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European Aviation Safety Agency

EOFDM WORKING GROUP A

REVIEW OF ACCIDENT PRECURSORS FOR LOSS OF CONTROL IN FLIGHT

17th of December 2015
(re-edition 7th of February 2017)

Summary

This report studies potential precursors that could result in loss of control accidents while the aircraft is airborne. From this list several flight data measurements are proposed for further analysis and development by EOFDM Working Group B.

Introduction

In the context of this study, loss of control (LOC) refers to loss of aircraft control or deviation from the intended flight path in-flight.

The analysis of precursors was structured in three steps:

1. Group all types of foreseeable LOC events into generic scenarios.
2. Identify and justify all foreseeable precursor factors for each LOC category

   The factors are listed in tabular format and ordered to facilitate the construction of plausible "sequences of events". For example, Figure 1 suggests that a Loss of Control due to Crew incapacitation could be preceded by the following precursors:

   High cabin altitude → Pressurization System Malfunction → O2 masks not used by crew

   Precursors listed in the same column are assumed to be independent from each other, but possibly occurring in combination. This means that the following sequence from table 2 is also plausible:

   Special operations → Inadequate energy + Envelope protection systems failure or ignored → Inadequate Lift

   The simplicity of this tabular format is convenient because it enables a very compact representation of multiple sequences of events in the same diagram. The drawback of this arrangement is that not all combinations of precursors are plausible (or even logical), such as the following, which could be extracted from Figure 3:

   Electromagnetic Interference → Structural Failure → Inadequate Thrust

   This inconsistency is not really problematic because:

a. The relevant and applicable sequences are easy to detect and the irrelevant ones are easy to ignore.
b. The objective of the diagram is the identification of the accident precursors and not necessarily the accurate representation of their chronological order. This order would only be important in the context of a risk assessment or in the development of a formal bowtie diagram.

   For this application this tabular arrangement is therefore deemed to be an adequate compromise between simplicity and correctness.

3. Consolidate all the precursor factors identified in step #2 and produce actionable recommendations for WG B.

   This consolidation is useful to reduce the number of recommendations without loss of detail. For example, the precursor "Instrument malfunction" is mentioned under the "Environmental Factors" and "System Failure" categories, however only one recommendation is produced (see LOC 24).

The human analyst part of the FDM system

The recommendations - and hence the precursors - stated here are meant to drive the development of "alerts" and measurements to identify situations that otherwise could go unnoticed. It is assumed that each event highlighted by the FDM software program will be reviewed by qualified analysts, taking in consideration the circumstances and context of each individual event. This assumption significantly reduces the complexity and scope of the work. For example, once a "windshear event" has been detected by the software, it is not necessary to develop further events to detect whether or not the windshear escape maneuver has been correctly executed by the crew: this task will be delegated to the analyst who is better positioned to do it anyway.

Redundancy with Reportable Events

Several recommendations suggested as FDM "alerts" or measurements in this document relate to significant operational occurrences which should be evident to the flight crew (e.g. loss of lift, extreme attitudes, etc) and therefore should also be covered by Safety Reports. While this redundancy could be viewed as undesirable, it offer a tangible benefit: there are genuine cases where the flight crew may not be aware of certain occurrences, especially when their severity is low (e.g. minor and momentary flap overspeeds or incorrect performance calculations). FDM events could then fill the void of a missing safety report.

Synergy with Aircraft Health Monitoring (AHM)

Several recommendations in this document are aimed at monitoring the condition of aircraft systems and components. While the motivation behind this document is on safety assurance, the implementation of these recommendations represents an opportunity to explore the synergies between AHM and FDM with possible financial benefits which can often offset the cost of the FDM programme itself.

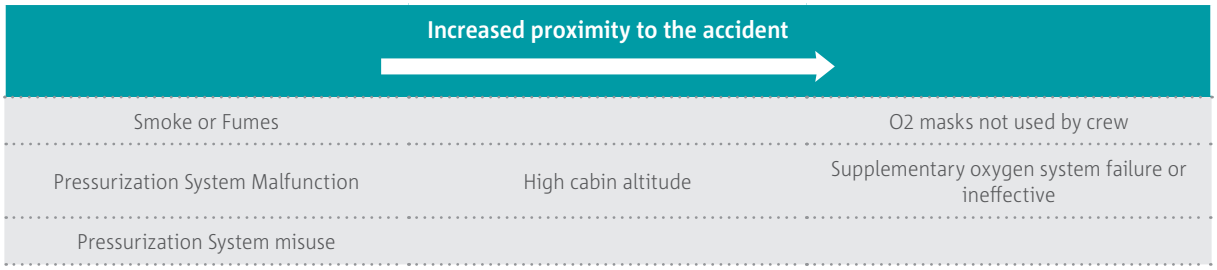
Step 1: List of Foreseeable Loss of Control Scenarios

1. LOC due to Crew incapacitation
2. LOC due to Flight Envelope exceedance
3. LOC due to Environmental Factors
4. LOC due to System Failure
5. LOC due to Inadequate Flight Management

Step 2: Identification of precursor factors

Accident Scenario #1: Loss of Control due to Crew incapacitation

Figure 1



Note: This discussion is relevant only for pressurized aircraft.

Note: Crew incapacitation could also be caused by laser beam exposure, fatigue, food poisoning, medical conditions or other causes. These precursors are unlikely to be captured by flight data, therefore are not included in this analysis.

Discussion

Smoke and Fumes: Smoke and fumes in the cabin or flight deck could cause crew incapacitation if the available countermeasures fail or are not used.

Pressurization System Malfunction: Could cause high cabin altitude or situations with adverse impact on crew physiology and crew incapacitation if undetected and/or the available countermeasures fail or are not used.

Pressurization System Misuse: Could cause high cabin altitude or situations with adverse impact on crew physiology and crew incapacitation if undetected and/or the available countermeasures fail or are not used.

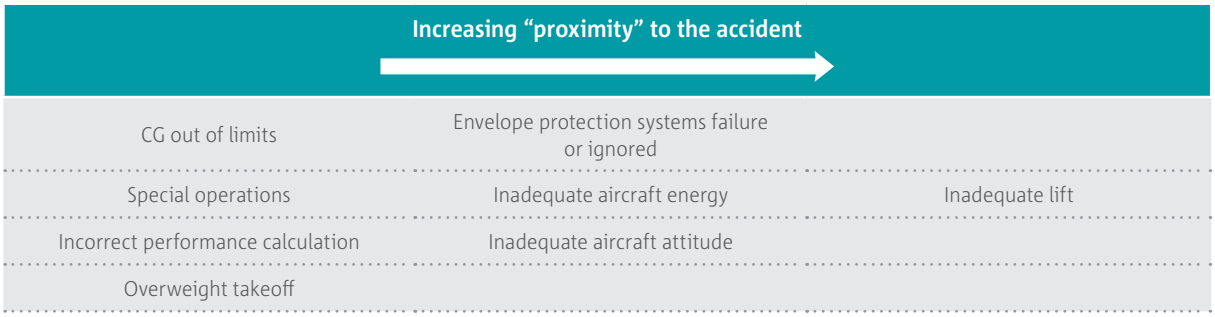
High cabin altitude: Could cause hypoxia and affect the performance and well-being of the crew and passengers if undetected and/or the available countermeasures fail or are not used.

Oxygen masks not used: Failure to promptly use oxygen masks in case of emergency may cause crew incapacitation. It is reasonable to assume that incidents of this kind will be reported by the crew, or investigated as a follow-up of an accident. The role of FDM in this case could be to provide factual information to support the investigation process.

Supplementary oxygen system failure or ineffective: The role of FDM in this case is similar to the case described above, but it could also play a role in preventive maintenance.

Accident Scenario #2: Loss of Control due to Flight Envelope Exceedance

Figure 2



Discussion

CG out of limits: load shift in flight / takeoff, incorrect loading or fuel imbalance could cause the CG to move out of limits resulting in controllability issues.

Special operations: maintenance check flights, flight tests and some special conditions may place the aircraft at the edges or even outside the operating envelope (airspeed, angle of attack, bank angle) or cause deviations from normal aircraft trajectory.

Incorrect performance calculation: Incorrect calculation of reference speeds might cause controllability/performance issues during any phase of flight.

Overweight Takeoff: Undetected errors in loading or fueling (not necessarily exceeding aircraft limitations) may cause climb performance issues and reduce obstacle clearance margins on performance limited departures.

NOTE 1: This is considered as a precursor for LOC and not CFIT because the crew will not be in control of the aircraft.

Envelope protection systems: Some aircraft are equipped with automatic protection systems to warn the crew or systems to keep the aircraft within the safe envelope in case the aircraft is outside of the envelope. If these systems fail or are ignored this could lead to an inadequate aircraft energy / attitude situation.

Inadequate aircraft energy: excessive or insufficient airspeed and/or altitude and/or thrust for any phase of the flight could result in controllability issues due to inadequate lift.

Inadequate aircraft attitude: regardless of the causes, aircraft attitudes which are unusual for each phase of the flight should be effectively and promptly recovered before they result in uncontrollable situations.

Inadequate lift: Lift is one of the basic forces required to maintain a controllable and safe trajectory for any aircraft.

Accident Scenario #3: Loss of Control due to Environmental Factors

Figure 3

Increasing "proximity" to the accident →		
FOD		Inadequate thrust
Electromagnetic interference	De-icing system failure or ineffective	Inadequate lift
Adverse Weather	Engine failure	Inadequate aircraft attitude
Windshear	Instrument malfunction	Inadequate aircraft Energy
Severe Turbulence	Structural failure	
Icing Conditions		

Discussion

FOD: May cause damage/failure of flight controls, airframe structures, engines or instruments, possibly resulting in inadequate aircraft attitudes, loss of thrust or lift.

Electromagnetic interference: may cause instrument malfunction and then loss of situational awareness or navigation errors.

Adverse Weather: Hail, lightning strikes, volcanic ash, sand storms and other manifestations of significant weather may cause damage to structures, engines and aircraft instruments. (Reportable event)

Windshear: Negative windshear will cause a reduction in indicated airspeed and loss of lift, if the appropriate windshear recovery maneuver is not effectively and quickly executed.

Severe Turbulence: There are multiple causes for severe turbulence (mountain waves, aircraft vortex, thunderstorms) which may result in extreme aircraft attitudes.

Winter Operation/Icing conditions**:** Ice accumulation on engines, wings or flight control surfaces may lead to loss of lift, loss of thrust or engine failure. Icing of instrument sensors could cause unreliable instrument readings.

Anti-icing failure or ineffective: Anti-ice (and de-ice) systems are normally tested during pre-flight checks, however some failures and its actual effectiveness may not be evident for the crew until they are airborne and need to use the system. The effectiveness of these systems depends on their correct utilization and even then, they may not be able to cope with extreme icing conditions.

Engine failure/Damage: Any situation where the engine is not producing the expected thrust or is displaying symptoms of an impending failure in the near future. Single engine failures are relatively benign events (in multi-engine aircraft) due to advances in aircraft design, certification and crew training. Nevertheless they affect the controllability and performance of the aircraft and introduce additional workload for the crew which could have adverse consequences, especially when combined with additional failures.

Instrument Malfunction: Environmental factors could cause instrument malfunction and result in loss of situational awareness or confusion for the flight crew or even trigger inappropriate responses from aircraft automation, possibly resulting in extreme aircraft attitudes and loss of thrust or lift.

Structural failure: The failure of primary structures like wings, engine mounts, control surfaces, etc may be a direct cause of loss of control. However the failure of secondary structures may affect the serviceability of flight controls and other safety critical systems possibly resulting in extreme aircraft attitudes, loss of thrust or lift.

Inadequate thrust: Thrust is one of the basic forces required to maintain a controllable and safe trajectory for fixed wing aircraft.

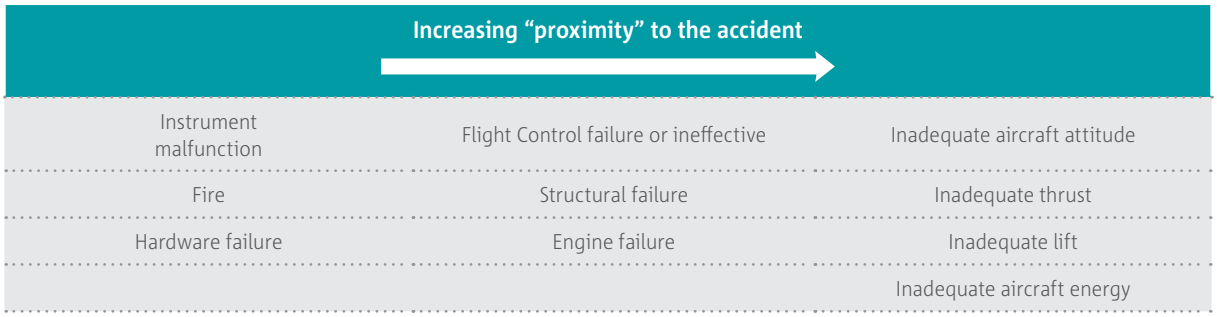
Inadequate lift: Refer to Flight Envelope Exceedances.

Inadequate Aircraft Attitude: Refer to Flight Envelope Exceedances.

Inadequate Aircraft Energy: Refer to Flight Envelope Exceedances.

Accident Scenario #4: Loss of Control due to System Failure

Figure 4



Discussion

Instrument Malfunction: Could be caused by technical failures and result in loss of situational awareness or confusion for the flight crew or even trigger inappropriate responses from aircraft automation, possibly resulting in extreme aircraft attitudes and loss of thrust or lift.

Fire: Some system failures could result in fire in the cabin, cargo compartment, wheel well or engines, causing secondary failures on flight control systems, airframe structures, or other safety critical systems, possibly resulting in extreme aircraft attitudes, loss of thrust or lift.

Hardware failure: Modern aircraft are designed and certified to be resilient against multiple system failures. However, some situations may degenerate into more severe failures seriously affecting flight control systems or engines, possibly resulting in extreme aircraft attitudes, loss of thrust or lift.

Flight Control Failure or ineffective: Functional and effective flight controls are essential for the stability and controllability of any aircraft.

Structural failure: Refer to environmental factors.

Engine failure: Refer to environmental factors.

Inadequate aircraft attitude: Refer to Flight Envelope Exceedances.

Inadequate thrust: Refer to Environmental Factors.

Inadequate lift: Refer to Flight Envelope Exceedances.

Inadequate aircraft energy: Refer to Flight Envelope Exceedances.

Accident Scenario #5: Loss of Control due to Inadequate Flight Management

Figure 5

Increasing "proximity" to the accident →	
Mismanagement of automation	Loss of thrust
Abnormal flight control inputs	Inadequate aircraft attitude
Incorrect aircraft configuration	Inadequate aircraft Energy
Fuel exhaustion	Inadequate lift

Discussion

Mismanagement of automation: Misunderstanding, inadvertent disconnection or inadequate utilization of automation (especially for complex and highly automated aircraft) may cause inappropriate aircraft attitude and / or energy levels.

Abnormal flight control Inputs: Abnormal thrust inputs or control surfaces inputs (including dual inputs) for any phase of the flight could be caused by spatial disorientation, visual illusions, poor CRM, inadequate training or SOP violations. These then could result in inappropriate aircraft attitude, energy or deviation from the normal trajectory (vertical and lateral)

Fuel Exhaustion: Inadequate planning, undetected refueling errors and inadequate enroute fuel management may result in fuel exhaustion and consequently in loss of thrust.

Incorrect aircraft configuration: incorrect trim, lift augmenting devices, speedbrakes, etc. could cause inadequate aircraft energy levels and / or deviation from normal trajectory.

Inadequate thrust: Refer to Environmental Factors

Inadequate aircraft attitude: Refer to Flight Envelope Exceedances.

Inadequate aircraft energy: Refer to Flight Envelope Exceedances.

Inadequate lift: Refer to Flight Envelope Exceedances.

Consolidated precursors and recommendations for EOFDM Working Group B

Based on the previous discussion the following possible precursors result as recommendation to being monitored using Flight Data Monitoring Systems.

	LOC categories					
Precursor	1	2	3	4	5	Recommendation
Fire, smoke and fumes	●			●		LOC01
Press. System Malfunction	●					LOC02
Press. System Misuse	●					LOC03
						Reserved
High Cabin altitude	●					LOC05
O2 masks not used by crew	●					LOC06
Supp. O2 system failure	●					LOC07
CG out of limits		●				LOC08
Special Operations		●				LOC09
Incorrect performance calculation		●				LOC10
Overweight takeoff		●				LOC11
Envelope protection systems		●		●		LOC12
Inadequate aircraft energy		●	●	●	●	LOC13
Inadequate aircraft attitude		●	●	●	●	LOC14
Loss of lift		●	●	●	●	LOC15
FOD			●			LOC16
Electromagnetic Interference			●			LOC17
Adverse Weather			●			LOC18
Windshear			●			LOC19
Severe turbulence			●			LOC20
Icing conditions			●			LOC21
De-icing system failure			●			LOC22
Engine failure			●	●		LOC23
Instrument Malfunction			●	●		LOC24
Structural Failure			●	●		LOC25
Loss of thrust			●	●	●	LOC26
Hardware failure				●		LOC27
Flight control failure or ineffective				●		LOC28
Mismanagement of automation					●	LOC29
Abnormal flight control inputs					●	LOC30
Fuel exhaustion					●	LOC31
Incorrect aircraft configuration					●	LOC32

Expected Result

LOC01 Fire, smoke or fumes: Develop means to detect the presence of fire, smoke or fumes in the cabin, cargo compartment, engines, and landing gear bay.

LOC02 Pressurization system malfunction: Develop means to identify malfunctions of the pressurization system which could cause crew incapacitation or discomfort. System malfunctions could cause abnormal or unexpected rates of cabin pressure, inability to cope with transients in engine regime, abnormal cabin altitude (not necessarily high enough to trigger alerts for the crew) or reversion from automatic to manual control. There might be scope for integration with Aircraft Health Monitoring Systems and continued airworthiness.

LOC03 Pressurization system misuse: Develop means to identify situations where pressurization system is not used correctly. For example, failure to turn on the bleed pressure after takeoff, failure to set the landing pressure altitude or inadequate use in manual control mode.

LOC04 Reserved

LOC05 High cabin altitude: Develop means to identify situations of abnormal cabin altitude, including but not limited to values that would trigger cabin altitude alerts (possibly in combination with LOC02).

LOC06 Oxygen masks not used by crew: Develop means to identify situations when the crew failed to deploy and use the oxygen masks in response to real or nuisance situations.

LOC07 Supplementary oxygen system failure: Develop means to identify failure or leaks in the flight crew supplementary oxygen system.

LOC08 Abnormal CG position: Develop means to estimate the CG position and to detect situations where it is out of limits or not consistent with pitch trim settings, as a result of load shifts, incorrect loadings or fuel imbalances.

LOC09 Special operations: Develop means to identify operation at or beyond the edges of the operating envelope or not in compliance with SOP. This should cover all airframe and engine limitations (as specified in the AFM, including but not limited to indicated airspeed/Mach vs altitude, vertical speed, G limits, flap speed limits, speedbrake limits, tire speed limits, gear limits, temperature limits, maneuverability speeds, engine parameters, tailwind, crosswind, excessive rudder inputs).

LOC10 Incorrect performance calculation: Develop means to detect erroneous data entry or calculation errors which could lead to incorrect thrust settings, incorrect V speeds or incorrect target approach speeds (To be reconciled with recommendation 01 for Runway Excursions).

LOC11 Overweight takeoff: Develop means to identify overweight situations that could have an adverse effect on climb performance and obstacle clearance for performance limited departures (possibly in combination with LOC10).

LOC12 Envelope Protection systems: Develop means to detect the in-flight activation of aircraft envelope protection systems.

LOC13 Inadequate aircraft energy: Develop means to identify situations of inadequate aircraft energy (speed and/or altitude and/or thrust) for each phase of the flight.

LOC14 Inadequate aircraft attitude: Develop means to identify cases of excessive angles of pitch and roll. This identification should take in consideration the range of values acceptable for each phase of flight.

LOC15 Loss of lift: Develop means to identify situations of actual loss of lift and cases of operation close to the edges of the lift envelope.

LOC16 Foreign Object Damage: Develop means to identify cues that could suggest events of foreign object damage.

LOC17 Electromagnetic Interference: Develop means to identify cues that could suggest situations of EMI (possibly in combination with LOC24).

LOC18 Adverse Weather: Develop means to identify the presence of adverse weather in the vicinity of the aircraft.

LOC19 Windshear: Develop means to identify situations of windshear (reactive and predictive).

LOC20 Severe turbulence: Develop means to identify situations of severe turbulence, caused by different sources (clear air, wake vortex, mountain waves, etc).

LOC21 Icing conditions: Develop means to identify situations of extremely cold conditions or icing of engines, nacelles, propellers, wings and airframe. Operation in cold or icing conditions is frequent in most aircraft operations, therefore these should not be considered as abnormal. The objective is to develop a set of measurements to enable a better understanding of such environmental conditions, to assess the response of aircraft ice detection systems and to support recommendation LOC22.

LOC22 De-icing system failure: Develop means to identify failure, ineffectiveness or incorrect utilization (e.g. late activation) of de-icing and anti-icing systems.

LOC23 Engine failure: Develop means to identify situations of latent or active engine failure, including FOD and hardware degradation and failure. There might be scope for integration with Engine Condition Monitoring and continued airworthiness.

LOC24 Instrument Malfunction: Develop means to identify situations of instrument malfunction (possibly in combination with LOC17).

LOC25 Structural failure: Develop means to identify cues that could suggest the existence of latent or active failures in primary structures (possibly in combination with LOC16 and exploring potential of advanced instrumentation and sensors available in modern aircraft).

LOC26 Loss of thrust: Develop means to identify situations of unintended loss of thrust, or reduced engine performance taking in consideration (but not only) the range of values acceptable for each phase of flight and fuel flow.

LOC27 Hardware failure: Develop means to identify cues that could suggest the existence of latent failures in safety critical components (including but not limited to landing gears, doors, brakes, wheels, hydraulic systems, etc). There might be scope for integration with Aircraft Health Monitoring Systems and continued airworthiness.

LOC28 Flight Control failure: Develop means to identify cues that could suggest the failure or ineffectiveness of flight controls.

LOC29 Mismanagement of Automation: Develop means to identify situations of inadequate or unexpected use of automation or unexpected disconnection of automation.

LOC30 Abnormal flight control inputs: Develop means to identify situations of abnormal inputs on thrust controls, control surfaces and lifting devices taking in consideration the range of values acceptable for each phase of flight.

LOC31 Fuel exhaustion: Develop means to identify situations of low fuel quantity - by comparison to the planned fuel quantity - as the flight proceeds to its destination.

LOC32 Incorrect aircraft configuration: Develop means to identify situations of incorrect or unusual aircraft configuration for each phase of the flight.

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