IATA

CFIT – Controlled Flight into Terrain

A Study of Terrain Awareness Warning System Capability and Human Factors in CFIT Accidents 2005-2014

1st Edition

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Acronyms

AAL	Above Airport Level
ACTF	Accident Classification Task Force
AGL	Above Ground Level
ALAR	Approach and Landing Accident Reduction
AMDB	Airport Mapping Database
ANSP	Air Navigation Service Provider
APV	Approach Procedures with Vertical Guidance
ATC	Air Traffic Control
ATSU	Air Traffic Services Unit
CFIT	Controlled Flight into Terrain
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
DH	Decision Height
EAFDM	European Authorities coordination group on Flight Data Monitoring
EFB	Electronic Flight Bag
EGPWS	Enhanced Ground Proximity Warning Systems
ELISE	Exact Landing Interference Simulation Environment
FAF	Final Approach Fix
FDA	Flight Data Analysis
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FMS	Flight Management System
FOBN	Flight Operations Briefing Notes
FOQA	Flight Operations Quality Assurance
FSF	Flight Safety Foundation
GADM	Global Aviation Data Management
GPWS	Ground Proximity Warning System
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMC	Instrument Metrological Conditions
IOSA	IATA Operational Safety Audit

LOC-I	Loss of Control Inflight
MDA	Minimum Descent Altitude
OEM	Original Equipment Manufacturer
OM	Outer Marker
PBN	Performance Based Navigation
PF	Pilot Flying
PM	Pilot Monitoring
PNF	Pilot not flying
PANS OPS	Procedures for Air Navigation Services — Aircraft Operations
ROPS	Runway Overrun Prevention System
SAAFER	Situational Awareness & Alerting For Excursion Reduction
SMS	Safety Management System
SOP	Standard Operating Procedure
TAWS	Terrain Awareness and Warning System
TOD	Top-of-Descent
VMC	Visual Metrological Conditions

Abstract

The IATA Accident Database shows that CFIT is not the most frequent of accident categories. However, the poor survivability of these accidents, means that CFIT accounts for a substantial number of fatalities: a total of 1,346 from 67 CFIT accidents during this period (2005-2014). A CFIT accident during this period meant that hull loss was experienced 99% of the time and fatalities occurred in 88% of those accidents. Therefore, this report was commissioned to see if there are commonalities with these accidents and if lessons could be learned from the findings.

The study finds that, where fitted, the GPWS/EGPWS performed as designed but not always in a manner that could have prevented the accident. Poor pilot response was found to contribute to the CFIT accidents with a functioning terrain warning system. In these cases, the system provided adequate time to react to a hazard, but the flight crew delayed their response or made an inadequate avoidance maneuver.

Multiple human performance deficiencies and undesirable behaviors were indicated in all accidents under review and these constituted by far the largest group of factors in the accident set. Situational Awareness was found to be deficient in all cases, which is to be expected. Poor crew resource management and sub-optimal interaction between the pilots was also a frequent contributing factor, as was procedural non-compliance.

The objective of this study is to create recommendations for industry that can help mitigate CFIT accidents. A total of sixteen recommendations have been made.

Full analysis follows.

Introduction

Throughout the history of aviation, controlled flight into terrain (CFIT) has been a major cause of fatal accidents. In response to this concern, the aviation industry developed the ground proximity warning systems (GPWS), which warned pilots if the aircraft was in proximity to terrain. This system became a mandatory installation for large aircraft in 1974 and it is evident that since then, the number of CFIT accidents has reduced significantly.

Although GPWS was very successful, it was limited in that it was only able to detect terrain directly below the aircraft. If there is a sharp change in terrain, GPWS does not detect the aircraft closure rate until it is too late for evasive action. To overcome this limitation, a more advanced technology, known as Enhanced Ground Proximity Warning (EGPWS) was introduced. This technology combines a worldwide digital terrain database with an accurate navigation system, ideally using the Global Positioning System. The aircraft's position is compared with a database of the Earth's terrain; if there is a discrepancy, pilots receive a timely caution or warning of terrain hazards. This enhanced system provides a warning in advance of steeply rising ground and also extends the warning area almost to the runway threshold, overcoming the limitations of GPWS. The EGPWS is also widely known as Terrain Awareness Warning System or TAWS. EGPWS/TAWS systems are a critical component during low visibility operations and during approach and landing.

The IATA Accident Database shows that while CFIT is not the most frequent of accident categories, the poor survivability of CFIT accidents means that it continues to account for a substantial number of fatalities – a total of 1,346 from 67 CFIT accidents during this period 2005-2014. This equates to 88% of CFIT accidents incurring fatalities. Therefore, this report was commissioned to see if there are commonalities with these accidents and if lessons could be learned from the findings.

A limiting factor for this study, was the number of accidents that had sufficiently detailed reports (in English) to support comprehensive study. In total, nine (9) CFIT accidents were selected for analysis. Both jet and turboprop transport airplanes were included. The desire was to understand if there are identifiable human factors issues within these accidents and, as a secondary investigation, the effects of degraded GPWS /EGPWS/TAWS (if any).

Each accident report was analyzed for evidence of the functioning of the terrain warning system (if installed), to determine whether it operated as designed. Further analysis attempted to determine what role the system software standard, accuracy of the terrain and runway databases, or the absence of GPS position information and geometric altitude, played in the genesis of the accidents.

The reports were also analyzed for contributory human performance factors and two separate models were used to categorize these factors. The first model is the Dupont Human Factors model, which identifies 12 separate precursors. The second model is the ICAO Pilot Competencies Model, an example of which is given in ICAO Manual of Evidence-based Training. The analysis examines deficiencies in these competencies, as recorded in the accident reports.

Full analysis details can be found in the section "Consolidated Human Performance Analysis" below.

Multiple human performance deficiencies and undesirable behaviors were indicated in all of the accidents and these constituted by far the largest group of factors in the accident set. Situational Awareness was found to be deficient in all cases but this should hardly be a surprise. Poor crew resource management and sub-optimal interaction between the pilots was also a frequent contributing factor, as was procedural non-compliance. Because of the limitations of the data source it is likely that some human conditions have not been identified in every accident, including for example stress, fatigue and complacency.

Airline processes and regulatory oversight are not the main focus of this document. For the purpose of this report, the acronym TAWS is considered as identical to EGPWS and both terms appear interchangeably. The recommendations from this study may be found at the end of this report.

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Section 1—Terrain Awareness Technology Survey (Appendix A)

CFIT mitigations primarily rely upon terrain awareness technologies, such as GPWS/EGPWS. The latest iterations of these technologies provide pilots with real-time terrain information, not only below the aircraft but all around it with Enhanced Ground Proximity Warning System (EGPWS). This enhanced equipment has a forward looking terrain awareness function and is available for most aircraft types. GPWS has been mandated by ICAO standards (Annex 6 Part 1). In order for these systems to be most effective, it is essential that the accompanying software is up-to-date.

IATA created a survey to assess the use of available terrain warning technologies and how frequently the software/database is updated. This survey, which included 14 mandatory questions, was sent to IATA member airlines. Between January and May 2016, 157 airlines had responded. Appendix A presents the analysis of the survey responses.

Section 2—Definitions

2.1 Terrain Awareness and Warning System (TAWS)

A terrain awareness and warning system (TAWS) aims to prevent controlled flight into terrain (CFIT) accidents. The actual systems in current use are known as ground proximity warning (GPWS) system and enhanced ground proximity warning (EGPWS). Strictly speaking, the term TAWS encompasses all systems which warn of terrain. However, the term TAWS is often used to refer to second-generation EGPWS systems as opposed to first generation GPWS systems.

For the purpose of this document, this usage (TAWS equals EGPWS) is employed.

2.2 Controlled Flight into Terrain

In-flight collision with terrain, water, or obstacle without indication of loss of control.

2.3 Accident

An occurrence associated with the operation of a manned aircraft, which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked and the primary propulsion system is shut down, in which:

1. A person is fatally or seriously injured as a result of:
    - Being in the aircraft, or
    - Direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
    - Direct exposure to jet blast,
2. The aircraft sustains damage or structural failure which:
    - Adversely affects the structural strength, performance or flight characteristics of the aircraft, and
    - Would normally require major repair or replacement of the affected component,

or

3. The aircraft is missing or is completely inaccessible.

2.4 Fatality

A passenger or crewmember who is killed or later dies from injuries resulting from an operational accident. Injured persons who die more than 30 days after the accident are excluded.

2.5 Data Source

This report is focused on the commercial air transport industry; it uses accident data from Global Aviation Data Management (GADM) accident database over the period of 2005-2014. Heavy use was made of the final reports produced by the relevant investigative body on each of the accidents. The data set for accident analysis only includes aircraft over 5,700 kg maximum take-off weight, which were engaged in commercial operations according to the IATA definition.

The final reports used in this analysis are as follows:

Table 0.1. Accidents used in this report

Accident Number	Date of Accident	GPWS/TAWS Issues?	HF Issues Identified
1	3 February 2005	Not Known	Not Known
2	7 May 2005	Yes (TAWS fitted)	Yes
3	3 May 2006	No	Yes
4	24 August 2008	Yes	Yes
5	12 May 2010	No	Yes
6	28 July 2010	No	Yes
7	20 August 2011	Yes (TAWS fitted)	Yes
8	13 April 2013	No	Yes
9	14 August 2013	No	Yes

Section 3—Trends

For purposes of comparison, 2015 saw an all-time low in CFIT accidents, with only one, well below the average for 2010 to 2014. Figure 0.1 below indicates the percentage of all CFIT accidents and the yearly rate over the past ten years.

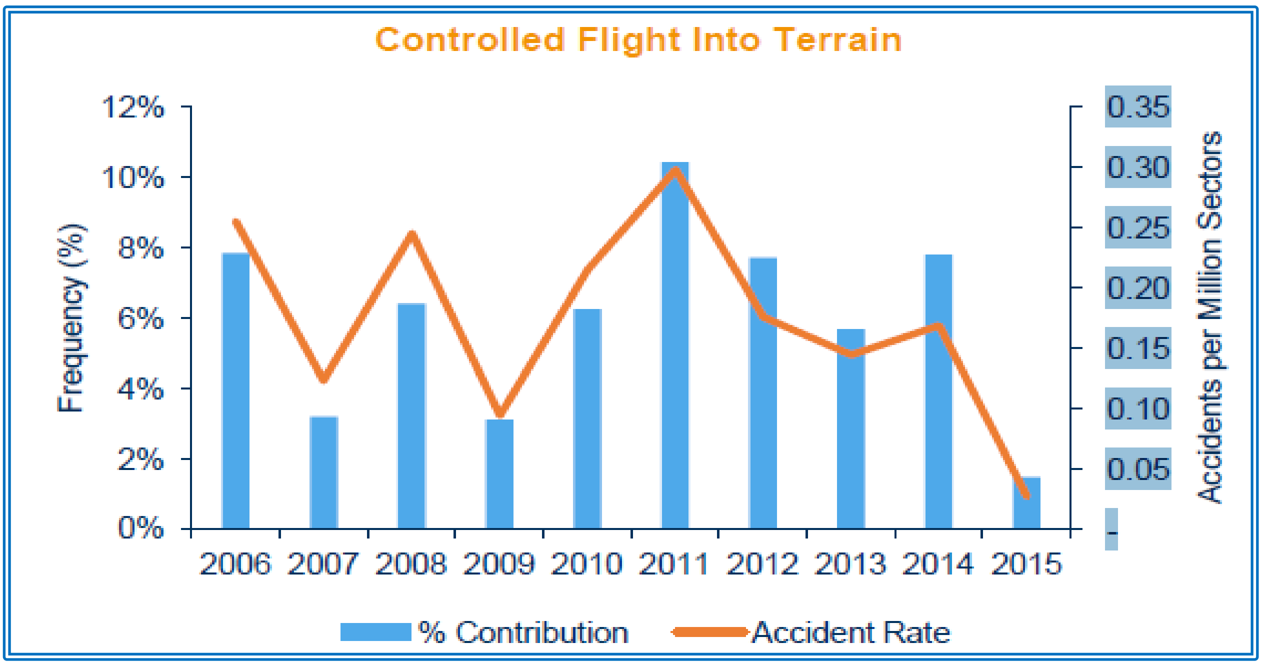


Figure 0.1. Distribution of CFIT accidents

While air travel remains one of the safest modes of transport, controlled flight into terrain (CFIT) continues to remain the second leading cause of commercial aircraft fatal accidents (loss of control in-flight being the leading cause).

The factors leading to CFIT events can be varied. They can include: loss of situational awareness, loss of terrain awareness, non-adherence to procedures, conduct of improvised approach procedures in instrument meteorological conditions (IMC) and operations in areas of low cloud base and/or poor visibility. IATA Accident database shows that there were 67 CFIT events involving commercial aircraft operators between 2005 and 2014. The report found that the approach phase accounted for 32 (47.7%), while landing accounted for 11 (16.4%) percent of these CFIT accidents.

Section 4—Why does CFIT occur?

It seems somewhat unbelievable that an aircraft capable of a safe flight can be flown into terrain, water, or obstacle while under the control of the pilot. While CFIT accidents are often the product of a chain of events, the investigation of these nine CFIT accidents has identified the following:

- CFIT can occur during most phases of flight, but is more common during the approach-and landing phase.
- Non-precision approaches were associated with CFIT accidents.
- Inappropriate action by the flight crew was cited as a contributing factor. This refers to the flight crew continuing descent below the minimum descent altitude (MDA) or decision height without adequate visual reference
- Lack of positional awareness, resulting in an accident.
- Failure in CRM (cross-check, communication, coordination, leadership etc.) was cited as a contributing factor.
- Pilots have either failed to respond or delayed their response to ground proximity warnings
- Non-adherence to Standard Operating Procedures (SOPs)
- The use of early Ground Proximity Warning System (GPWS) equipment

Overall, when compared with the total number of accidents recorded in the GADM accident database over the period, the likelihood of a CFIT accident occurring is very low. However, when CFIT accidents did occur, 99% resulted in hull loss and 88% incurred fatalities.

Section 5—Analysis of Accidents

The sections giving a precis of the events for each accident are extracted and summarized from the official accident reports. Some accidents are presented in more detail than others are; this generally reflects the scope, content and detail of the original reports. The analysis is similarly dependent on the available information. This study contains information, which was subjected to a careful process of de-identification.

Section 6—Human Factors Models

In order to categorize the findings of the study, it was considered appropriate to use two different human factors models, as follows:

6.1 Dupont Human Performance

The concept developed by Gordon Dupont, in 1993, formed part of a training program for human performance in aircraft maintenance. It identifies twelve common human error conditions that can act as precursors to accidents or incidents. The model has since become foundational for human factors training in maintenance, as exemplified in UK CAA CAP 715.

The model does not provide a comprehensive list of human errors. To gain an insight into the potential variety, see ICAO Circular 240-AN/144, which lists over 300 such precursors. However, the model is now used in many areas of aviation (not just maintenance), from ground service providers to air traffic controllers, as it is a very useful tool to introduce the key concepts of human error. The original list of precursors can be seen in many formats and is reproduced here:

Lack of communication; Lack of teamwork; Lack of knowledge; Lack of awareness; Lack of assertiveness; Lack of resources; Fatigue; Pressure; Complacency; Stress; Distraction and Norms

6.2 Pilot Competencies Model

The following list outlines a human factors model in use in the ICAO Procedures for Air Navigation Services - Training (PANS-TRG: 9868), in IATA's MPL Implementation guide and in the IATA Evidence Based Training Implementation guide:

Competency; Application of Procedures; Communication; Aircraft Flight Path Management, automation; Aircraft Flight Path Management, manual control; Leadership and Teamwork; Problem Solving and Decision Making; Situational Awareness; Workload Management.

As may be seen, there are some commonalities in the two models and these have been identified in the following charts, by color coding. Carrying out this exercise highlights that there are indeed fundamental differences in the approaches - hence the use of two models in the following analysis.

Table 0.2. Dupont Human Factors Model

Lack of communication	Lack of teamwork	Lack of knowledge
Lack of awareness	Lack of assertiveness	Lack of resources
Fatigue	Pressure	Complacency
Stress	Distraction	Norms

Table 0.3. ICAO Pilot Competencies Model

Application of Procedures	Identifies and applies procedures in accordance with published operating instructions and applicable regulations, using the appropriate knowledge.
Communication	Demonstrates effective oral, non-verbal and written communications, in normal and non-normal situations.
Aircraft Flight Path Management, automation	Controls the aircraft flight path through automation, including appropriate use of flight management system(s) and guidance.
Aircraft Flight Path Management, manual control	Controls the aircraft flight path through manual flight, including appropriate use of flight management system(s) and flight guidance systems.
Leadership and Teamwork	Demonstrates effective leadership and team working.
Problem Solving and Decision Making	Accurately identifies risks and resolves problems. Uses the appropriate decision-making processes.
Situational Awareness	Perceives and comprehends all of the relevant information available and anticipates what could happen that may affect the operation.
Workload Management	Manages available resources efficiently to prioritize and perform tasks in a timely manner under all circumstances.

Section 7—Accident number 1

7.1 Sequence of events

On February 3, 2005, a jet aircraft operating a scheduled passenger domestic flight was destroyed, when it impacted a mountain during descent. All 105 on board were killed. The flight crew were approaching the destination airport in extremely low visibility, during a snowstorm. The flight was normal until it failed to maintain flight level 130 during the VOR/DME approach (VHF omnidirectional range (VOR) and distance measuring equipment (DME)). The accident investigation report revealed that the aircraft did not proceed to the VOR as instructed by air traffic control (ATC) and descended below the minimum assigned altitude prior to being established on any segment of the approach. As a result, the aircraft collided with a mountain. The cause of descending below the assigned altitude could not be determined due to the non-availability of the flight data recorder (FDR) and Cockpit Voice Recorder (CVR) data read outs.

Although, ATC had cleared the aircraft to FL130 for VOR approach to runway 29 and instructed them to maintain VFR, it was reported that the aircraft did not adhere to the minimum altitude of the VOR/DME approach. The aircraft was in continuous descent until the time of impact, at about 9960 feet and had not leveled out at FL130, as required for that approach. There was no recorded sudden loss of altitude before collision of the aircraft with the mountain. The aircraft was evidently under control of the pilot until the time of the accident.

The airport as indicated in the investigation report had meteorological conditions compatible with Special VFR: visibility reported at the time of accident was two kilometers with snow and the ceiling was broken at 2,200 feet. The aircraft hit the mountain at approximately 9960 feet. Under the prevailing weather conditions it appears that the flight crew did not see the mountain in time to take appropriate action to clear it.

Table 1. Flight Rules

VFR	IFR
	Yes

Table 2. Light as a function of weather

	Day	Night
IMC	Yes	
VMC		

7.2 Terrain Avoidance and Warning System

The aircraft was equipped with Ground Proximity Warning System (GPWS) which should have provided warning to the flight crew while coming close to terrain. This would have been recorded on the CVR. Due to non-availability of CVR, it could not be confirmed if the warning occurred or what action the flight crew took.

Table 3. Terrain Warning Systems

	Fitted
TAWS	No
GPWS	Yes
GPS system	Not determined
GPWS warning given	Not determined (but likely)

7.3 Key Human Factors findings

This accident contains inadequate data and evidence due to the non-availability of the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) data. Therefore, no assessment of human factors can be made.

Section 8—Accident Number 2

8.1 Sequence of events

On May 7, 2005, a domestic scheduled passenger flight twin turboprop aircraft was being operated on an instrument flight rules (IFR). The aircraft impacted terrain on the north-western slope of a heavily timbered ridge, approximately 11 km north-west of the destination airport. At the time of the accident, the flight crew was conducting an area navigation global navigation satellite system (RNAV (GNSS)) non-precision approach to runway 12. The aircraft was destroyed by the impact forces and an intense, fuel-fed, post-impact fire. There were no survivors from the 13 passengers and two pilots.

It was reported that the maneuvering of the aircraft resulted in the aircraft departing from the descent path and not adhering to the descent points identified on the Jeppesen approach chart for a constant angle approach. However, it was not until the aircraft passed the final approach fix that it descended below the minimum safe altitude of 2,060 feet.

It was reported that the aircraft was fitted with ground proximity warning system (GPWS) technology. However, due to a lack of information from the cockpit voice recorder (CVR), the accident investigation was unable to determine if the GPWS functioned as designed.

Table 4. Flight Rules

VFR	IFR
	Yes

The accident investigation report identified a range of contributing safety factors relating to the flight crew of the aircraft, installation of the TAWS; airline's processes, regulatory oversight of the airline by the Civil Aviation Safety Authority, RNAV (GNSS) approach design and chart presentation.

8.2 Weather

At the time of the accident, the weather conditions would not permit aircraft to be operated under visual flight rules but only under instrument flight rules (IFR) in instrument meteorological conditions (IMC). The weather condition was described as overcast, with broken low cloud with a base between 500 and 1,000 ft. above mean sea level (AMSL). It was reported that the aircraft probably entered the low cloud at about 3,000 ft. and was in IMC for most of the final 90 seconds of flight. The aircraft impacted terrain at about 1,210 ft. As the cloud base was as low as 500 ft. at the time of the accident, then it is likely that the terrain below the aircraft would have been obscured by clouds.

Table 5. Light as a function of weather

	Day	Night
IMC	Yes	
VMC		

According to the accident investigation report, this CFIT accident would have been avoided if an Enhanced Ground Proximity Warning System (EGPWS), and not just GPWS, had been fitted. The aircraft was operated under the control of the flight crew and was flown unintentionally into terrain, probably with little or no prior awareness by the flight crew of the aircraft's proximity to terrain.

Table 6. Terrain Warning Systems

	Fitted
TAWS	No
GPWS	Yes
GPS system	Yes
GPWS warning given	Yes (probably) 25s before impact

8.3 Terrain Avoidance and Warning System

There was no evidence that the GPWS was not functioning as designed. Simulation by the GPWS manufacturer indicated that the flight crew should have received a one (1) second 'terrain terrain' alert about 25 seconds prior to impact, followed by a second 'terrain terrain' alert and a continuous 'pull up' warning for the final five (5) seconds of flight. However, research has shown that the alerts and warnings in the final five (5) seconds of flight would not have been sufficient for the flight crew and aircraft to effectively respond to the GPWS annunciations. A terrain awareness and warning system (TAWS) if fitted, would have provided advantages over the fitted GPWS. Enhanced situational awareness from colored terrain information on a continuous terrain display in the cockpit would have provided more timely alerts and warnings. Had the aircraft been fitted with EGPWS/TAWS, it is possible that the accident would not have occurred.

8.4 Key Human Factors findings

During the approach, the aircraft descended below the minimum safe altitude for the aircraft's position on the approach. The aircraft's high rate of descent, and the descent below the segment minimum safe altitude, were not detected and/or corrected by the flight crew before the aircraft collided with terrain. Neither pilot had received human factors management training.

While the investigation was complicated by an inoperative CVR, no witnesses, and the extent of destruction of the aircraft, it was determined that the flight crew probably experienced a very high workload during the approach and probably lost situational awareness of the aircraft's position along the approach path.

Dupont HF model: Lack of Knowledge; Lack of Awareness; Pressure;

Pilot competencies model: Application of Procedures; Situational Awareness; Workload Management; Aircraft Flight Path Management (manual)

Table 7. Flight Crew Performance

Dupont	Pilot Competencies
Lack of Knowledge	Application of Procedures
Lack of awareness	Situational Awareness
Pressure	Workload Management;
	Aircraft Flight Path Management (manual)
	Leadership and Teamwork

Section 9—Accident Number 3

9.1 Sequence of events

On 2 May 2006, a jet aircraft was carrying out a scheduled international passenger flight at night, under instrument meteorological conditions (IMC) and crashed into the sea, while performing the approach. All 113 occupants on board were killed. As the aircraft was destroyed due to the impact and sank, it was impossible to determine the exact point of impact.

Pre-flight briefing of the crew was conducted on the day of departure under the guidance of the Captain and the crew passed the pre-flight medical examination. The crew's pre-flight rest period exceeded 24 hours but it was difficult to take adequate rest during the day before the night flight, due to circadian rhythms. No conversations recorded on the CVR the pilots mentioned that they had not got enough sleep.

The crew obtained the weather data for the takeoff, landing and alternate aerodromes, which met the requirements for IFR flights. The airplane takeoff weight and the center of gravity were within the FCOM limitations.

Takeoff, climb and cruise were uneventful. On first contact, the approach controller and the crew discussed the observed and forecast weather, and as a result the crew decided to return to departure airport. After the decision had been made, the crew again asked the controller for the latest weather and the controller replied that visibility was 3,600 meters and the cloud ceiling 170 meters. The crew then decided to continue the flight to destination airport.

The next communication with the approach controller was as the airplane was descending to an altitude of 3,600 m, tracked by arrival tower radar. The approach controller cleared further descent to 1,800 m and reported the weather at arrival airport, which was above the aerodrome minima. Then the crew was cleared for descent to 600 m on aerodrome QNH, before making the turn onto final. The crew reported gear down, on glideslope and ready for landing and were cleared for landing by the controller. However, about 30 seconds later, the controller advised the crew of the cloud ceiling at 100 m and instructed them to stop their descent, make a right turn and climb to 600 m. No further contact was made with the aircraft and shortly thereafter it impacted the sea and was destroyed.

The accident was classified as CFIT and the investigation found that during the execution of the climb maneuver the pilot flying made inappropriate nose-down pitch inputs. The resulting descent was not properly observed, reported or corrected by the monitoring pilot and there was no adequate response to the EGPWS warnings prior to impact.

Table 8. Flight Rules

VFR	IFR
	Yes

9.2 Weather

Before the accident, the weather conditions at the destination airport were unstable. At the time of the accident, meteorological conditions were extremely variable and did not correspond to the meteorological minima of the subject runway, due to a low cloud ceiling. The flight crew was informed of the weather changes by the air traffic controller (ATC) in a timely manner.

It is to be noted that the inaccuracies committed by the ATC while reporting the weather were not directly connected with the cause of the aircraft accident, but they influenced the initial decision of the flight crew to return to the departure airport.

The tower controller gave instruction to the flight crew to abort the descent and perform a right-hand climbing turn to 600 m. This instruction, which was given after the cloud ceiling decreased below the established minima for the runway, did not fully comply with the provisions of the controller's operational manual. However, the investigating authority concluded that it did not directly influence the outcome of the flight. According to the Aeronautical Information Publication (AIP) of the State, the controller had a right to refuse the landing. It should be noted that a number of AIP items contradict each other and are ambiguous.

Table 9. Light as a function of weather

	Day	Night
IMC		Yes
VMC		

9.3 Terrain Avoidance and Warning System

The aircraft was fitted with Enhanced Ground Proximity Warning System (EGPWS). It was reported that after the activation of the EGPWS warning, the two pilots made control inputs simultaneously. The take-over button was not pressed by either of the flight crew. The control inputs by the captain and the co-pilot, both in roll and pitch were not coordinated and made in opposite directions. The DUAL INPUT warning was not activated because of its lower priority compared to the EGPWS warning. Before the airplane collided with the water, the flight crew had almost completed retraction of the wing high-lift devices in several steps (the slats were still moving). Neither of the flight crew was monitoring the aircraft descent parameters or following the Flight Crew Operating Manual (FCOM) requirements for actions after EGPWS warning activation, as delineated in "Emergency Procedures" section of the Quick Reference Handbook (QRH).

Table 10. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	NK
GPWS warning given	Yes

9.4 Key Human Factors Findings

The information about weather changes below the established meteorological minima caused a negative overreaction by the flight crew. The emotional reaction of the flight crew to the ATC's information could have led to an increase in the psycho-emotional strain of the flight crew during the final stage of flight.

Along with the inadequate control inputs of the flight crew, the contributing factors to development of the abnormal situation into a catastrophic situation were also the lack of necessary monitoring of the aircraft descent parameters (pitch attitude, altitude, vertical speed) by the co-pilot and the absence of proper reaction by the flight crew to the EGPWS warning.

It was also reported that both pilots were tired and stressed, conditions which would have degraded their performance capabilities. The pilot flying disengaged the autopilot during the climb, probably because he believed it was not following his commands, and then made significant and sustained inappropriate control inputs in pitch, roll and yaw. This resulted in the aircraft entering a steep descent and accelerating rapidly, exceeding flap limit speeds and triggering the master warning. The pilot monitoring was aware of the speed excursion but apparently failed to observe the descent rate. He made some additional flight control inputs without informing the pilot flying. The EGPWS generated appropriate alerts and warnings prior to impact, but the aural warnings competed for attention with the continuous repetitive chime (CRC) of the master warning and a lengthy radio message from ATC. No adequate recovery was established in time to avoid the impact.

Dupont HF model: Lack of communication; Lack of resources (training); Lack of knowledge; Lack of awareness; Lack of teamwork; Distraction; Fatigue; Norms

Pilot competencies model: Application of procedures; Communication; Aircraft Flight Path Management (manual control); Situational Awareness; Workload Management; Leadership and Teamwork.

Table 11. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of communication	Application of Procedures
Lack of resources (training)	Communication
Lack of knowledge	Aircraft Flight Path Management (manual control)
Lack of awareness	Situational Awareness
Lack of teamwork	Leadership and Teamwork
Distraction	Workload Management
Fatigue	
Norms	

Section 10—Accident Number 4

10.1 Sequence of Events

On 24 August, 2008, a commercial jet aircraft was flying a scheduled passenger flight at night in visual meteorological conditions with a total of 90 occupants. The aircraft flew into terrain and was destroyed by fire and 64 of the 85 passengers on board died. Shortly after take-off, the flight crew reported that the cabin would not pressurize and they decided to return back to the departure airport. While they were descending for visual approach, about 10 km from the airport, radar contact with the airplane was lost. The airplane collided with the ground, was catastrophically damaged on impact and burnt.

The flight trajectory analysis showed that when the aircraft was turning left, the flight crew lost visual contact with both the runway and ground references. The flight crew failed to report this to ATC, nor make the decision to continue the flight using Instrument Flight Rules.

The pilot in command decided to make a visual straight-in approach, without taking into account the aircraft position with reference to the runway in terms of altitude, distance and descent profile. The flight crew did not follow the published instrument flight rules for visual approach. Performing flight in the visual maneuvering area the flight crew did not maintain the established minimum descent altitude required by the visual approach pattern.

Furthermore, the flight crew did not maintain the established minimum descent altitude before the final turn for the landing course, and lost visual contact with the runway and/or ground references. In addition, the flight crew did not exercise a missed approach from any point of the visual approach when they lost visual contact with the runway and/or ground references in accordance with the established IFR missed approach pattern.

Table 12. Flight Rules

VFR	IFR
	Yes

10.2 Weather

The weather was favorable for the flight at the departure airport and at the destination airport and did not impede flight operations.

Table 13. Light as a function of weather

	Day	Night
IMC		
VMC		Yes

10.3 Terrain Awareness Warning System

Terrain Awareness Warning System (TAWS) was installed on the aircraft and was functioning correctly. The turn back was performed in level flight (without descending). In this case there would be no triggering of the TAWS warning. The system activates if the aircraft descends with a certain vertical speed or if the level flight is over an elevating terrain. The elevation of the accident site is 10 m lower than the elevation of the airport.

Table 14. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	Yes
GPWS warning given	Yes

10.4 Key Human Factors Findings

The cause of the accident was loss of visual reference during a night time visual approach and descent below the minimum descent altitude (MDA). Numerous ground proximity alerts and warnings were ignored, prior to the impact.

A combination of the following factors contributed to the accident:

- Deviation from SOP and pilot flying/pilot monitoring (PF/PM) task sharing principles;
- Non-adherence to visual approach rules - failure to maintain visual contact with the runway and/or ground references and to follow prescribed procedures after visual contact was lost;
- Loss of altitude control during the visual approach;
- Non-adherence to procedures after the GPWS alerts and warnings activated;
- The flight crew lost visual contact with the runway and/ or its ground references and failed to inform ATC that visual contact with runway was lost.

Analysis of the flight crew's actions during the approach and their answers during subsequent interviews suggest that they were not properly trained for visual approaches. The pilot in command (PIC) elected to conduct a visual approach when an instrument approach was available, although the pressurization failure which led to the air return did not imply any need for haste. During the descent the PIC failed to recognize that there was insufficient distance in which to descend and slowdown in order to make a straight in approach. The pilots did not utilize the precision approach path indicator (PAPI) system to provide approach slope information.

Dupont HF model: Lack of knowledge; Lack of awareness; Lack of resources (training); Complacency; Norms

Pilot competencies model: Application of procedures; Aircraft Flight Path Management (automation); Aircraft Flight Path Management, manual control; Problem Solving & Decision Making; Situational Awareness.

Table 15. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of knowledge	Application of procedures
Lack of awareness	Aircraft Flight Path Management (automation)
Lack of resources (training)	Aircraft Flight Path Management (manual control)
Complacency	Problem Solving & Decision Making
Norms	Situational Awareness

Section 11—Accident Number 5

11.1 Sequence of Events

The subject jet aircraft was operating a scheduled international flight on May 12th 2010 to an airport which had no instrument landing system available. At this airport, the subject runway had non-precision VOR and NDB approaches available. However, according to a NOTAM in effect, the VOR signal may have been unreliable. Of the 104 passengers and crew on board, there was a sole survivor. During final approach towards runway 09, the flight crew initiated go-around and commenced the missed approach procedure with the knowledge and confirmation of the destination tower. During the missed approach phase, the aircraft responded to the flight crew's inputs, velocity and altitude increased above the minimum descent altitude (MDA), then the aircraft descended dramatically until it collided with the ground about 1200 meters from the threshold of the runway and 150 meters right of the runway center line. The impact and the subsequent post-impact fire caused complete destruction of the aircraft.

The cockpit voice recorder (CVR) indicated a general lack of adherence to procedures during the flight and ineffective communications between the pilots. There were apparent differences in expectations between the PF and PNF during the final approach, especially regarding the flight management modes engaged. Neither of the pilots recognized that the final descent was commenced too early and therefore the aircraft was consistently below the required approach slope. Poor communications were exacerbated by a non-operational radio call from another aircraft to the Captain shortly before MDA, which distracted him and inhibited communications at a critical phase of flight.

The EGPWS 'too low, terrain' alert prompted the Captain to command a go-around, which was duly initiated by the pilot flying but thereafter the procedures for go-around were not followed. The autopilot was disengaged and due to inadequate nose-up pitch input, the aircraft rapidly accelerated. The investigation concluded that this induced a somatogravic illusion of excessive rotation and the pilots both made large flight control inputs on their sidesticks. The Captain pressed the sidestick push button, thereby disabling the other sidestick, and applied significant nose-down inputs, in spite of numerous EGPWS alerts and warnings, until the aircraft struck the ground.

The investigation concluded that the accident resulted from

- The lack of a common action plan during the approach and a final approach continued below the MDA without required visual reference.
- The inappropriate application of flight control inputs during a go-around and on activation of TAWS warnings.
- The lack of monitoring and controlling of the flight path.

These events can be explained by the following factors:

- Limited CRM on approach that degraded further during the missed approach. This degradation was probably amplified by numerous radio communications during the final approach and the crew's state of fatigue,
- Aircraft control inputs typical of somatogravic perceptual illusions,
- Non adherence to the company operation manual, SOP and standard phraseology.

In addition, the investigation committee found the following as contributing factors to the accident:

- Weather conditions reported to the crew did not reflect the actual weather situation in the final approach.
- Inadequacy of training received by the crew.
- Radio frequency congestion due to use by both air and ground movements control.

11.2 Weather

The weather conditions reported to the flight crew did not reflect the actual weather situation at the time of the accident.

Table 16. Light as a function of weather

	Day	Night
IMC	Yes	
VMC		

11.3 Terrain Awareness and Warning System

TAWS performance was not a factor in this accident. The approach was continued below the Minimum Descent Altitude of 620 feet but the crew still did not have the runway in sight. At an altitude of 280 feet the GPWS sounded ('too low terrain'). The captain then instructed the co-pilot to execute a go-around, after which he informed the tower controller. The aircraft began to climb, reaching an altitude of 450 feet above ground level. The aircraft then nosed down, causing the captain to take priority over the flight controls and the aircraft was fully under the captain's control who applied a sharp nose down input. The captain did not verbally state that he was taking control. He applied both pitch-up and pitch-down inputs on his stick, until the airplane impacted the ground.

Table 17. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	NK
GPWS warning given	Yes

11.4 Key Human Factors findings

The sequence of events leading to the accident showed a lack of crew coordination, a lack of cross-checking and deviations from procedures. The investigation identified 'significant procedural drift' which impacted upon flight path management and flight strategy. The Captain as PNF did not monitor the flight path. For example, it is possible he was not aware of the selection of the glide path angle on the FCU before crossing TW locator. Similarly, the PF's callout "overhead TW" did not prompt the Captain to monitor the altitude, or detect that the aircraft was lower than specified in the procedure. During the go-around, he did not call out any deviations of flight parameters. This lack of monitoring may be explained by distraction from communication with the crew of another aircraft. The approach to a familiar airport may have also induced a degree of complacency, potentially exacerbated by fatigue following a long night flight after a daytime rest period. The element of surprise from the loss of visual references at MDA and the activation of the "TOO LOW TERRAIN" alert hampered the PNF in returning to the control loop during the missed approach. Overall, the management of tasks during the approach deteriorated very quickly.

The communication between the two crew members was limited from the initial approach onwards and as a result they no longer shared the same action plan. Inaccuracies in the terms used to define the approach strategy ('managed' or 'selected' guidance modes) were symptomatic of the loss of coordination. The radio communication from another aircraft also distracted the Captain and deprived the crew of the opportunity to restore coordination.

The Captain's callouts and answers to the co-pilot suggest that the activation of the "TOO LOW TERRAIN" warning had startled him. His actions did not correspond to what is required in such a situation. On several occasions the co-pilot had to urge the Captain to perform the tasks normally assigned to the PNF. The investigation found no evidence that the relief pilot made any intervention during the approach and concluded that he was probably looking outside.

The various flight modes available to the crew to perform the non-precision approach, combined with weak CRM and poor briefing, increased the risk of errors and misunderstanding.

Analysis of a previous flight operated by the same crew showed similarities to the accident flight, with an unstabilized approach and a loss of situational awareness during go-around. The investigation found that analysis of the earlier flight had not been performed before the crash and the crew had not been given the opportunity to review and learn from what happened.

The previous go-around and the accident flight revealed some apprehension on the part of PF with regard to the go-around maneuver, and possibly on the part of the Captain as well. In addition, during the go-around neither pilot made callouts in relation to deviation of flight parameters, indicative of inadequate monitoring. The approach was conducted with the autopilot engaged until the go-around was initiated on both flights but could not determine whether this behavior was specific to this crew or more generally adopted through training.

Dupont HF model: Lack of communication; Lack of teamwork; Lack of knowledge; Lack of awareness; Lack of assertiveness; Distraction; Fatigue; Complacency

Pilot competencies model: Application of procedures; Communication; Aircraft Flight Path Management (automation); Aircraft Flight Path Management (manual control); Leadership & Teamwork; Situational Awareness; Workload Management

Table 18. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of communication	Application of procedures
Lack of teamwork	Communication
Lack of knowledge	Aircraft Flight Path Management (automation)
Lack of awareness	Aircraft Flight Path Management (manual control)
Lack of assertiveness	Leadership & Teamwork
Distraction	Situational Awareness
Fatigue	Workload Management
Complacency	

Section 12—Accident number 6

12.1 Sequence of events

On 28 July 2010, a jet passenger aircraft was scheduled to fly a domestic sector at night. The aircraft was on approach to destination airport in poor weather conditions (monsoon rain and low visibility) when the airplane impacted a mountain about 10 nm north of the airport at a height of about 1000 feet above the city/airport. Air traffic controllers reportedly lost contact with the flight crew during its attempt to land in dense fog and heavy rain. This accident was categorized as CFIT and there were 152 fatalities reported.

The ILS to a circling approach was flown normally but the Captain twice requested for a right-hand downwind for runway 12, which was refused by ATC. The aircraft was levelled at 2,500 feet and continued on the localiser towards the airfield. The pilots eventually established visual contact with the runway, and ATC also had sight of the aircraft before it was turned to the right to join downwind for runway 12. At the same time the selected altitude was changed to 2,300 feet, contrary to SOP, which required the circling minima to be maintained until base leg. The Captain engaged NAV mode to follow the previously inserted waypoints, as opposed to using heading (HDG) mode as required by his procedures. The FO queried the Captain as to whether he was visual or not and the Captain abruptly replied that he was.

When 3.5 miles right of the runway the Captain selected the heading left to parallel the runway downwind but did not engage HDG mode, so the aircraft continued in NAV mode towards the selected waypoint. This took them close to a restricted area and ATC instructed a left turn. Shortly thereafter an EGPWS 'terrain ahead' alert activated and the FO pointed out terrain to the Captain, advising him to turn left. The Captain became 'jittery', displaying confusion, frustration and anxiety. He continued to turn the heading selector to the left but failed to engage HDG mode and therefore the aircraft did not respond. When he finally did engage HDG, the selected heading was to the right of the aircraft's actual heading and it began to turn right towards higher ground.

Further EGPWS alerts and warnings activated and the FO advised the need to pull up but did not take control or initiate the necessary recovery action. The Captain advanced the thrust and disengaged the autopilot but his subsequent actions appeared confused and contradictory and after a brief climb, the aircraft began to descend further. It impacted hills at approximately 2,800 feet QNH almost 10 miles north of the runway, heading northwest.

Table 19. Flight Rules

VFR	IFR
	Yes

12.2 Weather

The weather at the destination was cloudy and the wind favoured runway 12 for landing. On first contact with ATC, the flight crew was advised that they would be cleared for the ILS approach to runway 30, with visual circling to land on runway 12. The published visual circling minima for that particular aircraft was 2,510 feet on QNH. As pilot flying the Captain instructed the FO to insert waypoints into the FMS to create a left-hand downwind circuit for runway 12, contrary to the SOP for a visual circling approach.

Table 20. Light as a function of weather

	Day	Night
IMC		
VMC		Yes

12.3 Terrain Awareness and Warning System

The aircraft was equipped with an Enhanced Ground Proximity Warning System. A global terrain database with 100% coverage was installed and functional within the EGPWS. The captain did not respond to 21 EGPWS warnings related to approaching rising terrain and pull up.

Table 21. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	Yes
GPWS warning given	Yes

12.4 Key Human Factors findings

The investigation report identified the following human performance considerations:

- From the outset of the flight, the Captain quizzed the FO in a ‘harsh’ manner, which intimidated the FO and hindered effective communication and CRM thereafter.
- The Captain showed signs of anxiety, preoccupation, confusion and geographical disorientation in various phases of flight, especially after commencement of descent.
- The Captain descended below circling minima while tracking out to the downwind leg, contrary to the procedure which required him to maintain 2,510 feet.

- There was no appropriate response to the first ‘terrain ahead’ alert.
- During the last 70 seconds, there were multiple EGPWS alerts and warnings, including 15 ‘pull up’ warnings and several warnings from the FO, with no appropriate response; in fact the aircraft began to descend.
- The FO was clearly aware of the imminent danger but took no remedial action.

Dupont HF Model: Lack of Communication; Lack of Knowledge; Lack of Awareness; Lack of Teamwork; Lack of Assertiveness; Pressure; Stress.

Pilot competencies model: Application of procedures; Communication; Aircraft Flight Path Management (automation); Leadership & Teamwork; Situational Awareness; Workload Management.

Table 22. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of Communication	Application of procedures
Lack of Knowledge	Communication
Lack of Awareness	Aircraft Flight Path Management (automation)
Lack of Teamwork	Leadership & Teamwork
Lack of Assertiveness	Situational Awareness
Pressure	Workload Management
Stress	

Section 13—Accident number 7

13.1 Sequence of events

On 20 August 2011, the subject jet aircraft was operating a non-scheduled domestic flight with 4 crew members and 11 passengers on board. The approach to runway 35 was flown in daylight but with low cloud and drizzle in the vicinity. The aircraft struck a hill approximately one mile from the runway and was destroyed. Eight of the eleven passengers and all four crew members were killed.

The aircraft was destroyed by impact forces and a subsequent post-crash fire. The flight crew had initiated a go-around just two (2) seconds before impact. At this time, the flaps were set to position 40, the landing gear was down and locked, the speed was 157 knots and the final landing checklist was complete.

The Captain was the pilot flying (PF) and he and the dispatcher discussed the deteriorating weather conditions at Resolute Bay during the course of the flight. It was agreed that the flight should continue to destination. The aircraft's GPS navigation systems were programmed to intercept the inbound course to join the ILS/DME approach and ATC instructed the crew to report at 10 miles final. At 10 miles the crew began to configure for landing and speed was reduced.

Shortly thereafter the pilots engaged in a lengthy discussion about navigation of the aircraft, with the FO clearly uncomfortable with the indications. The Captain appeared to be confused by conflicting information and the FO continued to express his concern that aircraft was not on the desired track and that there was a hill to the right of the approach course. Eventually the FO stated his belief that the approach should be discontinued until they could resolve the navigation anomalies but the Captain replied that he intended to continue the approach. The FO acknowledged his decision and the discussion ended. However, as the aircraft passed 1,000 feet above touchdown the FO again made several statements with regard to the navigation and potential corrective actions.

30 seconds later the FO stated 'I don't like this' and immediately afterwards a GPWS 'sink rate' alert activated. The FO twice called 'go-around' as the GPWS annunciated 'minimums' and finally the Captain announced 'go-around thrust'. As the go-around was initiated the aircraft collided with terrain 1 mile to the east of the airfield. The investigation found that a significant compass error was present, which misled the Captain to believe that the aircraft was converging with the ILS localizer when in fact it was slowly diverging due to an undetected flight mode change.

Table 23. Flight Rules

VFR	IFR
	Yes

13.2 Weather

In the hours before the accident, the weather at the destination airport was variable, with fluctuations in visibility and cloud ceiling. Forty minutes before the accident, the visibility was ten (10) miles in light drizzle, with an overcast ceiling at 700 feet above ground level. A weather observation taken shortly after the accident, reported visibility of five miles in light drizzle and mist with an overcast ceiling of 300 feet.

Table 24. Light as a function of weather

	Day	Night
IMC	Yes	
VMC		

13.3 Terrain Awareness and Warning System

The aircraft was equipped with a ground proximity warning system (GPWS). This is an older generation GPWS based on 1970's technology. This system only provides warnings for terrain immediately below the aircraft. When the aircraft is configured for landing (as was the case in this accident) the tolerance limit for the safety warnings is desensitized to prevent nuisance warnings as the aircraft approaches the ground for landing. The first GPWS aural alert 'sink rate' was annunciated 4.1 seconds before impact. At 2.6 seconds before impact, the aural alert 'minimums' was annunciated.

The aircraft was scheduled to have EGPWS installed at the next major maintenance check. This generation of terrain awareness equipment provides an aural as well as visual warning of terrain in front of the aircraft. In this occurrence, the crew's situational awareness would have been enhanced had the aircraft been equipped with EGPWS.

Table 25. Terrain Warning Systems

	Fitted
TAWS	No
GPWS	Yes
GPS system	No
GPWS warning given	Yes

13.4 Key Human Factors findings

Shared situational awareness, communication, workload management, problem solving and decision making are all integral components of CRM. The crew did not successfully employ any of these practices, therefore their CRM was found to be ineffective. Investigation report findings included:

- Late initiation of descent led to the aircraft turning onto final approach 600 feet above the glideslope, thereby increasing the crew's workload.
- The mental models of the two pilots differed significantly during the approach, with the Captain believing the aircraft was converging with the localizer whereas the FO understood that it was not.
- The pilots did not maintain a shared situational awareness and did not effectively communicate their respective perception.
- The FO was task saturated and had less time and cognitive capacity to communicate his concerns.
- Due to attentional narrowing and task saturation, the Captain did not have a high level overview of the situation.
- SOP adaptations resulted in ineffective communications, increased workload and contributed to the breakdown of shared situational awareness.

Dupont HF Model: Lack of Awareness; Lack of Communication; Lack of Teamwork; Lack of Resources; Lack of Assertiveness; Pressure; Norms

Pilot competencies model: Application of Procedures; Communication; Aircraft Flight Path Management (automation); Leadership & Teamwork; Problem Solving & Decision Making; Situational Awareness; Workload Management.

Table 26. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of Awareness;	Application of Procedures
Lack of Communication	Communication
Lack of Teamwork	Aircraft Flight Path Management (automation)
Lack of Resources	Leadership & Teamwork
Lack of Assertiveness	Problem Solving & Decision Making
Pressure	Situational Awareness
Norms	Workload Management

Section 14—Accident number 8

14.1 Sequence of events

The aircraft was operating a scheduled domestic passenger flight with 2 pilots, 5 cabin crew and 101 passengers onboard. The FO was designated as pilot flying (PF) and the Captain as pilot monitoring. The flight was uneventful in climb, cruise and descent and joined the VOR/DME non-precision approach to runway 09, in cloud and rain.

Passing 1,300 feet, the aircraft was cleared to land and at 900 feet the Captain said that he had the approach lights in sight, whereas the FO did not. The approach was continued and following the altitude auto-callout ‘minimum’, the FO disengaged the autopilot - the minimum descent altitude for the approach was 465 feet. Passing 300 feet, the view from the cockpit reportedly went ‘totally dark’ and the CVR recorded the sound of heavy rain on the windscreens. At 150 feet the FO said that he could not see the runway and the Captain took over the controls. As the altitude auto-callout ‘twenty’ (20 feet radio altitude) annunciated, the Captain called for a go-around.

The aircraft impacted the sea surface and came to rest partially submerged on rocky coastline close to the airport perimeter. All on board survived although there were numerous injuries, 4 of them serious. The investigation concluded that the aircraft entered heavy rainfall from a thunderstorm on short final and lost virtually all visibility. The operator’s SOP stated that whenever visual reference was lost below MDA, a go-around should be initiated.

Table 27. Flight Rules

VFR	IFR
In use (against SOP)	Yes

Table 28. Light as a function of weather

	Day	Night
IMC	Yes	
VMC		

14.2 Terrain Avoidance and Warning System

The aircraft was equipped with EGPWS. However, examination of the flight data recorder (FDR) and CVR information indicated that no EGPWS warnings occurred during the accident sequence. Also, after further examination of the FDR data, it was indicated that the aircraft did not enter the EGPWS alert/warning envelope during the approach. The final approach phase of the flight profile was outside the envelope. Therefore, there was no EGPWS 'terrain' warning.

Table 29. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	No (not pertinent)
GPWS warning given	No

It was only when the EGPWS annunciated a 20 ft. height alert that the pilot in command called for a go-around but, just one second later, the aircraft impacted the water. The report indicates that the captain's go around decision came far too late.

14.3 Key Human Factors findings

The investigation identified a number of human performance factors:

- On final approach, the crew was faced with a high workload and in such circumstances good CRM and good situational awareness were required to identify and communicate any unsafe conditions. Although both pilots had undergone CRM training, their CRM was not effective in identifying and managing risks during this approach.
- During the last part of the approach neither of the pilots could see the runway and according the operator's procedures, this required an immediate go-around.
- Once the autopilot was disengaged, the rate of descent increased to more than 1,000 feet per minute. This was outside of the operator's stabilized approach criteria and required an immediate go-around.
- The go-around was initiated too late to be successful.

Dupont HF Model: Lack of Awareness; Lack of Communication; Lack of Teamwork; Lack of Assertiveness; complacency

Pilot competencies model: Application of Procedures; Communication; Aircraft Flight Path Management (manual control); Leadership & Teamwork; Problem Solving & Decision Making; Situational Awareness.

Table 30. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of Awareness	Application of Procedures
Lack of Communication	Communication
Lack of Teamwork	Aircraft Flight Path Management (manual control)
Lack of Assertiveness	Leadership & Teamwork
Complacency	Problem Solving & Decision Making
	Situational Awareness

Section 15—Accident number 9

15.1 Sequence of events

On August 14, 2013, a scheduled cargo flight crashed short of runway 18 during a localizer non-precision approach. The Captain and FO were fatally injured, and the airplane was destroyed by impact forces and post-crash fire. The flight was operating on an instrument flight rules flight plan, and night visual meteorological conditions (VMC) prevailed at the airport; variable instrument meteorological conditions with a variable ceiling were present north of the airport on the approach course at the time of the accident.

A notice to airmen (NOTAM) in effect at the time of the accident indicated that runway 06/24, the longest runway at the airport and the one with a precision approach, would be closed from 0400 to 0500 CDT. Because of the flight's scheduled arrival time only the shorter runway 18 with a non-precision approach was available to the crew. Forecast weather at arrival airport indicated that the low ceilings upon arrival required an alternate airport, but the dispatcher did not discuss the low ceilings, the single-approach option to the airport, or the reopening of runway 06/24 about 0500 with the flight crew. Further, during the flight, information about variable ceilings at the airport was not provided to the flight crew.

The captain was the pilot flying, and the first officer was the pilot monitoring. Before descent, while on a direct-to-arrival leg of the flight, the captain briefed the localizer runway 18 non-precision profile approach, and the first officer entered the approach into the airplane's flight management computer (FMC). The intended method of descent (a "profile approach") used a glidepath generated by the FMC to provide vertical path guidance to the crew during the descent from the final approach fix (FAF) to the decision altitude, as opposed to the step-down method ("dive and drive") that did not provide continuous vertical guidance. When flown as a profile approach, the localizer approach to runway 18 had a decision altitude of 1,200 ft. mean sea level (msl), which required the pilots to decide at that point to continue descending to the runway if the runway was in sight or execute a missed approach.

As the airplane neared the FAF, the air traffic controller cleared the flight for the localizer 18 approach. However, although the flight plan for the approach had already been entered in the FMC, the captain did not request and the first officer did not verify that the flight plan reflected only the approach fixes; therefore, the direct-to-arrival leg that had been set up during the flight from departure airport remained in the FMC. This caused a flight plan discontinuity message in the FMC flight plan, which rendered the glideslope generated for the profile approach meaningless. The controller then cleared the pilots to land on runway 18, and the first officer performed the Before Landing checklist. The airplane approached the FAF at an altitude of 2,500 ft. msl, which was 200 ft. higher than the published minimum crossing altitude of 2,300 ft.

Had the FMC been properly sequenced and the profile approach selected, the autopilot would have engaged the profile approach and the airplane would have begun a descent on the profile glidepath to the runway. This did not occur but neither pilot recognized that the flight plan was incorrect. Further, because of the meaningless FMC glidepath, the vertical deviation indicator (VDI), which is the primary source of vertical path correction information, would have been pegged at the top of its scale (a full-scale deflection), indicating the airplane was more than 200 ft. below the (meaningless) glidepath. Once again, neither pilot recognized the meaningless information even though they knew they were above, not below, the glideslope at the FAF. When the autopilot did not engage in profile mode, the captain changed the autopilot mode to vertical speed mode but did not brief the first officer of the mode change. Further, by selecting vertical speed mode, the approach essentially became a "dive and drive" approach. In a profile approach, a go-around is required upon arrival at the decision altitude (1,200 ft.) if the runway is not in sight; in a "dive-and-drive" approach, the pilot descends the airplane to the minimum descent altitude (also 1,200 ft. in the case of the localizer approach to runway 18) and levels off. Descent below the minimum descent altitude is not permitted until the runway is in sight and the aircraft can make a normal descent to the runway. A go-around is not required for a "dive and drive" approach until the airplane reaches the missed approach point at the minimum descent altitude and the runway is not in sight. Because the airplane was descending in vertical speed mode without valid vertical path guidance from the VDI, it became even more critical for the flight crew to monitor their altitude and level off at the minimum descent altitude.

About 7 seconds after completing the Before Landing checklist, the FO noticed that the Captain had switched to vertical speed mode; shortly thereafter, the Captain increased the vertical descent rate to 1,500 feet per minute (fpm). The FO made the required 1,000-ft. above-airport-elevation callout, and the captain noted that the decision altitude was 1,200 ft. msl but maintained the 1,500 fpm descent rate. Once the airplane descended below 1,000 ft. at a descent rate greater than 1,000 fpm, the approach would have violated the stabilized approach criteria defined in the flight operations manual and would have required a go-around. As the airplane descended to the MDA, the FO did not make the required callouts regarding approaching and reaching the MDA but the Captain did not arrest the descent.

At about 250 ft. above ground level, an enhanced ground proximity warning system (EGPWS) "sink rate" alert was triggered. The Captain began to adjust the vertical speed in accordance with trained procedure, and he reported the runway in sight about 3.5 seconds after the "sink rate" caution alert. The airplane continued to descend at a rate of about 1,000 fpm. The FO then confirmed that she also had the runway in sight. About 2 seconds after reporting the runway in sight, the Captain further reduced the commanded vertical speed, but the airplane was still descending rapidly on a trajectory that was about 1 nautical mile short of the runway. Neither pilot appeared to be aware of the airplane's altitude after the FO's 1,000-ft. callout. The cockpit voice recorder then recorded the sound of the airplane contacting trees followed by an EGPWS "too low terrain" alert.

The investigation determined that the probable cause of this accident was the flight crew's continuation of an unstabilized approach and their failure to monitor the aircraft's altitude during the approach, which led to an inadvertent descent below the MDA and subsequently into terrain.

According to the investigation report, contributing to the accident were:

(1) The flight crew's failure to properly configure and verify the flight management computer for the profile approach;

(2) The Captain's failure to communicate his intentions to the FO once it became apparent the vertical profile was not captured;

(3) the flight crew's expectation that they would break out of the clouds at 1,000 feet above ground level due to incomplete weather information;

(4) The FO's failure to make the required minimums callouts;

(5) The Captain's performance deficiencies likely due to factors including, but not limited to, fatigue, distraction, or confusion, consistent with performance deficiencies exhibited during training; and

(6) The FO's fatigue due to acute sleep loss resulting from her ineffective off-duty time management and circadian factors.

Table 31. Flight Rules

VFR	IFR
	Yes

15.2 Weather

Forecast weather at destination airport indicated that the low ceilings upon arrival required an alternate airport, but the dispatcher did not discuss the low ceilings, the single-approach option to the airport, or the closure of runway 06/24 with the flight crew. Furthermore, during the flight, information about variable ceilings at the airport was not provided to the flight crew. The investigation revealed that VMC was officially reported over the airport at the time of the accident.

Table 32. Light as a function of weather

	Day	Night
IMC		
VMC		Yes

15.3 Terrain Avoidance and Warning System

The aircraft was equipped with EGPWS, which provided two types of alerts: caution and warning. These alerts include "sink rate," "don't sink," "too low terrain," and "terrain ahead" alerts, among others. The warning alerts call attention to terrain or obstacles and also issue a command to the pilot; these alerts include the "pull up," "terrain, terrain, pull up," "terrain ahead, pull up," and "obstacle ahead, pull up" alerts.

It was reported that at about 250 ft. above ground level, an EGPWS "sink rate" alert was triggered. The Captain began to adjust the vertical speed in accordance with company procedure. The airplane continued to descend at a rate of about 1,000 fpm. The First Officer (FO) confirmed the runway in sight. About 2 seconds after this, the Captain further reduced the commanded vertical speed, but the airplane was still descending rapidly on a trajectory that was about 1 nautical mile short of the runway. Neither pilot appeared to be aware of the airplane's altitude after the FO's 1,000-ft. callout. The cockpit voice recorder then recorded the sound of the airplane contacting trees followed by an EGPWS "too low terrain" alert.

The investigation determined that a later version of the EGPWS software (than that used on the accident airplane) would have improved the terrain clearance floor alert envelope and provided earlier alerts. However, its effect on the outcome of this accident is unknown because it cannot be determined how aggressively the pilots would have responded to an earlier "too low terrain" alert.

An automated "minimums" and/or altitude above terrain alert would have potentially provided the flight crew with additional situational awareness upon their arrival at the minimum descent altitude and made them aware that their continued descent would take them below the minimum descent altitude.

Table 33. Terrain Warning Systems

	Fitted
TAWS	Yes
GPWS	N/A
GPS system	Not indicated
GPWS warning given	Yes

15.4 Key Human Factors findings

The investigation identified several areas in which communication was lacking, both before and during the flight, which played a role in the development of the accident scenario:

- Before departure, the dispatcher and the flight crew did not verbally communicate with each other concerning runway closure.
- The captain's failure to communicate his intentions to the first officer once it became apparent that the vertical profile was not captured;
- The first officer's failure to make the required minimums callouts;
- The captain's performance deficiencies likely due to factors including, but not limited to, fatigue, distraction and confusion
- The first officer's fatigue due to acute sleep loss resulting from ineffective off-duty time management and circadian factors.
- Errors were likely the result of confusion over why the profile did not engage, the captain's belief that the airplane was too high, and his lack of compliance with standard operating procedures.
- The captain's belief that they were high on the approach and his distraction from the captain's flying duties likely contributed to his failure to adequately monitor the approach.

The investigation determined that the probable cause of this accident was the flight crew's continuation of an unstabilized approach and their failure to monitor the aircraft's altitude during the approach, which led to an inadvertent descent below the minimum approach altitude and subsequently into terrain.

Dupont HF model: Lack of communication; Lack of teamwork; Lack of knowledge; Lack of awareness; Lack of Resources; Fatigue

Pilot competencies model: Application of procedures; Communication; Aircraft Flight Path Management (automation); Leadership & Teamwork; Situational Awareness.

Table 34. Human Performance issues/precursors

Dupont	Pilot Competencies
Lack of Communication	Application of Procedures
Lack of teamwork	Communication
Lack of Knowledge	Aircraft Flight Path Management (automation)
Lack of awareness	Leadership & Teamwork
Lack of Resources	Situational Awareness
Fatigue	

Section 16—Consolidated Analysis of EGPWS Information

The terrain awareness and warning capabilities of the aircraft involved in the foregoing accidents ranged from 1970's technology to the latest generation of EGPWS, and therefore the strengths and weaknesses of the systems exposed by the accidents were equally varied. Furthermore, the stated intention of the study to determine more detail regarding software standards, terrain and runway databases, GPS input and geometric altitude was largely frustrated by the absence of such information from the majority of accident investigation reports.

There was no evidence that GPWS/EGPWS on any of the accident aircraft malfunctioned or performed in any way other than as designed. This highlights one common inherent design weakness, more significant in GPWS logic but nevertheless a factor with EGPWS as well. Terrain alerting and warning functions are, of necessity, less protective in the very final segment of an approach. Clearly the ultimate goal of the approach is to make contact with the surface and therefore the systems must allow for that condition. GPWS achieves this by reducing the sensitivity of the Mode 2 terrain functions when the aircraft senses that it is in the landing configuration and EGPWS by creating a terrain clearance floor (TCF) which slopes down towards the surface in the vicinity of runways within the database. These features prevent nuisance warnings on every landing but in some cases prevent the systems from warning pilots in time to initiate an escape maneuver. This is illustrated in Accident 2, where it was reported that there would have been insufficient time for the flight crew and aircraft to effectively respond to the GPWS annunciations. Furthermore, in Accident 8, in which the aircraft impacted the sea close to the runway without ever penetrating the EGPWS alert or warning envelopes.

The issue of 'nuisance warnings' is also a significant factor for operators and pilots whose network requires them to operate under VFR in mountainous terrain. For them 'normal' operations may often take the aircraft into the alerting and warning envelopes of EGPWS or GPWS, without any breach of VFR or any unacceptable reduction in margins of safety (in terms relative to the demands of the operation). A proliferation of warnings when the aircraft is not in imminent danger of terrain contact is likely to lead pilots to either switch the systems off or to simply ignore the warnings – in both cases rendering the system effectively useless. The same is true of terrain awareness displays, whether associated with warnings or not, in that the displays will frequently be yellow or even red in close proximity to the aircraft during routine operations. Two separate accidents illustrate this factor, both operating in mountainous regions, the first with no terrain awareness system and the second with a simple display but no warning logic. The two accidents bear a disturbing similarity.

In one of the accidents, the investigators considered it possible that the Captain had experienced GPWS warnings on the same approach, when he previously flew it in VMC. This hypothesis was supported by subsequent evidence from other pilots who reported that they could not fly the approach without encountering warnings, even though ground contact was not an imminent risk. Once again, 'nuisance' warnings may have played a part in the genesis of a CFIT accident, by conditioning pilots to expect them. The design of approaches, especially modern GNSS approaches which can offer previously impossible instrument guidance to runways in challenging terrain, should always take account of the warning logic of the GPWS/TAWS equipment likely to be installed on the aircraft using them – and *vice versa*.

As part of the commissioned brief for this report, the following questions were posed for each accident under analysis:

- Which GPWS/EGPWS software version was in use?
- Were the terrain and runway databases updated?
- Was the GPS wired to EGPWS/EGPWS and enabled?
- Was the geometric altitude function activated?

The following table gives this information for each accident, where available:

Table 35. GPWS/EGPWS information

#	Software Version	Database Up to Date	GPS Wired and Enabled	Geometric Altitude Function Activated
1	NK	NK	NK	NK
2	Sundstrand MK VI Software version 024 TDB version 440 PACIFIC	N/A	N/A (GPWS fitted)	N/A (GPWS fitted)
3	N/A – no GPWS system fitted (not required)	N/A	N/A	N/A
4	TAWS/RMI SANDEL ST3400	Not recorded but not considered an issue (pilots did not follow protocols)	Not recorded but not considered an issue (pilots did not follow protocols)	Not recorded but not considered an issue (pilots did not follow protocols)
5	Not recorded but not considered an issue (pilots did not follow protocols)	Not recorded but not considered an issue (pilots did not follow protocols)	Not recorded but not considered an issue (pilots did not follow protocols)	Not recorded but not considered an issue (pilots did not follow protocols)
6	Honeywell 965-0976-003-206-206	Not recorded but not considered a factor (pilots did not follow protocols)	Not recorded but not considered a factor (pilots did not follow protocols)	Not recorded but not considered a factor (pilots did not follow protocols)

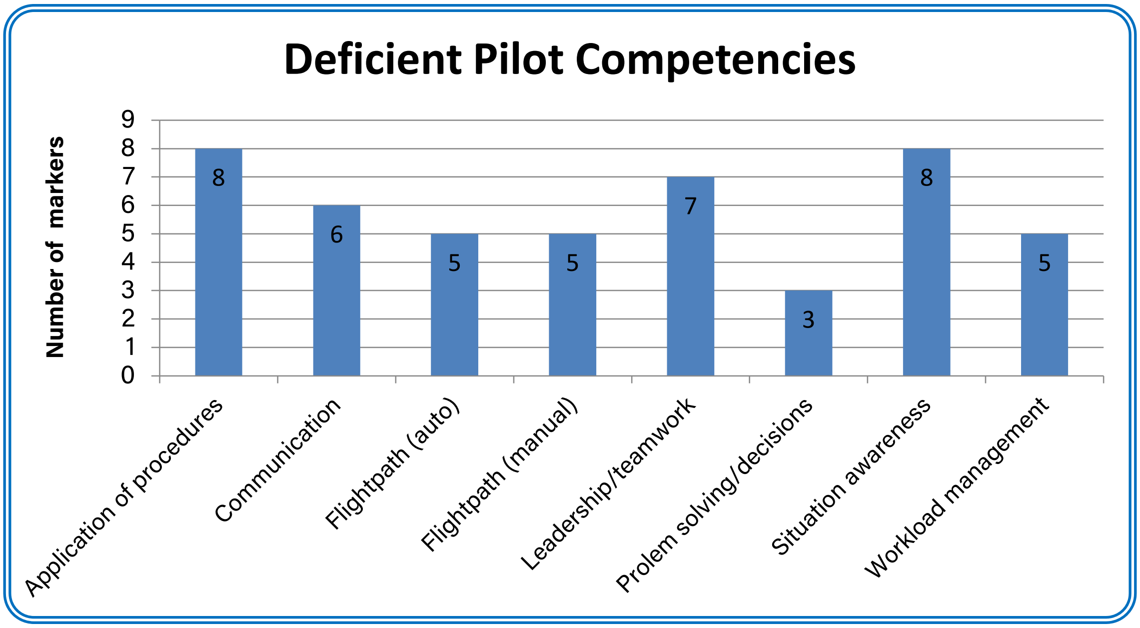
#	Software Version	Database Up to Date	GPS Wired and Enabled	Geometric Altitude Function Activated
7	Sundstrand Mk II GPWS Software not recorded	GPWS – no terrain database	GPWS	GPWS
8	Honeywell EGPWS 965-1690-055	Not recorded but aircraft did not enter warning envelope	Not recorded but aircraft did not enter warning envelope	Not recorded but aircraft did not enter warning envelope
9	965-0976-003-218-218 Not latest but not considered a factor as sink rate was too fast and even enhanced warnings would have been to compressed	No. "Although it cannot be said for certain that these upgrades would have prevented the crash… can say for certain that it would have provided the crew with a greater opportunity for avoiding the crash."	Due to nuisance alerts, no Mode 2 or terrain look-ahead alerts were generated	Yes

16.1 Consolidated Human Performance Analysis

Human performance deficiencies were identified in the investigations of all the accidents and human factors overwhelmingly dominated the lists of causes and contributory factors. The study set out to analyze these deficiencies against two separate models, Dupont and the Pilot Competencies, as described at the outset. All of the accidents had identifiable factors from both models; indeed some accidents appeared to include deficiencies in virtually all of the Pilot Competencies together with many of the Dupont precursors.

The graph below shows the number of accidents from the accidents, in which each of the markers from the Pilot Competencies Model was found to be deficient:

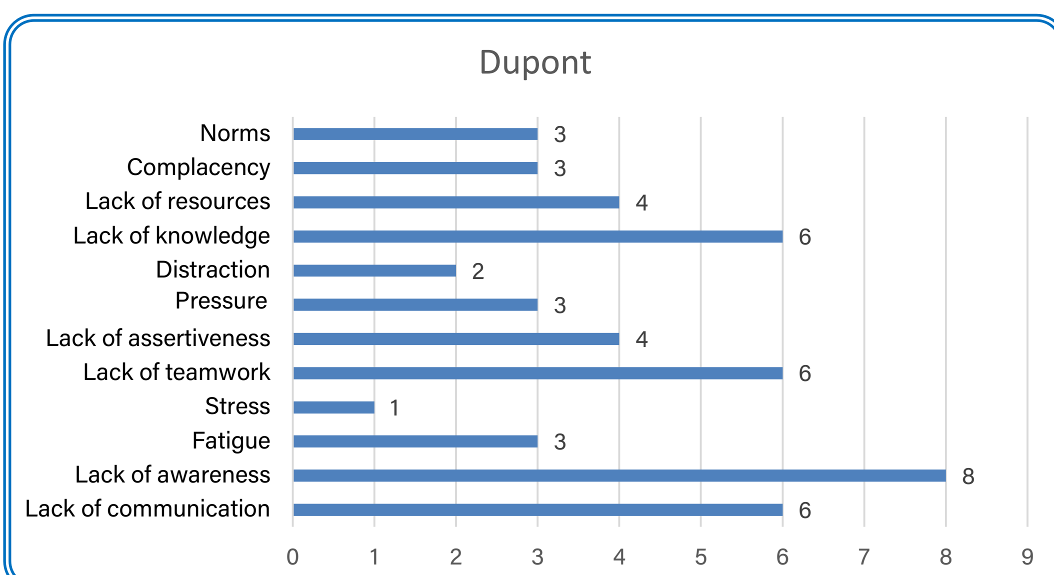
Chart 1 – Pilot competencies precursors



It is perhaps not surprising that the pilots in every accident exhibited deficient Situational Awareness: had they been more aware of the situation it seems likely that they would have taken more appropriate action to avoid terrain. It is disappointing to see that the pilots in all accidents were also deficient in the application of their procedures but on the other hand this may be encouraging, in that procedural compliance is possibly indicated as a significant factor in the mitigation of CFIT risk. Leadership and teamwork was also identified in most (7) of the accidents, supporting a view that CRM in general and communication in particular, are vital for the avoidance of CFIT.

The next graph illustrates the same information for the Dupont precursors:

Chart 2 – Dupont precursors

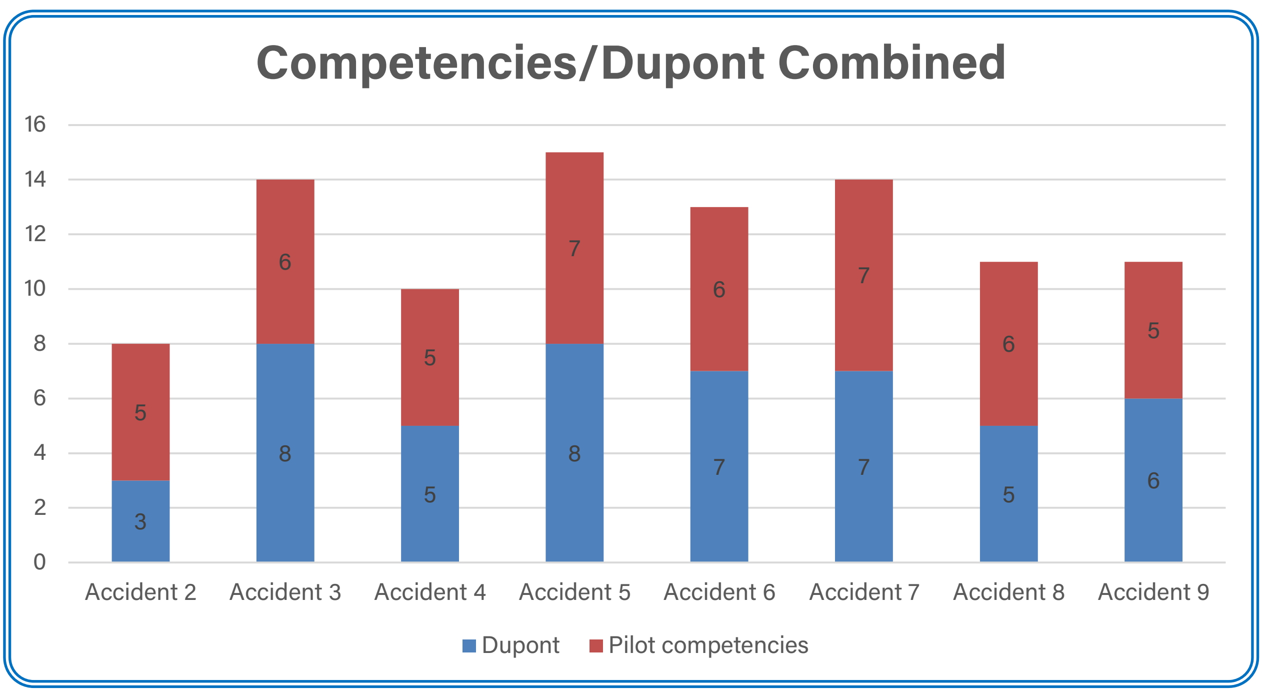


Once again Lack of *Awareness* tops the table, appearing in all of the accidents and reflecting the deficient Pilot Competency of *Situational Awareness*. There is no Dupont marker that corresponds to the Pilot Competency of *Application of Procedures* so we cannot see a correlation *but Lack of Communication* appears in 6 accidents. *Lack of knowledge* was reported in almost all accidents and is indicative of a paucity of training and various flying skills. *Lack of Teamwork, Lack of resources* and *Lack of Assertiveness* were identified in half of all accidents (4 each) and these two markers are in some ways related. If the Captain in particular is not a 'team player' and fails to respect colleagues and their opinions, the FO may become isolated and feel unable to intervene, even to save their own life. This risk is exacerbated by a steep authority gradient in the cockpit. Norms featured as a marker in 37% of the accidents, when pilots developed and employed their own processes, either when they found that the promulgated process was inefficient, ineffective or difficult, or when there was no applicable process for them to employ.

Stress, Pressure, Fatigue, Complacency and *Distraction* each appeared in 3 or fewer of the accidents but these conditions are sometimes difficult to identify from investigation reports. Unless the CVR records specific and attributable voice characteristics, or the individual mentions that they are affected by a condition, it may be that the condition goes unnoticed in the investigation.

If we look at the total number of human performance deficiencies in the precursors to each accident, we see a high number, as can be seen on the following chart.

Chart 3 – combined precursors



It is worthy of note that neither model specifically addresses markers for Monitoring and/or Cross-checking, although *Lack of Awareness* and *Situational Awareness* respectively could be taken to include those competencies. Deficiencies in monitoring and cross-checking were apparent in several of the accidents. It is precisely these functions, functions we know humans perform quite poorly, that the GPWS/EGPWS seeks to augment in CFIT prevention.

Accidents with a greater number of markers from one model also appear to have a similarly greater number from the other model – total markers per accident varied from 8 to 15 but the variation between models was never greater than 2. This may indicate that the two models identify similar human performance deficiencies but it may also be a reflection of the amount of information available from the accidents reports upon which the study was based. These varied from a few pages to well over one hundred.

Section 17—Consolidated Conclusions

The sample size of just 9 accidents is too small to produce any statistically meaningful conclusions in terms of mathematical trends but there are some unmistakable commonalities between the factors which contributed to each accident. These factors were analyzed using two separate human factors models and the results were very similar in the areas in which the models overlap.

1. There is no evidence that the GPWS/EGPWS fitted to any of the accident aircraft malfunctioned or functioned in a manner other than as it was designed.
2. The current forms of GPWS/EGPWS are not best suited to VFR operations in mountainous terrain due to the persistent proximity of terrain.
3. For 'normal' commercial transport operations the terrain awareness and warning capability of EGPWS is superior in CFIT prevention terms to the simple 'look down' functionality of GPWS, in that it provides a much earlier and more complete awareness of the terrain.
4. 'Nuisance' GPWS/EGPWS warnings can erode the benefits of the systems, either through the consequent need to desensitize the system's warning logic shortly before landing, or by conditioning pilots to expect and disregard alerts and warnings.
5. The design of approaches must take account of the prevailing warning logic of terrain awareness and warning systems to avoid 'nuisance' warnings.
6. Human performance deficiencies are identifiable in all of the CFIT accidents reviewed and constitute by far the largest contribution to the accident causes.
7. The two human performance models used produced similar results in many respects.
8. Lack of Awareness (Dupont) and Situational Awareness (Pilot Competencies) were identified as deficient in all of the accidents.
9. Some degree of procedural non-compliance (Application of Procedures), either intentional or inadvertent, was identified in all of the accidents – it is probably reasonable to conclude therefore that procedural compliance is a strong CFIT mitigating factor.
10. If confronted with a situation for which no procedure has been provided, or when the procedure is (rightly or wrongly) considered to be inappropriate, pilots may develop their own procedures, which risk becoming normalized into routine behavior (Norms).
11. Both models indicated that poor CRM, and especially poor communication, was a factor in many of the CFIT accidents reviewed.
12. The combination of a Captain with poor teamwork skills and an under-assertive FO is not conducive to good CRM and increases CFIT risk – in several accidents the FO was aware that terrain contact was imminent when the Captain apparently was not.
13. Monitoring and cross-checking are not specifically addressed by either of the models used but deficiencies in those functions are identified as factors in several of the CFIT accidents.

Section 18—Recommendations

Because this study focused on CFIT accidents its findings are related to the 'causes' and 'contributory factors' of CFIT; the 'what not to do' rather than the best practices. In order to identify those best practices in CFIT avoidance, it might be beneficial to study near-misses to determine what prevented them from becoming accidents, and to examine operators with a long operational history in challenging environments who have learnt how best to mitigate CFIT risk. It is therefore suggested that further investigation is carried out to review cases studies on near misses to identify errors and corrective actions. It may also be useful to work with industry to study and identify best practices.

In many cases aircraft equipment standards are dictated not by best practice but by regulation. It is recommended that states ensure that regulations require operators under their jurisdiction to install the most effective CFIT prevention technology on their aircraft, with due regard to the size and type of aircraft and the nature of the operating environment. This would need to be driven by legislation at ICAO.

It is clear from the foregoing analysis that poor CRM frequently contributed to CFIT accidents. It is recommended that states review the relevant regulations and assess the implementation of operator CRM programs, with due regard for the local operational and cultural influences, and offer assistance to operators with the design and delivery of CRM training.

CFIT near misses offer operators the opportunity to learn and develop appropriate mitigations prior to an accident, and the best medium for gathering this data is Flight Data Analysis (FDA). It is recommended that operators implement a comprehensive FDA program which specifically facilitates the detection and analysis of CFIT precursors, and to use the derived knowledge to develop mitigations and inform pilot training programs.

Situational awareness was found to be deficient in all of the accidents analyzed. It is recommended that operators increase training on maintaining situational awareness at all times, especially when close to the ground, and provide pilots with appropriate language and procedures to communicate, and respond to, positional concerns without delay.

Procedural non-compliance is a common factor in CFIT accidents. It is recommended that operators promote and enforce a culture of universal compliance with policies and procedures, unless unusual circumstances directly affecting safety dictates otherwise. Such situations also need to be trained.

Emergency checklists are essential tools that flight crews use to respond to serious and time-critical situations. The lists must be well designed and clear; and adherence to these lists must be trained.

SOPs for communication between pilots on approach frequently give no special authority for the pilot not flying to command a go-around, and this is of particular concern when the pilot not flying is the more junior crew member. It is recommended that operators devise and implement Policies to allow the "Emergency authority" for pilots not in command to take control in emergency situation should be encouraged and enforced.

'Nuisance' warnings have the potential to exacerbate CFIT risk for the reasons described above. It is recommended that system manufacturers review the warning logic to ensure that the frequency of nuisance warnings is minimized, without unduly compromising the systems terrain awareness and warning capabilities.

Most terrain awareness systems currently available are incompatible with VFR operations in mountainous terrain. It is recommended that system manufacturers work with such operators to develop systems and software which can more effectively protect their aircraft from CFIT risk.

'Nuisance' warnings can also be inherent in the design of approach procedures, especially those using satellite based guidance to provide instrument approaches in challenging terrain. It is recommended that air navigation services providers work with terrain awareness system manufacturers to ensure that airspace and approach design minimizes the risk of undue warnings.

However, it needs to be borne in mind that if the obstacles environment is already as challenging as to require an approach outside the standard parameters, adding constrains to the approach to avoid warnings, could increase the distance from standard approaches. This needs to be considered in the overall safety assessment.

In summary, the following recommendations are offered for consideration:

18.1 Recommendations from CFIT analysis

Recommendation 1: IATA to carry out or commission further investigation to review case studies on near misses, in order to identify errors and corrective actions.

Recommendation 2: IATA to work with industry to study and identify best practices.

Recommendation 3: IATA Operations to work with ICAO to explore enhanced legislation on the mandated use of CFIT preventive technologies.

Recommendation 4: Commission IATA Flight Operations Group to review current CRM training and implementation to explore potential enhancements

Recommendation 5: GADM to continue to actively promote FDA services and carry out analysis to identify CFIT precursors, which may feed into operators' training programs.

Recommendation 6: IATA to encourage operators to review training programs with regard to situational awareness and enhance where necessary.

Recommendation 7: IATA to encourage operators to review training programs with regard to non-compliance with SOPs, with emphasis on adherence to emergency checklists in all situations.

Recommendation 8: IATA to encourage operators to devise and implement procedures that allow PNF to easily and quickly initiate a go-around when circumstances dictate.

Recommendation 9: IATA to encourage TAWS system manufacturers to review warning logic to ensure that the frequency of nuisance warnings is minimized, without unduly compromising the system's capabilities.

Recommendation 10: IATA to encourage TAWS system manufacturers to develop systems and software which can more effectively protect aircraft from CFIT risk.

Recommendation 11: IATA Infrastructure to lobby air navigation services providers to work with TAWS manufacturers to ensure that airspace and approach design minimizes the risk of nuisance warnings.

18.2 Recommendations reproduced from survey analysis (Appendix A)

In appendix A, the results of the survey and associated analysis can be seen. For information, the recommendations from that analysis are as follows:

Recommendation A1: encourage operators to fit aircraft with systems capable of aircraft position reference connected to EGPWS/EGPWS

Recommendation A2: encourage operators to ensure that a single department has overall control and responsibility for the updating of terrain databases.

Recommendation A3: encourage operators to ensure that terrain databases are updated as and when issued by the EGPWS manufacturer (OEM).

Recommendation A4: encourage operators to ensure that there is a formal process for updating EGPWS software versions.

Recommendation A5: ask the NASIA regional office to urge operators in the region to ensure that there is a formal process for updating EGPWS software.

Recommendation A6: through the regional offices (and by distribution of this report) remind operators to have a formal process for updating EGPWS software.

Section 19—Appendix A

19.1 Executive summary

This analysis looks at the implementation of EGPWS technology and how GPS data is integrated into the system. The main findings are that, as expected, EGPWS is very important as a mitigation against CFIT accidents, that timely updating of terrain databases to be encouraged, that there should be a very clear process or procedure for updating and that there should be clear ownership of that process within each airline.

The recommendations are as follows:

Recommendation 1: encourage operators to fit aircraft with systems capable of aircraft position reference connected to EGPWS/EGPWS

Recommendation 2: encourage operators to ensure that a single department has overall control and responsibility for the updating of terrain databases.

Recommendation 3: encourage operators to ensure that terrain databases are updated as and when issued by the EGPWS manufacturer (OEM).

Recommendation 4: encourage operators to ensure that there is a formal process for updating EGPWS software versions.

Recommendation 5: ask the NASIA regional office to urge operators in the region to ensure that there is a formal process for updating EGPWS software.

Recommendation 6: through the regional offices (and by distribution of this report) remind operators to have a formal process for updating EGPWS software.

19.2 Terrain Awareness Technology Survey

The IATA 2015 Safety Report showed that CFIT was far from the most frequent of accident categories in the 10 year period from 2005–2015 but the poor survivability of CFIT accidents (18% of occupants) means that it continues to account for a substantial number of fatalities. During the time under review in the accompanying study to this appendix (2005 – 2014), there were a total of 1,346 fatalities as a result of the 67 CFIT accidents. The fatality rate was 88%.

CFIT mitigations primarily rely upon terrain awareness technologies, such as GPWS/EGPWS. The latest iterations of these technologies provide pilots with real-time terrain information, not only below the aircraft but all around it with Enhanced Ground Proximity Warning System (EGPWS). This enhanced equipment has a forward looking terrain awareness function, is available for most aircraft types. GPWS has been mandated by ICAO standards (Annex 6 Part 1). In order for these systems to be most effective, it is essential that the accompanying software is up-to-date.

IATA has designed a survey to assess the use of available terrain warning technologies and how frequently the software/database is updated. This survey, which included 14 mandatory questions, was sent to IATA member airlines. Between January and May 2016, 157 airlines had responded. This report presents the analysis of the survey responses.

Pleases refer to Appendix B to see the actual questions, as presented to the respondents.

19.3 Survey Summary

19.3.1 Question 1

Question 1 asked who completed the survey. The answers were as follows (percentage and actual number of respondents):

Avionics Engineer	47.1%	74
Engineering Management	25.5%	40
Other (please specify)	27.4%	43

In the "other" category, there were a total of 43 but 3 identified as avionic engineers with slightly different titles. The full breakdown is as follows:

Flight Operations	10
Maintenance Engineer	6
Pilot	13
Safety Manager	7
Technical Services Engineer	4
Technical Services Engineer (Avionics)	3
Total	43

The responses to this question give a broad view that various engineering departments are heavily involved in the maintenance and management of EGPWS as would be expected. If we take the total number of engineering related fields that responded, we see that 127 (80%) of the respondents are from engineering departments, with rest being made up as follows:

Flight Operations	10
Pilot	13
Safety Manager	7

19.3.2 Question 2

Question 2 was to collect name of the company and was designed to ensure that the region was correct and that any duplicates were identified. Survey participants were assured that confidentiality would be maintained, so analysis for this question was intentionally not carried out.

19.3.3 Question 3

This question identified the region where the carrier was based and produced the following results. Of the 157 total responses to this question, the distribution of the survey participants were as follows:

	Response Percent	Response Count
Africa (AFI)	8.9%	14
Asia Pacific (ASPAC)	28.7%	45
Commonwealth of Independence States (CIS)	2.5%	4
Europe (EUR)	27.4%	43
North America (NAM)	6.4%	10
North Asia (NASIA)	3.2%	5
Latin America and the Caribbean (LATAM)	12.1%	19
Middle East and North Africa (MENA)	10.8%	17
Total	**100%**	**157**

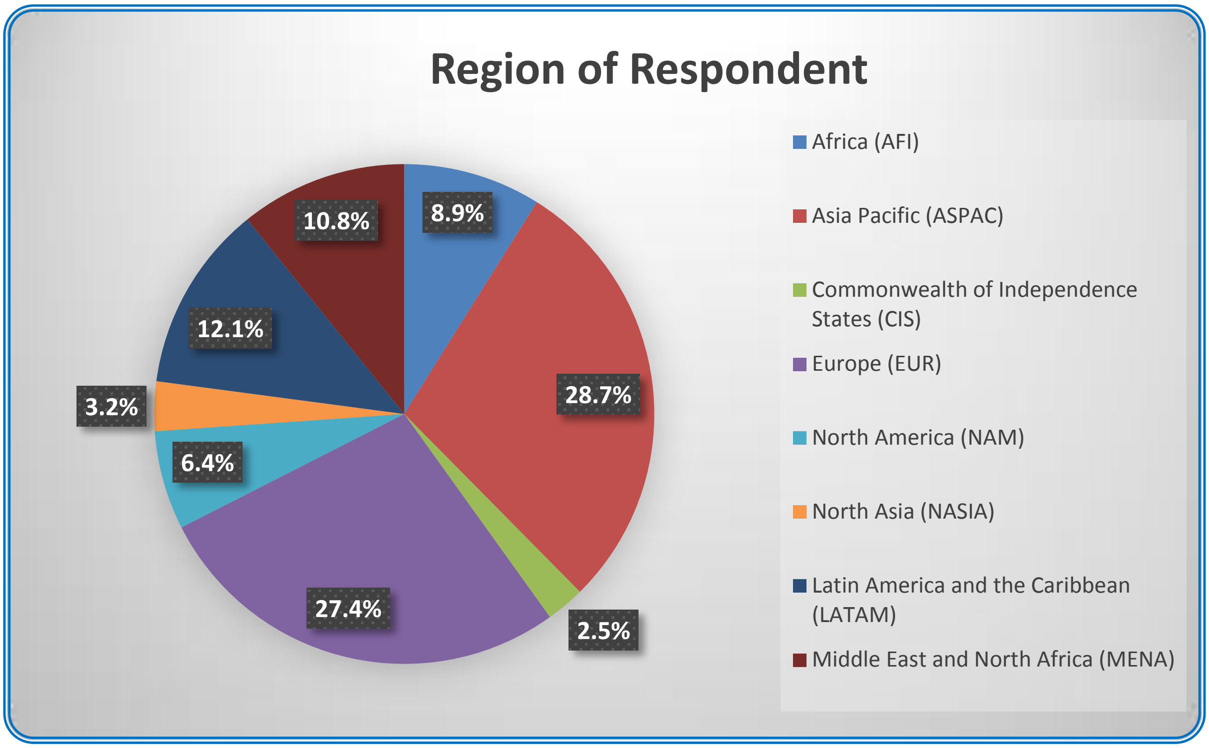
As can be seen, the highest response was from ASPAC with 45 responses (28.7%), followed by Europe with 43 responses (27.4%). It should be noted that this was an international survey but was conducted in English. Although the international language of aviation is English, there may be some reticence to work in English if it is a second (or third) language.

If we plot this against the global figures, for traffic, we can see how the response rates compare to the number of flights in each region. The results look like this:

	SURVEY Response	GLOBAL Traffic
Africa (AFI)	8.90%	3.38%
Asia Pacific (ASPAC)	28.70%	16.59%
Commonwealth of Independence States (CIS)	2.50%	3.22%
Europe (EUR)	27.40%	21.73%
North America (NAM)	6.40%	30.14%
North Asia (NASIA)	3.20%	11.60%
Latin America and the Caribbean (LATAM)	12.10%	8.75%
Middle East and North Africa (MENA)	10.80%	4.60%
Total	**100.00%**	**100.00%**

Again, as response rates were quite low, we do not see any correlation between regional traffic versus global traffic and response rates to questionnaire.

The data displayed graphically looks like this:



19.3.4 Question 4

To get an idea of the sort of operation, question 4 asked if the respondent was involved in long haul, or short haul. This question allowed the participants to check more than one answer and hence the numbers are higher than the number of survey respondents. The distribution of the 157 total respondents are as illustrated below:

	Response Percent	Response Count
Long Haul	56.7%	89
Short Haul	93.0%	146

This means that almost half (49.7%) operate both long and short haul routes.

19.3.5 Question 5

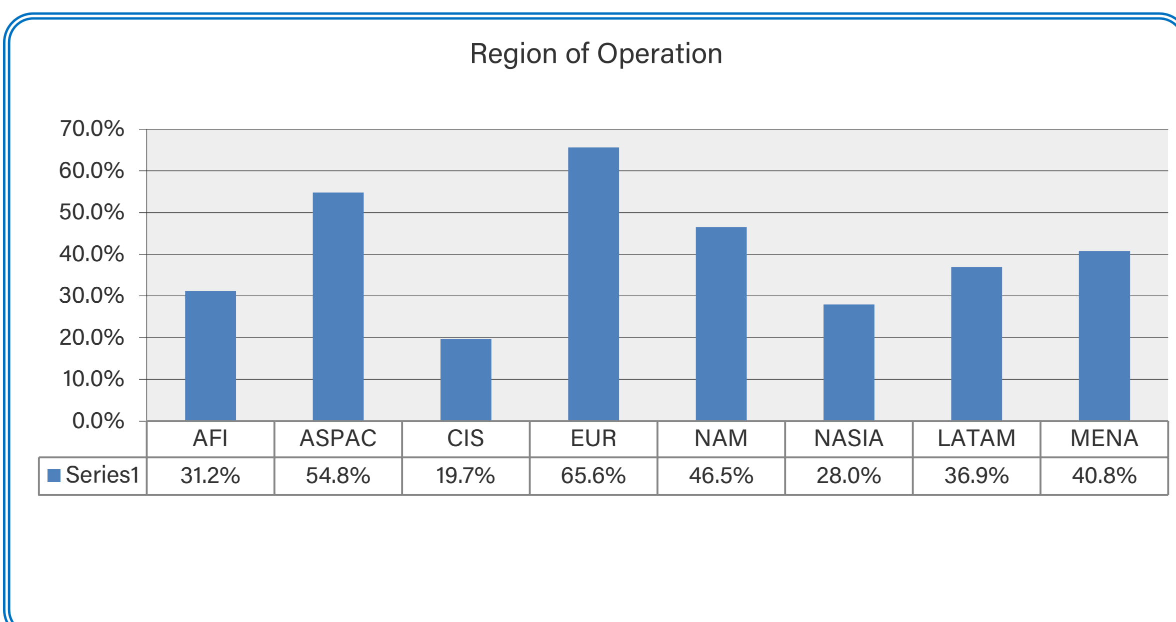
This question asked about the sphere of operations for the airline. The respondents were asked to record which geographical areas they operated into and to record all such areas. This question allowed the participants to check more than one answer and hence the numbers exceed the total number of survey responses, as seen below. It should be noted that the areas of choice were the IATA geographical areas, as follows:

Africa; Asia Pacific; Commonwealth of Independent States; Europe; North America; North Asia; Latin America and the Caribbean and the Middle East and North Africa.

The results of the 157 total respondents were as follows:

	Response Percent	Response Count
Africa (AFI)	31.2%	49
Asia Pacific (ASPAC)	54.8%	86
Commonwealth of Independent States (CIS)	19.7%	31
Europe (EUR)	65.6%	103
North America (NAM)	46.5%	73
North Asia (NASIA)	28.0%	44
Latin America and the Caribbean (LATAM)	36.9%	58
Middle East and North Africa (MENA)	40.8%	64

Given the totals seen above (508 regions from 157 respondents), it is clear that there are considerable overlaps, which one would expect from the international nature of modern airline operations. The largest incident of regional operations is Europe, with 65.6% of all polled airlines having operations there. This is followed by Asia Pacific (86 airlines; 54.8%), then North America (73 airlines; 46.5%). Represented graphically, the results are as follows:



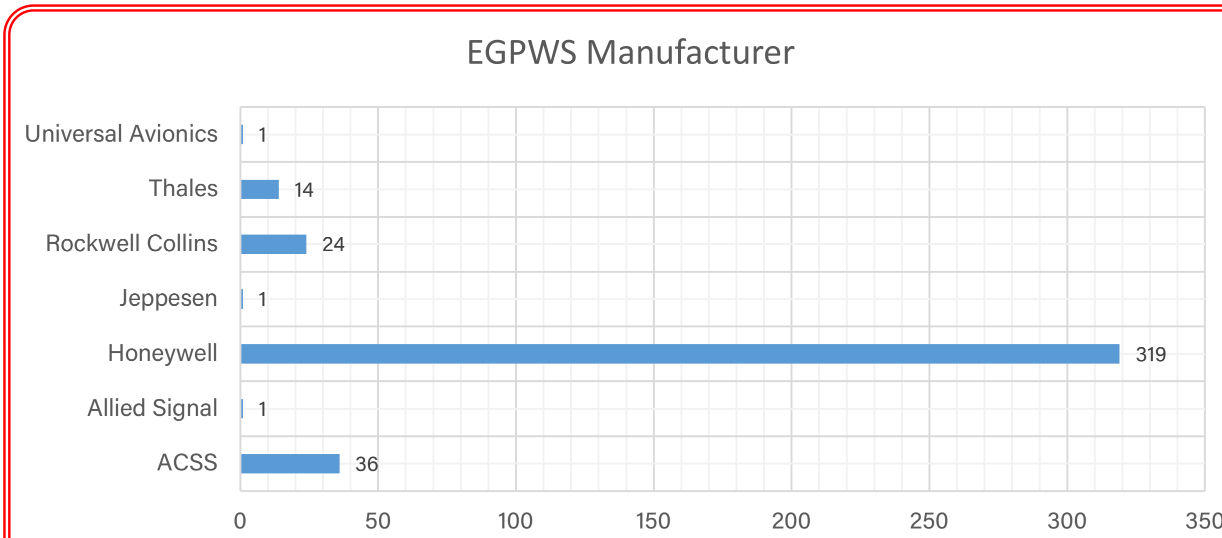
19.3.6 Question 6

Question six set about trying to establish the manufacturers of the EGPWS system and the aircraft types they were fitted to. Upon analysis, there was found to be no correlation or conclusions to be drawn from the equipment fitted or which airframe type it was fitted in. Therefore, the only analysis presented here is concerned with the distribution of equipment fitted.

Bearing in mind that there were 157 respondents and each had a mixed fleet, the total number of fleet types fitted was 396, with the break down as follows:

ACSS	9.1%	36
Allied Signal	0.3%	1
Honeywell	80.6%	319
Jeppesen	0.3%	1
Rockwell Collins	6.1%	24
Thales	3.5%	14
Universal Avionics	0.3%	1
		396

And graphically, we see it as follows:



	ACSS	Allied Signal	Honeywell	Jeppesen	Rockwell Collins	Thales	Universal Avionics
Series1	36	1	319	1	24	14	1

We can see that the biggest majority of equipment fitted across all aircraft types is Honeywell, with over 80 percent of the fleets fitted with this equipment. As there was no investigation into incidents or correlation with events, there are no conclusions to be drawn from this and this merely represents a snapshot of manufacturers. No conclusions are drawn or implied.

19.3.7 Question 7

This question asked for the model number of the equipment fitted and it was broken down by fleet. There is no meta-data from this question, so no analysis has been made. However, for those that are interested, the data collected may be may be viewed on request.

19.3.8 Question 8

This question asked for the software version of the equipment fitted and it was also broken down by fleet. The intention of this question was to prepare the respondents for the following questions on software updates and currency. Therefore, there is no meta-data from this question and no analysis has been made. However, for those that are interested, the data collected may be may be viewed on request.

19.3.9 Question 9

This question inquired whether or not the terrain warning system receive aircraft position reference directly from a GNSS receiver. As can be seen from the table below, the majority of respondents (over 75%) indicate that the system did indeed receive position reference. An analysis of the "Other" category, revealed a similar picture, with the majority either in the process of fitting GPS or having it embodied in another system. Examples of this are using the GPS vertical position in the EGPWC to compute a blended vertical position from all available sensors, EGPWC is fitted with internal GPS mercury card, The EGPWS receives GPS data via MMR to ADIRS (the GPS signal is not directly fed into the EGPWS) and the global position received from the MMR.

	Yes	No	Count
A310/A300	9	7	16
A320 Series	45	17	62
A330	32	12	44
A340	13	5	18
A350	7	2	9
A380	9	4	13
B707	1	0	1

	Yes	No	Count
B737 Series	40	14	54
B777	33	7	40
B787	16	3	19
B757	12	5	17
B767	19	5	24
B747 Classic	3	0	3
B744	14	0	14
B717	4	0	4
Bombardier C series	2	0	2
Embraer E170/E175/E190/E195	11	4	15
BAE 146	2	1	3
MD11	3	0	3
MD80	1	4	5
MD90	1	2	3
F70	2	1	3
F100	2	2	4
Bombardier CRJ Series	3	0	3
Bombardier Dash 7	0	0	0
Bombardier Dash 8	8	1	9
Embraer ERJ 135/145	1	1	2
ATR42	9	2	11
ATR72	19	6	25
	321 (75.3%)	105 (24.6%)	426

As can be seen, the majority (75.3%) of systems are using aircraft position reference. This is a positive trend, as EGPWS/TAWS combine with a worldwide digital terrain database and on-board computers compare current location with a database of terrain. The terrain display gives pilots a visual orientation to high and low points near the aircraft. Having a high rate of aircraft connected to GNSS is an improvement in safety. However, this rate can always be improved and this forms the first recommendation to come from this survey.

Recommendation 1: encourage operators to fit aircraft with systems capable of aircraft position reference connected to EGPWS/TAWS

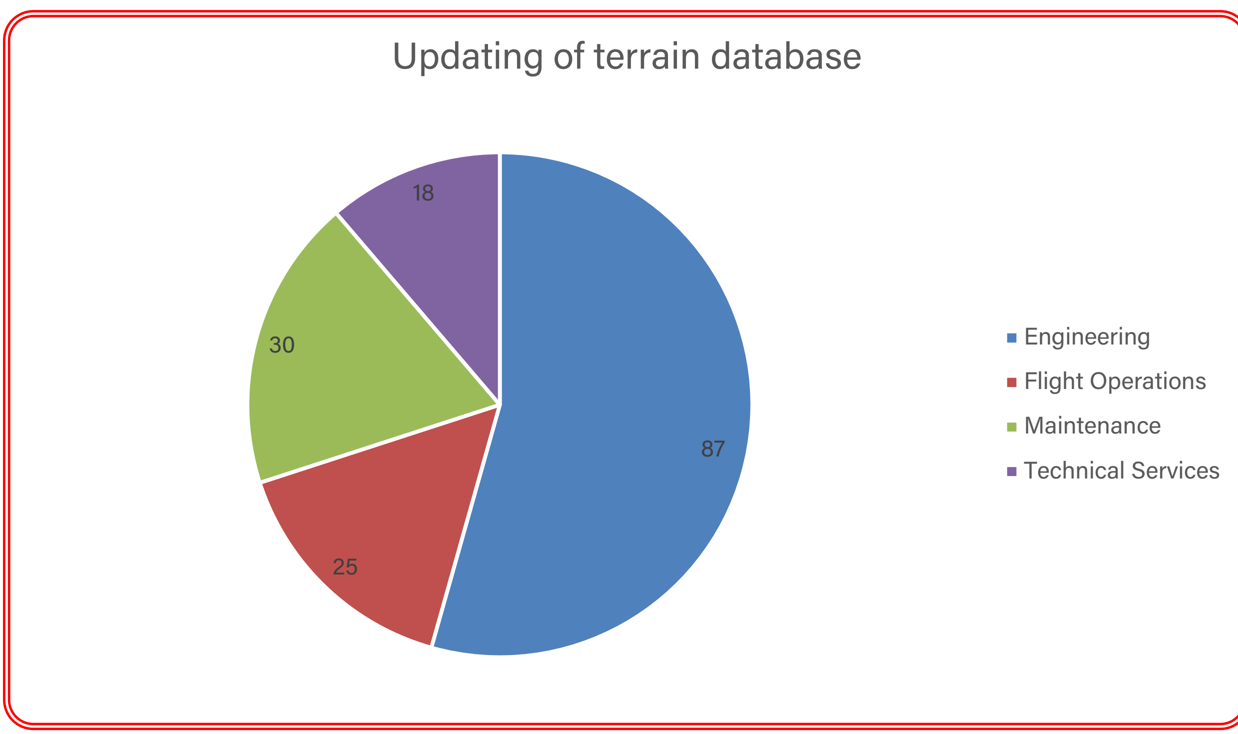
19.3.10 Question 10

Question 10 asked which department was responsible for updating the terrain database. As this question as not correlated to any other incident data, it does not really tell us very much about the efficacy (or otherwise) of any particular department carrying out this function. Therefore, for information purposes, it is an 'interest only' type of question.

Not surprisingly, the majority of companies opted to have the Engineering department to update, with 54.4%, as follows:

Engineering	87	54.4%
Flight Operations	25	15.6%
Maintenance	30	18.8%
Technical Services	18	11.3%
	160	100.0%

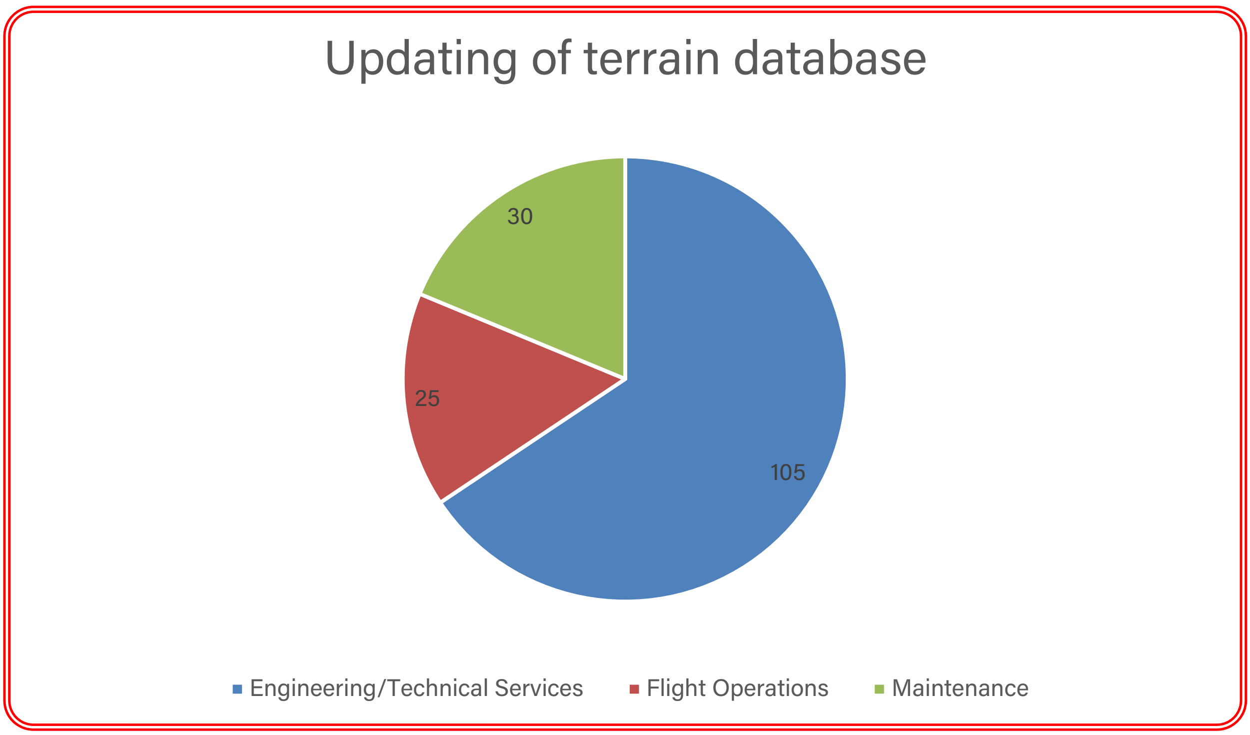
Graphically, these figures looks like this:



Technical services is often either a sub-division of Engineering or is the name that the company gives to the Engineering department. If we add these two together, we find that the percentage increases to 65.5%.

Engineering/Technical Services	**105**	**65.6%**
Flight Operations	25	15.6%
Maintenance	30	18.8%
	160	100.0%

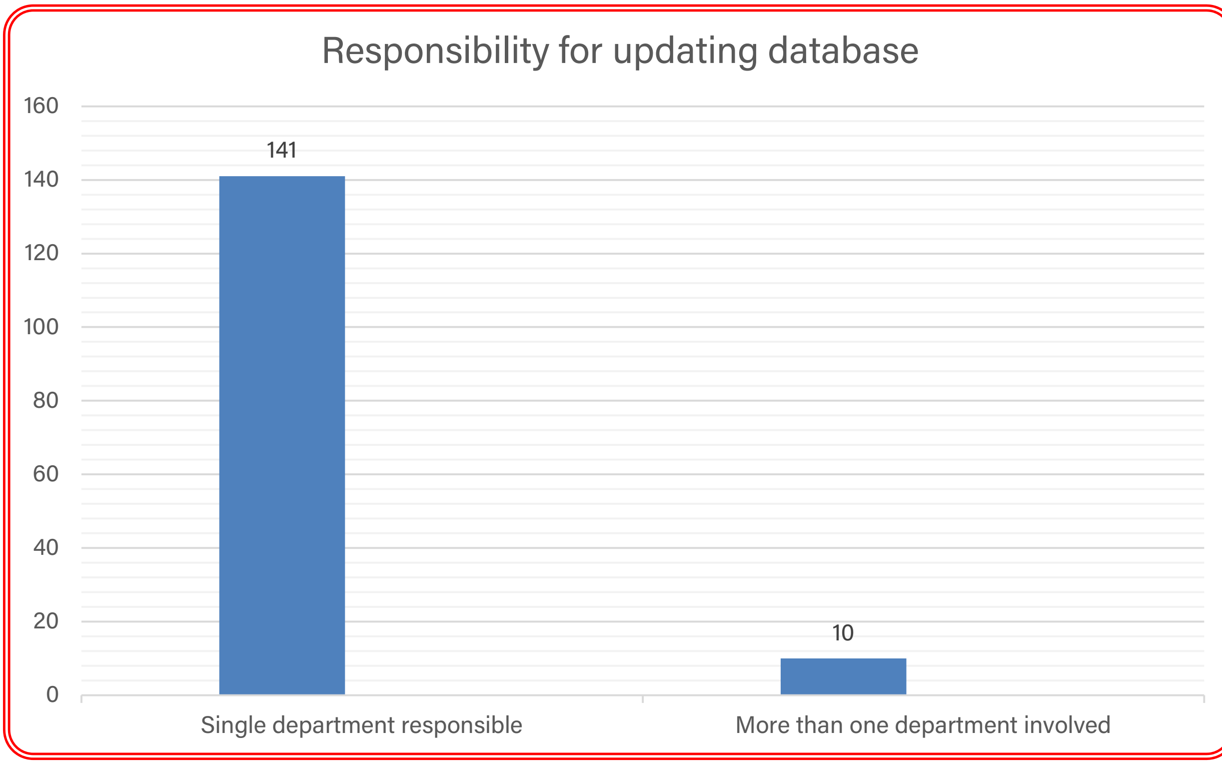
Which now looks like this:



As stated above, there is no correlation in this survey with failures or incidents, so it is not possible to comment on the efficacy of any one department. However, Engineering (or Technical Services) Departments have robust programs in place for the tracking of maintenance, life-limited parts, mandatory inspections, recurrent inspections etc. Therefore, they will already be well-placed to monitor changes and schedule updates.

What is possibly more interesting, is that a number of airlines listed two (or more) departments responsible for the updating of terrain databases. Without further interrogation of respondents, it is difficult to know the full role of each department and who has overall control. However, all of them listed Engineering has being involved in the updates. This would seem to suggest that Engineering Department would take the lead and monitor/ call out updates.

The percentages of single ownership/responsibility versus multiple looks like this:



It is clear from the survey that in the majority of cases (93.4%) a single department takes full responsibility and ownership. Having such an arrangement is highly recommended. A basic understanding of human factors informs us that unless a single entity has overall control and responsibility, a system is prone to errors. That is, if two systems monitor and track independently, there is an increased chance that certain functions will be missed. Therefore, it is strongly recommended that, even where two or more departments are involved in the update of terrain databases, a single department has overall control and responsibility.

Recommendation 2: encourage operators to ensure that a single department has overall control and responsibility for the updating of terrain databases.

19.3.11 Question 11

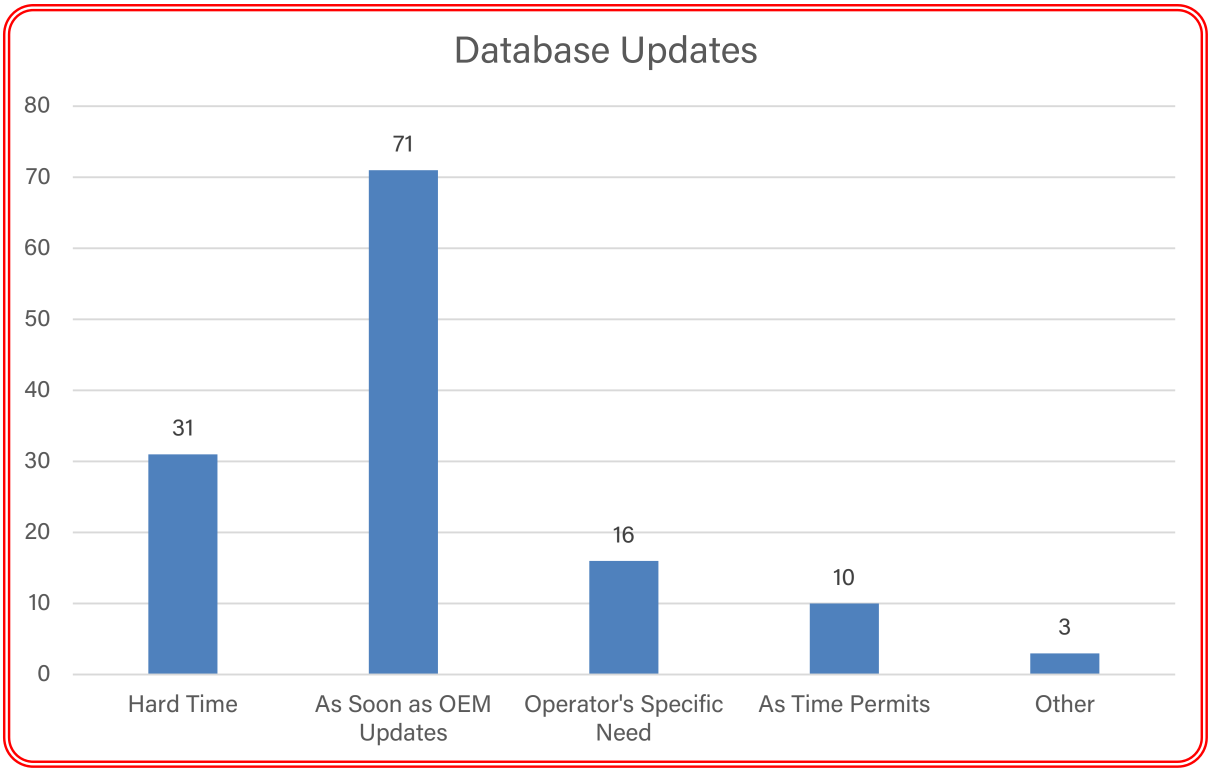
This question asked how frequently the terrain database was updated by the respondent's system. That is, are the updates required by the OEM installed into the aircraft promptly? In the majority of cases (64.8%), it was found that the respondents updated the terrain database as soon as they became available (see table below ~ 71* plus 16* = 87/131 total responses equals 64.8%). The responses look like this:

Hard Time		As soon as OEM Updates		Operator Specific		As Time Permits		Other	
Annually, unless technical issue	3	As required	2	updated if required	16	As time permits	10	Being evaluated due to cost	1
During major maintenance	3	as soon as OEM updates	69					No set time	2
Every 3 - 5 months	1								
Every 12 - 24 months	1								
Every 12 months	6								
Every 2 months	1								
Every 3 months	3								
Every 4 months	3								
Every 6 - 12 months	1								
Every 6 months	1								
Every month	8								
	31		71*		16*		10		3
								Total	**131**

For the sake of simplicity, these responses were categorized into 4 categories: 'hard time'; 'as soon as OEM updates'; 'operator's specific need' and 'as time permits'. These categories look like this:

Hard Time	31	23.7%
As Soon as OEM Updates	71	54.2%
Operator's Specific Need	16	12.2%
As Time Permits	10	7.6%
Other	3	2.3%
	131	100%

And graphically:



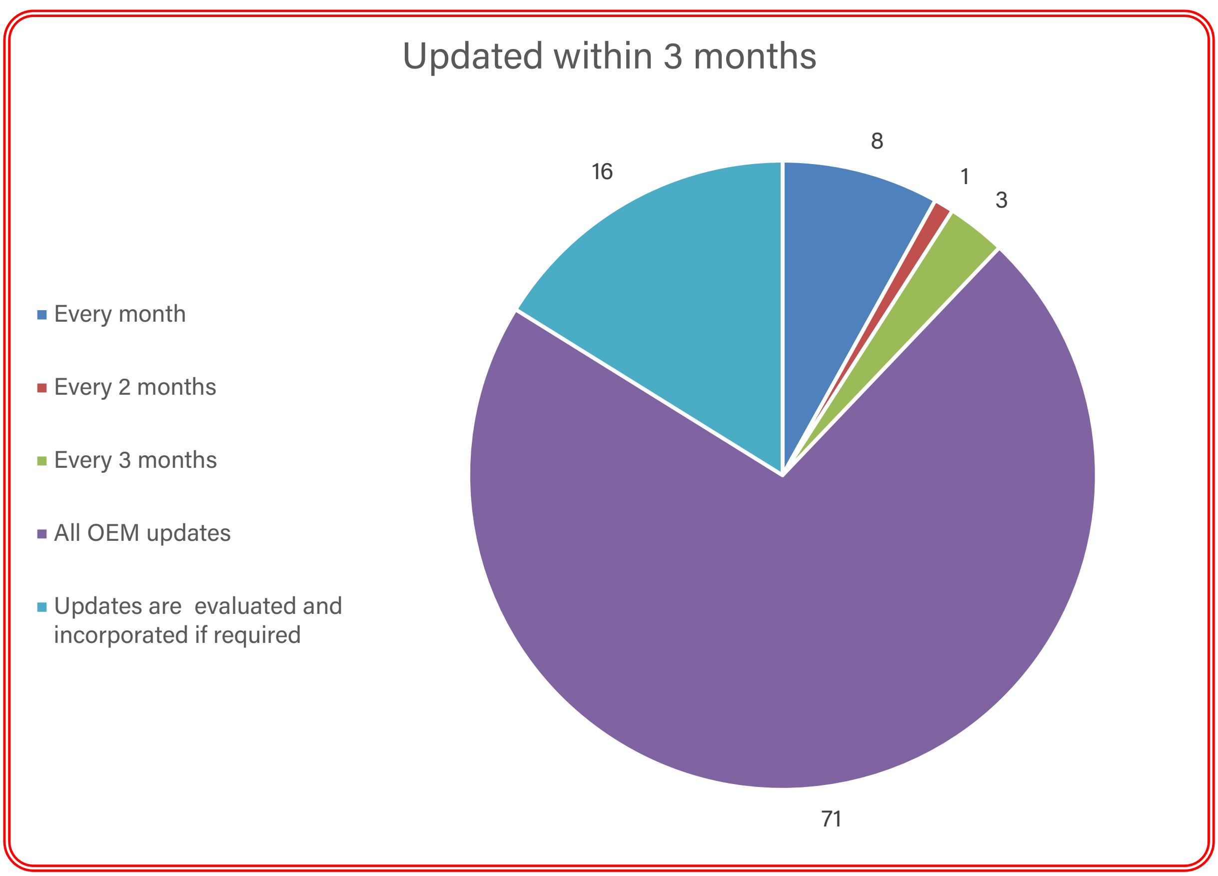
However, this needs a little explanation. The category "Hard Time" was created to encapsulate all the respondents that had a fixed time for installation. This ranges from 'every month' to every 1-2 years. The point of this is that the periodicity as based on a calendar date, which means that any updates will not be incorporated until the next scheduled update. Further break down of this category is as follows:

Hard Time	
Annually, unless technical issue warrants	3
During major maintenance	3
Every 3 - 5 months	1
Every 12 - 24 months	1
Every 12 months	6
Every 2 months	1
Every 3 months	3
Every 4 months	3
Every 6 - 12 months	1
Every 6 months	1
Every month	8
	31

As can be seen, the first category actually allows the respondent to react to a technical need but this is not defined, so there is still a chance that important updates may be missed until the next annual check. Given that some OEMs issue updates every 3 months, it might be useful to see what number of respondents would capture these updates in a timely manner. Therefore, if we count all of the respondents that update at least every three months, we see this:

Every month	8	8.08%
Every 2 months	1	1.01%
Every 3 months	3	3.03%
All OEM updates	71	71.72%
Updates are evaluated and incorporated if required	16	16.16%
	99	**100.0%**

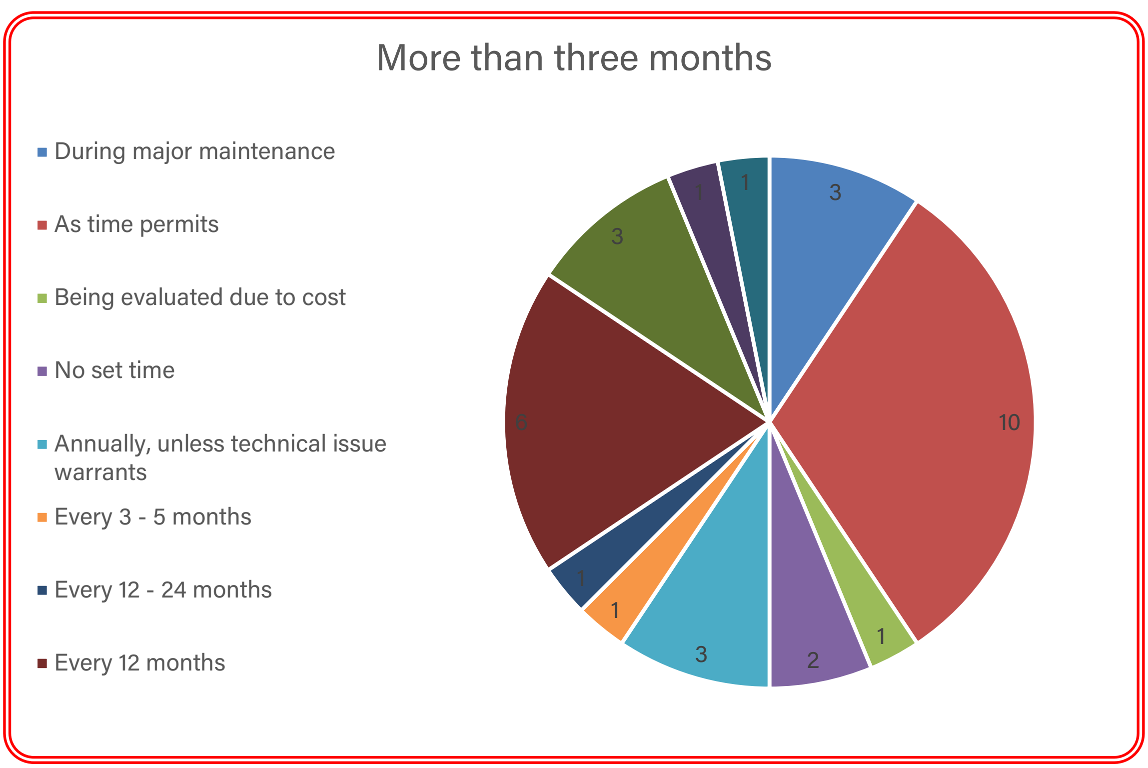
That is, a total of 99 respondents will capture OEM updates in a timely manner. This equates to 75.6% of the total number of respondents to this question (131 total), which looks like this:



And we can show the total number of respondents updating within 3 months against the others as:

During major maintenance	3	
As time permits	10	
Being evaluated due to cost	1	
No set time	2	
Annually, unless technical issue warrants	3	
Every 3 - 5 months	1	
Every 12 - 24 months	1	
Every 12 months	6	
Every 4 months	3	
Every 6 - 12 months	1	
Every 6 months	1	
Total over 3 months	32	24.4%
Total updating within 3 months	99	75.6%
Grand Total	**131**	**100%**

The breakdown of those that update in a period greater than 3 months, is as follows:



The important factor to consider here is that the manufacturer issues updates every three months. In order to ensure that the operator's terrain database is always up to date, these updates should be incorporated as soon as is practical. It may be more practical to only incorporate updates that are applicable to the operation but these should be assessed and incorporated as soon as possible, to ensure that the latest data is available to pilots.

Recommendation 3: encourage operators to ensure that terrain databases are updated as and when issued by the EGPWS manufacturer (OEM).

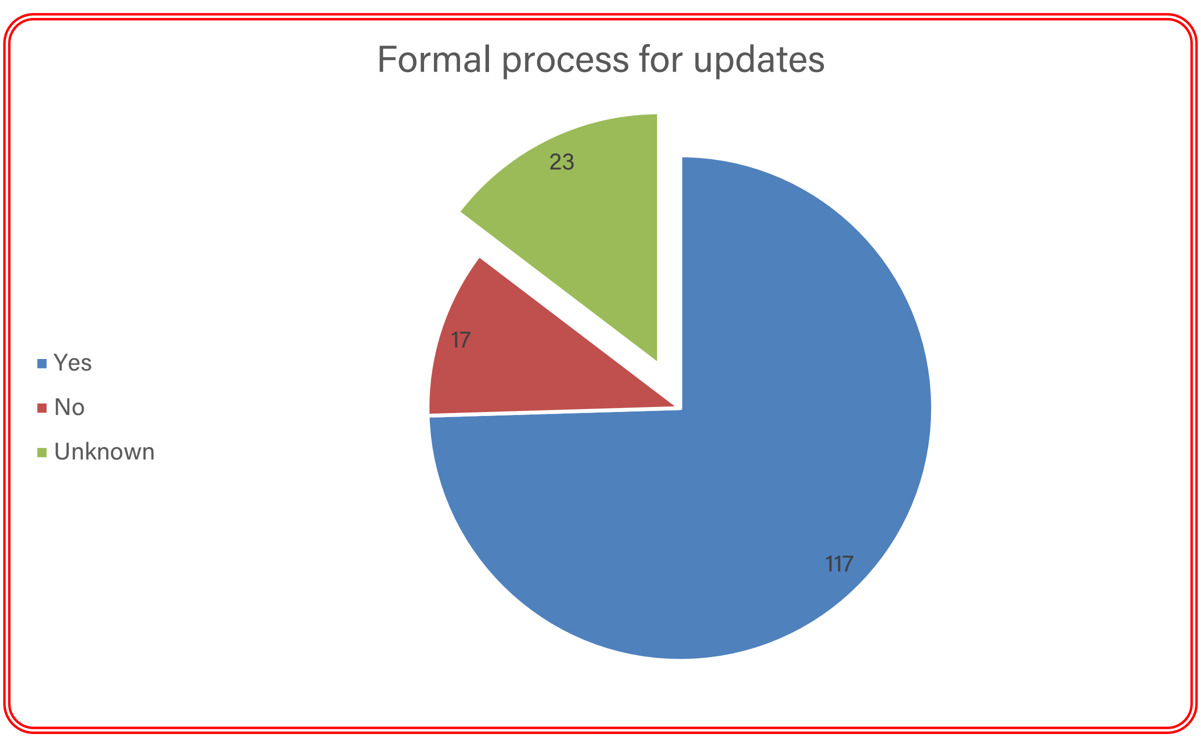
19.3.12 Question 12

This questions asks if the organisation has a formal process for updating the software version of the EGPWS. This is a key question with regard to safety, as software updates for these systems (as with any system) may contain critical safety updates or operational improvements. The analysis is very simple here, as the question is framed for a simple YES/NO response, as follows:

Yes	117	87.3%
No	17	12.7%
Total responses	**134**	**(85.3% of respondents)**

This is a disappointing number, as wherever there is no formal process, there is margin for error. That is, where there is no formal process and no clear lines of responsibility, updates can be overlooked. Basic human factors theory tells us that if we rely on informal processes, with no clear guidelines (or rules) the system will be prone to errors.

Shown graphically (including those that did not respond, marked as unknown), the chart looks like this:



Recommendation 4: encourage operators to ensure that there is a formal process for updating EGPWS software versions.

19.3.13 Question 13

This question sought to find out if the software of the EGPWS system was updated regularly. Unfortunately, the question was phrased in such a way that it was not clear to respondents and the majority assumed that it was referring to the terrain databases updates. There were 13 responses that were possibly answering the intended question but without further interrogation, it is not possible to make any assumptions.

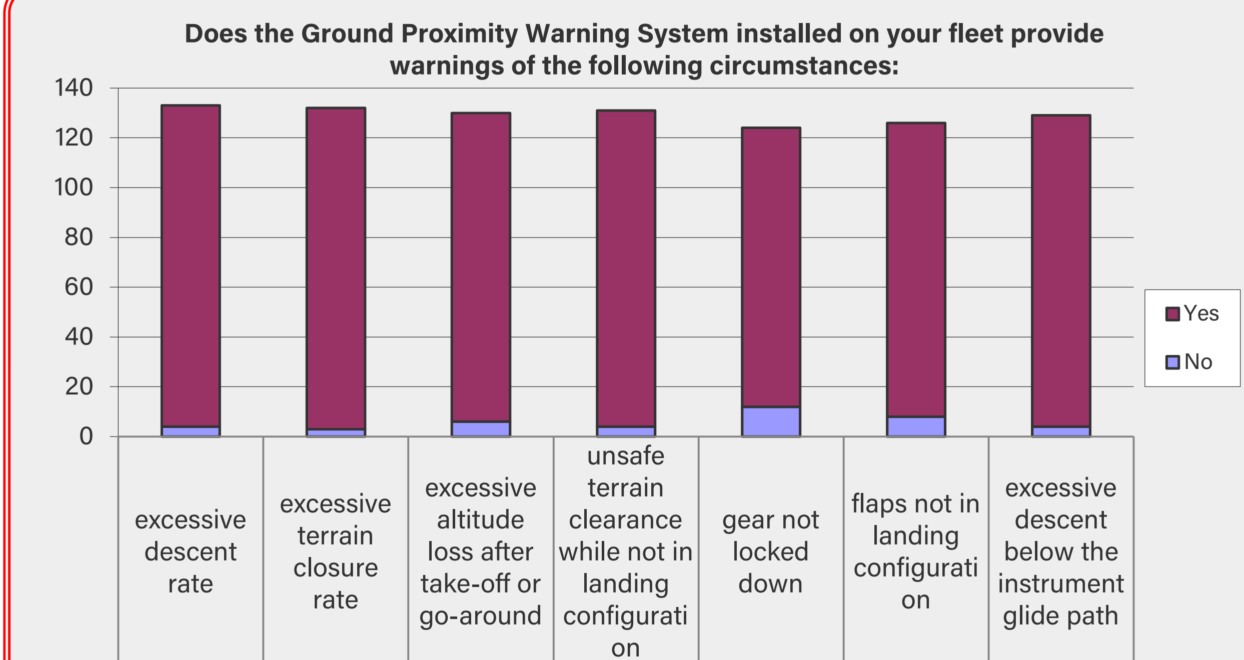
From further research, it would appear that any software updates to the actual EGPWS system are either controlled by service bulletin or are mandatory from the manufacturer. The majority of manufacturers will incorporate software updates in the latest terrain database updates, so the periodicity will depend on the answers to question 11.

19.3.14 Question 14

The final question sought data on the types of warnings that the system provides. There is no analysis to be done on this question but the results are as follows:

Does the GPWS installed provide warnings of the following circumstances:			
Answer Options	**Yes**	**No**	**Response Count**
excessive descent rate	129	4	133
excessive terrain closure rate	129	3	132
excessive altitude loss after take-off or go-around	124	6	130
unsafe terrain clearance while not in landing configuration	127	4	131
gear not locked down	112	12	124
flaps not in landing configuration	118	8	126
excessive descent below the instrument glide path	125	4	129
		answered question	**134**
		skipped question	**23**

And graphically:

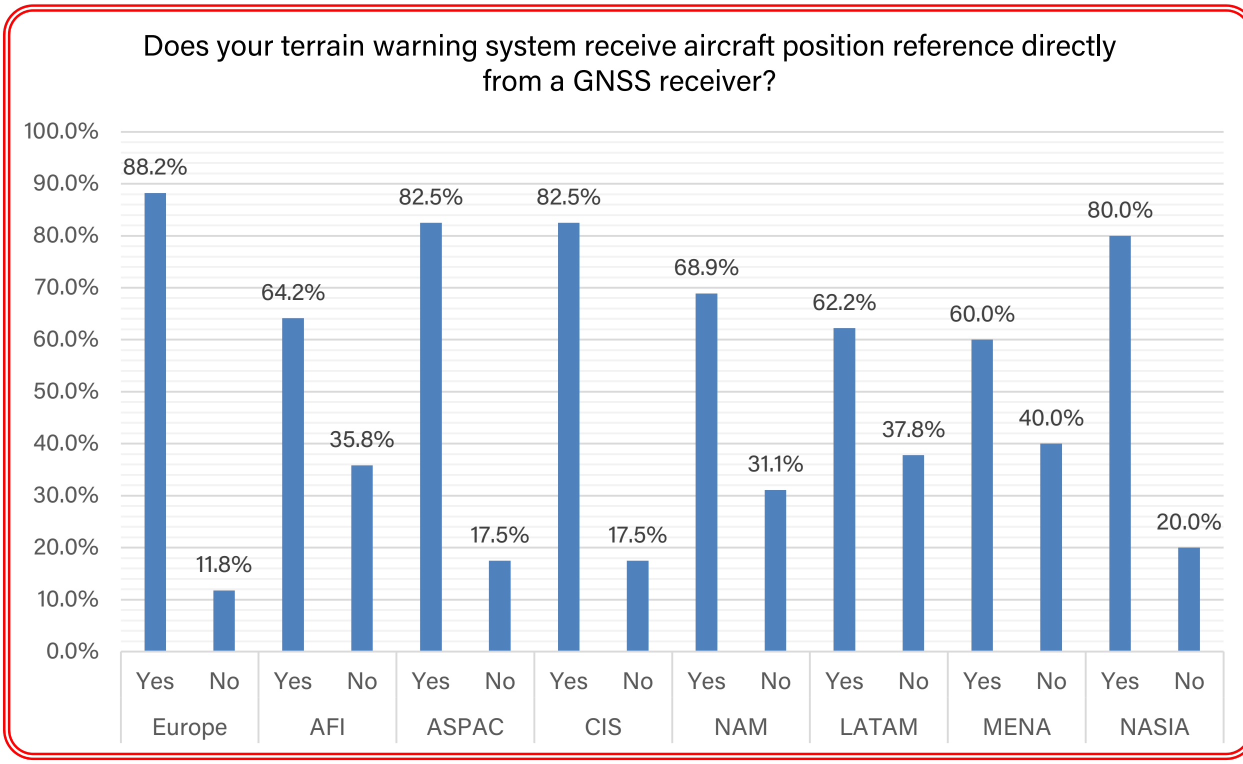


	excessive descent rate	excessive terrain closure rate	excessive altitude loss after take-off or go-around	unsafe terrain clearance while not in landing configuration	gear not locked down	flaps not in landing configuration	excessive descent below the instrument glide path
Yes	129	129	124	127	112	118	125
No	4	3	6	4	12	8	4

19.4 Regional analysis on key questions

There follow some analysis on some of the key questions in the survey, by region. The first such question is concerning the aircraft positioning data being linked to the EGPWS/TAWS system via the GNSS, which as addressed in Question 9. “Does your terrain warning system receive aircraft position reference directly from a GNSS receiver?”

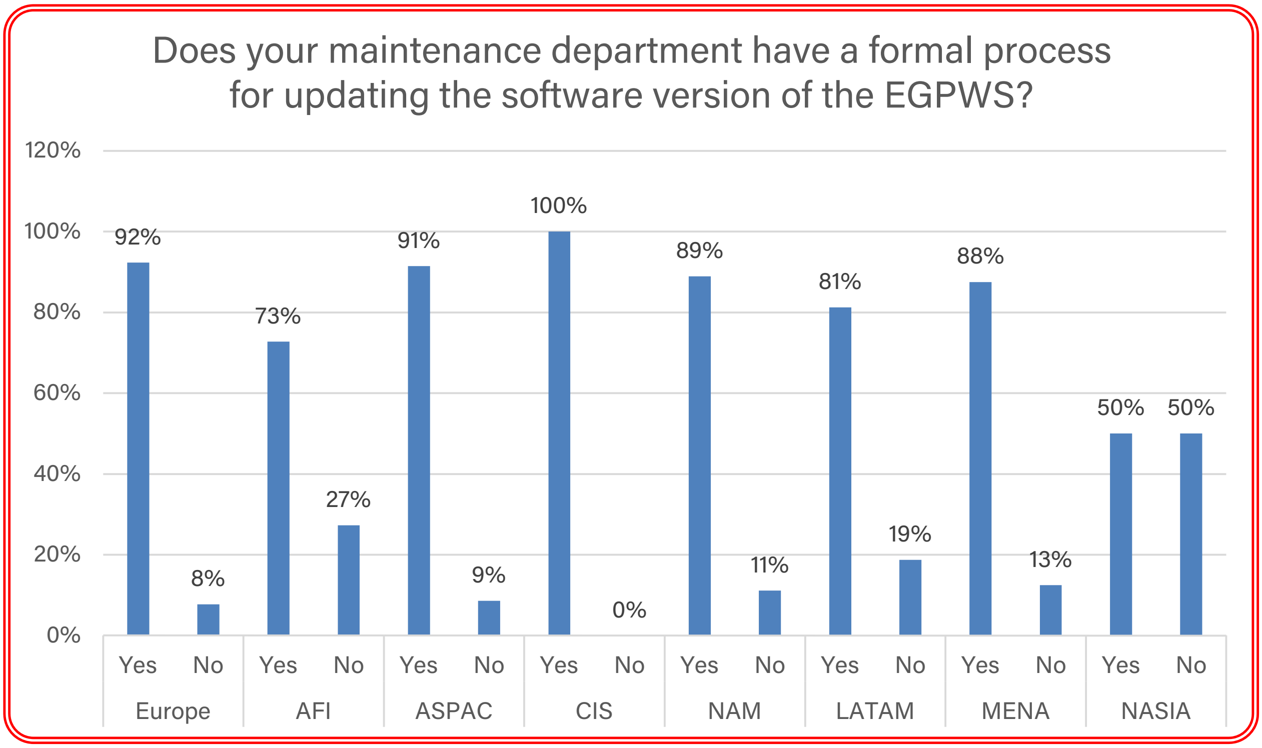
When extracted regionally, the results looks like this:



As can be seen, the values for Europe, ASPAC, NASIA and CIS are reasonably high and show good rates. The relatively lower rates for AFI, NAM, LATAM and MENA would seem to suggest that some attention is needed in these areas.

The second key question concerns the formal process for updating the terrain database. As we saw above, this is a key component in ensuring that the latest terrain is correctly uploaded and in a timely fashion.

When we look at the data regionally, we see this:



From this, we can see that the rates are generally good for all regions, with the exception of NASIA. As before, we must exercise caution in analyzing these results, as the numbers for NASIA on this question were particular low, with just four responses.

We can however, recommend to the regional office that they follow up with the carriers ask the region for further information and urge them to ensure that there is a formal process.

In addition, a general reminder may be issued, reminding that it is very important to update the database in a timely manner and that the best way to do this is to have a formal process/procedure for doing so.

Recommendation 5: ask the NASIA regional office to urge operators in the region to ensure that there is a formal process for updating EGPWS software.

Recommendation 6: through the regional offices (and by distribution of this report) remind operators to have a formal process for updating EGPWS software.

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