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USE OF TRANSPARENT DISPLAYS IN AVIATION

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Abstract

The introductory part deals with the design and technologies used in HUD systems and their history of introduction into the aviation industry. Furthermore, the work deals with the implementation of transparent displays in civil transport aircraft and the benefits of their use with respect to the human factor of the crew in low visibility operations. After the part devoted to airliners, there is a chapter describing the possibilities and technical solutions for the installation and use of HUD technology in general aviation aircraft. The final points then point out the advantages and disadvantages of installing this technology in aircraft.

Keywords

Transparent display, display symbols, combinator, human performance, efficiency and safety of flight with HUD

1. INTRODUCTION

This article deals with the use of instrumentation of modern aircraft called Head-up Display. These displays are intended to assist pilots in all phases of flight, from taxiing to landing. The main use occurs when the LVO conditions are announced at the airport. The main task of the Head-up display is to increase situational awareness during critical phases of flight or taxiing on taxiways. Not only the Head-up Display itself helps the pilots, but this display can be equipped with additional systems such as EFVS, SVS or CVS. My motivation for writing this diploma thesis was that this device is not commonly known, it is not taught in schools and also because in the future this device will be widely used by all air operators.

2. HISTORY

The history of Head-up Displays begins with the French test pilot Gilbert Klopfstein. This test pilot invented the first Head-up display, which he introduced in the Nord aircraft. He paid for the production of this equipment from his own finances. At the exhibition, he demonstrated to other test pilots all the possibilities of his device. This device had only a limited number of functions such as an angle of attack indicator, artificial horizontal and speed and altitude indicators. Thanks to this advanced technology, he was able to approach and land on any runway without the use of navigation aids such as PAR or ILS. However, this system was not successful at that time. A few years later, however, Klopfstein was asked to install his display on a Mirage aircraft. During the test flights, he was monitored by ground personnel, who found that the flight trajectory was much more accurate than on the same aircraft without Head-up display technology.

Klopfstein was introducing HUD technology in the USA. There, the Head-up Display found great success. The US Air Force installed this technology in the A-7 aircraft, where it helped pilots with controling the aircraft, but also with the use of weapon systems.

3. HEAD-UP DISPLAY DESIGN

The head-up display is actually any transparent display on which information can be projected. Nowadays, we no longer have to meet them only in airplanes, but they are also installed in cars or even tractors. However, in my diploma thesis I deal only with aviation HUDs.

We recognize the basic types of HUD. The first, the most used, is the HUD, which is permanently installed to the airframe. The display is completely linked to the direction of the aircraft and also the position of the pilot. [1]

The second group of view displays are the so-called HMD or Helmet Mounted Displays, which are installed on the pilot's helmet, and therefore rotate with his head / view and are not firmly attached to the aircraft airframe. Most modern combat aircraft and helicopters use both applications, the classic HUD and HMD. We are talking about aircraft such as F / A-18, F-22, Eurofighter, SU-35, MiG-29 and others. The exception is the latest F-35 Lightning II aircraft, which uses only HMD technology. [1]

A typical HUD consists of three components: a projector, a combiner, and a computer that generates video information. For further simplification, we will refer to the visualization parts of the HUD, ie the projector and the combiner, by one name – the pilot display unit (PDU). All transparent displays require an image source, a generally high brightness cathode ray tube, and an optical system for projecting the information contained in the image at an optical infinity. The pilot views the image after reflection from a semi-transparent element called a HUD combiner. The combiner is located between the pilot's eyes and the aircraft's windshield and is tilted to reflect the light from the image source to the pilot for viewing. The special surface treatment of the combiner simultaneously displays the HUD system information and allows a view of the real environment through the collimator glass so that the pilot perceives both information at the same time.

4. OPTICAL CONFIGURATIONS OF THE HUD SYSTEM

The optical system in the HUD system is designed to collimate the image generated by the HUD computer, ie basic flight parameters, navigation information and command data, while maintaining the background image of the outside world. We distinguish four basic field of view (FOV) characteristics, which will help us describe the nature of the angular range in which the HUD image is still visible to the pilot. [2]

Total field of view (TFOV) - the maximum perimeter in which the symbols from the image source are seen through both eyes of the pilot, which allows vertical and horizontal movement of the head inside the eye box of the HUD. [2]

Instantaneous Field of View (IFOV) - contains what both the left and right eyes see fixed in position inside the HUD's eye box. [2]

Binocular overlapping field of view - is formed by the intersection of two instantaneous fields of view with the standard "eyebox" setting. It defines the maximum range from which the HUD is visible to both eyes at the same time.

Monocular field of view - a perimeter reached by one eye when viewed through the optics of the HUD. Its size and shape vary depending on the position of the eye inside the eyebox.

The field of view characteristics are designed and optimized for the specific geometric configuration of the cockpit based on the intended HUD function. In some cases, the cockpit geometry can affect the maximum achievable field of view.

A significant advance in the design of the optical parts of the HUD is the transition from refractive collimation optical systems to reflection or, in some cases, diffraction collimating systems. The move to more complex (and more expensive) reflex collimation systems led to the implementation of larger display units, which could thus become the primary flight display, thanks to the much lower workload of the pilot in terms of human performance.

5. LIMIT RANGE OF THE PILOT'S HEAD

The limit range of the pilot's head for a given view or "eyebox" is a three-dimensional space surrounding the DEP, from which the HUD display is visible to at least one eye. The location of the eye reference point (DEP) depends on a number of ergonomic parameters of the cockpit, such as visibility of displays in head down mode, angle between the extended axis of the aircraft with a line intersecting the pilot's eyes and nose, steering column or chassis controls. [2]

The HUD's eyebox should be as large as possible to allow maximum head movement without losing the information displayed. The output aperture of the transfer lenses, the distances between the transfer lenses and the combiner, or the distances between the combiner and the DEP or the focal length of the combiner - all these parameters affect the size of the eyebox. The eyebox of modern transparent displays is most often characterized by the following dimensions: 13.2 cm laterally, 7.6 cm vertically and 15.2 cm longitudinally. [2]

In all HUDs, the monocular instantaneous field of view decreases as the head moves, especially at the eyebox boundaries. By defining a minimum monocular field of view at the eyebox boundary, it ensures that even when the pilot's head is moved from the ideal center position, the usable field of view for at least one eye will be maintained. In general, the eyebox limit values for the monocular field of view reach 10 degrees horizontally and vertically. [2]

6. SYMBOLOGY OF HUD

The symbols that are displayed on the HUD must be known and understood by each trained pilot using this technology. Only a limited amount of information was displayed on the first displays, such as the A-7, and pilots were confused if they had to switch between the Head-up display and the Head-down display, as the information displayed was interpreted by different symbols on each. Nowadays, designers strive to display the same symbols on both the HUD and the HDD. Today, HUDs also have many more functions than in the past. Examples are the various modes for taxiing, take-off, surface flight and landing, or the display of a symbol that protects the aircraft from possible tail strike during take-off.

7. HUD SYSTEM IN CIVIL AIRCRAFT

The main purpose of the HUD concept in civil aviation is to offer airlines a cost-effective solution for achieving a high percentage of take-offs, approaches and landings in bad weather conditions. The implementation of transparent displays significantly increases the pilot's situational awareness when reducing or completely missing real visual stimuli. Another advantage is the easier selection of unusual positions, increased accuracy in manual flight and the actual "involvement" of the pilot in the control of the aircraft, ie the elimination of the unfortunate phenomenon, which is a pilot focusing exclusively on monitoring systems. The ability to extend the access of airlines to less well-equipped airports even in bad weather conditions is another factor that motivates the installation of the HUD system.

Alaska Airlines pioneered the commercial concept of HUD. With its 24 Boeing 727-200s equipped with transparent displays, in 1986 it became the first commercial user of this technology in the world. By 1995, it had made 225 landings and 35 takeoffs that could not have taken place without the HUD. During this period, 138 captains qualified for the CAT III approach. Only one of all CAT III approaches was interrupted due to insufficient visual reference at decision height, which means a success rate of 99.6 percent. [3], [4]

Southwest Airlines also has experience with HUD systems. This company also tried to follow its flight schedule very precisely and had two options to achieve this. The first option was to activate the Autoland automatic landing system, which involved high costs for the aircraft manufacturer, but also for the maintenance and monitoring of these systems. The second option seemed to be the installation of a pioneering view display system, which represented a much lower cost. Subsequently, the management of Southwest decided to install the HUD system in the entire fleet of 236 Boeing 737-300, -500 and also -700. [3], [4]

Because HUD has fewer items to certify and retest compared to Autoland, it provides a cost-effective low visibility approach solution.

8. ADDITIONAL SYSTEMS OF HUD

8.1. EFVS - Improved Flight Vision System

EFVS is an electronic means of displaying the external environment using imaging sensors such as an infrared sensor (FLIR), millimeter wave radar or low light image intensification, etc. EFVS must also provide additional flight information / symbology on the HUD (or equivalent display) required to favor lower landing minima. It must also be integrated with the flight guidance system. The elements of the EFVS include: [5], [6]

- EFVS sensor system
- Sensor display processor
- EFVS display
- Pilot controls / interfaces

8.2. SVS-Synthetic vision system

Synthetic vision is a computer-generated image of the external environment from the perspective of the flight deck, derived from the position of the aircraft, highly accurate positioning and terrain database, obstacles created by human activity or nature. Synthetic vision creates an image with respect to the terrain and the airport within the possibilities of the navigation source (position, altitude, course, route and database restrictions). The SVS can provide situational awareness, but no operational credit due to meteorological minima. The components of the SVS include: [5], [6]

- Display
- Terrain and obstacle database
- Location, altitude, course and route

8.3. CVS-Combined vision system

CVS can include database-driven synthetic vision images combined with real-time sensor images that are superimposed and correlated on the same display (eg, HUD, HDD). This involves the selective blending of two technologies based on the intended function of the system. CVS can provide situational awareness, but whether CVS qualifies for operating credit depends on how it is configured and whether it meets the legal requirements for EFVS operating credit. [5], [6]

Each of these systems can be an additional equipment of the HUD system. However, they can also be used in cockpits without a HUD system, as they can also be displayed on HDD displays.

9. APPLICATION OF TRANSPARENT DISPLAY IN GENERAL AVIATION

The first commercially successful design for a general aviation aircraft display application is a product of the American company SkyDisplay, which was approved by the STA in June 2021 by the US Air Force for the use of this technology. Specifically, it is the STC for SkyDisplay AID (Aircraft Interface Device), which is the basic unit for the HUD itself. This avionics kit has been approved for Part 23 aircraft operating under Part 91 rules. In just a few months, more than 20 aircraft owners have begun working with SkyDisplay, who have shown interest in the technology and are also involved in the certification process. These were aircraft such as Cirrus, Cessna, Beechcraft, Phenom, TBM, Piper, AirTractor / Fire Boss, ie aircraft equipped with both piston, turboprop and jet propulsion units. In these cases, the entire SkyDisplay system has been integrated with the onboard avionics of several manufacturers: Aspen Avionics, Garmin and Honeywell, and this is not their final list. Development for the SkyDisplay HUD took place with the direct support of Duncan Aviation of Denver, Colorado. Technically, the HUD SkyDisplay has two main components: a HUD projector with a collimator and an interface unit (AID), ie a computer providing an interface with aircraft systems via the Arinc 429 bus. ground or flying pilot or non-pilot vehicles. [15] To date, SkyDisplay offers the option of installing a classic flight information HUD or an enhanced version that already includes the EFVS enhanced vision system, which comes from Astronics under the trade name Max Viz and is based on an infrared sensor. to install in a wide range of aircraft types, here is a partial list: Air Tractor, Beechcraft Bonanza, Beechcraft Baron, Cessna 421, Cessna Conquest, Cessna Mustang, Cessna Citation CJ2 +, Cessna Citation CJ4, Cirrus SR22, Cirrus Vision Jet, Embraer Phenom 100, King Air 300, Mooney M20, Pilatus PC12, Piper Twin Commanche, Piper Cheyenne, Piper Malibu Matrix, TBM 700a, TBM 850. [7]

10. A PRACTICAL EXAMPLE OF USING HUD AT AIR VANUATU

In my diploma thesis I presented the practical use of the HUD system at the company Air Vanuatu. This company leased two Boeing 737-800 aircraft in 2018, which were not equipped with the HUD system, and in 2019 the company had the same aircraft, but equipped with the HUD system. In my diploma thesis I presented the practical use of the HUD system at the company Air Vanuatu. This company leased two Boeing 737-800 aircraft in 2018, which were not equipped with the HUD system, and in 2019 the company had the same aircraft, but equipped with the HUD system. First of all, however, it is important to say that this company operates in remote areas, where it is very expensive if the aircraft fails to land at its home airport and has to fly to an alternate airport.

Several types of instrument approaches can be used for runway 11/29, unfortunately the airport is not equipped with the ILS system. Due to the terrain in front of the runway threshold and in the direction of the missed approach, most instrument approaches are characterized by a relatively high minimum descent height MDH / DH. Of course, this high altitude relative to the runway threshold then corresponds to the minimum visibility for which this procedure is certified. Contrary to European standards, where we talk about visibility in hundreds of meters, we work with thousands here. During the rainy season, the density of precipitation reaches such an intensity that even with the reported visibility of 2500 meters, it is very difficult for the aircraft crew to establish at a minimum the visual reference necessary for the successful completion of the approach and landing. And this is exactly the reason that leads the new technologies used by the operator to acquire the aircraft with HUD equipment or to its additional installation.

Air Vanuatu's Flight Ops very cleverly chose the B737-800 HUD-equipped fleet as the backbone. In collaboration with the New Zealand State Agency for Procedures for IFR Flights (APP, SID, STAR, etc.), it developed spatial navigation approaches for both runway 11 and runway 29. HUD equipment and dual FMS assembly played a key role here, which made it possible, thanks to the accuracy of flight guidance, to design RNP approaches, which have much lower meteorological limits than the two used so far.

Operational experience with these approaches showed an approximately 97% success rate for Air Vanuatu's B737-800 landing in bad weather, while only 88% of the approach without a HUD system. The implementation of these RNP approaches has led to a very significant increase in the economics of operation on the international routes of Air Vanuatu, where the company has avoided frequent losses due to waiting or departing to a very remote backup airport, as well as reducing the amount of additional fuel.

After completing all the calculations, we found that in 2019, when the company had HUD aircraft, all costs for alternate departures, HUD acquisition and maintenance included $ 566,416. In 2018, when the company did not operate aircraft with the HUD system, the additional costs for departures to the alternate airport and holding company amounted to 1,283,500 USD. This difference is due to the already mentioned large distance between the destination and the alternate airport, which in some cases was up to 4.6 hours of flight.

11. EVALUATION OF THE HUD SYSTEM

The HUD system offers a number of advantages, but also a few disadvantages. The main benefits include: better situational awareness of pilots; the possibility of using additional systems to assist pilots in controlling the airplane during all phases of flight; increasing the accuracy of aircraft control; ground error reduction; increase safety; allows pilots to land in worse weather conditions; relatively fast financial return. Disadvantages include: insufficient field of view; poor readability of the display in direct sunlight; when using the EFVS system, it is sometimes difficult to estimate altitude and distance from objects; frequent updating of synthetic maps required.

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