assistance option utilizing the SGS

6.3 Gulfstream EVS, EVS II and EVS III

In 2001 Gulfstream has become the first aircraft manufacturer in the world to obtain FAA certification for the installation of EVS on board Gulfstream V aircraft, and on all of the following models. The system uses a Kollsmann infrared camera and image projection on a head-up display. After proving the effectiveness and reliability of EVS, the equipped aircraft have received additional operational minimums from the FAA. That would mean that provided the aircraft and the flight crew are properly certified for EVS operations, the aircraft could be hand-flown below the typical decision height (DH) of 200 feet down to the DH of 100 feet.

At the end of 2007, Gulfstream received FAA certification for the EVS II system, projected on a HUD II. This modernization is a part of the Gulfstream's modern flight deck concept called PlaneView 280. The system's second generation's specialty is mainly due to the increased computing capabilities of the processors and overall size and weight reduction, which is achieved by using an LCD instead of a CRT display. The manufacturer claims that the systems is 22 pounds lighter, has four times the computational power and four times the memory of the previous system.

The third generation of the EVS system for Gulfstream aircraft is EVS III. In this system, the image's resolution has been increased by four times. Kollsmann infrared camera of the third generation enables an automatic image dimming when leaving an area of low visibility. This feature prevents the pilot's eyes to be overstressed with the light of the approach lighting system itself. The company's future plans include installation of EVS III in Gulfstream G500 and G600 as standard equipment. [16]

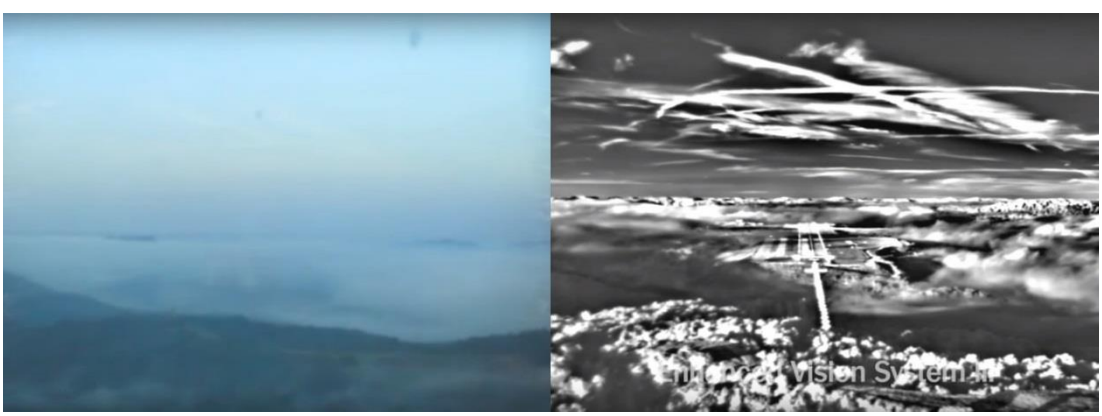


Figure 18: Comparison of the cockpit outside view with and without the help of Gulfstream EVS III

7 Regulatory aspects of HUD, EVS and SVS

7.1 USA (FAA)

The main state aviation authority of the United States, Federal Aviation Administration (FAA), develops and updates all legislative aspects of transport aviation on US territory and oversees the whole civil aviation in the US. FAA publishes regulations and rules which regulate the usage of EVS and SVS in different segment of civil aviation.

By the definition of FAA EVS operations are aircraft operations, where an EVS output is used instead of the pilot's natural vision. During these operations, the pilot descends below the DA/DH of an instrument approach, where a visual segment of an approach begins. Without the use of EVS, in some cases the pilot wouldn't necessarily have the runway in sight, thus such operations would be considered illegal.

7.1.1 Types of operations

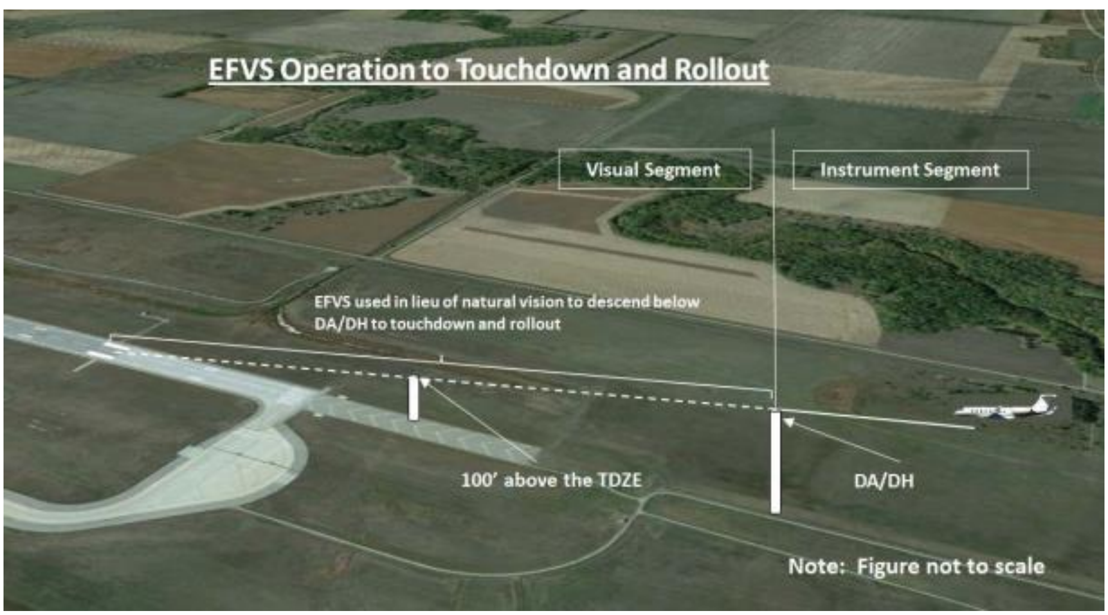


Figure 19: EVS operations down to touchdown and rollout

FAA has defined two types of operations with the use of EVS: EVS operations down to touchdown and rollout, and EVS operations down to 100 ft. above the touch down zone's altitude. EVS operations to touchdown and rollout enables the operator to bring the aircraft all the way down to the runway and roll out after landing using EVS as a main source of outside visual information. In order for an air operator to acquire permission for this type of operations, they must define minima for visibility based on the specific performance of the equipment installed in each aircraft. If the operator's fleet is equipped with different variations of EVS products, minima must be calculated separately for each individual system. Instrument approach phases for EVS operations down to touchdown and rollout are illustrated on an image above,

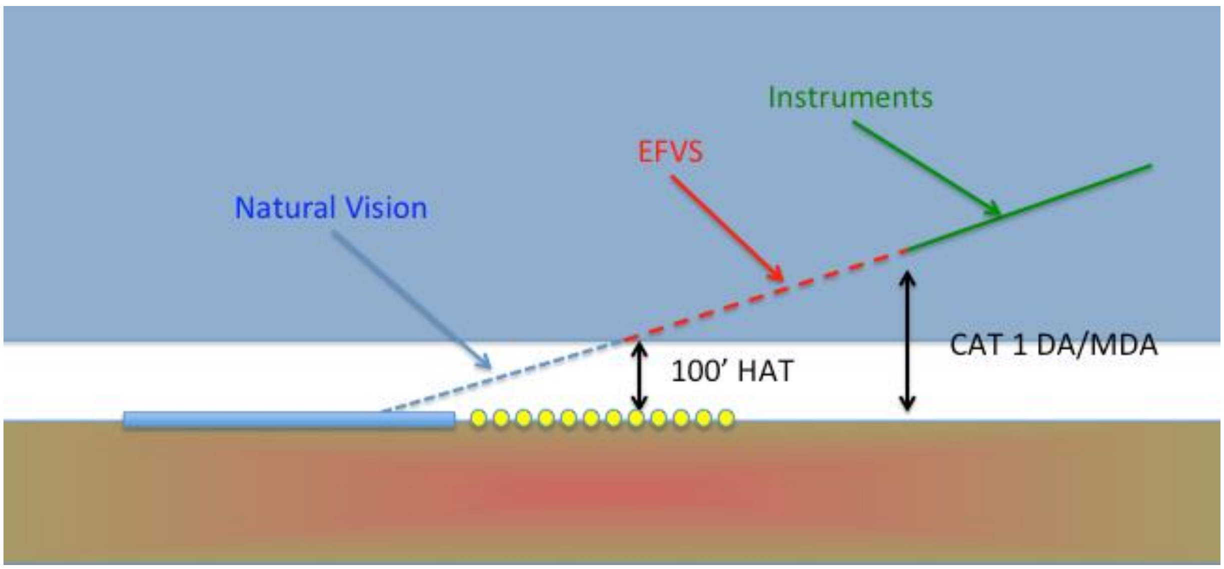


Figure 20: EVS approach down to 100 feet HAT

FAA also regulates the requirements for a flight under a normal DA/MDA. After some time, FAA modified these requirements in order to enable aircraft operators to operate in low visibility conditions while maintaining a high level of flight safety. For many years, a descent below DA or MDA was only possible after meeting certain criteria such as a stabilized approach, bust most importantly, continuous visual contact with the runway by using only the pilot's natural vision. [17]

On the 9th of January 2004, FAA has published a so-called Final Rule called FR 1620, Enhanced Flight Vision Systems. This rule enabled the operators to use output from the EVS instead of natural vision for the continuation of the approach and to descend under a normal DA down to 100 feet above the touchdown zone during a published instrument approach. The exception is low visibility procedures also known as CAT II and III approaches.

However, at or below 100 feet HAT, the approach lighting system or the touchdown zone lights must be visible by only using natural vision. A pilot cannot continue any further descent below 100 feet and only rely on the visual information generated by the EVS sensors output. The 2004 final rule has also defined requirements for the equipment installed in order to perform EVS operations and created definitions for EVS and increased flight visibility.

On the 13th December 2016, FAA has published an updated rule, that contained a revision of operational requirements for the EVS system usage. This rule enables the pilot to use EVS output instead of natural vision to descend below 100 feet above the touchdown zone in case certain conditions are met. The rule also defined changes that related to the requirements for visual references for EVS operations below the DA/MDA down to 100 feet above the touchdown zone, as well as EVS operations to touchdown and rollout. [18]

7.1.2 EVS regulatory aspects for commercial air transport

The 2016 rule was written for the operation of the EVS by operators under part 121, 125 and 135.

Part 121 includes the operating rules for regular air transport (regional and so-called major carriers, big airlines). Part 125 defines the rules for the operator, who operate large aircraft with seating capacity of 20 or more passengers or with a maximum useful load of 6000 pounds or more. For example, that could be airplanes of a company that uses it to fly its employees, or it could be an operator that do not transport passengers or cargo. Part 135 includes the rules for operators that operate their aircraft “on request”. The aircraft used for part 135 operations can have a maximum seating capacity of 30 passengers, or a maximum useful load of 7500 pounds or less.

Operators of aircraft under parts 121, 125 and 135, which are equipped with an EVS system, are allowed to initiate an instrument approach is the weather at the destination aerodrome is bad and below the minima for the given type of an approach. FAA requires initial flight crew ground and flight training. So far, FAA does not allow these operators to use the EVS output instead on natural vision for the descent below the published minima to 100 feet HAT.

However, FAA rules have newly enabled the part 121, 125 and 135 operators to use EVS during standard instrument departures (SIDs). [19]

7.1.3 EVS operations requirements to touchdown and rollout

In order to conduct the EVS operations in the United States, there are a set of requirements to be met that include equipment, operational, visibility and visual reference requirements. The full list of requirements can be found in the FAA regulation 14 CFR, part 91. Here are some of the selected requirements:

1) Equipment. The EVS must:

a) Have an electronic means to provide a display of the forward external scene topography (the applicable natural or manmade features of a place or region especially in a way to show their relative positions and elevation) through the use of imaging sensors, including but not limited to forward-looking infrared, millimeter wave radiometry, millimeter wave radar, or low-light level image intensification.

Basically, the aircraft must be equipped with a functioning EVS system based on any selected technology.

b) Present EVS sensor imagery, aircraft flight information, and flight symbology on a head up display, or an equivalent display, so that the imagery, information and symbology are clearly visible to the pilot flying in his or her normal position with the line of vision looking forward along the flight path.

This means that a head-down display cannot be used in EVS operations, as mentioned earlier.

c) When a minimum flight crew of more than one pilot is required, the aircraft must be equipped with a display that provides the pilot monitoring with EVS sensor imagery

Either a dual HUD installation, or EVS imagery displayed on an HDD is required.

2) Operations.

a) The pilot conducting the EVS operation may not use circling minimums.

This also applies to EVS operations down to 100 feet HAT.

b) When a minimum flight crew of more than one pilot is required, the pilot monitoring must use the display to monitor and assess the safe conduct of the approach, landing, and rollout.

Not only a second display for the pilot monitoring must be installed, the PM must use it during the whole duration of an EVS approach.

c) A person conducting operations under this part must conduct the operation in accordance with a letter of authorization for the use of EVS unless the operation is conducted in an aircraft that has been issued an experimental certificate under §21.191 of this chapter for the purpose of research and development or showing compliance with regulations, or the operation is being conducted by a person otherwise authorized to conduct EVS operations under paragraphs (a)(2)(ix) through (xii) of this section.

In other words, a Letter of Authorization (LoA) if it's a non-commercial general aviation operator, or an Operations Specification (OpSpec) for commercial operators is required for EVS operations.

3) Visibility and visual reference requirements

a) No pilot operating under this section of this chapter may continue an approach below the authorized DA/DH and land unless:

Followed by a long list of requirements that include the functionality of an EVS and its ability to actually enhance the visibility compared to natural vision. Further requirements include the identification of the runway threshold by any of the listed visual references. After that a similar list is included for the flight under 100 ft. HAT all the way down to the runway. [20]

7.1.4 EVS operations requirements to 100 feet HAT

The requirements to these operations are similar to the ones used in operations down to touchdown and rollout,

1) Equipment

a) The EVS must meet the requirements of paragraph (a)(1)(i)(A) through (F) of this section, but need not present flare prompt, flare guidance, or height above ground level.

Requirements for equipment for this kind of operations are slightly less strict.

2) Operations

a) The aircraft must continuously be in a position from which a descent to a landing on the intended runway can be made at a normal rate of descent using normal maneuvers.

b) For operations conducted under part 121 or part 135 of this chapter, the descent rate must allow touchdown to occur within the touchdown zone of the runway of intended landing.

c) A person conducting an EFVS operation during an authorized Category II or Category III operation must conduct the operation in accordance with operations specifications, management specifications, or a letter of authorization authorizing EFVS operations during authorized Category II or Category III operations.

Special permission from an aviation authority is required

3) Visibility and visual reference requirements

From the DA or an MDA of the selected approach down to 100 feet above the runway threshold, the same requirements apply as for EVS operations to touchdown and rollout, after that:

"At 100 feet above the touchdown zone elevation of the runway of intended landing and below that altitude, the flight visibility must be sufficient for one of the following visual references to be distinctly visible and identifiable to the pilot without reliance on the EFVS"

At this altitude, the pilot must see the runway only relying on his natural vision. [21]

7.2 Europe (EASA)

So far, European legislation is much more restrictive towards EVS operations in the EASA states. However, some progress has been made, and even though the rules are not as permitting as those of the FAA, today EVS operations are a real possibility in the European skies.

The legislative base has been created and published in EU-OPS 1.430 (paragraph h) in September of 2008. The chapter states the following:

(h) Enhanced vision systems

1. A pilot using an enhanced vision system certificated for the purpose of this paragraph and used in accordance with the procedures and limitations of the approved flight manual, may:

i) continue an approach below DH or MDH to 100 feet above the threshold elevation of the runway provided that at least one of the following visual references is displayed and identifiable on the enhanced vision system:

A) elements of the approach lighting; or

B) the runway threshold, identified by at least one of the following: the beginning of the runway landing surface, the threshold lights, the threshold identification lights; and the touchdown zone, identified by at least one of the following: the runway touchdown zone landing surface, the touchdown zone lights, the touchdown zone markings or the runway lights;

3. A pilot may not continue an approach below 100 feet above runway threshold elevation for the intended runway, unless at least one of the visual references specified below is distinctly visible and identifiable to the pilot without reliance on the enhanced vision system:

A) The lights or markings of the threshold; or

B) The lights or markings of the touchdown zone. [22]

No regulations have been created for EVS operations to touchdown and rollout. This means, that in Europe, pilots can only descend down to 100 feet HAT with the use of EVS instead of natural vision.

In 2004, Dassault Aviation has published a Proposed Special Condition on Enhanced Vision System applicable to a Falcon F7X aircraft, a safety requirements document developed to introduce EVS operations in Europe. This document consists of two main parts: special condition for pilot's compartment view and acceptable means of compliance. Requirements that the EVS must meet in order to avoid unacceptable interference with the pilot's compartment view are described in the first part.

These requirements include:

1) The EVS design must minimize display characteristics such as image noise or running water droplets, that impair pilot's ability to detect and identify visual references

2) Effective control of the display brightness in changing lighting conditions. Automatic brightness adjustment is preferred, but if it's not available, a one-time manual setting must be proven to be enough.

3) A control enabling the pilot to immediately activate or deactivate the EVS must always be available

4) The EVS imagery on the HUD must not impair the pilot's ability to read guidance information or any other flight instruments displayed on the HUD. This means that the infrared image must not overlap or interfere with other displayed parameters.

5) The EVS imagery must align perfectly with the actual outside world imagery (the image must be conformal). In case the image cannot be perfectly aligned, such as in strong crosswind conditions, the system must be able to recognize that and perform some sort of a corrective action to avoid being misleading, cause pilot confusion or increase pilot workload.

In the next part, requirements for image characteristics, installation, system requirements and testing requirements are described. A few of the selected requirements include:

1) Resolution

2) Luminance

3) Display quality – no noticeable display noise, flicker or any other display defects should be noticeable to the pilot

4) Display dynamics – the image on the display must "catch up" with the changing outside imagery during aircraft maneuvering in the whole range of maneuvering capabilities of the aircraft

5) Image controls – for the pilot to manually adjust EVS image parameters as necessary [23]

The first aircraft certified by EASA for EVS operations down to 100 feet HAT were Gulfstream aircraft equipped with a Kollsman EVS, that uses an infrared camera, with an EVS image projected on a HUD. Interestingly enough, US operators that have been approved for EVS operations by the FAA in their home country, can perform EVS operations down to 100 feet HAT without any additional approval or certification on the European side, while European operators must first acquire operational approval from an aviation authority of the country the aircraft are registered in. [24]

In July 2010, EASA has issued an operational approval for Dassault Falcon F7X second generation EVS based on the SureSight CMA-2600 I-Series Integrated Sensor System. Operators of this aircraft now can also perform EVS operation down to 100 feet HAT. [25]

7.2.1 HUD approach application

At many aerodromes, instrument approach minima must be increased without the use of certain equipment, among such equipment is a head-up display.

A figure below shows an instrument approach chart with a remark in the minimums section. Without HUD, autopilot or a flight director system, the minimum RVR for the approach is increased by 200 meters to 750 m. This is an example of a very common operational benefit a HUD can bring.

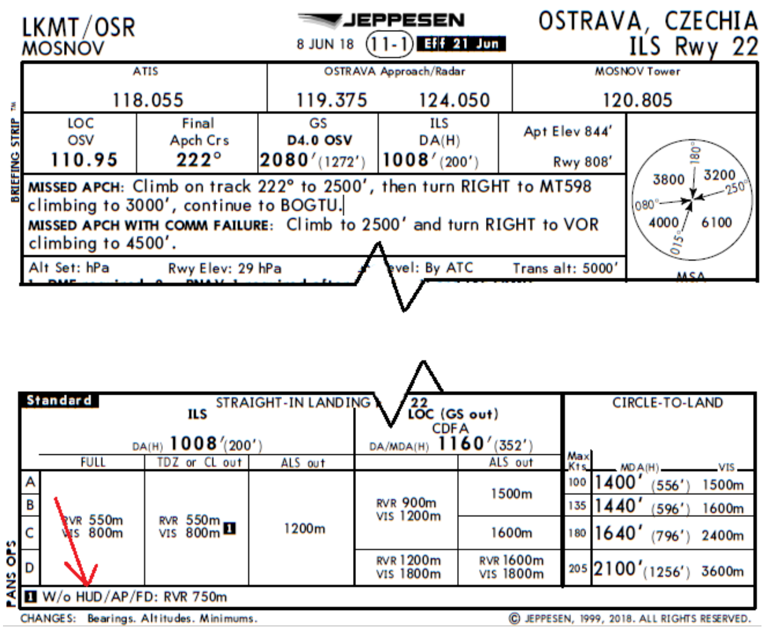


Figure 21: HUD application in an instrument approach. LKMT instrument approach chart

8 Flight crew operational procedures and training for HUD

In this chapter, flight crew HUD training will be described on an example of the Boeing B787 aircraft. The source of information for this chapter is the B787 Flight Crew Operations Manual (FCOM).

8.1 B787 HUD training

Boeing 787 aircraft has become the first mass-produced widebody twin-engine jet airliner to be equipped with a head-up display as a part of standard equipment installed in every aircraft. The HUD installed in a 787, to this day, does not have EVS or SVS capabilities. Therefore, the only training pilots receive on this aircraft is the use of standard HUD functions that include flight instruments symbology, flight path vector, ground deviation and other indications. There is no special training dedicated to just the HUD operation. Instead of that, familiarization with the HUD is done during the type rating training. Both theoretical preparation and practical usage of the HUD is incorporated into the type rating course as a part of general familiarization with the aircraft's avionics and systems. Because the HUD's symbology is relatively similar, and in some cases, identical to PFD symbology, pilots only need to get accustomed to the symbology that is unique to a head-up display. [26]

In chapter 10 section 22 of the FCOM, the Head-Up description, the user is familiarized with some of the basic theoretical data about the HUD, without going into too much technical detail and inner workings of the HUD. This part includes information about HUD components such as the combiner, the overhead unit, and HUD controls that include brightness and symbology control. The reader is also familiarized with how to manipulate with the display hardware: how to unlatch it, open it up, and how to stow it away correctly. Other useful information about HUD manipulation is also mentioned, such as the following:

"If there is a sudden and sustained deceleration, the combiner rotates forward and locks in a breakaway position. This prevents the pilot's head from impacting the combiner. Release the combiner by pushing forward to relieve pressure on the latch and slide the locking lever to the right. Then reposition the combiner to the desired position." [27]

Next, the symbology that is only unique to a HUD is described and explained. This symbology includes: pitch scale compression and chevrons, unusual attitude symbology, digital heading, ground deviation during a HUD takeoff, TO/GA reference line, flight path vector symbol, angle of attack limit symbol and other symbology. In chapter 10 section 12 of the FCOM, the symbology is depicted in many images, with an explanation to each one. First, the two main HUD modes are described: normal mode and decluttered mode.

After that, all the possible symbology of both full and decluttered modes is individually illustrated and described with all necessary comments as to how to interpret each individual symbol and how to work with the display as a whole. [28]

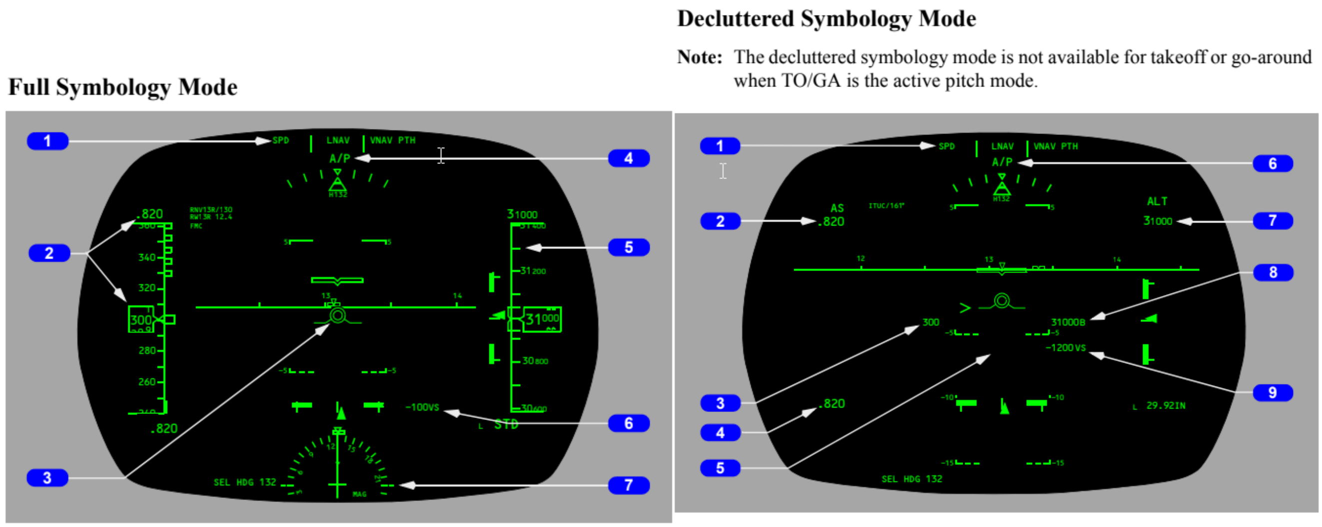


Figure 22: Illustrations of full and decluttered symbology modes. B787 FCOM

9 Evaluation of the possibility of using HUD, SVS and EVS in commercial air transportation

A head-up display system is a relatively complex and expensive avionics component to be installed in an aircraft, and its presence in an aircraft's cockpit must be justified. The same principle applies for an Enhanced Vision System, and even more so, because apart from the equipment purchasing and installation, EVS operations require additional aircraft certification and flight crew training.

This section of the thesis is divided into two parts. In the first part, the goal is to analyze airline pilots' familiarity with HUD and EVS, as well as to understand how widespread these systems are in the present day. This was carried out through an online survey sent to pilots who fly large aircraft with turboprop or turbofan engines.

In the second part, an attempt to justify the usage of a HUD in an airplane's cockpit is made. This is done through an evaluation of a 2009 study carried out by Flight Safety Foundation, an international nonprofit research organization aimed at research and spread of knowledge in the field of aviation safety.

9.1 Online survey

The survey in this part was created and spread to respondents via an online survey service called SurveyMonkey. Communication with most of the respondents was through social media, and some respondents were contacted by e-mail. A total of 16 pilots were asked to complete the survey, however, only 6 pilots did so and answered all of the questions.

Before answering questions, the respondents were greeted with a brief introduction about the survey, its goal and purpose as well as instructions on how to fill out the survey correctly. The respondents were also informed about the usage of their personal information. Next, all of the questions were presented. Out of the total of 8 questions, 6 questions were multiple choice with either only one option, or an option to select multiple answers. Some questions contained an answer box if the respondent wished to enter their own answer. The overall appearance and questions asked in this survey are presented below, beginning with the introduction text:

“Dear respondent!
This survey is a part of my Bachelor's thesis on the topic of "Use of modern imaging methods in transport aircraft cockpits". The goal of this survey is to evaluate familiarity of transport pilots with systems such as HUD and EVS and to hear their opinions about these systems. Furthermore, the survey will give an idea about how widespread the systems are in transport and business aviation.
To fill out this survey, please select one of the answers, or fill your own response if there is a separate field provided. In question 8 please select multiple responses if appropriate.
This survey is completely anonymous, no data will be connected to an individual respondent. Only the data you enter will be used.
Thank you for your time and effort!
Yegor Spitsyn”

Question 1: Do you have any experience using a head-up display (HUD)?

- Yes
- No (if "No" is your answer, please ignore question 2)

Question 2: When you fly an aircraft equipped with a HUD, how often do you use it?

- Every flight or almost every flight
- Sometimes (once per several flights)
- Rarely
- Never

Question 3: How would you rate the HUD's benefit of improving the situational awareness? (1- no benefit, 10- very significant benefit)

Question 4: What do you know about EVS (Enhanced Vision System)?

- I have never heard about it
- I know what it is, but don't have any personal experience
- I was trained to use it during type rating or any other training course
- I was trained to operate EVS and use it during actual flights
- Other (please specify)

Question 5: Approximately how many times per year do you perform a go-around due to negative visual contact during the approach?

- 1-2
- 3-4
- 5 or more

Question 6: Would you welcome an option to descend below DA/MDA to 100 ft. HAT with the help of EVS?

- Yes
- No
- Other (please specify)

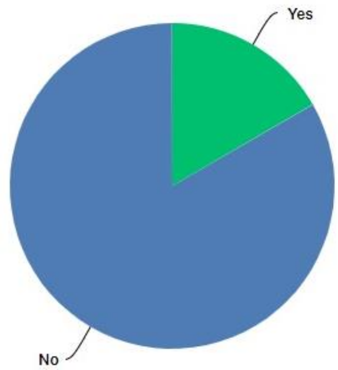
Question 7: Please list type(s) of aircraft flown, including those flown in the past

Question 8: Please choose the regions where you fly or have flown (multiple answers could be selected in this question)

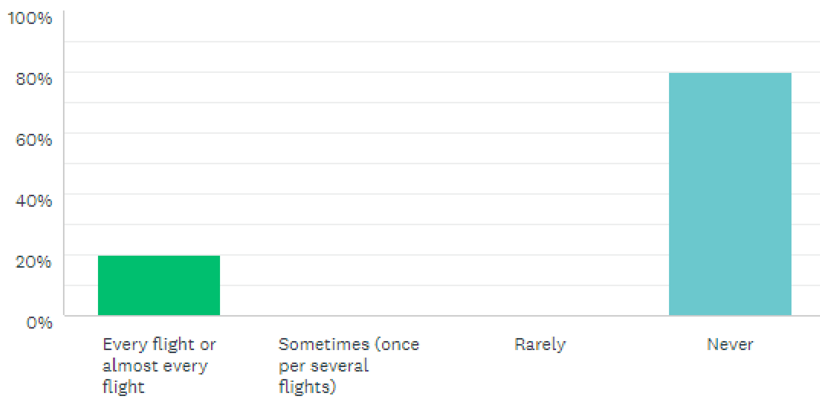
- Europe
- Russia
- North/South America
- Africa
- Southeast Asia
- Australia and Oceania

The results of the survey are presented below:

Question 1: Do you have any experience using a head-up display (HUD)?



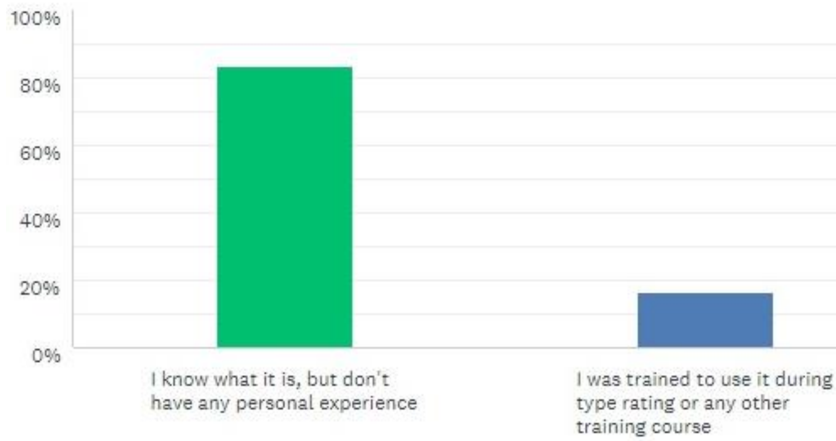
Question 2: When you fly an aircraft equipped with a HUD, how often do you use it?



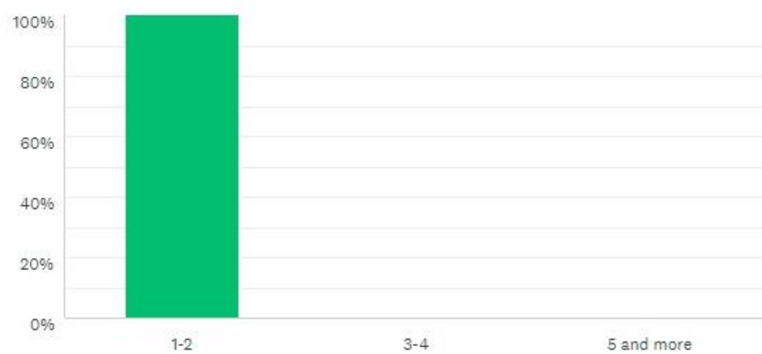
Question 3: How would you rate the HUD's benefit of improving the situational awareness? (1- no benefit, 10- very significant benefit)

- The average result value for this question was 7.

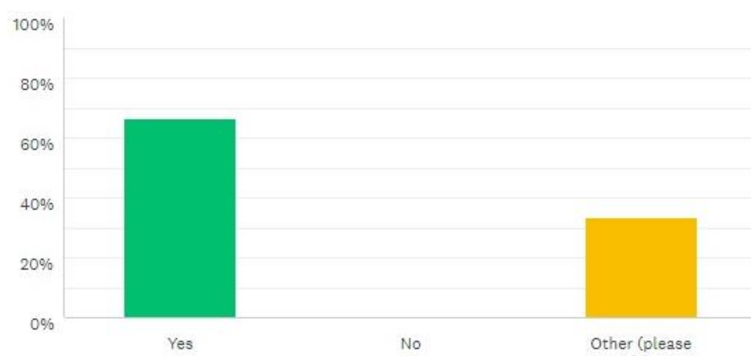
Question 4: What do you know about EVS (Enhanced Vision System)?



Question 5: Approximately how many times per year do you perform a go-around due to negative visual contact during the approach?



Question 6: Would you welcome an option to descend below DA/MDA to 100 ft. HAT with the help of EVS?



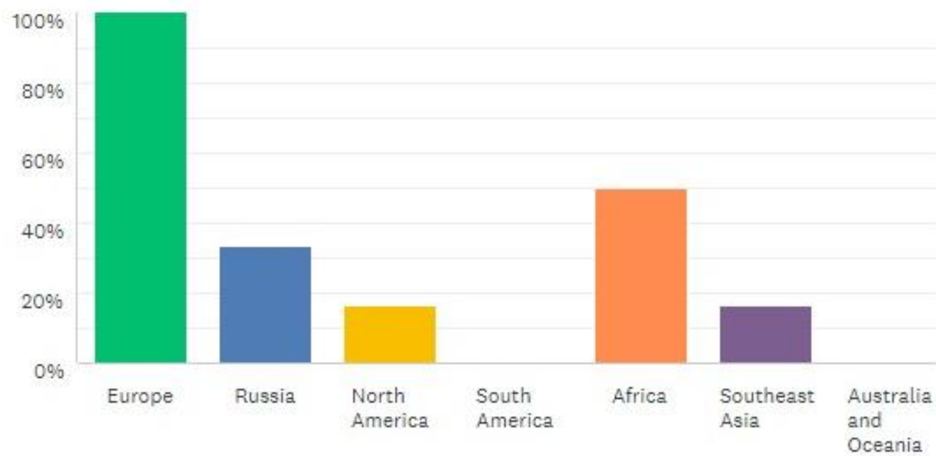
The respondents who wished to enter their own answer wrote: “Not applicable to my aircraft that operates CATIIIB landing, not needed at the airports we use” and “Yes, if officially approved”

Question 7: Please list type(s) of aircraft flown, including those flown in the past

- ATR42/72 (3x), B737NG (3x), B787, Saab 340*

*Only aircraft that belong in performance class A (multi-engine JETs and some Turboprops (5700kg or > 9 seats) were selected from the answers.

Question 8: Please choose the regions where you fly or have flown



The results show that all pilots except for one do not have any personal experience with using a head-up display. The pilot who does have the experience is the pilot who flies a B787 aircraft, which has a HUD installed as a part of standard equipment. Most of the pilots know about the existence of EVS and its function. Only one pilot was trained to use it, however, in question 1 they also answered that they don't have any experience with using a HUD, most probably that means that the pilot only has the appropriate training, but no real experience. The overall opinion about the HUD's benefit in improving situational awareness was quite high among pilots, with the highest rating being 10 from three pilots, and the lowest being 4 from one pilot.

However, due to a very low number of respondents, this survey does not have any significant statistical value, and therefore, will not depict the real situation accurately. This survey is considered unsuccessful by the author.

9.2 2009 Flight Safety Foundation study evaluation

In 2009, Flight Safety Foundation has conducted a study of real aircraft accidents that occurred between 1995 and 2007. The goal of this study was to estimate a possible different outcome of these accidents if the accident aircraft were equipped with a head-up guidance system, or simply a HUD. The criteria for their selection were: civil multi-engine turboprop or turbojet airplanes with an MTOW of 12500 lb. or greater. Ground accidents that happened on an airport ramp were not included in the database. Accidents that occurred on an active runway or taxiway remained in the database.

The method used was a subjective evaluation done by a highly skilled aviation professional, and then a separate audit was done by another safety professional to confirm the result.

The conclusions of this study stated the following:

- HUD safety properties were found to be most effective in the phases of flight where the pilot was directly involved (takeoffs and landings)
- The greatest number of accidents happened with the pilot directly involved

The likely effect on the outcome of the accidents in percentage ratio is shown in the table below. Types of accidents are divided into three categories.

Accident Category	Number of Accidents	Accidents Affected by HGST
Takeoff & Landing	341 accidents	237 (69%) affected by HGST
Loss-of-Control	123 accidents	70 (57%) affected by HGST
Miscellaneous	110 accidents	37 (33%) affected by HGST

Figure 23: Accidents affected by the use of a head-up guidance system.

With the miscellaneous category excluded, 344 out of 584 accidents, or 59%, were likely to be positively influenced by a head-up guidance system. [29]

10 Conclusion

In the modern days, the aviation manufacturers are constantly introducing new technologies to the aviation world. Travelling by air has become a normal way of transportation, and the air carriers are struggling to keep up with the demand. Flight safety must always come before regularity. The technology described in this thesis has the capability to improve both, while being relatively inexpensive for the operator. Operators, who purchase newly manufactured aircraft will most likely already have a HUD installed as standard equipment, so no extra expenses would be necessary. Even a HUD alone will improve situational awareness and may help to avoid accidents associated with loss of control or CFIT. EVS as a standard equipment in large transport aircraft might take a while to become a norm, but for private jets it is a norm already today. As technology develops, it usually becomes more affordable. A simplified example could be the spreading of mobile phones among general population. Although I cannot say that every aircraft will have a HUD with an EVS in 10 years, but I have no doubts that it will be much more widespread. This opinion is based on the fact that a lot of new aircraft (A 350, B787, MC 21) have a HUD as standard equipment, so most probably this trend will continue.

What's equally important, a legislation base for the use of EVS already exists today in the two major aviation regions of the world: Europe and USA. And even though European legislation is slightly behind in terms of the variety of EVS operations used, one can assume that it is only a question of time when an aircraft will be legally able to land on the runway safely, using only an EVS as a means of visual reference. Perhaps, new EVS procedures that improve safety and/or regularity will be developed in the future, but it's too early to talk about that right now. Currently, the focus should be made on the continuation of implementing the technology and legislation we have today in regular air operations, until it becomes a norm.

The goal stated in the introduction of this thesis was to introduce the reader to the technology and to justify its further spreading in aviation. And although the pilot survey was rather unsuccessful, the descriptive part presents all the basic necessary information to have a basic understanding of the equipment, its characteristics, advantages and disadvantages. The legislation was re-written in plain language to avoid misunderstanding and confusion. Hopefully, the potential reader would find the information presented in this thesis useful and what's equally important, easy to read.

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