Journal of Safety Research 69 (2019) 155–165

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

An analysis of human factors in fifty controlled flight into terrain aviation accidents from 2007 to 2017

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ARTICLE INFO

Article history:
Received 3 December 2018
Received in revised form 12 February 2019
Accepted 6 March 2019
Available online 20 March 2019

Keywords:
Controlled flight into terrain
Plane crash
Aviation accidents
Human factors analysis and classification system
Human factors in aviation, aviation safety

ABSTRACT

Introduction: Controlled Flight Into Terrain (CFIT) account for a considerable amount of fatalities when compared to other accident categories. Human factors are deemed significant contributory causes in these accidents. This paper aims to identify the human factors involved with aviation accidents that resulted in CFIT. *Method*: The study used the Human Factors Analysis and Classification System (HFACS) framework to determine the factors involved in 50 CFIT accidents from 24 counties over a 10 year period, i.e. 2007–2017. Interviews with five senior aviation safety experts were used to provide a better comprehension of the human factors affecting the flight safety. *Results*: The study identified 1289 individual causal and contributory human factors with unsafe actions and preconditions for unsafe actions being the main subcategories of the accidents. The study found that CFIT occur across a range of pilot experience and 44% of accidents occurred in cruise flight. Distraction, complacency and fatigue are all elements that flight crews may experience as contributors to CFIT during cruising. *Conclusions*: Human factors represent a major component of CFIT accidents. The analysis revealed a similar pattern of contributory and causal human factors across the various flight categories, with some noteworthy isolated variations. The prevalent factors were decision and skill-based errors along with communication, coordination and planning issues. *Practical applications*: Provision of specific CFIT awareness, pilot training focusing on improved decision-making and revision of basic flight skills, development of specific Global Positioning System routes for transiting high terrain areas are necessary to prevent CFIT accidents. Installation of Terrain Avoidance and Warning System and Ground Proximity Warning System and appropriate equipment training, specific CFIT Crew Resource Management training and improvement of organizational knowledge on the elements involved in CFIT are also recommended.

1. Introduction

Accidents in aviation have decreased globally since the 1960's. This can be attributed mainly to improvements and innovation in aircraft design, reliability, and safety. This declining trend continued until the late 1990's, when it began to plateau from approximately 1997 (Boeing, 2013). This trend was also reflected in the US National Transportation Safety Board's (NTSB) review of fatal accidents in commuter and on-demand operations 1992–2011 (NTSB, 2012). This plateau has remained relatively constant since then (ICAO, 2013), indicating the importance that organizations are placing on current aviation accident prevention and mitigation strategies as well as continued advances in aircraft design.

Historically, humans have received a substantial portion of the blame for aviation accidents and incidents. Pilot error has been attributed as the cause of many aviation accidents in the past. As much as 75% of all aviation accidents were attributed to pilot error (Gramopadhye and Drury, 2000). It was also recognized that human errors within complex systems are impossible to avoid, and indeed managing the risks of human influence will never be 100% effective (Reason, 1995). Therefore, human fallibility can be managed to a certain extent, but not eliminated.

Human error can arise from many factors, including intentional or unintentional violation of procedures, or from organizational influences from a managerial level that inadvertently affect the flight. Human error is the most significant factor involved in CFIT accidents (IATA, 2014).

CFIT is defined as “In-flight collision or near collision with terrain, water, or obstacle without indication of loss of control.” (IATA, 2017, pp. 3). The most important factor of this type of accident is the fact that the aircraft is fully under the control of the flight crew at the time of impact. Technical or equipment malfunctions are not considered to be factors in the immediate cause of the accident, thus human error is determined as the most likely cause.

CFIT, according to Boeing (2013), is a leading cause of aviation accidents that involve loss of life, and is responsible for over 9000 fatalities

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https://doi.org/10.1016/j.jsr.2019.03.009

since the advent of the commercial jet age. The majority of CFIT accidents have catastrophic outcomes. A report from International Air Transport Association (IATA) on CFIT stated that 91% of CFIT accidents between 2010 and 2014 involved fatalities to passengers and/or crew (IATA, 2014). Over this period, only 8.3% of all accidents were categorized as CFIT, but CFIT contributed to 28% of the total fatalities (707 out of 2541). These statistics clearly identify CFIT as a major, constant threat, which requires the implementation of mitigation measures from an organizational perspective.

This paper analyzes CFIT accidents occurring in commercial, military and general aviation including both fixed wing and rotary wing aircraft. These instances are analyzed through the application of the Human Factors Analysis and Classification System (HFACS) framework to determine the common human factors across the various flight categories and recommend possible improvements. The paper reveals how accident investigators think about human error in CIFT accidents.

A small number of studies have been conducted on human factors involved in CFIT accidents by IATA (2014) the U.S. Dept. of Transportation (Bud et al., 1997) and Wiegmann and Shappell (1996). These studies focused on one specific type of aviation, such as, commercial jet or general aviation accidents, whereas this paper conducted analysis across commercial, military, and general aviation categories with both fixed wing and rotary wing aircraft, to determine if the human factors involved in CFIT accidents have common occurrences across a broad spectrum.

The remainder of the paper is organized as follows. Section 2 begins by elaborating on the literature review associated with the human factor models and technological preventative measures currently utilized. The methodology followed is outlined in Section 3. Section 4 outlines the results while Section 5 concludes the paper.

2. Controlled flight into terrain (CFIT) human error factors

CFIT is the second most common category of fatal accidents, after Loss of Control In-Flight (LOCI). CFIT accidents have been identified as mainly catastrophic events with 91% of CFIT accidents in 2010 to 2014 involving fatalities (IATA, 2014). Maurino (1992) and ICAO (1995) identified human error as a major causal factor in CFIT accidents, thus determining that human factor analysis is key to the investigation of CFIT accidents.

CFIT accident fatalities since 1931 have been estimated at 30,000 people (Cooper, 1995). These accidents mainly occur in two defined phases of flight; cruise and approach. The approach phase accounts for just a 4% portion of a flight, however, it is responsible for 50% of all CFIT accidents (Matthews, 1997). CFIT occurs most commonly during the approach and landing phase.

CFIT has numerous factors that can be attributed to human error. For example, it is commonplace for flight crews in CFIT accidents to have a causation factor attributed to them known as “lack of situational awareness” (Phillips, 1999). Situational awareness (SA) can be defined as the perception, understanding, and ability to forecast the factors affecting the aircraft at any moment in time (Wickfield, 1997). It is essentially a pilot's ability to retain an accurate mental model, in three-dimensional space of the aircraft's position, altitude, speed, and prediction of the aircraft's future path, etc. Loss of SA can occur due to poor workload management, conflicting information, weather conditions, lack of aircraft systems knowledge, and inadequate planning. An increased reliance on automation is also viewed as a major contributing factor. Aircraft automation exists to aid flight crew in conducting a safer flight. Complacency and a lack of vigilance, when system monitoring is required, can result in a loss of SA with devastating consequences. This complacency can be attributed to the human operators over dependence on an aircraft's automated systems (Endsley, 1995).

In order to maintain good SA, a pilot must be attentive and perceptive at all stages of the flight. Preventative measures can be implemented through thorough pre-flight planning, improving manual flight skills, and maintaining a high-level of specific aircraft mechanical and avionics knowledge. One of the most famous instances of losing SA was the American Airlines flight 965 in Cali, Columbia in 1995 where experienced pilots entered the incorrect data into the flight management system (FMS) which resulted in CFIT into a mountain (NTSB, 1995). Loss of SA is one of the most common human factors attributed to CFIT accidents (Cooper, 1995; Gore, 1997; Scott, 1996; Wickfield, 1997).

Other factors that also have an effect, according to IATA (2014) are:

- Non-compliance with established Standard Operating Procedures (SOPs).
- Inadequate flight path management.
- Lack of vertical and/or horizontal position awareness in relation to terrain.
- Un-stabilized approaches.
- Failure to initiate a go-around when required.
- Conducting operations in poor weather conditions.
- Incorrect action/response by flight crew.
- Failure in Crew Resource Management (CRM) such as cross-checking, communications, coordination, leadership, etc.

3. Methodology

3.1. Data

An expansive range of accidents, including both fixed wing and rotary wing; multi-engine and single-engine; commercial, military aviation and general aviation, were chosen (Table 1). In order to achieve a varied timeline of CFIT accidents, five accidents per year were analyzed over a ten year period from 2007 to 2017, totalling 50 reports (Table 2). It was decided to select reports from January 1, 2007 to January 1, 2017. Reports from 24 countries from different continents were used in order to account for varying factors that may affect different global regions.

Qualitative data were collected through interviews with five relevant and senior aviation safety personnel. The interviewees are listed as follows:

- Flight Safety Manager – Military
- Flight Operations Safety Manager - Airline A
- Director of Flight Safety - Airline B
- Chairman in an Aviation Safety Council - Government agency
- Air Accident Investigator at an Air Accident Investigation Unit - Government agency

A variety of international, aviation accident database sources were utilized to assemble the accident reports, as listed below.

- United States of America - National Transportation Safety Board (NTSB)
- Australian Transport Safety Bureau (ATSB)
- United Kingdom - Air Accident Investigation Board (AAIB)
- Ireland - Air Accident Investigation Unit (AAIU)
- German Federal Bureau of Accident Investigation (BFU)
- Transportation Safety Board of Canada (TSB)
- Flightsafety Foundation Accident Database

Databases from government organizations were primarily utilized to ensure the reliability and credibility of the reports. The reports from each of these organizations are available from the relevant national authority. The final listed source is an independent initiative called Flightsafety Foundation Accident Database providing over 20,000 global accident reports.

3.2. Human factors model

The study of human factors in aviation has been an important factor in the evolution of flight safety, in modern aviation. There has been an

Table 1
Reports analyzed.

Flight cat	A/C reg	A/C make	A/C model	Type of operation	A/C damage	Fatalities	Phase of flight	Impact	VMC/IMC	Light	Pilot in control
Commercial	9 N-AHH	Twin Otter	VIKING DHC6–400)	Pax Transfer	Destroyed	23	En Route	Mountain	IMC	Night	Co-Pilot
Military	49–3043	Raytheon U-125	Hawker 800	Multi Role Transport	Destroyed	6	En Route	Mountain	IMC	Day	Co-Pilot
General Aviation	RA-33462	Antonov 2SX	2SX	Survey	Destroyed	2	En Route	Level Ground	VMC	Day	Captain
General Aviation	N208SD	Cessna	208D Grand Caravan	Pax & Cargo Transfer	Destroyed	3	En Route	Mountain	IMC	Day	Co-Pilot
Helicopter Military	HKP14D	NH Industries	NH90 (Formation)	Multi Role Transport	Damaged	0	En Route	Frozen Lake	VMC	Day	Captain
Commercial	PK-YRN	Aerospatial	ATR 42–300	Pax Transfer	Destroyed	54	En Route	Mountain	IMC	Day	Captain
General Aviation	N757ZM	Cessna	Cessna 152	Private	Destroyed	1	En Route	Level Ground	IMC	Night	Captain
Commercial	D-AIPX	Airbus	A320	Pax Transfer	Destroyed	150	En Route	Mountain	VMC	Day	Co-Pilot
Helicopter Military	168,792/SE-08	Bell	UH-1Y Huey	Medical	Destroyed	13	En Route	Mountain	IMC	Day	Captain
General Aviation	N8749A	Beech	A35	Private	Destroyed	2	En Route	Mountain	IMC	Day	Captain
General Aviation	BFU1	Cessna	Citation 501	Pax Transfer	Destroyed	4	Approach	Level Ground	IMC	Day	Captain
Commercial	B-22810	Aerospatial	ATR 72	Pax Transfer	Destroyed	48	Approach	Level Ground	IMC	Day	Captain
General Aviation	EP-FIC	Dassault	Falcon 20E	Aerial Survey	Destroyed	4	Approach	Water	VMC	Day	Captain
General Aviation	N248SP	Piper	PA-46	Private	Destroyed	1	Departure	Mountain	IMC	Day	Captain
Helicopter GA	G-LABL	Augusta Westland	AW139	Pax Transfer	Destroyed	4	Departure	Level Ground	VMC	Night	Captain
Commercial	N155UP	Airbus	A300	Cargo	Destroyed	2	Approach	Level Ground	IMC	Night	Captain
Helicopter GA	C-GCFU	Bolkow	Bo105	Survey	Destroyed	3	En Route	Water	VMC	Day	Captain
General Aviation	N9078X	Cessna	182D	Private	Destroyed	2	Approach	Mountain	VMC	Night	Captain
Helicopter GA	C-GIMY	Sikorsky	S-76A	Medical	Destroyed	4	Departure	Level Ground	VMC	Night	Captain
Commercial	RDPL-4223	Aerospatial	ATR 72	Pax Transfer	Destroyed	49	Approach	Water	IMC	Day	Captain
Military	6840	Douglas	Dakota C47	Multi Role Transport	Destroyed	11	En Route	Mountain	IMC	Day	Captain
Military	5630	Lockeed Martin	Hercules C130	Multi Role Transport	Destroyed	5	En Route	Mountain	IMC	Day	Captain
Commercial	97,004	Sukjoi	RRJ-95	Pax Transfer	Destroyed	45	EN Route	Mountain	IMC	Day	Captain
General Aviation	VH-CWQ	Cessna	Cessna 182	Private	Destroyed	1	En Route	Mountain	IMC	Day	Captain
Commercial	AP-BKC	Boeing	737–200	Pax Transfer	Destroyed	127	Approach	Level Ground	IMC	Day	Captain
Helicopter Comm	C-GQCH	Sikorsky	S-92	Pax Transfer	No Damage	0	Departure	Water	IMC	Day	Captain
Commercial	PK-MZK	Xian	MA60	Pax Transfer	Destroyed	25	Approach	Water	VMC	Night	Captain
General Aviation	VH-LKI	Piper	Saratoga PA-32	Private	Destroyed	3	Approach	Level Ground	VMC	Night	Captain
Commercial	EC-ITP	Fairchild	Metro III SA 227	Pax Transfer	Destroyed	6	Approach	Level Ground	IMC	Day	Co-Pilot
Commercial	PK-TLF	Airbus	CASA 212	Pax Transfer	Destroyed	18	En Route	Mountain	IMC	Day	Captain
Military	101	Tupelov	TU-154 M	Multi Role Transport	Destroyed	96	Approach	Level Ground	IMC	Day	Captain
Commercial	PT-GKQ	Embraer	EMB-110P	Cargo	Destroyed	0	Approach	Level Ground	IMC	Night	Captain
Commercial	N455A	De Havilland	DHC-3 T	Pax Transfer	Destroyed	5	En Route	Mountain	VMC	Day	Captain
Commercial	5A-ONG	Airbus	A330–200	Pax Transfer	Destroyed	103	Approach	Level Ground	IMC	Day	Captain
Commercial	AP-BJB	Airbus	A321	Pax Transfer	Destroyed	152	Approach	Mountain	IMC	Day	Captain
Military	265	Pilatus	PC-9 M	Pilot Training	Destroyed	2	En Route	Mountain	IMC	Day	Captain
Helicopter HEMS GA	N911LZ	Eurocopter	EC145	Medical	Destroyed	0	Approach	Water	VMC	Night	Captain
Helicopter GA	C-GNLK	Bell	206	Survey	Destroyed	2	En Route	Mountain	IMC	Day	Captain
General Aviation	8Q-MAG	De Havilland	DH6	Survey	Destroyed	0	En Route	Water	VMC	Day	Captain
Commercial	PK-BRD	British Aerospace	BAE-146	Cargo	Destroyed	6	Approach	Mountain	IMC	Day	Captain
Military	19	Airbus	CASA 295	Multi Role Transport	Destroyed	20	Approach	Level Ground	IMC	Night	Captain
Helicopter GA	C-GIMR	Sikorsky	S-76A	Medical	Damaged	0	Approach	Level Ground	VMC	Night	Captain
Air Taxi Part 135 Comm	N410NB	Hawker Beechcraft	1900C	Cargo	Destroyed	1	Approach	Water	VMC	Night	Captain
General Aviation	ZS-OSD	Britten Norman	Islander	Pax Transfer	Destroyed	9	En Route	Mountain	IMC	Day	Captain
Commercial	YV102T	Boeing	737	Pax Transfer	Destroyed	3	Approach	Mountain	IMC	Day	Captain

(continued on next page)

Table 1 (*continued*)

Flight cat	A/C reg	A/C make	A/C model	Type of operation	A/C damage	Fatalities	Phase of flight	Impact	VMC/IMC	Light	Pilot in control
General Aviation	N45MF	Beechcraft	200	Medical	Destroyed	3	Approach	Mountain	VMC	Night	Captain
Commercial	TC-AKM	McDonnell Douglas	MD-83	Pax Transfer	Destroyed	57	Approach	Mountain	IMC	Night	Captain
Commercial	N1116Y	Cessna	208B	Cargo	Damaged	1	Approach	Level Ground	IMC	Night	Captain
Commercial	Ra-65,421	Tupelov	134A-3	Pax Transfer	Destroyed	6	Approach	Level Ground	IMC	Day	Captain
General aviation	N364KW	Beechcraft	A36TC Bonanza	Private	Destroyed	3	En Route	Mountain	IMC	Day	Captain

evolution of frameworks, most important of which are the Human Factors Analysis and Classification System (HFACS), the Systems Theoretic Accident Modelling and Processes (STAMP) model, Dupont Human Performance Model, Accimap, Pilot Competencies Model.

The Systems Theoretic Accident Modelling and Processes (STAMP) model is a constraints-based model that uses control theory to describe the interaction between system components and the implemented controls used within a specific system (Leveson, 2004). In accident analysis, STAMP generates a description of a specific systems control structure where it then identifies failures within this structure that were factors in the accident (Leveson, 2012).

The Dupont Human Performance Model, also known as Dupont's Dirty Dozen includes 12 defined human error elements that act as precursors to accidents. According to Dupont (1997) those are: (1) Lack of communication; (2) Lack of teamwork; (3) Lack of knowledge; (4) Lack of awareness; (5) Lack of assertiveness; (6) Lack of resources; (7) Fatigue; (8) Pressure; (9) Complacency; (10) Stress; (11) Distraction and (12) Norms. This model, having been created for aircraft maintenance, was subsequently adapted for use amongst all personnel involved with aviation. The Dupont model was also used by ICAO (1995) in their investigation of specific CFIT accidents in 2014.

Accimap is used to graphically illustrate system failures, decisions and specific acts that are involved in an accident (Rasmussen, 1997). This approach differs from other accident analysis techniques by identifying causal factors from all parts of the system in which the accident took place. This ranges from the physical sequence of events and activities of the individuals involved, right up to the causes at the governmental, regulatory, and societal levels. Unlike other methods for accident analysis, this approach also assembles the contributing factors into a coherent causal diagram that illustrates the interrelationships between them, thereby highlighting the problem areas that should be addressed to prevent similar accidents from occurring in the future. This process is useful for highlighting the organizational and systemic inadequacies that contributed to the accident, so that attention is not directed solely towards the events and human errors that led direct to the accident.

The Dupont model does not offer a comprehensive list of human error accident precursors. The model has been widely utilized across the aviation maintenance industry allowing future use in other sectors of aviation. While the model has deficiencies it could be developed or used in conjunction with another model when investigating aviation accidents. This is also the case with the "Pilot Competencies Model" where a comprehensive list of factors is lacking, however, it can be purposefully utilized with another model.

Both STAMP and Accimap can be viewed as cumbersome and time consuming when applied to complex aviation investigations. Leveson (2012) suggested that STAMP does not lend itself to a simple graphical representation of an accident. While HFACS is time consuming it was specifically designed for the investigation of aviation accidents and is more consistent due to its use of classifications and nanocodes (Salmon, Cornelissen and Trotter, 2011).

Human Factors Analysis and Classification System (HFACS) model was created to address the difficulty of applying Reason's Swiss Cheese Model in a practical manner (Lower, Magott, & Skorupski, 2018; Wiegmann and Shappell, 1996; Wiegmann & Shappell, 2017). Wiegmann and Shappell (2001, 2003, 2005) investigated the reasons surrounding U.S. naval aviation accidents and tried to identify how to reduce the accident rate. Traditional accident investigation techniques were not sufficiently applicable to identify key aspects of human factors throughout the various accidents. Therefore, the Human Factors Analysis and Classification System (HFACS) was developed. Ultimately, the goal of HFACS is not to attribute blame, rather to understand the underlying causal factors that led to an accident (Wiegmann and Shappell, 2000).

Wiegmann and Shappell (2003) acknowledged that the Swiss Cheese Model identified that the defence barriers of an organization could be breached to ultimately permit a hazard to become an accident. They decided that the layers required labelling in order to be classified into an acceptable structure (Wiegmann and Shappell, 2003). This resulted in respective layers being identified as four defined layers that allowed for the exact methods of failure for each level to be determined more definitively, as illustrated in Fig. 1.

HFACS classified the layers of the framework as Unsafe Acts, Pre-Conditions for Unsafe Acts, Supervisory Failures and Organizational Influences (Wiegmann and Shappell, 2003). Within each level of HFACS,

Table 2
Analyzed CFIT accident reports characteristics.

CFIT accident reports (n = 50)					
20 from general aviation		8 from military aviation[*]		22 from commercial aviation	
Percentage of rotary & fixed wing analysis					
41 fixed wing			9 rotary wing		
Types of operations					
21 passenger flights	7 private flights	5 medical flights	5 cargo	5 survey flights	7 multi-role flights
Phase of flight					
24 CFIT during the approach phase		22 CFIT during the en-route phase		4 CFIT during the departure phase	
Type of impact					
24 Mountain		18 level ground		8 water	

[*] A lower number of military accidents were analyzed due to many militaries not allowing public access to their accident investigation reports.

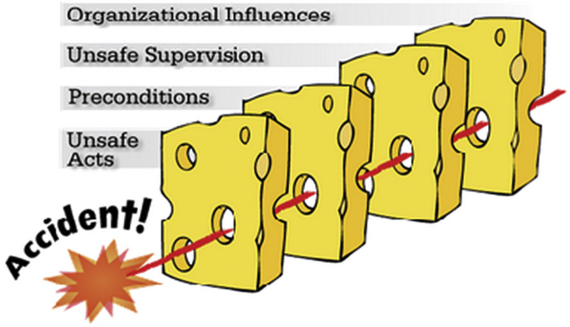

Fig. 1. HFACS Layers (HFACS, 2018).

causal sub-categories were outlined (Table 3) that could identify the active and latent failures that occur with greater accuracy.

The sub-categories explained above are then dissected into "nanocodes." For example, skill-based errors are sub-divided into breakdowns in visual scan, inadvertent use of flight controls, poor technique/airmanship, over or under-controlling the aircraft, omitting a checklist item, omitting a step in a procedure, over reliance on automation, failing to prioritize attention, task overload, negative habit, failure to see and avoid, distraction, etc. (Wiegmann and Shappell, 2003).

It has been suggested that it may be possible to supplement the use of HFACS with less laborious analytical methods if conducting multiple minor investigations (ICAO, 1993). This would allow for the Dupont Model and Pilot Competencies Model to be used in conjunction with HFACS. It has also been suggested, that in the majority of incident investigations, HFACS is only required for more in-depth human factors analysis of more serious, or specific, incidents (Liu, Sun, and LV, 2011). HFACS supports a data collection and categorization process that can be applied both during and post-accident investigation (Stolzer and Goglia, 2016).

HFACS has received some criticism due to a perceived failure to consider contributory external influences outside of the organizational level, such as, government policy, regulatory oversight, manufacturers, political, economic, and customers influence (Omole and Walker, 2015; Salmon, Cornelissen and Trotter, 2011). HFACS has also been criticized regarding its nanocoding system being under-identified in terms of the detection of specific operational problems (Beaubien and Baker, 2002). Dekker (2001) argued that the relationship between human error and environmental factors does not go far enough. Dekker (2001) claimed that confusion can arise between categorization and analysis, and that the assignment of errors to categories does not provide ample explanation of the actual errors, or of the interventions necessary to directly tackle the specific errors, rather than the categories to which they were assigned.

Aside from these criticisms, the use of the HFACS framework as a template for accident or incident analysis is valuable for highlighting areas within an organization that require attention, which may otherwise be overlooked. The use of a classification system to investigate incidents and accidents has several benefits compared to a less structured, procedure (Reinach and Viale, 2006).

HFACS is now widely accepted across numerous industries such as medical, rail, mining, pharmaceutical, and manufacturing (Chen et al., 2013; Ergai et al., 2016). It has been proven to be an important framework to utilize when investigating the human factors involved in the causation of aviation accidents (Cintron, 2015). Therefore, the HFACS model framework was used to analyze each accident report in order to highlight the human factors involved, as it supports a data collection and categorization process that can be applied, both during and post-accident investigation (Stolzer and Goglia, 2016).

The project database was based on nanocodes that represent a further breakdown of each HFACS level, developed by the US Navy. These nanocodes allowed for a detailed identification and description of each of the HFACS levels outlined in Table 3. A value of "1" or "0" was given to each sub factor depending on whether it was encountered within each report or not. A "1" illustrated the presence and "0" indicating the absence of a given factor. Each sub factor was totalled in order to gain an overall understanding of the number of human factors involved. This ensured that specific categorized HFACS instances were accounted for throughout the analysis.

4. Research results

4.1. HFACS analysis

The research identified 1289 individual causal and contributory human factors responsible for these CFIT accidents. These causal and contributory human factors were extracted as HFACS nanocodes (Table 4), with each nanocode categorized under HFACS sub-categories within the overall HFACS framework of the four main levels of failure: Unsafe Acts, Pre-Conditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences.

The number of sub-category occurrences per report provide a true representation of the analysis. This is evident where certain sub categories such as "Mental States" and "Communication, Coordination and Planning" have 14 and 12 defined factors, respectively, that may occur per report, compared to that of "Perceptual Errors" that contains only one factor.

The analysis revealed that some accidents contain a much higher number of sub-categorical errors. In order to avoid the over-misrepresentation of any single accident, it was determined that each sub-category would initially be counted once per accident where it occurred. The four levels of HFACS failure (colour-coded) for the analyzed accidents are illustrated in Fig. 2, with the percentage breakdown of occurrences as indicated.

4.1.1. Unsafe acts

Decision, Skill-Based and Perceptual Errors are all common errors in CFIT accidents. Elements of Decision and Skill-Based errors both occurred in 98% of the analyzed reports with Perceptual Errors representing 74% of reports. The most common types of decision error were, "The Assessment of Risk during the Operation" and the "Ignoring of a Necessary Action".

This "Assessment of Risk during the Operation" error occurs in real-time when formal risk assessment procedures are not possible. Flight crews were unable to make the appropriate decisions during flight in order to maintain a safe operating condition. This can be due to a number of reasons such as perceived pressure, distraction, inexperience, complacency, and lack of knowledge. While the reports list inexperience as a contributing factor, both airline interviewees stated that pilots who become complacent, despite considerable experience, are more commonly at fault in CFIT issues. In accident report number 24 for example, the weather continued to deteriorate, where the decision to continue into cloud, without adequate evaluation of the risks involved, led to an unsafe situation and ultimately, a terrain impact.

"Ignoring a Necessary Action" was a factor, as a caution or warning was perceived and understood by the flight crew but was ignored leading to an unsafe situation. This error represented a major decision making factor in CFIT accidents that was identified in 40% of analyzed reports. For example, in accident number 23, as the aircraft approached high terrain a ground proximity warning sounded to alert the crew, however, it was ignored intentionally and resulted in a collision with terrain.

"Procedural Errors" and the "Breakdown of the Visual Scan" of the flight crew were skill-based errors that occurred in 72% and 84% of the reports, respectively. "Procedural Errors" occurred either when a procedure was accomplished in the incorrect sequence, when the incorrect technique was used or the incorrect control/switch was selected. "Procedural Errors" may also occur while conducting navigation, calculation

Table 3
HFACS model (HFACS, 2018).

<table>
<tr><td colspan="5">Level 1. Unsafe acts:
Unsafe Acts are active failures resulting in an accident or incident and are composed of errors and violations. Numerous unsafe acts are associated with mistakes that can be too great in number to measure (Reason, 1990).</td></tr>
<tr><td>Errors:</td><td>A) Decision Errors represent thought provoked, goal orientated behavioural mistakes that inevitably manifest into poor execution of procedures and choices.</td><td colspan="2">B) Skill-based Errors represent behaviour that repeatedly occurs with little conscious thought involved, ultimately resulting in a mistake occurring due to the instigation of a complacent approach.</td><td>C) Perceptual Errors occur with the degradation of sensory inputs at night or experiencing challenging environments resulting in inaccurate, or incorrect actions being implemented.</td></tr>
<tr><td>Violations:</td><td colspan="2">(A) Routine Violations can be habitual in nature and are often facilitated by a management structure that accepts these violations in order to complete a task effectively.</td><td colspan="2">(B) Exceptional Violations are regarded as departure from rules and procedures on a rare occasion, which is not condoned by the organization.</td></tr>
<tr><td colspan="5">Level 2. Preconditions for unsafe acts:
These pre-conditions are latent conditions and/or active failures and indicate the final defensive barrier to the committal of an Unsafe Act (Shappell et al., 2007).</td></tr>
<tr><td>Situational Factors:</td><td colspan="2">(A) Physical Environment categorizes the physical operational setting i.e. weather, light, heating, terrain etc.</td><td colspan="2">(B) Tools/Technology categorizes a wide variety of technological issues i.e. equipment design, cockpit displays, checklists etc.</td></tr>
<tr><td>Condition of the Operators:</td><td>(A) Mental States refer to serious psychological conditions that adversely affect performance such as mental fatigue, attitude, inadequate motivation etc.</td><td>(B) Physiological States refer to acute physiological conditions that inhibit safe operation i.e. physical illness, intoxication, etc.</td><td colspan="2">(C) Physical/Mental Limitations are categorized as a permanent physical/mental disability that negatively impacts on operational performance i.e. vision, strength, intelligence etc.</td></tr>
<tr><td>Personnel Factors:</td><td colspan="2">(A) Communication, Coordination, & Planning refer to the identification of a number of communication, coordination and teamwork issues that negatively impact the operational task.</td><td colspan="2">(B) Fitness for Duty is the consideration of off-duty activities that are required to operate effectively i.e. sufficient rest prior to duty, alcohol restrictions, etc.</td></tr>
<tr><td colspan="5">Level 3. Supervisory factors:
They allow for Pre-Conditions to become active failures (Wiegmann and Shappell, 2000).</td></tr>
<tr><td></td><td>(A) Inadequate Supervision refers to inappropriate oversight and supervision of personnel and resources.</td><td>(B) Planned Inappropriate Operations are the task assignment of known inappropriate operational issues i.e. risk assessment, etc.</td><td>(C) Failed to Correct Known Problems are classified as such when problematic issues are known to management and they fail to act on them accordingly.</td><td>(D) Supervisory Violation refers to the knowing disregard of procedures, regulations and policy by management.</td></tr>
<tr><td colspan="5">Level 4. Organizational influences:
Organizational Influences stem from high-level management influences, resource management, and organizational climate.</td></tr>
<tr><td></td><td>(A) Organizational Culture is viewed as the overall organizational atmosphere with regard to culture, policy and strategic direction.</td><td>(B) Operational Process is categorized as the procedures that are carried out by management in order to achieve the desired</td><td colspan="2">(C) Resource Management is the management of assets along with personnel and financial issues in order to achieve the organizations output goal.</td></tr>
</table>

or during the operation of automated systems by the flight crew. Diverging from a published set procedure can have serious consequences for the safety of a flight. In report number 45, while on approach to an airport located near high terrain, the aircraft unintentionally, failed to maintain the published approach procedure and diverted from their track, impacting with mountainous terrain.

The “Breakdown in Visual Scan” refers to the flight crews' inadequate visual analysis of the aircraft's flight instruments. Flight crews failed to execute effectively learned internal or external visual scan patterns in 84% of reports. This is a basic flight skill that is constantly required throughout all flights in order to maintain a safe flight condition. It was evident in a total of 42 analyzed reports that, through distraction, complacency or lack of skill, a critical parameter such as altitude was ignored and an unsafe situation occurred.

“Perceptual Errors” were prevalent in 74% of the analyzed reports. This type of error represents a major factor in CFIT accidents when misperception of an object, threat or situation results in human error. “Perceptual Errors” include visual, auditory, vestibular illusions, and attention failures. These errors were evident in 37 reports and occurred when a member of the flight crew acted, or failed to act, based on an illusion, misperception or disorientated state, resulting in an unsafe situation. Sixteen of those thirty-seven reports occurred while the aircraft flew under VFR and inadvertently entered cloud in IMC. As evident in reports 30 and 36, the transition from external visual references to internal instruments, with no external references, had an adverse effect on the senses of the human body resulting in a misperception that ended in a terrain impact. Specialized training is required to handle adequately this state of flight.

Procedural compliance can be viewed as a strong mitigating factor in the avoidance of CFIT. This assumption is supported by opinions expressed by airline A interviewees where both respondents reported that focussing on crews following correct procedures as defined by the company, act as a large barrier to CFIT occurrences. These procedures are not only emphasized and conditioned through strict training procedures but also through check flights and simulator training every 6 months.

In a commercial aviation context, the airline B interviewee stated that they would view aircraft in visual meteorological conditions, while on an approach, being more at risk of committing a violation, as some pilots will tend to continue flight on receiving an alert or warning. If they are operating in IMC a go-around (GA) is more likely to be conducted as the option of continuing with no visual contact with the ground is available. A “sink rate” or “windshear” warning on an approach is an automatic GA situation; some pilots, however, were inclined to continue due to visual ground contact. The accident investigator interviewee stated that this “tunnel vision” draws pilots in to inadequately assessing the risk involved with continuing the approach and through this flawed decision-making process, decide to continue flight.

Violations represent the wilful disregard for rules and instructions. While evident in less than 50% of the analyzed reports, a noteworthy discovery arose when comparing both “Routine” and “Exceptional” violations results. Routine violations represent the calculated or systemic violation of policy or procedure, whereas “Exceptional Violations” represent an intentional violation due to a lack of discipline.

A larger percentage of routine violations occurred in military aviation. This variation between routine and exceptional military violations

Table 4
Highest scoring sub-categories and corresponding nanocodes.

Sub-category	Nanocodes	Count	%
Decision errors	Risk assessment - during operation	45	10%
	Task misprioritization	19	
	Necessary action - rushed	2	
	Necessary action - delayed	13	
	Necessary action - ignored	20	
	Decision-making during operation	44	
Skill-based errors	Inadvertent operation	4	8%
	Checklist error	10	
	Procedural error	36	
	Overcontrol/undercontrol	21	
	Breakdown in visual scan	42	
Physical environment	Vision restricted by meteorological conditions	44	4%
	Vision restricted in workspace by dust/smoke etc.	1	
	Windblast	1	
	Thermal stress - cold	1	
	Thermal stress - heat	0	
	Manoeuvring forces - in flight	11	
	Lighting of other aircraft	3	
	Noise interference	1	
	Brownout/whiteout	1	
Mental states	Pre-existing personality disorder	0	13%
	Pre-existing psychological disorder	1	
	Pre-existing psychosocial problem	1	
	Emotional state	6	
	Personality style	7	
	Overconfidence	18	
	Pressing	25	
	Complacency	30	
	Inadequate motivation	2	
	Misplaced motivation	1	
	Overaggressive	7	
	Excessive motivation to succeed	34	
	Get-home-it is/get-there-it is	30	
	Response set	20	
	Motivational exhaustion (burnout)	4	
Coordination/communication/planning factors	Crew/team Leadership	28	15%
	Cross-monitoring performance	32	
	Task delegation	10	
	Rank/position authority gradient	10	
	Assertiveness	18	
	Communication critical information	15	
	Standard/proper terminology	12	
	Challenge and reply	10	
	Mission planning	38	
	Mission briefing	30	
	Task/mission-in-progress re-planning	41	
	Miscommunication	12	
Inadequate supervision	Leadership/supervision/oversight inadequate	25	6%
	Supervision – modelling	4	
	Local training issue/programs	20	
	Supervision – policy	24	
	Supervision – personality conflict	4	
	Supervision – lack of feedback	6	
Planned inappropriate operations	Ordered/led on mission beyond capability	8	9%
	Crew/team/flight makeup/composition	13	
	Limited recent experience	18	
	Limited total experience	14	
	Proficiency	32	
	Risk assessment – formal	29	
	Authorized unnecessary hazard	10	
Organizational culture	Unit/organizational values/culture	17	4%
	Evaluation/promotion/upgrade	3	
	Perception of equipment	3	
	Unit mission/aircraft/vehicle/equipment change or unit deactivation	11	
	Organizational structure	2	
Operational process	Ops tempo/workload	13	5%
	Program and policy risk assessment	14	
	Procedural guidelines/publications	12	
	Organizational training issues/programs	12	
	Doctrine	2	
	Program oversight/program management	13	

can be explained through the military's rigid disciplinary culture that is instilled in military personnel resulting in lower "exceptional" or "lack of discipline" violations while they may also be more open to being guided by colleagues and committing a routine violation that has become a norm amongst peers. This can be due to the fluid nature of flight that at times, requires calculated, accepted routine violations of procedures in order to complete a task, often with lives at risk compared to that of an intentional lack of discipline. The organizational structure is not present in the majority of "General Aviation" accidents and therefore a lower percentage of intentional violation is experienced.

4.1.2. Pre-conditions for unsafe acts

The prevalent pre-conditions subcategories that existed within the reports analysis were "Physical Environment" (94%), "Mental States" of the crew (92%) and "Communication/Coordination and Planning" (92%). They were determined as common precursor factors to unsafe acts.

The "Physical Environment" sub-category represented the analyzed accidents that involved environmental phenomena such as weather or climate conditions, which effected the actions of the flight crew resulting in human error. The most frequent occurring physical environment element, from the analysis conducted, was the event of having the flight crews "Vision Restricted by Meteorological Conditions." This was a resultant factor in 94% of the accidents analyzed. It became a critical factor when weather, haze, or darkness restricted the vision of the flight crew to a point where normal duties were effected. Distraction from critical flight tasks occurred in report number 31 when vision was restricted and led to a terrain impact on the approach phase of the flight.

The "Mental States" sub-category refers to the mental conditions of the crew, which was identified as factors in 92% of cases analyzed. Such incidences arose when specific personality traits, psychosocial problems, psychological disorders, or inappropriate motivation created a critical situation. "Pressing" was identified as an important nanocode element and was highlighted in 50% of the analyzed reports. This was evident in report number 29, when a member of the flight crew knowingly committed to a course of action that pressed both them and their equipment beyond reasonable limits. This is closely related to two other nanocode elements, "excessive motivation to succeed" and "get-home-itis."

"Excessive Motivation to Succeed," evident in 68% of the reports analyzed, was a factor when the flight crew was preoccupied with the success of the mission, to the exclusion of other mission factors. "Get-home-itis," evident in 60% of the reports analyzed, and specifically, report 44, was a factor when a crew was motivated to reach a mission goal/destination for personal reasons, thereby cutting short necessary procedures or exercising poor judgement. These three "Mental States" factors highlight the pressure that was felt by flight crews to reach a destination in 92% of CFIT reports analyzed, while forcing the aircraft into an unnecessary unsafe situation.

"Complacency" was a factor when a member of the flight crew has a state of reduced conscious attention, due to an attitude of overconfidence, under motivation or the sense that the situation is "under control." This was a factor in 60% of reports where the cockpit gradient was high and one member of the crew was considerably more experienced than the other. This situation led to decisions not being assessed or questioned correctly which, ultimately led to a chain of unsafe events.

Flight crews with considerable experience became overconfident and over reliant on an aircraft's automated systems, which inflicted a reduced state of conscious attention on the flight parameters, required for a safe flight condition. Commercial flight reports analyzed represented over 70% of the complacency instances, however the average captain hours were over 14,000 h of flight experience (Table 5).

The flight safety manager interviewee stated that there were similar experience issues encountered with both of their recent CFIT accidents in 1999 and 2008, which have highlighted the importance of training and crew flying currency to them.

Airline A has related this to an overreliance on automation and allow their pilots to conduct a considerable amount of manual handling flight of the aircraft with the autopilot deselected. However, in doing so, they have identified an increase in unstabilized approaches through manual handling thus increasing overall risk. Airline B also allow manual handling flight but restrict it to quiet airspace locations.

The accident investigator interviewee also noted an overreliance in automation in the general aviation community. The interviewee stated that there is a belief that technology offers protection from a CFIT event. This belief can only be corrected with further specific training, which unfortunately, seems to be limited for the general aviation enthusiast. The interviewee from the general aviation safety council identified

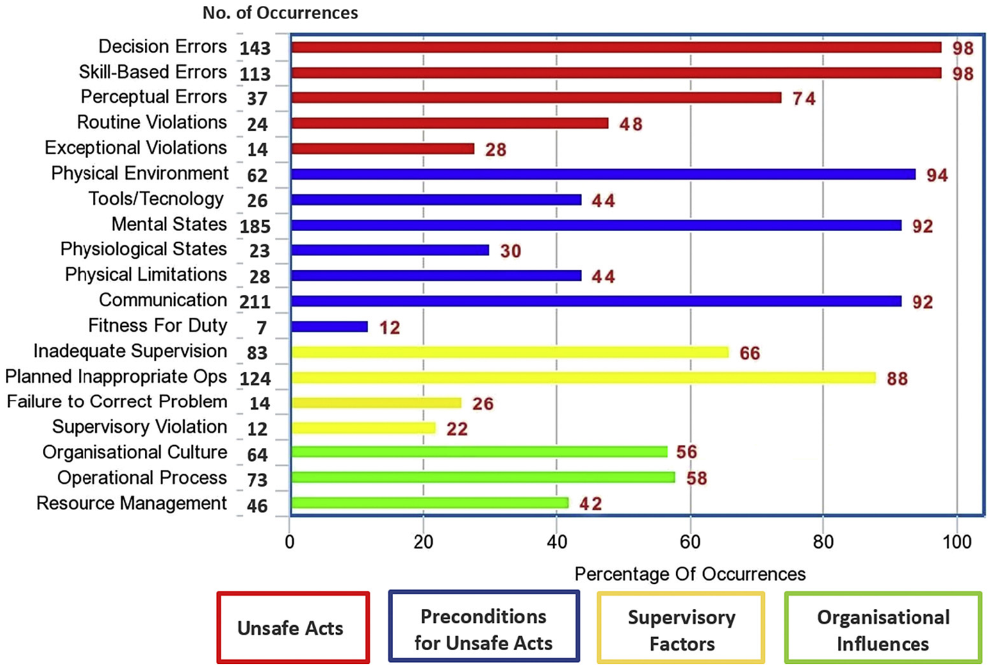

Fig. 2. HFACS occurrences.

Table 5
Identified complacency elements by flight category and captain experience.

Flight category type	Average captain experience (hours)	Percentage of complacency instances
Commercial	14,312	72%
Military	4500	62%
General aviation	2875	40%

the installation of GPS and terrain warning equipment as critical factors to the mitigation of CFIT occurrences while citing that financial cost of this equipment is the main barrier to installation.

The "Communication/Coordination and Planning" subcategory was identified as a major factor in CFIT accidents with 92% of reports analyzed containing at least one element. "Crew Leadership," "Cross-monitoring Performance," "Mission Planning," "Briefing," and "Mission in Progress Re-planning" were all highlighted as critical contributing HFACS nanocodes to this sub-category.

"Crew Leadership" was a factor in 56% of reports analyzed when, the leadership techniques failed to facilitate a proper crew climate. This included establishing and maintaining an accurate and shared understanding of the evolving mission and its requirements. A lack of this leadership was identified in many reports including report numbers 6, 13, and 49. This deficiency originated from several sources such as inexperience, task saturation, overconfidence, poor personal relationship, and distraction.

"Cross-monitoring Performance" is essential to achieve an efficiently operating flight crew. Despite this, "Cross-monitoring Performance" was identified as an issue in 62% of reports when crewmembers failed to monitor or assist in necessary cockpit actions and decisions. Thirty-two analyzed accident reports encountered cross-monitoring issues on entering cloud or at night where effective instrument monitoring was of the utmost importance in order to achieve safe flight conditions.

"Mission Planning" and "Briefing" by flight crews were identified as deficient in 72% and 60% of reports. Planning was a factor when information and instructions provided to crews was insufficient, or crews failed to discuss contingencies for strategies if required. For example, this occurred in report number 21 where, the inadequate pre-flight plan, unintentionally resulted in the incorrect flight level being filed with ATC for the cruise phase of flight. The aircraft then cruised at a lower, unsafe level, resulting in an impact with mountainous terrain. The air accident investigator interviewee highlighted the importance of proper planning, especially when utilising automated systems, with the last two CFIT occurrences in Ireland both containing planning deficiencies.

"Briefing" was determined to be closely related to planning when information and instructions provided to crews was insufficient or crews also failed to discuss strategies to handle contingencies. A lack of adequate briefing was highlighted in 60% of CFIT accident reports.

This pre-flight preparation is a proven method to provide awareness and readiness to the crew for the planned mission. More importantly, this procedure highlights any unexpected issues that may arise such as worse than expected weather, alternate airports, etc.

While a mission may have been appropriately briefed prior to departure, "Mission-in-Progress Re-planning" was noted with high occurrence of 81%. Crewmembers failed to adequately reassess changes in their dynamic environment during a mission and alter their mission plan accordingly in order to ensure the adequate management of risk was provided. This was often related to perceived pressures on the crew, mission fixation, and complacency.

4.1.3. Supervisory factors

Supervision is an important factor that applies influence higher in the error chain. Factors are viewed as decisions or policies of the chain of command that directly affect practices, conditions, or actions of a crew member. "Inadequate Supervision" and "Planned Inappropriate Operations" were identified as important sub-categories with 66% and 88% of reports respectively effected.

Inadequate supervision was a factor when supervision was inappropriate; failing to identify hazards, to recognize and control risk, to guide, train and oversee. "Leadership/Oversight Inadequate" and "Local Training Issue" were both identified as the main supervisory HFACS nanocodes encountered through these results.

"Leadership/Oversight Inadequate" was identified as a factor in 50% of reports. This included the availability, competency, and quality of supervision or oversight not meeting task demands and provided for an unsafe situation. This occurred mainly within smaller and military organizations, such as the small aerial survey company in report number 13. In this instance, supervisory staff were required to oversee multiple roles and neglected or overlooked certain supervisory aspects, such as appropriate flight crew fatigue management. This factor was identified throughout the commercial and military reports; however, most of general aviation reports were without a supervisory facility in place.

"Local Training Issues" occurred when re-current training programs, upgrade programs, and any other local training was provided inadequately or was unavailable to flight crews. It was evident in 40% of reports and in turn, created issues with proficiency, aircraft type currency, aircraft systems knowledge and appropriate experience. Training is a crucial element of efficient and safe flight situations that was found to be deficient in 20 CFIT accident reports analyzed.

The "Planned Inappropriate Operations" sub-category was evident in 88% of reports when, supervision failed to assess adequately the hazards associated with an operation and allowed for unnecessary risk. This was also a factor when supervision allowed non-proficient or inexperienced personnel to attempt missions beyond their capability as evident in report number 35. "Proficiency" and "Risk Assessment – Formal" were both identified as important reoccurring HFACS nanocode elements.

"Proficiency" was proven to be a factor in 63% of reports when a flight crew was not proficient in a task, mission or event. Analyzed CFIT accidents identified proficiency as a major contributing factor in 32 reports. This was evident where flight crews that were not trained appropriately for instrument flight, night operations, or marginal weather conditions.

"Risk Assessment – Formal" was a factor when supervision did not adequately evaluate the risks associated with a mission or risk assessment programs were inadequate. This was evident as the case in 58% of reports. Assessment of risk at a supervisory level was a necessary requirement to provide a barrier to unsafe flight conditions. In the events where this was not adequate, such as report numbers 50 and 41, crews were deployed together with low-levels of training and an inadequate assessment of weather prior to departure.

4.1.4. Organizational influences

Organizational factors were evident when the communications or policies of upper-level management directly affected supervisory practices of the operator and resulted in a system failure. Over half of the analyzed reports contained two organizational factors. "Organizational Culture" and "Operational Process" were both factors resulting in 56% and 58% occurrence rates, respectively. Organizational influences occurred in all sizes of organization and were affected by overall strategy and specific processes.

"Organizational Culture," as a sub-category factor, occurred when organizational variables including policies and culture influenced crew actions that resulted in unsafe flight parameters. Norwegian airlines as a group operate four different Air Operators Certificates (AOCs) across their four companies and experienced organizational culture issues due to the diversity of its location base. Scandinavians, Argentineans and Irish employees operate with differing cultural values. Norwegian aim to bring these cultural values together by defining a common aim for the Norwegian group as a whole.

With a 34% report occurrence rate, "Unit Culture" was identified as a nanocode element when actions or attitudes of unit leadership, defined a unit culture that allowed an unsafe environment to occur. For example, report 41 within a European military, it was noted that there were attitudes of mission completion pressures along with inappropriately experienced crews being matched together which ultimately ended in the loss of aircraft and all on board. These cultures can be endemic in an organization and difficult to change.

"Operational Process" was evident as a sub-category factor in 28 reports when, processes such as, operations and procedures negatively influenced individual performance and results. "Operations Workload," "Procedural Guidelines," and "Training Issues" were the main factors identified throughout the reports analyzed resulting in a 56% occurrence rate.

"Operations Workload" was identified as a factor in 26% of reports when, the pace of deployments, workload and additional duties created an unsafe situation. Crews that were over-tasked often suffered from stress and fatigue, which effected their efficiency and decision making as flight crew. Workload management was highlighted as an important element of aviation management.

"Procedural Guidelines" were factors when written direction, checklists, tables or charts were inadequate, misleading, or inappropriate. This was identified in 28% of CFIT analyzed accident reports. Flight crews expected these elements to be correct, however, many proved to be deficient in many areas and had a detrimental effect on flight safety. For example, report number 47, which occurred while on the final approach, was in part, due to flying the wrong approach, having been supplied with the incorrect approach charts.

4.2. Factors contributing to CFIT accidents

Visual and lighting conditions are an important factor in CFIT accidents. While 35 of the analyzed accidents occurred in Instrument Meteorological Conditions (IMC) while in cloud, the interviewees highlighted that 34 CFIT accidents occurred in daytime lighting conditions. On further analysis it was determined that in over 90% of CFIT accidents that occurred in daytime conditions, flight crews committed a skill-based error such as a procedural error, breakdown in visual scan, or error due to misperception.

In addition, pilot experience is a key element in CFIT accidents. By identifying 5000 flying hours as a considerable amount of experience from the reports analysis, 50% of Pilots Flying (PF) had less than 5000 h experience and 50% had a greater number of flying hours. This identifies the fact that CFIT occurs across a range of pilot experience. General aviation pilots involved in CFIT had low flight experience with 40% of general aviation analyzed reports having less than 1000 h compared to 82% of commercial pilots that had greater than 5000 h.

Matthews (1997) suggested that the approach phase in all aviation accounts for just 4% portion of a flight; however, it is responsible for 50% of all CFIT accidents. The present data support this statement along with IATA, as the approach phase occurrences were 48% and are aligned with previous IATA analysis conducted on CFIT commercial accidents (IATA, 2014). IATA identified CFIT occurring in 53% of analyzed accidents in the approach phase of flight. Airline interviewees have also identified the approach phase, as the phase of flight with most minor CFIT occurrences and CFIT risk factor. It is possible to determine from these data with regard to fixed wing aircraft, that the descent and approach stages of flight are the most at risk of CFIT.

An interesting result to note is that 44% of accidents occurred in cruise flight. During the "en route" phase, the flight crews' workload is at its lowest. Human factors play a major role in this phase of flight, as the aircraft is stabilized in safe flight. Distraction, complacency, and fatigue are all elements that flight crews may experience as contributors to CFIT during this phase of flight.

The introduction and installation of terrain warning equipment such as EGPWS and GPWS has been instrumental to the dramatic reduction in the rate of CFIT accidents since the 1970's. Nevertheless, a high percentage of general aviation aircraft had no terrain warning equipment installed, when compared with military and commercial aircraft. General aviation aircraft are primarily privately owned and operated. According to the interviewee from the Aviation Safety Council, this is as a result of the high cost of purchasing and installing such equipment which operators would need to personally fund and there is no international requirement to install the equipment like in commercial aviation (FAA, 2000). Wiegmann and Shappell (1996), in their HFACS analysis of CFIT General Aviation accidents, stated that the affordability of this equipment is a major issue in CFIT mitigation amongst the general aviation community.

5. Conclusions and recommendations

The controlled flight of a fully serviceable aircraft into terrain will always attract considerable attention. Due to the nature of CFIT, difficulties can be experienced when attempting to determine the root cause of such accidents. This research determined that human factors represent a major component of CFIT accidents. These human factors were broad in nature ranging from loss of situational awareness to intentional violation of procedures. The prevalent factors were decision- and skill-based errors along with communication, coordination, and planning issues.

The following recommendations are made to reduce the risk of common human factors across the various aviation flight categories and mitigate against CFIT in the future:

(1) Provision of specific CFIT awareness and prevention training: Operators should provide specific annual training on the risks of CFIT and actions on how to avoid a CFIT situation. Improving the situational awareness of pilots is a key aspect to this training. The general aviation community could benefit through further awareness from the national regulatory body with targeted awareness campaigns and safety training days. Training focusing on the awareness of adverse mental states is also important. Pilots, regardless of their level of experience, should be reminded that it is the safety of the aircraft and those on board that takes priority over a mission, requiring pilots to be reticent of changing conditions.

(2) Pilot Training – with focus on improved decision-making and revision of basic flight skills: With both sub-categories so prominent in over 90% of analyzed reports in this research, further training is required. Training pilots to be more conscious of the options available during a mission could greatly reduce the risk of tunnel vision and allow a safer course of action to be selected. Skill-based errors were also prominent, thus further revision of the correct scan technique for scanning cockpit instruments and following the correct documented procedures could aid in CFIT mitigation. Compliance with procedures and policies is a necessary requirement that can be trained and monitored for. The use of FDM to provide feedback for pilots on all flights conducted would be of great benefit, although the high cost involved is restrictive for smaller organizations and the general aviation community.

(3) Develop specific GPS routes for transiting high terrain areas: With the advent of Performance-Based Navigation (PBN), approaches/departures are currently being developed that provide for high accuracy and efficiency as aviation traffic volumes continue to increase. The provision of GPS routes through high terrain areas would allow aircraft to traverse an area safer than without. It is important to note that this may instil an over reliance on the automation of an aircraft and this would also require prior appropriate training.

(4) TAWS/GPWS Equipment Installation and appropriate equipment training: The evidence available from this analysis may be

suggestive that the installation of this equipment is a critical mitigation factor in the prevention of CFIT. Current systems provide excellent cautionary and warning information to prevent an impact with terrain or water. Commercial and military operators have identified its value with the general aviation sector lagging considerably behind While installation of the equipment is a key mitigation element, appropriate specific training on its usage should also be provided due to many of the analyzed CFIT accidents occurring with a terrain warning system installed.

(5) Specific CFIT Crew Resource Management (CRM) training: Most operators currently conduct CRM training annually, with its benefits widely recognized. A focus on the human factors involved with CFIT could greatly improve flight crew awareness on a regular basis. This type of training would greatly benefit the general aviation community, but this could prove difficult, as general aviation enthusiasts tend not to have the same appreciation of flight safety training as professional pilots. The air accident investigator interviewee and the interviewee from the general aviation safety council support this view and they acknowledge the poor reporting culture and safety awareness that exists in the general aviation community.

(6) Improve Organizational knowledge on the elements involved in CFIT: Appropriate oversight and leadership were identified as issues in a large number of accidents. National aviation regulatory authorities could improve an organization's knowledge of the issues that may result in a CFIT occurrence. When provided with sufficient knowledge, it is at the organizational level that further training can be implemented and acknowledged. Supervision could then be improved which would mitigate further against the risk of CFIT.

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