EASA
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EUROPEAN OPERATORS FLIGHT DATA MONITORING
WORKING GROUP B

SAFETY PROMOTION
Good Practice document

GUIDANCE FOR THE IMPLEMENTATION OF FDM PRECURSORS

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Rev 02

Contents

Table of Revisions

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Introduction

This document contains a description of the ”Industry good practices recommendations” produced by EOFDM Working Group B (WGB) based on the risk based analysis issued by Working Group A (WGA).

All the good practices documentation from EOFDM is available on EASA website (https://www.easa.europa.eu/).

Some of the precursors described in this document may need external information to provide additional contextual information e.g. weather information, runway data or flight management performance information.

This document is the result of the collaborative work from EOFDM WGB comprising organisations with different experiences, such as operators, research institutions and universities, regulators and FDM software vendors.

Within the operators represented in EOFDM there are common issues about the risks involved in their operation, but also some specific issues. This document will reflect these inputs in terms of the creation of precursors that allow each operator to monitor and detect trends to undesirable situations.

Each fleet has its own capability in terms of parameters recorded onboard, and depending on the aircraft and the airborne FDM equipment, there is the possibility to customize the dataframe so that the recorded data can be adapted to the solutions proposed in this document.

EOFDM is a voluntary and independent safety initiative, therefore this document should be considered as industry good practice which EASA promotes actively and not one alternative to any applicable regulatory requirement.

Occurrence Reporting and FDM interaction

Occurrence Reports are a valuable source of information to complement FDM. As highlighted in the document from WGA, most of the precursors identified and under analysis in this document may fall under the scope of the Mandatory Occurrence Reporting Scheme (Regulation EU 376/2014).

Information sharing between Occurrence Reporting and FDM is beneficial for both sides. FDM provides information which may complement the occurrence report and may also be used as an alert in case the crew was not aware of a certain event and no report was filled. Likewise, occurrence reporting can help contextualize FDM events from a human perspective and adjustments to the analysis or the assessment of the needs for new parameters and measurements may become evident. Statistical associations between Occurrence Reporting and FDM data is also beneficial to study possible causal (predictive. The integration of reporting data and other sources of data into the FDM analysis is presented with deeper detail in the WGC document “Braking the silos”.[1]

Precursor Description

The description for each precursor follows a common structure based on the following items:

- Summary
- Rationale
- Aircraft Parameters

1 This document can be found in the EOFDM webpage (https://www.easa.europa.eu/easa-and-you/safety-management/safety-promotion/european-operators-flight-data-monitoring-eofdm-forum)

- Measurements and Events
- Future Developments and Recommendations
- Maturity Level

This structure allows some degree of versatility for tackling different situations, in which some may be of a direct approach using current technology and others may require to merge flight data with other sources of data or even new technical solutions.

Aircraft Parameters

Information recorded by the FDM recorders results from the information provided by aircraft sensors and systems. The parameters recorded on a specific aircraft and the way to convert from binary raw data into engineering units (decoding process) is normally described in a “dataframe layout” document.

The recommended parameters along this text appear in the form of tables as in the example below:

Parameter	Type
Altitude STD	Analogue
Eng (*) Thrust Lever Angle (TLA)	Analogue
Eng (*) N1	Analogue
Main Landing Gear (L+R)	Discrete
Nose Landing Gear	Discrete

There are two types of signal to consider. The analogue, indicating parameters that vary continuously over a certain range and time. These correspond normally to physical quantities such as the altitude, temperature or engine rotation. For digital recording, these quantities are submitted to a process of sampling which transforms the original analogue signal into a continuous set of levels which are digitalized in binary numbers and consequently recorded on the FDR. On the other hand, the discrete signals can only take a small number of values and can correspond to simple binary states, such as the opening/closing of one valve or a limited number of states such as the autopilot modes.

The description of the parameters should guide the operator to use the corresponding parameter from his dataframe. In the example of the table above, “Altitude STD” directs to the standard altitude recorded parameter. The nomenclature (*) indicates that there is more than a parameter to consider. For example:

1. Eng (*) Thrust Lever Angle (TLA)
   Refers to TLA1 and TLA2 for an aircraft with two engines indicating the thrust lever angle for each engine
2. Eng (*) N1
   Similarly indicates the N1 fan speed for each engine. In case of one aircraft with 4 engines, it indicates, N11, N12, N13 and N14.

The Annex 2 of this document (List of recommended parameters) provides a full description of the parameters that are necessary to be recorded in order to program the precursors defined in this document.

Measurements and Events

This section contains the description of fundamental entities for the flight data monitoring process and is summarised in tables such as in the example below:

Search Window	Measurements	Event	Event Threshold
Takeoff	***COUNT*** = Number of seconds discrete is active	"Master Warning During Takeoff"	Raise event if ***COUNT*** > 1
Takeoff – 60sec Until start of Takeoff	***NA***	"Slat/Flap Change 60 seconds before Takeoff"	Raise event if any movement on the Flap/Slat Lever is produced.

The objective of the table above is to provide an answer to the following questions:

When to measure?	Search window
What is the value that needs to be available for analysis?	Measurements
How to detect deviations from normal operation?	Event
How to establish the limit to identify the deviations?	Event Threshold

Search Window – provides the logic conditions to determine where to proceed with a measurement or detect one event. The flight phases as normally defined on FDM software tools are here used as a base reference to indicate the area where the search is to be performed. When a more specific condition is necessary, the logic is explained in this column (see example on table above).

Measurements – Quantities extracted during the flight profile that may reflect calculations performed on parameters such as average, maximum and minimum or specific snapshots at certain points of the flight. Examples: maximum EGT during takeoff, ground speed at touch-down, difference between ENG1 N1 and ENG2 N1, etc.

Events / Event Threshold – Parameters and measurements can be directly compared with pre-defined thresholds which when exceeded result in "events". These correspond to deviations from normal operation according to the operator's SOPs, from the airframe structural limits, or from engine limitations.

Whenever there is the need to complement with additional information or more deep content, a set of notes can be used to provide this content.

Future Developments and Recomendations

When it is assumed that FDM by itself is not sufficient to provide a complete solution to address a precursor, other sources of information are needed, aircraft parameters or advanced algorithms must be implemented, this is left to the section about future developments and recommendations.

Maturity Levels

The Maturity Level is the evaluation of implementation of precursors throughout Working Group members. The goal for all precursors is to escalate to Level 2 according to the definition in Table 1 - Maturity Levels.

Table 1: maturity levels.

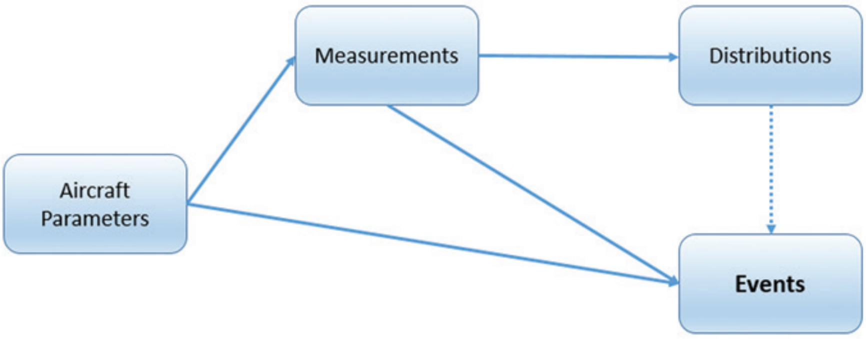
Level	Description
2	WG-B has proposed a solution and it has evidence that the proposed solution (or similar) is already implemented in the industry for at least one aircraft type.
1	WG-B has proposed a solution, but was unable to gather evidence of its implementation in the industry. In most cases, the description is theoretical or intentionally made in general terms since it may also depend on future technology, special types of data or analysis techniques yet to be developed or tested.
0	WGB was unable to address WGA recommendation either because of lack of time, could not find a way to solve the problem or has to get some inputs from other areas (meteorology, aircraft systems, etc). In either case, this is a way to let the industry know that there is a safety concern which needs further work and/or an innovative idea.

It is assumed by the working group members that there is the capability in the operators to produce the FDM analysis as described in this document or by equivalent methods. The goal of the maturity level is to reflect the status of this implementation within the community. Due to constraints related to the decision from the working group about focusing on different objectives, the exact level of maturity in each operator was not yet assessed. For this reason, the working group decided to assign one conservative value of Level 1 to most of the precursors. This figure is to be used for control of this document and does not reflect the maturity of FDM programmes in general.

Methodology for Flight Data Monitoring

The representation of the building blocks for one FDM programme is described in Figure 1 - FDM Programme basic entities., The Aircraft Parameters represent the entry point and correspond to the data collected from the FDM recorders. These are used for the measurement calculations, its distributions and the analysis of deviations using the events. All these concepts are important and deeply interconnected.

➨ **Figure 1:** FDM programme basic entities.



The Measurements result from calculations performed on the parameters, such as the average, maximum, minimum or any other quantity derived as a function of one or several parameters. As an example, the parameter EGT (Exhaust Gas Temperature) is available on different fleets. Normally its maximum value during takeoff is determined, and this corresponds to a measurement performed on the parameter. This identifies the margin to EGT limit, which is one possible indicator for engine degradation and can consequently be used to generate one event in case this limit is exceeded.

The setting of thresholds is one important way to increase the benefit from the FDM programme by adapting to the specificities of the operation. The FDM software vendor or the aircraft manufacturer may have already some values set, but normally these can be changed to reflect the operator´s needs.

The thresholds can be selected in various ways:

1. Airworthiness or other physical or maintenance-related limits (AFM, AMM or other OEM documentation)
2. Internal procedures (SOP), or external or industry recommendation (if not transposed to SOP)
3. Detection of outliers (Using measurements distributions)

The Figure 1 - FDM Programme basic entities:

– Illustrates how events are triggered (diagram boxes)
– Proposes criteria for setting thresholds: airworthiness, SOP or external or industry recommendation, detection of outliers (table)

Here are some examples:

1) The structural limit to hard landing is an airworthiness limitation. It is set at 2.6g for the Airbus A320 fleet and when this value is reached, some maintenance action must be performed before releasing the aircraft. In order to proactively detect trends, the threshold should be set to a lower value, so that the event becomes a possible precursor to hard landings, ultimately avoiding these from occurring. If the FDM software allows, different levels of severity for the event can be included, using thresholds increasingly closer to the hard limit, which will normally be used for the higher severity event (example: level 3, Red event), etc.). The same methodology is valid for the Vmo, flap placard speed, gear operation speed, engine temperatures, maximum flight load, etc[2].

2) The criteria for unstable approach, maximum sink rate on approach or taxi speed are SOP limitations. These relate to actions or boundaries that are decided by the operation and considering the internal risk assessment. The lower threshold can be set at or slightly above or below the SOP value, depending whether you accept very small exceedances or prefer to be conservative. Thresholds for higher severity events can be set considering the risk assessment from the operator or simple rules like +10%, +20%.

3) Measurements or parameters that are not bound by any specific document or procedures can still be used to highlight abnormal instances. For example, the vertical and lateral accelerometer readings can be used to detect possible turbulence encounters, while the maximum airborne roll and pitch rates can be useful to highlight possible wake turbulence events. There are no absolute references for these parameters, so an alternative is to plot the distribution of values (typically in one histogram). These will immediately show what the typical range for that parameter or measurement is. You may decide based solely on that information or investigate which is the value that will return a certain percentage of flights, let's say 0.1%. This assessment needs to be done considering what your actions will be when finding these events. Note there may be interesting values on both tails of the histogram.

Independently of the methodology, the operator needs to perform a validation of the events that are being generated. False positives may appear due to bad data or noise but also if there is a high rate of events, maybe the threshold was not set with a suitable value and it needs to be evaluated again. False negatives are a difficult problem to solve, but one obvious way is to verify if occurrences subject to ASRs are being detected by the software.

The best practices written in this document are the result of different experiences and the proposed thresholds that are valid for one operator may not be appropriate for others with a different kind of operation. It is up to each operator to find the values that make sense from a safety perspective.

As a general guidance, the thresholds for safety should be more conservative than the thresholds determined by aircraft manufacturers for triggering continued airworthiness activities (inspection, repair, etc) or by SOP, so that there is the opportunity to track trends from the FDM programme. The values presented in this document are not prescribed by the working group B, however, they reflect what members of the working group consider to be best practice.

2 Setting the threshold to a lower value than the structural limit does not prevent the events with higher thresholds that impact the Continuous Airwothiness, to be detected and properly forwarded to the relevant area within the operator.

Runway Excursions (RE)

Runway Excursion is defined in the document from CAST/ICAO taxonomy team which is titled "Aviation Occurrence Categories".[3]

Each recommendation identified by working group A (WGA), corresponds to a possible precursor for a *Runway Excursion* incident or accident. The current chapter presents the algorithms proposed by working group B to address each of the recommendations identified.

3 The document can be found on the link: http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf

RE01 – Incorrect Performance Calculation

Summary

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.

Rationale

The method proposed to address this precursor relies on the assessment from the pilot on not having the correct power to perform the takeoff. In this case, any movement of the throttle levers during the takeoff run is detected and a corresponding event generated. This approach requires that a human analyst validates the real reasons for this behaviour and identify those that may be due to any performance error.

Erroneous data entry in the FMC is a typical area of concern when dealing with aircraft performance. Invalid values of OAT[4] can be accepted by some FMC units leading to the wrong calculation of results, such as thrust targets (N1 Limit) or the takeoff speeds, V1, Vr, and V2. This case is illustrated in the Serious Incident report from AAIB from a B737-800, C-FWGH on 21st July 2017. In this incident a wrong OAT insertion in the FMC produced the wrong calculation of the thrust target for takeoff, resulting in a low acceleration during the run and invalidating the performance speeds calculations.

This is a case that supports the need in terms of FDM for the comparison of temperatures inserted into the FMC and the readouts from other sources, namely the ADC. Other fleets may rely on different temperature input, such as Flex temperature, but the same principle of comparison should be applied, in order to detect differences in the OAT above a pre-established threshold. The main goal is to provide a warning to the safety analyst, to proceed with further investigations.

The push forward of the Thrust levers during takeoff roll or climb as an indication of lack of performance is also supported by this serious incident.

It is important to emphasise that after a wrong input is entered in the FMC, the resulting calculations become invalid, with potentially catastrophic consequences.

The Incorrect Performance Calculation is also addressed in LOC10.

Aircraft Parameters

Parameter	Type
Eng (*) Thrust Lever Angle (TLA)	Analogue
FMS_Temp (Note 1)	Analogue
Static Air Temperature	Analogue

Note 1: This can be OAT or FLEX or other, depending on the fleet. It corresponds to the outside temperature or one assumed temperature for the FMS to perform its calculations.

4 OAT – Outside Air temperature. Depending on the parameters available this can be SAT (Static Air Temperature) or TAT (Total Air Temperature). For the definition of events SAT will be used.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff + Climb	***DeltaTLA*** = TLA – TLA(-1) (Note 1)	"Thrust lever Increase During Takeoff roll or Climb"	Raise event if ***DeltaTLA*** > 0
Takeoff	***DeltaTLA*** = TLA – TLA(-1) (Note 1)	"Thrust lever Decrease During Takeoff"	Raise event if ***DeltaTLA*** < 0
Takeoff	***Delta_Temp*** = FMS_temp - SAT	"Abnormal Input Temperature"	Raise event if ***Delta_Temp*** > Threshold

Note 1: The indication of (-1) stands for the value of the previous sample. This number can change to control the number of false positives and more samples may be considered provided that there is clear indication of the parameter trend.

Future Developments and Recommendations

In order to fully address this precursor, some external information is needed to complement FDM. It is important to access the value of VSpeeds from their calculation and also the values introduced on the FMS system by the pilots. Human error is possible, both in the computation and in the manual insertion of the values. This is normally mitigated by the separate calculation from both pilots and the resultant cross-check.

The following sources are recommended to be integrated into the FDM system, in order to have a full coverage of this process:

- **Electronic Flight Bag Database** – Provides information on the calculations for the performance parameters. It allows FDM to compare with the recorded data (manually inserted) and detect any possible introduction errors.
- **Runway Information Database** – Contains information about runway lengths, thresholds positions and other supporting information not only to this precursor but for others in the remaining of this document.
- **Weather Database** – Information about weather conditions for the flight. All related information, METARS, ATIS, etc. This information should reflect the weather and runway conditions in an accurate way. Outdated information may not reflect the actual conditions of the operation.

All the Flight Management System parameters related to performance should be part of the dataframe. This recommendation is also supported by AAIB Incident investigation provided in the link below.

- https://assets.publishing.service.gov.uk/media/5422fefb40f0b613420008fd/Airbus_A340-313_4R-ADG_12-12.pdf.

Maturity Level

Level 1

RE02 – Inappropriate Aircraft Configuration

Summary

Develop means to detect inappropriate aircraft configurations (lifting devices, pitch trim) which could cause takeoff and landing performance problems; Not all aircraft are equipped with takeoff configuration warning systems and some of these systems can't detect all types of configuration errors.

Rationale

The events proposed for dealing with this precursor are presented on the list below. Any one of these occurrences may generate a warning by itself during takeoff depending on the fleets. Splitting all possible causes into individual events allows a direct evaluation of which misconfiguration was present during the takeoff and possibly the cause of any occurrence during this flight phase.

- Master Warning During takeoff
- Slat/Flap Configuration out of takeoff limits
- Autobrakes not selected to the maximum
- Spoilers armed and at least one is out
- Stabilizer Trim out of takeoff limits
- Brake Temperature Overheat
- Side-Stick Not in takeoff configuration
- Trim Horizontal Stabiliser (THS) Displaced During takeoff
- Slat/Flap Change During takeoff
- Slat/Flap Change 60 sec Before takeoff

Aircraft Parameters

Parameter	Type
Master Warning	Discrete
Brake (*) Temp	Analogue
Autobrake Selection	Discrete
Ground (*) Spoiler Out	Discrete
Stabiliser Trim Position	Analogue
Flap/Slat Lever Position	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***COUNT*** = Number of seconds discrete is active	"Master Warning During Takeoff"	Raise event if ***COUNT*** > 1 (Note 1)
Takeoff	***MaxBrakeTemp*** = Maximum Brake Temperature	"High Brake Temperature during Takeoff"	Raise event if ***MaxBrakeTemp*** > Threshold (Note 1)
Takeoff	***CurrConf*** = Current Slat/Flap Configuration	"Slat/Flap Configuration out of Takeoff limits"	Raise event if ***CurrConf*** ≠ Threshold (Note 2)
Takeoff	***NA***	"Autobrakes not in Maximum"	Raise event if Autobrake Selection is not in Maximum during Takeoff
Takeoff	***NA***	"Spoilers not Armed"	Raise event if Spoilers not Armed during Takeoff
Takeoff	***COUNT*** = Number of seconds discrete is active	"Spoiler Out During Takeoff"	Raise event if ***COUNT*** > 1 (Note 1 and 3)
Takeoff	***TO_TrimPos*** = Takeoff Trim Position (Note 3)	"Stabiliser Trim Out of Takeoff Limits"	Raise event if ***CurrStabPos*** ≠ Threshold (Note 2)
Takeoff	***TO_TrimPos*** = Takeoff Trim Position (Note 4)	"Stabiliser Displaced During Takeoff"	Raise event if ***CurrStabPos*** ≠ ***TO_TrimPos*** during Takeoff
Takeoff	***COUNT*** = Number of seconds discrete is active	"Side Stick Fault"	Raise event if ***COUNT*** > 1 (Note 1 and 5)
Takeoff	***TO_Config*** = Takeoff Slat/Flap Configuration (Note 6)	"Slat/Flap Change during Takeoff"	Raise event if ***CurrConf*** ≠ ***TO_Config***
Takeoff – 60sec until start of Takeoff	***NA***	"Slat/Flap Change 60 seconds before Takeoff"	Raise even if any movement on the Flap/Slat Lever is produced.

Note 1: The value of the threshold can increase to control the number of false positives.

Note 2: In this case, the Threshold represents the set of normal values that the surface may have during takeoff. It can be more than one value, and in this case an "OR" condition is necessary to add to the code or a range, and in this case, the limitation within the limits is necessary.

Note 3: In combination with the event "Spoilers not armed", allows the assessment of "Spoilers Armed AND at least one is out".

Note 4: This measurement is extracted from the Stabiliser Position parameter when the takeoff starts. The value is stored to be compared with the stabiliser position parameter during the takeoff run. Any difference indicates that there was a movement of the horizontal stabilizer during the takeoff and the corresponding event is produced.

Note 5: For fleets where side-stick does not exist, the corresponding signal from the control column is to be used in this event.

Note 6: Saving Configuration position at the beginning of takeoff. The same reasoning as Note 4. Alternatively this event can be detected using the Flap/Slat Lever position. Any movement during takeoff can be detected and the corresponding event generated.

Maturity Level

Level 1

RE03 – Monitor CG Position

Summary

Develop means to detect CG out of limits on takeoff or not consistent with pitch trim settings.

Rationale

The centre of gravity position and its misplacement are addressed in more detail on Loss of Control In -Flight (LOCI) chapter of this document (see LOC08 for a full description).

While for LOCI, the position of the CG can be a precursor in both situations when it is abnormally forwards or afterwards, in the case of runway excursions only the first case can be considered as a precursor, as it may lead to the sensation of heavy aircraft and not allowing a proper and timely lift off of the airplane.

- To address the current precursor, the same rationale used for LOC08 will be applied, but limited to the following events, which are the relevant ones for runway excursions:
  - CG beyond Fwd Limit
  - Possible Trim Error

The full description is available on LOC08.

Maturity Level

Level 1

RE04 – Reduced Elevator Authority

Summary

Develop means to detect abnormal rotation in response to elevator inputs, reduced elevator movement or excessive force required to move elevator surfaces.

Rationale

The driver for this precursor determination is the FAA Safety Alert for Operators (SAFO 01001) and EASA Safety Information bulletin (SIB 2010-28). These documents are provided in the link below:

- http://ad.easa.europa.eu/ad/2010-28

This document states that for unpowered elevator control surfaces require higher control forces for proper rotation after treatment with certain types of anti-ice fluids (see the document to complete reference).

As there is no assessment of the level of surface contamination which may indicate one abnormal lift-off, the solution for this precursor relies on a similar approach as proposed for LOC28, specifically on the events:

- Control Column Force High
- Control Column Stiffness High
- Elevator and Control Surface Mismatch

Full description on Loss of Control In-Flight Chapter of the current document.

Maturity Level

Level 1

RE05 – Slow Acceleration

Summary

Develop means to measure acceleration during the takeoff roll and detect abnormal values, taking consideration the various factors that affect the takeoff performance.

Rationale

One of the most common reasons for insufficient acceleration is incorrect FMS inputs (aircraft empty mass, fuel quantities, runway length amongst other parameters). This will affect the takeoff performance calculations and precipitate the inappropriate use of de-rated takeoff power settings, leading to the slow acceleration and potentially to a runway overrun. Incorrect FMS inputs are difficult to detect using flight data; the same applies to abnormal acceleration on takeoff because the relevant data is typically not available in official aircraft performance manuals.

One possible approach to detect reduced acceleration on takeoff (which may include cases of incorrect FMS inputs) is to build a statistical regression model using historical data, which will hopefully provide us with a reference acceleration value given a certain set of conditions.

This method will lead to the calculation of a predicted acceleration according to a mathematical model. This value can be directly compared with the longitudinal acceleration recorded on the data stream, and a possible event be generated.

The mathematical model can be built based on the following reasoning:

The longitudinal acceleration of an aircraft during takeoff is affected by several factors including weight, power settings, temperature, airport altitude, flap setting, etc. Opposite to some other takeoff and landing performance reference values, like V1, V2, VR or VREF, the expected longitudinal acceleration on takeoff is not commonly tabulated in the aircraft documentation. Given the physics involved, obtaining this value is a complex task, as it is multivariable-dependent, and will need to be calculated dynamically for each flight.

As referred above, one possibility is to build a regression model using historical data. This concept is an elaboration of other types of performance related event definitions which are more commonly available in FDM software tools, such as *High Airspeed on Approach*: with aircraft that do not record the target approach speed on the data stream, the FDM software tool can calculate the appropriate VREF using the recorded flap setting and aircraft weight; the instantaneous airspeed is then compared against this value.

Aircraft Parameters

Parameter	Type
Altitude Standard	Analogue
Gross Weight (Note 1)	Analogue
Static Air Temperature (Note 2)	Analogue
Eng (*) EPR (Note 3)	Analogue
Flap/Slat Lever Position	Analogue
Acceleration Longitudinal	Analogue

Note 1: Because wrong FMS weights are one of the causes for problems, one should assess carefully which source to use for weight (FMS, Flight Plan or other).

Note 2: Alternatively use “Total Air Temperature”.

Note 3: Alternatively use “Eng (*) N1” to have one assessment of Engine Thrust.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***Weight_80KT*** = Gross Weight @ 80 Knot ***PALT_80KT*** = Altitude Standard @ 80 Knot ***SAT_80KT*** = Static Air Temperature @ 80 Knot ***EPR_80KT*** = Engine Pressure Ratio @ 80 Knot ***FLAP_80KT*** = Surface Configuration @ 80 Knot ***LONG_80KT*** = Longitudinal Acceleration @ 80 Knot (Note 2)	“Longitudinal Acceleration Prediction Mismatch”	Raise event if ***LONG_80KT – PRED_LONG_80KT*** > Threshold (Note 1 and 3)

Note 1: The value of the threshold can increase to control the number of false positives

Note 2: The best speed to be used as a reference for the 80 Knot value extraction is the Ground Speed. Should be preferred to any derived from barometric pressures which are less stable during takeoff.

Note 3: The value of PRED_LONG_80KT refers to the predicted acceleration at the speed of 80 knot and can be obtained using the formula:

PRED_LONG_80KT = C1·WEIGHT_80KT+C2·PALT_80KT+C3·SAT_80KT+C4·EPR_80KT+C5·FLAP_POS_80KT

The coefficients C1 to C5, are calculated when the model is first built and should not require recalculation unless there is a significant change to the aircraft performance (e.g. new engines, BEW – Basic Empty Weight or take-off technique).

The coefficients C1 to C5, are calculated when the model is first built and should not require recalculation unless there is a significant change to the aircraft performance (e.g. new engines, BEW – Basic Empty Weight or take-off technique).

The measurement of acceleration can be done at any instance (examples: at the maximum acceleration or at a specific speed), which will be defined while developing the model. In the example above, the decision was to use longitudinal acceleration at 80kt. This means that the inputs to the model should take that into consideration (should be measured at the same instant).

Once the estimated value of acceleration is calculated, it can be compared against the measurement value. If a significant difference exists between the estimated and measured values, the corresponding event should be the triggered to allow additional investigation and validation. This should enable to understand the causes.

A sample of the results, based on one operator's experience, can be seen below:

Flight ID	Actual Acceleration	Estimated Acceleration	Difference
1	0.3603456	0.3596766	0.0006690
2	0.353600	0.3509070	-0.0026929
3	0.3858048	0.3875163	0.00171145
4	0.313344	0.3145062	0.00116221
5	0.256768	0.2552293	-0.0015387

Future Developments and Recommendations

Add definitions for events (detected by other means) that can create outliers of the statistical model.

Maturity Level

Level 1

RE06 – Aircraft Malfunction

Summary

Develop means to detect aircraft malfunctions which are likely to cause rejected takeoffs, (e.g. Master Warning and Master Caution alerts and airspeed indication disagreements)

Rationale

There are numerous types of aircraft malfunctions that could cause rejected takeoffs. In general, these failures are serious enough to trigger a Master Warning or Master Caution alert in the cockpit. The proposed solution is based on the assumption that these alerts are recorded on the flight data stream and are appropriate to high-light the situations that should cause the takeoff to be aborted.

The understanding of the actual causes for the Master Warning or Master Caution alert will normally require access to information not included in the flight data stream. However, the tracking of these events should be enough to prompt a subsequent investigation.

Aircraft Parameters

Parameter	Type
Master Warning	Discrete
Master Caution	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***COUNT*** = Number of seconds discrete is active	"Master Warning During Takeoff"	Raise event if ***COUNT*** > 1
Takeoff	***COUNT*** = Number of seconds discrete is active	"Master Caution During Takeoff"	Raise event if ***COUNT*** > 1

Maturity Level

Level 1

RE07 – Late Rotation

Summary

Develop means to detect rotations conducted after Vr or beyond the expected distance (or time) after the start of the takeoff roll.

Rationale

This precursor evaluates the time it takes from the point where rotation should start, i.e., when the Indicated Airspeed assumes the value of the rotation Speed (Vr) and the point of liftoff from the Main Landing Gear.

Aircraft Parameters

Parameter	Type
Indicated Airspeed (Note 1)	Analogue
Vr (Note 2)	Analogue

Note 1: During takeoff IAS may be unstable and better results may come up from the use of the "Ground Speed" instead of IAS.

Note 2: In case the Rotation Speed (Vr) is not recorded, other means are valid to access this speed (See RE01, Future Developments)

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***Trot*** = Rotation Time (Since IAS=Vr to Liftoff)	"Late Rotation"	Raise event if ***Trot*** > Threshold (Note 1)

Note 1: The value of the threshold may be set by reference to historical trend.

Maturity Level

Level 1

RE08 – Slow Rotation

Summary

Develop means to detect slow rotations

Rationale

Measure the time within the first Elevator input and Lift-Off. This corresponds to the rotation time and will be referenced in the document as *Trot*.

Special care should be taken on the determination of the first elevator input. The instant may not be evident to determine from the control column or side-stick pitch control. Other methods can be used such as:

- Extract the reference value from a pool of significant flights
- Use the pitch rate parameter
- This extraction may be facilitated if the SOP indicates that the elevator control should be pushed forward during the takeoff roll.

Aircraft Parameters

Parameter	Type
Pitch Command	Analogue
Pitch Rate	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***Trot1*** = Rotation Time 1 (Since the application of the first Elevator input to Liftoff)	"Long Time During Liftoff"	Raise event if ***Trot1*** > Threshold (Note 1)
Takeoff	***NA***	"Low Pitch rate During Liftoff"	Raise event if ***Pitchrate*** < Threshold (Note 1)

Note 1: The value of the threshold can increase to control the number of false positives.

Maturity Level

Level 1

RE09 – No Liftoff

Summary

Develop means to detect late Lift-Off (in time and/or distance) after rotation or start of Takeoff roll.

Rationale

This precursor evaluates the distances run by the aircraft since the application of takeoff power until each of the performance speeds V1 and V2 are attained. These distances will be named in this document as DV1 and DV2 respectively.

It is proposed a check from each of these distances against the available distances for takeoff, ASDA and TODA in a way that:

- DV1 is compared with ASDA
- DV2 is compared with TODA

For this solution to be implemented, an external source of information concerning the Runway Database is necessary (see RE01, Future Developments).

Aircraft Parameters

Parameter	Type
Ground Speed (Note 1)	Analogue
Indicated Airspeed (Note 2)	Analogue
V1 (Note 3)	Analogue
V2 (Note 3)	Analogue

Note 1: To be used to perform the distance calculation by its integration over time. The position (LAT/LONG) and also be used to determine the distance.

Note 2: During takeoff IAS may be unstable and better results may come up from the use of the “Ground Speed” instead of IAS.

Note 3: In case the performance speeds (V1 and V2) are not recorded, other means are valid to access these speeds (See RE01, Future Developments).

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***DV1*** = Distance from the application of Takeoff Power until the speed attains V1	“ ASDA short limit”	Raise event if ***DV1*** > Threshold
Takeoff	***DV2*** = Distance from the application of Takeoff Power until the speed attains V2	“ TODA short limit”	Raise event if ***DV2*** > Thersold

Maturity Level

Level 1

RE10 – Rejected Takeoff

Summary

Develop means to identify rejected takeoffs.

Rationale

Rejected Takeoff RTO is identified by the following conditions, happening during the takeoff flight phase:

- Decrease of Thrust Lever Position
- Sudden Power Reduction
- Brake Pressure Application
- Aircraft Groundspeed Decrease

Some FDM software programmes may have difficulty with this, as for a RTO the programme may not recognize the data as a complete flight and thus classify it accordingly. All Software vendors should be approached to see if it is feasible for a RTO to be recognized as complete flight without throwing up a lot of false positives. The issue may be one of differentiating between maintenance activity (e.g. high power ground runs) and a genuine RTO, particularly if the RTO is at low speed. This should be a *nice-to-have* feature, but not mandatory.

High Speed RTOs should be comparatively easier to detect. Low speed RTOs could be problematic.

Aircraft Parameters

Parameter	Type
Eng (*) Thrust Lever Angle (TLA)	Analogue
Eng (*) N1	Analogue
Eng (*) EPR	Analogue
Ground Speed	Analogue
Brake (*) Pressure	Analogue
Brake (*) Pedal Position	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***DeltaTLA*** = TLA – TLA(-1) ***DeltaGS*** = GS – GS(-1) ***DeltaPower*** = EngPower – EngPower(-1) ***BrakeApp*** = Brake Application (Note 1 and 2)	“Rejected Takeoff”	Raise event if ***DeltaTLA*** < 0 OR ***DeltaGS*** < 0 OR ***DeltaPower*** < 0 OR ***BrakeApp***

Note 1: The indication of (-1) stands for the value on the second before. This number can change to control the number of false positives or more samples may be considered provided that there is clear indication that there was movement on the throttle levers.

Note 2: Engine power can be determined either by N1 or EPR depending on the engine type. Brake application can be derived either from Brake Pedal Position or Brake Pressure.

Maturity Level

Level 1

RE11 – Runway Remaining After Rejected Takeoff

Summary

Develop means to estimate runway remaining ahead of the aircraft after the start of the Rejected Takeoff and to estimate ground distance spent during the RTO

Rationale

This precursor is dependent on the generation of a Rejected Takeoff event. The logic for this detection is addressed on precursor RE10.

Each time a RTO is detected, a measurement of the distance from where it was detected until the end of the Runway is performed. This distance will be designated in this document as ***Drem*** (remaining distance).

For this solution to be implemented, the calculation of ***Drem*** will rely on the availability of information about the End of Runway coordinates. This requires that the Runway Database is providing this input to the FDM System (see RE01, Future Developments). Both the coordinates of the point where RTO was detected and the End of Runway are the used to determine the remaining distance.

Aircraft Parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
When a RTO is detected (RE10)	***Drem*** = Distance from the RTO detection point to the End of the Runway	"Short Remaining Distance after RTO"	Raise event if ***Drem*** < Threshold

Maturity Level

Level 1

RE12 – Inadequate Use of Stopping Devices

Summary

Develop means to identify late or inadequate activation of thrust reverser, brakes, airbrakes or other stopping devices during rejected takeoffs and landings.

Rationale

This precursor considers the following scenarios:

- Ground Spoiler Deployment
- Time to Thrust Reverse Application
- Time to Brake Application
- Speed brakes NOT Armed prior to landing
- Reverse Thrust Asymmetry

Aircraft Parameters

Parameter	Type
Ground (*) Spoiler Out	Discrete
Reverse (*) Deployed	Discrete
Speed Brakes Armed	Discrete
Brake (*) Pressure	Analogue
Brake (*) Pedal Position	Analogue
Eng (*) Thrust Lever Angle (TLA)	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***COUNT*** = Number of seconds discrete is active	“Ground Spoiler Deployment”	Raise event if ***COUNT*** > 1 (Notes 1)
Landing	***Treverse*** = Time between Touchdown and Reverse Deployed	“Time to Thrust Reverse Application”	Raise event if ***Treverse*** > Threshold
Landing	***Tbrake*** = Time between Touchdown and First Brake Application (Note 2)	“Time to Brake Application”	Raise event if ***Tbrake*** > Threshold
Before Landing	***NA***	“Speed Brakes not Armed prior to Landing”	Raise event if ***Speed Brakes Not Armed*** in the search window
Landing During Reverse Application	***Diff_TLA*** = TLA_Eng1 – TLA_Eng2	“Reverse Assymetry”	Raise event if ***Diff_TLA*** ≠ 0 (Note 3)

Note 1: **The value of the threshold can increase to control the number of false positives.**

Note 2: Brake application can be determined either by Brake Pressure or Brake Pedal Position parameters.

Note 3: A small margin may be considered instead of zero if there exists an offset in any of the sensors.

Maturity Level

Level 1

RE13 – Insufficient Deceleration

Summary

Develop means to detect slow deceleration after landing or RTO, taking into consideration the various factors that affect the landing and RTO performance.

Rationale

This precursor is to be addressed by calculating the distance between the Touchdown point and when the aircraft attains the speed of 80 Knot during the deceleration run..

The High-speed taxiways are to be excluded from this calculation as these represent a different reality. This separation can be achieved using the Aircraft Heading during the run not diverging significantly from the landing Runway Heading. This difference in Headings allied with the speed this action takes place will provide the information to separate these landing rolls.

Aircraft Parameters

Parameter	Type
Ground Speed (Note 1)	Analogue

Note 1: To be used to perform the distance calculation by its integration over time. Alternatively, positions can be used to determine the distance.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	***D80*** = Distance between Touchdown and when the speed is 80knot during the landing roll.	"Insufficient Deceleration on Landing"	Raise event if ***D80*** > Threshold
Rejected Takeoff	***Drto*** = Distance between the RTO detection and when the speed is 30knot during the landing roll	"Insufficient Deceleration on RTO"	Raise event if ***Drto*** > Threshold

Future Developments and Recommendations

Application of the method described in:

Runway Excursion Risk Assessment Diagram

Pere Fabregas Camara

Flight Safety Foundation / FSF 64th Annual IASS, Singapore, November 2011

Maturity Level

Level 1

RE14 – Engine Power Increase

Summary

Develop means to detect engine power increase during the takeoff roll.

Rationale

The increase of power during takeoff was addressed in RE01 within the context of an indirect indication of abnormal performance settings. In the current precursor, the situation where full power is applied still during the end of taxi-out but with the aircraft not yet aligned with the runway.

Aircraft Parameters

Parameter	Type
Eng (*) Thrust Lever Angle (TLA)	Analogue
Heading True	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Taxi-out (Before runway alignment)	***DeltaTLA*** = TLA – TLA(-1) (Note 1)	"Power applied before runway allignment"	Raise event if ***DeltaTLA*** > Threshold AND Heading True ≠ Runway Heading (Note 2)

Note 1: The indication of (-1) stands for the value of the previous sample. This number can change to control the number of false positives and more samples may be considered provided that there is clear indication of the parameter trend.

Note 2: Runway Heading has to be obtained from external sources. Some margin may be incorporated between both headings.

Maturity Level

Level 1

RE15 – Runway Remaining at Liftoff

Summary

Develop means to estimate runway remaining ahead of the aircraft at the moment of liftoff and detect abnormal values

Rationale

Each time a Liftoff is detected, a measurement of the distance from where it happen until the end of the Runway is performed. This distance will be designated in this document as ***Dlift*** (remaining Liftoff distance).

For this solution to be implemented, the calculation of ***Dlift*** will rely on the availability of information about the End of Runway coordinates. This requires that the Runway Database is providing this input to the FDM System (see RE01, Future Developments). Both the coordinates of the point where Liftoff was detected and the End of Runway are the used to determine the remaining distance.

Aircraft Parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***Dlift*** = Distance from the Liftoff detection point to the End of the Runway	"Short Remaining Distance after Liftoff"	Raise event if ***Dlift*** < Threshold

Maturity Level

Level 1

RE16 – Aircraft Handling

Summary

Develop means to monitor the use of aircraft controls (rudder and nose wheel steering) and brakes during the takeoff, rejected takeoff, and landing and detect non-standard cases . In addition, monitor simultaneous control inputs of both flight crew and analyze their potential negative influence on safety.

Rationale

In this topic, it is assumed that a number of events may indicate incorrect technique, but contextual data may be used to support any further investigation.

This precursor is to be addressed using the information on:

- Brake application during takeoff
- Rudder use at low speed
- No forward Side-Stick on takeoff
- Into-Wind Aileron
- Braking Asymmetry
- Rejected takeoff after V1
- Dual Input (Note 1)

Note 1: See LOC30 which monitors Dual Input for the whole flight

Aircraft Parameters

Parameter	Type
Brake (*) Pedal Position	Analogue
Rudder	Analogue
Rudder Pedal	Analogue
Pitch Command	Analogue
V1	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***TimeUsingBrakes*** = Total Time Using Brakes During Takeoff. (Note 1)	"Brake Application During Takeoff"	Raise event if ***TimeUsingBrakes*** > Threshold
Ground Phases Takeoff Landing	***TimeUsingRudder*** = Total Time Using Rudder on Ground For Ground Speed < Threshold. (Note 3 and 4)	"Rudder use at low speed" (Note 2)	Raise event if ***TimeUsingRudder*** > Threshold
Takeoff	***SumPitchCmd*** = Sum of Pitch Command values during Takeoff Run. (Note 6)	"No Forward Side-Stick during Takeoff" (Note 5)	Raise event if ***SumPitchCmd*** < Threshold
Takeoff Landing (Note 8)	***NA***	"Into-Wind Aileron" (Note 7)	Raise event if Any Aileron use during the search window.
Ground Phases	***DiffBrakePedal*** = BrakePedal_L – BrakePedal_R (Note 9)	"Braking Asymmetry"	Raise event if ***ABS(DiffBrakePedal)*** > Threshold
Takeoff	***RTO_Speed*** = Aircraft Ground Speed when RTO is determined.	"Rejected Takeoff after V1"	Raise event if ***RTO_Speed*** > V1 (Note 10)

Note 1: The usage of Brakes can be determined either by Brake pedal Position or Brake Pedal position or both.

Note 2: This event identifies when the rudder has been used at low speeds where nose-wheel steering would be more effective.

Note 3: Threshold for the speed is dependent on the fleet. For each aircraft type the minimum speed for which nose wheel steering is more effective than rudder should be used here. The time for the use of rudder below this peed is summed on measurement ***TimeUsingRudder***

Note 4: The usage of Rudder can be determined either by the Rudder Surface Position parameter (Rudder) or Rudder Pedal position parameter or both.

Note 5: This event identifies when no forward Side-Stick (SS) input is made during the takeoff roll (in accordance with Airbus SOP).

Note 6: Care should be taken to identify the Pilot Flying which is the only with a resulting number from this sum (Positive number for Airbus fleet). Pilot Non-Flying is expected to have a zero result.

Note 7: This event identifies if a significant Into-Wind Aileron input happens while a crosswind takeoff is being performed. The conception of this event is according to Airbus SOP transcribed below:

Airbus aircraft (Text from Airbus Flight Crew Operations Manual)

For crosswind takeoffs, routine use of into wind aileron is not recommended. In strong crosswind conditions, some lateral control may be used, but care should be taken to avoid using large deflections, resulting in excessive spoiler deployment which increases the tendency to turn into the wind, reduces lift and increases drag. Spoiler deflection starts to become significant with more than one third sidestick deflection. As the aircraft lifts off, any lateral control applied will result in a roll rate demand

Another fleet with different aerodynamic conception, may require some Aileron input and this event has to be redesigned for those conditions.

Note 8: Takeoffs and landings performed in strong crosswind conditions (see Note 7). Crosswinds are addressed on RE17.

Note 9: Necessary Pedal Position for Left and Right pedals available independently. The use of the pedal positions directs this event to the inadequate aircraft control. Braking asymmetry will be revisited on RE21 with a different perspective, making use of brake pressure, indicating a possible system malfunction.

Note 10: V1 may be recorded on the datastream or recovered from an external source. See RE01, Future Developments.

Maturity Level

Level 1

RE17 – Crosswind

Summary

Develop means to estimate crosswind during takeoff, approach and landing and detect abnormal values.

Rationale

Crosswinds can be identified using the left and right values of Angle of Attack (AOA). When there are strong crosswind conditions these values diverge instead of the same value that is normally present on both sensors when operating in steady conditions.

Aircraft Parameters

Parameter	Type
Angle of Attack (L + R)	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff Approach Landing	***DeltaAOA*** = AOA_Left – AOA_Right	"Crosswind"	Raise event if ***ABS(DeltaAOA)*** > Threshold

Maturity Level

Level 1

RE18 – Forward Thrust Asymmetry

Summary

Develop means to identify forward thrust asymmetry during the takeoff roll.

Rationale

The Thrust from the engines on both sides of the aircraft, when it is uneven, will provide the measurement of asymmetry. From this measurement, the corresponding event can be generated when compared to a Threshold.

Aircraft Parameters

Parameter	Type
Eng (*) N1 (Note 1)	Analogue

Note 1: Depending on the fleet, the thrust parameter can be EPR.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***DiffEngN1*** = N1_Eng1 – N1_Eng2 (Note 1)	"Thrust Asymmetry"	Raise event if ***ABS(DiffEngN1)*** > Threshold

Note 1: The same measurement can be performed with EPR.

Maturity Level

Level 1

RE19 – Steering System Malfunction

Summary

Develop means to identify problems with steering system which could affect lateral controllability

Rationale

Lateral controllability on the ground from the steering system can be affected due to different reasons. This precursor will focus on three that are relevant to monitor, which are:

- Detection of a steering system failure warning.
- Verify if the steering command has correspondence with the Heading movements.
- Monitor the values of accelerations (vertical, lateral and longitudinal)

The first two items can be directly obtained from the data analysis, provided the relevant parameters are recorded. The last item of the list involves some exploratory work to measurements over the accelerations to determine the cases where there are accelerations over the normal values during the ground phases so that vibrations and shimming are detected. Due to the incertitude of this last point to provide accurate results, it will be left for future developments in this text.

Aircraft Parameters

Parameter	Type
Acceleration Longitudinal	Analogue
Acceleration Lateral	Analogue
Acceleration Vertical	Analogue
Nose Wheel Steering Fault	Discrete
Steering Command (*)	Analogue
Heading True	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Ground	***COUNT*** = Number of seconds discrete is active	"Steering System Malfunction"	Raise event if ***COUNT*** > Threshold (Note 1)
Ground	Pi = Positive Input (right) Ni = Negative Input (Left) Delta_Input = Pi-Ni Delta_HDG >0 => Right Turn Delta_HDG <0 => Left Turn (Note 2)	"Unexpected Aircraft Turn"	Raise event if there is a mismatch between ***Delta_Input*** and ***Delta_HDG*** after some time (Note 3)
Ground	RMS (Acceleration(*)) (Note 4)	"Acceleration (*) Too High on ground"	Raise event if ***RMS_Accel*** > Threshold

Note 1: The value of the threshold can increase to control the number of false positives.

Note 2: It is expected that there is a direct causality between the steering command and the aircraft turn on the ground. The identification of a response that does not correspond to the command or a deficient / delayed one is the core of the code proposed in this event.

Note 3: Testing with data should be performed to determine the amount of time needed for the reaction to the command to take place. It depends on the fleet. Typical values can be obtained, so that delayed responses may also be detected. The weight of the aircraft may also be taken into consideration for this analysis.

Note 4: This method consists of calculating the Root Mean Square of the accelerations Lateral (LATG), Longitudinal (LONG) and vertical (VERTG) during a given time interval (sliding window).

$$x_{\mathrm{rms}} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_n^2\right)}.$$

The determination of the appropriate length of the sliding window (n) can be determined from flight data exploration. In this formula the “x” represents one of the accelerations.

Future Developments and Recommendations

Studies should be conducted to use the accelerations (LATG, LONG and VERTG) to detect abnormal values during the ground phases. The proposal is to perform the analysis of the RMS component of these signals during a relevant period of the ground path or determine their corresponding spectrum in order to perform a frequency analysis. In the limit, a typical spectrum pattern may be the identification of a runway. In these conditions, an increasing vibration trend may suggest that some malfunction with steering may be in place.

There is the absolute need for these studies to draw any conclusions about the system, as false positives may appear due to the roughness of the runways or any abnormal vibration may be due to any other component from the Landing Gear.

Maturity Level

Level 1

RE20 – Lateral Deviation

Summary

Develop means to identify excessive lateral deviations or oscillations during the Takeoff, rejected Takeoff and landing taking in consideration the runway width.

Rationale

The excessive Lateral Deviation is to be evaluated by the use of Rudder Pedal Position close to full deflection when the airspeed is high. The combination of high deflection and airspeed will be monitored and a corresponding event proposed to cope with this precursor.

Aircraft Parameters

Parameter	Type
Rudder Pedal	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Ground Flight Phases Takeoff Landing	***NA***	"High Rudder Deflection on Ground"	Raise event if ***Rudder Pedal*** > Threshold For ***GS*** > Threshold

Maturity Level

Level 1

RE21 – Reverse Thrust Asymmetry

Summary

Develop means to identify reverse thrust asymmetry during a RTO or landing.

Rationale

Same rationale as RE18 but having both reversers deployed.

Aircraft Parameters

Parameter	Type
Reverse (*) Deployed	Discrete
Eng (*) N1 (Note 1)	Analogue

Note 1: Depending on the fleet, the thrust parameter can be EPR.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing RTO	***DiffEngN1*** = N1_Eng1 – N1_Eng2 (Note 1)	"Reverse Thrust Asymmetry"	Raise event if ***ABS(DiffEngN1)*** > Threshold AND ***Reverse Deployed***

Note 1: The same measurement can be performed with EPR.

Maturity Level

Level 1

RE22 – Braking Asymmetry

Summary

Develop means to identify braking asymmetry during a rejected takeoff or landing (Possibly in combination with WGA12).

Rationale

The event identified in this section focus on the brake pressure, which may indicate a system malfunction. Braking Asymmetry was addressed in RE16 making use of the pedal inputs, possibly indicating in this way an inadequate aircraft control.

Aircraft Parameters

Parameter	Type
Brake (*) Pressure	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
RTO Landing	***DiffBrakePressure*** = BrakePress_L – BrakePress_R (Note 1)	"Braking System Asymmetry"	Raise event if ***ABS(DiffBrakePressure)*** > Threshold

Note 1: Depending on the fleet an insight on the braking system may be necessary to separate among different braking pressure circuits, which are from the left side and from the right.

Maturity Level

Level 1

RE23 – Poor Visibility

Summary

Develop means estimate visibility conditions from METAR data, time of the day and runway lighting, so it can be used in conjunction with FDM data.

Rationale

To comply with this precursor there is the need to have access on the FDM system to external Weather data. The link with other sources of information was already addressed in RE01 and it is of great importance to complement the information provided by the flight data itself.

The information of the closest METAR to the Takeoff or Landing is the most reliable source of information for visibility.

Future Developments and Recommendations

Integrate other sources of information in the FDM system. In this case Weather data. See RE01, Future Developments.

Maturity Level

Level 0

RE24 – Tailwind

Summary

Develop means to estimate tailwind during takeoff, approach and landing.

Rationale

To address this precursor the tailwind component has to be determined. Depending on the dataframe capability, different approaches are presented below as guidelines for this calculation.

For fleets equipped with Inertial and Air data (barometric) systems, the values for the wind vector are computed onboard from the speed triangle and the result is presented normally on electronic displays.

For flight phases closest to the ground, the barometric part of this calculation may be affected by the "Ground Effect" resulting in values for Tailwind that are affected by noise. Despite this fact, the recorded values are the best one analyst can have for wind values. Some processes may be established to overcome this problem otherwise a large number of false events may be generated. Some possible methods are:

- A timing of 3 to 5 seconds
- The average value during the period under study

Aircraft Parameters

Parameter	Type
Wind Speed	Analogue
Wind Direction	Analogue
Airspeed True	Analogue
Ground Speed	Analogue
Heading True	Analogue
Drift Angle	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff Approach Landing	***Tailwind*** = Determined geometrically from recorded values (Notes 1 and 2)	"Excessive Tailwind"	Raise event if ***Tailwind*** > Threshold

Note 1: Depending on the dataframe capabilities there are different ways of determining the Tailwind value, which are:

Case 1: Wind Speed and Wind Direction Recorded

In this case, geometrically the following formulas provide the wind component and the crosswind.

$$WindComponent = WindSpeed * \cos(WindDir - TrueHeading)$$
$$WindCross = WindSpeed * \sin(WindDir - TrueHeading)$$

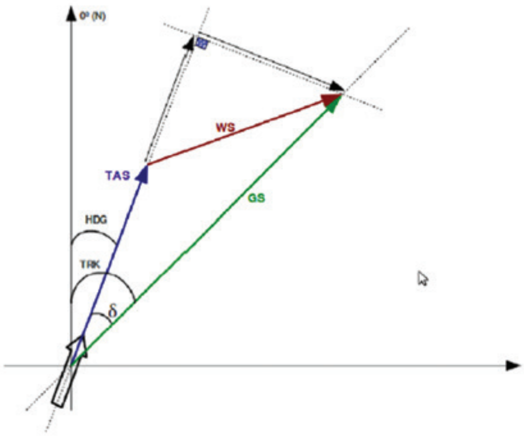
The calculation resulting for *WindComponent*, provides either the *Headwind* or *Tailwind* depending on the signal.

$$WindComponent < 0 => TailWind = WindComponent$$
$$WindComponent > 0 => HeadWind = WindComponent$$

For this precursor just the first equation to derive the value of *Tailwind*.

Case 2: Wind Speed and Wind Direction NOT Recorded

The wind component is one auxiliary calculation based on velocity triangle. Once the aircraft is airborne it suffers the wind effect and a drift angle (δ) appears between the True Airspeed and Ground Speed Vectors. This situation is valid if there is no side-slip angle (β=*0*).



In this case:

$$WindComponent = TrueAirspeed - GroundSpeed * \cos(\delta)$$
$$WindCross = -GroundSpeed * \sin(\delta)$$

And Again:

$$WindComponent < 0 => TailWind = WindComponent$$
$$WindComponent > 0 => HeadWind = WindComponent$$

If the value of drift is not recorded or the aircraft touches the ground (δ = 0), the value of the wind component can be approximated by:

$$WindComponent = TrueAirspeed - GroundSpeed$$

Maturity Level

Level 1

RE25 – Excessive Engine Power

Summary

Develop means to monitor engine power reduction before touchdown and to identify abnormal engine utilization in this phase of the flight

Rationale

This precursor is closely related with RE32 (Excess Aircraft Energy at Touch Down). While in RE32 the proposal is to deal in terms of kinetical energy of the aircraft during touch-down, in this precursor other solutions are proposed to identify possible improper power management before touch-down or high speed at touch-down. Also, in RE26 (Unstable approach), the speed is monitored so that it does not divert from Vref.

In detail, the following points will be covered in this precursor:

- High Speed at touch-down
- Thrust lever higher than IDLE before touch-down
- Takeoff power set before aligned to the runway

Aircraft Parameters

Parameter	Type
Groundspeed	Analogue
Eng (*) Thrust Lever Angle (TLA)	Analogue
Runway Heading (Note 1)	Analogue

Note 1: Runway heading may be available from the recorded data stream or be available by an external source.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing Touch-Down	***Vtd*** = Groundspeed at touch-down	"High speed at touch-down"	Raise event if ***Vtd*** > Threshold
Landing Touch-Down	***NA***	"TLA Greater than IDLE before TD"	Raise event if ***TLA(*)*** > IDLE
Approach Landing Touch-Down	***T_align*** (Note 1)	"TO Power applied before RWY alignment at Landing"	Raise event if ***TO Power applied***

Note 1: This is the instant when the heading of the aircraft is aligned with the runway heading. It should be determined by backward verification of the two headings to check when they start to diverge.

Maturity Level

Level 1

RE26 – Unstable Approaches

Summary

Develop means to identify and quantify unstable approaches, whether or not they result in go-around manoeuvres.

Rationale

An *Unstable Approach* is detected when one or more of the following stabilization conditions, presented below, are not met. One possible way to evaluate the unstability is to start at touchdown and move backwards in time. At each time point t, the stabilization conditions are checked only if they were fulfilled at the previous time point t+1 (backward analysis!). Another way to detect one unstable approach is to start from a specific height based on SOP all the way to touchdown, logic to run every second and identify & capture the instance where the SOP specified logic is not met. The minimum height where one of the conditions is not fulfilled corresponds to the output of the event. It is recommended that together with this height, the output also contains the condition that caused the instability.

The conditions are:

- Incorrect Landing Configuration (fleet and SOP Specific)
- More than 1/4 dot Localizer Deviation
- More than 1 dot Glide Slope Deviation
- IAS too high or too low relative to a reference speed. Lower than *VAPP* – 5*Kts* or higher than *VAPP* + 10*Kts*.
- Vertical Speed Higher than 1000 ft/min
- Pitch attitude too low or too high (fleet and SOP Specific)
- Bank angle greater than 7 deg
- Thrust Power not stabilized or below idle

Referring to the SOP's, the A/C have to be stabilized at 1000ft when the flight is IMC (at night, bad weather condition, low visibility, etc.) and at 500ft when the flight is VMC (at day, good weather, good visibility, etc.). This last item should be reflected in the specification for this precursor.

An additional set of measurement capture can complete the event detection, these include the height/distance at which aircraft became first stable, then first Unstable and then final stable again.

Aircraft Parameters

Parameter	Type
Localiser Deviation	Analogue
Glideslope Deviation	Analogue
Flap/Slat Lever Position	Analogue
Indicated AirSpeed	Analogue
Vertical Speed	Analogue
Pitch	Analogue
Roll	Analogue
Eng (*) N1 (Note 1)	Analogue

Note 1: Alternatively, EPR

Measurements and Events

Search Window	Measurements	Event	Event Threshold
From Touchdown to 1000ft (backwards)	***NA***	"Unstable Approach"	Raise event if Any monitoring condition is not met (see Note 1)
From 1000ft to Touchdown	***Margin to Vref*** – difference between the current IAS and Vref	"Short Margin to Vref"	Raise event if ***Margin to Vref*** < Threshold
From 1000ft to Touchdown	***PowMargin*** = Margin to minimum recommended power	"Short Margin to Minimum recommended Power"	Raise event if ***PowMargin*** < Threshold
Height first stable	Stable condition criteria		
Height unstable	Stable condition criteria		
Height last stable	Stable condition criteria		

Note 1: The monitoring conditions are those listed in the Rationale and some are dependent on specific fleet or SOPs. Each of the conditions leads to a separate event that verifies if the condition is met. When the scanning is being performed, from Touchdown to 1000ft, an "OR" of all the conditions is produced. At the instant that any condition does not meet the criteria, the search stops and the event is generated. Together the altitude, the condition that was not met are provided as an output of the event.

Maturity Level

Level 1

RE27 – High Energy over Threshold

Summary

Develop means to estimate height, airspeed and ground speed while crossing the runway threshold.

Rationale

The determination of the Threshold Crossing Height is the key point for this precursor to be addressed. Two methods will be proposed which are dependent on the dataframe capability in terms of the existence and accuracy of the necessary parameters. It is to the operator to test the capability of the algorithms proposed on his fleet and decide based on this evidence which one can be more reliable.

The methods proposed to determine the crossing height are based on:

- ILS Signal
- Position parameters (Latitude / Longitude)

Both have positive and negative points which can be summarized in the table below:

	Positive	negative
ILS	No need for external data	Bad results when ILS signal is unstable Only applies to runways with ILS approach Elaborated Algorithm
Position	Applies to all airports/runways Simple Algorithm	Needs external data Depends on the accuracy of the position parameters

In this precursor, the altitudes and speeds of the aircraft will be extracted when the threshold crossing is identified as a measurement of the energy at this point.

Aircraft Parameters

Parameter	Type
Radio Altitude	Analogue
Glide Slope Deviation	Analogue
Latitude	Analogue
Longitude	Analogue

Measurements and Events

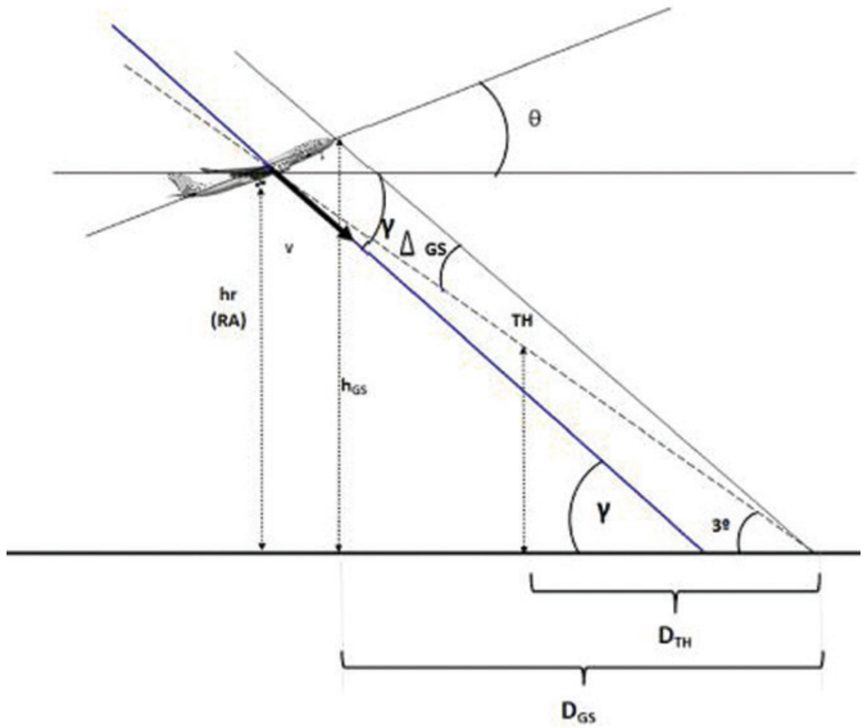
Search Window	Measurements	Event	Event Threshold
Landing	***HeightOnThreshold*** (Note 1)	"Too High over Threshold" (Note 2)	Raise event if ***HeightOnThreshold*** > Threshold
Landing	***HighSpeedOnThreshold***	"High Speed over Threshold"	Raise event if ***HighSpeedOnThreshold*** > Threshold

Note 1: The calculation of the Height over the Threshold can be accomplished in the following ways:

Note 2: The Threshold referred here is the Runway Threshold and should not be confused with the Threshold general definition used on this document to refer a value that triggers one event (right column of all measurements and Events Tables)

Case1: Using ILS Signal

Threshold height can be computed geometrically provided there is an ILS stable signal (Glide-Slope). This method is based on the geometry as shown in the figure below[5].



In This figure:

DTH -> distance on the runway between the glide-slope antenna and the point corresponding to the Threshold of 50ft, i.e., for a three-degree slope the distance is, *DTH* = 50/ tan(3deg) = 954*ft*

(in this formula any slope angle other than 3deg can be used)

The following calculations assume that Radio Altitude is measuring the height between the ground and the Main Landing Gear (MLG) point closest to the ground. This is true provided *PITCH* < 6deg due to the calibration process of the Radio Altimeter during its installation (Airbus fleets).

For next figure the values of VGS and LGS are determined geometrically from the aircraft drawings. To reach the point where the ILS signal is being captured, the following calculation is performed:

$$h_{GS} = h_r + V_{GS} \cos\theta + L_{GS} \sin\theta$$

The Threshold is crossed when $D_{GS} = D_{TH}$

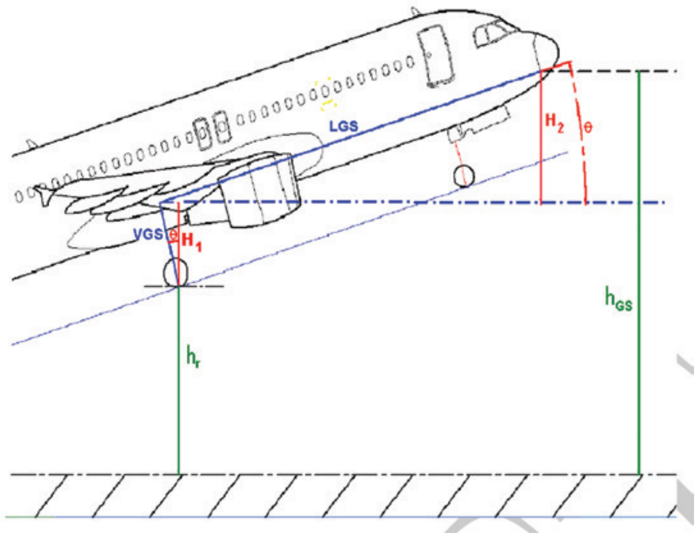
Assuming a 3 deg slope the calculations below provide the value of ***HeightOnThreshold***

$$D_{TH} = \frac{50\,ft}{\tan(3^o)} = 954\,ft$$

$$D_{GS} = \frac{h_{GS}}{\tan(\Delta_{GS} + 3^o)}$$

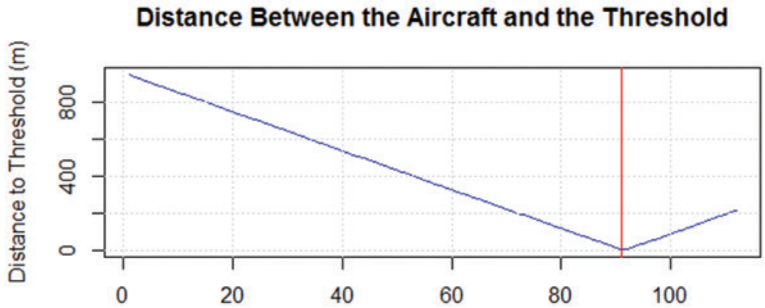
$$HeightOnThreshold = RALT_{TH}$$

5 Further details on this method can be found on DOT/FAA/AR-07/7, *A Study of Normal Operational Landing Performance on Subsonic, Civil, Narrow-Body Jet Aircraft During Instrument Landing Approaches. DOT/FAA, Washington,*DC, 2007



Case 2: Using Position Parameters

This approach relies on the calculation of the distance between the aircraft position and the runway Threshold coordinates. This value has to be provided by one external source. The procedure is to calculate the distance between two points given as coordinates (LAT, LONG) and determine the minimum value attained. This minimum value corresponds to the threshold crossing (image below). For this method to be successfully applied, it is assumed that the position parameters are accurate enough. Before the implementation, a test on this accuracy should be performed (See Annex 1 - Accurate Position Computation).



Once determined the Threshold point, the height is given by:

$$HeightOnThreshold = RALT_{TH}$$

Future Developments and Recommendations

The calculations proposed in case 2 relies on the information about the correct coordinates of the runway threshold. This value has to be provided by one external runway database. This is is to be explored as part of the merging of flight data with other sources (see RE01).

This precursor addresses the high energy condition over the threshold. If the need is raised in the future the same kind of reasoning can be used for the low energy condition.

Maturity Level

Level 1

RE28 – Long Flare

Summary

Develop means to detect the start of the flare and to estimate the ground distance covered from the start of the flare until touchdown.

Rationale

The detection of the point where the flare was initiated is the major challenge to cope with this precursor. This detection is highly dependent on the aircraft handling and can be well pronounced or smoothly driven and this constitutes a major difficulty to derive a reliable algorithm that conducts to one minimum of false positives.

A proposal to find this point is given in the following document:

DOT/FAA/AR-07/7, *A Study of Normal Operational Landing Performance on Subsonic, Civil, Narrow-Body Jet Aircraft During Instrument Landing Approaches*. DOT/FAA, Washington, DC, 2007.

Some more testing on this or other methodology is needed within the working group to derive a method that suits a broad scope of aircraft handling. For this reason, an intermediate solution was found to monitor the time it takes during landing from 50ft AAL to the touchdown point.

Aircraft Parameters

Parameter	Type
Radio Altitude	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	***TimeFlare*** = Time between 50ft AAL and touchdown point (Note 1)	"Long Flare"	Raise event if ***TimeFlare*** > Threshold

Note 1: Once the algorithm proposed in the rationale or other equivalent is tested to determine the flare initiation time, this should be the starting point to initiate the time counting.

Future Developments and Recommendations

Explore new methodologies as proposed in Rationale.

Maturity Level

Level 1

RE29 – Deep Landing

Summary

Develop means to estimate the distance from the runway threshold until the touchdown point and also the runway length available after touchdown.

Rationale

This precursor relies on the determination of the Runway Threshold crossing. The methods proposed are described in RE26. The distance between this point and the Touchdown point will be named ***AirDistance*** and is the central measurement to cope with this precursor.

Aircraft Parameters

Parameter	Type
Radio Altitude	Analogue
Glide Slope Deviation	Analogue
Latitude	Analogue
Longitude	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	***AirDistance*** = Distance between runway Threshold crossing and touchdown point.	"Deep Landing"	Raise event if ***AirDistance*** > Threshold

Maturity Level

Level 1

RE30 – Abnormal Runway Contact

Summary

Develop means to identify and quantify bounced (main or nose wheels), tail and wingtip strikes, off-centre, *nose-first* or asymmetrical landings.

Rationale

Abnormal runway contact (ARC) may be the result of some of the precursors already addressed in this document, among these can be the unstable approaches, the aircraft handling but other contributive factors may result in an inappropriate contact with the runway. Under the scope of ARC, the following situations that are to be studied in this section:

- Bounced Landing
- Bounced Landing with ground spoiler deployment
- Landing With Roll
- Nose Landing
- Lateral Acceleration at Landing
- Pitch High at Touchdown
- Hard Landing
- Tail Strike

Tailstrike

The tailstrike happens when excessive pitch attitude provokes the contact of the tail of the aircraft with the runway. It can happen during takeoff or landing and statistics from the industry indicate that the majority of the tailstrikes happen during landing. The number of occurrences during this flight phase is about 2.5 times those that happen at takeoff.

In both situations, the pitch-up angle is a fairly good indicator of the imminence of the tailstrike. Aircraft manufacturers provide normally a table, based on the geometry of the aircraft, with the maximum pitch angle for the main landing gear (MLG) fully compressed and fully retracted. The limits for the gear fully compressed are necessarily smaller than in the case when it is fully extended. This is easily derived from the geometric analysis of each case.

For both takeoff and landing, the most stringent limits for pitch angle are those for the MLG fully compressed and the published values by the manufacturers for this case should be used as a reference for the thresholds to adopt. This pitch angle indicates the value for which there is a tailstrike with the gear fully compressed. This is one extreme case and FDM by definition has the goal to extract from the data the information to avoid these cases that may result in one incident or accident. Having this in mind and that there no knowledge a priori if the gear is fully compressed, the value for the threshold should be selected by reducing one convenient amount of degrees to the published value of pitch for the MLG fully compressed.[6] In this way, the trend to the tailstrike can be detected by the FDM programme. The runway slope and vertical acceleration at landing may aggravate the imminence of the tailstrike incident and operators should be alert for these factors on their operation.

In order to evaluate the proximity of the tailstrike, the pitch angle has to be measured with the highest possible accuracy both at the liftoff and touchdown points. The methodology proposed to estimate these points is the following:

6 Studies have to be conducted by the operators for each fleet in order to determine which value is the most convenient.

Touch-down Point	Considering that the MLG swat-switch provides the ground information with some delay imposed by the shock-absorber and the radio altimeter is calibrated to provide zero feet with the landing gear fully extended[7], the methodology proposed should make use of these features and perform the calculations of two points in the following way: **Point A** **Time when MLG sqwat-switch changes from Air -> Ground (Left OR Right)** ↓ **Point B** **Time when radio altitude changes from, RALT>0 to RALT<=0** It is expected that Point B < Point A, i.e., it is detected before. In this case Point B should be considered as the touch-down point. Otherwise, if Point B > Point A, some error occurred in this process and Point A should be considered as the touchdown point as it represents the most solid observation. More elaborated methodologies can be applied, relying on parameters other than the radio altitude. A good example can be found in the presentation from Joachim Siegel, Lukas Höhndorf, on EOFDM Conference 2016, named "**Landing Trajectory and Touchdown Point Reconstruction**"[8]
Liftoff point	Having in mind the same premises used for the touch-down point extraction, the liftoff can be obtained from the MLG squat switch as a rough measurement and fine-tuned with radio altitude measurements in the following way: **Point A** **Time when MLG sqwat-switch changes from Ground -> Air (Left OR Right)** ↓ **Point B** **Time when radio altitude changes from, RALT<0 to RALT>=0** It is expected that Point B < Point A, i.e., it is detected before. In this case Point B should be considered as the liftoff point. Otherwise, if Point B > Point A, some error occurred in this process and Point A should be considered as the liftoff point as it represents the most solid observation.

Aircraft Parameters

Parameter	Type
Main Landing Gear (*) (Note 1)	Discrete
Nose Landing Gear	Discrete
Roll	Analogue
Pitch	Analogue
Acceleration Vertical	Analogue
Acceleration Lateral	Analogue
Ground (*) Spoiler Out	Discrete

Note 1: It is assumed that the signals from Left and Right Main Landing Gear are separated in the dataframe.

7 This is true until a limit of the pitch-up specific for each fleet. Above this limit this methodology may introduce one error in the determination of the touchdown point.

8 This presentation is available on the Event Proceedings section of https://www.easa.europa.eu/newsroom-and-events/events/4th-conference-european-operators-flight-data-monitoring-forum-eofdm#group-easa-event-proceedings

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	***COUNT*** = Number of transitions, Air -> Ground from Main Landing Gear (Note 1)	"Bounced Landing" (Note 2) (Note 5)	Raise event if ***COUNT*** > 1
Landing in the vicinity of the Touchdown point	***MaxRoll*** = Maximum value of Roll in the monitoring window	"Landing with Roll " (Note 5)	Raise event if ***MaxRoll*** > Threshold
Landing	***Tn*** = Instant in which there is the transition Air -> Ground from Nose Landing Gear ***Tmlg*** = Instant in which there is the transition Air -> Ground from main Landing Gear	"Nose Landing" (Note 5)	Raise event if ***Tn < Tmlg***
Landing in the vicinity of the Touchdown point	***MaxVertAccel*** = Maximum Vertical Acceleration in the monitoring window (Note 4)	"Hard Landing" (Note 3) (Note 5)	Raise event if ***MaxVertAccel*** > Threshold
Landing in the vicinity of the Touchdown point	***MaxLatAccel*** = Maximum Lateral Acceleration in the monitoring window	"Lateral Acceleration at Landing " (Note 5)	Raise event if ***MaxLatAccel*** > Threshold
Landing in the vicinity of the Touchdown point	***MaxPitch*** = Maximum Pitch in the monitoring window	"Pitch High at Touchdown"	Raise event if ***MaxPitch*** > Threshold
Landing in the vicinity of the Touchdown point	***PitchMargin2TailStrike*** = Pitch – Max pitch for Tail Strike	"Short Margin to Tail Strike"	Raise event if ***PitchMargin2TailStrike*** < Threshold
Determine the liftoff point	***pitch@liftoff***	"Tailstrike low clearance at liftoff"	Raise event if ***pitch@liftoff*** > Threshold
Determine the touchdown point	***pitch@touchdown***	"Tailstrike low clearance at touchdown"	Raise event if ***pitch@touchdown*** > Threshold

Note 1: Consider the readings of both Left and Right sides of Main Landing Gear to produce this count (AND condition).

Note 2: The deployment of Ground Spoilers during transitions produces an extra risk condition which may lead to severe consequences due to the sudden loss of lift. An additional event should be created on the top of the recommended "Bounced Landing".

Note 3: The threshold limits to be established for hard landing should be conservative regarding the structural limits so that the events and measurements recommended in this precursor can be used to evaluate trends. The structural limits are normally used for maintenance purposes so that this area can decide which maintenance action is convenient depending on the amount of vertical acceleration experienced by the aircraft.

Note 4: The maximum value of vertical acceleration can be complemented with the maximum of vertical speed in the monitoring window.

Note 5: The cumulative effects of the stresses applied to the Landing Gears should be evaluated among all the previous flights performed by the aircraft and not just the one under analysis in order to detect stresses applied above a determined threshold. Accidents are reported which this can be a contributing factor (see VT-JGA accident from 13th April 20115 in Khajuraho Airport - HJR/VAKJ, India). This example is for hard landings but all the abnormal stresses contribute to the weakening of the Landing Gear.

Maturity Level

Level 1

RE31 – Go–Around

Summary

Develop means to identify go-arounds and balked landings.

Rationale

During landing, it is expected that the height always decreases. If there is any reversal on this behaviour and the height starts to increase a Go-Around is detected end the corresponding event generated. It is recommended that additional information on this event be stored such as the time it happens, the minimum height attained and the position coordinates. Other relevant information may be recorded according to the operator's needs and experience.

Engine Power may be used to complement the information in the following way:

- TOGA applied during landing is a direct indicator that a Go-Around is happening
- A sudden Increase in Power during landing, even if it is not TOGA, is also an indicator for Go-Around. This increase may be used together with the height increase.

Aircraft Parameters

Parameter	Type
Altitude Standard	Analogue
Eng (*) Thrust Lever Angle (TLA)	Analogue
Eng (*) N1 (Note 1)	Analogue

Note 1: Alternatively use "Eng (*) EPR" to have one assessment of Engine Thrust.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	***DeltaHeight*** = Height – Height(-1) ***TOGA*** = Takeoff GoAround Power applied to the engines. (Note 1 and 2)	"Go Around"	Raise event if ***DeltaHeight*** > 0 OR ***TOGA*** (Note 3)

Note 1: The indication of (-1) stands for the value on the second before. This number can change to control the number of false positives and more samples may be considered provided that there is clear indication of the parameter trend.

Note 2: TOGA Power may be determined from the Throttle Lever Angle position or from N1 or EPR parameters.

Note 3: The instant where Go-Around was initiated may be determined from the instant when Throttle Levers where pushed to TOGA position (Equivalently any sudden increase of power). It is expected in the sequence of power increase, to have a positive Pitch Rate variation. This can be used to help on the finding of the instant, but due to the Flare manoeuvre close to the ground, the pitch rate should not be used independently as it can lead to false positives.

Maturity Level

Level 1

RE32 – Excessive energy at touchdown

Summary

Develop means to correctly identify the touchdown instant, measure airspeed and ground speed and to identify cases of excessive energy.

Rationale

Runway excursions occur either as overruns or as veer-offs. It is assumed that the aircraft's longitudinal kinetic energy (Ek) affects predominantly the risk for an overrun. The veer-off risk is assumed to be more affected by controllability problems. Therefore, this event is developed with the overrun in mind.Since the event specifies 'at touchdown' the potential energy component is considered to be zero and only the kinetic energy is to be considered.

Ideally, an event should signal the approach to an undesirable outcome. In the case of the RE/overrun, the most suitable quantity to monitor is the *runway length remaining* after the aircraft has stopped, *approaching zero.* It allows individual flight risk assessment as well as trending (fleet, crewmember, destination…).

This involves deriving parameters from recorded flight data, such as touchdown point and distance covered. In particular the touchdown point determination is notoriously difficult with the customary accuracy and recording rate of the required parameters. In addition, such an event would have to take different runway lengths into account depending on destination-runway used, rendering the event definition impractically complicated.

Alternatively, instead of determining proximity to an undesirable outcome, one can monitor a quantity which is related to the undesirable outcome, determine its value range in normal operation and define an event that signals unacceptable deviation from normality.

In this case, we need to relate an aircraft's Ek at TD to the landing roll, the complement of the runway remaining.

Under the simplifying assumption that the aircraft is decelerated at a constant rate, the distance (x) covered during the landing roll is given by:

$$x = \frac{1}{2}at^2 + v_0 t + x_0$$

The initial conditions at the touchdown point are respectively $v_0 = v_{TD}$ and $x_0 = 0$, such that

$$x = \frac{1}{2}at^2 + v_{TD} t + 0$$

The speed during landing roll is given by

$$v = at + v_{TD}$$

Setting v = 0, meaning the aircraft is brought to a full stop, we can solve this for *t*:

$$t = \frac{-v_{TD}}{a}$$

Re-inserting the expression for *t* in the equation for x this yields

$$x = \frac{1}{2}a\left(\frac{-v_{TD}}{a}\right)^2 + v_{TD}\frac{-v_{TD}}{a} + 0$$

$$x = \frac{1}{2}\frac{v_{TD}^2}{a} - \frac{v_{TD}^2}{a} + 0$$

$$x = -\frac{1}{2}\frac{v_{TD}^2}{a}$$

V_{TD}^2 being proportional to Ek, this expresses the relation between the landing roll and Ek.

If we assume the ***reference*** landing manoeuver to be flown such that the threshold is crossed at 50ft height at the approach target speed, Vapp, and during the flare speed is bled off to a reference speed Vref = Vapp-5 knots, then the ratio of the actual kinetic energy at TD and the reference TD kinetic energy, the ***Ek ratio***,

$$\frac{x_{act}}{x_{ref}} = \frac{V_{TD,act}^2}{V_{ref}^2} = Ek\ ratio$$

...expresses the effect of excess Ek at touchdown on the landing roll, under equal and constant deceleration.

Note 1: Vref being derived from Vapp, the aircraft mass is taken into account.

Note 2: As the speed relative to the ground is relevant when considering ground roll, $V_{TD,act}$ is the aircraft's ground speed.

Aircraft Parameters

Parameter	Type
Approach Target speed (VAPP)	Analogue
Groundspeed	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
First WOW	***Vapp*** *from performance data* ***GS*** at touchdown ***Ek ratio*** *calculated from* ***GS*** *and* ***Vapp***	*Excess Energy on Touch Down*	Raise event if ***Ek ratio*** > Threshold

Note 1: Threshold for Ek ratio to be determined from the Ek ratio distribution in normal operations.

Future Developments and Recommendations

Subject to developments in functionality such that accurate touchdown point determination and availability of runway length become straightforward features in FDM software, this precursor should be re-developed into a runway remaining event.

Maturity Level

Level 1

RE33 – Wrong runway or wrong entry point used

Summary

Difference between actual and planned runway or entry point used should be monitored.

Rationale

One wrong runway or entry point chosen by the pilot will lead to a performance mismatch between the FMS inputs and the actual situation of the aircraft. It is possible to use the wrong runway entry point with the FMS programmed for different distances and speeds. Whether or not this has a safety implication depends on the nature of the error(s) and can be summarised in the table below, where the distance resulting from Performance data are compared with the actual one.

		Actual departure	
		Intersection	Full Rwy
Perf data	Intersection	OK	ACCEPTABLE
	Full Rwy	ERROR	OK

The mismatch of the runway entry point may lead to two problematic situations, one in which there is more runway available than the planned (Acceptable) and the opposite case (Error). While the first does not represent one unsafe situation by itself the second in the limit may have catastrophic consequences. As there is one error associated with each of the cases and being on the safe or unsafe side is a matter of chance, both should be identified as accurately as possible by the use of FDM. In this precursor, it is assumed that there was no wrong input to the FMS system and the error was committed when entering the runway. For wrong FMS inputs, see RE01 or LOC10 (Incorrect Performance Calculation).

FMS data input reflects the planned actions[9] which should be compared with the actual flight performed (from the flight data). This assessment requires that the planned information is made available to the FDM programme. This can be from:

- ATC messages[10]
- EFB calculations

The comparison between the RWY entry point and the planned require the maximum accuracy of the recorded position (see Annex 1). For both sources, the planned entry will normally be provided/captured as ASCII string, designating the name of the intersection. There is, therefore, the need to convert this designation to a geographic point, or vice-versa, for direct comparison. This conversion tables may need to be manually built, which will limit the feasibility of this precursor for operators that fly to a large number of destinations, due to the overhead of creating and maintaining such a reference.

This precursor may be related with RE15 (Runway remaining after Liftoff). All the cases where a short distance is detected should be confronted with the entry point of the respective runway so that any incorrect entry point may be identified in this way. This is a work for the analyst in a case by case basis.

9 The entry point may be defined by a name. In this case some additional work on geolocation is required to convert all these names into accurate positions. This can be part of an external database available to the FDM system.

10 These messages whenever possible can be collected from the CPDLC system.

Aircraft Parameters

Parameter	Type
Latitude	Analog
Longitude	Analog

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Taxi - out	***Delta DEP = Distance between the actual entry point and the expected one (Note 1) (Note 2)***	*"Wrong Runway Entry Point"*	Delta DEP > Threshold

Note 1: DEP stands for "Distance Entry Point"

Note 2: Expected entry point should be obtained from an external source (see Rationale)

Future Developments and Recommendations

Some efforts should be dedicated to the integration of ATC data to incorporate the information of the RWY entry point into the FDM programme. Alternatively, this information can be obtained via the EFB.

Maturity Level

Level 1

RE34 – Erroneous Guidance

Summary

Develop means to detect cases of erroneous guidance during approach and landing.

Rationale

This precursor is directly related to the way the monitoring of the correct trajectory is performed. For altitudes close to the ground the deviation is part of the conditions for unstabilised approaches and this is already addressed in this document on RE26.

There are some cases though that is worth to perform a deeper analysis, namely if there is a false ILS lobe capture. This is valid both for glideslope and localizer. The major problem in this situation is that the recorded deviations signals do not display any significant deviation value as the repetition contains the same characteristics as the original lobe but on a different position in the space. In this way, there is no possibility to determine this deviation by the Localiser and Glideslope signals recorded onboard and different strategies are proposed in this precursor to overcome this situation.

In the case of glideslope, the descent angle can be validated by the use of:

- Flight path angle (FPA)
- Rate of descent (ROD or Inertial Vertical Velocity-IVV)

This value can be compared with either the correct glide angle for the approach or the standard 3 deg.

In the case of Localiser, the only option to cross-check the correct positioning of the aircraft is by using the geographical coordinates and comparing it to the expected position from the original lobe.

Future Developments and Recommendations

FMS systems can provide parameters to verify if the aircraft is in the planned track and/or measure its deviation. This capability is recommended to be further explored in each fleet so that the correct flight path can be evaluated in all flight phases. This can be also of extreme value to verify the correct guidance in the case of RNAV approaches.

Maturity Level

Level 1

Loss of Control in Flight (LOC-I)

Loss of Control in Flight (LOC-I) is defined in the document from CAST/ICAO taxonomy team which is titled "Aviation Occurrence Categories".[11]

Each recommendation identified by Working group A, corresponds to a possible precursor for an incident or accident related to Loss of Control in Flight. The current chapter presents the algorithms proposed by Working group B to cope with each of the recommendations identified.

11 The document can be found on the link: http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf

LOC01 – Fire, smoke and fumes

Summary

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

Rationale

The detection of fire and smoke or fumes in the cabin will rely mainly on measurements and events based on smoke and fire detectors. Other parameters may indicate an abnormally high value such as temperatures from Brakes and Engine Oil and act as fire precursors.

Regarding Brakes, its use on the ground may be monitored, using the Brakes Pressure and/or the Brake Pedals Position during the Taxi phase to detect possible brake excessive use which may lead to temperature increase and consequent fire.

The events proposed for dealing with this precursor make use of the discrete signals indicating Fire or Smoke warnings and the analogue values on temperature measurements for the Brakes and Engine Oil.

Detect an excessive use of brakes during ground phases can lead to an increase in brakes temperature and act as an igniter to this precursor. The use and the temperature are proposed to be monitored.

Aircraft Parameters

Parameter	Type
Eng (*) Fire	Discrete
APU Fire	Discrete
Smoke Avionics (*) Warning	Discrete
Smoke Cargo (*) Warning	Discrete
Smoke Lavatory (*) Warning	Discrete
Brake (*) Pressure	Analogue
Brake (*) Pedal Position	Analogue
Brake (*) Temp	Analogue
Eng (*) Oil Temp	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Engine/APU Fire Warning"	Raise event if ***COUNT*** > 1 (Note 1)
Whole Flight	***COUNT*** = Number of seconds discrete is active	"(*) Smoke Warning" (Note 2)	Raise event if ***COUNT*** > 1 (Note 1)
Taxi OUT	***TimeUsingBrakes*** = Total Time Using Brakes During Taxi [In/Out] (Note 3)	"Brakes Intense Use During [Taxi IN / Taxi OUT]"	Raise event if ***TimeUsingBrakes*** > Threshold (Note 4)
A/C is on the ground and Climb Flight Phase (see Note 3)	***MaxBrakeTemp*** = Maximum Brake Temperature	"High Brake Temperature"	Raise event if ***MaxBrakeTemp*** > Threshold (Note 4)
Whole Flight (With Engines Running)	***MaxEngOilTemp*** = Maximum Engine Oil Temperature	"High Engine Oil Temperature"	Raise event if ***MaxEngOilTemp*** > Threshold

Note 1: The value of the threshold can be increased to control the number of false positives.

Note 2: Smoke Warning Event is, in fact, a set of three events, indicated by the (*), depending on which smoke warning signal is activated.

- Avionics Smoke Warning
- Cargo Smoke Warning
- Lavatory Smoke Warning

Note 3: The usage of Brakes can be determined either by Brake Pedals Position, Brake Pressure or both. In this event, the Brake Temperature is not considered. Indeed, there is a time delay between the brake usage and the rising of the temperature. This measures the immediate action of brake use.

Note 4: Thresholds depend on which path the aircraft is following for a specific Runway/Taxiway and a figure for each combination may be derived from the recorded data.

Future Developments and Recommendations

It was identified by the working group that for the fleets represented there was no smoke detector in the cockpit and consequently no recorded warning. It is recommended that when a smoke detector is installed in the cockpit, its signal is recorded in the dataframe, so that precursors in this area can be tracked.

Maturity Level

Level 1

LOC02 – Pressurization System Malfunction

Summary

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.

Rationale

Identification of pressurization system malfunction can be done by monitoring standard parameters available that can identify the onset of an abnormal condition related to the pressurization system malfunction. These are recorded parameters and not limited to the below only, other aircraft specific parameters can be added to enhance the monitoring,

This precursor is to be addressed using:

- Monitoring of cabin pressure.
- Monitoring of cabin altitude rate.
- Monitoring of outflow valve positions for abnormal values.
- Monitoring of discrete warnings:
  - Excessive high differential pressure[12]
  - Excessive negative differential pressure
  - Residual excessive pressure

One event is generated when the pressure value or cabin altitude rate goes above a pre-established threshold (based on A/C type) and/or when a discrete signal is active and validated using the measurement of duration together with confirmation time duration to avoid nuisance warnings.

One abnormal value for the outflow valve position not related with a device failure is the first symptom for the existence of small leaks. These are compensated by the valve, which acts to keep the internal pressure of the aircraft with the correct value. This compensation will be in place until the valve is fully closed. In this situation, the small leak can be detected by the cabin pressure decreasing or cabin altitude increasing.

Aircraft Parameters

Parameter	Type
Cabin Pressure	Analogue
Cabin altitude rate	Analogue
Outflow Valve Position	Analogue
Excessive cabin pressure Warning	Discrete
Excessive Cabin Altitude Warning	Discrete
Excessive high differential pressure Warning	Discrete
Excessive Negative differential pressure Warning	Discrete

12 Difference between cabin pressure and the atmospheric pressure

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight	***MaxCabPress*** = Maximum Cabin Pressure achieved	"High Cabin Pressure"	Raise event if ***MaxCabPress*** > Threshold
Whole Flight	***MinCabPress*** = Minimum Cabin Pressure achieved	"Low Cabin Pressure"	Raise event if ***MinCabPress*** < Threshold
Whole Flight	***MaxCabAltRate*** = Maximum Cabin altitude Rate	"High Cabin Vertical Speed"	Raise event if ABS(***MaxCabAltRate***) > Threshold (see Notes 2 and 3)
Whole Flight	(see Note 4)	"Abnormal Outflow Valve Position"	(see Note 4)
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Excessive Cabin Pressure"	Raise event if ***COUNT*** > 1 (See Note 1)
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Excessive Cabin Altitude"	Raise event if ***COUNT*** > 1 (See Note 1)
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Excessive Cabin Differential Pressure"	Raise event if ***COUNT*** > 1 (See Note 1)
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Excessive Negative Differential Pressure"	Raise event if ***COUNT*** > 1 (See Note 1)

Note 1: The value of the threshold can increase to control the number of false positives.

Note 2: If justified the values achieved during Climb and Descent can generate two independent events

Note 3: Aircraft type specific Boeing 777 (300~600 fpm). Thresholds to be set per aircraft type and adapted to each specific operation.

Note 4: Studies can be carried out by different operators in order to determine the normal positions of the Outflow valve during the different flight phases. Once these values are determined, the range of normal values can be set as threshold limits. As referred in the Rationale this is the first symptom for a small leak to be detected.

Future Developments and Recommendations

Note 4 above provides guidelines for developments for the creation of one event that detects abnormal values for the outflow valve position.

Maturity Level

Level 1

LOC03 – Pressurization System Misuse

Summary

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

Rationale

The pressure inside the aircraft should be equalized with the exterior before takeoff and after landing. Automatic systems make use of the information, 'Standard Altitude' and 'Cabin Altitude' to regulate one outflow valve in order to match the interior and exterior pressures and therefore create a suitable environment for passengers and crew.

Cabin Pressurisation System manages pressure inside the cabin in four basic functions:

- **Ground** – outflow valve is fully open and cabin and exterior pressure are equalised. This is equivalent to saying that the differential pressure is zero.
- **Prepressurisation** – Before Lift-Off increases the cabin pressure to avoid a surge during rotation.
- **Pressurisation in Flight** – Adjust cabin altitude and cabin vertical speed to maximize passenger's comfort.
- **Depressurisation** – After touchdown gradually opens the outflow valve until it is the ground mode.

This precursor is to be addressed using:

- Differential Pressure at takeoff and landing
- Flight Management Computer Airport Standard Altitude Setting
- Pressurisation MAN mode selected during takeoff

Aircraft Parameters

Parameter	Type
Cabin Differential Pressure (see Note 1)	Analogue
Landing Elevation (FMC)	Analogue
Standard Altitude	Analogue
Mode SEL P/B MAN	Analogue

Note 1: This pressure can be calculated obtaining the pressures out of the corresponding altitudes, i.e., standard pressure from standard altitude and cabin pressure from cabin altitude. The differential pressure can be calculated subtracting the standard pressure to the cabin pressure.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff (until Lift-off)	***COUNT*** = Number of seconds the Differential Pressure is not zero on ground	"Differential Pressure at Takeoff"	Raise event if ***COUNT*** > Threshold (see Note 2)
Landing (from Touch-down)	***COUNT*** = Number of seconds the Differential Pressure is not zero on ground	"Differential Pressure at Landing"	Raise event if ***COUNT*** > Threshold (see Note 2)
Landing	***NA***	"Airport Standard Altitude Setting"	Raise event if ***STD Altitude*** different than ***Landing Elevation*** (see Note 3)
Takeoff	***COUNT*** = Number of seconds MAN mode is selected during Takeoff	"Pressurisation MAN Mode selected during Takeoff"	Raise event if ***COUNT*** > Threshold (see Note 1)

Note 1: The value of the threshold can increase to control the number of false positives.

Note 2: Considering that there are the Prepressurisation and Depressurisation modes on the ground, there are typical values for COUNT which don't correspond to any misuse of the system. The value of the Threshold should be adjusted accordingly.

Note 3: Just after touchdown and after standard altitude stabilization. Comparison between the values for landing elevation introduced in the Flight Management Computer and the real value of the Standard Altitude at the airport. Due to ground effect, Standard Altitude may have variations during this flight phase and some additional work has to be performed to verify the correct point to extract this value. This behaviour may produce the appearance of false positives and an error margin may exist on the code to reduce or eliminate this nuisance warnings.

Maturity Level

Level 1

LOC04 – Reserved

This precursor is not part of the specification document provided by Working Group A.

LOC05 – High Cabin Altitude

Summary

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).

Rationale

The event created is based on Cabin Altitude recording and the detection of its maximum value for each flight. Any abnormal value of this measurement can be directly identified and an event generated.

Aircraft Parameters

Parameter	Type
Cabin Altitude	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Cruise	***MaxCabAlt*** = Maximum Cabin Altitude	"High Cabin Altitude"	Raise event if ***MaxCabAlt*** > Threshold (Note 1)

Note 1: The threshold value may depend on the fleets. One possible value is 8000ft for maximum cabin altitude

Maturity Level

Level 1

LOC06 – O2 Masks not used by the Crew

Summary

Develop means to identify situations when the crew failed to deploy and use the oxygen masks in response to real or nuisance situations.

Rationale

After review of this recommendation from EOFDM Working Group A, EOFDM Working Group B decided not to address it due to the two main following reasons:

Lack of available parameters about O2 masks use in FDM data

Considering the current status in terms of attributes of FDM recording frames and resulting characteristics of the FDM data acquired onboard of commercial aircraft, there is generally no parameter recorded about the use of O2 masks. However, such parameters would be necessary so as to design a rational capturing scenario of crew failing to use adequately O2 masks. As a consequence, no rationalecan be proposed at this stage so as to address the LOC06 recommendation.

Furthermore, due to the current level of instrumentation of the O2 masks onboard of commercial aircraft, there is generally no sensor available at aircraft systems level and that could be used to produce the required information about the use of O2 masks. Thus, considering current aircraft systems designs, it appears that there is no possibility to acquire the required information even after adequate recording frame update.

Therelative risk of this precursor when compared to others

Based on the modelling of LOC-I scenarios provided by EOFDM Working Group A and especially the analysis of the precursors of such scenarios directly related to the LOC-I risk, LOC06 precursor is considered of lower priority compared to some other precursors like for example LOC14 (Inadequate aircraft attitude) or LOC13 (Inadequate aircraft energy). Also, the added value of enabling such a monitoring of O2 masks use thanks to the adequate instrumentation of commercial aircraft appears to be very limited compared to the significant industrial effort it would require.

Maturity Level

Level 1

LOC07 – Supplementary O2 system failure

Summary

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

Rationale

Depending on the Aircraft Type, the Supplementary O2 system may also be known as Crew Emergency Oxygen system or Cockpit Oxygen system, referring to the system supplying O2 to the oxygen masks the crew are supposed to use in case of depressurization/smoke/fumes.

One of the possible failures modes of this system is caused by low O2 pressure in the reservoir. Therefore, it would make sense to monitor this pressure during flight similarly to hydraulic pressure.

The minimum O2 pressure is normally stated in the aircraft maintenance manual. This event/measurement might be useful for maintenance purposes such as to assess O2 usage under normal operations (how quickly it is depleted by daily/pre-flight checks or due to slow leaks).

Aircraft Parameters

Parameter	Type
Oxygen Low Pressure	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight	***COUNT*** = Number of seconds discrete is active	"Oxygen Low Pressure"	Raise event if ***COUNT*** > Threshold (See Note 1)

Note 1: The value of the threshold can increase to control the number of false positives.

Future Developments and Recommendations

It is recommended that the dataframe includes a discrete parameter indicating the status of low pressure on the oxygen system in order to produce the contents described in this precursor.

Maturity Level

Level 1

LOC08 – CG out of limits

Summary

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.

Rationale

This recommendation is linked to two 'failure' modes:

- The CG is outside the aircraft limitations (which most likely could mean it is uncontrollable in flight regardless of pitch trim settings)
- The pitch trim settings are inconsistent with the CG position, which means that the crew might experience some controllability issues at rotation or once airborne.

The first failure mode should be obvious to the crew and discoverable also by means other than FDM (such as a safety report submitted by the flight crew or accident report in the case of serious events). The second failure mode is less severe and depending on the magnitude of the discrepancy, it might even be unnoticed by the flight crew. FDM might then be the only possible way to detect such cases. It is important to also track the less severe cases because their investigation might reveal systemic causes which could end up in more serious events in the future.

There are several possible causes for those failure modes, such as,

- an incorrect loading of the aircraft which is left undetected, or
- the aircraft is correctly loaded but the flight crew is given incorrect information, or
- both the aircraft loading and the information passed to the flight crew are correct but the flight crew sets the trim incorrectly

The solution to a recommendation for this precursor depends on whether or not the recorded flight data includes a parameter dedicated to CG position.

If the CG position is readily available, the failure modes may be detected directly as follows:

- Comparison of the recorded CG position against the CG envelope limitations, just like any other aircraft limitation.
- Comparison of recorded CG position and recorded pitch trim setting against the recommended/prescribed values of both variables in accordance with the aircraft documentation (i.e. verify consistency between pitch trim and CG position)

Aircraft Parameters

Parameter	Type
Centre of Gravity Position	Analogue
Stabiliser Trim Position	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Ground (as soon as CG parameter becomes valid) and Airborne (see Note 1)	***FwdCGMargin*** = FwdCGLimit - CG (Note 2)	"CG beyond Fwd limit"	Raise event if ***FwdCGMargin*** < 0 (Notes 3 and 4)
Ground (as soon as CG parameter becomes valid) and Airborne (see Note 1)	***AftCGMargin*** = CG- AftCGLimit (Note 2)	"CG beyond Aft limit"	Raise event if ***AftCGMargin*** < 0 (Notes 3 and 4)
Ground (as soon as CG parameter becomes valid). (see Notes 1 and 5)	***TrimDeviation*** = abs(Actual Trim Position - Expected Trim Position) (Note 6)	"Possible Trim Error"	Raise event if ***TrimDeviation*** is excessive (Note 4)

Note 1: In some aircraft types and frame layouts, the CG position parameter is based on the estimated CG position initially entered by the crew and then updated throughout the flight to account for changes in fuel mass and distribution. For this reason, it's important to delay the monitoring logic until the parameter is properly initialized and valid. One possibility might be instant when the aircraft begins to roll for taxi-out because by then it should be fully refuelled, loaded and configured for takeoff.

Note 2: Under normal circumstances, the centre of gravity is within the envelope limits (*AftCGLimit* < CG < *FwdCGLimit*) as defined in the aircraft documentation, therefore the measurements *FwdCGMargin* and *AftCGMargin* normally take non-negative values.

Note 3: Cases of negative CG margin represent a very serious situation and should be very rare. It might be useful to set the event threshold more conservatively to a small positive value in order to capture also less severe situations.

Note 4: The definition of the event threshold will require a preliminary analysis of the corresponding measurement for a representative sample of flights in order to define normality

Note 5: The monitoring flight phase is limited to Ground (not Airborne) because the relationship between CG and Expected Pitch Trim is normally simpler and documented on the Ground phase. Also, if the aircraft is properly trimmed on the ground for takeoff, it should remain trimmed immediately after lift-off unless there are sudden and abnormal changes in CG (such as due to cargo shifts, but those cases will eventually be known by other means).

Note 6: The expression "Trim position" is used here as a generic term to represent the setting of the physical mechanism used to achieve a longitudinal trim, which depends on the aircraft type under consideration. This must be translated into a suitable recorded parameter as required (e.g. horizontal stabilizer position, trim tab angle, etc). The *Expected Trim Position* is a value to be derived for each flight from other parameters (it could be simply a function of CG or could also depend on flap setting, and/or weight, etc). In other words, the calculation or lookup that flight crew are supposed to carry out to set the pitch trim before takeoff needs to be replicated by the FDM software.

Alternative solution if parameter "CG Position" is not available:

In the absence of a recorded parameter for CG position and without robust methods for its estimation, the detection of the failure modes must rely on indirect detection of their most likely symptoms:

a) Abnormally slow or fast pitch rates on takeoff due to "nose heavy" or "nose light" aircraft

b) Abnormal pitch oscillations while airborne

c) Abnormally large control surface deflections and/or force required to maintain longitudinal control immediately after lift-off (extreme forward CG and/or incorrect trim setting)

d) Abnormal changes in pitch trim immediately after lift-off (manual or automatic attempt to re-trim the aircraft in flight)

Symptoms a) and b) can be largely influenced by pilot technique and therefore not very reliable (too many false positive and false negative events). Symptoms c) and d) are less sensitive to pilot technique and might be detected as follows:

Search Window	Measurements	Event	Event Threshold
Rotation to takeoff and initial climb	• Max(elevator deflection) • Max(control column force) • Range of trim position	"Possible Trim Error"	Raise event if any of the three recommended measurements is abnormal (Note 1)

Note 1: The definition of the event threshold will require a preliminary analysis of the corresponding measurement for a representative sample of flights in order to define normality

Future Developments and Recommendations

All future aircraft designs should offer the following features:

- Enable direct measurement of aircraft weight and CG position while on the ground and include such data on the recorded data stream.
- Once airborne, the initial CG and Weight measurements taken on the ground, should be updated in real time based on remaining fuel quantity onboard.

Maturity Level

Level 1

LOC09 – Abnormal Operations

Summary

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).

The intent of the precursor is to capture normal operations as well as non-revenue ops such as post maintenance flight tests, positioning flights and other flights that are likely to have some exceedance outside the known flight envelope scenarios.

Rationale

The goal of this precursor is to adapt the FDM analysis to the type of operation being performed. At least the following types of operation can be recognised:

- Commercial Flight
- Maintenance Check Flight
- Test Flight
- Ferry to Maintenance
- Positioning Flight
- Training Flight

Commercial flights are those that are normally analysed in an FDM program and these flights are the core of any airline operation. Nevertheless, the remaining flights are also part of the airline activity and other sets of thresholds, measurements or events, may apply to these flights that are different than those used for a regular operation.

In addition, not separating commercial flights from other types of operation may add information to the databases that will distort the reality for the commercial operation.

Future Developments and Recommendations

Flights other that commercial should be identified by the FDM analysis and those are subject to another set of events that suits this particular operation. One practical way to separate those flights can be using special flight numbers prefixes or postfixes, but other solutions may exist to achieve the same result.

Maturity Level

Level 1

LOC10 – Incorrect Performance Calculation

Summary

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).

Rationale

Erroneous data entry or calculation errors can be precursors for inadequate aircraft energy on takeoff and landing. The detection of inadequate aircraft energy is covered by recommendation LOC13 (Inadequate Aircraft Energy), therefore the scope of LOC10 must focus only on the detection of incorrect performance without overlapping with LOC13.

Incorrect performance calculation can also be a precursor for incorrect takeoff and landing configuration. However, such consequences are covered in recommendation LOC32 (Incorrect Aircraft Configuration) and therefore out of the scope of LOC10.

Given the constraints above, the parameters and settings to be monitored in this precursor are: V_1, V_R, V2, V_{REF}, takeoff mass, landing mass and takeoff power.

Parameter to monitor: V_1

If V_1 is incorrectly calculated too high, it could lead the crew to initiate a rejected takeoff when it is no longer safe to do so, possibly leading to a runway overrun. If V_1 is incorrectly calculated too low, it could lead to a premature commitment to the takeoff.

If V_1 is a recorded parameter on the aircraft's data stream, it can be compared against a value calculated by the FDM software emulating the AFM performance tables using aircraft weight and other relevant data. Let the V_1 value calculated by the software be called cV_1[13]

Flight Phase	Measurements	Event	Event Threshold
Takeoff	SelectedV1Error = V_1-cV_1	"Incorrect V_1 Selection" if abs(SelectedV1Error) > Threshold	Small differences between V_1 and cV_1 are expectable and usually inconsequential. A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

If V_1 is not a recorded parameter, nothing can be done since there is no indirect way to determine the **selected** V_1 in the cockpit.

Parameter to monitor: V_R

If V_R is incorrectly calculated too high, it could lead to a late rotation (and then perhaps a runway overrun) and/or exceedance of tyre speed limits. If it is calculated too low, it could lead to a premature rotation. In turn, this could lead to a tail strike and/or runway overrun (because the aircraft is too slow to lift-off) or even to a stall after lift-off.

13 One possible way to obtain the calculated speeds is to have the performance tables available on the FDM software so that a lookup can be performed using the aircraft weight and the runway altitude.

There often is a small – but normal – reaction delay between reaching V_R speed, the call for 'Rotation' and the actual start of the rotation. Therefore, the beginning of the actual aircraft rotation is expected to occur at an airspeed greater than V_R. In other words, due to the reaction delay, 'late' rotations should be the norm (within reason) and 'early' rotations should be considered as abnormal. The acceptable delay in rotation should be determined through the analysis of a suitable sample of normal takeoffs in order to minimize the occurrence of spurious events.

If V_R is a recorded parameter, it can be compared against a value calculated by the FDM software emulating the AFM performance tables using aircraft weight and other relevant data. Let the V_R value calculated by the software be called cV_R

Flight Phase	Measurements	Event	Event Threshold
Takeoff	SelectedVrError = $V_R - cV_R$	"Low V_R Selection" if SelectedVrError < 0	The threshold should be 0 because premature rotations are unexpected.
		"High V_R Selection" if SelectedVrError > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

Let 'aV_R' be the airspeed at which the rotation is actually initiated for any given takeoff. The comparison of aV_R against V_R would be useful to detect cases of inadequate aircraft energy rather than incorrect performance calculation. Refer to LOC13 for further details.

If V_R is not recorded, use cVr as a substitute. Abnormally large differences between aV_R and cV_R could be an indication of a possible performance calculation error.

Parameter to Monitor: V_2

If V_2 is calculated too high it could lead to a shallow climb profile and reduced obstacle clearance. If it's calculated too low it could lead to controllability problems (especially on takeoffs after engine failure) and eventually stall.

If V_2 is a recorded parameter, it can be compared against a value calculated by the FDM software emulating the AFM performance tables using aircraft weight and other relevant data. Let the V_2 value calculated by the software be called cV_2.

Flight Phase	Measurements	Event	Event Threshold
Takeoff	SelectedV2Error = $V_2 - cV_2$	"Incorrect V_2 Selection" if abs(SelectedV2Error) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

If V_2 is not a recorded parameter, refer to LOC13 where the actual and expected climb gradients are used to detect possible errors in the selected V_2 parameter.

Parameter to monitor: V_{REF}

If V_{REF} is calculated too high it could lead to excessive energy on approach (unstable approach) and possibly to a hard landing and/or runway excursion. If V_{REF} is calculated too low it could lead to a stall.

If V_{REF} is a recorded parameter, it can be compared against a value calculated by the FDM software emulating the AFM performance tables using aircraft weight and other relevant data. Let the V_{REF} value calculated by the software be called cV_{REF}.

Flight Phase	Measurements	Event	Event Threshold
Takeoff	SelectedVrefError = $V_{REF} - cV_{REF}$	"Incorrect V_{REF} Selection" if abs(SelectedVrefError) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

If V_{REF} is not a recorded parameter, nothing can be done since there is no indirect way to determine the selected Vref in the cockpit. NOTE: the selected airspeed (if recorded) is not an acceptable approximation to V_{REF} because it often includes a wind correction factor which is normally not known to the FDM system. In other words, the selected target airspeed includes too much variability to be used for this purpose.

Note: the risk of stall and runway overrun are monitored by RE32 and LOC13 respectively.

Parameter to monitor: Takeoff mass and engine power

If the takeoff mass is incorrectly calculated too low (from load sheets) it could lead to inappropriate power settings leading to a runway overrun. If it is incorrectly calculated too high it could have adverse commercial consequences (can't takeoff under current conditions or require higher thrust settings).

Check #1: Use a takeoff performance model to assess the reasonableness of mass vs engine power vs ambient conditions as described in RE05 (Slow acceleration on takeoff).

Check #2: Compare the aircraft gross weight (from a recorded parameter such as FMS Weight) against an estimate of the takeoff gross weight (fuel quantity + payload + aircraft basic empty weight (BEW)). Differences between these two weight estimates are expectable and normal but excessive values should be flagged up as events and investigated more closely. If any other sources for aircraft gross weight are available, the same cross-check should be performed.

Flight Phase	Measurements	Event	Event Threshold
Takeoff	WeightError = FMSWeight –(takeoff fuel Qty + payload + BEW)	"Possible error in takeoff weight" if abs(WeightError) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

Check #3: Compare all available sources of aircraft weight against the Maximum Takeoff Weight as stated in the AFM Limitations. Exceedances of the MTOW are sometimes real but occasionally they could indicate errors in FMS weight values entered by the crew or loadsheet / flight log data.

Flight Phase	Measurements	Event	Event Threshold
Takeoff	MTOWMargin1 = MTOW - FMSWeight	"Possible overweight takeoff" if MTOWMargin1 < Threshold1	Small errors in mass values are common due to rounding of fuel figures or other causes and could lead to spurious events. A suitable threshold must be determined depending on what constitutes an acceptable MTOWMargin.
	MTOWMargin2 = MTOW – (Takeoff fuel qty + payload + BEW)	"Possible overweight takeoff" if MTOWMargin2 < Threshold2	

Parameter to monitor: Landing Mass

If the landing mass is incorrectly calculated too low, it could lead to overweight landings (crew believing the aircraft is operated within AFM limits when it's not). If the landing mass is calculated to high it could lead to incorrectly high V_{REF} values (and perhaps excessive energy on the approach and landing)

Check #1: Compare the aircraft gross weight (from a recorded parameter such as FMS Weight) against an estimate of the landing gross weight (fuel quantity at landing + payload + aircraft basic empty weight). Differences between these two weight estimates are expectable and normal but excessive values should be flagged up as events and investigated more closely. If any other sources for aircraft gross weight are available, the same cross-check should be performed.

Flight Phase	Measurements	Event	Event Threshold
Landing	WeightError = FMSWeight –(landing fuel Qty + payload + BEW)	"Possible error in landing weight" if abs(WeightError) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal takeoffs.

Check #2: Compare all available sources of aircraft weight against the Maximum Landing Weight as stated in the AFM Limitations. Exceedances of the MLW are sometimes real but occasionally they could indicate errors in FMS weight values entered by the crew or in the flight log data.

Flight Phase	Measurements	Event	Event Threshold
Landing	MLWMargin1 = MLW - FMSWeight	"Possible overweight landing" if MLWMargin1 < Threshold1	Small errors in mass values are common due to rounding of fuel figures or other causes and could lead to spurious events. A suitable threshold must be determined depending on what constitutes an acceptable MLWMargin.
	MLWMargin2 = MLW – (landing fuel qty + payload + BEW)	"Possible overweight landing" if MLWMargin2 < Threshold2	

Maturity Level

Level 1

LOC11 – Overweight Takeoff

Summary

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).

Rationale

The maximum limit for takeoff weight is expressed for each fleet by the figure of MTOW (Maximum Takeoff Weight). This value is closely related to the performance calculation and if wrong may be on the origin of precursors related to performance calculation, affecting both runway excursions and Loss of Control In-flight (see RE01 and LOC10).

Being overweight is equivalent for the aircraft to be out of the performance envelope provided by the manufacturers, resulting in a mismatch between the calculated performance speeds and centre of gravity and its corresponding real values.

It is not expected in any situation that the weight is above the value of MTOW, but the initial value for gross weight provided by the load-sheet may be affected by human and/or assumption errors. Currently, the initial gross weight is calculated based on some average values for the weight of passengers and luggage added to the weight of the fuel furnished to the aircraft. The load-sheet is the base for both weight and centre of gravity initial values.

Flying under these circumstances submits the structures of the wings and flight surfaces to abnormal efforts producing cumulative effects. These may not reflect immediately but will have its effect on the overall performance of the aircraft.

Aircraft Parameters

Parameter	Type
Gross Weight (Note 1)	Analogue

Note 1: The initial value is provided manually out of the load-sheet and all the sequent values are reduced by the aircraft fuel consumption.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff	***NA***	*"Overweight Takeoff"*	Raise event if ***GW*** > MTOW (Note 1)

Note 1: MTOW depends on the fleet.

Future Developments and Recommendations

The calculation of GW depends on an initial value that may be affected by human and/or weight assumption errors. Technology for aircraft weight measurement may evolve so that the real weight for the specific conditions can be recorded and available on the data stream. This initial value is of extreme importance as it is used for the initial calculation of takeoff speeds and centre of gravity, but then, all the values recorded for gross weight are the subtraction of the fuel consumption from this initial value. This enhances its importance and its correct measurement would eliminate several sources of errors related to this precursor.

Maturity Level

Level 1

LOC12 – Envelope Protection Systems

Summary

Develop means to detect in-flight activation of aircraft envelope protection systems.

Rationale

Envelope protection systems can vary significantly across aircraft types in terms of philosophy, sophistication and integration with other aircraft systems. In the broadest sense, the expression “Envelope Protection System” could include aural and/or visual alerts to the crew about exceedance of aircraft limitations (such as VMO, VFE, MMO, N1, etc) or even more active elements such as Flap Load Relief systems.

In the context of LOC12, “Envelope Protection System” refers to systems designed to alert and possibly react to unsafe cases of impending stall or low energy. The most basic implementations are commonly known as “Stall Warning”, “Stick Pusher” and “Stick Shaker”. Recommendations LOC13 (“Inadequate Aircraft Energy”) and LOC15 (“Loss of Lift”) are closely related and are meant to be used as a backup or in cases where the activation of the envelope protection system is not recorded.

Under European legislation, the activation of envelope protection systems in flight is a situation that represents a significant safety risk and falls within the scope of the Mandatory Occurrence Reporting scheme. Being a legal requirement, this kind of event should therefore be covered by a safety report submitted by the crew. The role of FDM in this case is to provide supplementary information as explained in the Introduction.

Many aircraft types record in the flight data stream the activation of these systems in the form of discrete (‘On-Off’) parameters. Whenever these parameters are available, the detection of in-flight activation of an envelope protection system is trivial and simply consists of scanning the relevant discrete parameters searching for the ‘ON’ state.

Aircraft Parameters

Parameter	Type
Envelope Protection System (Note 1)	Discrete
Angle of Attack	Analogue

Note 1: The name of the event should reflect the name of the system to which is related, such as “Stick Pusher ON”, “Alpha Floor ON”, “Stick Shake”, etc. The Table above includes a single row for the sake of illustration, but in real FDM implementations there should be as many events and measurements as required to cover all available parameters related to envelope protection

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Airborne	***COUNT*** = Number of seconds discrete is active	“Envelope Protection Active	Raise event if ***COUNT*** > 1 (Notes 1 and 2)
Airborne	***MaxAOA*** = Maximum Angle of Attack	“High Angle of Attack” (Note 3)	Raise event if ***MaxAOA*** > Threshold (Note 4)

Note 1: The minimum time for the event to be generated is one second which may lead to spurious events. This value can be increased to prevent the appearance of false positives after a careful analysis by the operator, especially about the data quality (bad data or noise), the attitude and speeds of the aircraft when the envelope protection is activated. This allows the operator to increase the number of seconds in order to reduce the number of false positives.

Note 2: Alpha Protection events on Airbus aircraft are usually coincident with low speed encounters. This operator's experience indicates that most events where Valpha Prot is close to VLS, are not due to turbulence.

Note 3: Event for fleets that don't have the flight envelope concept. It relies on the measurement of high AOAs attained while airborne.

Note 4: Stall warnings are proactively set before the actual stall of the aircraft. The value of the stall AOA is normally not known to the operator but known to the aircraft manufacturer. In order to establish this threshold:

- We recommend that aircraft vendors provide the information for the best threshold for each configuration.
- The operator may use historic flights from the database so that the normal range of AOA values are determined for each configuration and consequently derive the values for the thresholds.

Maturity Level

Level 1

LOC13 – Inadequate Aircraft Energy

Summary

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

Rationale

This precursor identifies whether the aircraft's energy is suited to the current flight phase.

In terms of the aircraft's energy, the primary focus should be to monitor the total mechanical energy (M_E) which will be given by adding up the aircraft's kinetic energy (K_E) and potential energy (P_E):

$$M_E = K_E + P_E$$

$$K_E = \frac{1}{2}mv^2$$

$$P_E = mgh$$

Where ´m´ is the aircraft's gross weight, ´v´ is the true airspeed, ´g´ is the Earth-Aircraft gravitational acceleration and ´h´ is a reference altitude, such as the standard altitude. For simplicity purposes, it is possible to assume that the Earth-Aircraft and Earth-Surface gravitational accelerations are equal, and therefore constant.

Regarding the thrust force and its relation with speed and energy, both the thrust lever angle and the engine N1 (fan shaft) can be used to monitor this feature.

Taking a closer look at the previous energy formulas, the main energy variations come from speed and altitude deviations in (K_E) and (P_E) espectively, since the mass rate of the aircraft decreases slowly over time due to fuel consumption in comparison with the feasible variations of both speed and altitude. Taking this into account, on one hand, it is possible to look for inadequate speed and altitude values for the current flight phase in a simpler method, on the other hand, we may include the gross weight value to monitor the real aircraft energy as shown in the energy formulas.

Aircraft Parameters

Parameter	Type
Airspeed True	Analogue
Indicated Airspeed	Analogue
Altitude Standard	Analogue
Altitude Selected	Analogue
V2 Speed	Analogue
Approach Target Speed	Analogue
Gross Weight	Analogue
Eng (*) Thrust Lever Angle	Analogue
Eng (*) N1	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff: Start of Rotation	***IAS*** = Indicated Airspeed ***V2*** = V2 Speed	*"Low Energy at Takeoff"*	Raise event if ***IAS*** < V2 + Threshold
Takeoff: Start of Rotation	***IAS*** = Indicated Airspeed ***V2*** = V2 Speed	*"High Energy at Takeoff"*	Raise event if ***IAS*** > V2 + Threshold
Initial Climb	***PE*** = Potential Energy ***PERateOfChange***= ΔPE/Δt	*"Loss of Altitude During Initial Climb"*	Raise event if ***PERateOfChange*** < Threshold DURING Threshold
Initial Climb	***KE*** = Kinetic Energy ***KERateOfChange***= ΔKE/Δt	*"Loss of Speed During Initial Climb"*	Raise event if ***KERateOfChange*** < Threshold DURING Threshold
Climb; Cruise	***N1RateOfChange***= ΔN1/Δt ***AltSelectedRateOfChange*** = ΔAltSel/Δt ***AltRateOfChange*** = ΔAlt/Δt (See Notes 2 & 3)	*"Uncommanded Loss of Performance"*	Raise event if ***AltRateOfChange*** < 0 AND ***N1RateOfChange*** < 0 AND ***AltSelectedRateOfChange*** = 0 DURING Threshold
Descent; Approach	***ME*** = Mechanical Energy ***MERateOfChange***= ΔME/Δt	*"Energy Increase During Descent"*	Raise event if ***MERateOfChange*** > Threshold DURING Threshold
Final Approach	***VAPP*** = Approach Speed ***IAS*** = Indicated Airspeed	*"Speed High During Final Approach"*	Raise event if ***IAS*** > ***VAPP*** + Threshold
Final Approach	***VAPP*** = Approach Speed ***IAS*** = Indicated Airspeed	*"Speed Low During Final Approach"*	Raise event if ***IAS*** < ***VAPP*** + Threshold

Note 1: The definition of event thresholds may require a preliminary analysis of the corresponding measurements and parameters for a representative sample of flights, in order to define normality.

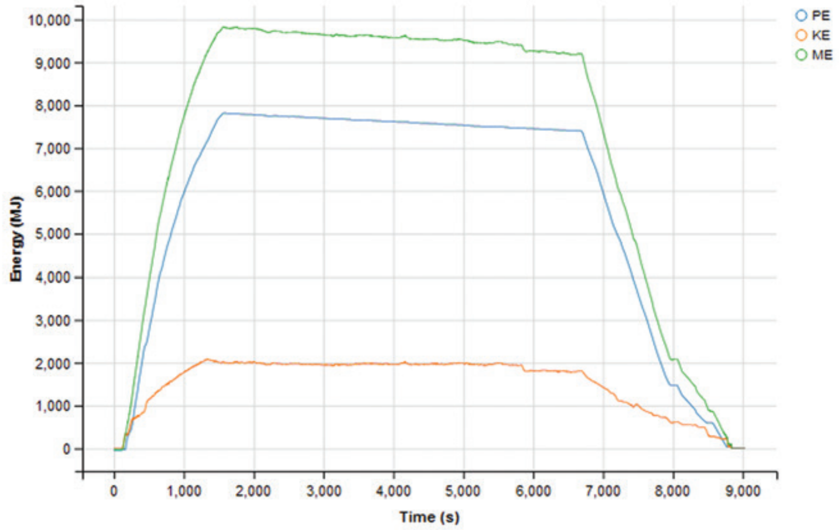
Note 2: May be applied without the ***N1RateOfChange*** setting, in order just to monitor an uncommanded loss of altitude.

Note 3: If the aircraft is changing to a lower flight level, there should be a standby period for this event to avoid false triggers.

Future Developments and Recommendations

For a standard flight, it is expected a continuous increase of energy from takeoff up to the top of climb, then a slow decrease of energy during cruise due to fuel burning and thus mass loss, and finally a larger decrease of energy during descent and approach. Anything that deviates out of this regular behaviour can be a potential matter of study. Essentially, the descent phase should be the harder flight phase to detect inadequate aircraft energy (observing other parameters and not just speed) since there are several ways of performing a descent and approach. For example, a descent using several flight levels and increasing speed in one of those level offs would be an interesting event to monitor.

The graphical display of a mid-range narrow-body aircraft is shown below for further reference.



Maturity Level

Level 1

LOC14 – Inadequate Aircraft Attitude

Summary

Develop means to identify cases of excessive angles of pitch and roll. This identification should take into consideration the range of values acceptable for each phase of flight.

In the context of Inadequate Aircraft Attitude situations, this report summarizes an example operator's FDM triggers and results generated, from a variety of aircraft fleet types, in various phases of flight.

Rationale

Inadequate Aircraft Attitude considers the following scenarios:

- Abnormal Pitch High on landing
- Abnormal Pitch Low on landing
- Pitch Attitude High on takeoff
- Excessive Pitch Attitude (High or low) in flight
- Excessive Bank near ground (takeoff)
- Excessive Bank near ground (landing)
- Excessive Bank 100 ft to 500 ft
- Excessive Bank above 500 ft
- Excessive Roll Rate

Aircraft Parameters

Parameter	Type
Pitch	Analogue
Radio Altitude	Analogue
Main Landing Gear (MLG)	Discrete
Roll	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing : From TimeLdg - 10 sec to TimeLdg + 20 sec	*NA*	"Pitch High on Landing"	Raise event if **Ralt** < 20 ft **Pitch** > Threshold (see Note 1)

Search Window	Measurements	Event	Event Threshold
Landing : From TimeLdg - 5 sec to TimeLdg	***NA***	"Pitch Low on Landing"	Raise event if **Ralt** < 10 ft **Pitch** < Threshold (see Note 2)
Takeoff : From TimeTO - 5 sec to TimeTO + 2 sec (see Note 11)	***NA***	"Pitch High on Takeoff"	Raise event if MLG On Ground **Pitch** > Threshold (see Note 3)
Whole Flight	***NA***	"Pitch High in Flight"	Raise event if **Pitch** > Threshold (see Note 4)
Whole Flight	***NA***	"Pitch Low in Flight"	Raise event if **Pitch** < Threshold (see Note 5)
Takeoff: Start of Rotation through to initial climb	***NA***	"Excessive Bank near ground during Takeoff"	Raise event if **Ralt** < 20 ft **Roll** > Threshold (see Note 6)
Landing: Final approach, Landing, On Ground After	***NA***	"Excessive Bank near ground during Landing"	Raise event if **Ralt** < 20 ft **Roll** > Threshold (see Note 6)
Approach Initial Climb	***NA***	"Excessive Bank from 100ft to 500ft"	Raise event if 100 ft < **Ralt** < 500 ft **ABS(Roll)** > Threshold (see Note 7)
All phases from Initial Climb to Approach	***NA***	"Excessive Bank above 500ft"	Raise event if **Ralt** > 500 ft **ABS(Roll)** > Threshold (see Note 8)
Whole Flight	***RateOfRolll*** = rate of roll calculation (derived from Roll angle)	"Excessive Roll Rate"	Raise event if **RateOfRoll** < Threshold (see Notes 9 and 10)

Note 1: The value of the threshold is fleet specific. Based on one operator's implementation, examples of trigger thresholds are:

- Airbus A320: 9 deg
- Airbus A321: 7 deg

Note 2: The value of the threshold is not fleet specific. Based on one operator's implementation one possibility is:

- Threshold = 0 deg

Note 3: The value of the threshold is fleet specific. Based on one operator's implementation, examples of trigger thresholds are

- Airbus A320: 11 deg
- Airbus A321: 10 deg

Note 4: The value of the threshold is not fleet specific. Based on one operator's implementation one possibility is:

- Threshold = 25 deg

Note 5: The value of the threshold is not fleet specific. Based on one operator's implementation one possibility is:

- Threshold = -10 deg

Note 6: The value of the threshold is fleet specific. Based on one operator's implementation, examples of trigger thresholds are:

- Airbus A320: 8 deg
- Boeing 777: 8 deg

Note 7: The value of the threshold is fleet specific. Based on one operator's implementation one possibility is:

- Threshold = 30 deg

Note 8: The value of the threshold is fleet specific. Based on one operator's implementation, examples of trigger thresholds are:

- Airbus A320: 35 deg
- Boeing 777: 40 deg

Note 9: The value of the threshold is fleet specific. Based on one operator's implementation one possibility is:

- Threshold = 15 deg/sec (For Airbus Fleet)

Note 10: Excessive Roll rate events are almost always due to wake encounters, usually (but not exclusively) whilst in the hold in busy ATC environments. Symptomatic of these events are indications of very sudden changes to vertical acceleration, with associated autopilot disconnects and recovery manoeuvres using sidestick. The brief nature of the Normal Acceleration spike is an indication that the aircraft in question was passing through the wake of an aircraft in front.

Note 11: TimeTO corresponds to the Lift-Off Instant.

Maturity Level

Level 1

LOC15 – Loss of Lift

Summary

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

Rationale

It is possible to estimate the lift coefficient (C_L) of an aircraft using recorded flight data.

The lift coefficient is given by:

$$C_L = \frac{L}{\frac{1}{2}\rho S_w v^2}$$

Where ´L´ is the lift force, ´rho´ is the air density, (S_W) the wing area and ´v´ the aircraft true airspeed.

However, it is impossible to calculate the lift force directly using aircraft recorded data. To do so, it is necessary to determine the lift coefficient at standard gravity (C_{L1g}) where it is assumed that ´L=W´, and then multiply this coefficient by the recorded vertical acceleration divided by ´g´ ($V_{acceleration}$), in order to be dimensionless.

$$C_{L1g} = \frac{W}{\frac{1}{2}\rho S v^2}$$

$$C_L = C_{L1g} \times V_{acceleration}$$ [14]

Air density at a given altitude can be estimated using the Ideal Gas Law:

$$\rho = \frac{p \times M}{R \times T}$$

While the air pressure at a given altitude (h) can be estimated according to:

$$p = p_0 \left(1 - \frac{l \times h}{t_0}\right)^{\frac{g \times M}{R \times l}}$$

The list of constants needed is given in the table below:

Parameter / Unit	Description
p_0 – 101325 *Pa*	Sea Level Standard Atmospheric Pressure
t_0 – 288.15 *K*	Sea Level Standard Atmospheric Temperature
ρ_0 – 1.225 kg/m^3	Sea Level Standard Atmospheric Density
g – 9.80665 m/s^2	Earth-Surface Gravitational Acceleration
M – 0.0289644 *kg/mol*	Molar Mass of Dry Air
R – 8.31447 *J/(mol × K)*	Universal Gas Constant
l – 0.0065 *K/m*	Atmospheric Temperature Lapse Rate
k – 1.401	Specific Heat Ratio of Air (for generic operational temperatures)

14 This formula doesn't consider the bank angle and flight path angle. During turning, the L should be modified as L*cos(bank angle). During the final approach, the W should be modified as W*cos(flight path angle)

The maximum obtainable lift coefficient (CLmax) can be also estimated assuming that the aircraft can maintain the same lift coefficient with the lowest speed possible (by changing flap configuration or increasing the angle of attack for example). For this purpose, the recorded stall speed should be used instead of the aircraft's true airspeed.

$$C_{Lmax} = \frac{L}{\frac{1}{2}\rho S_w V_{stall}^2}$$

All the other needed parameters can also be obtained from the aircraft's recorders, such as speed (or Mach number is also equivalent), the aircraft's gross weight, air temperature, normal acceleration and the wing surface area. Note that the wing surface area may change according to flap settings.

Aircraft Parameters

Parameter	Type
Airspeed True	Analogue
Mach Number	Analogue
Gross Weight	Analogue
Vertical Acceleration	Analogue
Total Air Temperature	Analogue
Flap Lever Setting	Analogue
Stall Speed	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
In-Flight	***CL*** = Lift Coefficient	*"Low Lift Coefficient"*	Raise event if ***CL*** < Threshold
In-Flight	***CL*** = Lift Coefficient ***CLmax*** = Maximum Lift Coefficient	*"Low Lift Ratio"*	Raise event if ***CL/CLmax*** < Threshold

Future Developments and Recommendations

Note that the true lift value is rather complex to determine accurately, and it is necessary to use approximations in order to estimate such values. However, the most important thing is to compare these lift coefficients in the same conditions, since that there are several factors that can contribute to lift variations, that may be commanded or uncommanded. This will ensure that the estimated coefficients can be compared with each other since the speed and wing area references remain the same.

Maturity Level

Level 1

LOC16 – Foreign Object Damage (FOD)

Summary

Develop means to identify cues that could suggest events of foreign object damage.

Rationale

Foreign Object Damage correspond to a multitude of situations where any object or wildlife can collide with the aircraft producing some degree of damage. The impact may be on the skin surface, wings, radome or any exposed part of the aeroplane or it can correspond to the engine ingestion or impact to a rotating fan.

The impact may be caused by parts being projected from other aircraft or runway debris pushed through the Jetstream. This can be any solid object from different origins, aircraft or ground vehicles parts, rocks or even ice. The wildlife, especially birds, are also a significant cause of impacts. This is a special type of incident known in the industry as "Bird Strike". Other sources for impact may include insects, dust or volcanic ash.

There is a large range of objects, wildlife and impact situations that make this precursor one of the most difficult to monitor through FDM, if not impossible. For the catastrophic impacts, the FDM analysis does not play any role, as normally these are severe accidents that are subject to the analysis of the competent investigation authorities. In the case of smaller impacts, normally there is no precision from the accelerometers which only start to detect it when a more serious situation, a stronger impact, occurs and this may be one of the cases referred previously.

Considering the engine ingestions, of dust, insects or even small birds, normally these situations will cause a loss of performance of the affected engine that can be detected by the Engine health Monitoring programs. Some degradation patterns should be reflected in this analysis which conducts to the appropriate maintenance actions.

The safety of the operation may benefit from identifying where and when these incidents happen so that the locations and time of the year distributions may provide insights on repetitive patterns.

Other than these smaller impacts, the working group considers that either it is impossible for FDM to create precursors for FOD or it is out of scope due to the catastrophic nature of the incident or accident.

Maturity Level

Level 0

LOC17 – Electromagnetic Interference

Summary

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

Rationale

Operators of commercial aeroplanes have reported numerous cases of portable electronic devices affecting avionics systems during flight. These devices, including laptop computers, audio players/recorders, electronic games, cell phones, compact-disc players, electronic toys, and laser pointers, have been suspected of causing such anomalous events as autopilot disconnects, erratic flight deck indications, aeroplanes turning off course, and uncommanded turns. It has been recommended that devices suspected of causing these anomalies be turned off during critical stages of flight (takeoff and landing) and that the use of devices that intentionally transmit electromagnetic signals, such as cell phones, be prohibited during all phases of flight.

As far as FDM is concerned, it appears that little data is available to evaluate the root cause of an aeroplane unexpected behaviour and specifically to target electromagnetic interference (EMI) as this root cause. As a matter of fact, only localizer and glideslope signals are commonly recorded in FDR/QAR. Besides, they can be affected by a number of factors such as atmospheric or terrain disturbances and the validity of the signals are guaranteed only within a limited volume in approach to the airfield (as per ICAO annex 10).

The main difficulty in identifying possible EMI within the navigation system is to compare the actual trajectory with the intended or expected one, which is generally unknown to an automatized FDM system. The only situation where the expected trajectory can be quite easily determined is on an ILS approach as soon as LOC and/or GS track modes are engaged (which implies the a/c should follow a straight path down to the runway). In this specific situation (LOC and/or G/S track modes engaged) clues of potential EMI can be found in one or a combination of indications including but not limited to:

- change of AP/FD mode (to other than go-around or land modes)
- successive disengagement and re-engagement of the AP/FD
- erratic or quick variations in the LOC and/or GS deviation signals
- significant roll increase with regards to atmospheric conditions (turbulence)
- significant heading change

Maturity Level

Level 1

LOC18 – Adverse Weather

Summary

Develop means to identify the presence of adverse weather in the vicinity of the aircraft.

Rationale

Adverse weather phenomena are meteorological conditions that, if aircraft encountered during ground or flight operations, could directly diminish and even threaten the safety of those operations:

a. Strong surface winds (exceed the aircraft max. certification limitations, such as tailwind > 15 kts, cross-wind > 40 kts)

b. Thunderstorms

c. Meteorological conditions that contaminate a runway or takeoff surface and adversely affect aircraft performance

d. Natural hazards such as cyclones, hurricanes, typhoons, tropical storms, sandstorms/dust storms, volcanic ash.

It is highly recommended that the FDM system should integrate with weather data analysis system, such that more detailed information may be available in the "**Algorithm to describe weather conditions at European airports.**"

(a) Strong surface wind

- Using acquired parameters "wind speed", "wind direction" and "heading" to calculate tailwind and head-wind component, then evaluate the severity of strong surface wind. Headwind/tailwind limits are aircraft type dependent while crosswind limit is usually set at 35 kt during takeoff/landing operation.
- Vw, crs (crosswind) = Wind Speed * Sin (wind direction – runway heading)
  Vw, hw (headwind) = Wind Speed * Cos (wind direction – runway heading)

  (<0 for tailwind)
- According to NLR report NLR-TP-2001-003, tailwind limitation for subsonic civil transport aircraft is type-dependent. For Airbus aircraft, tailwind limit sets at 15 kts for A320/330/340 while for Boeing aircraft the limit sets at either 10 kts (B737 Classics) or 15 kts (B747/757/767/777).

Aircraft Parameters

Parameter	Type
Wind Speed	Analogue
Wind Direction	Analogue
Heading True	Analogue
Radio Altitude	Analogue
Runway Heading	Analogue

Measurements and Events

(strong surface wind)

Search Window	Measurements	Event	Event Threshold
Approach Phase Go-Around ✓ WOW "AIR" ✓ RA <= 100 ft.	***Xwind*** = WindSpeed*sin (Wind_ direction – Runway Heading) ***HeadWind***=WindSpeed*cos(Wind_ direction-Runway Heading)	"Strong crosswind" "Strong headwind" "Strong tailwind"	Raise event if ***Xwind*** > 35 (kts) / 20 (kts, autoland) ***HeadWind***> threshold (see Note 1) ***HeadWind***<threshold (see Note 2, 3)

Note 1: Tailwind if the value <0. RWY Headwind limitation varies by aircraft type. For example, 35 kts for autoland operation, 45 kts otherwise.

Note 2: RE24 also covers tailwind precursor.

Note 3: Aircraft type dependent. For instance, most Airbus aircraft tailwind limits are set at 15 kts (-15) while those for Boeing aircraft could be either 10 kts (-10 for B737 Classics) or 15 kts (-15 for B747/757/767/777). 10 kts (-10) for autoland operation.

Maturity Level

Level 1

LOC19 – Windshear

Summary

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

Rationale

In aviation, windshear encounters are described as a sudden increase or decrease in the headwind (positive or negative WS encounter, respectively). The "direction" of the variation of headwind changes its associated risks. Since windshear events are usually very contained from a spatial perspective, any corrections performed during the encounter can negatively impact the control of the aircraft when the encounter ceases.

The common definition of windshear also correlates the change in headwind with downdrafts and updrafts.

Systems to detect these events are available and typically integrated with TAWS. Generically speaking, these systems will issue a caution (less serious) in the case of a positive windshear encounter and a warning (more serious) if negative windshear is found. This difference is justified by the associated risks to each type of encounter.

Implementation of a detection algorithm in FDM software will be divided into two methodologies, depending if the aircraft is equipped with a system to detect such occurrences.

Methodology 1: Detection of windshear conditions when onboard detection is available and recorded

If an onboard detection equipment is available, operational and its outputs are recorded, then these can be used to activate events in the FDM software. Typically, the equipment will differentiate between caution and warning, so different events can be triggered, similarly to what happens on the flight deck. If not, the categorization can only be made by the analyst.

Strong winds and turbulence are always evident when a windshear discrete is triggered, although false warnings can be detected occasionally.

Methodology 2: Detection of windshear conditions when onboard detection is NOT available or NOT recorded

Typical onboard detection of windshear encounters looks at changes in the headwind and vertical speed, meaning it should be possible to replicate in an FDM software.

One difficulty is the fact that vertical speed is much more sensitive than longitudinal speed. The amount of downward momentum on an aircraft in the approach phase is around 20 times smaller than forward momentum, which means that the same disturbance (in each specific axis), will have a much greater impact on vertical speed. On top of that, it's difficult to differentiate if changes are due to normal aircraft dynamics (response to inputs or changes in airspeed) or downdrafts/updrafts since their impact on vertical speed is of the same order of magnitude.

For this reason, at least on this first approach, we will focus only on changes in the headwind. Two proposals will be made using headwind as a reference. Care must be taken if using a derived parameter for headwind. The operator should ascertain if the parameter provides enough accuracy, resolution and sampling rate.

Standard deviation

- Calculate the standard deviation of the headwind parameter on the period of interest. A large enough value means that maximum or minimum values were far from the average value - this approach is more conservative and may cause false positives for gusty conditions, depending on the threshold chosen.
- This method does not allow to differentiate between positive and negative windshear.

Rate of headwind

- Calculate the maximum and minimum instantaneous rate of the headwind parameter. A large enough rate (in absolute value), representing a steep change in the headwind, may be interpreted as windshear.
- This method allows to determine if windshear is positive or negative, although care must be taken since a windshear encounter will almost always have a positive change and a negative change, and what determines the type is the "direction" of the first change.
- This method may look similar to what's represented in the airspeed trend vector, but the fact it's looking at headwind means it's not measuring the same.

Use of airspeed is not recommended since it is more sensitive to inputs, namely pitch and thrust.

Aircraft Parameters

Parameter	Type
Windshear Warning	Discrete
Windshear Caution	Discrete
True Airspeed	Analogue
Indicated Airspeed	Analogue
Groundspeed	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Takeoff Approach Missed-Apprs Go-Around (see Note 2)	***COUNT*** = Number of seconds discrete is active	"Windshear Warning"	Raise event if ***COUNT*** > 1 (See Note 1)
500 ft to 1500ft AAL (See Note 3)	***HeadWind*** (Note 4) ***StdHeadWind*** = Standard Deviation of Head Wind	"Possible Windshear Encounter"	Raise event if ***StdHeadWind*** > Threshold (see Note 5)
500 ft to 1500ft AAL (See Note 3)	***HeadWindRate*** (Note 6) ***MaxHeadWindRate*** = Maximum HeadWind Rate	"Positive Windshear"	Raise event if ***StdHeadWind*** > Threshold (see Note 5)
500 ft to 1500ft AAL (See Note 3)	***MinHeadWindRate*** = Minimum HeadWind Rate	"Negative Windshear"	Raise event if ***StdHeadWind*** < Threshold (see Note 5)

Note 1: The value of the threshold can increase to control the number of false positives.

Note 2: Generically speaking, windshear events are important when happening close to the ground. With this methodology, and since it implies close to no computational power to apply, no special care must be taken to limit the search window, being enough to limit the search to approach, takeoff and missed approaches/go-arounds

Note 3: Generically speaking, windshear events are important when happening close to the ground, so the search window should reflect that. With this methodology, there are some calculations being performed on-the-fly. If performance is an issue, the search windows can be reduced to a lower height above the runway. A search window from the runway up to 500ft to 1500ft AAL should be acceptable.

Note 4: The Headwind can be derived from by subtracting Groundspeed from True Airspeed.

Note 5: Thresholds for the events must be carefully chosen to minimize the cases of false positives. This will vary by aircraft type, since it's closely related to aircraft dynamics, wing configuration and shape, etc.

Note 6: The Headwind Rate can be derived from the variation of Headwind parameter with time (DeltaHeadWind/DeltaTime).

Maturity Level

Level 1

LOC20 – Severe Turbulence

Summary

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

Rationale

In the context of Severe Turbulence situations, this report summarizes an example operator's current FDM triggers and offers suggestions from an analyst's perspective as to how to identify different scenarios. The most significant incidents usually result in multiple FDM events and would normally have a supporting crew report.

For all worldwide aircraft operators, turbulence encounters are a familiar phenomenon and occurrences can be expected year-round.

The three (industry recognised) intensities of turbulence are light, moderate and severe. Turbulence can be defined as random and frequent changes to air velocity. The effect on an aircraft is to disturb its flight path. FDM can be used to capture these disturbances.

The following (not necessarily exhaustive) list contains recorded parameters that can typically be measured to detect potential instances of turbulence in flight.

- Vertical (normal) acceleration (accelerometer reading)
- Altitude (uncommanded changes)
- Pitch Attitude (erratic or abrupt changes) (Note 1)
- Roll / Bank Angle (abrupt changes, or rate of roll) (Note 1)
- Activation of Stick Shake (Boeing fleets) or AlphaProt (Airbus)
- Rudder deflection (Note 1)
- TAWS Windshear Alert Mode

Note 1: Both the surface deflection and the input are recommended to be recorded in order to detect uncommanded deflections.

Analysis of detected events

There is no hard or fast rule that enables a data analyst to positively identify the exact type of turbulence that is affecting an aircraft, be it thermal, mechanical (mountainous terrain), shear (weather), or aerodynamic (wake).

Should there be a requirement by an operator to categorise any encounters, it is reliant on the analyst to refer to other parameters (or external data) to form an opinion based on various factors that are present. For example:

- Geographical position (Latitude/Longitude) in relation to terrain
- Altitude
- Wind changes (TAS vs Groundspeed)
- Duration of event (NMLA , rate of roll)
- Any available METAR data
- Air Safety Reports filed by the operating crew

Aircraft Parameters

Parameter	Type
Acceleration Vertical	Analogue
Altitude Standard	Analogue
Pitch	Analogue
Roll	Analogue
Envelope Protection System (Note 1)	Discrete
Rudder	Analogue
TAWS Windshear Warning	Discrete

Note 1: The name of the event should reflect the name of the system to which is related, such as “Stick Pusher ON”, “Alpha Floor ON”, “Stick Shake”, etc. The Table above includes a single row for the sake of illustration, but in real FDM implementations there should be as many events and measurements as required to cover all available parameters related to envelop protection

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	***NA***	“High Normal Acceleration In Flight”	Raise event if ***Normal Acceleration*** > Threshold1 OR ***Normal Acceleration*** < Threshold2 (see Notes 1 and 2)
Whole Flight (From unstick to landing)	***NA***	“Altitude Deviation”	Raise event if Positive or negative deviation of ALT over 120 secs (see Note 3)
All phases from Initial Climb to Approach	***NA***	“Excessive Bank Angle”	Raise event if **ABS(Roll)** > Threshold (see Note 4)
Whole Flight	***RateOfRoll*** = rate of roll calculation (derived from Roll angle)	“Excessive Roll Rate”	Raise event if **ABS(RateOfRoll)** > Threshold (see Note 5)
Whole Flight	***NA***	“Stick Shake” “Alpha Protection”	(see Note 6)
All phases from Initial Climb to Approach AND ALT > 1000ft	***NA***	“Excessive Rudder Deflection”	Raise event if **ABS(RuddDeflection)** > Threshold (see Notes 7 and 8)

Note 1: The value of the threshold is fleet specific and should cope with both high positive and negative vertical accelerations. The second case is normally the one that leads to more injuries on-board. Based on one operator’s implementation, examples of trigger thresholds for clean configuration are:

- Threshold1 = 1.4 g
- Threshold2 = 0.6 g

Note 2: The effect of Severe turbulence results in (+ve or -ve) variations in the (vertical) accelerometer reading of more than 1g at the aircraft’s centre of gravity. Variations of less than 1g are classified as light, moderate (or negligible).

The value of NMLA (Vert Accel) is 1g when the aircraft is motionless (level), thus the event tests for values of 0.6 (or lower), or 1.4 g and above.

The example operator additionally establishes a specific aircraft datum (for each flown sector). Thus, if a motionless recording of NMLA for an aircraft on a particular day is (eg) 0.995g, then a datum of 0.005g is factored into the event condition, to ensure more accurate results. This "datum" is usually due to the accelerometer installation. It can be computed by observing the normal acceleration when the aircraft is on the ground and not moving.

By implication, Scenario 1 is only (in theory) triggering events for cases of severe turbulence and not collecting information for moderate or light turbulence encounters. This event is the primary one used for detection of severe turbulence.

Note 3: This event was originally constructed to detect potential occurrences of altitude busts. In practice though, it generates results which are typically controlled deviations (supported by selected altitude mode changes and radio transmission indications). However, a by-product of the results is a visible audit that suggests the majority of events triggered are due to crews changing altitude in the search for smoother air. Any recorded turbulence in evidence, however, is usually of a moderate rather than severe nature.

Note 4: The value of the threshold is fleet specific and either from aircraft documentation from flight data from the operation this value can be determined.

Note 5: This event was already described in LOC14.

Note 6: Events already addressed on LOC12.

Note 7: The value of the threshold is fleet specific.

Note 8: Rudder deflection events are usually only triggered during turbulent conditions. On certain aircraft types, they can be automatically generated as a result of yaw damper action

Future Developments and Recommendations

Proposal for new events definition:

1) Rapid or Abrupt Pitch Change Rates

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	***NA***	"Rapid or Abrupt Pitch Attitude Changes"	(see Note 1)

Note 1: No specific event defined to detect rapid pitch changes. In practice, significant uncommanded pitch rate changes only occur in concert with High G in-flight incidents, so such occurrences are picked up in "High Normal acceleration In-Flight".

2) High Temperature Variations in Cruise

Turbulence can be associated with temperature variations and be happening in regions where there are air masses of different temperatures are in collision (ex: North African West Coast with Sahara and Atlantic air masses). In this case, either SAT or TAT variations (or both) can be used as a precursor for the turbulence measurement.

A similar methodology used to extract stability points for Engine Health Monitoring (EHM) to determine the variance of the temperature on a sliding window. Normally a window of 100sec is used and this value can be used as initial guidance to build this event. Whereas in EHM the search is for windows where the variance stays within pre-defined limits, here the proposal is to search where the variance exceeds these limits, indicating that some high temperature variations are present. Care should be taken when there is a change of flight level during cruise.

Search Window	Measurements	Event	Event Threshold
Cruise	***MeanTemp*** = Mean Temperature ***VarTemp*** = Temperature Variance (see Notes 1, 2)	"High Temperature Variations in Cruise"	Raise event if ***VarTemp*** > Threshold within the sliding window (See Note 3)

Note 1: Standard Deviation can be used instead of Variance.

Note 2: Can be applied either to SAT or TAT

Note 3: Sliding Window of 100sec proposed for initial conception of this event (based on EHM values)

3) RMS-g calculation

This method consists of calculating the Root Mean Square of the vertical acceleration during a given time interval (sliding window).

$$x_{\text{rms}} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_n^2\right)}.$$

This is a general equation to represent the calculation of the RMS. Under the context of turbulence measurement, the "x" will be the vertical acceleration and the "n" represents the window dimension. Some exploratory work has to be conducted to determine the value that best suits the goal of describing in the best way possible the turbulence suffered by the aircraft.

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	***RMS-g***	"High RMS-g Value"	Raise event if ***RMS-g*** > Threshold within the sliding window (See Note 1)

Note 1: Values for the dimension of the sliding window (n) using flight data in known turbulence events.

4) The Wake vortex detection can be accomplished by:

- Using the combination of events "Roll Abrupt changes" + "High Normal Acceleration in Flight". These events may have to be created or adjusted from the existing "Excessive Bank Angle" and "Excessive Roll Rate"
- The creation of one event "Uncommanded Roll Attitude" to detect the correction of induced roll attitudes (or abrupt roll) from spoilers or ailerons without the corresponding pilot command

Maturity Level

Level 1

LOC21 – Icing Conditions

Summary

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.

Rationale

- Using recorded parameters "airspeed", "OAT" and "AOA" to analyze possible in-flight icing. Due to ice accretion on wings, the tail section may experience light vibration, slow or rapid airspeed decay. Furthermore, if the autopilot is engaged, the AFCS will try to maintain proper airspeed, and trim the attitude. Therefore, airspeed decay and the associated increase in AOA could be an indicator, when OAT between 2 deg C ~ -15 deg C.
- Using the recorded parameters of "de-icing airframe on", "icing AOA", and "icing detected", to identify the aircraft encountered the in-flight icing.

Aircraft Parameters

Parameter	Type
De-Icing Airframe ON	Discrete
Icing AOA	Discrete
Icing detected	Discrete
Indicated airspeed	Analogue

Measurements and Events

Measurements and Events (moderate/severe in-flight icing)

Search Window	Measurements	Event	Event Threshold
Whole Flight ✓ WOW "AIR" ✓ AIRSPEED > = 120 kt	***COUNT*** = Number of seconds discrete is active	"airframe icing warning"	Raise event if ***COUNT*** > 1
Whole Flight ✓ WOW "AIR" ✓ AIRSPEED > = 120 kt	***COUNT*** = Number of seconds discrete is active	"icing detected warning"	Raise event if ***COUNT*** > 1
Whole Flight ✓ WOW "AIR" ✓ AIRSPEED > = 120 kt	***COUNT*** = Number of seconds discrete is active	"icing AOA warning"	Raise event if ***COUNT*** > 1
Crusie phase ✓ WOW "AIR" ✓ AIRSPEED > = 120 kt	***DeltaofCAS*** =rate of change in airspeed	"derived severe icing"	Raise event if ***DeltaofCAS*** > Threshold (see Note 1)
Whole Flight ✓ WOW "AIR" ✓ AIRSPEED > = 120 kt	***DeltaofAOA*** =rate of change in AOA	"derived severe icing"	Raise event if ***DeltaofAOA*** > Threshold (see Note 2)

Note 1: depending on aircraft type, i.e. airspeed decay more than 20 kt, during 5 min.

Note 2: depending on aircraft type, i.e. AOA increase > 5 deg, during 5 min.

Future Developments and Recommendations

Some articles available on this area[15] describe that anomalous variations of TAT at high altitude may be indicators of the presence of ice crystals. It is recommended that studies should be conducted in the operators to get more insight knowledge in this area and extract some TAT patterns that can identify these conditions.

Maturity Level

Level 1

15 1) Icing, A nearly undetectable weather hazard can knock out a jet engine, by Mark Lacagnina (http://www.flightsafety.org/asw/jun08/asw_jun08_p12-16.pdf)

2) Engine Power Loss in Ice Crystal Conditions, by Jeanne Mason (https://www.boeing.com/commercial/aeromagazine/articles/qtr_4_07/article_03_1.html)

LOC22 – De–Icing system Failure

Summary

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

Rationale

All aircraft manufacturers have procedures related to flight in icing conditions that obviously depend on the design of ice protection systems for the airframe, engines, probes, that can vary among manufacturers.

In the context of LOC22 recommendation, only the part related to ice protection systems (activation or failure) is studied, the challenges associated with the detection of such icing conditions lying within the scope of LOC21.

Failure cases may be quite obvious, e.g. captured by discrete parameters in the dataframe layout. If it is not the case, the failure of an anti or de-icing system will most probably be seen through performance degradation (airframe/engines icing) or indication issues (probes icing). Those consequences also fit with a scenario of icing conditions that are beyond the certification envelope, sometimes referred to as “severe icing” conditions.

For certain aircraft types, some anti-icing systems are switched on for all the flight, typically the air data probe heating. Others are switched on when the a/c enters icing conditions (defined by low TAT / visible moisture) and off when the aircraft is confirmed free of ice. As soon and as long as those are turned on, the AOA thresholds for the stall protection system (stick shaker/pusher) are often lowered. The de-icing systems are turned on when ice accretion starts and off when the aircraft is free of ice.

Detection of ice accretion can be based on visual indications (ice accreting on the windshield, wipers, propeller spinners, wing leading edge, etc.), or via ice detection systems providing the crew with a caution message when it detects ice accretion.

Future Developments and Recommendations

Although not necessary to highlight every flight where anti-ice systems are in use or warnings of ice detected, it is of interest when they are not used correctly or there is a system failure.

- the delay between an ice detection caution and the activation of the de-icing system ; theoretically, the activation of de-icing systems could be done even before an ice detection message, but at the latest should be done quickly after such indication.
- the monitoring of the aircraft performance: such monitoring allows detecting a loss of performance that would be most likely due to icing of the airframe. The performance may be reflected by the rate of climb (in climb) or IAS (in cruise).
- the monitoring of different air data sources, when applicable - mainly on IAS but also altitude - that could indicate a probe icing (see LOC24).
- the adequacy of the use of ice protection systems: at “high” temperature, it is not necessary anymore and may reduce the lifetime of some components.
- system failure e.g. left-wing anti-ice vs. right-wing anti-ice asymmetric usage

Maturity Level

Level 1

LOC23 – Engine Failure

Summary

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.

Rationale

It is possible to identify engine failures through the use of recorded flight data.

Engine failures can be classified as active or latent. An active failure is defined as an unsafe act or situation that may have direct influence in an accident/incident while a latent failure can carry on for larger periods of time before being responsible for an accident/incident itself.

Usually, latent failures are easier to forecast using FDM and EHM tools since it is possible to perform trend analysis for the engine's primary parameters such as N1, N2, EPR, FF and EGT, or any other parameter that is also recorded. However, both active and latent failures are equally important and should be monitored as strictly as possible.

The list of events to monitor may include:

- Excessive engine vibration
- Low oil pressure
- High oil temperature
- Maximum EGT exceedance
- Thrust asymmetry
- Engine rollback
- In-flight engine shutdown
- Fire warning
- FADEC system fault warning

Aircraft Parameters

Parameter	Type
Eng(*) N1	Analogue
Eng(*) N2	Analogue
Eng(*) N3 (see Note 1)	Analogue
Eng (*) Thrust Lever Angle	Analogue
Eng (*) Exhaust Gas Temperature	Analogue
Eng (*) Oil Pressure	Analogue
Eng (*) Oil Temperature	Analogue
Eng (*) Vibration N1	Analogue

Parameter	Type
Eng (*) Vibration N2	Analogue
Eng (*) Vibration N3 (see Note 1)	Analogue
Eng (*) Master Switch	Discrete
Eng (*) Fire Warning	Discrete
FADEC System Fault Warning (see Note 2)	Discrete
Eng (*) Nh (Note 3)	Analogue
Eng (*) Np (Note 3)	Analogue
Eng (*) Torque (Note 3)	Analogue

Note 1: When Applicable

Note 2: Applicable to Airbus fleets referring the engine automatic control system.

Note 3: Applied to turboprop engines

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight	***MaxEngVibN1*** ***MaxEngVibN2*** ***MaxEngVibN3*** Maximum Engine Vibration for each engine shaft (See Note 1)	"Excessive Engine Vibration"	Raise event if **MaxEngVibN1** > Threshold OR **MaxEngVibN2** > Threshold OR **MaxEngVibN3** > Threshold
In-Flight	***MinEngOilPrs*** = Minimum Engine Oil Pressure	"Engine Low Oil Pressure"	Raise event if ***MinEngOilPrs*** < Threshold
Whole Flight	***MaxEngOilTemp*** = Maximum Engine Oil Temperature	"Engine High Oil Temperature"	Raise event if ***MaxEngOilTemp*** > Threshold
In-Flight	***DiffEngN2*** = Difference between N2_Eng1 and N2_Eng2	"Thrust Asymmetry"	Raise event if ***ABS(DiffEngN2)*** > Threshold (see Note 2)
In-Flight	***N1RateOfChange***= ΔN1/Δt ***N2RateOfChange***= ΔN2/Δt ***N3RateOfChange***= ΔN3/Δt (if applicable) ***TLARateOfChange***= ΔTLA/Δt	"Engine Rollback"	Raise event if (***N1RateOfChange*** < Threshold OR ***N2RateOfChange*** < Threshold OR ***N3RateOfChange*** < Threshold) AND ***TLARateOfChange*** = 0 DURING Threshold2 (Note 5)
Takeoff Go Around	***MAXEngineEGT*** = Maximum EGT	"Maximum EGT Exceedance"	Raise event if ***MAXEngineEGT*** > Threshold
Whole Flight	***TimeEngFire*** = Number of seconds the Engine Fire Discrete is in the ON State	"Engine Fire"	Raise event if ***TimeEngFire*** > Threshold (See Note 4)
In-Flight	***EngMstSw*** = Engine Master Switch	"Engine In-Flight Shutdown"	Raise event if ***EngMstSw*** = 0 (or OFF)
Whole Flight	***FADECFault*** = FADEC System Fault Warning	"FADEC System Fault"	Raise event if ***FADECFault*** = 1 (or ON)

Note 1: Use N3 when applicable

Note 2: See LOC26 for further recommendations on the loss of thrust/thrust asymmetry.

Note 3: The definition of event thresholds may require a preliminary analysis of the corresponding measurements and parameters for a representative sample of flights, in order to define normality.

Note 4: As for other discrete signals there may be spikes on the Engine Fire Warning, which correspond to nuisance warnings. The threshold value may be used to control these cases.

Note 5: A reduction of thrust could also be commanded by the autothrottle i.e. without change of TLA position. In that case, it is not an engine rollback. Since the aircraft becomes lighter during the flight (because of burnt fuel), the thrust needed for maintaining airspeed at a given flight level will become less. A threshold is used to control the slope of this reduction so that only more abrupt changes produce events.

Future Developments and Recommendations

This list of events refers only to FDM data. However, to identify possible engine failure scenarios it may be of great interest to monitor more engine parameters through an EHM tool, and keeping an updated database for each fleet and engine type that is being operated. Also, other types of FDM parameters can be included for an engine failure analysis.

It is necessary to investigate more engine failure trends using a representative sample of flights and if possible by looking at engine failure data that already occurred before while in operation.

Identifying unusual trends in the engine's primary parameters may predict a failure due to hardware degradation or other sources, such as an increase of EGT over time or a decrease of N2 over time. These type of trends are usually associated with specific types of hardware failures such as valves, vanes, compressor or turbine blades, and more. When doing this kind of research, it is essential to monitor the engine parameters on a similar condition from flight to flight, or a stability point, to ensure that the data collected is comparable.

Maturity Level

Level 1

LOC24 – Instrument Malfunction

Summary

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

Rationale

Develop means to identify situations of instrument malfunction. The most direct approach is to compare and identify failures related to key parameters utilized for flight envelope showing differences between two sources. For example Airspeed source 1 vs Airspeed source 2.

Monitoring of system malfunction is critical in preventive identification (instead of reactive) leading to possible LOCI event, as malfunction system resulting in inaccurate inflight parameter values have been identified as a major contributor to many fatal and serious incidents and accidents.

Some insight into key parameter monitoring and their respective effects related to the WGA Document LOCI, Scenario #3 (LOC due to Environmental Factors) and especially Scenario #4 (LOC due to System Failure),

- Angle of Attack, Monitoring of left and right values of angle of attack probes. Identification of a stuck or lagging probe.
- Altitude, Comparison of ADR based altitudes between two systems to identify any discrepancy in the altitude values being used by the system and avoid a potential altimetry system error in RVSM airspace. Based on the system in use Left AP vs Right AP the aircraft can target an incorrect actual altitude resulting in RVSM events.

AoA Monitoring: Capture both AoA values and monitor their difference for a set delta maintained over a specific number of seconds i.e. to eliminate both instantaneous delta for short duration as well as a delta of smaller values. Hence the event is triggered e.g. if the AoA values differ by 0.8 deg for a continuous duration of 10 seconds.

Altitude Monitoring: Capture the delta between ADR1 and ADR2 altitude values. If the value exceeds a preset threshold limit, then flag event

Aircraft Parameters

Parameter	Type
Roll	Analogue
Angle of Attack	Analogue
Standard Altitude	Analogue

Note: For this precursor, it is assumed that the parameters are collected from different sources independently, i.e., one parameter for system #1 and another parameter for system #2.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight (see Note 1)	***AOA_DeltaValue*** = Difference of AOA between two sources.	"Angle of Attack Monitoring"	Raise event if ***AOA_DeltaValue*** > Threshold1 DURING Threshold2 sec (Notes 2 and 3)
Whole Flight (see Note 1)	***ALT_DeltaValue*** = Difference of Altitude between two sources.	"Altitude Monitoring"	Raise event if ***ALT_DeltaValue*** > Threshold (Note 4)

Note 1: Some flight phase specific monitoring can also be implemented as well such as altitude deviation allowance as per FCOM i.e. above F/L 200 monitoring only.

Note 2: Some stabilization in Roll may be required for the generation of this event, based on one operator's implementation, a possible solution is to have the roll angle within:

- ABS(Roll) < 15 deg

Note 3: The definition of event thresholds will require a preliminary analysis of the corresponding measurements and parameters for a representative sample of flights, in order to define normality. Based on one operator's implementation, the thresholds can be set as:

- Threshold1 = 0.8 deg
- Threshold2 = 10 sec

Note 4: The definition of event thresholds will require a preliminary analysis of the corresponding measurements and parameters for a representative sample of flights, in order to define normality. As a reference, the maximum differences between altitude indicators are normally described in the Aircraft Flight Manual for different flight levels. The thresholds for safety purposes should be lower than those documented to indicate a trend before the operational limit is attained.

Maturity Level

Level 1

LOC25 – Structural Failure

Summary

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 the potential of advanced instrumentation and sensors available in modern aircraft).

Rationale

The current technology normally available in the operator's common fleets doesn't include real-time structural analysis of the skin and airframe, available in research and development programmes, such as SHM (Structural Health Monitoring). This means that any sudden structural failure due to an impact cannot be immediately detected by any aircraft system.

On the other hand, the life of the aircraft since its new condition suffers a natural degradation during its operation. This is normally monitored in the airlines through the APM (Aircraft Performance Monitoring) programmes which separate the degradation due to the engines (also covered on LOC16 through EHM programme) and due to the aerodynamics of the aircraft.

Despite the bottom reason of any aerodynamic degradation cannot be identified, it can be due to any structural deviation either from the skin or from any control surface deviation. Another common reason is the increase of the roughness of the skin due to dust accumulation. The bottom reason has always to be evaluated individually by an expert.

Flight data monitoring plays one important role on the good results provided by the APM (or EHM) programmes, as these programs rely on the determination of a stable cruise point where several conditions are to be verified. Once it is found, the stable cruise point is extracted. On recent fleets, this point is produced in the form of an onboard report generated directly by the acquisition data box on the aircraft and optionally transmitted to ground.

The benefits of using the data available on FDM is that the stability condition can be studied and controlled by the operator to collect the best stability points in the whole operation of the aircraft, and in this way improve its performance programmes.

The identification of an aerodynamic degradation is the closest that can be performed to identify a structural failure using current technology. This method relies on a post-analysis by an expert to identify the real cause of this degradation.

Maturity Level

Level 0

LOC26 – Loss of Thrust

Summary

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.

Rationale

Monitoring an engine's performance is best performed by using an accurate model which understands the typical Fuel Flow ranges for each phase of flight taking into account the engine's performance based on age, flight conditions and cost index in use. This modelling approach is proposed in Future Developments.

Comparing the difference between the maximum and minimum N1or EPR across all engines (where an aircraft has more than one engine) provides the Thrust Asymmetry, a measurement of the loss of thrust between engines. The assumption is that all engines are commanded the same power, but if they are not, from takeoff, through the flight and during landing this is normally of interest too.

For turboprop aircraft, the Torque is also an important factor during flight, hence the addition of Torque Asymmetry.

The Throttle Levers can also be assessed for Asymmetric usage to indicate commanded loss of thrust, which may or may not have been initiated intentionally by the crew.

- Eng N1 Thrust Asymmetry > THRESHOLD %
- Eng EPR Thrust Asymmetry > THRESHOLD % of EPR range
- Eng Torque Asymmetry > THRESHOLD %
- Throttle Lever Asymmetry > THRESHOLD %

During cases of reduced thrust compared to that expected by the crew, there are often signs of crew reaction. The use of the Takeoff and Go Around (TOGA) switch is one such measurement, or the equivalent rapid application of power.

- Use of TOGA selection (when not in Takeoff or Go Around)
- Commanded application of > 90% power from < 70% within 2 seconds

Aircraft Parameters

Parameter	Type
Eng (*) N1	Analogue
Eng (*) Engine Pressure Ratio	Analogue
Eng (*) Torque	Analogue
Eng (*) Thrust Lever Angle	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold	Maturity
Whole Flight (see note 1)	***N1_DeltaValue*** = max(Eng (*) N1) - min(Eng (*) N1) (see note 2 and 3)	"Thrust Asymmetry"	Raise event if ***N1_DeltaValue*** > [5% to 15% as appropriate]	Level 2
Whole Flight (see note 1)	***EPR_DeltaValue*** = max(Eng (*) EPR) - min(Eng (*) EPR) *100 (see note 2, 3 and 4)	"Thrust Asymmetry"	Raise event if ***EPR_DeltaValue*** > 5% (of EPR Max - EPR Min values observed from normal operation)	Level 1
Whole Flight (see note 1)	***TORQ_DeltaValue*** = max(Eng (*) Torque) - min(Eng (*) Torque) (see note 2 and 3)	"Torque Asymmetry"	Raise event if ***TORQ_DeltaValue*** > 10%	Level 1
Whole Flight (see note 1)	***TLA_DeltaValue*** = max(Eng (*) Throttle Lever) - min(Eng (*) Throttle Lever) (see note 2 and 3)	"Throttle Lever Asymmetry"	Raise event if ***TLA_DeltaValue*** > [5% for jet, 10% turboprop]	Level 1
Whole Flight excluding Takeoff or Go-Around	***TOGA_Selected*** = duration(TOGA=ACTIVE)	"Unusual TOGA Usage"	Raise event if ***TOGA_Selected*** > 1 sec	Level 1
In-Flight excluding Go-Around	***Rapid_Thrust*** = duration(Eng (*) Throttle Lever < 70%; Eng (*) Throttle Lever > 90%) (see note 2)	"Rapid Thrust Commanded"	Raise event if ***Rapid_Thrust*** < 2 secs	Level 1

Note 1: Events are recommended to be split into the following flight phases:

- Takeoff
- In-Flight (Between Liftoff and Touchdown)
- Approach
- Go-Around
- Thrust Reversers

Note 2: max(Eng (*) N1) represents the maximum N1 value measured across all engines during the search window, thus accounting for 2, 3 or 4 engine aircraft with the same nomenclature.

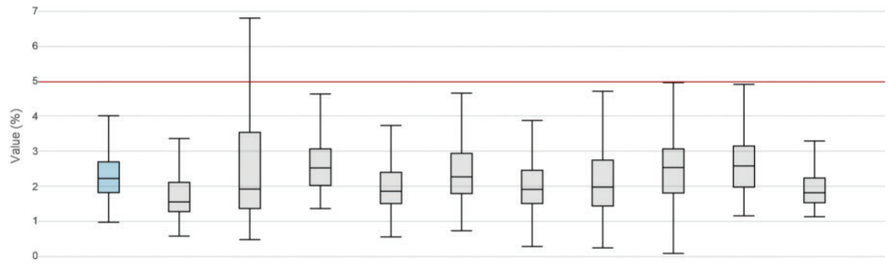
Note 3: A 5 second moving average applied to the time-series data or a 5 second confirmation time desensitizes the measurement to transient differences as engines accelerate.

Note 4: In the case of Engine EPR, treat EPR=2.0 as 100% and EPR=1.0 as 0%. Therefore the Thrust Asymmetry is max(Eng (*) EPR) - min(Eng (*) EPR) ***100**.

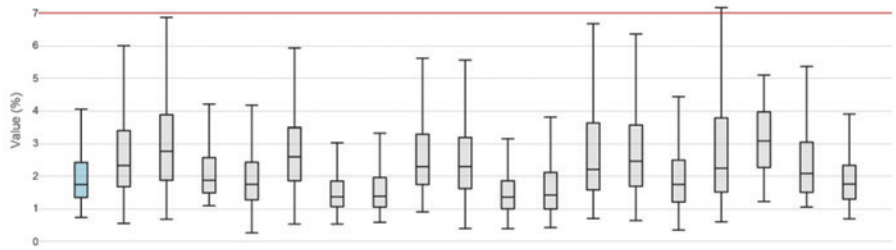
Thrust Asymmetry During Flight Max

Thrust Asymmetry During Flight Max measurement distributions are provided below for selected operators and de-identified for publication. The Y axis represents Thrust Asymmetry based on N1 or EPR where available.

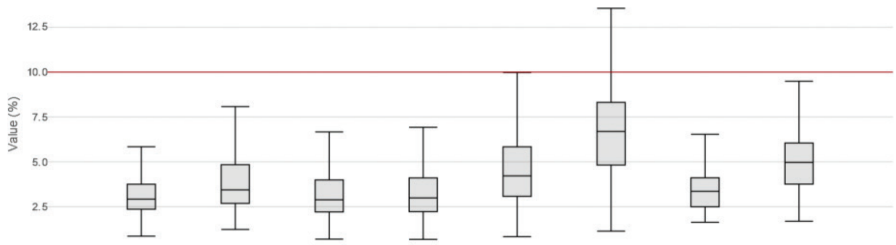
➨ **Figure 1:** thrust asymmetry during flight max, 11 x A320 operators, 2016-01 to 2016-12.



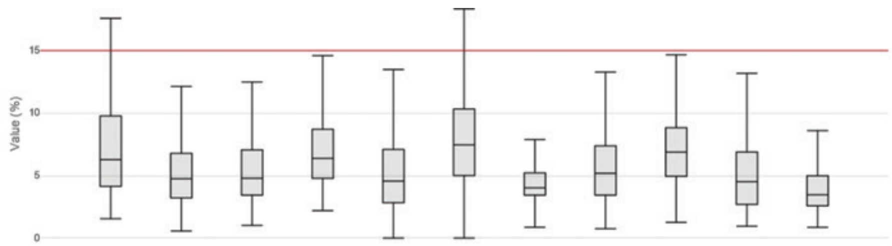
➨ **Figure 2:** thrust asymmetry during flight max, 19 x B737-NG operators, 2016-09 to 2016-12.



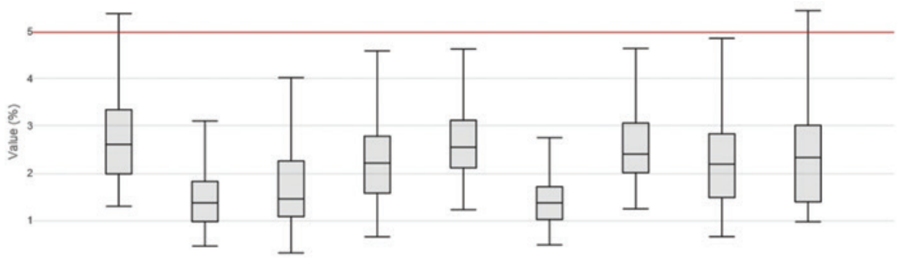
➨ **Figure 3:** thrust asymmetry during flight max, 8 x ATR-42 operators, 2016-01 to 2016-12.



➨ **Figure 4:** thrust asymmetry during flight max, 11 x ATR-72 operators, 2016-01 to 2016-12.



➨ **Figure 5:** thrust asymmetry during flight max, 9 x Gulfstream 5 operators, 2016-01 to 2016-12.



Future Developments and Recommendations

Loss of an engine's thrust can be determined by developing a performance model of an engine, considering many engine parameters including where available [N1, N2, Np, Fuel Flow, Gas Temp etc.] for each phase of flight. This process may be monitored and managed by powerplant engineers by the use of continued Engine Health Monitoring (EHM), a process supplementary to that of Flight Data Monitoring.

Simplified engine models can determine a crude actual performance compared to expected performance, for example by modelling expected N1 (thrust) compared to the commanded power (Throttle Levers or Flight Computer Commanded Power). Due to the variations between Engine types, this is a recommendation for manufacturers to provide specific models to support this work.

Airspeed loss during continued thrust which would indicate engine performance loss. This may require continued attitude and may result in detecting various atmospheric conditions. If the aircraft auto pilot is flying to maintain Airspeed or Mach, this may not be valid.

Maturity Level

see table above

LOC27 – Hardware Failure

Summary

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.

Rationale

This precursor relies largely from information on numerous flight data parameters. For example, in Airbus fleet potential parameters monitored might include, but not limited to:

Parameter	Type
ELAC 1 or ELAC 2 fault	discrete
SEC 1 or SEC 2 fault	discrete
ADR 1+2+3 fault	discrete
Side stick fault –Capt. or F/O side	discrete
Engine bleed fault – no.1 or no.2	discrete
Yaw damper fault	discrete
NAV Static fault – L/R	discrete
L+R Elev fault	discrete
Ice detector 1/2 fault	discrete
Eng 1/2 anti-ice valve fault	discrete
Antiskid fault	discrete
Normal brake / Autobrake fault	discrete
Fault detected on WHC 1/2	discrete
FADEC 1/2 Fault	discrete
FCSC 1/2 Fault	discrete
FCPC 1/2/3 Fault	discrete
FCMC 1/2 Fault	discrete
Slat or Flap 1/2 fault	discrete
GPWS related Fault	discrete
Rudder norm CTL Fault	discrete
FWC 1/2 fault	discrete
FG 1/2 fail	discrete
IRS 1/2/3 fault	discrete
TCAS fail	discrete

Each hardware fault/failure represents different severity level to operation safety of an aircraft. The application to other fleets depends on the analysis of which warning and fault parameters are available on the dataframe and proceed with the implementation of the measurements and events in a similar way as described here.

Measurement and Events

For example:

Search Window	Measurements	Events	Event Threshold
Whole Flight	COUNT= Number of seconds discrete is active	ELAC 1 or 2 fault SEC 1 or 2 fault ADR 1+2+3 fault Side stick fault Engine bleed fault Yaw damper fault NAV Static fault L+R Elev fault Ice detector 1/2 fault FADEC 1/2 fault FCSC 1/2 fault FCMC 1/2 fault Rudder norm CTL fault FWC 1/2 fault FG 1/2 fault IRS 1/2 fault TCAS failure	Raise event if COUNT> set threshold
Taxi Take off Climb Descent Landing	COUNT= Number of seconds discrete is active	GPWS related fault Slat or Flap 1/2 fault	Raise event if COUNT> set threshold
Take off Landing	COUNT= Number of seconds discrete is active	Antiskid fault Normal brake / Autobrake fault	Raise event if COUNT> set threshold

Maturity Level

Level 1

LOC28 – Flight Control Failure

Summary

Develop means to identify cues that could suggest the failure or ineffectiveness of flight controls

Rationale

This precursor is to be addressed using the information on:

- Control Column Force High
- Control Column Stiffness High
- Actuator and Control Surface Mismatch
- Precursors to Flight Control Failure

Control Force High

When the pilot flies the aircraft, he expects the control forces to be within a relatively small range. An excessive force is indicative of problems with the controls, although they could, equally, be the normal force for an abnormal manoeuver which might also be a cause for safety concern.

Note: Pilots are fairly sensitive to changes in the “feel” of the controls and this may also be reported through air safety reporting.

The distribution of Control Column/Wheel Force values across B737-NG operators is shown below:

Figure 6: control column force max, 19 x B737-NG operators, 2016-08 to 2016-12.

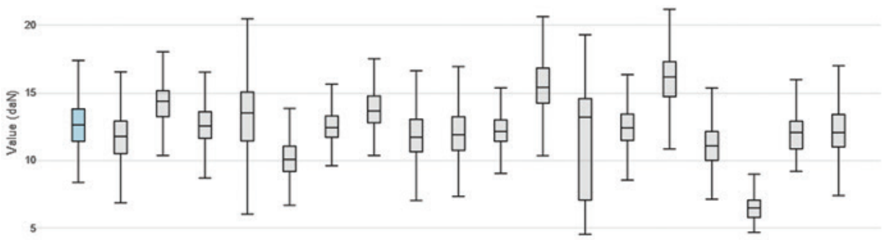
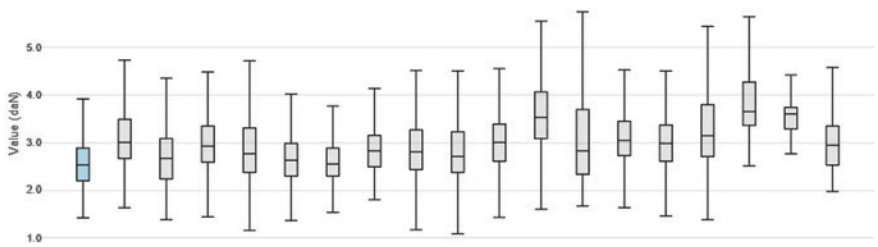


Figure 7: control wheel force max, 19 x B737-NG operators, 2016-08 to 2016-12.



Control Column Stiffness High

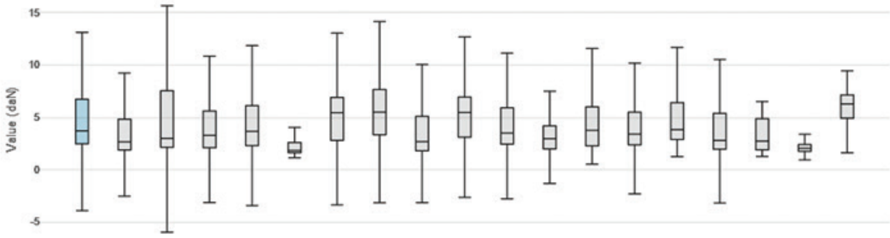
One way to detect flight control failure is to monitor the controls for an increase in stiffness. On aircraft where the control column forces are recorded (and this is a relatively recent inclusion in the list of mandatory parameters) the force relative to displacement characteristic should be consistent. When the force is unusually high this is an indication of a problem in the control actuation system.

The two places in flight where substantial and clear movement of the controls takes place are on rotation at lift-off and the flare before touchdown. Indeed, on many flights these are the only significant control inputs that the pilot makes. With only one or two brief moments during a flight when the control force can be checked it is important to make the best assessment of the stiffness using the available data. The technique currently used is to compute the best fit straight line to all data for the period that the pilot is operating the flying controls.

The calculation of stiffness looks for periods of manual control input (>3 daN force) during flight and for each period performs a linear correlation with the Control Column displacement. So long as there is a correlation (assume > 0.85), record the slope of the correlation as the measure of stiffness.

The distribution of values across B737-NG operators is shown below:

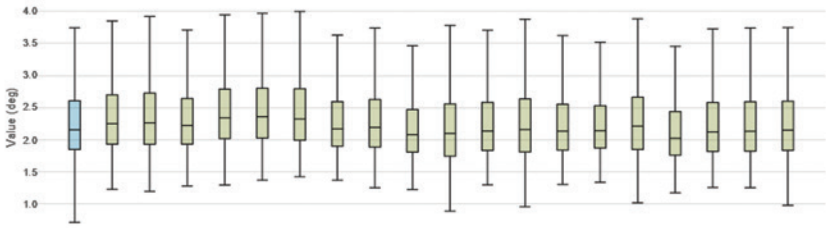
➨ **Figure 8:** control column stiffness, 19 x B737-NG operators, 2016-08 to 2016-12.



Actuator and Control Surface Mismatch

Following an incident with a control runaway, investigation showed that the elevator servo was not operating correctly. As the B737-NG instrumentation includes both Elevator Quadrant and Surface positions, it is possible to identify mismatch between the two parts of the control system due to actuator misoperation.

➨ **Figure 9:** elevator actuator mismatch max, 20 x B737-NG aircraft, 2016-08 to 2016-12.



Precursors to Flight Control Failure

Several additional events are needed to monitor a failure, or partial failure of any flight control including an increase in “stiffness”. Events could also be developed to measure a progressive decrease of full flight control movement for any given phase of flight. The pre-flight control check event is currently the only event to assess the quality of control movement prior to flight. Pilots are generally sensitive to the normal feel of the flight controls but it’s not an exact science. Assuming that pre-flight control checks are completed properly, parameters/events could be developed to measure the changes and or decreasing quality of the flight controls over many flights.

Fly-by-wire systems pose a different problem as there is no direct feel to restricted movement of the flight controls. If the flight control indices move their full travel as indicated on the ECAM (Airbus) flight control page or Boeing EICAS, then, the flight controls are serviceable.

The ability to assess a change or increase in stiffness of the flight control is difficult during normal operations when the Auto Pilot (AP) is engaged. The AP would maintain stable flight by continuously compensating for restricted movement of the flight control by adjusting trim tabs to their limits before the AP would “normally disengage”. It is possible that the AP may force the aircraft into an unusual attitude requiring manual disengagement.

Progressive changes to the rate of trim (Trim Rate Max) could be a precursor indication of increasing stiffness to any flight control surface

Aircraft Parameters

Parameter	Type
Control Column Force (Capt) (Note 1)	Analogue
Control Column Force (FO) (Note 1)	Analogue
Control Column (Capt) (Note 1)	Analogue
Control Column (FO) (Note 1)	Analogue
Control Wheel Force (Capt)	Analogue
Control Wheel Force (FO)	Analogue
Elevator Actuator/Quadrant (Note 2)	Analogue
Elevator Surface	Analogue
Aileron Trim Position	Analogue
Elevator Trim Position	Analogue
Rudder Trim Position	Analogue
Stabilizer Trim Position	Analogue

Note 1: The recorded parameters Control Column Force (Capt) and Control Column Force (FO) are used. These are used to derive the parameter Control Column Force which does not recognise the pilot flying.

Cautionary Note on B737 NG Control Column Forces:

There are problems with the 737NG control column force sensors in that, while they work well if only one pilot is operating the controls, they give erroneous signals if both pilots are applying force at the same time. That is, the recorded force values are NOT independent and one cannot add the two signals to compute the total force applied. This may also be prevalent on other aircraft types. In addition, a modification can be applied to aircraft which affects the scaling of these parameters. Note the distributions in Figure 6 Control Column Force Max, 19 x B737-NG operators, 2016-08 to 2016-12 to assess the correct values.

Note 2: Elevator Quadrant / Elevator Actuator are mostly seen on newer Boeing aircraft (e.g. B737-NG, B787) and various corporate jets (e.g. Gulfstream, Bombardier).

Measurements and Events

Search Window	Measurements	Event	Event Threshold	Maturity
In Flight (exclude pre-flight checks and takeoff roll)	***ControlColumnForceMax*** = max(Control Column Force) (Note 1)	"Control Column Force High"	Raise event if ***ControlColumnForceMax*** > 20daN (Note 3)	Level 2
In Flight (exclude pre-flight checks and takeoff roll)	***RollHighestPosForce*** = max_ absolute(Control Wheel Force) (Note 2)	N/A	N/A (Note 3)	Level 1

Search Window	Measurements	Event	Event Threshold	Maturity
Airspeed > 60 knots and Control Column Force > 3 daN	***ControlColumnStiffness*** = correlation_slope(Control Column Force, Control Column)	"Control Column Stiffness High" (Note 5)	Raise event if ***ControlColumnStiffness*** > Threshold	Level 1
In Flight	***ElevatorControlMismatchMax*** = max_absolute(Elevator (*) Surface - Elevator (*) Actuator)	"Elevator Actuator and Control Surface Mismatch"	Raise event if ***ElevatorControlMismatchMax*** > Threshold	Level 1
In Flight	***AileronTrimRateMax*** = max(rate_of_change(Aileron Trim))	N/A	N/A	Level 1
In Flight	***ElevatorTrimRateMax*** = max(rate_of_change(Elevator Trim))	N/A	N/A	Level 1
In Flight	***RudderTrimRateMax*** = max(rate_of_change(Rudder Trim))	N/A	N/A	Level 1
In Flight	***StabilizerTrimRateMax*** = max(rate_of_change(Stabilizer Trim))	N/A	N/A	Level 1

Note 1: The basic measurement is Control Column Force High, which is the highest positive (nose up) force experienced on that flight. Nose down force has not been raised as a concern. Requires a control column.

Note 2: In roll, the basic measurement is Control Wheel Force High, which is the highest positive (roll right) force experienced on that flight. Requires a control wheel.

Note 3: Thresholds based on experience are set for the nose up pitching force which is normally that applicable during the flare. Currently there are no control wheel force thresholds applied

Future Developments and Recommendations

Presently the only time prior to flight that pilots are aware that there could be a problem with restricted flight control movement is during the pre-flight, flight control check. During times of winter weather or when de-icing is required consideration should be given to completing the flight control check, post de-icing and then again just prior to takeoff to ensure full and free movement. Even this check does not ensure subsequent flight control restrictions could occur due to freezing conditions. The events to be developed could measure increased restriction to the force required to move the control but the increase in any force required may not be significant enough to be noticed by the pilots and the flight may still get airborne. Once airborne, with auto pilot engaged, subsequent restrictions could be measured and monitored by abnormal changes to the trim required to maintain stable flight.

Fly by wire systems could be monitored by displayed indications. Parameters could be developed to record the movement of the flight control indices ("Side Stick Pitch/Roll Command (Capt/FO)"). When there are failures to any flight control computer and or flight augmentation computer there are degradations of the flight control movements. Additional events could be developed to monitor failure of specific flight control computer and measure the subsequent flight control degradation. As mentioned above, events can monitor abnormal trim changes for fly by wire systems.

Additional parameters and measurement development is required to monitor EICAS and ECAM flight control pages which indicate actual flight control positions. i.e, flight control indices.

Maturity Level

Assigned for each event on the table above

LOC29 – Mismanagement of Automation

Summary

Develop means to identify situations of inadequate or unexpected use of automation or unexpected disconnection of automation.

Rationale

Automation is certainly a great help for the pilot to operate the aircraft, but in certain situations, the interface man-machine may lead to distractions or misunderstandings that may be precursors for incidents or even accidents. Despite the acknowledged evident general benefit of the automation, an excessive dependence on its use may conduct to the increase of risks when manual handling of the aircraft is necessary. One assessment of the use of automation, namely during approach and landings may be accomplished with the use of FDM. By performing such a study over the whole fleet, one operator may evaluate what is the weight of the automation on its operation. FDM can provide measurements and trigger events for some of these situations, but it is highly recommended that the human analyst, especially someone with a deep knowledge of each fleet automation system be involved in the analysis.

The use of Autopilot and Autothrust, or Autothrottle, is currently widespread for almost all the fleets. Inadverted situations may happen with the automation devices engaged, and these are normally unexpected guidance of the aircraft or provoked during the disconnection of one of these automatic devices. These are normally situations not easy to detect using FDM.

For the unexpected guidance, some clues may be obtained if each operator performs a proper assessment of the normal flight modes for each flight phase and its possible sequence order. This is information that is normally obtained from the flight operation manuals, but it can be always driven from a historical database containing all flights from the operator. Due to the amount of different systems and fleets, each operator has to adapt this study to his own reality.

Regarding the disconnection of any of the automation devices, by itself, it is a perfectly normal operational action. One assessment of the normal pattern of engagement/disengagement of the AP and AT should be carried out using the existing historical data from the operator. This should conduct to the identifications of the normal flight phases when these engagements/disengagements happen and extract those that are out of this pattern.

There are though a minority of cases that are useful to analyse. Some fleets allow performing the distinction between the volunteer disconnections with those that result from abnormal conditions, by recording the P/B that the pilot presses to disconnect the device. Having this possibility the distinction can be made if it is a voluntary act from the pilot or some disengagement due to any atypical condition from the aircraft. In this case, the device is disconnected but no manual input is present. Other than this evaluation, another recommendation is for the FDM system to measure the time elapsed between the disengagement of these devices (manual or automatic) and the application of any manual input, either in flight controls of thrust levers. A high amount of time may indicate that some misunderstanding of the situation may be in place, but this analysis always requires further knowledge and should be always taken as a warning flag to produce more investigation. The disengagement may also conduct to some kind of disruption from the flight if there was some application of flight controls before this happens. This is especially true in the case of the trimming of the aircraft. In this case, it is recommended that FDM verifies if there is any kind of manual flight control (including trimming) or thrust application before the autopilot or autothrust disengage that can lead to a wrong configuration of the aircraft and produce sudden impacts when the automatic device disconnects.

Special care should also be taken for those fleets that allow the selection of HDG/TRK and VertSpeed/FPA, in which the value is indicated in the same position, normally one display window in the autopilot control panel. Whenever possible the selection of the parameter should be recorded and the evaluation of the corresponding input verified if it is consistent with the selection. This recommendation identifies situations where the pilot is introducing one value for one parameter, not realizing that the selection is in a different one (for example, introducing vertical speed when in fact the value is for FPA).

There are some cases where some malfunction of the Radio Altitude systems may interfere with the aircraft automation (Report - Dutch Safety Board, Ref M2009LV0225_01 from a B737-800 that crashed near Amsterdam Schiphol Airport, 25th Feb 2009). In this specific case, there was a mismatch between the two radio altimeter systems, being system #1 providing false values to the automatic system.. To cope with the rationale in the current precursor the mismatch between the two RA systems is considered on LOC24.

Some incidents have also been reported for using improper modes during approach (BEA Report - Airbus A320-214 registered F-HEPE, 3rd April 2012). For this fleet (A320) this report clearly indicates that there was one improper use of OPEN DESCENT during Approach. Airbus A320 operators can use this information to create one event. For other fleets, similar mismatches can be identified in past incidents or accidents, aircraft manuals or from the experience of the pilots that can lead to a similar definition of events.

To summarise the recommendations from the WGB for this precursor are:

- Assessment of the normal engage/disengage pattern for a specific fleet. This can be fine-tuned for a specific leg if necessary.
- Assessment of the use of automation during the operation, especially on the landings (automatic vs manual landings)
- Perform one study of the normal automatic modes and its normal sequence in terms of autopilot (Lateral and Vertical) and autothrust for all flight phases.
- AP or AT disengagement without any volunteer P/B pressing from the flight crew.
- Time elapsed between any device disengagement and the application of a manual command (Flight Controls or Thrust)
- Verify if there was any application of any manual flight control (including trimming) or thrust application before the AP or AT disengagement.
- Whenever possible cross-check the HDG/TRK (VS/FPA) selection with the input value.
- Verify any Mismatch between RA systems (Included in LOC24).
- Detect the use of OPEN DESCENT during Approach (Airbus A320) – similar events to other fleets.
- These studies conduct necessarily to the creation of measurements that can be used to detect profiles of normal/abnormal patterns (as an example, the altitude or speed for a flight mode to be engaged can be recorded as measurements).

Aircraft Parameters

Parameter	Type
Autopilot (*) Engaged	Discrete
Autopilot Lateral Modes	Discrete
Autopilot Vertical Modes	Discrete
Autothrust Modes	Discrete
Control Column Force	Analogue
Control Wheel Force	Analogue
Eng (*) Thrust Lever Angle	Analogue
HGG/TRK P/B Selection (VS/FPA)	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold	Maturity
TDB	TBD	TBD	TBD	TBD

Maturity Level

Level 1

LOC30 – Abnormal Flight Control Inputs

Summary

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

Rationale

Hazardous conditions related to crew proficiency and human factors are present when the pilot is flying manually. Crews of modern airliners do not conduct flights "manually" or in raw data in compliance with safety standards, Company policies and environmental issues (noise abatement). However, these practices may lead to unexpected consequences, our crews may degrade its proficiency during manual flying, which may lead to incorrect flight control inputs, increasing the risk of suffering an UPSET condition at any altitude (problem also addressed in LOC29). The typical scenarios where these values can appear are:

- Adverse weather and high wind speeds during departure or arrival, windshear.
- Change of runway with very short notice (localizer overrun).
- High altitude turbulence.
- ACAS alert at any altitude.
- Use of spoilers during climb.

Abnormal flight control inputs can be detected directly from the pilot commands provided the operators conduct some studies to determine the most extreme inputs applied. These studies should be performed for each flight leg operated, so that flight control inputs that are normal for one specific flight leg are not considered as abnormal if all flight legs are considered together. In the case the flight control input parameters are not present in the data-stream the values of the deflection from the primary flight control surfaces can be used to determine these extreme cases.

The flight control inputs may be directly related to the increase of angles (pitch, roll, AOA) which may lead to low energy situations or drive the aircraft close to stall. These precursors are addressed in LOC12 (Envelope Protection Systems) and LOC13 (Inadequate aircraft energy). The case of "Dual Input" can be identified from the data stream and an event should be produced.

Excessive flight control inputs on both pitch and roll attitudes can also be detected which can result in pilot induced oscillations whereby cyclical inputs are continuously provided leading to an exaggerated undesirable aircraft attitude.

The deployment and retraction of the flaps/slats when not properly performed conducts to the misconfiguration of the aircraft. This is addressed in LOC32 (Incorrect A/C Configuration). To complement the proposals on this precursor, some assessments should be carried out by the operator for each fleet (if necessary for each flight leg), concerning the correct deployment and retraction sequence for the flaps/slats. Adding to this study, the timing for Landing Gear extension should be correlated with this sequence. Out of this assessment, a normal pattern should be identified. To document this recommendation, see the report from the serious incident from AAIB-UK about the landing gear retraction at the same time as the reducing of flaps/slats (AAIB Bulletin: 9/2017, G-EZEW from 30 Jun 2016).

The deployment of speed brakes should be also closely monitored. There are flight phases that it is expected that these surfaces are retracted such as during climb and cruise. Any detection out of these flight phases for the use of these surfaces should be identified and considered as one event.

Additionally, rudder pedal inputs during flight and during takeoff and landing rolls need to be monitored as full control inputs on the rudder pedals can lead to runway veer off and heading excursions during landing roll during high crosswind scenarios.

To summarise the recommendations from the WGB for this precursor are:

- Assessment of the extreme flight controls applied for each leg (either using the flight commands or surfaces)
- Dual Input
- The correct sequence for flaps/slats deployment (Landing) and retraction (Takeoff) correlated with the timing for the action for the Landing Gear. Creation of normal patterns for each fleet.
- Identify the use of speed brakes during climb or cruise.

Aircraft Parameters

Parameter	Type
Pitch Command (column or side-stick)	Analogue
Roll Command (column or side-stick)	Analogue
Rudder pedal	Analogue
Speedbrake (*)	Discrete
Main Landing Gear (*)	Discrete
Flap Angle	Analogue
Slat Angle	Analogue
Spoilers	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole Flight	NA	“Dual Input”	Raise event if Dual Input was applied
Excessive pitch/roll inputs	NA	“Excessive inputs”	Opposing direction control inputs within a short span e.g. side stick value change above N deg within X sec. (Note 1)
Full rudder Pedal inputs	NA	“Full pedal inputs”	Count or cycles of full rudder inputs in opposing or cycle format. Above N cycles as threshold. (Note 2)
Climb	“Spoiler Activation”	“Spoiler use during Climb”	Issue event in case there is a spoiler activation during the climb phase.

Note 1: Possible values for Airbus fleets are 4 deg within 2 sec.

Note 2: Possible value for Airbus fleets is above 4 cycles as a threshold

Maturity Level

Level 1

LOC31 – Fuel Exhaustion

Summary

Develop means to identify situations of low fuel quantity - by comparison to the planned fuel quantity - as the flight proceeds to its destination

Rationale

Two events are considered for this precursor. The first event describes a fuel quantity at touchdown that is not sufficient for legal requirements or company procedures.

The second event considers the comparison between the actual remaining fuel at touchdown and the planned remaining fuel at touchdown.

Aircraft Parameters

Parameter	Type
Fuel Quantity	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Touchdown	***FuelRemaining*** = Remaining Fuel At Touchdown	“Low Fuel Remaining”	Raise event if ***FuelRemaining*** < Threshold (Note 1)
Touchdown	***FuelRemaining*** = Remaining Fuel At Touchdown	“Remaining Fuel significantly less than planned”	Raise event if ***FuelRemaining*** - ***FuelPlanned*** < Threshold (Note 2, Note 3)

Note 1: The threshold depends on the aircraft type, company procedures and further factors. Fuel requirements are given in ICAO Annex 6 Operation of Aircraft Part 1 International Commercial Air Transport — Aeroplanes. There, final reserve fuel is indicated as a remaining time to fly. Depending on factors including aircraft type, mass, environmental factors this time constraint can be transformed into a fuel quantity constraint. Depending on the aircraft type, in ICAO Annex 6 final reserve fuel is indicated to be 30 minutes or 45 minutes.

Note 2: The value of the planned fuel at touchdown might not be available in the FDM data and need to be obtained from other data sources.

Note 3: The threshold should be given in minutes to fly which can be translated into a fuel quantity for the given aircraft type and circumstances (see also Note 1).

Future Developments and Recommendations

Other than the proposed analysis based on the fuel remaining on touchdown, situations of unexpected high fuel consumption should be detected, including:

- the monitoring of long periods of flight other than an approach flown at lower altitudes (flight level or altitude thresholds to be adapted per aircraft types)
- The detection of unusual flight profiles (e.g. several go-arounds, abnormal holding patterns)
- Misadjusted flight surfaces conducting to drag increase during the flight (addressed in LOC32)
- The incorporation of the expected fuel on the end of the leg from the flight plan. This would allow a direct comparison with the actual fuel onboard from the flight data.
- The previous bullet can be extended to the whole flight plan, creating the basis for a “Fuel Monitoring Programme”.

Maturity Level

Level 1

LOC32 – Incorrect Aircraft Configuration

Summary

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

Rationale

Correct configuration of an aircraft is essential for safe operation. Unintended or inappropriate configurations are a significant causal factor in documented Loss of Control Incident reports.

Identification of incorrect aircraft configuration in FDM can be achieved by monitoring of standard recorded parameters in association with the phase of flight and aircraft speed.

This precursor is closely related with LOC30 (Abnormal Flight Control Inputs). Complements to the proposals in this section may be found there. It may also be related with LOC31 (Fuel exhaustion) by inducing an increase in the drag during the flight.

Aircraft Parameters

Parameter	Type
Flap/Slat Lever Position (Note 2)	Discrete
Speedbrake (*)	Discrete
Main Landing Gear (*)	Discrete
Static Air Temperature (Note 1)	Analogue
Indicated Airspeed	Analogue

Note 1 – If not available on the datastream can be obtained from TAT

Note 2 – If flap lever is not available then flap lever can be derived from Flap Angle

Measurements and Events

Search Window	Measurements	Event	Event Threshold
“Start of Flight” (engine start and taxi out)	*NA*	“Taxi without takeoff flap set”	Raise event if **GroundSpeed** > 8 kts, **Flap Lever** <> Position **SAT** > 0 (deg) (see Notes 1 and 2)
Whole Flight (From unstick to landing)	*NA*	“Airspeed low for configuration”	Raise event if **CAS** < Threshold (see Note 3)

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	*NA*	"Flap placard exceedance"	Raise event if **CAS** > Threshold + 5 kts (see Note 4)
Whole Flight (From unstick to landing)	*NA*	"Gear down speed exceedance"	Raise event if **GearDown** = True, CAS > VLE
Takeoff, Initial Climb	*NA*	"Early configuration change after takeoff"	Raise event if **Flap Lever** selection change, **AAL** < 1000 ft (see Note 5)

Note 1: The value of the position is fleet specific. Based on one operator's implementation, examples of trigger positions are:

- A319/320/321: Flap Lever <> 1, 2 or 3
- Boeing 777: Flap Lever = 0 or 1

Note 2: De-icing procedures may permit initial taxi without takeoff flap set. The FDM test for SAT (Static Air Temp) > 0 diminishes false positive events being detected in icing conditions.

Note 3: The value of the threshold is fleet specific. Based on one operator's implementation, examples of trigger positions are:

- A319/320/321: Calibrated Airspeed (CAS) < VLS-3 kts
- Boeing 747: Calibrated Airspeed (CAS) < VREF at touchdown + *constant*, where *constant* depends on current Flap Lever setting.

Note 4: The value of the threshold is fleet specific and defined in FCOM documentation. Based on one operator's implementation, its FDM system event adds a constant 5 kts buffer (allowance) to the defined placarded threshold value, to diminish false events.

Note 5: This event traps inadvertent early flap retraction in the takeoff and initial climb phases.

Future Developments and Recommendations

Proposal for new events definition:

1. Speedbrake deployed with high thrust setting

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	*NA*	"Speedbrake in use with high thrust"	(see Note 1)

Note 1: No specific event defined to detect Speedbrake deployed with high thrust settings. Based on one operator's implementation, Speedbrake usage with Land Flap and Speedbrake usage below 1000 ft events are both defined in FDM, but these are Runway Excursion risk events rather than LOC.

2. Inappropriate Trim inputs

Search Window	Measurements	Event	Event Threshold
Whole Flight (From unstick to landing)	***NA***	"Inappropriate Trim inputs"	(see Note 2)

Note 2 Based on one operator's FDM implementation, no specific events are defined to detect trim changes in critical stages of flight. For example, trimming during rotation or during the flare may contribute to a tail strike risk.

3. Surface out of normal position during the flight
   - The monitoring of long periods of flight other than an approach flown at lower altitudes (flight level or altitude thresholds to be adapted per aircraft types).
   - Detection of incorrect aircraft configurations along the flight inducing increased drag (related to LOC31)

Maturity Level

Level 1

Controlled Flight Into Terrain (CFIT)

Controlled Flight Into Terrain (CFIT) is defined in the document from CAST/ICAO taxonomy team which is titled "Aviation Occurrence Categories".[16]

Each recommendation identified by working group A, corresponds to a possible precursor for an incident or accident related to Controlled Flight into Terrain (CFIT). The current chapter presents the algorithms proposed by Working group B to cope with each of the recommendations identified.

The frequency of CFIT accidents has decreased due to TAWS systems that have been incorporated into the aircraft for several decades as a result from studies performed on CFIT accidents. The carriage of a TAWS by aircraft improved significantly the statistics for this type of accidents.

The need to integrate external data sources was identified. These are:

- Terrain
- Weather
- Navigation

Studies will be necessary to perform assesments of the state-of-the-art for the integration of those databases into the FDM systems. The solutions proposed will be constrained by the quality of the information existing on these databases and the existence of the technical solution for this kind of data fusion. The table below shows the dependence of each precursor from these databases.

Table 2: incorporation of external databases in the FDM programme.

CFIT Precursors				
Precursor	Description	External Data Sources		
		Terrain	Weather	Navigation
CFIT01	Poor visibility condition	No	Yes	No
CFIT02	Wrong altimeter settings	No	Yes	No
CFIT03	Flight below MSA	Yes	No	Yes
CFIT04	Deviation below glideslope	No	No	No
CFIT05	FMS incorrectly set	No	No	Yes
CFIT06	Inadequate vertical mode selections on AFCS	No	No	No
CFIT07	Incorrect descent point	No	No	No
CFIT08	Incorrect TAWS escape manoeuvre	Yes	No	Yes
CFIT09	Inadequate missed approach and go-around flight path	No	No	Yes
CFIT10	Loss of communication	No	No	No
CFIT11	Low energy state during apprach / unstable approach	No	No	No
CFIT12	Inadequate response to windshear warning	No	No	No
CFIT13	Reduced horizontal distance to terrain	Yes	No	No
CFIT14	Reduced time to terrain impact	Yes	No	No

16 The document can be found on the link: http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf

In order to maximise the benefit from the proposed precursors, the working group recommends:

1) to record at least one accurate position from the best navigation system available onboard (FMS, GPS or IRS). Figures to have one assessment of the degradation of the position signals should be also be recorded (such as the Figure of merit and/or Dillution of Precision (DOP) signals from GPS)
2) All the modes from TAWS should be recorded separately and not only a discrete parameter indicating when the TAWS produced a warning.

CFIT01 – Poor visibility condition

Summary

Develop means to identify present visibility conditions (e.g. IMC or VMC).

Rationale

Using the current technology available onboard and the existing dataframes there are no means to identify the prevalent visibility conditions for a specific flight.

Nonetheless, there are some cues that may be used to estimate the approximate conditions:

1) The METAR information provides some information about visibility. Data in METARs reflect average conditions close to the airport. Despite this can be used as guidance, it is not a direct measurement of the real visibility conditions.
2) FDM systems may rely on the number of landings performed with both APs engaged at the moment of TD[17] to have one assessment of landings performed with CAT III conditions. This depends on the number of flights analysed over a period of the day by the FDM system and may be only one indication of poor visibility conditions. Not all CAT III landings are IMC, but when a pattern on concentrated landings appears during a period of the day, this may be a symptom of low visibility.

Future Developments and Recommendations

New developments in this area are dependent on the integration of new technologies onboard, especially image recording and processing. This goes beyond the current normal set of equipment available and provided by manufacturers. Studies on algorithms for image processing capable of determining the visibility can be conducted in case the equipment is available in the future.

Maturity Level

Level 1

17 This may be fleet dependent. Operator should check what are the conditions for CAT III landings on his specific fleet.

CFIT02 – Wrong altimeter settings

Summary

Develop means to identify wrong altimeter settings

Rationale

This precursor relies on the comparison between the local barometric pressure and the value set on the aircraft altimeter (Barometric correction). The value of QNH can be taken from METARs and it's useful to use as reference value on a specific time and location. This measurement does not change significantly on these two dimensions, so it can be considered accurate, assuming that the METARs are available.

Aircraft Parameters

Parameter	Type
Destination QNH	Analogue
Static Pressure (Note 1)	Analogue

Note 1: For fleets not recording directly this parameter it can be obtained from the altitude standard.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Landing	DestQNH – StPres	"Wrong Altimeter Setting"	Raise Abs(DestQNH-StPress) > Threshold

Future Developments and Recommendations

CFIT accidents may happen out of airport areas in remote locations. The solution provided just includes the landing and departure phases since there is the need for a valid reference value to compute the measurement.

The integration of airport database data allows checking if the recorded corrected altitude on landing and take-off matches the geographic altitude reported on the AIP/NAV charts (within a certain margin).

There is the need to integrate meteorological data from external data sources both for CFIT01 and 02. The existence of more extensive data on this area should be explored, namely being used for other industries, but capable of providing data that covers more locations than those available on the METARS. The meteorology science has been increasingly developed during the last decades and one assessment on the possibilities that its integration can benefit the FDM analysis.

Maturity Level

Level 1

CFIT03 – Flight below MSA

Summary

Develop means to identify situations of aircraft flying below MSA

Rationale

The acronym MSA stands for "Minimum Sector Altitude" and it provides a minimum clearance of terrain obstacles. The definition for Minimum Sector Altitude (MSA) according to ICAO doc 8168, Procedures for air navigation services, aircraft operations (PANS-OPS), Volume I – Flight Procedures, is:

Minimum sector altitude (MSA). The lowest altitude which may be used which will provide a minimum clearance of 300 m (1000 ft) above all objects located in an area contained within a sector of a circle of 46 km (25 NM) radius centred on a significant point, the aerodrome reference point (ARP) or the heliport reference point (HRP).

Navigation charts have a representation of the minimum altitude corresponding to each geographical location. This is useful information if incorporated in the FDM system (see future developments).

The most direct way to address this precursor is to monitor the radio altitude clearance from the ground and verify that this value is always above or equal to 1000ft. During any approach to the runway, there is necessarily one point, part of its correct approach path from which it is necessary to reduce the terrain clearance and, therefore, the radio altitude readings. This point can be determined by using the runway threshold position and assuming a 3 degree descent slope.[i] This will determine the point until which the 1000 ft radio altitude terrain clearance is to be verified, and must include adequate margins for small lateral and vertical deviations. This approach has a limitation since it "ignores" any severe deviation from track after the point is reached.

Another approach may consist of defining boundary areas around the airfield and/or approach path in which the minimum Radio Altitude clearance check will be disregarded. Due to the overhead of creating these areas, it should only be applied to locations with significant CFIT risk.The accurate recording of the geographical position of the aircraft is of paramount importance to cope with this calculation (see Annex 1). This precursor should take into consideration RE34 (Erroneous Guidance) to determine if the aircraft is on the expected flight path.

Aircraft Parameters

Parameter	Type
Radio Altitude	Analog

Measurements and Events

Search Window	Measurements	Event	Event Threshold
All flight phases except Cruise up to 2500ft (Note 1)	***Terrain_Clearance = Radio Altitude value for the current location***	*"Insuficcient Terrain Clearance"*	Terrain_Clearance < 1000ft (Note 2)

i The value of 3 deg can be adjusted to any possible value that suits better the runway environment.

Note 1: Validity of the radio altitude parameter.

Note 2: In case the aircraft is not in the correct flight path this event should be disabled. This validation can be done using RE34 (Erroneous Guidance).

Future Developments and Recommendations

This precursor can benefit from future developments on:

- The integration of terrain databases in the FDM analysis. Having this possibility the altitude and most accurate position of the aircraft can be used to evaluate the surrounding elevations on the map and complement the radio altitude measurements which are just below the aircraft.
- Navigation database integration. This will allow to fine tune which is the correct flight path for each approach and the published altitude limitations.

Maturity Level

Level 1

CFIT04 – Deviation below glideslope

Summary

Develop means to identify (severe) deviations below glideslope that increase *CFIT* risk

Rationale

The deviation from the glideslope was already addressed in this document under RE26 (Unstable Approaches). All instrument approaches should be stable by 1000 feet RA (assuming that radio altitude indicates the height above airport elevation) and ILS approaches should be stable when intercepting the glideslope well above 1000 feet. The criterion used was:

- More than 1 dot Glide Slope Deviation

Large deviation from glideslope below 1000 feet RA implies an unstable situation which could lead to reduced obstacle limits and risk of CFIT. The collision with the ground may happen if the deviation from the glideslope is significant.Therefore in the context of CFIT, the discussion of deviation below glideslope will focus on RA <1000 feet, unlike RE26 where the altitude is above 1000 feet.

Aircraft Parameters

Parameter	Type
Radio Altitude	Analog
Flight Phase	Discrete
FMA Mode	Discrete
Glideslope Deviation	Analogue

Measurements and Events

Search Window	Measurements	Event	Event Threshold
FMA mode or Flight phase is in either “Final Approach” or “Land”, and radio altitude is below 1000 feet.	***GS_Max_Dev_Down*** = glideslope maximum deviation below the beam	“Deviation below glideslope”	Raise event if ***GS_Max_Dev_Down*** > Threshold for a certain period of time (e.g. 3 seconds)

Maturity Level

Level 1

CFIT05 – FMS incorrectly set

Summary

Develop means to identify errors in FMS settings, especially those associated to close to terrain operation (e.g. approach in a mountainous area).

Rationale

Wrong FMS inputs have been addressed in this document on RE01 and LOC10 related to the incorrect performance calculation and LOC08 (CG out of Limits). These inputs may also have CFIT consequences and it is useful to enphasize that the accurate takeoff speeds (V1, Vr and V2) should be based on accurate values for aircraft weight and CG. Currently, these values are obtained manually from the load sheets and human errors may occur so that the whole system is undermined by these manual procedures.

Other than the initial weight and CG position, the input values after calculations can be again a source or error. Despite of double-check procedures to prevent this from happening, the fact that it relies normally on manual input may again be the source of lack of performance.

Considering the CFIT risk area, adding to the already identified problems there is the need to include on the FDM system, navigation information about the SIDs and STARs so that deviations from the standards paths to be followed can be identified.

Future Developments and Recommendations

Any recommendation for this precursor relies on data to be available to the FDM system, such as:

- Automatic measurement of the weight of the aircraft on ground (initial weight)
- Idem for the centre of gravity
- Have SIDs and STARs available for the FDM system by an external source
- Compare the path followed with the standard SIDs and STARs
- In parallel, have the next waypoint from the FMS recorded so that it can be compared with the previous bullets.

Maturity Level

Level 1

CFIT06 – Inadequate vertical mode selections of AFCS

Summary

Develop means to identify inadequate vertical mode selections of the aircraft flight control system, especially those associated to close to terrain operation (e.g. approach in a mountainous area).

Rationale

The possible misuse of vertical modes in automatic systems on the aircraft is a subset of LOC29 precursor which is dedicated to the mismanagement of automation. In the current precursor it is enphasized that studies should be conducted based on, historical data, internal investigations or published accident reports, to perform an assessment of the abnormal patterns of autopilot and autothrust modes during takeoff and landing. The correct use of the modes and its sequence should be taken into account.

The procedure should consist of:

- Limit the altitude for this analysis to below 1000ft AGL, so that the focus is close to terrain.
- Identify modes that are abnormal (eg: Climb mode during approach flight phase)
- FCOM / AFM limitations
- General SOPs which preclude certain modes (eg: prohibited use of VS during certain phases of flight)
- Particular RWY specific procedures

Maturity Level

Level 1

CFIT07 – Incorrect descent point

Summary

Develop means to identify incorrect descent points

Rationale

This precursor is closely related to CFIT03 (Flight below MSA). The rationale of CFIT03 can be used to overcome the difficulties associated with the accurate determination of top-of-descent point. This is not a fixed position in the map but rather, it can be variable during the day due to ATC constraints or any military activity on the area.

Due to the difficulties associated with the determination of the top-of-descent point it is not possible to classify in a clear way whether it is correct or not. In this way, this precursor reverts to the minimum terrain clearance previewed in CFIT03.

Maturity Level

Level 1

CFIT08 – Inadequate TAWS escape manoeuvre

Summary

Develop means to identify escape manoeuvres after a triggered TAWS alert that are non compliant with the correct manoeuvre or airline SOPs. And beyond that, approaches with repeated TAWS soft warnings (or just one TAWS warning) should be monitored. Repeated TAWS soft warning during an approach can evidence that either the aircraft was not safe with regards to the terrain potentially due to the approach procedure design, or that the TAWS needs to be adjusted for that particular approach.

Rationale

TAWS is composed of a set of modes that identify how close to the ground is the aircraft. Each of these modes correspond to a different warning. The basic modes are from the first generation of systems and just rely on the radio altimeter measurement. More recent systems, other than these basic modes, incorporate a terrain database comprising natural terrain elevations and human made obstacles.These systems can both monitor the proximity to the ground as well as the forward risk collision in the path direction. Each warning has its appropriate crew response which can vary with the fleet and or SOPs.

The following table summarises the TAWS warnings and their corresponding typical escape manoeuvre.

TAWS Warning	Typical escape manoeuvre
Too Low Terrain	TBD
Terrain Pull Up	TBD
Terrain	TBD
Pull Up	TBD
Glideslope	TBD
Too Low Flaps	TBD
Too Low Gear	TBD
Don’t Sink	TBD
Sink Rate	TBD
Terrain Ahead Pull Up	TBD
Terrain Ahead	TBD

It is recommended that the operator performs the assessment of the geographical distribution of the TAWS warnings. The systematic repetitions of these warnings should be studied so that improper reactions from the crew are avoided. A proper evaluation of the risk involved in these cases should be performed. It is also recommended that these conclusions are shared with the equipment vendor so that a fine-tuning of the envelope can be performed, when justified.

Maturity Level

Level 1

CFIT09 – Inadequate Missed Approach and Go Around flight path

Summary

Develop means to identify Missed Approaches and Go Around flights paths that are non compliant with published information or airline SOPs.

Rationale

For this precursor, we should identify the start point of missed approach or go around firstly. RE31 (Go-Around) already mentions the possible methods. Pilots always do the approach briefing including the missed approach procedure before landing. The missed approach procedure obtained from airlines procedure mainly includes the flight heading or track to follow and the altitude to climb to according to the nearby navigation fix. The lateral and altitude deviation should be monitored.

The lateral deviation can be calculated according to the distance to the navigation fix and different angle between the desired heading and desired course (from navigation systems like VOR or NDB). For the altitude deviation, the change of height during the initial missed approach or go around should be positive. Radio altitude is also an important parameter caused by terrain. In the low altitude situation, the change of radio altitude should also be more than a threshold. Climb rate and climb gradient should be positive and more than a threshold.

However, the real flight path can be changed based on the Air traffic controller. The desired flight path should be known before monitoring.

Required Parameters

Parameter	Type	Data Sources
Longitude position	Analog	Aircraft
Latitude position	Analog	Aircraft
Climb rate	Analog	Aircraft
Radio altitude	Analog	Aircraft
Desired Heading True	Analog	Airlines procedure
Desired Course	Analog	Airlines procedure
Climb gradient	Analog	Airlines procedure
Navigation fix positon	Analog	Navigation database
Terrain height	Analog	Navigation database

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Missed approach Go around	***R*** = Distance to navigation fix **= *ABS*** (Current position – Navigation fix position) **DA** = ***ABS***(Desired Heading True- Desired Course) ***LateralDeviation = R*sin*(DA)**	"Big Lateral Deviation"	Raise event if ***LateralDeviation*** > Threshold (Note 1)
Missed approach Go around	***ClimbRate*** = Climb rate during missed approach or go around	"Low Climb rate"	Raise event if ***ClimbRate*** < Threshold
Missed approach Go around	***ClimbGradient*** = Climb gradient during missed approach or go around	"Low Climb Gradient"	Raise event if ***ClimbGradient*** < Threshold (Note 2)
Missed approach Go around	***H = Radio altitude + terrain height*** ***ChangeOfH*** = change of the height	"height decreases"	Raise event if ***ChangeOfH*** < Threshold
Missed approach Go around	***ChangeOfRH*** = change of the Radio attitude	" Terrain"	Raise event if ***ChangeOfRH*** < Threshold1 and Radio attitude < Threshold2

Note 1:

This lateral deviation can also be obtained from the Course Deviation Indicator (CDI). Air Traffic Controllers (ATC) play a big role on the missed approach or go around flight path. The desired flight path should be set according to the missed approach procedure and updated in time according to the ATC.

Note 2:

In the landing configuration, the steady gradient of climb may not be less than 3.2 % with all-engines operating according to CS 25.119. For climb with one-engine inoperative, the steady gradient of climb may not be less than 2.1 % for two-engined aeroplanes, 2.4 % for three-engined airplanes and 2.7 % for four-engined aeroplanes in approach phase according to CS25.121. The climb gradient limit depends on the aircraft configuration and numbers of the engine.

Maturity Level

Level 1

CFIT10 – Loss of communication

Summary

Develop means to identify loss of communication.

Rationale

In-flight radio failure may constitute an emergency, as determined by the pilot. Aircraft equipped with a transponder should indicate a “loss of communication” situation by setting the appropriate transponder code 7600. Loss of communication aircraft declaring an emergency are given priority over other aircraft (providing a more serious emergency does not occur on another aircraft)

If the radio failure occurs in visual flight rules (VFR) conditions in an area where radio communication is required, the pilot is expected to continue under VFR and land when feasible. If flying under instrument flight rules (IFR) conditions, and VFR conditions exist or are encountered after the failure, the flight should be continued in VFR conditions and the pilot shall land as soon as practicable. If VFR conditions do not exist, the pilot will then continue the route last assigned by ATC

The speech communications includes the HF and VHF communication, where the HF (High Frequency) is a long-range communication system between the aircraft, or between the aircraft and ground stations and the VHF (Very High Frequency) communications system supply two-way voice and data communications between aircraft, and between aircraft and ground stations.

Aircraft Parameters

Parameter	Parameter Description	Type	Display Option
PTT_HF_2 (Note 1)	HF-2 - PTT - HF 2 RxTx	Discrete	0-RX 1-TX
PTT_HF_1	HF-1 - PTT HF 1 RxTx	Discrete	0-RX 1-TX
PTT_VHF_1	VHF-1 - PTT VHF 1	Discrete	0-RX 1-TX
PTT_VHF_2	VHF-2 - PTT VHF 2	Discrete	0-RX 1-TX
PTT_VHF_3	PTT VHF 3 RxTx	Discrete	0-RX 1-TX
VHF_1_FAIL	CAS Caution VHF 1 FAIL	Discrete	
VHF_2_FAIL	CAS Caution VHF 2 FAIL	Discrete	
VHF_3_FAIL	CAS Caution VHF 3 FAIL	Discrete	
ATC_CODE	Selected ATC Transponder Code	Decimal	

Note 1 – In this context PTT stands for “Push to Talk”

Measurements and Events

Search Window	Measurements	Event	Event Threshold
IN_FLIGHT	COUNT = Number of times of PTT_VHF_1 and PTT_VHF_2 and PTT_VHF_3 and PTT_HF_2 and PTT_HF_1 is active	"LOSS OF COMMUNICATION DURING FLIGHT"	Raise event if ***COUNT*** <= Threshold OR VHF_FAIL = TRUE OR ATC_CODE=7600 (Note 1)

Note 1 – Pseudocode implementation for the event generation

If (IN_FLIGHT = TRUE) THEN

IF (COUNT<= Threshold OR (VHF_3_FAIL = TRUE AND VHF_2_FAIL = TRUE AND VHF_1_FAIL = TRUE) OR ATC_CODE=7600) THEN

Raise Event Loss of Communication

ENDIF

ENDIF

Maturity Level

Level 1

CFIT11 – Low energy state during approach / unstable approach

Summary

Develop means to identify low energy states during approach and unstable approaches.

Rationale

Energy management per flight phase is covered in LOC13 and Unstable approach in RE26. This precursor can be considered as a specific case of LOC13 for flight phases close to the ground.

Aircraft with low energy state during approach with low speed and/or low altitude and/or low thrust setting is in a high risk situation, as any of the mentioned state could lead to a short or hard landing and there may not be sufficient engine response to counteract any late downdraft in final approach.

Therefore, this event concerns following three types of aircraft states:

1. Continuously low altitude during final approach
2. Continuously slow during final approach
3. Thrust low in final approach

Aircraft Parameters

Parameter	Type
Glideslope Deviation	Analog
Radio Altitude	Analog
Computed Airspeed	Analog
VAPP	Analog
Engine 1/2 N2	Analog
Flight Phase	Discrete
FMA Mode	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold
FMA mode or Flight phase is in either “Final Approach” or “Land”, and radio altitude is below 1000 feet (500 feet for thrust low).	***GS_Max_Dev_Down*** = glideslope maximum deviation below the beam ***CAS_Deficit*** = computed airspeed deviation from Vapp. ***THR_Deficit*** = N2_1 and N2_2 deviation from a preset threshold	“Deviation below glideslope” “Deviation from approach speed” “Low thrust final approach”	Raise event if ***GS_Max_Dev_Down*** > Threshold for a certain period of time (e.g. 3 seconds) Raise event if ***CAS_Deficit*** > Threshold Raise event if ***THR_Deficit*** > Threshold for a certain period of time (e.g. 3 seconds) , and ***RA*** < 500 feet

Maturity Level

Level 1

CFIT12 – Inadequate response to wind shear warning

Summary

Develop means to detect inadequate responses to wind shear warnings, especially in situations close to terrain (e.g. approach in a mountainous area).

Rationale

This precursor involves firstly the identification or detection of wind shear either via onboard avionics systems and indication or based on crew assessed scenarios of wind shear based on changes of wind speed and direction with inputs ranging from weather warnings and other vicinity provided reports. The second element involves the response that once wind shear identified the actions of the crew to mitigate the risks associated with wind shear.

System wind shear detection: For the most modern aircraft have two types of wind shear detection “Predictive Wind Shear” and “Reactive Wind shear”. The warnings output vary so that the flight deck crew can identify the type of wind shear detected.

Crew assessed wind shear detection: Crew have guidance from the METAR and other weather observations identifying wind shear conditions. Additionally changes in wind speeds, direction and aircraft attitude and heading excursions point towards wind shear conditions.

Correct response based on the phase of flight of wind shear detection. Main element is application of maximum thrust available to counter onset of loss of speed, monitor speed trend and not to change the flap or landing gear configuration. When out of wind shear to retract gear and flaps and increase the airspeed.

Aircraft Parameters

Parameter	Type
Wind speed , direction	Analogue
Predictive wind shear warning	Discrete
Reactive wind shear warning	Discrete
Thrust lever position	Analogue / Discrete
Auto thrust disconnect discrete	Discrete
Flap lever AND / OR Flaps position	Analogue / Discrete
Landing lever or gear position	Discrete

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Take off / Initial Climb	WSHR Warning duration Wind speed Wind direction	Wind shear detected (time t) , check post response (See Note 1)	Event if below conditions not met; If (WSHR=TRUE) , Thrust=Max available Flaps @ Wshr = Flaps @ t+ x (sec) Gear @ Wshr = Gear @ t+ x (sec)
Approach / Landing	WSHR Warning duration Wind speed Wind direction	Wind shear detected (time t) , check post response (See Note 1)	Event if below conditions not met; If (WSHR=TRUE) , Thrust=TOGA Flaps @ Wshr = Flaps @ t+ x (sec) Gear @ Wshr = Gear @ t+ x (sec)

Note 1: Changes to thrust is immediate however not changing the flaps and gear configuration can be dynamic i.e. based on time or a level off post a go around execution.

Maturity Level

Level 1

CFIT13 – Reduced horizontal distance to terrain

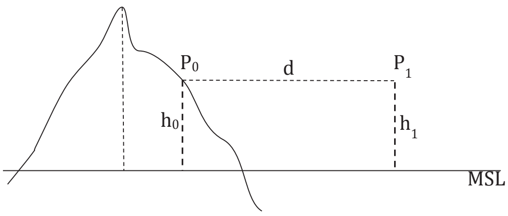
Summary

Develop means to identify scenarios of reduced horizontal distance to terrain

Rationale

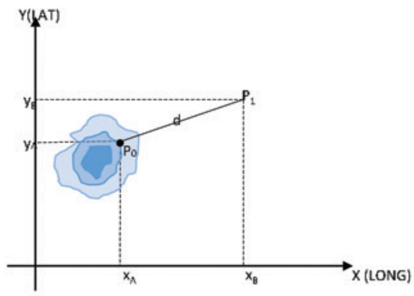
This precursor relies on the comparing the distance between consecutive positions recorded on board of the aircraft with respect to the respective altitude from the nearby terrain on the same horizontal plane (Fig 2).

➨ **Figure 2:** terrain position (fixed point P_0) and aircraft position (moving point P_1).



In order to compute the minimum horizontal distance a plane corresponding to the aircraft altitude is assumed. The terrain elevation at the given altitude is obtained through the use of an external terrain database. The altimetry reference from both aircraft and terrain has to be the same. The altitude h1 from Fig1 has to reflect the altitude to the mean sea level (MSL), i.e., with the QNH baro correction (ALT_QNH).

➨ **Figure 3:** terrain and aircraft positions, horizontal view.

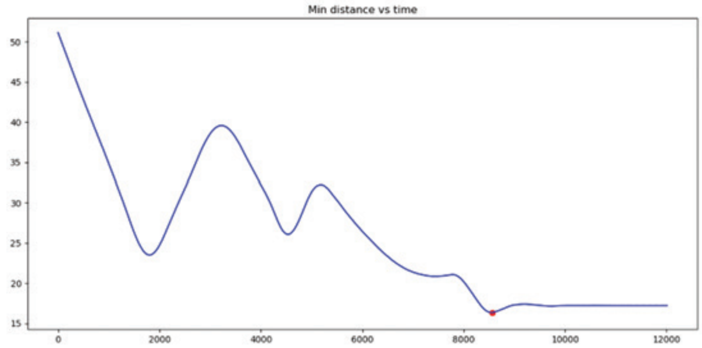


To compute the distance from any point of the flight path to the closest point in the terrain at the same altitude, assume both the positions of the points and the position of the aircraft are available so that this distance is calculated at every new sample of aircraft position (LAT, LONG). Such distances can be calculated using the Haversine formula[18]. This formula calculates the great circle distance, which is an approximation of the distance between two latitude and longitude points assuming that the earth is a perfect sphere. However, if we're calculating the distance between two points that are close to each other, which is the case for this precursor, the error with this method will be negligible.

18 See: https://en.wikipedia.org/wiki/Haversine_formula

For each flight path close to one elevation, one will conduct the calculations for one value for a minimum distance (dmin). There is only a need to calculate this distance as proximity to the terrain, so it can be triggered if terrain is detected in a proximity of 10NM[19] of the aircraft position. This can be used to assess the closest proximity to the terrain (Fig 4).

Figure 4: minimum distance with respect to time.



All distances have to be internally checked against operator requirements for a minimum distance. In the following sections this operator approved distance is referred to as threshold and it depends on the features of the geographical area and data collected from previous approach procedures.

Aircraft Parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue
Radio Altitude/Height	Analogue
ALT STD	Analogue
QNH correction (Note 1)	Analogue

Note 1: alternatively ALT_QNH if available in the data stream or the QNH correction can be obtained by other means.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
In flight (Nearby a high elevation point)	d	Reduced horizontal distance	Raise event if $d < Threshold$
In flight (Nearby a high elevation point)	d_{min}		

19 This distance can change according to operator's experience

Future Developments and Recommendations

Values recorded for latitude and longitude parameters often do not match the desired accuracy. The use of correct values is particularly important in approach procedures through mountainous and dangerous areas. Thus the algorithm for reduced horizontal distance to terrain can serve as a method to check for possible errors with the recorded aircraft position.

Two studies can be used as a reference for the integration of terrain databases with flight data which provide more advanced concepts on this area. One was performed by the Technical University of Munich (TUM)[20] and the second by TAP Portugal[21.]

Maturity Level

Level 1

20 Technical University of Minich (TUM), Controlled Flight into Terrain Analyses in Flight Data Monitoring, Niclas Bahr (https://mediatum.ub.tum.de/1403391), 2017

21 Instituto Superior Tecnico, Development of a Terrain Awareness Warning System Tool for Aircraft Operation Monitoring, Miguel Melo Mata (https://fenix.tecnico.ulisboa.pt/cursos/meaer/dissertacao/1409728525632609), 2018

CFIT14 – Reduced time to terrain impact

Summary

Develop means to identify scenarios of reduced time to terrain impact assuming the aircraft maintains current track and speed.

Rationale

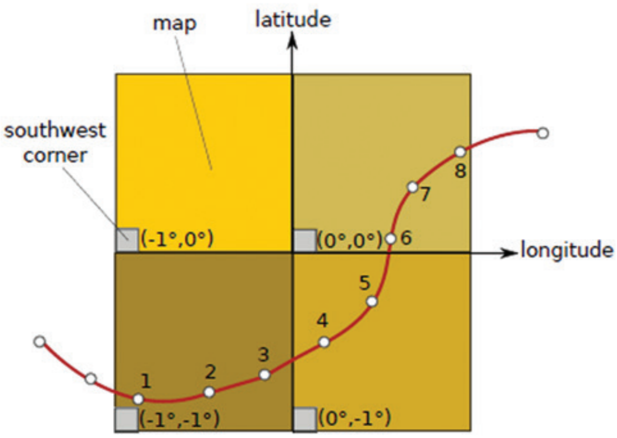
The studies used as a reference in the previous chapter (CFIT13) from TUM and TAP will be used to develop the rationale for this precursor. The following definitions introduce the concepts that will be used in this precursor.

Definitions[22]

Map – In the current context, map will be referred as the set of grid terrain cells each one with a corresponding altitude. This is available through a terrain database[23].

Flight Path Map – The set of all the terrain cells that are necessary to cover the flight path completely (Figure 5 - Flight Path Map).

➡ **Figure 5:** Flight Path Map.



CFIT Trajectory – Defined as the trajectory tangent to the flight path in the direction of the speed vector. This is the escape trajectory in the case there was no aircraft control.

Time to impact – Shortest time for which the terrain elevation from the terrain database becomes greater than the actual height of the CFIT trajectory.

In order to produce meaningful results, a set of procedures is proposed to cope with this precursor (Table 3 - Sequence of procedures).

22 Credit for the images used in this section: Technical University of Minich (TUM), Controlled Flight into Terrain Analyses in Flight Data Monitoring, Niclas Bahr (https://mediatum.ub.tum.de/1403391), 2017

23 A comparison between different terrain databases can be found in the WGA document, "Review of controlled flight into terrain (CFIT) precursors from an FDM perspective"

Table 3: sequence of procedures.

Procedure	Description	Input	Output
#1	Extract the cells from the terrain database to determine the Flight Path Map	Aircraft Position (Latitude, Longitude)	Set of cells from the terrain database that are covered by the flight path (Figure 5 - Flight Path Map)
#2	Extract the altitude from each terrain cell obtained in Proc #1	Flight Path Map	Altitude corresponding to each cell from the flight path map
#3	Determination of the speed vector (Note 1)	Ground Speed Track Angle Flight Path Angle	Speed Vector
#4	Determination of the CFIT trajectory (Note 2)	Aircraft Position (Latitude, Longitude) Speed vector	CFIT trajectory
#5	Calculate CFIT trajectory altitudes (Note 3)	CFIT trajectory	CFIT trajectory altitudes
#6	Determine the CFIT trajectory terrain cells	CFIT tajectory	CFIT Trajectory cells
#7	Extract the CFIT terrain cells altitudes	CFIT Trajectory cells	Altitudes from CFIT trajectory cells
#8	Check if the altitude from the CFIT trajectory (Proc #5) is lower than the corresponding trajectory cell.	CFIT trajectory CFIT Trajectory cells	Identify any CFIT trajectory point lower than the corresponding trajectory cell.

Note 1:

As documented in the work from TUM, the speed vector at any point of the trajectory is given by:

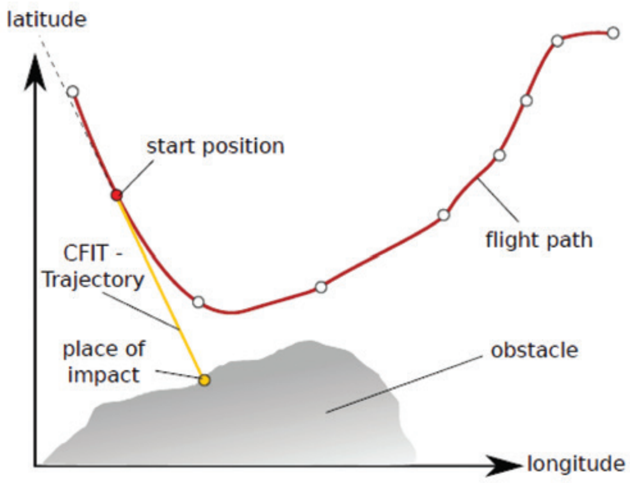
$$\mathbf{v} = GS * \begin{pmatrix} cos(track\ angle) \\ sin(track\ angle) \\ tan(flight\ path\ angle) \end{pmatrix}$$

Note 2:

CFIT trajectory is a tangent line to each new position on the flight path (Figure 6 - CFIT Trajectory). This line is determined using the speed vector to calculate the next position for the CFIT trajectory. This is a potencial trajectory corresponding to the escape path from the real aircraft trajectory (flight path). In the formula below, Pn is the next position (LAT, LONG), Pn-1 is the previous position and the function Tau is to convert the result of v.t from meter to degrees (more details can be found on TUM work).

$$P_n = P_{n-1} + \tau(\mathbf{v}.\Delta\mathbf{t})$$

➨ **Figure 6:** CFIT trajectory.



In order not to extend this calculation indefinitely, it is considered that it can be performed for 60 sec. This value is a design parameter, the operator may adjust it according to his experience and specific needs.

Note 3:

The computation of the CFIT trajectory altitudes is based on a start position (Figure 6 - CFIT Trajectory). This point is obtained from the position parameters (Latitude and Longitude) and the corresponding altitude from the barometric parameters (pressure altitude). This value is to be compared with the corresponding terrain cell altitude.

There are two distinct ways to model the earth surface. One using a geoid which represents a surface corresponding to the mean-sea-level (MSL) and another using an ellipsoid which is a mathematical model consisting of a surface of revolution on a 3 dimensional Cartesian coordinate system with the origin at the centre of the earth.

Altitude values provided by the terrain databases refer to the ellipsoid whereas the pressure altitude refer to the MSL. This feature leads to discrepancies between the altitudes that need to be compared. At this stage the operator should be aware of which parameters refer to which altimetry reference.

Aircraft Parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue
Radio Altitude/Height	Analogue
ALT STD	Analogue
QNH correction (Note 1)	Analogue
Ground Speed	Analogue
Track angle	Analogue
Flight Path angle	Analogue

Note 1: alternatively ALT_QNH if available in the data stream or the QNH correction can be obtained by other means.

Measurements and Events

Search Window	Measurements	Event	Event Threshold	Event Criticality
In flight (Nearby a high elevation point)	Difference between CFIT trajectory altitudes and the corresponding terrain cell altitudes.	"CFIT trajectory below terrain"	Raise event if ALT_CFIT_TRJ < ALT_TERR_CELL	The time to impact implies the criticality of the event.

Future Developments and Recommendations

Instead of considering a straight line as proposed in the text above, an envelope in front of the nose of the aircraft could be considered. One implementation of this idea can be found on the work developed by TAP, in which the size of the envelope is dependent on the ground speed. This approach has the advantage of extending the foresight of possible collisions for greater speeds.

Maturity Level

Level 1

Mid-Air Collision (MAC)

Mid-Air Collision (MAC) is defined in the document from CAST/ICAO taxonomy team which is titled “Aviation Occurrence Categories”.[24]

This chapter focuses on the analysis of the proximity between two aircraft and the way the on-board warnings display the correct information to the pilot. Operators’FDM programmes need to complement the recorded data with supplemantary, which for MAC incidents involve a second aircraft. The information provided by the ANSPs is a paramount for a correct evaluation of the risk involved in one of these incidents. When complementary data is needed, if possible it is worth downloading data recorded by avionics boxes (TCAS or ACAS). Manufacturers may provide ways to download this information and in this way complement the FDM data.

24 The document can be found on the link: http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf

MAC01 – Incorrect altimeter setting or incorrect transition timing

Summary

Develop means to detect incorrect altimeter settings and incorrect timing of the transitions, which could lead to situations with an increased MAC risk

Rationale

When the altimeter is set to QNH, the altitude indicated in the aircraft altimeter is the same as the published runway altitude. This feature can be used to assess the correct setting of the altimeter. Moreover this can be also achieved using the QFE correction, for which the indicated altitude should be zero when landing.

Whenever there is the possibility, the operator should have access to the altitude recordings from different sources, i.e., all the systems than can provide the altitude, typically captain, first-officer and standby. This would allow the comparison among the different altitude recordings in order to detect any mismatch. Also helpful in this context is the identification of which altitude is the altimetry parameter providing, QNH, QFE or STD.

The incorrect timing for the transition from standard to corrected altitude, should be also derived as part of this analysis. The most important information to extract is the altitude where this transition takes place. In case of Europe, no specific altitude is prescribed for this transition to occur. It is expected to happen within the 5000ft to 8000ft range. This information can be used as a base to search for this transition until the TOC and from the TOD. This procedure excludes the cruise flight phase and concentrates the search on climb and descent phases.

In case of US operations, the search can be more simple as it is previewed that after the TOD at 18 000 ft +/- 500ft, the reference should change from STD to QNH.

To tackle this precursor some external data has to be made available to FDM, so that the weather data is available. These can be:

- METARS
- Flight Plan

Aircraft Parameters

Parameter	Type
ALT STD	Analogue
QNH correction (Note 1)	Analogue

Note 1: alternatively ALT_QNH if available in the data stream or the QNH correction can be obtained by other means.

Measurements and Events

Search Window	Measurements	Event	Event Threshold
TBD	TBD	TBD	TBD

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC02 – Lateral deviation

Summary

Develop means to detect situations where the actual flight trajectory is deviating from the published, cleared or intended trajectory

Rationale

Deviations from the flight path may occur without consequences in most areas, except for dangerous or temporary restricted ones. The possibility to verify whether an actual flight path corresponds to the one documented in the flight plan is not directly available through the FDM software. In fact, this requires that external data sources have to be available in order to compare the path from the aircraft and from the flight plan.

Having this assumption in mind, the way to tackle this precursor always involves the aid from one or more of the following data sources:

- ATC data
- NAV Charts
- Flight Plan

The measurement of lateral deviation is a way to verify the compliance with SIDS and STARS.

Aircraft Parameters

Parameter	Type
Latitude	Analog
Longitude	Analog

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Full Flight	TBD	TBD	TBD

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC03 – Level bust

Summary

Develop means to identify level busts, i.e. situations where the cleared and intended altitude or flight level is overshot during climb or undershot during descent

Rationale

Relying on FDM by itself to achieve a wide-ranging solution for identifying level busts carries a few challenges, because it is not possible to access the altitude clearance given by the ATC without relying on other sources of information. However, assuming that the altitude selected by the crew is the clearance altitude or the flight level intended, it is possible to find a viable solution to monitor overshoots or undershoots during flight level changes and other abnormal altitude patterns during operation, particularly during climb, cruise and descent flight phases.

We propose to divide MAC03 in two types of precursors. Firstly, flight level overshoots or undershoots pose a significant MAC risk and have to be monitored. This can be done by identifying the flight level selected by the crew in the autopilot control panel[25] while monitoring the corresponding altitude of the aircraft during climb or descent.

> Example 1: While climbing to cruise altitude, the crew selects FL380 in the autopilot control panel. If the aircraft overshoots the selected altitude by 500ft, it is considered a level bust.
>
> The second type of precursor to monitor is a diverting aircraft behaviour from the expected, w.r.t. the altitude selection. Examples could be going on different paths or maintaining altitude, after an altitude selection by the crew.
>
> Example 2.1: After top of descent at FL380, the crew selects FL200 to begin descent. During descent at FL250, the aircraft climbs to FL260 and resumes its descent thereafter.
>
> Example 2.2: During cruise at FL350, the crew selects FL360 and maintains altitude during a threshold period after the new altitude selection.
>
> Note that some of these type 2 events may occur due to TCAS warnings for example. In this case the event should be invalidated. **Also, the altitude reference used by the crew should be the altitude being monitored, either STD/QNH/QFE.** Changes in the barometric reference or of the flight level might stimulate small jumps in the computed parameters used for monitoring. Thus, to avoid false alerts, one can inhibit the level bust monitoring for a few seconds after these situations.

25 In Airbus terminology this refers to the Flight Control Unit (FCU)

Aircraft Parameters

Parameter	Type
Altitude STD/QNH/QFE	Analog
Barometric Reference Selection (STD/QNH/QFE)	Analog
Altitude Selected	Analog
Inertial Vertical Velocity	Analog

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Climb	***ALT*** = Altitude ***ALT_SEL*** = Altitude Selected	"Flight Level Overshoot"	Raise event if (***ALT-ALT_SEL***) > Threshold (See Notes 1 & 2)
Descent	***ALT*** = Altitude ***ALT_SEL*** = Altitude Selected ***IVV*** = Vertical Speed	"Flight Level Undershoot"	Raise event if (***ALT-ALT_SEL***) < Threshold ***AND*** abs(IVV) < Threshold (See Notes 1 & 2)
Climb, Cruise, Descent	***ALT*** = Altitude ***ALT_SEL*** = Altitude Selected ***IVV*** = Vertical Speed ***DeltaALT*** = **abs(*ALT-ALT_SEL*)**	"Altitude Misbehavior During Climb/Descent "	Raise event if ***DeltaALT*** increases over time ***AND*** abs(IVV) > Threshold ***DURING*** Threshold (See Notes 1, 2 & 3)
Climb, Cruise, Descent	***ALT_SEL*** = Altitude Selected ***IVV*** = Vertical Speed	"Altitude Misbehavior after Altitude Selection Change"	Raise event if ***ALT_SEL*** changes ***AND*** abs(IVV) < Threshold ***DURING*** Threshold (See Notes 1, 2 & 4)

Note 1: Altitude is according to the respective barometric reference selection.

Note 2: Immediately after flight level/barometric reference changes, it might be necessary to inhibit the event monitoring during a short period, as one can have additional computed parameters that can swing and breach the thresholds defined.

Note 3: The current altitude is expected to move towards the selected altitude. This event will trigger when the selected altitude is moving away from the current altitude, as it was mentioned in Example 2.1.

Note 4: If no action is performed after any altitude selection change, this would trigger an event as mentioned in Example 2.2.

Future Developments and Recommendations

As stated before, the major challenge in monitoring flight level busts via FDM is not having access to the ATC clearance given and relying only on the altitude selection by the crew. However, as FDM progresses it might be possible in a near future to have such data and monitor these type of events with more sources of information. As a final note, one should take in consideration that there are external occurrences during aircraft operation that may trigger one of these level bust events. Such can be TCAS warnings or severe turbulence. While they are not directly related to aircraft attitude misbehaviors, each airline should treat these events according to its own internal policies and EOFDM recommendations.

Maturity Level

Level 1

MAC04 – High rates of climb / descent

Summary

Develop means to identify climbs and descents with high rates. Due to the trigger logic of ACAS alerts, these high rates can lead to the generation of nuisance alerts (see MAC08).

Rationale

Some information regarding the control of the rates of descent or climb to avoid unnecessary Resolution Advisories (RAs) is presented in the following webpage from EUROCONTROL:

https://www.eurocontrol.int/eec/public/standard_page/EEC_News_2006_2_ACAS.html

The most direct way to tackle this precursor is through the use of the vertical speed, combined with

The selected altitude parameter. This can lead though to a large number of false positives due to the fact that the selected altitude may not be in use during the leveling of the aircraft. The use of vertical speed mode to approach a flight level depends both on FMS modes and on the fleet. The correct use of automation can present a degree of difficulty concerning the vertical modes to use.

Due to the complexity related to the different automation systems, the proposal for this precursor is to concentrate on the vertical speed and check its progress until one level is attained. For this computation some reverse calculation is necessary to extract the information of the different flight level changes during one flight. . A two pass algorithm is proposed:

- Identify the Level Off
- Apply the algorithms concerning vertical speeds

The monitoring of the vertical speed is to be performed during the 1000ft before the level is attained. Any abnormal level should be identified.

Aircraft Parameters

Parameter	Type
Vertical Speed (Note 1)	Analog
Latitude	Analog
Longitude	Analog
Altitude STD	Analog

Note 1 – in some fleets this parameter is given by the inertial vertical velocity (IVV)

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Whole flight	Actual level off altitude Location of level off Vertical speed before level off (last 1000ft)	“High rate of climb / descent”	Vertical Speed > Threshold

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC05 – Inadequate use of automation

Summary

Develop means to identify situations of inadequate use of automations related to the trajectory

Rationale

The mismanagement of automation was already addressed by LOC29 in the context of Loss of Control in flight (LOCI). The types of scenarios that are intended to be detected are those:

- Where automation should be in use and it isn't
- Autopilot is disengaged in RVSM airspace (See also MAC06)
- Flying with inappropriate modes
- Improper use of Selected/Managed

As the inappropriate use of automation is one extensive subject, the proposal is to revert to the flight data to learn which autopilot modes are used for normal operation for each flight phase (already described in LOC29). In case of MAC the misuse of automation leads the aircraft to a different position than the one where it should be. This context is different than for LOCI.

As there is a broad set of options, the WG proposed to produce generic text about the possible identified cases, and produce deeper context for the Go-Around.

Go-Around is a complex scenario which can be described in different ways:

1. Go-Around
2. Aborted Approach
3. Aborted Landing

Automation in go-around phase can be interesting; go-around mode can give a lot of power which can make the pilot overshoot the required altitude and/or attitude, so can sometimes select a different (unexpected) mode.

> Note: When the Go-around is performed at high altitudes, Embraer no longer recommend use of go-around mode, but instead the use of vertical speed mode to prevent high energy status with high pitch up. Airbus have also introduced a "soft" go around mode.

Aircraft Parameters

Parameter	Type
TBD	TBD

Measurements and Events

Search Window	Measurements	Event	Event Threshold
TBD	TBD	TBD	TBD

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC06 – Automatic altitude control system off in RVSM conditions

Summary

Develop means to identify situations with inappropriate settings of the automatic altitude control system in RVSM conditions

Rationale

RVSM defined altitudes are between FL290 and FL410. Complete information can be found in the webpage:

https://www.skybrary.aero/index.php/Reduced_Vertical_Separation_Minima (RVSM)

It is considered as a bad practice if the autopilot is disconnected at these altitudes. In order to cope with this precursor it is proposed to set one altitude of 20.000 ft. to detect if there is one disengagement of the autopilot above it. This includes all the flight levels from RVSM.

Aircraft Parameters

Parameter	Type
Altitude STD	Analog

Measurements and Events

Search Window	Measurements	Event	Event Threshold
Cruise (Altitude > 20.000ft)	Autopilot disengaged	"Autopilot disengaged above 20.000tf"	NA

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC07 – Last minute change of SID and STAR

Summary

Develop means to identify last minute changes of the SID or STAR (possibly in combination with MAC02)

Rationale

Possible ways to cope with this precursor include:

- Some fleets allow the recording of the waypoints from the FMS. This is data that could be compared with the messages from the CPDLC. The name of SIDs and STARS are present in this system
- Reverse engineer from the flight path to identify a possible SID/STAR by the NAV Charts

Aircraft Parameters

Parameter	Type
TBD	TBD

Measurements and Events

Search Window	Measurements	Event	Event Threshold
TBD	TBD	TBD	TBD

Future Developments and Recommendations

It is recommended, to cope with this precursor, that the flight plan waypoints from the FMS are included in the dataframe.

Maturity Level

Level 1

MAC08 – ACAS alerts

Summary

Monitor every safety relevant information with respect to the ACAS that is available within FDM. In particular, resolution advisories shall be identified and further investigated in detail

Rationale

It is assumed that all the ACAS warnings are analysed manually after being detected by the FDM system. The maximisation of the results for this analysis, is achieved if:

1) All the ACAS modes are part of the recorded parameters
2) Support information is produced for the analysis process, such as
   - RA Warning Duration
   - RA Reaction Delay
   - RA To AP Disengaged Duration
   - RA Direction
   - RA Acceleration
   - RA Change Of Vertical Speed
   - Compliance with the Vertical Speed band margins

In addition, for the operator to assess the hotspots for his operation, it is recommended to monitor the TCAS warning locations, both for TAs and RAs.

Also the TAs should be monitored, more specifically if there was any input from the crew as a reaction to a TA.

Aircraft Parameters

Parameter	Type
TBD	TBD

Measurements and Events

Search Window	Measurements	Event	Event Threshold
TBD	TBD	TBD	TBD

Future Developments and Recommendations

TBD

Maturity Level

Level 1

MAC09 – Inappropriate ACAS setting

Summary

Develop means to monitor the settings of the ACAS and to verify their suitability

Rationale

Different configurations are possible through selections on ACAS control panels. Normally the system can be manualy configurated as using the full capability for TAs and RAs, being set as TA only or off. Depending on the fleet, there is also the range selection which can be common to other systems such as the wheather radar.

These different settings should be part of the dataframe so that the proper assessment of its correct use can be performed.

Aircraft Parameters

Parameter	Type
TBD	TBD

Measurements and Events

Search Window	Measurements	Event	Event Threshold
TBD	TBD	TBD	TBD

Future Developments and Recommendations

TBD

Maturity Level

Level 1

Annex 1 – Accurate Position Computation

Summary

Many monitoring algorithms are linked to a good estimation of the aircraft position. Depending on which is the source of your recorded position, its sampling rate and resolution, the recorded position is sometimes not usable for the algorithm. The importance of having the **Best Position** measurement led working group B to create this specific section in order to present some ideas on this matter.

Rationale

Some monitoring algorithms may require a relatively accurate aircraft position. The data source, sampling rate and recording resolution will greatly influence the usability of geographical position data.

Possible sources for position parameters are:

- IRS[26]
- FMS
- GNSS

Note: due to the inherent drift characteristics of an IRS platform, currently IRS position data is not recommended for any algorithms which compute information related to the aircraft's geographical position.

The errors associated with these systems can be visualised by the following sequence of images which show the position parameters from the same flight from each of these systems.

IRS

26 In most recent fleets associated with Air Data Computer (ADC) and named ADIRS

GNSS

FMS

For capturing any geographical position data, it is recommended that the relevant parameter (i.e. latitude or longitude) is captured at the maximum update rate (1 Hz or greater) and to a resolution greater than six decimal places (in the case of recording DD(D).dddddd recording format).

Sample Resolutions:

$$0.001° \approx 111M\ resolution$$

$$0.00001° \approx 1M\ resolution$$

Some developments of these concepts is available on the presentation from Joachim Siegel, Lukas Höhndorf, on EOFDM Conference 2016, named "**Landing Trajectory and Touchdown Point Reconstruction**"[27]

27 This presentation can be found on the Event Proceedings section of https://www.easa.europa.eu/newsroom-and-events/events/4th-conference-european-operators-flight-data-monitoring-forum-eofdm#group-easa-event-proceedings

Annex 2 – List of Recommended Parameters

The list of parameters presented in this section corresponds to the parameters that are necessary to be recorded in order to program the precursors defined in this document.

- **Description** – Brief description of each Parameter
- **Rate** – Minimum Recording Rate
- **Unit** – Engineering Units
- **Resolution** – Minimum Recommended Resolution
- **Type** – Signal Type (Discrete - **D** or Analogue - **A**)

The minimum information to be recorded by the flight data recorder (FDR) is specified in the Acceptable Means of Compliance into Part CAT (CAT.IDE.A.190) of the EU rules for air operations. It is important to note that this recorder and its contents are mainly to be used by the investigation authorities in case there is an accident or a serious incident. This acceptable means of compliance should not be confused with the parameters table provided in this section.

Despite some operators rely on the FDR Recorder to perform the Flight Data Monitoring (FDM) there are some limitations, in terms of the existence of the parameters or recording rate may appear, due to the fact that this dataframe was conceived initially for investigation analysis. The goal of FDM analysis is different, i.e., it uses the data to detect precursors from unsafe situations and avoid in this way that accidents happen. In order to achieve this goal, the requests for FDM dataframes are higher and operators may rely on dataframe customisation to adapt the frames to FDM needs for fleets that have FDM recorders for this kind of analysis (commonly named Quick Access Recorder or similar). In this case, the FDR dataframe should always be used as a baseline and any customisation should be built on the top of this dataframe to increase its contents. All the performance specifications in the tables below are as stringent or more stringent than FDR parameters performance specifications in AMC to CAT.IDE.A.190.

For those fleets that don’t allow this kind of customisation, aircraft manufacturers should keep in mind the dual use of the data recorded in the FDR and take into account the list of parameters from this section when creating the FDR´s dataframe. This is especially valid for new aircraft which also benefit from the new technologies available in this area.

The parameters described in this section are a recommendation resulting from the Best Practices identified by EOFDM members to support all the precursors described in this document. It is not intended to be prescriptive and every special need from the operator shall be incorporated into the definition.

Air Conditioning – ATA 21

Description	Rate Hz	Units	Resolution	Type
Cabin Pressure	1	psi	TBD	TBD
Cabin Altitude Rate	1	ft/min	50	A
Outflow Valve Position	1	%	1	A
Cabin Differential Pressure	1	psi	0.02	A
Cabin Altitude	1	ft	16	A
Excessive Cabin Pressure Warning	1	NA	NA	D

Description	Rate Hz	Units	Resolution	Type
Excessive Cabin Altitude Warning	1	NA	NA	D
Excessive High Differential Pressure Warning	1	NA	NA	D
Excessive Negative Differential Pressure Warning	1	NA	NA	D
Mode SEL P/B MAN	1	NA	NA	D

Autoflight – ATA 22

Description	Rate Hz	Units	Resolution	Type
Altitude Selected	1	ft	64	A
FMS_Temp[28]	1	degC	TBD	A

Fuel – ATA 28

Description	Rate Hz	Units	Resolution	Type
Fuel Quantity	1	Tones	18.14	A

Flight Controls – ATA 27

Description	Rate Hz	Units	Resolution	Type
Ground (*) Spoiler Out	1	NA	NA	D
Speed Brakes Armed	1	NA	NA	D
Stabiliser Trim Position	1	deg	0.09	A
Flap/Slat Lever Angle	1	deg	0.04	A
Flap/Slat Lever Position	1	NA	NA	D
Flap Angle	1	deg	NA	A
Slat Angle	1	deg	NA	A
Rudder	2	deg	0.09	A
Rudder Pedal	2	deg	0.09	A
Angle of Attack (*)	1	deg	0.09	A
Envelope Protection System	1	NA	NA	D
Pitch Command (column or side-stick)	1	deg	0.09	A
Roll Command (column or side-stick)	1	deg	0.08789	A
Control Column Force	TBD	TBD	TBD	TBD
Control Column	TBD	TBD	TBD	TBD
Control Wheel Force	TBD	TBD	TBD	TBD

28 Temperature that is inserted in the FMS before takeoff. Can be OAT or FLEX or other depending on the fleet.

Description	Rate Hz	Units	Resolution	Type
Elevator Actuator / Quadrant	TBD	TBD	TBD	TBD
Elevator Surface	1	deg	0.09	A
Aileron Trim	TBD	TBD	TBD	TBD
Elevator Trim	TBD	TBD	TBD	TBD
Rudder Trim	TBD	TBD	TBD	TBD

Ice and Rain Protection – ATA 30

Description	Rate Hz	Units	Resolution	Type
De-Icing Airframe ON	1	NA	NA	D
Icing AOA	1	NA	NA	D
Icing Detected	1	NA	NA	D

Instruments – ATA 31

Description	Rate Hz	Units	Resolution	Type
Master Warning	1	NA	NA	D
Master Caution	1	NA	NA	D
Acceleration Longitudinal	4	G	0.004	A
Acceleration Lateral	4	G	0.002	A
Acceleration Vertical	8	G	0.004	A
Smoke Avionics (*) Warning	1	NA	NA	D
Smoke Cargo (*) Warning	1	NA	NA	D
Smoke Lavatory (*) Warning	1	NA	NA	D
Windshear Warning	1	NA	NA	D
Windshear Caution				
HGG/TRK P/B Selection (VS/FPA)	1	NA	NA	D

Landing Gear / Wheels and Brakes – ATA 32

Description	Rate Hz	Units	Resolution	Type
Brake (*) Temperature	1	deg C	1	A
Brake (*) Pressure	1	psi	1	A
Brake (*) Pedal Position	1	deg	1	A
Autobrake Selection	1	NA	NA	D
Main Landing Gear (*)	4	NA	NA	D
Nose Landing Gear	4	NA	NA	D
Nose Wheel Steering Fault	1	NA	NA	D

Navigation – ATA 34

Description	Rate Hz	Units	Resolution	Type
Altitude Standard	1	ft	1	A
Altitude QNH Corrected (Note 1)	1	ft	1	A
Gross Weight	1	Kg	18.14	A
Static Air Temperature	1	deg C	0.25	A
Indicated Airspeed	1	Knot	0.25	A
Ground Speed	2	Knot	1	A
Airspeed True	1	Knot	0.5	A
Approach Target Speed (VAPP)	1	Knot	0.25	A
V1	1	Knot	0.25	A
V2	1	Knot	0.25	A
Vr – Rotation Speed	1	Knot	0.25	A
Pitch Command	2	Deg	0.09	A
Pitch Rate	4	deg/s	0.06	A
Latitude	1	Deg	1.7e-4	A
Longitude	1	Deg	1.7e-4	A
Wind Speed	1	knot	0.063	A
Wind Direction	1	Deg	0.09	A
Heading True	1	Deg	0.09	A
Drift Angle	1	Deg	0.09	A
Runway Heading	1	Deg	0.09	A
Localiser Deviation	4	dots[29]	0.2	A
Glideslope Deviation	4	dots[30]	0.4	A
Vertical Speed	4	ft/min	16	A
Pitch	4	Deg	0.09	A
Roll	4	Deg	0.09	A
Radio Altitude	4	ft	0.5	A
Landing Elevation (FMC)	1	Ft	8	A
Centre of Gravity	1	%MAC	0.01	A
Angle of Attack	1	Deg	0.09	A
Mach Number	1	MACH	0.001	A
Total Air Temperature	1	deg C	0.25	A
Static Air Temperature	1	deg C	0.25	A
Stall Speed	1	Knot	0.25	A
Wind Speed	1	Knot	0.06	A
Wind Direction	1	Deg	0.09	A
TAWS Windshear Warning	1	NA	NA	D

Note 1: Alternatively the barometric correction can be recorded and applied to the Altitude standard parameter to derive either the ALT_QNH or ALT_QFE.

29 Alternatively mDDM
30 idem

Oxygen – ATA 35

Description	Rate Hz	Units	Resolution	Type
Oxygen Low Pressure	1	NA	NA	D

Auxiliary Power Unit – ATA 49

Description	Rate Hz	Units	Resolution	Type
APU Fire	1	NA	NA	D

Power Plant – ATA 7X / 8X / 9X

Description	Rate Hz	Units	Resolution	Type
Eng (*) Thrust Lever Angle	1	deg	0.04	A
Eng (*) Thrust Lever Position	1	NA	NA	D
Eng (*) Engine Pressure Ratio	TBD	TBD	TBD	A
Eng (*) N1	1	%	0.06	A
Eng (*) N2	1	%	0.13	A
Eng (*) N3	TBD	TBD	TBD	TBD
Eng (*) Fire Warning	1	NA	NA	D
Eng (*) Oil Temperature	1	deg C	1	A
Eng (*) Oil Pressure	1	psi	2	A
Eng (*) Oil Quantity	1	quart	0.25	A
Eng (*) Exhaust Gas Temperature	1	deg C	1	A
Eng (*) Vibration N1	1	TBD	0.2	A
Eng (*) Vibration N2	1	TBD	0.2	A
Eng (*) Vibration N3	TBD	TBD	TBD	TBD
Eng (*) Master Switch	1	NA	NA	D
FADEC System Fault Warning	1	NA	NA	D
Eng (*) Nh	TBD	TBD	TBD	TBD
Eng (*) Np	TBD	TBD	TBD	TBD
Eng (*) Torque	TBD	TBD	TBD	TBD

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