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Analyzing the Threats of the Failure of Visual Awareness during a Visual Approach for Transport Category Aircraft

Shlok Misra
Embry-Riddle Aeronautical University, Daytona Beach, misras@my.erau.edu

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Flight crew can land an aircraft on the runway through various methods prescribed by the Federal Aviation Administration (FAA). Pilots can either visually descend to the runway through a visual approach or land using instrument references and radio or satellite equipment which are generally classified as Instrument Approach Procedures (IAPs). Visual approach is a type of IAP that is frequently used by Air Traffic Controllers to improve the efficiency of a runway by increasing the arrival rate of aircraft (FAA, 2019).

While visual approaches are frequently used to increase efficiency and reduce controller workload, visual approaches pose a risk when considering the limitations of the human eye and visual awareness. Visual approaches require the pilots to either have the preceding aircraft in sight or the airport in sight while visually descending to the runway (FAA, 2019). Various visual stimuli that the pilots need to be aware and conscious of to execute a safe visual approach procedure test the limitations of visual awareness and pose risks that need to be identified and studied. This study analyzed the threats of the failure of visual awareness during a visual approach for transport category aircraft.

Literature Review

Visual Awareness

Visual awareness has been studied very widely in the field of neuroscience, psychology, cognitive science, and philosophy. Visual awareness can be defined "as the subjective sensation of seeing something" (Wyart & Tallon-Baudry, 2008, p. 1). Li and Geng (2009) define visual awareness as a subjective visual experience. The study of visual awareness is closely linked to studying visual consciousness, visual stimuli, and visual attention (Li & Geng, 2009).

The presence of visual stimuli does not translate to visual awareness by a human being. Li and Geng (2009) explain that under certain circumstances the retina of a human being might observe stimuli, however it may fail to perceive salient visual stimuli. This phenomenon has been studied in further detail by researchers. In a book titled *Inattentional Blindness* authored by Mack and Rock (1998), the authors conducted a study with 5,000 subjects from the University of California Berkeley and studied various aspects of perception and attention. Mack and Rock noted that as many as 25% of their participants failed to notice unexpected peripheral stimuli.

Visual awareness is closely linked to visual attention. Visual attention can be defined as a "set of cognitive operations that mediate the selection of relevant information and the filtering out of irrelevant information from cluttered visual scenes" (McMains & Kastner, 2009, p. 1). The studies of visual awareness, visual attention, and visual consciousness led aviation human factors experts to focus on studying visual scanning, collision avoidance, situational awareness, and task saturation in more detail. Visual scanning, collision avoidance, situational awareness, and task saturation will be covered in more detail.

Visual Scanning and Collision Avoidance

Advisory Circular AC 98-40D titled 'Pilots' Role in Collision Avoidance' issued by the Federal Aviation Administration on 19th April 2016 explains the responsibility of pilots during flight in terms of visual scanning and collision avoidance. The circular explains that "Pilots should remain constantly alert to all traffic movement within their field of vision, as well as periodically scanning the entire visual field outside of their aircraft to ensure detection of conflicting traffic" (FAA, 2016a, p. 2). The advisory circular stresses the importance of see-and-avoid procedures to prevent collisions.

FAA states that it takes about 12.5 seconds for a person to react to a threat in flight (FAA, 2016a). The circular advises pilots of techniques to improve the effectiveness of scanning outside the aircraft for traffic. It advises that if the pilot does have any specific object to focus on, the eyes will revert to relaxed intermediate focal distance which is about 10 to 30 feet. "This can be explained as "looking without actually seeing anything" (FAA, 2016a, p. 2).

Through multiple experiments Colvin, Dodhia, and Dismukes (2005) identify that humans are poor at monitoring and searching for targets that rarely occur. In another study by Moiser, Skitka, Burdick, and Feer (1998) that studied automation bias in the cockpit, it was observed that 81% of reported problems by pilots stemmed from not effectively monitoring instruments during the cruise phase of flight. Colvin et al. further explain that visual scanning is a cognitive process rather than just a physical function of our eyes.

The Federal Aviation Administration Safety Team published an article titled *How to Avoid Mid-Air Collisions* which identifies human factors as a major factor that causes collisions (FAA Safety Team). It specifically illustrates visual perception and limitations of visual scanning and the tendency of pilots to overestimate their visual abilities.

Failure of Visual Awareness

Several research studies in the field of psychology and cognitive psychology have demonstrated that people cannot retain all the details of the visual stimuli they are presented from one moment to the next (Simons & Rensink, 2003). Failure of visual awareness refers to the failure of human beings to retain or observe fully visible stimuli which might be caused due to a variety of reasons.

Failure of visual awareness occurs due to attentional processing limitations of human beings deter them from observing observable visual stimuli. Scientists studying how people acquire and process visual information have observed a lapse of visual awareness (Varkin, Levin, & Fidler, 2004). Failure of visual awareness can be induced in multiple ways. Inattentional blindness, visual masking, attentional blink, and change blindness are few of the many phenomena related to the failure of visual awareness (Simons & Rensink, 2003).

Varkin et al. (2004) studied the application of the failure of visual awareness in a human-computer interface and explained the application of their study in aviation. They explained that the failure of visual awareness of the pilot about the instruments and Flight Management computer can lead to the pilot selecting incorrect mode settings for the airplane that can have a fatal impact. The authors further explain that "people are not only unaware of great amounts of visual information but they are also unaware of the extent to which they may be unaware of visual information" (Varakin et al., 2004, p. 391).

Inattentional blindness. Humans have a wide variety of visual stimuli present at a point of time, but at each point, only a fraction of the available input can be processed (Most, 2013). Humans perceive only a fraction of all the stimuli as important. Selectivity is an important concept where there is a competition among stimuli for selection (Horstmann & Ansorge, 2016). Inattentional blindness is a failure of visual awareness where people fail to notice salient objects while looking right at them. This is caused due to the fixation of attention on a second object in the vicinity of the object (Most, 2013). Varakin et al. (2004, p. 392) explain inattentional blindness as "attention on one thing reduces the degree to which other, unattended things are processed." Studies using eye-tracking devices have demonstrated that inattentional blindness can occur when the eye of the person is fixated directly on the object and the object is visible to anyone else whose attention is not fixated on any other object.

Concerning the discussion earlier in this paper, to be visually aware of a visual stimulus, a person needs to have visual attention on the stimuli. Inattentional blindness is an illustration of that concept where visual attention plays a major role in a person being visually aware of a visual stimulus. Selectivity of processing information is an important aspect of attention. The selection of stimuli to which humans delegate attention to depending on the demands of the current goals of the human (Horstmann & Ansorge, 2016).

Another factor that plays a role in inattentional blindness is the difficulty of the task (Most, 2013). A task that requires intensive attention is more likely to result in inattentional blindness. Another phenomenon called cognitive load plays a vital role in the extent of inattentional blindness. Cognitive load can be defined as "a multidimensional construct representing the effort that performing a particular task imposes on the actor's cognitive system" (Vrij, 2014, p. 2). Cognitive load is formally studied under the Cognitive Load Theory (CLT) which is based on a working memory that has limited capacity and time when it comes to retaining and processing information (Pavlo, Pass, Grabner, & van Gog, 2010). Higher cognitive load implies a person is exposed to higher information to process and retain that the capacity of the working memory, which can lead to inattentional blindness.

Change blindness. Simons and Levin (1997, p. 1) describe change blindness as "the inability to detect changes to an object or scene." Change blindness is the phenomenon and failure of visual awareness where people, under certain circumstances, are poor at detecting large changes in the visual scene (Simons & Levin, 1997). Change blindness highlights the role of attention in visual awareness and visual change detection (Becker, 2013). The visual awareness of human beings of their surroundings is far sparser than people believe it to be.

Multiple experiments have been conducted to study change blindness in human beings (Becker, 2013). Studies have mostly involved bringing about a rapid change in an observable visual stimulus separated by a brief blank screen. Participants have often failed to observe large changes in the visual stimuli if the change is unexpected.

Visual masking. Visual masking is another failure of visual awareness which "refers to the reduced visibility of one stimulus, called target, due to the presence of another stimulus, called mask" (Ogemn & Breitmeyer, 2013). Visual masking is a general term and it can be classified into a broad range of masking effects types of target and masking stimuli. Masking by light is the most basic form of visual masking which has two other subtypes: masking of light by light and masking of pattern by light (Ogmen & Breitmeyer, 2013). Masking by light occurs when the masking stimulus is a uniform field of light. The presence of a uniform field of light as the masking stimulus can drastically reduce the visibility and clarity of the target stimulus.

Enns and Lollo (2000) researched visual masking and other failures of visual awareness. They concluded that attention is a crucial factor in visual masking. They explained that "almost no masking occurs if attention can be rapidly focused on the target, whereas powerful masking ensues if attention directed at the target is delayed" (p. 1).

Visual Approach

A visual approach is conducted on an Instrument Flight Rules (IFR) flight plan which authorizes the pilot to visually approach the runway while staying clear of clouds (FAA, 2019). Before accepting a visual approach clearance, the pilot must either have the airport in sight or the preceding identified aircraft in sight. The reported weather for a visual approach must be at least 1,000 feet of ceiling and 3 Statute Miles of visibility. A visual approach does not constitute an instrument approach procedure and does not have a published missed approach procedure. If a go-around is executed, the air traffic controller will issue a new clearance for the missed approach. The authorization for a visual approach does not constitute a cancellation of an IFR flight plan (FAA, 2019).

A visual approach may be issued if it's "operationally beneficial" as it allows for a reduction in "pilot/controller workload and expedites traffic by shortening flight paths to the airport" (FAA, 2019, p. 5-4-61) When the pilot is following the preceding aircraft, the responsibility of "safe approach interval" and wake turbulence separation is handed off to the pilot. This reduces the pilot/controller workload as well (FAA, 2019, p. 5-4-62).

When the pilot has the airport in sight but not the preceding aircraft in sight, the separation and wake turbulence separation is the controller's responsibility. The Federal Aviation Administration published an *Information for Operators* in 2011 that stated the responsibilities and roles of a pilot in a visual approach. The document stated that the pilot must inform the controller immediately if any of the following occurs: the pilot is unable to follow the preceding aircraft, the pilot is unable to remain clear of clouds, the pilot is unable to retain sight of the airport, or a climb is required (FAA, 2011).

The Flight Safety Foundation Approach and Landing Accident Reduction (ALAR) Toolkit briefing 7.4 discusses visual approaches in detail. Flight Safety Foundation reports that 41% of the 118 fatal approach-and-landing accidents from 1980 to 1996 involving jet aircraft with maximum takeoff weight above 12,500 pounds took place during visual approaches (Flight Safety Foundation [FSF], 2000a). Flight Safety Foundation warns against visual approaches at night and states that pilots should only conduct visual approaches at night weather is suitable under VFR, a published visual approach procedure is available, pattern altitude is defined, and the flight crew is familiar with airport obstruction and hazards.

Some potential risks that FSF reports related to visual approaches are as follows: steep approaches that results in high airspeed and excessive sink rate, shallow approaches that can lead to Controlled Flight Into Terrain (CFIT), various Ground Proximity Warning System call-outs, final approach course interception very close to the runway, incorrect crosswind correction on final, and excessive pitch movements or banking at a low altitude (FSF, 2000).

Purpose Statement

The purpose of this paper is to evaluate the risk posed by the failure of visual awareness during visual approaches for transport category aircraft. Visual awareness is critical while conducting visual approaches and it is important to study the factors that can limit the capabilities of human beings to maintain visual awareness during visual approaches.

This study will further explore the limitations of visual awareness with special emphasis on change blindness, inattentional blindness, and visual masking. This study explored visual approaches in aviation and conducted a detailed analysis of the Flight Safety Foundation Aviation Safety database to study the reported accidents during visual approaches for transport category aircraft. A total of 18 accident reports were analyzed in the study. The effect of human factors related to visual awareness will be studied in those accidents.

The study utilized a mixed-method approach as its research method using a causal analysis.

Research Question

How does the failure of visual awareness affect safety during visual approaches for transport category aircraft?

Methodology

The purpose of this paper was to evaluate the risk posed by the failure of visual awareness during visual approaches for transport category aircraft. Human factors play a dominant role in aviation accidents around the world. Visual approaches expose pilots to extremely high and critical visual stimuli that require strong visual awareness for safe operations (Thompson, 2010). Aviation has a variety of airplanes and the technology and corresponding visual cues for every aircraft during the visual approach are drastically different. For accuracy and coherency of data, only data from transport category aircraft has been analyzed in this paper.

The data analyzed in this paper is retrieved from the Flight Safety Foundation. The Flight Safety Foundation an Aviation Safety Network that is a "private, independent source of accurate and authoritative information on commercial accidents and safety issues" (FSF, 2016). The Aviation Network database reports are analyzed to study trends and common factors that have caused incidents and accidents for transport category aircraft from 1998-2018.

Aviation Safety Database

The Aviation Safety Database describes safety occurrences of commercials, military transport category, and commercial jetliner aircraft. The Aviation Safety Database is maintained under the Aviation Safety Network that is supported by Flight Safety Foundation. The Aviation Safety Network was founded in 1996 and it is described as a private and independent initiative (FSF, 2020a). The Aviation Safety Database claims to contain more than 20,300 incidents, accidents, and hijackings as of November 4, 2019 (Flight Safety Foundation, 2020b).

The Aviation Safety Database developed by the Flight Safety Foundation was used for this study due to the methodology of their analysis, reputation of the organization, and information sourcing of the database. Flight Safety Foundation is a non-profit international organization that has contributed to aviation safety through research, advocacy, and education. Flight Safety Foundation consists of aviation safety experts from all around the world and its members include airlines, educators, and manufacturers from all over the globe. The Aviation Safety Database draws insights and conclusions directly from either the state accident investigative agency reports. The input of official investigative agencies and subject matter experts enriches the validity of the data and improves the depth and accuracy of the analysis. This paper will focus on incidents and accidents for transport category aircraft. Flight Safety Foundation considers commercials to be aircraft capable of carrying more than 12 passengers**.**

Database Selection

The Aviation Safety Network allows users to filter events based on the year of the incident/accident, aircraft type, geographical region/country, airlines, contributory cause, airport, or registration of the aircraft. Each category allows the user to further filter the search for the appropriate.

Contributory Cause → *Flight Crew* was chosen as the classification criteria for the data for this study. The study required accidents that were caused due to human factors. The accidents identified were manually filtered to include accidents that occurred during visual approaches. The database was filtered to only include accidents that occurred during 1998-2018 and occurred during visual approaches and were caused due to human factors. This filtering of occurrences was carried out manually by the researchers to include the most relevant occurrences that directly address the research questions of this study.

These categories were chosen in correspondence to the literature review. This study focused on aspects of visual awareness and the above-mentioned categories fall perfectly under the scope of the failure of visual awareness. Data were filtered to only include occurrences between 1998 and 2018. This was carried out to account for the change in technology and procedures in the cockpit. Occurrences before 1998 were concluded by the researcher to be outdated for the scope and purpose of this study.

Data were further filtered to only include occurrences for transport category aircraft. This was done to maintain the coherency of occurrences analyzed. The Federal Aviation Administration defines transport category aircraft as those for which a type certificate is issued under Part 21 in transport category and meet transport category airworthiness requirements. Transport category aircraft are “multi-engine airplanes with more than 19 seats or a maximum takeoff weight greater than 19,000 lbs” (FAA, 2018).

Results

Flight Safety Foundation reports for the criteria illustrated above were analyzed. Additionally, accident reports of the state accident investigation agency were analyzed as well due to the integrity and depth of the results that were provided in the reports.

Table 1

List of Accidents that were Analyzed for this Study

Case	Aircraft	Date	Location	Reference
Case 1	Beechcraft 400A	17 April 1999	Beckley Airport, USA	(NTSB [NTSB], 2000)
Case 2	Lockheed C-130E Hercules	10 December 1999	Kuwait-Ahmed Al Jaber Air Force Base, Kuwait	(FSF, 2020b)
Case 3	Dassault Falcon 20F	13 June 2000	Peterborough Airport, ON, Canada	(Transport Safety Board, 2000)
Case 4	Boeing 737-200	17 July 2001	Patna Airport, India	(Court of Inquiry, 2001)
Case 5	Tupolev Tu-154M	4 July 2001	Irkutsk Airport, Russia	(FSF, 2020)
Case 6	Swearingen SA226-TC Metro II	11 October 2001	Shamattawa Airport, Canada	(Transport Safety Board, 2001)
Case 7	Antonov An24-RV	13 July 2002	Yakutsk Airport, Russia	(FSF, 2020)
Case 8	Beechcraft 1900C-1	14 January 2008	Kauai Island/Lihue Airport, USA	(NTSB, 2009)
Case 9	Swearingen SA227-AC Metro III	17 August 2006	Grain Valley-East Kansas City Airport, USA	(NTSB, 2007)
Case 10	Boeing 737-400	7 March 2007	Yogyakarta-Adisutjipto Airport, Indonesia	(National Transport Safety Committee, 2007)
Case 12	Boeing 737-800	22 May 2010	Mangalore International Airport, India	(Court of Inquiry, 2010)
Case 13	SAAB 340B	13 June 2013	Marsh-Harbour International Airport, Bahamas	(Air Accident Investigation Bureau, 2015)

Case 14	Boeing 777-200ER	6 July 2013	San Francisco International Airport, USA	(NTSB, 2014)
Case 15	Airbus 321-231	26 September 2013	Deauville-Saint Gatien Airport, France	(BEA, 2018)
Case 16	Dassault Falcon 20E	3 March 2014	Kish Island Airport, Iran	(Aircraft Accident Investigation Bureau, 2016)
Case 17	Pilatus Britten-Norman BN-2A-26 Islander	25 July 2017	Eteringbang Airport, Guyana	(Air Accident Investigation Unit, 2017)
Case 18	Bombardier Dash-8	12 March 2018	Tribhuvan International Airport, Nepal	(Accident Investigation Commission, 2019)

A total of 18 accidents were analyzed in this study. The accidents were analyzed to derive quantitative and qualitative data. The purpose of the quantitative analysis was to classify accidents on the basis of lighting conditions, time of the day, and type of operations. The quantitative analysis will be followed by the qualitative analysis that will include a deeper analysis of the 18 accidents to derive trends and commonalities in the accidents. The analysis helped analyze the role of the failure of visual awareness in accidents during visual approaches for transport category aircraft.

Quantitative Analysis

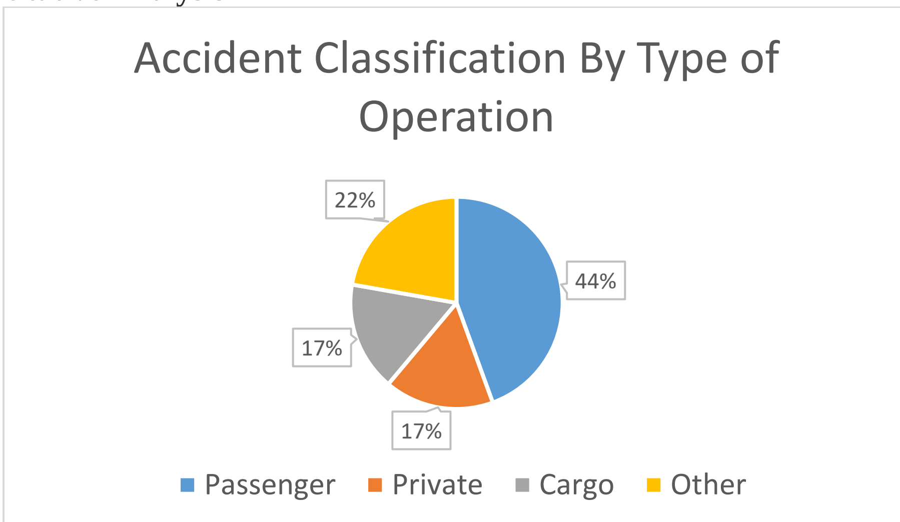

Figure 1. Classification of the accidents by the type of operations. This figure illustrates the classification of the accidents by the type of operations.

The operations have been classified into passenger, private, cargo, and others. The "other" category includes training, aerial work, ambulance, and military. The accidents were classified on the basis of the local time at the destination airport or the location when the accident occurred.

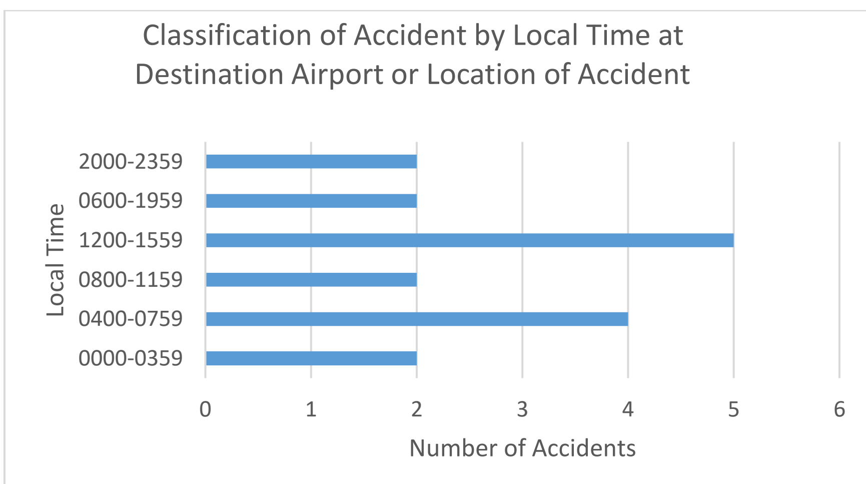

Figure 2. Classification of the accident on the basis of the local time at the destination airport or the location when the accident occurred.

This figure illustrates the classification of the accident on the basis of the local time at the destination airport or the location when the accident occurred. The entire day has been divided into the increments of 4 hours to provide a distribution of the period of the day when most accidents occurred. The purpose of this analysis

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is to derive data about the relation between the lighting conditions, fatigue, and level of circadian rhythm on safety during visual approaches. Local time was used instead of Zulu time because local time provides more relevant data for the purpose of the analysis.

This data was used to classify the accidents on the basis of the lighting conditions during the accidents. The exact lighting conditions were derived from the state accident investigation reports. The lighting conditions are presented as day (after sunrise) and night (after sunset). Accidents such as in the case of case 15 occurred during dusk where the entire operation was executed during the day but landing occurred during the night. For such accidents, the state aviation investigation report was consulted to analyze the exact time of the accident and the lighting conditions at that time.

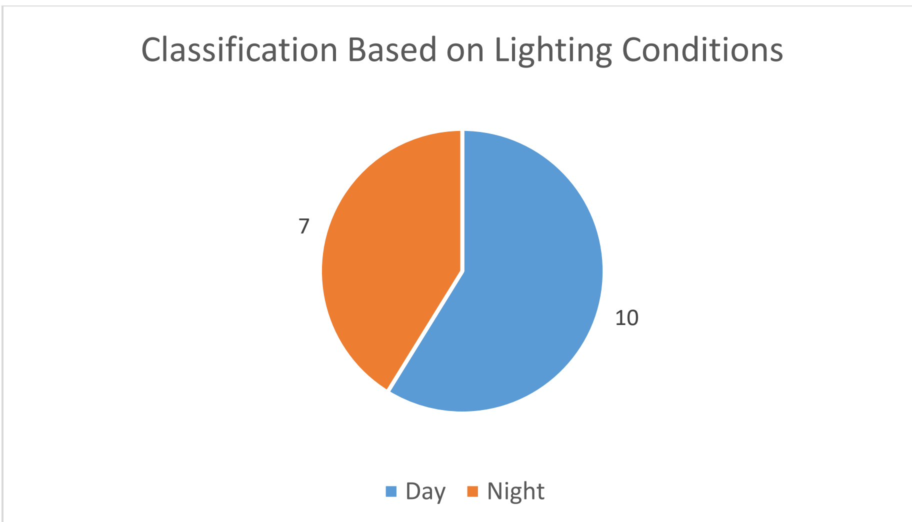

Figure 3. Classification of the accidents on the basis of the lighting conditions at the destination airport or the location of the accident at the time of the accident.

The flight experience of the pilot-in-command of each accident was retrieved from the state accident investigation agency reports. The information provided by all the reports developed by different state agencies varied and not all the information required for the analyses could be retrieved.

Table 2
Information of Flight Experience per Accident

	Total Time (Hours)	Time on Type(model) in hours	PIC Time in hours	Last 90 days (Hours)
Case 1	4719	107	2185	122
Case 3	11800	9400	-	100
Case 4	4361	1778	-	132
Case 6	3100	1100	-	-
Case 8	3098	1480	-	110
Case 9	1379	188	1127	178
Case 10	12421	3703	-	241
Case 11	3596	1186	2760	109
Case 12	10216	2845	10216	147
Case 13	8500	4700	-	-
Case 14	9684	33	3729	33
Case 15	7025	6124	1347	312
Case 17	4760	-	-	320
Case 18	5518	2824	-	191

The information in Table 2 has been compiled from all the accident reports studied for this study.

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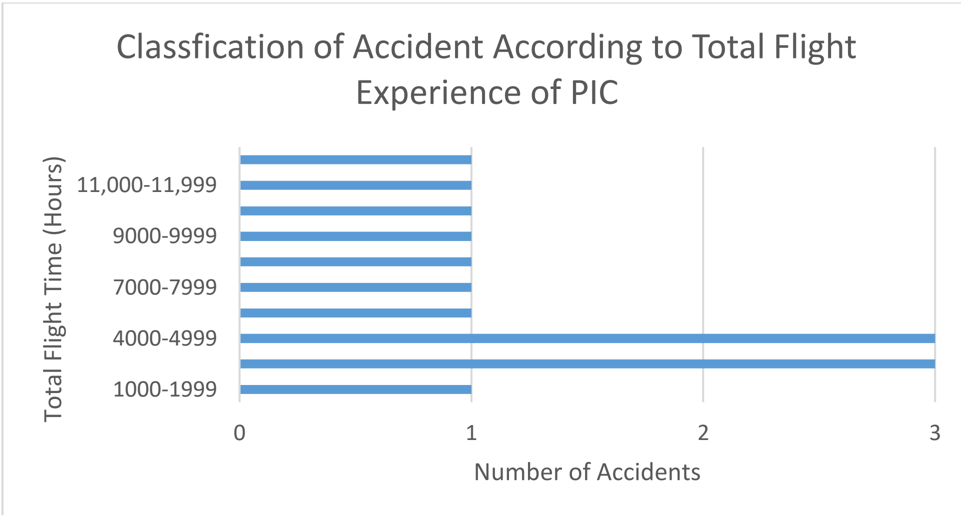

Figure 4. Classification of the accidents by the total flight time of the PIC before the accident. The purpose of this analysis is to study the variation of the accidents by total flight experience of the PIC. Due to the unavailability of complete data, some accidents have not been included in this analysis.

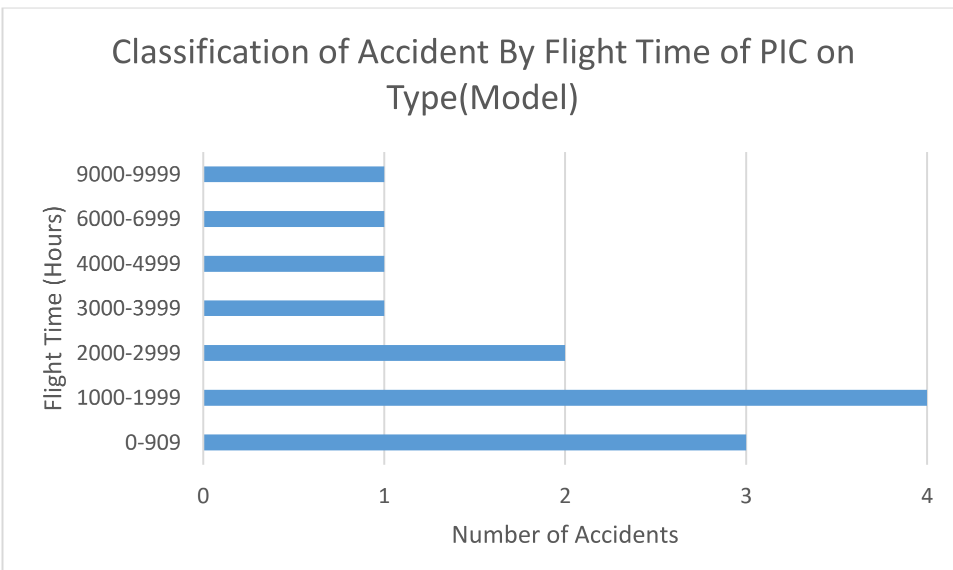

Figure 5: Classification of the accidents by the total flight time of the PIC on the type(model) of the aircraft flown during the accident. Due to the unavailability of complete data, some accidents have not been included in this analysis.

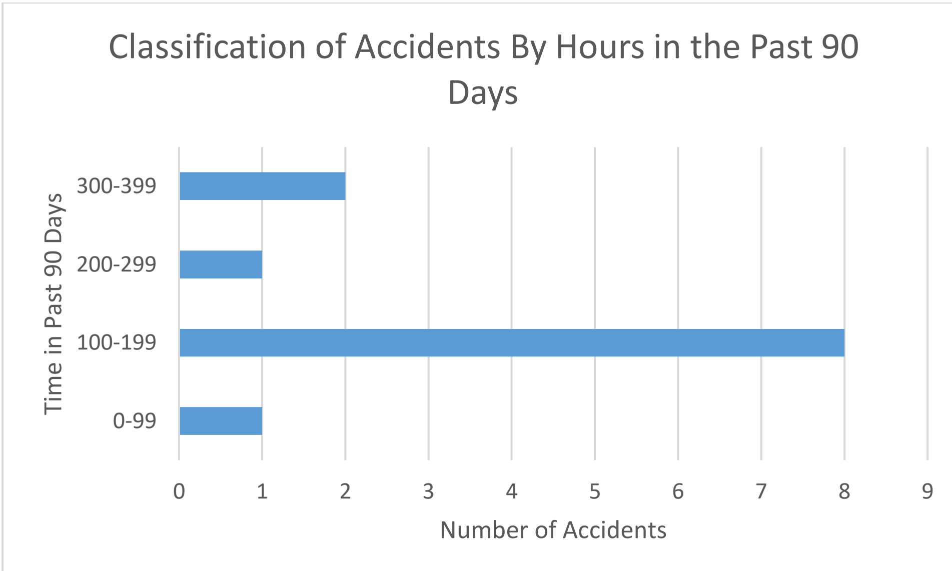

Figure 6. Classification of the accidents by the total flight time of the PIC in the 90 days before the accident. Due to the unavailability of complete data, some accidents have not been included in this analysis.

Qualitative Analysis

The 18 accidents that were analyzed for this study were selected according to the criteria detailed in the methodology section of this paper. The database was also filtered to study accidents for which at least one contributory factor could be linked to the failure of visual awareness during the approach phase. This allowed the researchers to study a much-focused database that allowed a detailed and relevant analysis to satisfy the scope of the study and research question.

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Table 3
Causal Factors Identified in the 18 Accidents

Case	**Causal Factors**
Case 1	Misjudgment of altitude and airspeed
Case 2	Situational Awareness, spatial disorientation, and CRM
Case 3	Somatogravic illusion, task saturation, and situational awareness
Case 4	CRM
Case 5	Pilot error (No relation to physiological factors noted)
Case 6	Somatogravic illusion, task saturation, and situational awareness
Case 7	Task saturation, situational awareness, and fatigue
Case 8	Task saturation, fatigue, and spatial disorientation
Case 9	Fatigue (long duty periods and irregular sleep for the pilots)
Case 10	CRM
Case 11	CRM and fatigue
Case 12	Fatigue and CRM
Case 13	CRM
Case 14	Fatigue and task saturation
Case 15	CRM
Case 16	Fatigue, spatial disorientation,
Case 17	Pilot error (No relation to physiological factors noted)
Case 18	Disorientation, CRM, and situational awareness

Table 3 was created after examining the contributory factors listed in the state aviation accident investigation reports. It was noted that each accident had more than one contributory factor.

Table 4
Frequency of Identified Causal Factors

Contributory Factors	**Frequency**
Misjudgment	1
Situational Awareness	5
Disorientation and Illusions	6
Fatigue	6
Lack of CRM	7
Task Saturation and Task Management	5

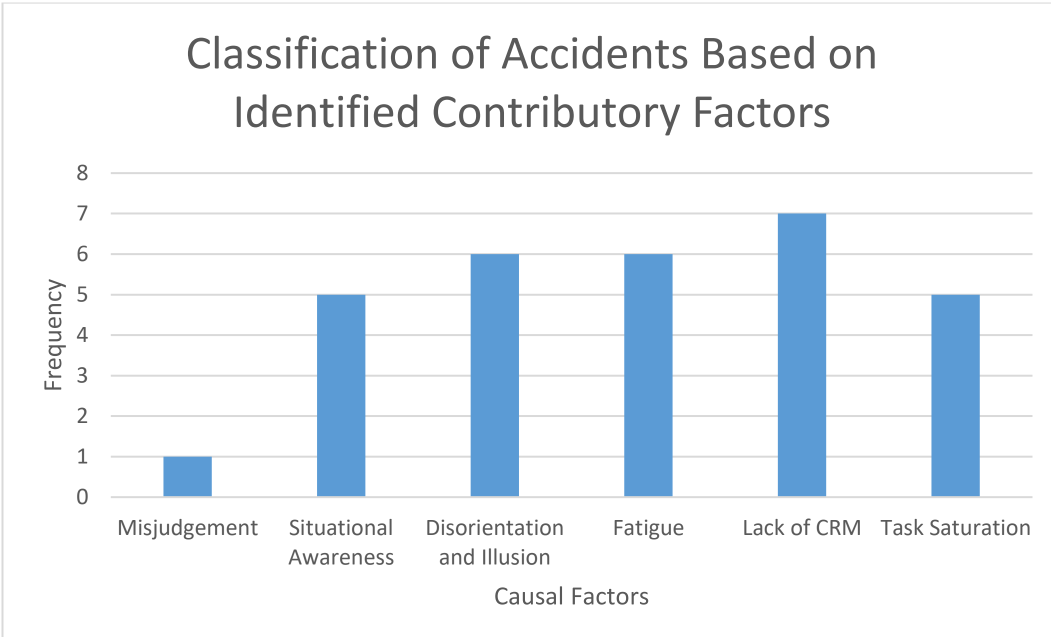

Figure 7. Classification of accidents based on identified contributory factors.

Based on the analysis of the 18 accidents, the following were regarded as the key takeaways:

- Lack of CRM, Fatigue, and situational awareness were analyzed to be the leading causes of accidents due to human errors related to visual awareness.
- Two fatal accidents where loss of visual references on final led to somatogravic illusions.
- Flying a visual approach during periods of 'Low Circadian Levels' was analyzed to pose a major risk.
- Poor CRM practices described as a major risk by investigating agencies.
- Lack of simulator training for visual approaches considered a factor in accidents.
- Incomplete approach briefings a major cause of errors during visual approaches.
- Geographical features around the airport play a role in illusions and misjudgment which can lead to black hole approaches.
- Lack of visual references during the visual approach (due to geographical features or environmental conditions) led to disorientation and incorrect input by pilots.
- The effect of fatigue on perceptual vision and visual attention during visual approaches was analyzed as a factor.

The key take-aways have been adapted from the detailed analysis of the accident reports of all 18 accidents. A more detailed analysis of the factors, causes, and recommendations by the investigators for each case that led to the take-aways of this qualitative analysis is presented below:

Loss of visual references on the final led to somatogravic illusions in two separate accidents. The two accidents are Case 3 (Dassault Falcon 20F, 13 June 2000) and Case 6 (Swearingen SA226-TC Metro II, 11 October 2001). In Case 6, the accident occurred during the night (Transport Safety Board, 2001). The state agency investigation report discusses the illusions that could have played a role in the pilot losing situational awareness. The report quotes a previous Transport Safety Board of Canada report for a crash involving a Metroliner 3 in September 1989. The report discusses that "errors in the perception of attitude can occur when aircrew are exposed to force environments that differ significantly from those experienced during normal activity on the surface of the earth where the force of gravity is a stable reference and is regarded as the vertical" (Transport Safety Board, 2001, p. 4). The report discusses how a lack of visual reference (possible in Case 6 as the approach was conducted in the night) leads the pilots into depending on the vestibular organs for the perception of motion and position. Vestibular illusions occur in circumstances when the vestibular organs incorrectly sense motion and/or position. Somatogravic illusion is a type of vestibular illusion (Transport Safety Board, 2001). When the body which is positioned in a relatively stable field undergoes horizontal acceleration (in the case of the flight, the pilot moves the throttle forward), the otolith organs in the semi-circular canal of the year are stimulated in the same way as when the head is titled backward. The human being (pilot) gets a false perception of pitching up and reacts by pushing the nose of the airplane forward. This results in an increase in airspeed and loss of altitude (Transport Safety Board, 2001). The TSBC report states that somatogravic illusions are "particularly dangerous when it occurs on take-off or when overshooting, especially at night or in poor visibility" (Transport Safety Board, 2001, p. 5). The report also states that "the loss of visual references as the aircraft accelerated along the runway and past the lights of the community were ideal for the onset of somatogravic illusion in the pilot flying" (p. 8). The report also states the loss of situational awareness after the go-around as a contributory factor for the accident.

While somatogravic illusion is a type of vestibular illusion, it is caused by a loss of adequate visual references for which failure of visual awareness of visual stimuli when the human being is presented with multiple visual stimuli can be a factor (FAA, 2016b). In the case of a go-around during the night, the pilots have to rely on a few unreliable visual references. Inadequate visual attention to the few visual references available will lead to losing that visual awareness or inattentional blindness (not observing visual references even while directly looking at them).

In Case 3, the accident was investigated by the Transport Safety Board of Canada (Transport Safety Board of Canada, 2000). The report states pilots losing situation awareness while being subjected to somatogravic illusion. This flight was conducted during the night as well and the accident occurred while the pilot was turning to final to align with the runway during a visually flown circling approach. The workload and limited visual cues on the final approach at a low altitude can lead a pilot to develop somatogravic illusion (Transport Safety Board of Canada, 2000). The report of the accident states that lack of a visual horizon, especially in the night, places a high risk for somatogravic illusion. The accident report also mentions "inadequate monitoring of flight instruments contributed to the loss of situational awareness” (Transport Safety Board, 2000, p. 11). The report also delegates the lack of crew resource management in the cockpit as a factor that leads to the loss of visual awareness of the surroundings. The pilots had delegated responsibilities for scanning instruments and the external visual references. The captain was primarily focused on the flight instruments and the first officer was responsible for altitude references. Even while the first officer warned the captain of the aircraft being low on the approach, mainly due to the Precision Approach Path Indicator (PAPI) light along the runway, the captain had an inadequate response which could primarily be due to loss of situational awareness.

The analysis of the two accidents presented a lot of similarities. The loss of visual awareness due to either lack of visual attention of references or the lack of visual references themselves present a high risk of developing somatogravic illusion (or any other vestibular illusion) and losing situational awareness. As in Case 3, the lack of adequate CRM practices can contribute to losing situational awareness due to the loss of visual awareness of references.

Loss of situational awareness and spatial disorientation was a major cause of accidents during visual approaches. The NTSB concluded that in Case 1, the accident was caused because the "pilot-in-command misjudged his altitude and airspeed" (NTSB, 1999, p. 1). AIB delegated loss of situational awareness and spatial disorientation to be a cause in Case 2 as well along with “lack of support from co-pilot and navigator” indicating poor CRM in the cockpit (FSF, 1999, p. 1). The Court of Inquiry that investigated Case 4 stated that several actions “indicated a lack of CRM” in the cockpit that led to the pilot stalling during the visual approach (Court of Inquiry, 2001, p. 107). The investigation for Case 7 leads to the conclusion that the pilots missed crucial visual cues while conducting the visual approach which was aggravated by the crew losing situational awareness and task saturation (FSF, 2020). The crew's action indicated signs of fatigue as well. In Case 8, the pilot was conducting a visual approach while following a Boeing 737 (NTSB, 2009). The NTSB report stated task saturation, fatigue, and spatial disorientation to be factors that led the pilot to miss the "few external visual references" that were present during the approach (NTSB, 2009, p. 1).

The NTSB report stated that the few available visual references during the visual approach “increased the importance of monitoring flight instruments to maintain awareness of the airplane attitude and altitude” (NTSB, 2009, p. 1). Due to the surrounding demographic features and lighting conditions, the pilot had few visual references during the visual approach while also delegating attention towards the preceding aircraft. These tasks required “visual attention outside the cockpit” while also focusing visual attention inside the cockpit towards the cockpit instruments (p. 1). The NTSB concluded that these conditions “created shifting visual frames of reference, left the pilot vulnerable to common visual and vestibular illusions, and reduced his awareness of the airplane's attitude, altitude, and trajectory” (p. 1).

The NTSB concluded that the unstable approach in Case 9 was caused by fatigue due to long duty periods and irregular sleep (NTSB, 2007). The most comprehensive analysis of the effects of fatigue on pilot performance was described in the NTSB report of Case 9. The report discussed the effects of fatigue on “Timing disruption” and “Disruption of the Perpetual field.” The report described “disruption of the perceptual field” as “Concentrating attention upon movements or objects in the center of vision and neglecting those in the periphery” (NTSB, 2007, p. 8). The threats of this effect include “loss of accuracy and smoothness in control movements” (p. 8). The pilots had revealed that he was "tired" and had missed out on sleep due to a variety of reasons mentioned in the report (p. 8). The effects of fatigue on perceptual vision and timing disruption were studied in depth in the report.

In Case 10, flight crew coordination and communication led to the ‘pilot flying’ maneuvering the airplane too steep on the approach (National Transport Safety Committee, 2007). The pilot did not pay visual attention to the indicators in the cockpit indicating an unstabilized approach. The pilot also ignored the auditory GPWS callouts indicating an unstabilized approach. The investigation also recommended enhanced simulator training for pilots on visual approaches and responses to warning such as GPWS warnings during approaches (NTSB, 2007).

In Case 11, the NTSB concluded that the pilots exhibited a lack of CRM procedures and extreme fatigue due to lack of sleep in the preceding days of the accident due to the duration of the pilots’ duty periods (NTSB, 2011).

In Case 12, fatigue played a major role that led to several decisions leading to the unstabilized approach (Court of Inquiry, 2010). The investigation report stated that the captain was asleep during the flight for the first 1 hour and 40 minutes of the 2 hours and 5 minutes of CVR records. The investigation stated that the pilot's sleepiness could have "possibly led to sleep inertia and impaired judgment" during the approach (Court of Inquiry, 2010, p. ix). The report also started the influence of flying during the "period of Window of Circadian Low" (WoCL) and its effects on the judgment and performance of the pilot (Court of Inquiry, 2010, p. 1). This led to the pilot not focusing visual attention on cockpit instruments during the approach and missing crucial visual warnings that indicated a highly unstabilized approach. The lack of CRM was investigated as well as the captain had ignored multiple concerns and go-around calls from the first officer (3 go-around calls from the first officer recorded in the CVR). The investigation also recommended enhanced simulator training for pilots to identify visual cues and warnings and responses to unstabilized approaches. Further, the investigation stated that the airline (Air India Express) operated to multiple “critical airfields” that characterized enhanced threats during approaches, especially visual approaches (p. 79). The investigation recommended the airline to develop enhanced simulator training for pilots for “critical airfields” (p. 79).

For Case 13, The investigating agency AAID Bahamas concluded “lack of crew resource management training” to be a contributory factor for the accident

(Air Accident Investigation Bureau, 2015, p. 15). The pilots continued the unstabilized approach visually and exchanged controls multiple times below 1000 feet AGL. The pilots were distracted by stimuli outside and inside the cockpit that resulted in the pilots missing various visual cues that indicated an unstabilized approach. The AAID Bahamas accident investigation report stated that the pilot and co-pilot stated at "differing times that they had the runway in sight, then they lost sight of it, then they had it again and then lost it again, this process repeated several times up to the point of touch down. It was evident from the CVR recording that neither pilot definitively had the runway in sight" (p. 11). An external factor that played a key role in the accident was the weather with a thunderstorm cell situated right over the airfield during the time of the approach. The report stated that "Due to the weather conditions, visibility of the runway was intermittent, yet the crew continued descending visually in an attempt to land the aircraft on a runway that was not in sight and not served by an instrument landing system (ILS) or other navigational aid used during inclement weather or periods of reduced visibility" (p. 13). The Aeronautical Decision Making of the pilots was examined in the investigation as well.

In Case 14, the investigation by the NTSB concluded that "although the ILS glideslope was out of service, the lack of a glideslope should not have precluded the pilots' successful completion of a visual approach" (NTSB, 2014, p. 77). Due to multiple visual cues available to the pilots such as the PAPI and "visual aspect of the runway" (p.77) The NTSB report also indicated that the pilots indicated fatigue that resulted in the pilots being "fixated" while cross-checking the instruments (p. 86). The NTSB concluded that "that the flight crew was experiencing fatigue, which likely degraded their performance during the approach" (p. 86). The NTSB advocated for Fatigue Risk Management System (FRMS) for airlines to collect data and make changes to factors such as scheduling to minimize the effects of fatigue. The NTSB also evaluated the cross-checking of instruments by the pilot-flying and stated that the plot "did not adequately monitor airspeed between 500 and 200 ft" which "likely resulted from a combination of workload, expectancy, and a coincidence of timing" (p. 88). The NTSB also stated about automation and its effect on visual approaches that "likely resulted from a combination of workload, expectancy, and a coincidence of timing" (p. 88). Additionally, NTSB also states that automation reduces monitoring performance "decreases the likelihood that a human operator will detect signs of anomalous or unexpected system behavior involving the processes under automatic control" (p. 90). The NTSB summarized that "insufficient flight crew monitoring of airspeed indications during the approach likely resulted from expectancy, increased workload, fatigue, and automation reliance" (p. 90). The NTSB recommended the operator to enhance simulator training for visual approaches to improve the pilot's response to unstabilized approaches, automation, and human-machine interaction.

In Case 15, the investigative agency concluded the lack of CRM during the final approach to be a cause of the "serious incident" (BEA, 2018, p. 1). During the approach, the pilots had missed vital visual cues of deviation of speed and descent profile and missed out on callouts as mandated by the Standard Operating Procedures (SOPs) of the airline. The aircraft was not stabilized during the approach and at 1, 000 feet AGL, the aircraft was 57 knots higher than the approach speed of the aircraft. The investigative agency concluded that fatigue due to the flight duty period of nearly 15 hours was a factor for the impaired judgment and inability of the pilots to recognize cues indicating an unstabilized visual approach. The investigative agency analyzed that flying over the ocean during the circling approach to play a factor in the pilots' developing illusions due to the lack of adequate visual references. The investigative agency also recommended enhanced simulator training to account for abnormal procedures such as rejection of landing at a low altitude during a visual approach. The agency also recommended the operator to include *evidence-based training* in its simulator training curriculum (BEA, 2018).

For Case 16, the investigative agency concluded fatigue to be the primary contributor to the accident during the visual approach (Aircraft Accident Investigation Bureau, 2016). The "main cause of the accident" was reported to be the pilots being fatigued which caused an inability of the pilots "to adopt themselves with flight conditions and their interactions are due to spatial disorientation (illusion)” (p. 3). The report also observed various external factors that contributed to the pilot’s losing visual references during the approach. The pilots were landing during sunset and the landing runway (Runway 27) was in the direction of the setting sun while flying over featureless terrain (the sea). These factors contributed to developing spatial disorientation during the visual approach.

For Case 17, the investigative agency recommended the operator to “review its special procedures and develop more comprehensive approach procedures” for the airport (Air Accident Investigation Unit, 2017, p. 28).

In Case 18, the investigative agency concluded that disorientation and loss of situational awareness to be causes for the accident (Accident Investigation Commission, 2019). The visual approach was unstabilized with an “offset to the proper approach path that led to maneuvers in a very dangerous and unsafe attitude to align with the runway” (p. 40). The pilots have initiated the visual approach without the runway or preceding aircraft in sight and sighted the airport at very close proximity to the airport and at a low altitude. Poor CRM procedures were concluded to be a cause of the accident as well due to a "steep gradient” between the crew (p. 40). The CVR data also revealed that “PIC lacked adequate sleep the previous night prior to the flight" (p. 36). This could have contributed towards the impaired judgment and loss of situational awareness during the visual approach. The airport of landing (Tribhuvan International Airport, Katmandu) was also an airport with high terrain and a steep approach path which made the visual approach to the runways particularly challenging. The investigation report revealed that none of the pilots had even practiced a visual approach to the airport in a simulator. While the PIC had operated to the airport multiple times before the accident, the co-pilot was flying to the airport for the first time which would have been a factor in the lack of CRM in the cockpit along with the "steep gradient" between the crew which "prevented FO in assisting and being more assertive in significant phases of flight like approach and landing" (p. 36). The investigation report also revealed that "there was a lack of clear communication between the crew members" (p. 36). The investigative agency recommended the operator to include the approach to the airport as a part of its simulator training curriculum and including a safety pilot (3rd pilot) for flights with high workload and high chances of task saturation, loss of situational awareness, and disorientation during the approach.

Discussion

The analysis of the accident investigation reports indicates that the failure of visual awareness poses significant risks for visual approaches in transport category aircraft. The literature review studied the theoretical aspects of the failure of visual awareness with an overview of inattentional blindness, change blindness, and visual masking. While the accident investigation reports did not directly cite any of the failure of visual awareness studied in the literature review, the reports did mention the role of visual acuity and awareness as factors for increasing the risks of disorientation or illusions and loss of situational awareness.

A direct correlation between factors such as fatigue, poor CRM, and lack of approach briefings and failure of visual awareness could not be established. However, fatigue, poor CRM, and lack of approach briefings were analyzed to be factors that posed risks during visual approaches for transport category aircraft.

While many of the findings from the qualitative analysis did corroborate many aspects reviewed in the literature review, the quantitative analysis did not corroborate any of the theoretical aspects studied in the literature review. The quantitative data studied helped provide a better overview and context of the accidents that were analyzed for this study.

Conclusion

The purpose of this paper was to evaluate the risk posed by the failure of visual awareness during visual approaches for transport category aircraft. The research question for this study was "How does the failure of visual awareness affect safety during visual approaches for transport category aircraft?"

The qualitative analysis of the accidents did significantly indicate that the failure of visual awareness is a significant risk for safety during visual approaches. It was analyzed that several other factors could contribute towards increasing the risk of pilots losing visual awareness and attention. Some factors that increased the likelihood of losing visual awareness and attention were analyzed were task saturation, fatigue, lack of CRM, low lighting conditions, and lack of visual references.

The analysis did highlight that in an environment when pilots were subjected any of the factors mentioned above, pilots did miss out on visual cues indicative of unstabilized approaches inside and outside the cockpit. Some of the visual cues the pilots were not visually attentive to inside the cockpit were the aircraft instruments that indicated an unstabilized approach such as vertical speed indicator or altimeter and other forms of visual warnings such as the Ground Proximity Warning Systems indications. Some of the visual cues outside the cockpit were the visual references outside the cockpit such as the runway environment and the PAPI or VASI lights on.

The lack of CRM, fatigue, low lighting conditions, lack of visual references, and task saturation posed hazards beyond impairing the visual awareness for the pilots. The factors also led to pilots developing visual and vestibular illusions such as somatogravic illusions. In fact, somatogravic illusion was attributed as a factor in two accidents. In total, six accident investigation reports revealed some form of illusion or disorientation as a factor for the accident.

An analysis of the reports revealed that task saturation during a visual approach was a major factor that led to pilots developing spatial disorientation or illusions. In conclusion, the data studied in study can be used to develop operating practices to mitigate the risk of the failure of visual awareness during visual approaches.

Limitations

The results and analysis of this study was just limited to the findings in the state aviation accident reports. No primary data was collected which restricted a more comprehensive analysis of the accidents. The accidents occurred that different countries around the world and the investigation was conducted by different aviation accident investigation agencies. There was a lack of uniformity in the reports and there were several cases where the reports lacked data that was needed for a more comprehensive analysis.

Practical Applications and Recommendations

The following recommendations have been formulated after studying the recommendations and analysis of all 18 accidents.

- Risk management procedures to identify ‘high risk airports’ and routes that consider flight duty periods, physiological factors such as ‘Low Circadian Levels’ during operations, and geographical features near the airport that could induce visual illusions.
- Enhanced simulator training and crew qualifications for conducting visual approaches at high risk airports.
- Fatigue risk management to study the risk of physiological factors on visual approaches.
- Enhanced crew resource management procedures during visual approaches at high risk airports.
- Improved approach briefings by flight crew to identify possible hazards to visual awareness and illusions.

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