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The Impacts of Advanced Avionics on Degraded Visual Environments

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Air transport is a mainstay of the modern global economy, without which many activities would cease to exist. Airplanes are used to transport people and goods across continents and within countries for business, educational, and even recreational purposes. They are also used for policing and military purposes. Due to these wide arrays of uses, airplanes of all kinds are an essential part of the transportation industry. Therefore, aircraft have to be developed in such a manner as to ensure safe, effective, and efficient operations are maintained. Achieving these milestones in aircraft development, therefore, calls for the deployment of advanced technologies to address key areas of concerns such as degraded visual environments (DVE).

Even in the age of drones and other forms of autonomy in aviation, the role of pilots is still important. Pilots are the ones who take control of the plane and provide guidance to the onboard computers through the provision of inputs they derive from visual cues (Sanders-Reed & Fenley, 2018). An example of such a visual provision of inputs can be seen through an assessment of how pilots utilize Instrument Landing System (ILS) markers on runways, alongside the approach, centerline and touchdown lights. The pilots analyze the visual cues provided by these inputs they are overflying and in doing so determine critical aspects such as the distance at which to touch down and how to orient the craft such that it lands safely.

The ability of pilots to not only observe but also interpret the relevant visual cues therefore depends on having a clear view, something that is only possible if the visual environment is not degraded. In cases where there is DVE, the airplane needs to have equipment that enables the pilot to sufficiently make decisions regardless of the visual environment. With such technological support, pilots are able to provide the inputs that enable the flight management system (FMS) to operate effectively, in addition to enabling other airplane functionalities. For this reason, a lot of technological developments in the airline industry have focused on advanced avionics to address the challenges brought about by degraded visual environments.

Background

A pilot's vision is a vital sense used in acquiring ground reference information during flight especially when performing ground reference maneuvers (Livingston, 1941). To maintain the required path during flight, a pilot needs to position a plane accurately in relation to specific references, particularly ground stations and geographical features. These references can be termed as visual cues as they include concrete objects that provide the pilot with positional information. The choice of visual cues often depends of the geographical features of the location or the infrastructure present. Visibility can be defined as a measure of distance at which an object can be discerned by an observer (SKYbrary, 2022b).

An inaccurate perception of visual cues has been associated with numerous aviation accidents, which result in hundreds of fatalities and loss of resources and infrastructure (Gibb et al., 2016). There are physiological impediments that affect a pilot's performance in sensing and perceiving their aviation environment, for example hypoxia, spatial disorientation, and illusions (Flight Study, 2021). Furthermore, certain occurrences often lead to low visibility or at times the disappearance of visual cues, for example, foggy weather. This is termed as a Degraded Visual Environment (DVE).

It is imperative to understand how visual perception can be improved in aviation by applying advanced technologies and how this is key to improving pilot performance and reducing aviation accidents. While DVEs are often unavoidable, aspects of visual perception can be automated by use of avionics instruments. This allows pilots to make informed decisions on the direction the plane should head to. Therefore, this paper investigates the various advanced avionics technologies that have been deployed and those still in development with an aim of helping pilots navigate degraded visual environments.

Literature Review

Many researchers pay critical attention to the area of avionics given its significance in overall performance of airborne vehicles (Moir & Seabridge, 2011; Moir et al., 2013). Therefore, studies conducted by experts in the field focus on a wide array of avionics systems including those on the flight deck, avionics systems that have a functional role, and multiple enabling technologies. In general, researchers investigate the ways development of avionics improve aspects such as the efficiency and maneuverability of aircraft, as well as their operation in different environmental conditions including under DVE.

According to Szoboszlay et al. (2021), the dominant factor in aircraft accidents is Degraded Visual Environments (DVEs), which reduce the capacity of the pilot to see the terrain and obstacles. DVEs are said to lead to the loss of situational awareness also known as spatial disorientation, a phenomenon whereby a person is incapable of determining his true body position and altitude, relative to the surroundings. The loss of situational awareness can the pilot to lose control or even unknowingly fly into an obstacle.

Losses in human life, destruction of equipment worth millions of dollars, and termination of critical missions caused by DVE has led to the development of the DVE Mitigation (DVEM) program, initiated by the United States Military (Szoboszlay et al., 2021). The aim is to develop technologies that increase the operation capability of aircraft in low visibility conditions. The military has a vested interest in the DVEM program because helicopters, the most preferred mode of air transportation in some areas, are more vulnerable to DVE. Gouré (2020) states DVE episodes involving U.S. forces in the Middle East resulted in the loss of approximately 400 aircraft and 153 lives in the period between 2002 and 2015 and within the same period, more than half of all private and commercial helicopter accidents were DVE related as stated by the International Helicopter Safety Team.

The major types of DVEs experienced are inadequate light especially when flying at night, fog, snow, brownout, and whiteout. Low-level flights present a higher risk of experiencing such. Helicopters eliminate the limitation of needing a runway to land or takeoff. This ironically is also a great disadvantage as landing in remote locations means that they are exposed to

DVEs, especially brownouts and whiteouts conditions that occurs when the downwash from helicopter blades near the ground blows up a dust cloud.

According to Theodore et al. (2020), the mitigation of DVEs has been a major point of focus in the recent years stimulating many research efforts commonly focused the following: the development of improved sensors which have more capability to detect the terrain and obstacles around the aircraft, night vision capabilities to see at night and in low light conditions, improving the heads-up and heads-down displays to provide the pilot with improved situational awareness and better flight controls through advanced control modes to reduce pilot workload and improve flight precision.

These developments led to the development of Synthetic Vision Systems (SVS) and according to Prinzel (2009), a SVS is an aircraft technology incorporated into the cockpit display and it has the capacity to depict or render the aircrafts external visual environment by using images simulated by onboard computers in a manner comparable to how it would appear to the pilot if his vision were not restricted. In DVE conditions, a pilot can use the system to tell the position and heading without relying on trying to manually decipher the position and orientation of the aircraft as this increases the risk of special disorientation.

Synthetic vision systems combine the advantages of modern high resolution display systems, terrain and obstacle sensors and the Global Positioning System (GPS). The system is thus able to give the pilot relevant information on their position and what to expect in specific locations. This is by using the cockpit display to show a model of the real world in 2D or 3D imagery that can easily be understood by pilots. This is the foundation of visual cueing as one can understand the flight environment by the imagery provided on encountering a DVE event.

A SKYbrary (2022a) assessment of SVS highlights a major potential flaw that may reduce their efficacy. The pilots may develop an overdependence on SVS systems and therefore, ignore other visual references for safe navigation. SVS system should be only used as a support system during flight and in DVE conditions rather than a replacement for other standard operating procedures. Furthermore, there is a risk of corrupted data thus requiring the validation of any received data to ensure that is it correct and current.

Most of the research papers majorly focus on rotorcraft, correctly so because of their operation principles and environments which increases their risk for encountering DVEs. According to Gouré (2020), the events that are highly prone to DVEs include low altitude maneuvers, landing, and taking off. DVEs are however not limited to rotorcrafts or low altitude maneuvers but also fixed wing aircrafts and high altitude flights.

Discussion

Advancement in Avionics

Avionics is a word that is derived from a combination of two words, aviation and electronics. It was conceived in 1949 by Philip Klass, as a technical and simpler term for "aviation electronics.” Therefore, an avionic system is one which is reliant on electronics for its functioning, despite the fact that the system may contain electro-mechanical components (Collinson, 2003). Such systems are applied in navigation, instrumentation, communication, safety, and landing assistance of planes.

Communication between pilots became a necessity in the early stages of the aviation industry. This stemmed from the need of pilots to share flight and weather information with each other. The earliest record of the use of radio in flight communications was in 1911, the first applications being sending of messages between planes and ground stations (Aviation Survival, 2022). During the First World War, there was a crucial need for communication from aircraft to aircraft and from ground stations to aircraft especially in the effective coordination of military operations. Radio communication can thus be considered as the first major use of avionic systems in aircraft.

For a long time until the 1950s, accidents especially due to mid-air collision were very common, especially with the increase in air traffic and the relative speeds of aircrafts (Bjorkman, 2020). The most crucial moment, in aviation is the Grand Canyon disaster of 1956 where two commercial planes collided, leading to the death all 128 people on board. The Civil Aeronautics Board (CAB) determined that the likely cause of this mid-air collision was that the pilots did not see each other in time to perform required evasive maneuvers.

The evidence suggests that this was as a result of several factors, one reason being, cloud formations that reduced cockpit visibility. There physiological limits to human vision which greatly reduce the time opportunity to see and avoid collisions with objects for example, mountains, buildings and other aircrafts. As a consequence of the disaster, the U.S. government enacted regulations to improve aviation safety, including mandating that manufacturers equip all aircraft with two-way radios (Aviation Survival, 2022). This set the foundation for the need to develop and maintain systems that made aviation safer.

Bratt and Walker (2019) state that private companies and government agencies operating in the aviation sector often collaborate with an aim to improve of avionics technologies. The aim of these collaborations is often meant to provide aircrew with better tools to navigate their crafts in poor visibility conditions such as those brought about by DVE. Similarly, Blasch et al. (2015) posit that in the past seven decades, the aviation industry has rapidly grown due to a combination of better policies and advances in avionics that have made air transport not only more efficient but also safer.

In this sense, they argue that two aspects of avionics technologies have been crucial in promoting safer flights: Communication, navigation, and surveillance (CNS) systems; and control and flight critical systems (FCS). The 2015 study by Blasch et al. goes on to further state that the advances in both mechanical and electronic engineering have facilitated the reduction of complexities in airplanes through integrated modular avionics (IMA). Taken together, the evolution of these have helped yield better performance on all varieties of aircrafts including through better integration of components;

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lowering aircraft weight, and reduction of electromagnetic interference (Liang et al., 2020; Wang & Niu, 2018).

Degraded Visual Environments

There are two main types of DVEs, aircraft induced and aircraft independent which indicates, that even while being affected by degraded visual environments from external sources, airplanes can also be the source of elements that degrade the visual environment.

Aircraft Induced DVE

These are conditions that are caused by the forces generated from the movement of an aircraft. These include brownouts and whiteouts. During takeoff an aircraft may by caught up in a DVE for example when a helicopter lands or takes off, its rotor blades rotate rapidly, creating a downwash which blows sand and dirt into a vortex. Depending on the surface conditions of the location, either dusty or snowy, this vortex may be brown or white in color, thus a brownout or whiteout respectively. The swirling dust gives pilots an illusion of aircraft movement even if they are stationary and this may lead to spatial disorientation in pilots (Schauer, 2018). This is more common in rotorcrafts hence the large number of reports targeting helicopters.

Aircraft Independent DVE

These are not induced by the aircraft, but they are caused by natural or manmade occurrences. They include, smoke, dust (sand storm), fog, smog, rain, clouds, snow, and darkness (at night). Flying at night presents certain risks main one being that humans are not nocturnal creatures. While the instrumentation makes it easier to fly at night, pilots are exposed to certain risks especially for a Visual Flight Rules (VFR) flight. The risks include pilot fatigue which may lead to errors in planning and decision making including limited attention spans and slower reaction times in the event of emergencies. Furthermore, it is more difficult to discern obstacles and there is more vulnerability to optical illusions for example false horizons (Federal Aviation Administration, 2022b).

Heavy rains and snow often limit the visibility thus making it unsafe for pilots to takeoff or land. Rain however, does not limit the capacity of a plane to generate lift and since it usually occurs at lower altitudes, one can mitigate this by flying at higher altitudes. As Collantes (2022) states, when the weather is poor, the probability of flight delays, cancelation and accidents is often higher. Delays and cancelation lead to a loss of revenue and time while accidents present safety concerns for users and losses in terms of the aircraft being written off and conducting expensive repairs.

Avionic Systems

As stated by Southern Wings (2019), there are two types of regulations that govern how and when pilots can fly aircrafts. These are named Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). VFR allows pilots to make judgement of flight conditions simply from what is visible to them. The pilot uses his vision to observe the outside conditions which advice on the steps of action to take in aircraft control, for example, a pilot may pull up to evade an obstacle. However, due to the aforementioned limitations, there are some conditions that may impact the pilot's vision capabilities, thus the need for IFR whereby, the pilot relies on the aircrafts on-board avionic instruments to control and maintain safe flight in the event of little or no external visual references.

Avionic systems form the foundation of IFR. The development of avionic systems to support flight is driven by the need for following outcomes: increased safety, air traffic control requirements, all weather operation, reduction in fuel consumption, improved aircraft performance and control and handling and reduction in maintenance costs (Collinson, 2003). It is also worth noting that unmanned aircrafts are fully reliant on avionic systems. The development of advanced avionic systems that are applied in flight and are necessary in mitigating DVE events are discussed below:

Development of Navigation Systems

Astronavigation had been applied for decades as the main mode of determining the location and heading of vessels. The navigators could use celestial objects like the sun, moon and stars to establish position. This was also initially applied in aircrafts and a good example is the Scandinavian Airlines (SAS) plane which made a historic first flight between the United States and Scandinavia in 1952 using astronavigation. Further advancements led to the development of the Global Positioning System in the 1960s that revolutionized navigation in that pilots could fly to different locations accurately using the system. Pilots often use GPS to support both VFR and IFR navigation depending on the receivers used. IFR receivers have the capability to detect inaccurate GPS signals eliminating them from position calculations. The accuracy of GPS was improved by development of Wide Area Augmentation System (WAAS) (Aeronautics Guide, 2022). A WAAS equipped aircraft is capable of conducting a precision approach into an airport, eliminating the need for ground-based approach equipment. A precision approach is further discussed in advanced radar technologies below.

Cockpit Evolution and Display Systems

Display systems provide an interface between the pilot and the airplane system, thus providing a measure of situational awareness (Collinson, 2003). Before the utilization of the Cathode Ray Tube (CRT), analog dials were applied to display important information. These was replaced by CRT screens that provided the same information more instantaneously reducing the risk of taking inaccurate readings due to parallax errors. Further advancements led to the development of glass cockpits which use Electronic Flight Displays (EFD).

There has also been the development of Cockpit Display of Traffic Information (CDTI), used to display positional information of any close aircrafts and the altitude and potential obstacles. In the event of a DVE, the pilot can maintain situational awareness. Displays can be classified according to where they are mounted in the cockpit (Collinson, 2003). These include Head up Displays (HUD), Head down Displays (HDD) and Helmet Mounted Displays (HMD). Using HUDs and HMDs, the pilot can view the crucial flight data generated by avionic sensors and systems in the aircraft without the need to look away thus maintaining full visual concentration on the outside world scene. This is important in poor visibility conditions as the pilot can maintain total concentration on the aircraft environment if he may need to perform a quick evasive maneuver.

Augmented Reality

According to Gillis (2022), augmented reality (AR) is the combination of user's environment and digital information concurrently. By adding a layer of additional information to the actual information, say by using images, the pilot could better visualize the situation thereby making better decisions. Applications of AR in DVE situations may include: During takeoff or landing in low visibility conditions, AR is used to overlay the runway path and during flight, information on the weather and terrain details could be overlaid to increase the pilot's awareness. AR can be viewed as a major improvement to synthetic vision systems (Behringer et al., 2000). SVS provides a virtual view of the flight environment and errors and inconsistencies can occur while on the other hand AR systems overlay real world objects on an appropriate display hence even in DVE environments, a pilot can operate in VFR conditions.

Artificial Intelligence (AI)

AI algorithms can evaluate the large volumes of flight data like route distance, altitudes and weather conditions. Current research is focused toward the development of unmanned aerial vehicles to facilitate landing, takeoff and obstacle avoidance (Batok, 2022). With the use of computer vision system and geospatial signal processing, AI may be used to identify and categorize hazards and dangers given pictures and videos of similar past occurrences. Machines can able to function on their own and are not subject to physiological limitations.

Being a tool for decision making and the high number of sensors in an aircraft that generates large amount of data, AI is potentially capable of being used in day to day use in aviation data processing. The AI system can be a form of artificial copilot in the near future, the pilot being required to play a supervisory role. AI can also be used to simulate certain environmental conditions that may occur during actual flight and hence can be used to train pilots in a safe environment (flight simulators) hence they are better prepared to handle real life situations. AI is also supported by cloud based technologies which help in the fast storage and access to aviation data for decision making.

Data Comm Technology

As stated by the Federal Aviation Administration (2022a), the conventional mode of communication provided by radio is timewasting, laborious slow and can lead to miscommunications between air traffic control and pilots. This can lead to accidents especially when the communication contains rerouting information, for example, due to bad weather conditions.

Data Comm solves this problem by allowing the transmission of crucial instructions instantaneously via text. This can also be done simultaneously targeting several aircrafts, for example if two aircrafts need to be rerouted due to a storm, flight plans can be transmitted to them at once instead of contacting them individually via radio communication. The efficiency in communication is key as early communication means early corrective actions that may prevent or reduce the impact of accidents.

Advanced Radar Technology

Radar transmits an electronic pulse and depending on the echo, it can determine the range and heading. This is applied in collision avoidance systems to midair aircraft crashes. Some technologies, like Precision Approach Radar (PAR), assist the pilot in landing by giving important information including distance and height from the landing point (Albright, 2019). The weather radar identifies potential hazardous weather patterns thus the pilot can take necessary precautions.

Integrated Modular Avionics

The use of Integrated Modular Avionics (IMA) is one of the most recent developments that are shaping up to enhance the capabilities of airplanes to provide pilots with the means of flying safely even when under degraded visual environments. Among the key attributes of IMA is that it comprises of an open-layout approach to computing, which enables the operating system to run in real time and process information from the visual environment in a rapid manner (Moir, et al., 2013). It, therefore, facilitates faster decision-making on the pilot's part. At the same time, this modular approach enables more efficient allocation of computing power through segregation of operations. Due to its potential benefits including in limiting the negative impacts of DVE, integrated modular avionics are being fitted in the latest generation of airplanes including the Boeing 787 and the Airbus A380.

Conclusion

The report outlines the negative impacts of degraded visual environments. These are the loss of human life in the event of accidents, loss of aircrafts and a high cost of repairs and loss of time in the event of delays and cancelations. The report further outlines how avionic systems function to provide support to pilots if they are caught up in DVE events. All pilots are vulnerable to spatial disorientation as it is a physiological flaw. It is therefore necessary to provide them with necessary support needed to offset the effects of a spatial disorientation. Given a reliable decision support system, a pilot can make informed decisions during flights and this may be the difference between a successful flight and a catastrophic accident.

Implications of Research Findings

The findings from this study indicate that DVE is a major impediment to safe flights. Consequently, all aircrafts should be fitted with appropriate and modern avionic systems that form the decision support system in navigating DVE conditions. At the same time, another observation made is that avionic equipment can be integrated to function as a single unit as in the case of synthetic vision systems. This incorporates the advantageous properties of various avionics equipment therefore; more accurate results can be computed from the resulting data and this make the information more reliable.

Additionally, it was noted that the display systems can be integrated with other systems being used to display the rendering of augmented reality. By use of displays, these images should be presented in a manner that eliminates all unnecessary information. Presenting this information in a simple manner ensures that the pilot has access to relevant items and reduces the possibility of reading errors. By incorporating faster methods of communication that efficiently give all the desired information on time, like Data Comm technology, a faster response is made possible.

There should be a move towards development, installment and use of augmented reality display systems in aircrafts. They are more intuitive and present a depiction of actual aircraft environmental conditions. The pilot can make better judgements and as explained earlier they allow VFR operation in poor visibility. Likewise, AI is very efficient in processing historical data to make predictions. This can be incorporated to give the pilot relevant information. For example, from past weather trends, one may predict that some routes have a high probability of stormy weather at a given time period. The pilot can reroute the plane appropriately.

Ultimately, all pilots should be trained on the use of avionic systems including newer technologies. An IFR rating is important as the pilot can be able to maneuver if he runs into a DVE on a seemingly clear day that would require only a VFR rating. For example, it is very common for the weather to experience rapid changes. However, by implementing AR technology, the pilots can be proficient with a VFR rating.

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