SAFETY PROMOTION
Good Practices Document

European Operators Flight Data Monitoring Working Group B

Guidance for the Implementation of Flight Data Monitoring Precursors

December 2022

Rev 04

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Introduction

The requirement to establish a flight data monitoring (FDM) programme, as one of the minimum conditions for an EASA Member-State-based air operator to obtain and maintain an air operator certificate (AOC) is, as of October 2012 contained in Annex III (Part-ORO) to Commission Regulation (EU) No 965/2012 (the Air Operations Regulation)[1]:

‘(a) The operator shall establish and maintain a flight data monitoring system, which shall be integrated in its management system, for aeroplanes with a maximum certificated take-off mass of more than 27 000 kg.

(b) The flight data monitoring system shall be non-punitive and contain adequate safeguards to protect the source(s) of the data.’

This document is the result of the collaborative work of Working Group B (WGB) of the European Operators Flight Data Monitoring (EOFDM) forum that comprises organisations from different areas, such as air operators, research institutions and universities, regulators, and FDM software vendors.

This document contains a description of industry good practices and recommendations produced by the EOFDM WGB based on the risk-based analysis performed and issued by Working Group A (WGA). This document describes the precursors for the four main risk areas identified by WGA:

CICTT aviation occurrence	**Commission Regulation Delegation (EU) 2020/2034**
runway excursion (RE)	excursion
loss of control in-flight (LOC-I)	aircraft upset
controlled flight into terrain (CFIT)	terrain collision
mid-air collision (MAC)	airborne collision

As regards the operators represented in the EOFDM forum, there are safety issues that affect all of them, but also some specific issues that affect some operators in particular. This document collects the experience from all the members in order to create the precursors that will allow each operator to monitor and detect trends that may lead to undesirable situations.

Each fleet has its own capabilities in terms of parameters recorded on board. It is the goal of WGB to make use of the parameters that are normally available in the mandatory flight data recorder (FDR) so that the maximum number of operators can implement the monitoring of precursors described in this document. Depending on the aircraft generation and the on-board recording equipment, there is the possibility to customise the data frame so that the recorded data can be adapted to the solutions proposed in this document. This is one option recommended to be explored by the operators whose fleets have this capability.

In addition, some of the precursors described in this document may require external sources of data to provide additional contextual information, e.g. weather information, runway data or flight management system (FMS) inputs and calculations.

[1] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (OJ L 296, 25.10.2012, p. 1) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1585563757916&uri=CELEX:32012R0965).

Since the EOFDM forum is a voluntary and independent safety initiative, this document should be considered as industry good practices, which the European Union Aviation Safety Agency (EASA) promotes actively, and not as an alternative to any applicable regulatory requirement.

All the good practices documentation from the EOFDM forum is available on the EASA website at https://www.easa.europa.eu/easa-and-you/safety-management/safety-promotion/european-operators-flight-data-monitoring-eofdm-forum.

Some complementary material to the current document can be found in the EOFDM WGC – Flight data monitoring, analysis techniques and principles. This document provides industry good practice regarding common analysis techniques used by flight data monitoring specialists. It also offers some principles to be aware of for successful implementation of these analysis techniques.

If you would like to send your comments or feedback on this document, please write to fdm@easa.europa.eu.

Combining FDM with other sources of information

Occurrence reports are a valuable source of information to complement FDM. As highlighted in the document from WGA, most of the precursors identified and analysed in this document may fall within the scope of Regulation (EU) No 376/2014[2], which defines the Occurrence Reporting Systems for the EASA Member States.

Information sharing between occurrence reporting and FDM is beneficial for both parties. FDM provides information which may complement the occurrence report and may also be used as an alert in case the crew were not aware of a certain event and no report was filed. Similarly, occurrence reporting can help contextualise 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. The integration of reporting data and other sources of data into the FDM analysis is presented with greater detail in the WGC document 'Breaking the silos'[3].

It is always a good practice to compare the results of the events and measurements with sources of information that can validate the results from the FDM. This practice is also a way to detect any errors that may exist in the FDM system and may lead to the improvement of the algorithms.

Precursor description

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

- Summary,
- Rationale,
- Aircraft parameters,
- Measurements and events,

[2] Regulation (EU) No 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation, amending Regulation (EU) No 996/2010 of the European Parliament and of the Council and repealing Directive 2003/42/EC of the European Parliament and of the Council and Commission Regulations (EC) No 1321/2007 and (EC) No 1330/2007 (OJ L 122, 24.4.2014, p. 18) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1585565606627&uri=CELEX:32014R0376).

[3] This document can be found on the EOFDM webpage at https://www.easa.europa.eu/easa-and-you/safety-management/safety-promotion/european-operators-flight-data-monitoring-eofdm-forum.

- Future developments and recommendations,

This structure allows for some degree of versatility for tackling the precursors that are presented in this document. This description is intended to be adapted to the different FDM software tools that exist on the market.

Aircraft parameters

The information recorded by the FDM recorders results from the information provided by the aircraft sensors and systems in the form of parameters. The process of converting binary raw data from the system sensors into engineering units is called ‘decoding process’ and is normally described in a ‘data frame layout’ document.

The recommended parameters included in the description of each precursor are presented in the form of tables as shown in the example below:

Parameter	Type
Altitude standard	Analogue
Eng (*) Thrust lever position	Analogue
Eng (*) N1	Analogue
Main landing gear (L+R)	Discrete
Nose landing gear	Discrete

There are two types of signals to consider:

The **analogue**, indicating the parameters that vary continuously over a certain range and time. They correspond normally to physical quantities such as 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 digitalised 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 its data frame. In the example of the table above, ‘Altitude standard’ directs to the standard barometric altitude recorded. The symbol ‘(*)’ indicates that there is more than one parameter to consider. For example:

- ‘Eng (*) Thrust lever position’ refers to the thrust lever position for each engine of the aircraft
- Similarly, ‘Eng (*) N1’ indicates the N1 fan speed for each engine. For an aircraft with 4 engines, it indicates N11, N12, N13 and N14.

Annex 2 ‘List of recommended parameters’ of this document 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 the fundamental entities for the FDM process and is summarised in tables as shown in the example below:

Search window	Measurements	Event	Event threshold
Take-off	***COUNT*** = Number of seconds the discrete is active	'Master warning during take-off'	Raise event if ***COUNT*** > 1
Take-off — 60 seconds until start of take-off	n/a	'Slat/flap change 60 seconds before take-off'	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 the analysis?	Measurements
How to detect deviations from normal operation?	Event
How to establish the limit to identify the deviations?	Event threshold

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

Measurements: it contains the 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 take-off, ground speed at touchdown, difference between ENG1 N1 and ENG2 N1, etc.

Event/Event threshold: the parameters and measurements can be directly compared to the predefined thresholds which, when exceeded, result in 'events'. These correspond to deviations from normal operations according to the operator's standard operating procedures (SOPs), from the airframe structural limits, or from engine limitations.

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

Future developments and recommendations

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

Methodology for flight data monitoring (FDM)

The representation of the building blocks for an FDM programme is described in Figure 1. The 'aircraft parameters' represent the entry point and correspond to the data collected from the FDM recorders. They are used for measurement calculations, which may be analysed by means of distributions or directly compared with a threshold to produce events. These events may also be directly generated from the aircraft parameters. All these concepts are important and deeply interconnected.

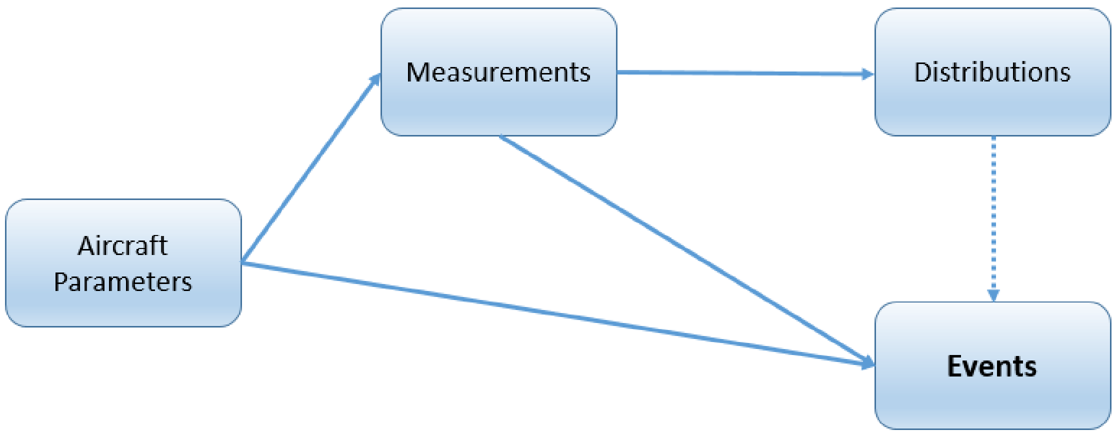


Figure 1 - Basic Entities of the FDM programme

The 'measurements' result from the 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 'exhaust gas temperature (EGT)' is available in different fleets. Normally, its maximum value during take-off is determined, and this corresponds to a measurement performed on the parameter. This identifies the margin to the 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 (standard operating procedures (SOPs)), or external or industry recommendations (if not transposed into SOPs);
3. detection of outliers (using measurement distributions).

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 into service. In order to proactively detect trends, the threshold should be set at a lower value, so that the event becomes a possible precursor to hard landings, ultimately preventing them from occurring. If the FDM software allows, different levels of severity for the event can be included, using thresholds increasingly closer to the hard landing 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.[4]

2. The criteria for unstable approach, maximum sink rate on approach or taxi speed are SOP limitations. They relate to actions or boundaries that are intrinsic to the operation and are considered for the internal risk assessment. The lower threshold can be set at or slightly above or below the SOP value, depending on whether very small exceedances are acceptable or is preferred to be conservative. Thresholds for higher severity events can be set considering the internal risk assessment of 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 normal 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. One 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 whether occurrences subject to mandatory reporting are being detected by the FDM programme.

The Best Practices presented in this document are the result of the considerable input from the WGB members, and the proposed thresholds that are valid for one operator may not be appropriate for others with different types of operations. It is up to each operator to find the values that make sense from a safety perspective.

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

[4] Setting the threshold at a lower value than the structural limit does not prevent the events with higher thresholds that impact on the continuous airworthiness from being detected and properly forwarded to the relevant area within the operator.

RUNWAY EXCURSION (RE)

Runway excursion (RE) is defined in the document 'Aviation Occurrence Categories'[5] developed by the CAST/ICAO Common Taxonomy Team.

Each recommendation identified by Working Group A (WGA) corresponds to a possible precursor for a *runway excursion* incident or accident. This chapter presents the algorithms proposed by Working Group B (WGB) to address each of the recommendations identified.

Some of the precursors for runway excursions require or benefit from the use of information not typically available in flight data. An example is the value of the several V speeds (V1, V2, VR). If possible, the values used by the crew should be compared to a second independent calculation (for example, by replicating the calculation during data analysis or using the values which are automatically calculated by the FMS or EFB). This comparison helps detecting and eliminating errors introduced by the crew.

The following sources, if available, may be integrated in the analysis of flight data to increase the reliability of the detections:

- **electronic flight bag (EFB) database:** provides information on the calculations for the performance parameters; it allows the FDM software to compare the recorded data (manually inserted) with the EFB calculation and detect any possible insertion errors.
- **runway information database:** contains information about the length of runways, threshold positions, and other supporting information not only for this type of occurrence but also for others that are addressed in this document.
- **weather database:** contains information about the weather conditions for the flight: all related information, meteorological terminal air reports (METARs), automatic terminal information service (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.

[5] The document can be found at http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf.

RE01 — Engine power changes during take-off

Summary

Develop means to detect engine power changes during take-off that may lead to a runway excursion.

Rationale

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

Aircraft parameters

Parameter	Type
Eng (*) Thrust lever position	Analogue
Heading true	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off + Initial climb	***DeltaTLA*** = TLA – TLA(– 1) (Note 1)	'Thrust lever increase during take-off roll or climb'	Raise event if ***DeltaTLA*** > 0
Take-off	***DeltaTLA*** = TLA – TLA(– 1) (Note 1)	'Thrust lever decrease during take-off'	Raise event if ***DeltaTLA*** < 0

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 a clear indication of the parameter trend.

Note 2: Runway heading must be obtained from external sources. Some margin may be incorporated into both headings.

Note for EASA SIB No.: 2016-02R1

SIB No.: 2016-02R1 addresses the subject of 'Use of Erroneous Parameters at Take-off'. It recommends using the current document from WGB, particularly RE01. When the SIB was published, it was based on Rev3 of the WGB document where precursor RE01 was named '**Incorrect performance calculation**'. The current revision renames RE01 to '**Engine power changes during take-off'** to address the engine power change precursors and uses RE14 to address the incorrect input performance data, in which the temperature input is addressed. For the sake of completeness, what was addressed in Rev3 of RE01, is now covered by RE01 and RE14.

RE02 — Inappropriate aircraft configuration

Summary

Develop means to detect inappropriate aircraft configuration (lifting devices, pitch trim) which could cause take-off and landing performance problems; not all aircraft are equipped with take-off configuration warning systems and some of these systems cannot detect all types of configuration errors.

Rationale

The events proposed for dealing with this precursor are presented in the list below. Any one of these occurrences may generate a warning by itself during take-off depending on the fleet. Splitting all possible causes into individual events allows for a direct evaluation of which misconfiguration was present during the take-off and possibly the cause of any occurrence during this flight phase. The objective of this list is to apply to a broader scope of fleets. It is also important to note that it not only identifies conditions that are not allowed, but also include those that are permitted but are changed during the take-off run, which correspond to unsafe conditions.

- master warning triggered,
- slat/flap configuration out of take-off limits or the occurrence of any changes,
- auto brakes not selected to the maximum,
- spoilers armed (1) and at least one is out,
- pitch trim out of take-off limits or any displacement,
- brake temperature overheat,
- sidestick not in the take-off configuration (1)(2),
- Thrust reversers unlocked or fault (1)
- Gust lock (1)

(1) Dependent on the aircraft type.
(2) This condition should be adapted to the specific aircraft type and SOPs. The dual input defined in “RE16 – Aircraft handling” and “LOC30 – Abnormal flight control inputs“ should also be considered here.

Other than the aircraft configuration, all the changes during the Taxi flight phase can be monitored by those operators for which this is significant according to their SOPs.

Aircraft parameters

Parameter	Type
Master warning	Discrete
Brake (*) temperature	Analogue
Autobrake selection	Discrete
Ground (*) spoiler out	Discrete
Pitch trim position	Analogue
Flap/slat lever position	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***COUNT*** = Number of seconds discrete is active	'Master warning during take-off'	Raise event if ***COUNT*** > 1 (Note 1)
Take-off	***MaxBrakeTemp*** = Maximum brake temperature	'High brake temperature during take-off'	Raise event if ***MaxBrakeTemp*** > threshold (Note 1)
Take-off	***CurrConf*** = Current slat/flap configuration	'Slat/flap configuration out of take-off limits'	Raise event if ***CurrConf*** ≠ threshold (Note 2)
Take-off	n/a	'Autobrakes not in maximum'	Raise event if autobrake selection is not in maximum during take-off
Take-off	n/a	'Spoilers not armed'	Raise event if spoilers are not armed during take-off
Take-off	***COUNT*** = Number of seconds discrete is active	'Spoiler out during take-off'	Raise event if ***COUNT*** > 1 (Notes 1 and 3)
Take-off	***TO_TrimPos*** = Take-off trim position	'Pitch trim out of take-off limits'	Raise event if ***CurrStabPos*** ≠ threshold (Note 2)
Take-off	***TO_TrimPos*** = Take-off trim position (Note 4)	'Pitch trim displaced during take-off'	Raise event if ***CurrStabPos*** ≠ ***TO_TrimPos*** during take-off
Take-off	***COUNT*** = Number of seconds discrete is active	'Side-stick fault'	Raise event if ***COUNT*** > 1 (Notes 1 and 5)
Take-off	***TO_Config*** = Take-off slat/flap configuration (Note 6)	'Slat/flap change during take-off'	Raise event if ***CurrConf*** ≠ ***TO_Config***
Immediately after lift-off (Note 7)	Maximum pitch trim surface displacement	'Significant Trim Change after take-off'	Maximum pitch trim surface displacement > Threshold
Take-off — 60 seconds until start of take-off	n/a	'Slat/flap change 60 seconds before take-off'	Raise event 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 take-off.

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 pitch trim position parameter when the take-off starts. The value is stored to be compared with the pitch trim position parameter during the take-off run. Any difference indicates that there was a displacement

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

Note 6: Saving the configuration position at the beginning of take-off. The same reasoning as for Note 4. Alternatively, this event can be detected using the flap/slat lever position. Any movement during take-off can be detected and the corresponding event produced.

Note 7: Depending on the fleet and operation, the typical displacement of the surfaces can be analysed from historical data. This allows to assess the normal displacement and the search window which should be used to extract the measurement and event.

RE03 — Monitoring the centre-of-gravity (CG) position

Summary

Develop means to detect CG out of limits on take-off or not consistent with the pitch trim settings.

Rationale

The CG position and its misplacement are addressed in more detail in the loss of control in-flight (LOC-I) chapter of this document (see LOC08 'Centre of gravity (CG) out of limits' for a full description).

While for LOC-I 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 aircraft.

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 forward limit,
- possible trim error.

The full description is available in LOC08.

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 the elevator surfaces.

Rationale

The driver for this precursor determination is the FAA Safety Alert for Operators (SAFO 01001) and the EASA Safety Information Bulletin (SIB) 2010-28 'Possible effects of Thickened Anti-icing Fluids on Take-off Rotation for Airplanes with Unpowered Elevator Controls' (link).

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

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

- control column force high,
- control column stiffness high,
- elevator and control surface mismatch.

The full description of these events can be found in the 'Loss of control in-flight' chapter.

RE05 — Slow acceleration

Summary

Develop means to measure the acceleration during the take-off roll and to detect abnormal values, taking into account the various factors that affect the take-off performance.

Rationale

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

One possible approach to detect reduced acceleration on take-off (which may include cases of incorrect FMS inputs) is to build a statistical regression model using historical data, which will hopefully provide 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 take-off is affected by several factors including weight, power settings, temperature, aerodrome altitude, flap settings, etc. Contrary to some other take-off and landing performance reference values (like V_1, V_2, V_R or V_{REF}), the expected longitudinal acceleration on take-off 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 mentioned 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 V_{REF} using the recorded flap settings and aircraft weight; the instantaneous airspeed is then compared against this value.

Aircraft parameters

Parameter	Type
Altitude standard	Analogue
Gross weight (GW) (Note 1)	Analogue
Static air temperature (SAT) (Note 2)	Analogue
Eng (*) engine pressure ratio (EPR) (Note 3)	Analogue
Flap/slat lever position	Analogue
Acceleration longitudinal	Analogue

Note 1: Since 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’ (TAT).

Note 3: Alternatively use ‘Eng (*) N1’ to have one assessment of the engine thrust.

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***Weight_80KT*** = Gross weight @ 80 kt ***PALT_80KT*** = Altitude standard @ 80 kt ***SAT_80KT*** = Static air temperature @ 80 kt ***EPR_80KT*** = Engine pressure ratio @ 80 kt ***FLAP_80KT*** = Surface configuration @ 80 kt ***LONG_80KT*** = Longitudinal acceleration @ 80 kt (Note 2)	‘Longitudinal acceleration prediction mismatch’	Raise event if ***LONG_80KT – PRED_LONG_80KT*** > threshold (Notes 1 and 3)

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

Note 2: The best speed to be used as a reference for the 80-kt value extraction is the ground speed. It should be preferred to any speed derived from barometric pressures, which are less stable during take-off.

Note 3: The value of PRED_LONG_80KT refers to the predicted acceleration at the speed of 80 kt 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, basic empty weight (BEW) or take-off technique).

The measurement of the 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 80 kt. 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 the 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 triggered to allow additional investigation and validation. This should enable understanding of the causes.

A sample of the results, based on an 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

Additional notes on RE05

To illustrate the intended outcome, below we show a possible model that predicts the value of the longitudinal acceleration (LONG) as a function of weight (GW), engine thrust (EPR), atmospheric pressure (ALTSTD), temperature (SAT) and flap configuration (FLAPPOS).

$$LONG80 = c1 * GW80 + c2 * EPR80 + c3 * ALTSTD80 + c4 * SAT80 + c5 * FLAPPOS80)$$

The model inputs and respective coefficients are determined during model construction, usually by multiple linear regression. More or fewer input parameters (predictors) may be necessary to obtain a good working model, and failing to identify a predictor will cripple its performance and will be visible as a variance when validating the model.

The selection of the best instant to collect the observations also influences the model's accuracy and should be subject to testing. From experience, it is recommended to use airspeed as a reference. The value (instant) that will provide the best observations cannot be ascertained without testing. From experience, the observations need to be taken after the initial moments of acceleration and should be taken before achieving V_S, thereby reducing the variability introduced by the increase in induced drag. In the example above, 80kt is used since it represented, in this particular case, a good balance within the requirements. The speed must also be high enough to ensure the aircraft is not taxiing.

The graph below is a simplified representation of the drag components during take-off. Parasitic drag is always present as long as there is motion, and it is primarily linear with airspeed during take-off. Induced drag becomes relevant as lift increases. It varies quickly with airspeed at low speeds, and it may present some non-linear characteristics. For these reasons, it is preferable to create a model of the aircraft acceleration using observations at an instant when induced drag is still not significant. Not following this recommendation does not preclude a reliable model from being created though.

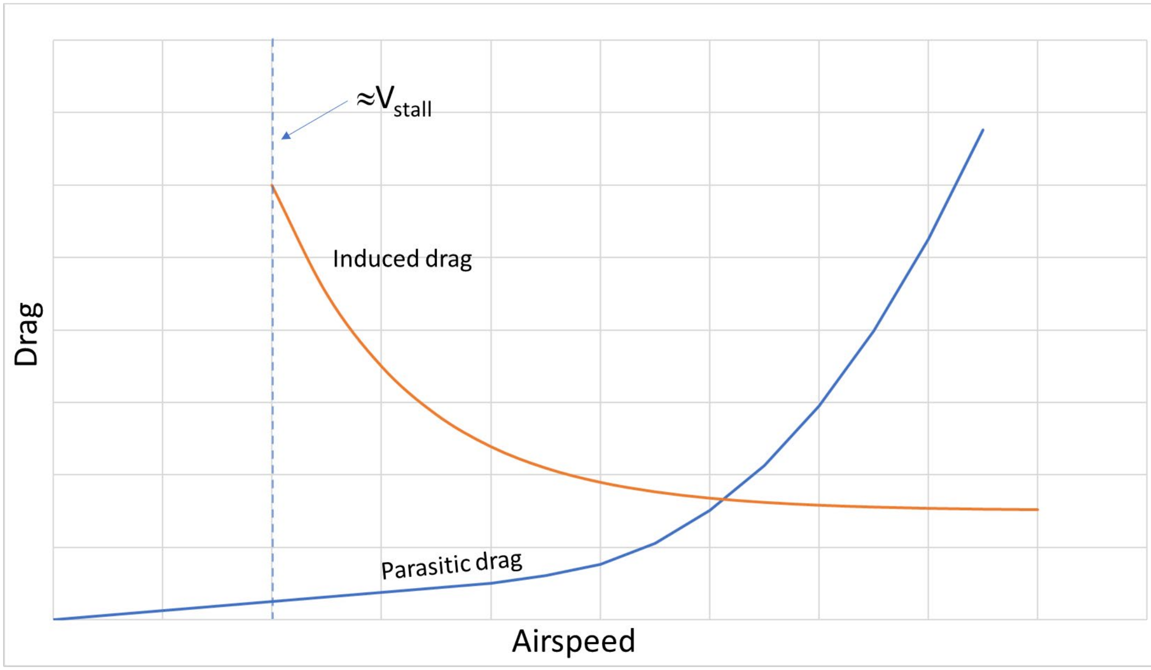


Figure 2 - Drag / Airspeed during take-off run

Plotting longitudinal acceleration as a function of time results in the graph below. Although the general shape is reasonably consistent, the values of the observed acceleration vary significantly, even for a specific aircraft type. As previously mentioned, factors that may influence acceleration must be tested to determine their influence on the model.

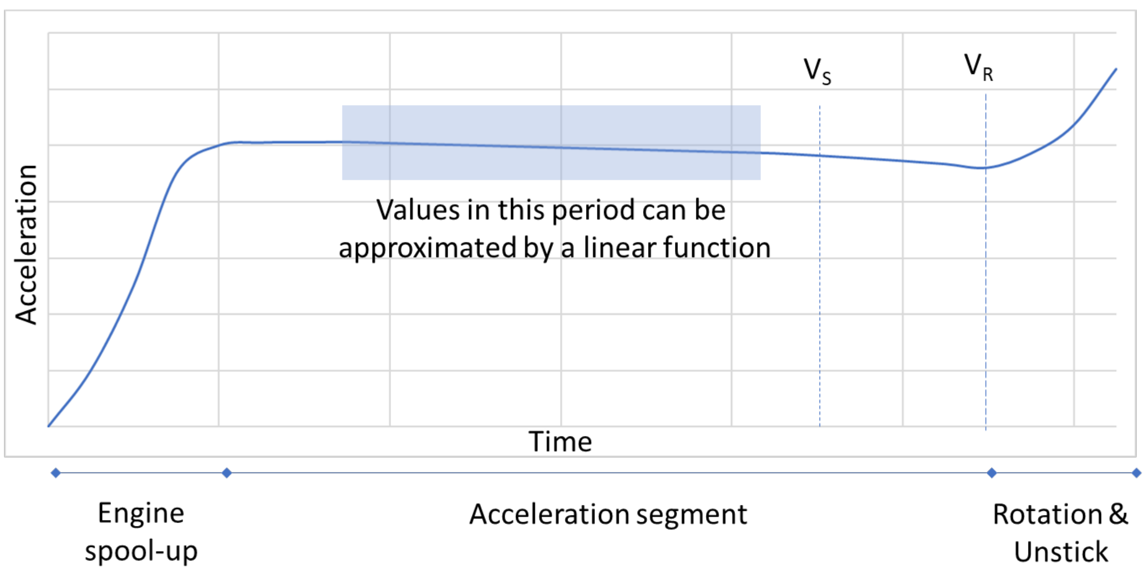


Figure 3 - Acceleration segment

Future developments and recommendations

Add definitions for events (detected by other means) that can create outliers of the statistical model. For example, a problem in any of the sensors used as source for the model's inputs will result in an incorrect prediction. Detecting possible problems in SAT, weight or EPR parameters may give immediate indications that the prediction is not reliable.

RE06 — Aircraft malfunction

Summary

Develop means to detect aircraft malfunctions which are likely to cause rejected take-offs (RTOs), (e.g. 'master warning' and 'master caution' alerts and airspeed indication disagreements).

Rationale

There are numerous types of aircraft malfunctions that could cause RTOs. In general, these failures are serious enough to trigger a 'master warning' or a '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 highlight the situations that should cause the take-off to be aborted.

The understanding of the actual causes for the 'master warning' or the '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
Take-off	***COUNT*** = Number of seconds discrete is active	'Master warning during take-off'	Raise event if ***COUNT*** > 1
Take-off	***COUNT*** = Number of seconds discrete is active	'Master caution during take-off'	Raise event if ***COUNT*** > 1

RE07 — Late rotation

Summary

Develop means to detect rotations conducted after V_R or beyond the expected distance (or time) after the start of the take-off roll.

Rationale

This precursor evaluates the time it takes from the point where rotation should start, i.e. when the indicated airspeed (IAS) assumes the value of the rotation speed (VR) and the point of lift-off from the main landing gear (MLG). In case VR is not recorded, it is proposed to create a second measurement, determining the time elapsed from the instant the nose landing gear (NLG) is in the air until the instant MLG is in the air (lift-off). This measurement may be used on the detection of early rotations.

A third measurement to be recorded is the value of IAS when the aircraft unsticks. This may be achieved by using the instant of the aircraft lift-off, i.e. when the MLG is in the AIR state. A high value for this speed may be indicative of a late rotation. On the follow-up of this measurement, it is also proposed to create the event 'High speed at lift-off'.

Aircraft parameters

Parameter	Type
Indicated airspeed (IAS) (Note 1)	Analogue
Rotation speed (V_R)	Analogue
Main landing gear (*)	Discrete
Nose landing gear	Discrete

Note 1: During take-off, the IAS may be unstable and better results may come up from the use of the 'ground speed' (GS) instead of the 'indicated airspeed' (IAS).

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	Delay = IAS when rotation starts - V_R	'Delayed rotation'	Raise event if ***Delay***> threshold (Note 1)
Take-off	***LIFT-OFF_SPEED*** = IAS when the aircraft lifts-off (MLG from GND to AIR)	'High Speed at lift-off'	***LIFT-OFF_SPEED*** > Threshold

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

RE08 — Slow rotation

Summary

Develop means to detect slow rotation.

Rationale

Rotation is defined as starting at the application of the first command with the intent to pitch up and finish at lift-off. The time that elapsed between these two events corresponds to the rotation time.

Special care should be taken when determining the first elevator input. The instant may not be evident to determine from the pitch-up command. In the figure below, one example of pitch command during the take-off roll and lift-off is displayed, highlighting a case where the behaviour of the parameter can lead to erroneous detection of the start of rotation. The algorithm must be robust to avoid this type of erroneous detection.

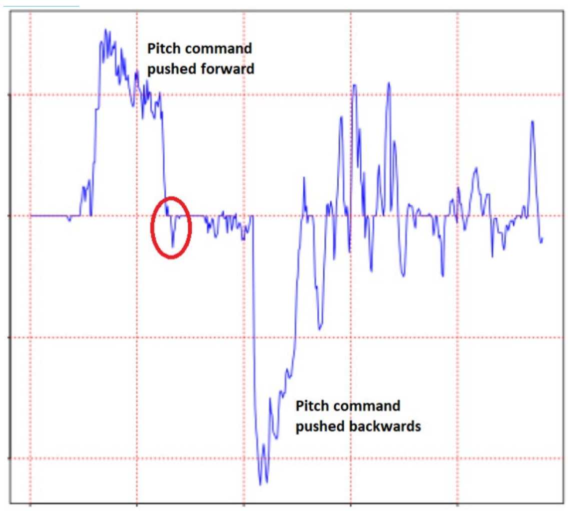


Figure 4 – Illustration of pitch command during take-off run

The maximum pitch rate within the start of rotation and the lift-off will identify the slow rotation when this is a low value, compared either with the target value (typically 3deg/sec) or the normal values for the same runway in similar conditions[6].

Other methods to calculate the maximum pich rate can be used, such as:

- extracting the reference value from a pool of significant flights;
- using the pitch rate parameter if available from the on-board recordings;

This extraction may be facilitated if the Standard Operating Procedure (SOP) indicates that the elevator control should be pushed forward during the take-off roll, so that the exact starting point to look for the pitch rate is accurately determined.

[6] When the pitch rate is a calculated value, it is recommended that a central derivative calculation (using three samples) is performed on the pitch parameter.

Aircraft parameters

Parameter	Type
Pitch command	Analogue
Pitch rate	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off (during rotation)	***TROT1*** = Rotation Time 1 (since the application of the first elevator input to lift-off)	'Long time during lift-off'	Raise event if ***TROT1*** > threshold (Note 1)
Take-off (during rotation)	**MAXPITCHRROT** = Maximum pitch rate during rotation	'Low pitch rate during rotation'	Raise event if ***MAXPITCHRROT*** < threshold (Note 1)
Take-off	***TROT*** = Rotation Time since the NLG is in the AIR until the MLG is in the AIR (Lift-off)	'Excessive time between nose gear and main gear lift-off '	Raise event if ***TROT*** > threshold (Note 1)

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

RE09 — No lift-off

Summary

Develop means to detect late lift-off (in time and/or distance) after rotation or start of the take-off roll.

Rationale

This precursor evaluates the distances run by the aircraft since the application of the take-off power until each of the performance speeds V_1 and V_2 are attained. These distances will be named in this document as DV_1 and DV_2 respectively.

It is proposed to compare each of these distances against the available distances for take-off, accelerate–stop distance available (ASDA) and take-off distance available (TODA) in a way that:

- DV_1 is compared with ASDA,
- DV_2 is compared with TODA.

For this solution to be implemented, an external source of information concerning the runway database is necessary.

Aircraft parameters

Parameter	Type
Ground speed (Note 1)	Analogue
Indicated airspeed (IAS) (Note 2)	Analogue
V_1 (Note 3)	Analogue
V_2 (Note 3)	Analogue

Note 1: To be used to perform the distance calculation by its integration over time. The position (LAT/LONG) can also be used to determine the distance in a less accurate way.

Note 2: During take-off, the 'indicated airspeed' (IAS) may be unstable and better results may come up from the use of the 'ground speed' instead of the IAS.

Note 3: If the performance speeds (V_1 and V_2) are not recorded, other means are valid to access these speeds (See future developments on RE01).

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***DV_1*** = Distance from the application of the take-off power until the speed attains V_1	'ASDA short limit'	Raise event if ***DV_1*** > threshold
Take-off	***DV_2*** = Distance from the application of the take-off power until the speed attains V_2	'TODA short limit'	Raise event if ***DV_2*** > threshold

RE10 — Rejected take-off (RTO)

Summary

Develop means to identify rejected take-off (RTO).

Rationale

A rejected take-off (RTO) is identified by the following conditions, occurring during the take-off flight phase:

- decrease of thrust lever position,
- sudden power reduction,
- brake pressure application,
- decrease of aircraft ground speed.

Some FDM software programs may have difficulty in capturing an RTO as they may not recognise the data as a complete flight and thus classify it accordingly. All software vendors should be approached to see whether it is feasible for an RTO to be recognised as a complete flight without throwing up many 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.

High-speed RTOs are easier to detect and correspond to those cases where the risk is higher to produce a runway excursion (RE) event. A low-speed RTO could be problematic to detect as it can be confused with decelerations before the actual take-off starts.

Aircraft parameters

Parameter	Type
Eng (*) Thrust lever position	Analogue
Eng (*) N1	Analogue
Eng (*) engine pressure ratio (EPR)	Analogue
Ground speed	Analogue
Brake (*) pressure	Analogue
Brake (*) pedal position	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***DeltaTLA*** = TLA – TLA(– 1) ***DeltaGS*** = GS – GS(– 1) ***DeltaPower*** = EngPower – EngPower(– 1) ***BrakeApp*** = Brake application (Notes 1 and 2)	'Rejected take-off (RTO)'	Raise event if ***DeltaTLA*** < 0 OR ***DeltaGS*** < 0 OR ***DeltaPower*** < 0 OR ***BrakeApp***

Note 1: The indication of '(– 1)' stands for the value at the second before. This number can be changed to control the number of false positives or more samples may be considered provided that there is a 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 the brake pedal position or the brake pressure.

RE11 — Runway remaining after rejected take-off

Summary

Develop means to estimate the runway remaining ahead of the aircraft after the start of the rejected take-off (RTO) and to estimate the ground distance spent during the RTO.

Rationale

This precursor is dependent on the generation of an RTO event. The rationale for detecting an RTO is addressed in precursor RE10 'Rejected take-off (RTO)'.

Each time an RTO is detected, the 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 provide this input to the FDM system. Both the coordinates of the point where the RTO was identified and the end of the runway are used to determine *Drem*.

Aircraft parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
When an 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

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 take-offs (RTOs) 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 position	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***COUNT*** = Number of seconds discrete is active	'Ground spoiler deployment'	Raise event if ***COUNT*** > 1 (Note 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	n/a	'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 thrust asymmetry'	Raise event if ***Diff_TLA*** ≠ 0 (Note 3)

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

Note 2: Brake application can be determined either by the brake pressure or the brake pedal position parameters.

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

RE13 — Insufficient deceleration

Summary

Develop means to detect slow deceleration after landing or rejected take-off (RTO), taking into consideration the various factors that affect the landing and the RTO performance.

Rationale

This precursor is to be addressed by calculating the distance from the touchdown point until the aircraft attains the speed of 80 kt during the deceleration run.

High-speed taxiways are to be excluded from this calculation as they represent a different reality. This separation can be achieved by 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 the 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 in a less accurate way.

Measurements and events

Search window	Measurements	Event	Event threshold
Landing	***D_80*** = Distance between touchdown and when the speed is 80 kt during the landing roll	'Insufficient deceleration on landing'	Raise event if ***D_80*** > threshold
Rejected take-off (RTO)	***D_RTO*** = Distance between the RTO detection and when the speed is 30 kt during the landing roll	'Insufficient deceleration on RTO'	Raise event if ***D_RTO*** > 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

RE14 — Incorrect input performance data

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

Erroneous data entry in the flight management computer (FMC) is a typical area of concern when dealing with aircraft performance. Invalid values of OAT[7] can be accepted by some FMC units leading to the wrong calculation of results, such as thrust targets (N1 limit) or the take-off speeds V_1, V_R, and V_2. This case is illustrated in the AAIB serious incident report for a B737-800, C-FWGH, on 21 July 2017. In this serious incident, a wrong OAT insertion in the FMC produced the wrong calculation of the thrust target for take-off, resulting in a low acceleration during the run and invalidating the performance speed 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 air data computer (ADC). Other fleets may rely on different temperature inputs, 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.

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

Aircraft parameters

Parameter	Type
FMS_Temp (Note 1)	Analogue
Static air temperature (SAT)	Analogue

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

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***Delta_Temp =*** FMS_temp – SAT	'Abnormal input temperature'	Raise event if ***Delta_Temp*** > threshold

[7] OAT: outside air temperature. Depending on the parameters available, it can be 'static air temperature' (SAT) or 'total air temperature' (TAT). For the definition of events, 'SAT' will be used.

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

RE15 — Runway remaining at lift-off

Summary

Develop means to estimate the runway remaining ahead of the aircraft at the moment of lift-off and to detect abnormal values.

Rationale

Each time a lift-off is detected, the measurement of the distance from where it happened until the end of the runway is performed. This distance will be designated in this document as *D_LO* (remaining lift-off distance). For this solution to be implemented, the calculation of *D_LO* will rely on the availability of information about the end-of-runway coordinates. This requires that the runway database provide this input to the FDM system. Both the coordinates of the point where the lift-off was detected and the end of the runway are used to determine the remaining distance.

Due to the fact that the calculation of D_LO relies on the position parameters, latitude and longitude, it may constitute a difficulty for those operators for which these parameters are not suitable to perform the distance calculation. In this case, it is recommended that an alternative calculation of the distance of the take-off run is performed by integrating the ground speed from the application of take-off power until the lift-off. This provides the measurement of the ground roll distance during the take-off, which can be compared with the runway length and thus assesses the remaining distance left.

Independently of the way the distance is calculated, this precursor also relies on the availability of a database containing the coordinates and runway length describing the runway layout. If the runway database is not integrated with the FDM software, the comparison of the distances can still be performed by comparison with historical measurements, provided that weight and temperature are taken into account.

Aircraft parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue
Ground speed	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***D_LO*** = Distance from the lift-off detection point to the end of the runway	'Short remaining distance after lift-off'	Raise event if ***D_LO*** < threshold

Take-off	***GroundRollDistance*** = Integration of ground speed from start of take-off until lift-off (Note 1)		

Note 1 – The starting point can be determined either by take-off runway alignment, application of take-off power or any suitable alternative.

RE16 — Aircraft handling

Summary

Develop means to monitor the use of aircraft controls (rudder and nose-wheel steering) and brakes during take-off, rejected take-off (RTO), and landing, and to detect non-standard cases.

In addition, monitor simultaneous control inputs of both flight crew and analyse 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 by using the information on the following:

- brake application during take-off,
- rudder use at low speed,
- no forward side-stick on take-off,
- into-wind aileron,
- braking asymmetry,
- rejected take-off after V_1,
- dual input (Note 1).

Note 1: See LOC30 ‘Abnormal flight control inputs’, which monitors dual input for the whole flight.

Aircraft parameters

Parameter	Type
Brake (*) pedal position	Analogue
Rudder	Analogue
Rudder pedal	Analogue
Pitch command	Analogue
V_1	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***TimeUsingBrakes*** = Total time using brakes during take-off (Note 1)	'Brake application during take-off'	Raise event if ***TimeUsingBrakes*** > threshold
Ground phases Take-off Landing	***TimeUsingRudder*** = Total time using rudder on ground for ground speed < threshold (Notes 3 and 4)	'Rudder use at low speed' (Note 2)	Raise event if ***TimeUsingRudder*** > threshold
Take-off	***SumPitchCmd*** = Sum of pitch command values during take-off run (Note 6)	'No forward pitch command during take-off' (Note 5)	Raise event if ***SumPitchCmd*** < threshold
Take-off Landing (Note 8)	n/a	'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
Take-off	***RTO_Speed*** = Aircraft ground speed when RTO is determined	'Rejected take-off after V_1'	Raise event if ***RTO_Speed*** > V_1 (Note 10)

Note 1: The use of brakes can be determined either by the brake pedal position or the brake pressure 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: The 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 the rudder should be used here. The time for the use of rudder below this peed is summed on the measurement ***TimeUsingRudder***.

Note 4: The use of rudder can be determined either by the rudder surface position parameter (rudder) or the rudder pedal position parameter or both.

Note 5: This event identifies when no forward side-stick or column input is made during the take-off roll (in accordance with the respective fleet's SOP).

Note 6: This calculation can be used to identify the pilot flying (PF) who is the one with a resulting number from this sum (typically a positive number). The pilot-non-flying (PNF) is expected to have a zero result.

Note 7: This event identifies whether a significant into-wind aileron input happens while a crosswind take-off is being performed. The conception of this event is according to the Airbus SOP cited below:

Airbus aircraft (*text from the Airbus Flight Crew Operations Manual*)

For crosswind take-offs, 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 side-stick 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: The take-offs and landings performed in strong crosswind conditions (see Note 7). Crosswinds are addressed in RE17.

Note 9: The necessary pedal position for the left (L) and right (R) pedals that are independently available. The use of the pedal positions directs this event to the inadequate aircraft control. Braking asymmetry will be revisited in RE21 ‘Reverse thrust asymmetry’ with a different perspective, making use of the brake pressure, indicating a possible system malfunction.

Note 10: V_1 may be recorded on the data stream or recovered from an external source. See ‘Future developments and recommendations’ of RE01.

RE17 — Crosswind

Summary

Develop means to estimate the crosswind during take-off, approach and landing, and to detect abnormal values.

Rationale

Crosswinds can be identified using the left (L) and right (R) values of the angle of attack (AoA). When there are strong crosswind conditions, the values of AoA from the left probe are different from those in the right probe and this divergence may be used as one indicator of the existence of crosswinds. On the other hand, in steady conditions, the readouts from both sides are very similar or even the same.

Aircraft parameters

Parameter	Type
Angle of attack (Left and Right)	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off Approach Landing	***DeltaAoA*** = AoA_Left – AoA_Right	'Crosswind'	Raise event if ***ABS(DeltaAoA)*** > threshold

RE18 — Forward thrust asymmetry

Summary

Develop means to identify forward thrust asymmetry during the take-off 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 set threshold.

Aircraft parameters

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

Note 1: Depending on the fleet, the thrust parameter can be the engine pressure ratio (EPR).

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off	***DiffEngN1*** = N1_Eng1 – N1_Eng2 (Note 1)	'Thrust asymmetry'	Raise event if ***ABS(DiffEngN1)*** > threshold

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

RE19 — Steering system malfunction

Summary

Develop means to identify problems with the 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 focuses on three items that are relevant to monitoring:

- detect a steering system failure warning;
- verify whether the steering command corresponds to the heading movements;
- monitor the values of accelerations (normal, lateral and longitudinal).

The first two items can be directly obtained from the data analysis, provided that the relevant parameters are recorded. The third item of the list involves some exploratory work on the measurements of the accelerations to determine the cases where there are normal values for the accelerations during the ground phases so that vibrations and shimming are detected.

Aircraft parameters

Parameter	Type
Acceleration longitudinal	Analogue
Acceleration lateral	Analogue
Acceleration normal	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 be increased to control the number of false positives.

Note 2: It is expected that there is a direct relationship 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 (rms) of the accelerations Lateral (LATG), Longitudinal (LONG) and Normal (VERTG) during a given time interval (sliding window).

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

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 by using the three-axis accelerations to detect abnormal values during the flight phases when the aircraft is still on the ground. The proposal is to perform the analysis of the rms component of these signals during a relevant time interval of the ground path or, alternatively, to determine their corresponding spectrum in order to perform a frequency analysis of each acceleration as the aircraft moves on ground, which will allow to determine the abnormal frequencies.

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 runway or any abnormal vibration may be due to any other component of the landing gear.

RE20 — Lateral deviation

Summary

Develop means to identify excessive lateral deviations or oscillations during take-off, rejected take-off (RTO) and landing, taking into consideration the runway width.

Rationale

Excessive lateral deviation is to be evaluated by the use of the rudder pedal position close to full deflection when the airspeed is high enough for the rudder to be effective. The combination of airspeed and high deflection will be monitored and a corresponding event proposed to address this precursor.

Aircraft parameters

Parameter	Type
Rudder pedal	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Ground flight phase Take-off Landing	n/a	'High rudder deflection on ground'	Raise event if ***RudderPedal*** > Threshold for ***GS*** > Threshold

RE21 — Reverse thrust asymmetry

Summary

Develop means to identify reverse thrust asymmetry during a rejected take-off (RTO) or landing.

Rationale

Same rationale as for RE18 'Forward thrust asymmetry', but having both reversers deployed.

Aircraft parameters

Parameter	Type
Reverser (*) deployed	Discrete
Eng (*) N1 (Note 1)	Analogue

Note 1: Depending on the fleet, the thrust parameter can be the engine pressure ratio (EPR).

Measurements and events

Search window	Measurements	Event	Event threshold
Landing Rejected take-off (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 the engine pressure ratio (EPR).

RE22 — Braking asymmetry

Summary

Develop means to identify braking asymmetry during a rejected take-off (RTO) or landing (possibly in combination with RE12 'Inadequate use of stopping devices').

Rationale

The event identified in this section focuses on the brake pressure, which may indicate a system malfunction. Braking asymmetry is addressed in RE16 'Aircraft handling' making use of the pedal inputs, possibly indicating in this way 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, gaining insight into the braking system may be necessary to assess the different braking pressure circuits, so that the left-side and the right-side parameters can be captured in a proper way.

RE23 — Poor visibility

Summary

Develop means to estimate the visibility conditions from meteorological terminal air report (METAR) data, time of the day and runway lighting, so that this data can be used in conjunction with the FDM data.

Rationale

To comply with this precursor, it is necessary for the FDM system to have access to external weather data. The link with other sources of information is already addressed in RE01 and it is of great importance to complement the information provided by the flight data itself.

The information included in the METAR that is issued at a time closest to the one when the take-off or landing is being performed, is the most reliable source of information as regards visibility.

Future developments and recommendations

Integrate other sources of information (in this case, weather data) in the FDM system.
See 'Future developments and recommendations' of RE01.

RE24 — Tailwind

Summary

Develop means to estimate the tailwind during take-off, approach and landing.

Rationale

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

For fleets that are equipped with inertial and air data (barometric) systems, the values for the wind vector are computed on board 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 an analyst can have for wind component 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 studied.

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
Take-off Approach Landing	***Tailwind*** = Determined geometrically from recorded values (Note 1)	'Excessive tailwind'	Raise event if ***Tailwind*** > Threshold

Note 1: Depending on the data frame capabilities, there are different ways to determine the tailwind value:

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 the *Tailwind* depending on the signal.

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

$$WindComponent > 0 => HeadWind = WindComponent$$

For this precursor, only the first equation is used to derive the value of the *Tailwind*.

Case 2: Wind speed and wind direction NOT recorded

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

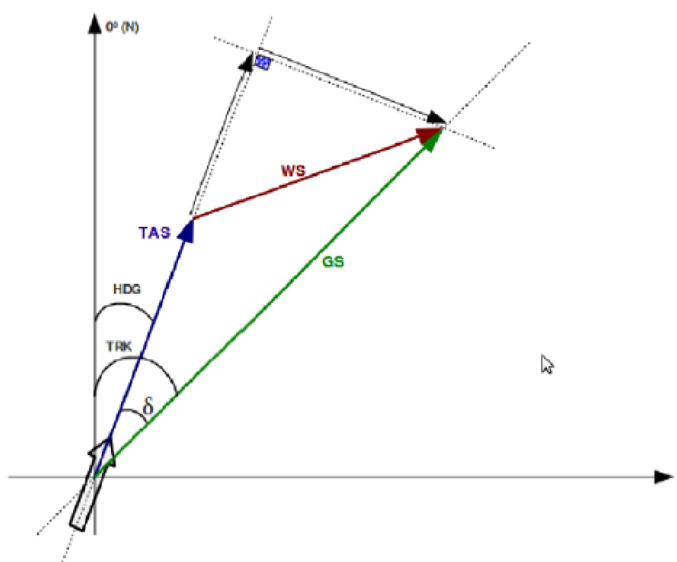


Figure 5 - Velocity triangle

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:

$$WindComponent = TrueAirspeed - GroundSpeed$$

RE25 — Excessive engine power

Summary

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

Rationale

This precursor is closely related to RE32 'Excessive aircraft energy at touchdown'. While in RE32 the proposal is to determine the kinetic energy (Ek) of the aircraft during touchdown in order to assess its high-energy condition, in this precursor other solutions are proposed to identify possible improper power management before touchdown or high speed at touchdown. Also, in RE26 'Unstable approach', the speed is monitored so that it does not divert from V_{REF}.

In detail, the following points are covered in this precursor:

- high speed at touchdown,
- thrust lever higher than IDLE before touchdown,
- take-off power set before aligning to the runway.

Aircraft parameters

Parameter	Type
Ground speed	Analogue
Eng (*) Thrust lever position	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 Touchdown	***Vtd*** = Ground speed at touchdown (TD)	'High speed at TD'	Raise event if ***Vtd*** > Threshold
Landing Touchdown	n/a	'TLA greater than IDLE before TD'	Raise event if ***TLA(*)*** > IDLE
Approach Landing Touchdown	***T_align*** (Note 1)	'Take-off (TO) power applied before runway (RWY) alignment at landing'	Raise event if ***TO power applied***

Taxi	**TLA_POS** = Thrust lever angle position	"Excessive power during taxi" (Note 2)	Raise event if **TLA_POS** > Threshold

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

Note 2: Alternatively, or in complement, the ground speed can be monitored during the taxi phases, in particular to detect the speed exceedances.

RE26 — Unstable approach

Summary

Develop means to identify and quantify unstable approaches, regardless of whether they result in go-around manoeuvres.

Rationale

European aviation regulations require (for CAT operators) or expect all approaches to be flown as stabilised. An approach is classified as unstable if one or more of the predefined stabilisation conditions are not met. Unstable approaches are common contributors to accidents in the landing phase, such as runway excursions, tail strikes, bounced and hard landings.

In AMC1 CAT.OP.MPA.115(a), EASA lists the criteria which should be satisfied in operations with aeroplanes. Aircraft stabilisation tolerances are to be defined by each operator to accommodate its specific requirements; for example, in particular special approach procedures. This process should be done based on the analysis of the risk associated with the combination of the type of operation, the tolerances used and the practicality of such set of conditions. The stabilisation criteria and tolerances must be reflected in the operator's operations manual. Note that AMC are non-binding, allowing the operator to deviate from them by using alternative means to comply with the implementing rules, subject to acceptance by the national authority and EASA.

The output of the monitoring should allow the identification of the criteria that were not satisfied. It is also recommended to output the lowest altitude above airfield level (AAL) where this happened. It is also good practice to store the measurements of all the margins to the criteria for all the approaches regardless of whether the approach was stable or not (e.g. maximum speed during approach, maximum and minimum sink rate, maximum deviation from localiser / glideslope).

Aircraft parameters

Parameter	Type
Localiser deviation	Analogue
Glideslope deviation	Analogue
Flap / Slat lever position	Analogue
Speed brake lever position	Analogue
Indicated airspeed	Analogue
Landing gears position	Discrete
Vertical speed	Analogue
Pitch	Analogue
Roll	Analogue
Engine thrust	Analogue
Autopilot status	Discrete
Autothrust status	Discrete

Altitude (AAL)	Analogue

Note: This list is not exhaustive and may vary depending on the criteria being verified.

Measurements and events

Search window	Measurements	Event	Event threshold
From the applicable SOP altitude to touchdown or a go-around is initiated	Maximum/Minimum values for applicable parameters (e.g. speeds, flaps, landing gear)	'Unstable approach'	Raise event if any monitoring condition is not met (Note 1)
From the applicable SOP altitude to touchdown or a go-around is initiated	Lowest altitude at which all the stable conditions remain satisfied		
From the applicable SOP altitude to touchdown or a go-around is initiated	Number of criteria not satisfied	(Note 2)	(Note 2)

Note 1: The output of the monitoring should allow the identification of the criteria that were not satisfied.
Note 2: This measurement can be used to rate the event in terms of severity.

Additional information — Data4Safety directed study

The Data4Safety (D4S) voluntary partnership published in April 2022 one directed study entitled 'Guidance For Identifying Unstable Approach With Flight Data'. One of the goals of this study is to support the identification of common criteria for the analysis of flight data at an industry-wide level. To achieve this goal, this study analysed a set of 1.4 million flights corresponding to more than 1000 aircraft from 8 different fleets. While this is one extremely important source of information based on the analysis of the data from different operators, it can be used at the organisational level to provide some inputs to improve the way each operator monitors the unstable approaches.

RE27 — High energy over the threshold

Summary

Develop means to estimate the 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 data frame capability in terms of existence and accuracy of the necessary parameters. It is for the operator to test the capability of the algorithms proposed on its fleet and decide based on this evidence which one can be more reliable.

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

- the ILS signal,
- the position parameters (Latitude/Longitude).

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

	Positive	**Negative**
ILS	No need for external data	Bad results when the ILS signal is unstable Only applies to runways with ILS approach Elaborated algorithm
Position	Applies to all aerodromes/runways Simple algorithm	Need for 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 height is identified as a measurement of the aircraft energy at this point.

Aircraft parameters

Parameter	**Type**
Radio altitude	Analogue
Glideslope 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 made by the two proposed methods, i.e. using the ILS signal and the position parameters.

Note 2: The threshold referred to here is the runway threshold and should not be confused with the its general definition used in this document to refer to a value that triggers one event (right column of all 'Measurements' and 'Event' tables).

Case 1: Using the ILS signal

The threshold height can be computed geometrically provided that there is an ILS stable signal (glideslope). This method is based on the geometry as shown in the figure below[8].

[8] 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.

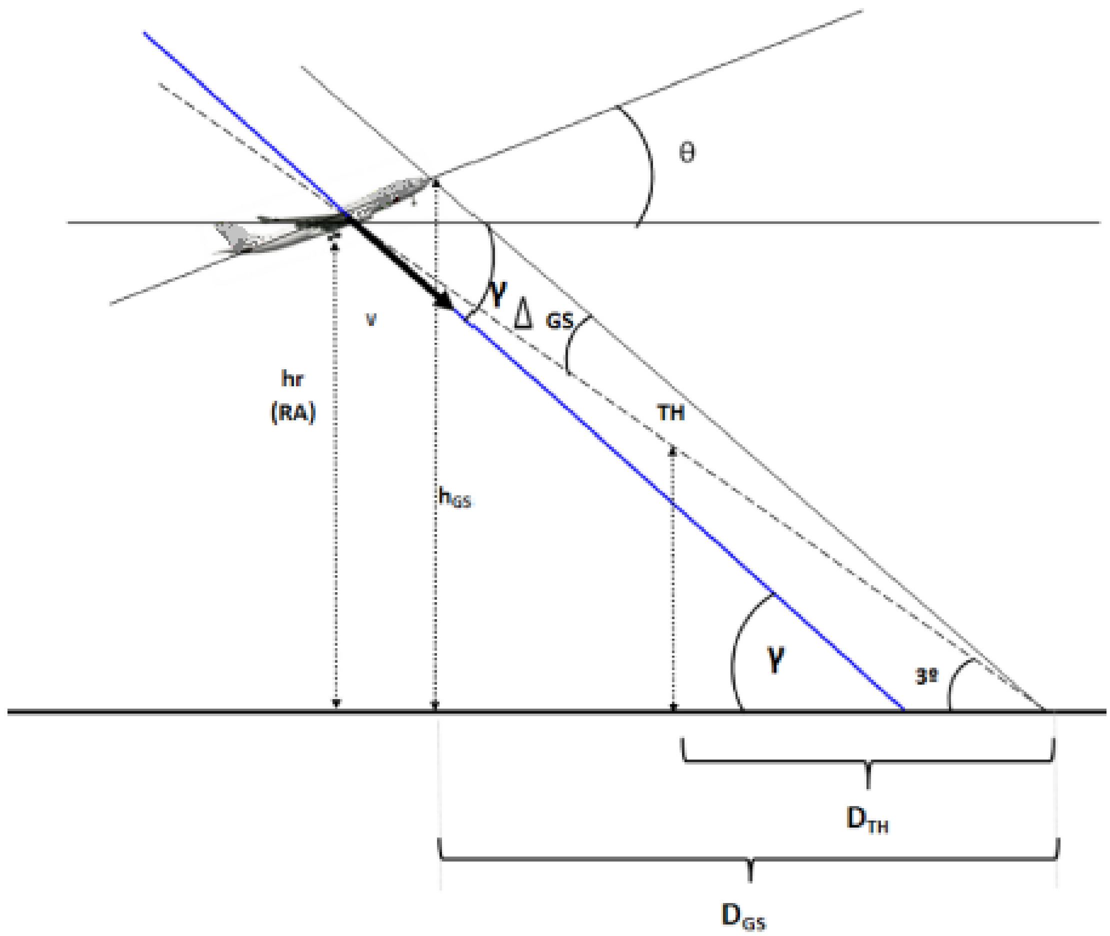


Figure 6 - Threshold crossing determination using ILS

In Figure 6:

D_{TH} — the distance on the runway between the glideslope antenna and the point corresponding to the threshold of 50 ft, i.e. for a 3-degree slope the distance is: D_{TH} = 50/tan(3deg) = 954 ft (in this formula, any slope angle other than 3deg can be used).

The following calculations assume that the radio altitude is measuring the height between the ground and the main landing gear (MLG) point closest to the ground. This is true provided that *PITCH* < 6deg due to the calibration process of the radio altimeter during its installation (Airbus fleets).

For the next figure, the values of V_{GS} and L_{GS} 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-degree slope, the calculations below provide the value of ***HeightOnThreshold***:

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

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

$$HeightOnThreshold = RALT_{TH}$$

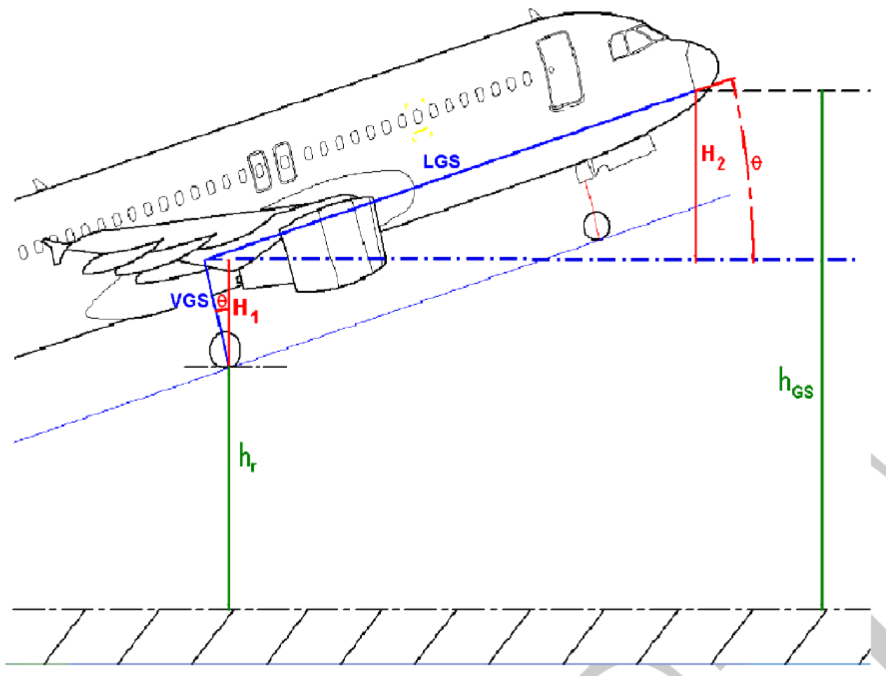


Figure 7 - Treshold crossing geometry

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 an 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**).

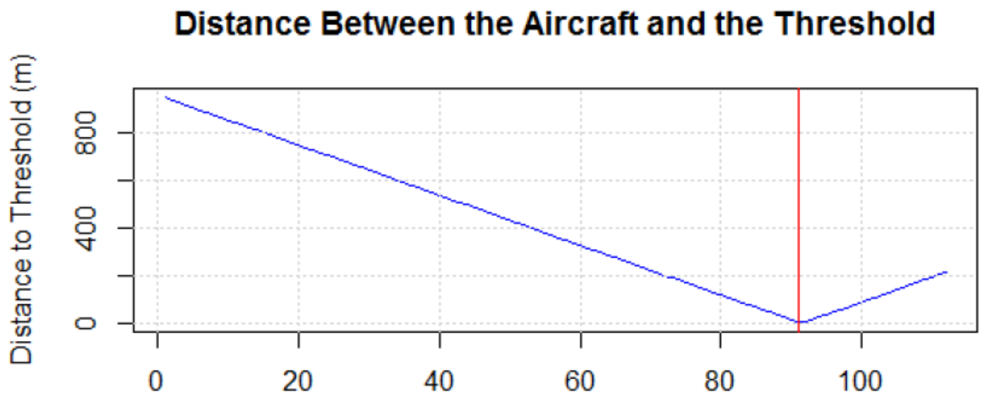


Figure 8 - Threshold crossing determination using positions

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

$$HeightOnThreshold = RALT_{TH}$$

Future developments and recommendations

The calculations proposed in Case 2 rely on the information about the correct coordinates of the runway threshold. This value must be provided by an external runway database.

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.

RE28 — Long flare

Summary

Develop means to detect the start of the flare and to estimate the ground distance the aircraft has 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 respond to for 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 a 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 for the EOFDM members 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 50 ft above aerodrome level (AAL) to the touchdown point.

Aircraft parameters

Parameter	Type
Radio altitude	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Landing	***Time_Flare*** = Time between 50 ft AAL and touchdown point (Note 1)	‘Long flare’	Raise event if ***Time_Flare*** > 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 the ‘Rationale’.

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 'Unstable approach'. The distance between this point and the touchdown point will be defined as ***AirDistance*** and it will be used in this precursor to determine the length of the landing.

Aircraft parameters

Parameter	Type
Radio altitude	Analogue
Glideslope deviation	Analogue
Latitude	Analogue
Longitude	Analogue
Main landing gear (*)	Discrete
Nose landing gear	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
Landing	***AirDistance*** = Distance between the runway threshold crossing and the touchdown point.	'Deep landing'	Raise event if ***AirDistance*** > Threshold
Landing	**DROT_TIME** = De-rotation time. Elapsed time between the MLG in on ground and the NG is on ground (Note 1)	"High time to de-rotation"	Raise event if **DROT_TIME** > Threshold

Note 1: During the conference SAFE 360 / 2022 (link), the presentation from Qantas Link on Day 3 (dedicated to FDM), identified a slow de-rotation of the aircraft as a possible activation of the Runway Overrun Protection System (ROPS).

RE30 — Abnormal runway contact (ARC)

Summary

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

Rationale

Abnormal runway contact (ARC) may be the result of some of the precursors already addressed in this document; among these, unstable approach, aircraft handling and other contributing factors may result in an abnormal contact with the runway. Within the scope of ARC, the following situations are to be studied in this section:

- bounced landing,
- bounced landing with ground spoiler deployment,
- landing with roll[9],
- nose landing,
- lateral acceleration at landing,
- pitch high at touchdown,
- hard landing,
- tail strike.

Notes on tail strike

A tail strike happens when excessive pitch attitude provokes the contact of the tail of the aircraft with the runway. It can happen during take-off or landing and statistics from the industry indicate that most of the tail strikes happen during landing. The number of occurrences during this flight phase is about 2.5 times greater than those that happen at take-off.

In both situations, the pitch-up angle is a fairly good indicator of the imminence of a tail strike. Aircraft manufacturers normally provide 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 MLG 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.

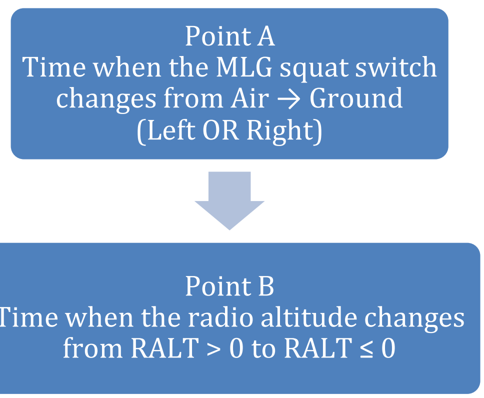
For both take-off and landing, the most stringent limits for the pitch angle are those for the MLG fully compressed and the published values by the manufacturers for this case should be used as a reference for the thresholds to adopt. This pitch angle indicates the value for which there is a tail strike with the MLG fully compressed. This is an extreme case and FDM by definition has the goal to extract from the data the information to avoid these cases that may result in an incident or accident. Having this in mind, and the fact that there is no *a priori* knowledge whether the MLG is fully compressed, the value for the threshold should be selected by reducing a convenient number of degrees to the published value of the pitch angle for the MLG fully compressed[10]. In this way, the trend to a tail strike can be detected by the FDM program. The runway slope and normal

[9] In extreme situations, landing with roll may lead to wingtip strike.

[10] Studies have to be conducted by the operators for each fleet in order to determine which value is the most appropriate.

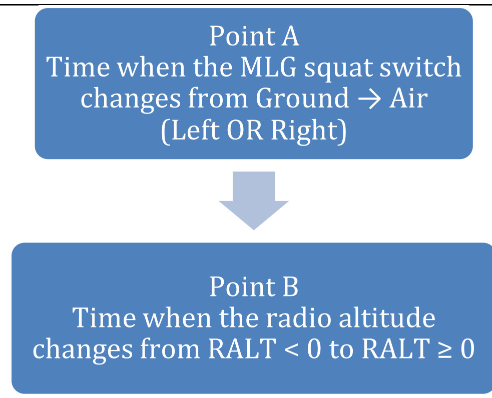
acceleration at landing may aggravate the imminence of the tail strike incident and operators should be alert to these factors in their operations.

In order to evaluate how likely it is for the aircraft to suffer a tail strike, the pitch angle has to be measured with the highest possible accuracy both at the lift-off and touchdown points. The methodology proposed to estimate these points is the following:

Touchdown point	Considering that the MLG squat 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[11], the methodology proposed should make use of these features and perform the calculations of two points in the following way:  It is expected that Point B < Point A. In this case, Point B should be considered as the touchdown point. Otherwise, if Point B > Point A, an 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 the EOFDM Conference 2016, named '**Landing Trajectory and Touchdown Point Reconstruction**'[12].
Lift-off point	Having in mind the same premises used for the touchdown point extraction, the lift-off can be obtained from the MLG squat switch as a rough measurement and fine-tuned with radio altitude measurements in the following way:

[11] This is true until a limit of the pitch-up specific for each fleet. Above this limit, this methodology may introduce an error in the determination of the touchdown point.

[12] This presentation is available in the 'EVENT PROCEEDINGS' section, available at https://www.easa.europa.eu/newsroom-and-events/events/4th-conference-european-operators-flight-data-monitoring-forum-eofdm#group-easa-event-proceedings.

	 It is expected that Point B < Point A. In this case, Point B should be considered as the lift-off point. Otherwise, if Point B > Point A, an error occurred in this process and Point A should be considered as the lift-off point as it represents the most solid observation.

Aircraft parameters

Parameter	Type
Main landing gear (MLG) (*) (Note 1)	Discrete
Nose landing gear	Discrete
Roll	Analogue
Pitch	Analogue
Acceleration normal	Analogue
Acceleration lateral	Analogue
Ground (*) spoiler out	Discrete

Note 1: It is assumed that the signals from the left and the right MLG are separated in the data frame.

Measurements and events

Search window	Measurements	Event	Event threshold
Landing	***COUNT*** = Number of transitions, Air → Ground from main landing gear (MLG) (Note 1)	'Bounced landing' (Notes 2 and 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 the nose landing gear ***TMLG*** = Instant in which there is the transition Air → Ground from the MLG	'Nose landing' (Note 5)	Raise event if ***Tn*** < ***TMLG***
Landing in the vicinity of the touchdown point	***MaxVertAccel*** = Maximum Normal acceleration in the monitoring window (Note 4)	'Hard landing' (Notes 3 and 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 lift-off point	***pitch@lift-off***	'Tail strike low clearance at lift-off'	Raise event if ***pitch@lift-off*** > Threshold
Determine the touchdown point	***pitch@touchdown***	'Tail strike low clearance at touchdown'	Raise event if ***pitch@touchdown*** > Threshold

Note 1: Consider the readings of both left and right sides of the main landing gear (MLG) to produce this count (AND condition).

Note 2: The deployment of the 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 in addition to the recommended 'bounced landing'.

Note 3: The threshold limits to be established for hard landings should be conservative regarding the structural limits so that the events and measurements recommended in this precursor can be used to evaluate the trends. The structural limits are normally used for maintenance purposes if the structural limits are exceeded. In this case, the amount of normal acceleration experienced by the aircraft should be provided to the maintenance staff for them to decide which maintenance action should be performed.

Note 4: The maximum value of normal 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 where this can be a contributing factor (see VT-JGA accident from 13 April 2015 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.

RE31 — Go-around

Summary

Develop means to identify go-arounds and balked landings.

Rationale

A go-around is a complex scenario which can be described in different ways:

1. go-around,
2. aborted approach,
3. aborted landing.

Automation in the go-around phase can be interesting; the go-around mode can give a lot of power which can make the pilot overshoot the required altitude and/or attitude. There is also the possibility that the flight crew may select a different (unexpected) autopilot mode.

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, and the corresponding event generated. When the height starts to increase, it is recommended that additional information for 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:

- take-off/go-around (TOGA) engine power is applied during landing, which is a direct indicator that a go-around is happening.
- a sudden increase in power during landing, even if it is not TOGA, may also be an indicator for a go-around; this may be used together with the height increase.

Note: When a go-around is performed at high altitude, Embraer no longer recommends the use of the go-around mode, but instead the use of the vertical speed mode to prevent high-energy status with high pitch-up. Airbus has also introduced a 'soft' go-around mode.

Aircraft parameters

Parameter	Type
Altitude standard	Analogue
Eng (*) Thrust lever position	Analogue
Eng (*) N1 (Note 1)	Analogue

Note 1: Alternatively, use 'Eng (*) Engine pressure ratio (EPR)' to have an assessment of the engine thrust.

Measurements and events

Search window	Measurements	Event	Event threshold
Landing	***DeltaHeight*** = Height – Height(-1) ***TOGA*** = Take-off go-round power applied to the engines (see Notes 1 and 2)	'Go-around'	Raise event if ***DeltaHeight*** > 0 OR ***TOGA*** (see Note 3)
Go-Around	Height at which the Go-around is initiated (Note 4)		

Note 1: The indication of '(-1)' stands for the value on the second before. This number can be changed 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 when the go-around was initiated may be determined from the instant when the throttle levers were pushed to increase the power (see the Rationale text). It is expected in the sequence of power increase to have a positive pitch rate variation. This can be used to help find the instant when the go-around was initiated. If the pitch rate is the only parameter being used, it can lead to false positives during the flare manoeuvre close to the ground, so it is recommended to use both the pitch rate and the engine power.

Note 4: This can be compared with the lowest height at which stable conditions were identified (measurement in RE26)

RE32 — Excessive energy at touchdown

Summary

Develop means to correctly identify the touchdown instant, to 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) is the predominant source of risk for an overrun. The veer-off risk is assumed to originate more from controllability problems. Therefore, this event is developed having 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 runway excursion/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, etc.).

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 the destination runway used, rendering the event definition extremely difficult to implement.

Alternatively, instead of determining the imminence of 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 touchdown to the landing roll, the complement of the runway remaining.

Under the simplifying assumption that the aircraft decelerates 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 the 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*:

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

Reinserting the expression for *t* in the equation for x, this yields:

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

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

If we assume the reference landing manoeuvre to be flown such that the threshold is crossed at 50 ft height at the approach target speed (V_{APP}), and during the flare the speed is bled off to a reference speed $V_{REF} = V_{APP} - 5$ kt, then the ratio of the actual Ek at TD and the reference TD Ek, 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: V_{REF} being derived from V_{APP}, 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 (V_{APP})	Analogue
Ground speed	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
First WOW	***V_{APP}*** *from the performance data* ***GS*** at touchdown ***Ek ratio*** *calculated from* ***GS*** *and* ***V_{APP}***	'Excess energy at touchdown'	Raise event if ***Ek ratio*** > Threshold

Note 1: The threshold for the 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 the FDM software, this precursor should be redeveloped into a *runway remaining* event.

RE33 — Wrong runway or wrong runway entry point used

Summary

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

Rationale

A wrong runway or a wrong runway entry point chosen by the pilot will lead to a performance mismatch between the FMS inputs and the actual position 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 the performance data is compared with the actual one.

		Actual departure	
		Intersection	Full RWY
Performance data	Intersection	OK	ACCEPTABLE
	Full RWY	ERROR	OK

The mismatch of the runway entry point may lead to two problematic situations: the case where there is more runway available than the planned runway (acceptable), and the opposite case (error). While the first case does not represent an unsafe situation by itself, the second, due to the lack of runway length to perform the take-off roll, may have catastrophic consequences. Due to the fact that there is an error associated with each of the cases and being on the safe or unsafe side is a matter of chance, both cases should be identified as accurately as possible using FDM. In this precursor, it is assumed that there was no wrong input to the FMS and the error was committed when entering the runway.

FMS data input reflects the planned actions[13] 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[14]
- EFB calculations.

The comparison between the runway entry point and the planned entry requires the maximum accuracy of the recorded position (see Annex 1 ‘Accurate position computation’). 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

[13] 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.

[14] These messages, whenever possible, can be collected from the controller–pilot data link communications (CPDLC) system.

vice versa, for direct comparison. This conversion table 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 lift-off'. For all the cases where a short distance is detected, the entry point of the respective runway should be determined so that any incorrect entry point may be identified. This is a work for the analyst on a case-by-case basis.

Aircraft parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue

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)***	'Wrong runway entry point'	Delta DEP > Threshold

Note 1: DEP stands for 'distance entry point'. The 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 runway entry point into the FDM programme. Alternatively, this information can be obtained via the EFB.

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 in RE26 ‘Unstable approach’.

There are some cases though where it is worth performing a deeper analysis, namely if there is a false instrument landing system (ILS) lobe capture. This is valid for both glideslope and localiser parameters. The major problem in this situation is that the recorded deviation 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 on board and different strategies are proposed in this precursor to address this situation.

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

- the flight path angle (FPA), and
- the rate of descent (ROD) or the inertial vertical velocity (IVV).

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

In the case of the localiser, the only option to cross-check the correct positioning of the aircraft is by using the geographical coordinates and comparing this position to the expected one in the localiser beam.

Future developments and recommendations

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

LOSS OF CONTROL IN-FLIGHT (LOC-I)

Loss of control in-flight (LOC-I) is defined in the document 'Aviation Occurrence Categories'[15] developed by the CAST/ICAO Common Taxonomy Team.

Each recommendation identified by Working Group A (WGA) corresponds to a possible precursor for an incident or accident related to LOC-I. This chapter presents the algorithms proposed by Working Group B (WGB) to address each of the recommendations identified.

[15] The document can be accessed at 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 the measurements and events derived from the smoke and fire detectors. Other parameters may indicate an abnormally high value, such as brakes and engine oil temperatures, and act as fire precursors.

Regarding brakes, their use on the ground may be monitored, using the brake pressure and/or the brake pedals position during the taxi flight phase to detect possible excessive break use which may lead to temperature increase and consequently to fire.

The events proposed for dealing with this precursor make use of the discrete signals indicating fire or smoke warnings and the analogue values of temperature measurements for the brakes and the engine oil.

The detection of excessive brake use during ground flight phases can lead to an increase in brake temperature and act as an igniter to this precursor.

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 (*) temperature	Analogue
Eng (*) oil temperature	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)	'Intense brake use during [Taxi IN / Taxi OUT]'	Raise event if ***TimeUsingBrakes*** > Threshold (Note 4)
Aircraft 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: The smoke warning event is, in fact, a set of three events, indicated by an asterisk (*), depending on which smoke warning signal is activated:

- avionics smoke warning,
- cargo smoke warning,
- lavatory smoke warning.

Note 3: The use of the brakes can be determined either by the brake pedals position, the brake pressure or both. In this event, the brake temperature is not considered. Indeed, there is a time delay between the brake use and the rising of the temperature. This measures the immediate action of the brake use.

Note 4: The 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 members of WGB 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 be recorded in the data frame, so that precursors in this area can be tracked.

LOC02 — Pressurisation system malfunction

Summary

Develop means to identify malfunctions of the pressurisation 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 control to manual.

There might be scope for integration with the aircraft health monitoring systems and support for continued airworthiness.

Rationale

The identification of the pressurisation system malfunction can be done by monitoring standard parameters available that can identify the onset of an abnormal condition related to the pressurisation system malfunction. These are recorded parameters and are not limited to those listed below; other aircraft-specific parameters can be added to enhance the monitoring.

This precursor is to be addressed by monitoring:

- the cabin pressure;
- the cabin altitude rate;
- the outflow valve positions for abnormal values;
- the discrete warnings:
  - excessive high differential pressure[16],
  - excessive negative differential pressure,
  - residual excessive pressure.

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

An 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 at 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 the cabin altitude increasing.

[16] Difference between cabin pressure and atmospheric pressure.

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

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 fight	***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 be increased 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 feet per minute (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 position 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 explained 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 the development of an event that detects abnormal values for the outflow valve position.

LOC03 — Pressurisation system misuse

Summary

> Develop means to identify the situations where the pressurisation system is not used correctly.
>
> For example, failure to turn on the bleed pressure after take-off, failure to set the landing pressure altitude, or inadequate use of the manual control mode.

Rationale

The pressure inside the aircraft should be equalised with the exterior pressure before take-off and after landing. Automatic systems make use of the information on 'Altitude standard' and 'cabin altitude' to regulate the outflow valve in order to match the interior and exterior pressures, thereby creating a suitable environment for passengers and crew.

The cabin pressurisation system manages the pressure inside the cabin in four basic functions:

- **ground:** the outflow valve is fully open and the cabin pressure is equalised with the exterior pressure; this is equivalent to saying that the differential pressure is zero;
- **pre-pressurisation:** before lift-off, the cabin pressure increases to avoid a surge during rotation;
- **pressurisation in flight:** the cabin altitude and the cabin vertical speed are adjusted to maximise passenger comfort;
- **depressurisation:** after touchdown, the cabin pressurisation system gradually opens the outflow valve until it is in the ground mode.

This precursor is to be addressed using:

- the differential pressure at take-off and landing;
- the flight management computer (FMC) airport standard altitude setting;
- the pressurisation manual (MAN) mode selected during take-off.

Aircraft parameters

Parameter	Type
Cabin differential pressure (see Note 1)	Analogue
Landing elevation (flight management computer (FMC))	Analogue
Altitude standard	Analogue
Mode SEL P/B MAN	Analogue

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

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off (until lift-off)	***COUNT*** = Number of seconds the differential pressure is not zero on ground	'Differential pressure at take-off'	Raise event if ***COUNT*** > Threshold (see Note 2)
Landing (from touchdown)	***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	n/a	'Airport standard altitude setting'	Raise event if ***STD Altitude*** different from ***Landing Elevation*** (see Note 3)
Take-off	***COUNT*** = Number of seconds the MAN mode is selected during take-off	'Pressurisation MAN mode selected during take-off'	Raise event if ***COUNT*** > Threshold (see Note 1)

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

Note 2: Considering that there are the pre-pressurisation and depressurisation modes on the ground, there are typical values for COUNT which do not 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 stabilisation. Comparison between the values for landing elevation introduced in the flight management computer (FMC) and the real value of the standard altitude at the aerodrome. Due to the ground effect, the 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 these nuisance warnings.

LOC04 — RESERVED

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

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 'Pressurisation system malfunction').

Rationale

The event created is based on the 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 fleet. One possible value is 8 000 ft for maximum cabin altitude.

LOC06 — Oxygen (O_2) masks not deployed and not used by the crew

Summary

Develop means to identify situations where the crew failed to deploy and use the oxygen (O_2) masks in response to real or nuisance situations.

Rationale

After the review of this recommendation made by Working Group A (WGA), WGB decided not to address it due to the two main following reasons:

<u>Lack of available parameters about the use of O_2 masks in the FDM data</u>

Considering the status in terms of attributes of the FDM recording frames and resulting characteristics of the FDM data acquired on board commercial aircraft, there is generally no parameter recorded about the use of O_2 masks. However, such parameters would be necessary so as to design a rationale-capturing scenario of crew failing to adequately use O_2 masks. Consequently, no rationale can be proposed at this stage so as to address the LOC06 recommendation.

Furthermore, due to the current level of instrumentation as regards O_2 masks on board commercial aircraft, there is generally no sensor available at aircraft systems level that could be used to produce the required information about the use of O_2 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.

<u>The relative risk of this precursor when compared to others</u>

Based on the modelling of LOC-I scenarios provided by the EOFDM WGA and especially the analysis of the precursors of such scenarios directly related to the LOC-I risk, the 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 the use of O_2 masks thanks to the adequate instrumentation on board commercial aircraft appears to be very limited compared to the significant industrial effort it would require.

LOC07 — Supplementary oxygen (O_2) system failure

Summary

Develop means to identify the failure of or leaks in the flight crew supplementary oxygen (O_2) system.

Rationale

Depending on the aircraft type, the supplementary O_2 system may also be known as 'crew emergency oxygen system' or 'cockpit oxygen system', referring to the system supplying O_2 to the oxygen masks the crew are supposed to use in case of depressurisation/smoke/fumes.

One of the possible failure modes of this system is caused by low O_2 pressure in the reservoir. Therefore, it would make sense to monitor this pressure during the flight, similarly to the hydraulic pressure.

The minimum O_2 pressure is normally stated in the aircraft maintenance manual (AMM). This event/measurement might be useful for maintenance purposes such as to assess O_2 usage under normal operations (how quickly it is depleted by daily/pre-flight checks or due to slow leaks).

Aircraft parameters

Parameter	Type
Low oxygen pressure	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
Whole flight	***COUNT*** = Number of seconds discrete is active	'Low oxygen pressure'	Raise event if ***COUNT*** > Threshold (see Note 1)

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

Future developments and recommendations

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

LOC08 — Centre of gravity (CG) out of limits

Summary

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

Rationale

This recommendation is linked to two 'failure' modes:

- The CG is outside the aircraft limitations (which most likely could mean that it is uncontrollable in flight regardless of the 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 an 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 go 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:

- the incorrect loading of the aircraft which goes unnoticed by the flight crew; or
- the aircraft is correctly loaded but the flight crew is given incorrect information; or
- both the aircraft loading and the information passed on to the flight crew are correct but the flight crew set 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 the 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 the recorded CG position and the recorded pitch trim setting against the recommended/prescribed values of both variables in accordance with the aircraft documentation (i.e. verify consistency between the pitch trim and the CG position).

Aircraft parameters

Parameter	Type
Centre-of-gravity (CG) position	Analogue
Pitch trim position	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Ground (as soon as the CG parameter becomes valid) and airborne (see Note 1)	***FwdCGMargin*** = *FwdCGLimit* – CG (see Note 2)	'CG beyond the fwd limit'	Raise event if ***FwdCGMargin*** < 0 (see Notes 3 and 4)
Ground (as soon as the CG parameter becomes valid) and airborne (see Note 1)	***AftCGMargin*** = CG – *AftCGLimit* (see Note 2)	'CG beyond the aft limit'	Raise event if ***AftCGMargin*** < 0 (see Notes 3 and 4)
Ground (as soon as the CG parameter becomes valid) (see Notes 1 and 5)	***TrimDeviation*** = abs(actual trim position – expected trim position) (see Note 6)	'Possible trim error'	Raise event if ***TrimDeviation*** is excessive (see 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 flight crew and then updated throughout the flight to account for changes in the fuel mass and distribution. For this reason, it is important to delay the monitoring logic until the parameter is properly initialised and valid. One possibility might be the instant when the aircraft begins to roll for taxi-out because by then it should be fully refuelled, loaded and configured for take-off.

Note 2: Under normal circumstances, the CG 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 the ground (not airborne) because the relationship between the CG and the expected pitch trim is normally simpler and is documented during the ground phase. Also, if the aircraft is properly trimmed on the ground for take-off, it should remain trimmed immediately after lift-off unless there are sudden and abnormal changes in the CG (such as due to cargo shifts, but those cases will eventually be known by other means).

Note 6: '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 stabiliser 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 the CG or could also depend on flap setting and/or weight, etc.). In other words, the calculation or lookup that the flight crew are supposed to carry out to set the pitch trim before take-off needs to be replicated by the FDM software.

Alternative solution if the parameter ‘CG position’ is not available:

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

a) abnormally slow or fast pitch rates on take-off 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 the 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 are 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 take-off 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 the aircraft weight and CG position while on the ground and include such data in the recorded data stream;
- once airborne, the initial CG and weight measurements taken on the ground should be updated in real time based on the remaining fuel quantity on board.

LOC09 — Abnormal operations

Summary

Develop means to identify operations at or beyond the edges of the operating envelope or not in compliance with the standard operating procedures (SOPs).

This should cover all airframe and engine limitations (as specified in the aircraft flight manual (AFM), including but not limited to indicated airspeed/Mach versus altitude, vertical speed, G limits, flap speed limits, speed brake limits, tire speed limits, landing gear limits, temperature limits, manoeuvrability speeds, engine parameters, tailwind, crosswind, excessive rudder inputs).

The intent of this precursor is to capture normal operations as well as non-revenue operations such as post-maintenance flight tests, positioning flights and other flights that are likely to exceed 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 operations can be recognised:

- commercial flights,
- maintenance check flights,
- test flights,
- ferry flights to maintenance,
- positioning flights,
- training flights.

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

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

Future developments and recommendations

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

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.

Rationale

Erroneous data entry or calculation errors can be precursors for inadequate aircraft energy at take-off and landing. The detection of inadequate aircraft energy is covered by recommendation LOC13 'Inadequate aircraft energy', therefore LOC10 must focus only on the detection of incorrect performance calculation without overlapping with LOC13.

Incorrect performance calculation can also be a precursor for incorrect take-off and landing configuration. However, such consequences are covered in recommendation LOC32 'Incorrect aircraft configuration' and are therefore outside the scope of LOC10.

Given the constraints above, the parameters and settings to be monitored in this precursor are: V_1, V_R, V_2, V_{REF}, take-off mass and engine power, and landing mass.

Parameter to monitor: V_1

If V_1 is incorrectly calculated too high, it could lead the flight crew to initiate a rejected take-off 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 flight crew premature commitment to take off.

If V_1 is a recorded parameter in the aircraft's data stream, it can be compared against a value calculated by the FDM software emulating the AFM performance tables by using the aircraft weight and other relevant data. Let the V_1 value calculated by the software be called 'cV_1'[17].

Flight phase	Measurements	Event	Event threshold
Take-off	$SelectedV_1Error = V_1–cV_1$	'Incorrect V_1 selection' if $abs(SelectedV_1Error) > Threshold$	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 take-offs.

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

Parameter to monitor: V_R

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

If V_R is incorrectly calculated too high, it could lead to a late rotation (and then perhaps to a runway overrun) and/or exceedance of the 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.

There is often a small — but normal — reaction delay between reaching V_R speed, the call for 'rotation', and the actual start of the rotation. Therefore, the start 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 the rotation should be determined through the analysis of a suitable sample of normal take-offs in order to minimise 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 by using the 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
Take-off	$SelectedV_RError = V_R – cV_R$	'Low V_R selection' if $SelectedV_RError < 0$	The threshold should be 0 because premature rotations are unexpected.
		'High V_R selection' if $SelectedV_RError >$ Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal take-offs.

Let 'aV_R' be the airspeed at which the rotation is actually initiated for any given take-off. 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 'Inadequate aircraft energy' for further details.

If V_R is not recorded, use cV_R 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 is calculated too low, it could lead to controllability problems (especially at take-offs 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 by using the 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
Take-off	$SelectedV_2Error = V_2 – cV_2$	'Incorrect V_2 selection' if $abs(SelectedV_2Error) >$ Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal take-offs.

If V_2 is not a recorded parameter, refer to LOC13 'Inadequate aircraft energy' 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 at 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 by using the 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
Take-off	SelectedV_{REF}Error = V_{REF}–cV_{REF}	'Incorrect V_{REF} selection' if abs(SelectedV_{REF}Error) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal take-offs.

If V_{REF} is not a recorded parameter, nothing can be done since there is no indirect way to determine the selected V_{REF} in the cockpit.

Note 1: 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 2: The risk of stall and runway overrun is addressed in RE32 'Excessive aircraft energy at touchdown' and in LOC13 'Inadequate aircraft energy' respectively.

Parameter to monitor: Take-off mass and engine power

If the take-off 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 (the aircraft cannot take off under current conditions or requires higher thrust settings).

Check #1: Use a take-off performance model to assess the reasonableness of mass versus engine power versus ambient conditions, as described in RE05 'Slow acceleration during take-off'.

Check #2: Compare the aircraft gross weight (GW) (from a recorded parameter, such as the FMS weight) against an estimate of the take-off GW (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 of the aircraft GW are available, the same cross-check should be performed.

Flight phase	Measurements	Event	Event threshold
Take-off	WeightError = FMSWeight –(take-off fuel Qty + payload + BEW)	'Possible error in take-off weight' if abs(WeightError) > Threshold	A suitable threshold must be determined through analysis of a suitable sample of normal take-offs.

Check #3: Compare all available sources for the aircraft weight against the maximum take-off weight (MTOW) as stated in the AFM limitations. Exceedances of the MTOW are sometimes real, but occasionally they could indicate errors in the FMS weight values inputted by the flight crew or in load sheet/flight log data.

Flight phase	Measurements	Event	Event threshold
Take-off	**MTOWMargin1** = MTOW – FMS_Weight	'Possible overweight take-off' 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 – (take-off fuel qty + payload + BEW)	'Possible overweight take-off' if **MTOWMargin2** < Threshold2	

Parameter to monitor: Landing mass

If the landing mass is incorrectly calculated too low, it could lead to overweight landing (flight crew believing the aircraft is operated within the AFM limitations when it is not). If the landing mass is calculated too 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 (GW) (from a recorded parameter, such as the FMS weight) against an estimate of the landing GW (fuel quantity at landing + 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 of the aircraft GW 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 take-offs.

Check #2: Compare all available sources of the aircraft weight against the maximum landing weight (MLW) as stated in the AFM limitations. Exceedances of the MLW are sometimes real, but occasionally they could indicate errors in the FMS weight values inputted by the flight 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	

LOC11 — Overweight take-off

Summary

Develop means to identify overweight take-off situations that could have an adverse effect on the climb performance and obstacle clearance for performance-limited departures (possibly in combination with LOC10 'Incorrect performance calculation').

Rationale

The maximum limit for the take-off weight is expressed for each fleet by the value of the maximum take-off weight (MTOW). This value of the aircraft weight is closely related to the performance calculation and if it is incorrectly introduced in the FMS, it may be the cause of serious incidents and accidents related to the performance calculation, affecting both runway excursions (REs) and loss of control in-flight (LOC-I).

Being overweight is equivalent to the aircraft being outside the performance envelope provided by the manufacturer. It is not expected in any situation that the weight would be above the MTOW value, but the initial value for gross weight (GW) provided by the load sheet may be affected by human and/or weight assumption error. Currently, the initial GW 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 GW and CG initial values.

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

Aircraft parameters

Parameter	Type
Gross weight (GW) (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
Take-off	n/a	'Overweight take-off'	Raise event if ***GW*** > MTOW (Note 1)

Note 1: The MTOW depends on the fleet.

Future developments and recommendations

The calculation of the gross weight (GW) depends on an initial value that may be affected by human and/or weight assumption error. The technology for aircraft weight measurement may evolve so that the real weight for the specific conditions can be recorded and be available on the data stream. This initial value is of extreme importance as it is used for the initial calculation of take-off speeds and centre of gravity (CG), but then, all the values recorded for the GW 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.

LOC12 — Envelope protection systems

Summary

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

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 term 'envelope protection system' could include aural and/or visual alerts to the flight crew about exceedance of the 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 the systems designed to alert and possibly react to unsafe cases of impending stall or low energy. The most basic implementation is 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.

In line with European Union legislation, the activation of the 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[18]. Being a legal requirement, this kind of event should therefore be covered by a safety report submitted by the flight crew. The role of FDM in this case is to provide supplementary information as explained in the 'Introduction' section of this document.

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 the 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 (AoA)	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 purpose of illustration, but in real FDM implementation there should be as many events and measurements as required to cover all the available parameters related to envelope protection.

[18] Regulation (EU) No 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation, amending Regulation (EU) No 996/2010 of the European Parliament and of the Council and repealing Directive 2003/42/EC of the European Parliament and of the Council and Commission Regulations (EC) No 1321/2007 and (EC) No 1330/2007 (OJ L 122, 24.4.2014, p. 18) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1585565606627&uri=CELEX:32014R0376).

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 1 second, which may lead to spurious events. This value can be increased to prevent the appearance of false positives after a careful analysis conducted by the operator, especially about the data quality (bad data or noise), the attitude and speeds of the aircraft when the envelope protection system 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 for Airbus aircraft are usually coincident with low-speed encounters. Operator experience indicates that most events where Valpha_prot is close to the minimum selectable speed (VLS) are not due to turbulence.

Note 3: Event for fleets that do not 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.

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 given flight phase.

In terms of aircraft 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):

$$M_E = K_E + P_E$$

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

$$P_E = mgh$$

'm' is the aircraft's total mass (corresponding to gross weight (GW)), 'v' is the true airspeed, 'g' is the Earth–aircraft gravitational acceleration, and 'h' is a reference 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 to speed and energy, both the thrust lever position 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) respectively, 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 given flight phase in a simpler method, and on the other hand, we may include the GW 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 (GW)	Analogue
Eng (*) Thrust lever position	Analogue
Eng (*) N1	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off: Start of rotation	***IAS*** = Indicated airspeed ***V2*** = V2 speed	'Low energy at take-off'	Raise event if ***IAS*** < V2 + Threshold
Take-off: Start of rotation	***IAS*** = indicated airspeed ***V2*** = V2 speed	'High energy at take-off'	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 and 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 normal flight, a continuous increase of energy from take-off up to the top of climb is expected, 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 from 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.

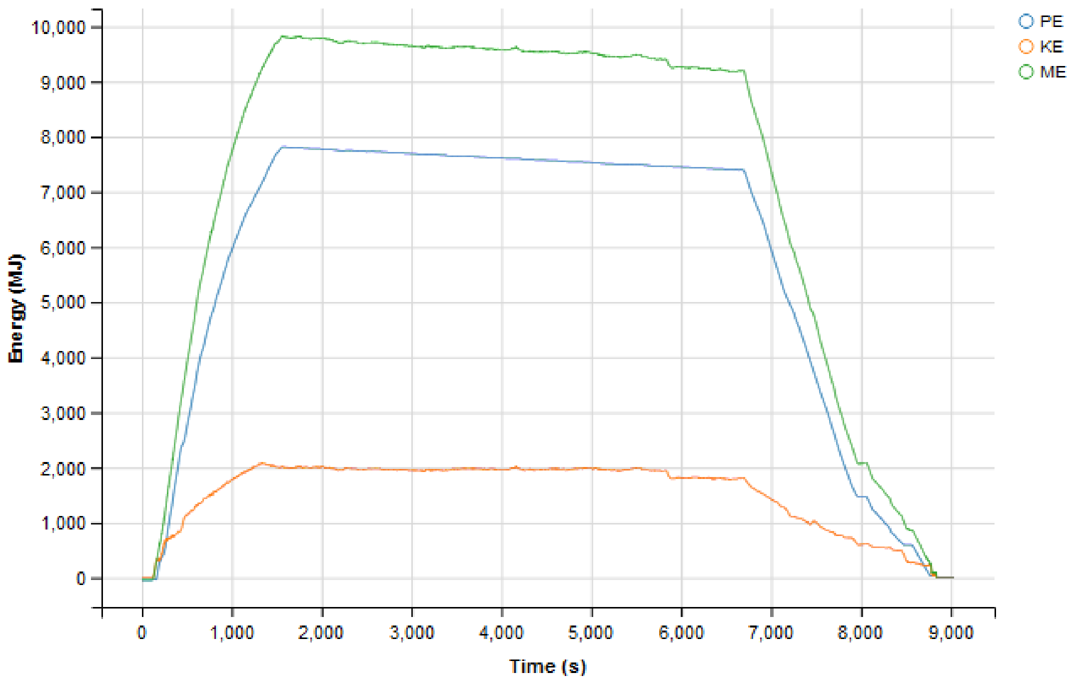

Figure 9 - Aircrfat energy during a flight

LOC14 — Inadequate aircraft attitude

Summary

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

Rationale

In the context of inadequate aircraft attitude situations, this precursor addresses the different ways in which the aircraft can attain such an attitude. Having this in mind, the following scenarios are considered:

- abnormal pitch high on landing,
- abnormal pitch low on landing,
- pitch attitude high on take-off,
- excessive pitch attitude (high or low) in flight,
- excessive bank near ground (take-off),
- excessive bank near ground (landing),
- excessive bank 100 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 s to TimeLdg + 20 s	n/a	'Pitch high on landing'	Raise event if **Ralt** < 20 ft **Pitch** > Threshold (see Note 1)
Landing: from TimeLdg – 5 s to TimeLdg	n/a	'Pitch low on landing'	Raise event if **Ralt** < 10 ft **Pitch** < Threshold (see Note 2)
Take-off: from TimeTO – 5 s to TimeTO + 2 s (see Note 11)	n/a	'Pitch high on take-off'	Raise event if MLG on ground **Pitch** > Threshold (see Note 3)
Whole flight	n/a	'Pitch high in flight'	Raise event if **Pitch** > Threshold (see Note 4)
Whole flight	n/a	'Pitch low in flight'	Raise event if **Pitch** < Threshold (see Note 5)
Take-off: start of rotation until initial climb	n/a	'Excessive bank near ground during take-off'	Raise event if **Ralt** < 20 ft **Roll** > Threshold (see Note 6)
Landing: final approach, landing, on ground after landing	n/a	'Excessive bank near ground during landing'	Raise event if **Ralt** < 20 ft **Roll** > Threshold (see Note 6)
Approach Initial climb	n/a	'Excessive bank from 100 to 500 ft'	Raise event if 100 ft < **Ralt** < 500 ft **ABS(Roll)** > Threshold (see Note 7)
All phases from initial climb to approach	n/a	'Excessive bank above 500 ft'	Raise event if **Ralt** > 500 ft **ABS(Roll)** > Threshold (see Note 8)
Whole flight	***RateOfRolll*** = rate of roll calculation (derived from the 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 as follows:

- 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 as follows:

- 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 as follows:

- 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 as follows:

- 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/s (for Airbus fleets)

Note 10: Excessive roll rate events are almost always due to wake encounters, usually (but not exclusively) whilst in holding patterns in busy ATC environments. Symptomatic of these events are indications of very sudden changes to normal acceleration, with associated autopilot disconnects and recovery manoeuvres using side stick. 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.

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, 'ρ' (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 normal acceleration divided by 'g' ($V_{acceleration}$), in order to be dimensionless.

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

$$C_L = C_{L1g} \times V_{acceleration}$$ [19]

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

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

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

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

[19] This formula does not consider the bank angle and the 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 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 $J/(mol \times K)$	Universal Gas Constant
l – 0.0065 K/m	Atmospheric Temperature Lapse Rate
k – 1.401	Specific Heat Ratio of Air (for generic operational temperatures)

The maximum obtainable lift coefficient (C_{Lmax}) 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 (AoA) for example). For this purpose, the recorded stall speed should be used instead of the aircraft 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 recorders, such as speed (or Mach number is also equivalent), the aircraft gross weight (GW), air temperature, normal acceleration, and the wing surface area. Note that the wing surface area may change according to the flap settings.

Aircraft parameters

Parameter	Type
Airspeed true	Analogue
Mach number	Analogue
Gross weight (GW)	Analogue
Acceleration normal	Analogue
Total air temperature	Analogue
Flap lever position	Analogue
Stall speed	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
In flight	C_L = lift coefficient	'Low lift coefficient'	Raise event if C_L < Threshold
In flight	C_L = lift coefficient C_{Lmax} = maximum lift coefficient	'Low lift ratio'	Raise event if C_L/C_{Lmax} < 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 there are several factors that can contribute to lift variations, which may be commanded or not. This will ensure that the estimated coefficients can be compared with each other since the speed and wing area references remain the same.

LOC16 — Foreign object damage (FOD)

Summary

Develop means to identify cues that could suggest foreign object damage (FOD) events.

Rationale

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

The impact may be caused by parts being projected from other aircraft or runway debris pushed through the jet stream. 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 industry as 'bird strike'. Other sources of 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, if not impossible, to monitor through FDM. 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 the smaller impact when a more serious situation, a stronger impact, occurs and this may be one of the cases referred previously.

Considering engine ingestion (of dust, insects or even small birds), normally such a situation will cause a loss of performance of the affected engine that can be detected by the engine health monitoring program. Some degradation patterns should be reflected in this analysis which would conduct 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 into repetitive patterns.

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

LOC17 — Electromagnetic interference (EMI)

Summary

Develop means to identify cues that could suggest situations of electromagnetic interference (EMI) (possibly in combination with LOC24 'Instrument malfunction').

Rationale

Commercial air transport (CAT) operators from WGB have reported numerous cases of portable electronic devices (PEDs) affecting avionics systems during the 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 and erroneous flight deck indications, aircraft turning off course, and uncommanded turns. It has been recommended that devices suspected of causing these anomalies be turned off during the critical phases of the flight (take-off and landing), and that the use of devices that intentionally transmit electromagnetic signals, such as cell phones, be prohibited during all phases of the flight.

As far as the FDM is concerned, it appears that little data is available to evaluate the root cause of an aircraft's unexpected behaviour and specifically to target EMI as the root cause. As a matter of fact, only localiser and glideslope signals are commonly recorded in the flight data recorder (FDR)/quick access recorder (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 'Aeronautical Telecommunications').

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 automatised FDM system. The only situation where the expected trajectory can be quite easily determined is on an ILS approach as soon as the LOC and/or GS track modes are engaged (which implies the aircraft should follow a straight path down to the runway). In this specific situation (LOC and/or GS track modes engaged), clues of potential EMI can be found in one or a combination of indications including but not limited to:

- change of the AP/FD mode (to other than the 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 regard to atmospheric conditions (turbulence);
- significant heading change.

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 encountered by an aircraft during ground or flight operations, could directly diminish and even threaten the safety of those operations:

a) strong surface winds (exceed the aircraft's maximum certification limitations, such as tailwind > 15 kt and crosswind > 40 kt);

b) thunderstorms;

c) meteorological conditions that contaminate the runway or the take-off surface and adversely affect the aircraft's performance;

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

It is highly recommended that the FDM system should integrate with the weather data analysis system, such that more detailed information may be available in the document 'Algorithm to describe weather conditions at European airports'[20].

Strong surface wind

- Use the acquired parameters 'wind speed', 'wind direction' and 'heading' to calculate the tailwind and headwind component, and then evaluate the severity of strong surface wind. The headwind/tailwind limits are aircraft type dependent while the crosswind limit is usually set at 35 kt during take-off/landing operations.
- 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 the NLR report NLR-TP-2001-003[21], the tailwind limitation for subsonic civil transport aircraft is type dependent. For Airbus aircraft, the tailwind limit is set at 15 kt for A320/330/340 while for Boeing aircraft the limit is set at either 10 kt (B737 Classic) or 15 kt (B747/757/767/777).

[20] https://www.eurocontrol.int/publication/algorithm-describe-weather-conditions-european-airports

[21] https://www.skybrary.aero/bookshelf/books/1148.pdf

Aircraft parameters

Parameter	Type
Wind speed	Analogue
Wind direction	Analogue
Heading true	Analogue
Radio altitude	Analogue
Runway heading	Analogue

Measurements and events

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 (kt) / 20 (kt, autoland) ***Headwind*** > Threshold (see Note 1) ***Headwind*** < Threshold (see Notes 2 and 3)

Note 1: Tailwind if the value is < 0.
RWY headwind limitation varies with aircraft type.
For example, 35 kt for autoland operations, otherwise 45 kt.

Note 2: RE24 'Tailwind' also covers the tailwind precursor.

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

LOC19 — Wind shear

Summary

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

Rationale

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

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

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

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

Methodology 1: Detection of wind shear conditions when on-board detection is available and recorded

If the on-board 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 categorisation can only be made by the analyst.

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

Methodology 2: Detection of wind shear conditions when on-board detection is NOT available or NOT recorded

Typical on-board detection of wind shear encounters looks at changes in the headwind and vertical speed, meaning it should be possible to replicate in the FDM software.

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

For this reason, at least on this first approach, we will focus only on the changes in the headwind. Two proposals will be made using headwind as a reference. Care must be taken when using a derived parameter for the headwind. The operator should ascertain whether 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 considerably high value means that the 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 wind shear.

Rate of headwind

- Calculate the maximum and minimum instantaneous rate of the headwind parameter. A considerably high rate (in absolute value), representing a steep change in the headwind, may be interpreted as wind shear.
- This method allows to determine whether the wind shear is positive or negative, although care must be taken since a wind shear 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 is represented in the airspeed trend vector, but the fact that it looks at the headwind means it does not measure the same as the airspeed trend vector.

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

Aircraft parameters

Parameter	Type
Wind shear warning	Discrete
Wind shear caution	Discrete
True airspeed	Analogue
Indicated airspeed	Analogue
Ground speed	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off Approach Missed approach Go-around (see Note 2)	***COUNT*** = Number of seconds discrete is active	'Wind shear warning'	Raise event if ***COUNT*** > 1 (see Note 1)
500 to 1 500 ft AAL (see Note 3)	***Headwind*** (Note 4) ***StdHeadwind*** = Standard deviation of headwind	'Possible wind shear encounter'	Raise event if ***StdHeadwind*** > Threshold (see Note 5)
500 to 1 500 ft AAL (see Note 3)	***HeadwindRate*** (Note 6) ***MaxHeadwindRate*** = Maximum headwind rate	'Positive wind shear'	Raise event if ***StdHeadwind*** > Threshold (see Note 5)
500 to 1 500 ft AAL (see Note 3)	***MinHeadwindRate*** = Minimum headwind rate	'Negative wind shear'	Raise event if ***StdHeadwind*** < Threshold (see Note 5)

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

Note 2: Generally speaking, wind shear events are important when they happen close to the ground. With this methodology, no special care must be taken to limit the search window, being enough to limit the search to approach, take-off and missed approaches/go-arounds.

Note 3: Generally speaking, wind shear events are important when they happen close to the ground, so the search window should reflect that. With this methodology, there are some calculations being performed on-the-fly. If the performance is an issue, the search window can be reduced to a lower height above the runway. A search window from the runway up to 500 to 1 500 ft AAL should be acceptable.

Note 4: The headwind can be derived by subtracting ground speed from true airspeed.

Note 5: The thresholds for the events must be carefully chosen to minimise the cases of false positives. This will vary with aircraft type, since it is closely related to aircraft dynamics, wing configuration and shape, etc.

Note 6: The headwind rate can be derived from the variation of the headwind parameter with time (DeltaHeadwind/DeltaTime).

LOC20 — Severe turbulence

Summary

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

Rationale

In the context of severe turbulence situations, this precursor description summarises an example operator's given FDM triggers and offers suggestions from an analyst's perspective on how to identify different scenarios. The most significant incidents usually result in multiple FDM events and would normally have a supporting flight 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. The 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:

- normal acceleration (accelerometer reading);
- altitude (uncommanded changes);
- pitch attitude (erratic or abrupt changes) (Note 1);
- roll/bank angle (abrupt changes, or high roll rate) (Note 1);
- activation of stick shake (for Boeing fleets) or Alpha Protection (for Airbus fleets);
- rudder deflection (Note 1);
- TAWS wind shear alert mode.

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

<u>Analysis of detected events</u>

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 (true airspeed (TAS) versus ground speed (GS));

- duration of event (NMLA, rate of roll);
- any available METAR data;
- air safety reports filed by the operating flight crew.

Aircraft parameters

Parameter	Type
Acceleration normal	Analogue
Altitude standard	Analogue
Pitch	Analogue
Roll	Analogue
Envelope protection system (Note 1)	Discrete
Rudder	Analogue
Wind shear 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 purpose of illustration, but in real FDM implementation 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)	n/a	'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)	n/a	'Altitude deviation'	Raise event if positive or negative deviation of ALT over 120 s (see Note 3)
All phases from initial climb to approach	n/a	'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	n/a	'Stick shake' 'Alpha Protection'	See Note 6

All phases from initial climb to approach AND ALT > 1 000 ft	n/a	'Excessive rudder deflection'	Raise event if **ABS(RuddDeflectio n)** > 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 normal accelerations. The second case is normally the one that leads to more injuries on board. Based on an operator's implementation, examples of trigger thresholds for clean configuration are:

- Threshold1 = 1.4g
- Threshold2 = 0.6g

Note 2: The effect of severe turbulence results in (+ve or –ve) variations in the (normal) accelerometer reading of more than 1g at the aircraft's centre of gravity (CG). 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 1.4g 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 (e.g.) 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 only (in theory) triggers events for cases of severe turbulence and does not collect information for moderate or light turbulence encounters. This event is the primary one used for the 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. This value can be determined optionally from two sources: either from the aircraft documentation or from the flight data itself.

Note 5: This event was already described in LOC14 'Inadequate aircraft attitude'.

Note 6: Events already addressed on LOC12 'Envelope protection systems'.

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 the yaw damper action.

Future developments and recommendations

Proposal for definitions of new events:

1) Rapid or abrupt pitch change rates

Search window	Measurements	Event	Event threshold
Whole flight (from unstick to landing)	n/a	'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 air masses of different temperatures are in collision (e.g. 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 measurement of turbulence.

A similar methodology is 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 100 s 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 the predefined limits, here the proposal is to search for situations where the variance exceeds these limits, indicating that some high temperature variations are present. Care should be taken when there is a change in the flight level during cruise.

Search window	Measurements	Event	Event threshold
Cruise	***MeanTemp*** = Mean temperature ***VarTemp*** = Temperature variance (see Notes 1 and 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: A sliding window of 100 s proposed for the initial conception of this event (based on EHM values).

3) root mean square (rms) g calculation

This method consists of calculating the root mean square (rms) of the normal acceleration during a given time interval (sliding window).

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

This is a general equation to represent the calculation of the rms. In the context of turbulence measurement, the 'x' will be the normal 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: The 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';
- creating an 'uncommanded roll attitude' event to detect the correction of induced roll attitudes (or abrupt roll) from spoilers or ailerons without the corresponding pilot command.

LOC21 — Icing conditions

Summary

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

Rationale

- Use the recorded parameters 'airspeed', 'OAT' and 'AoA' to analyse possible in-flight icing. Due to ice accretion on the 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 the AoA could be an indicator, when the OAT is between 2 ~ – 15°C.
- Use the recorded parameters 'de-icing airframe on', 'icing AoA', and 'icing detected' to identify that the aircraft has encountered in-flight icing.

Aircraft parameters

Parameter	Type
De-icing airframe ON	Discrete
Icing AoA	Discrete
Icing detected	Discrete
Indicated airspeed	Analogue

Measurements and events

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
Cruise 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[22] describe that anomalous variations of TAT at high altitude may be indicators of the presence of ice crystals. It is recommended for operators to conduct studies to gain more insight into this area and extract some TAT patterns that can identify these conditions.

[22] *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).

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 utilisation (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 the ice protection systems for the airframe, engines, and probes, which 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 are within the scope of LOC21 'Icing conditions'.

Failure cases may be quite obvious, e.g. captured by discrete parameters in the data frame layout. If it is not the case, the failure of an anti-icing or de-icing system will most probably be seen through performance degradation (airframe/engine icing) or indication issues (probe icing). Those consequences also fit with the 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 during the entire flight, typically the air data probe heating. Others are switched on when the aircraft enters icing conditions (defined by low TAT/visible moisture) and switched off when the aircraft is confirmed to be 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 turned off when the aircraft is free of ice.

The 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 they detect ice accretion.

Future developments and recommendations

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

- The delay between the ice detection caution and the activation of the de-icing system; theoretically, the activation of the de-icing system could be done even before the ice detection message is triggered, but it should be activated quickly after such indication at the latest.
- The monitoring of the aircraft performance: such monitoring allows to detect the loss of performance that would most likely be due to the icing of the airframe. The performance may be reflected by the rate of climb (in climb) or the IAS (in cruise).
- The monitoring of different air data sources, when applicable — mainly on the IAS but also altitude — that could indicate probe icing (see LOC24 'Instrument malfunction').
- System failure, e.g. left-wing anti-icing versus right-wing anti-icing asymmetric use.

LOC23 — Engine failure

Summary

Develop means to identify situations of latent or active engine failure, including foreign object damage (FOD) and hardware degradation and failure. There might be scope for integration with the engine health monitoring (EHM) 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 engine failure is defined as an unsafe act or situation that may directly influence an accident or incident whereas a latent engine failure can carry on for longer periods of time before contributing to an accident or incident.

Usually, latent engine failures are easier to predict using the flight data monitoring (FDM) and engine health monitoring (EHM) tools since it is possible to perform trend analysis for the engine's primary parameters such as N1, N2, engine pressure ration (EPR), fuel flow (FF) and exhaust gas temperature (EGT), or any other parameter that is also recorded. However, both active and latent engine failures are equally important and should be monitored in order to assess the degradation trend of the engines.

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,
- full authority digital engine control (FADEC) system fault warning.

Aircraft parameters

Parameter	Type
Eng(*) N1	Analogue
Eng(*) N2	Analogue
Eng(*) N3 (see Note 1)	Analogue
Eng (*) Thrust lever position	Analogue
Eng (*) exhaust gas temperature (EGT)	Analogue
Eng (*) oil pressure	Analogue
Eng (*) oil temperature	Analogue
Eng (*) vibration N1	Analogue
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 (see Note 3)	Analogue
Eng (*) Np (see Note 3)	Analogue
Eng (*) torque (see 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 (see Note 5)
Take-off 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 'Loss of thrust' 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 the 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 the FDM data. However, to identify possible engine failure scenarios, it may be of great interest to monitor more engine parameters through an engine health monitoring (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 data on engine failures that have already occurred in the past to extract the models or patterns from these failures. This allows the comparison of the engine data from the aircraft operation with these patterns to identify an imminent failure.

Identifying unusual trends in the engine's primary parameters may predict a failure due to hardware degradation or other sources, such as an increase in exhaust gas temperature (EGT) over time or a decrease in N2 over time. These types 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.

LOC24 — Instrument malfunction

Summary

Develop means to identify situations of instrument malfunction (possibly in combination with LOC17 ‘Electromagnetic interference (EMI)’).

Rationale

Development of means to identify situations of instrument malfunction. The most direct approach is to compare failures and identify those that are related to key parameters utilised for flight envelope showing differences between two sources. For example, Airspeed source 1 (normally captain’s side) versus Airspeed source 2 (normally first officer’s side).

The monitoring of system malfunctions is critical in preventive identification (instead of reactive) leading to a possible LOC-I event, as malfunctioning systems resulting in inaccurate in-flight parameter values have been identified as a major contributing factor to many fatal accidents as well as serious incidents and accidents.

Some insight into the monitoring of key parameters and their respective effects related to the WGA Document LOC-I, Scenario #3 (LOC due to Environmental Factors) and especially Scenario #4 (LOC due to system failure):

- Angle-of-attack (AoA) monitoring: monitoring of the left and right values of the AoA probes. Identification of a stuck or lagging probe.
- Altitude monitoring: comparison of the ADR-based altitudes between two systems to identify any discrepancy in the altitude values being used by the system and to avoid a potential altimetry system error in reduced vertical separation minima (RVSM) airspace. Based on the system in use, Left AP versus 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 a 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 degrees for a continuous duration of 10 seconds.

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

Aircraft parameters

Parameter	Type
Roll	Analogue
Angle of attack (AoA)	Analogue
Altitude standard	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 seconds (see 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 (see Note 4)

Note 1: Some flight-phase-specific monitoring can also be implemented, such as altitude deviation allowance as per flight crew operating manual (FCOM), i.e. above FL200 monitoring only.

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

- ABS(Roll) < 15 degrees

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 an operator's implementation, the thresholds can be set as follows:

- Threshold1 = 0.8 degrees
- Threshold2 = 10 seconds

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 (AFM) for different flight levels (FLs). The thresholds for safety purposes should be lower than those documented to indicate a trend before the operational limit is attained.

LOC25 — Structural failure

Summary

Develop means to identify cues that could suggest the existence of latent or active engine failures in primary structures (possibly in combination with LOC16 'Foreign object damage (FOD)' and exploring the potential of advanced instrumentation and sensors available in modern aircraft).

Rationale

The current technology normally available in the operators' representative fleets does not include real-time structural analysis of the skin and the airframe. These skin-related parameters are normally available in aircraft research and development programmes, such as structural health monitoring (SHM). This means that any sudden structural failure due to an impact cannot be immediately detected by any aircraft system.

On the other hand, during the lifetime of an aircraft, natural degradation occurs with its operation. This is normally monitored in the airlines through the aircraft performance monitoring (APM) programmes which differentiate degradation due to the engines through the engine health monitoring (EHM) programme and the other part due to the aerodynamics of the aircraft.

Despite the fact that the underlying reason for the aerodynamic degradation of an aircraft cannot be identified, it can be due to any dent on the skin due to some foreign object damage (FOD) collision, from any control surface abnormal deviation out of the correct position producing drag during the flight, or from the increase of the roughness of the aircraft skin due to dust accumulation. The reason behind the aerodynamic degradation has always to be evaluated individually by an expert.

Flight data monitoring (FDM) plays an important role in these types of analyses (APM or EHM) as these programmes 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.

The benefits of using the FDM data 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 the 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 the degradation.

Future developments and recommendations

This precursor provides the grounds to address the following points:

- tail strike (see RE30 'Abnormal runway contact (ARC)'),
- severe load factors,
- hard landing (see RE30 'Abnormal runway contact (ARC)'),
- structural overspeeds (e.g. VMO, MMO, VFE, VLE),
- abnormal vibrations (from the 3-axis accelerometer).

LOC26 — Loss of thrust

Summary

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

Rationale

The monitoring of 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 this section’s ‘Future developments and recommendations’.

Comparing the difference between the maximum and minimum N1 or engine pressure ratio (EPR) across all engines (where an aircraft has more than one engine) provides the thrust asymmetry, a measurement of the loss of thrust across all engines. The assumption is that all engines are commanded the same power. If this is not the case, it should be identified in order to assess the reasons why there is this asymmetry.

For turboprop aircraft, the torque is also an important factor during the 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 flight 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 flight crew, there are often signs of flight crew reaction. The use of the take-off and go-around (TOGA) switch is one such measurement, or the equivalent rapid application of power.

- Use of TOGA selection (when not in take-off or go-around).
- Commanded application of > 90 % power from < 70 % within 2 seconds.

Aircraft parameters

Parameter	Type
Eng (*) N1	Analogue
Eng (*) engine pressure ratio (EPR)	Analogue
Eng (*) torque	Analogue
Eng (*) Thrust lever position	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 Notes 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 Notes 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 Notes 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 Notes 2 and 3)	'Throttle lever asymmetry'	Raise event if ***TLA_DeltaValue*** > (5 % for jet, 10 % for turboprop)	Level 1
Whole flight excluding take-off or go-around	***TOGA_Selected*** = *duration(TOGA = ACTIVE)*	'Unusual TOGA usage'	Raise event if ***TOGA_Selected*** > 1 s	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 s	Level 1

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

- take-off,
- in-flight (between lift-off 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 desensitises 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 (which have been de-identified in the publication). The Y axis represents *thrust asymmetry* based on N1 or EPR, where available.

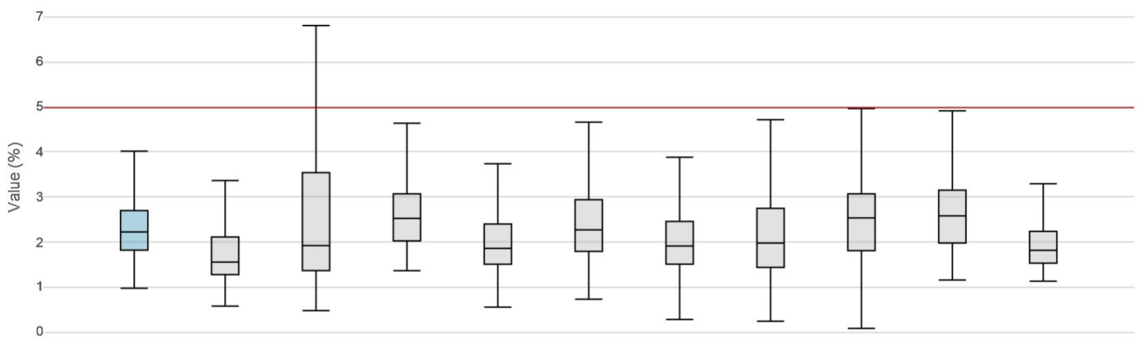

Figure 10 - Thrust asymmetry during flight max, 11 × A320 operators, 01–12/2016

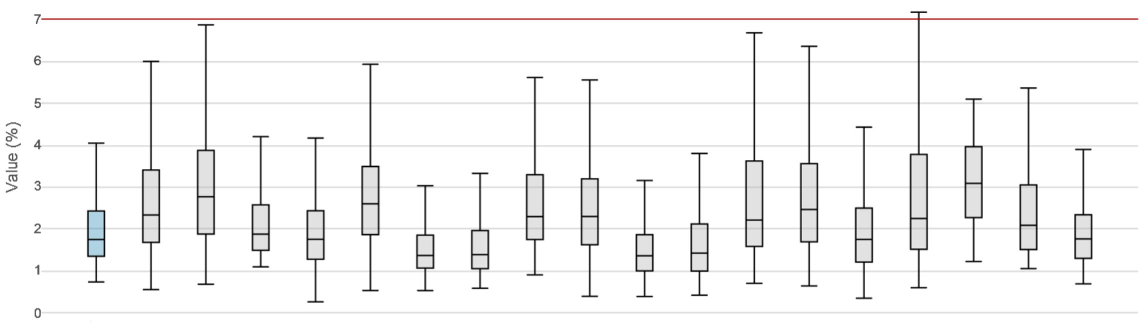

Figure 11 - Thrust asymmetry during flight max, 19 × B737-NG operators, 09–12/2016

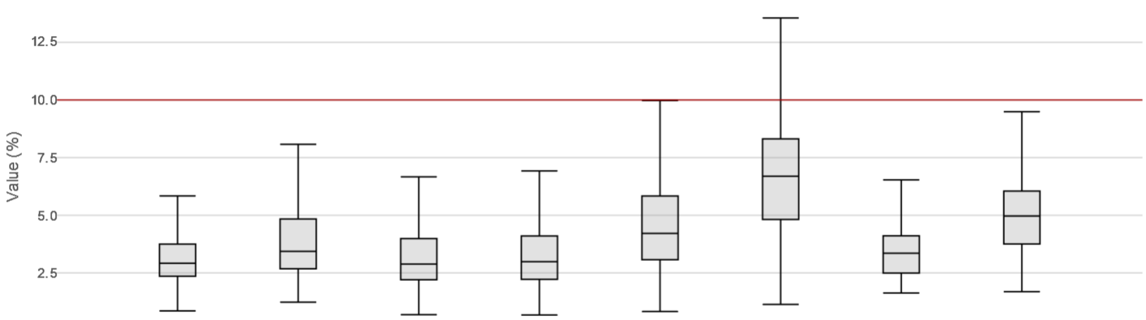

Figure 12 - Thrust asymmetry during flight max, 8 × ATR-42 operators, 01–12/2016

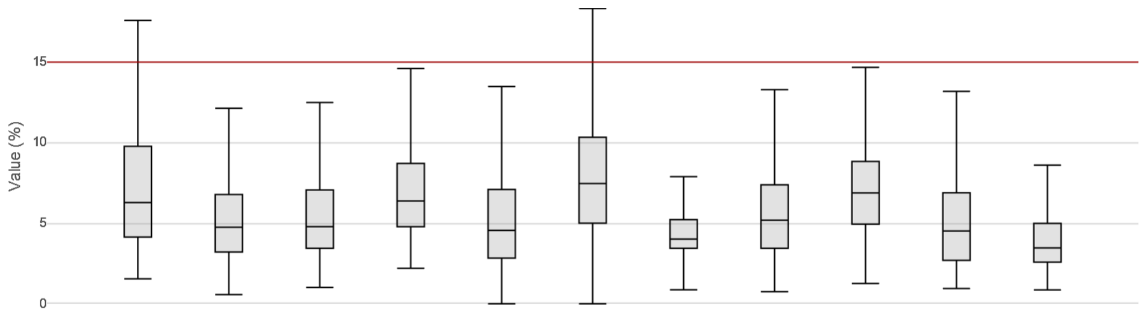

Figure 13 - Thrust asymmetry during flight max, 11 × ATR-72 operators, 01–12/2016

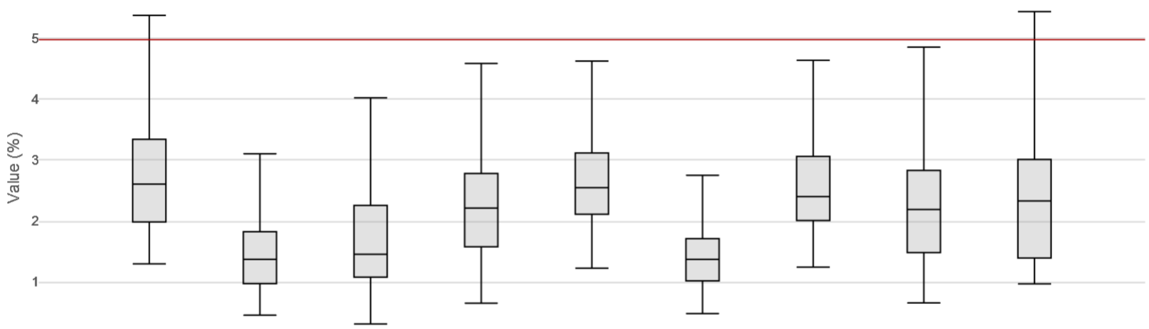

Figure 14 - Thrust asymmetry during flight max, 9 × Gulfstream 5 operators, 01–12/2016

Future developments and recommendations

The loss of an engine's thrust can be determined by developing a performance model of the engine, considering many engine parameters, including (where available) N1, N2, Np, fuel flow (FF), exhaust gas temperature (EGT), etc., for each phase of the flight. This process may be monitored and managed by power plant engineers by the use of continued engine health monitoring (EHM), a process supplementary to that of the flight data monitoring (FDM).

Simplified engine models can determine a crude actual performance compared to the expected performance, for example, by modelling the expected N1 (thrust) compared to the commanded power (throttle-levers- or flight-computer-commanded power). Due to the variations among the engine types, this is a recommendation for manufacturers to provide specific models to support this work.

The 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 autopilot is flying to maintain airspeed or Mach, this may not be valid.

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 the aircraft health monitoring (AHM) systems and continued airworthiness.

Rationale

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

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 elevator 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 fault	Discrete
IRS 1/2/3 fault	Discrete
TCAS fault	Discrete

Each hardware fault/failure represents different severity levels as regards the safe operation of an aircraft. The implementation of this precursor to other than Airbus fleets depends on the analysis of which warning and fault parameters are available in the data frame; 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 SEC 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

LOC28 — Flight control failure

Summary

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

Rationale

This precursor is to be addressed using the following information:

- control column force high,
- control column stiffness high,
- actuator and control surface mismatch,
- precursors to flight control failure.

Control column 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 manoeuvre 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/Control wheel force* values across B737-NG operators is shown below:

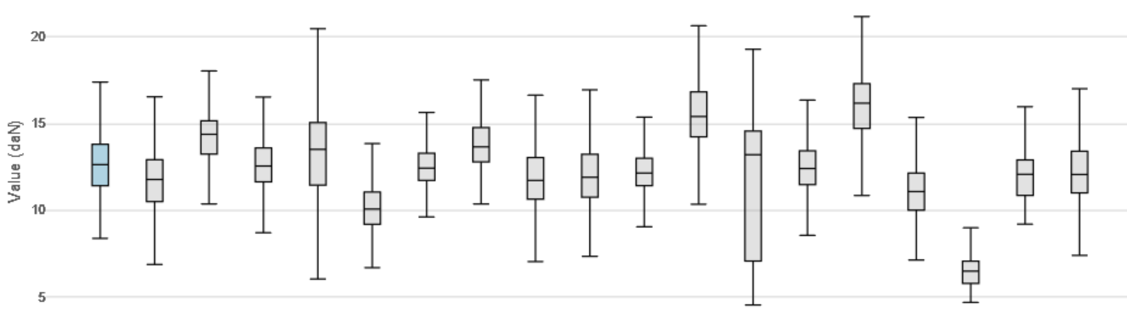

Figure 15- Control column force max, 19 × B737-NG operators, 08–12/2016

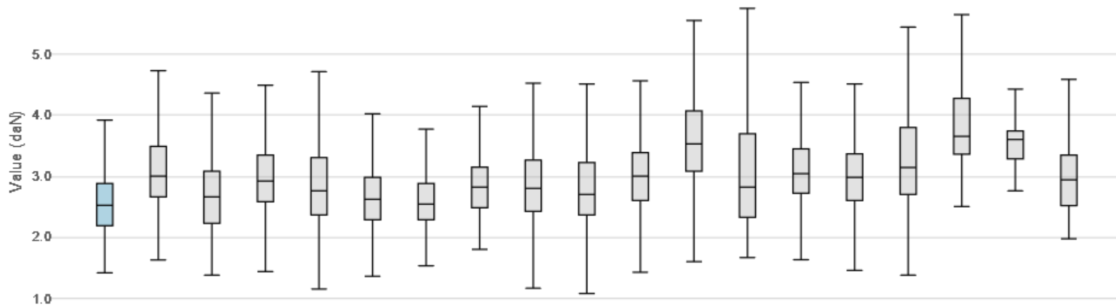

Figure 16 - Control wheel force max, 19 × B737-NG operators, 08–12/2016

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 the 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 situations piloting the aircraft 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 flight 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. As 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:

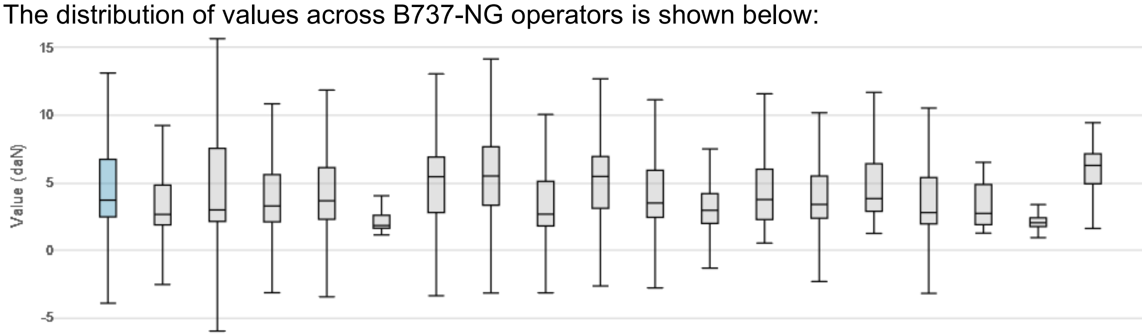

Figure 17 - Control column stiffness, 19 × B737-NG operators, 08–12/2016

Actuator and control surface mismatch

Following a control runaway incident, investigation has shown 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 the mismatch between the two parts of the control system due to actuator mis operation.

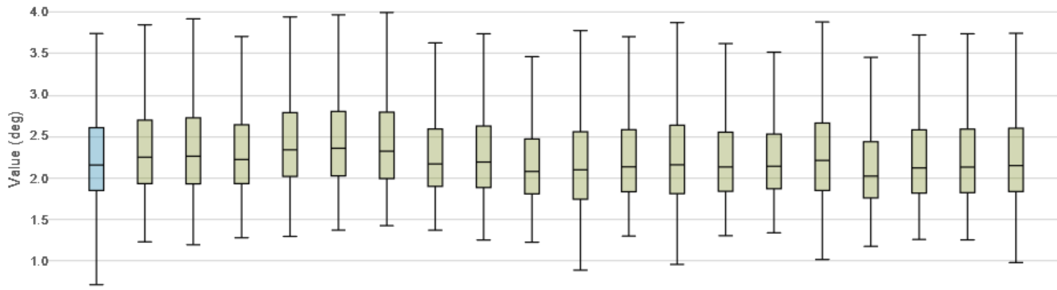

Figure 18 - Elevator actuator mismatch max, 20 × B737-NG aircraft, 08–12/2016

<u>Precursors to flight control failure</u>

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 the 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 the control movement prior to flight. Pilots are generally sensitive to the normal 'feel' of the flight controls but it is not an exact science. Assuming that pre-flight control checks are completed properly, parameters/events could be developed to measure the changes and/or the decreasing quality of the flight controls over many flights.

Fly-by-wire systems pose a different problem as there is no direct feel of the restricted movement of the flight controls. If the flight control indices move their full travel as indicated in the Airbus electronic centralised aircraft monitor (ECAM) flight control page or the Boeing engine-indicating and crew-alerting system (EICAS), then the flight controls are serviceable.

The ability to assess a change or increase in stiffness of the flight controls is difficult during normal operations when the autopilot (AP) is engaged. The AP would maintain stable flight by continuously compensating for restricted movement of the flight controls 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 its 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
Pitch trim position	Analogue

Note 1: The recorded parameters 'control column force (Capt.)' and 'control column force (FO)' are used to derive the parameter 'control column force', which does not recognise the pilot flying (PF).

Cautionary note on B737-NG *control column forces*:

There are problems with the B737-NG 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 × B737-NG operators, 08–12/2016*, 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 business jets (e.g. Gulfstream, Bombardier).

Measurements and events

Search window	Measurements	Event	Event threshold	Maturity
In-flight (excluding pre-flight checks and take-off roll)	***ControlColumnForceMax*** = max(Control column force) (Note 1)	'Control column force high'	Raise event if ***ControlColumnForceMax*** > 20 daN (Note 3)	Level 2
In-flight (excluding pre-flight checks and take-off roll)	***RollHighestPosForce*** = max_absolute(Control wheel force) (Note 2)	n/a	n/a (Note 3)	Level 1
Airspeed > 60 kt 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	***PitchTrimRateMax*** = *max(rate_of_change(Pitch 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. The 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 the completion of the flight control check, post-de-icing and then again just before take-off to ensure full and free movement. Even this check does not ensure that subsequent flight control restrictions could occur due to freezing conditions. The events to be developed could provide the data for the measurement of the 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 the autopilot (AP) 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 through 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 the failure of a 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.

The recording of additional parameters and the obtainment of new measurements are required to monitor (Boeing) EICAS and (Airbus) ECAM flight control pages which indicate actual flight control positions, i.e. flight control indices.

LOC29 — Mismanagement of automation

Summary

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

Rationale

The types of scenarios that are intended to be detected are the following:

- Situations where automation should be in use, and it is not.
- Autopilot is disengaged in RVSM airspace (see also MAC06 'Automatic altitude control system OFF in reduced vertical separation minima (RVSM) conditions').
- Flying with inappropriate modes.
- Improper use of 'selected/managed'.

As the inappropriate use of automation is an 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.

Automation is certainly a great help for the pilot to operate the aircraft, but in certain situations the human–machine interface (HMI) may lead to distractions or misunderstandings that may be precursors for incidents or even accidents. Despite the generally acknowledged and evident benefit of automation, the excessive dependence on its use may conduct to the increase of risks when the manual handling of the aircraft is necessary. The assessment of the use of automation, during approach and landings, may be accomplished with the use of the FDM. By performing such a study over the whole fleet, an operator may evaluate what is the weight of the automation in its operations. The 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's automation system, be involved in the analysis.

The use of autopilot (AP) and autothrust / autothrottle (AT) is currently widespread across almost all the fleets. Inadvertent situations may happen with the automation devices engaged, and these are normally unexpected guidance of the aircraft or are provoked during the disconnection of one of the automatic devices. These are normally situations not easy to detect using the FDM.

For the unexpected guidance of the aircraft, 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 for a given operator. Due to the amount of different systems and fleets, each operator has to adapt this study to its own reality.

Regarding the disconnection itself of any of the automation devices, it is a perfectly normal operational action. An assessment of the normal pattern of the AP and the AT engagement/disengagement should be carried out using existing historical data from the operator. This should conduct to the identification of the normal flight phases when the AP and the AT engagement/disengagement happens and identify those flights for which the use of automation is beyond this normal pattern (identified by historical data).

There are a few cases though that are useful to analyse. Some fleets allow to make the distinction between voluntary disconnections and those that result from abnormal conditions by recording the push-button (P/B) that the pilot presses to disconnect the device. Having this possibility, the distinction can be made if it is a voluntary action from the pilot or 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 (manual or automatic) disengagement of these devices and the application of any manual input, either in the flight controls or thrust levers. A high amount of time may indicate that some misunderstanding of the situation may have arose, but this analysis always requires further knowledge and should be always taken as a warning flag to carry out 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 happened. This is especially true in the case of the trimming of the aircraft. In this case, it is recommended that the FDM verify if there is any kind of manual flight control (including trimming) or thrust application before disengaging the AP or the AT 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 to make sure it is consistent with the selection. This recommendation identifies situations where the pilot is introducing one value for one parameter, not realising 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 sort of malfunction of the radio altitude systems may interfere with the aircraft automation (Report — Dutch Safety Board, Ref.: M2009LV0225_01 for a B737-800 that crashed near Amsterdam Schiphol Airport, 25 February 2009). In this specific case, there was a mismatch between the two radio altimeter systems, with system #1 providing false values to the automatic system. In the current precursor we will make use of the mismatch between the two radio altimeter systems, which is addressed in LOC24 'Instrument malfunction'.

Some incidents have also been reported as regards the use of improper modes during approach (BEA report — Airbus A320-214 registered F-HEPE, 3 April 2012). For this fleet (A320), the report clearly indicates that there was 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 WGB for this precursor are as follows:

- Assessment of the normal engage/disengage pattern for a specific fleet. This can be fine-tuned for a specific flight leg, if necessary.
- Assessment of the use of automation during the operation, especially on landings (automatic versus manual landings).
- Perform a study of the normal automatic modes and their normal sequence in terms of autopilot (AP) (Lateral and Vertical) and autothrust/autothrottle (AT) for all flight phases.
- AP or AT disengagement without the voluntary P/B pressing by the flight crew.
- Time elapsed between any device disengagement and the application of a manual command (flight controls or thrust).
- Verify whether 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 the radio altimeter (RA) systems (included in LOC24 'Instrument malfunction').
- Detect the use of OPEN DESCENT during *approach* (Airbus A320); assess equivalent events in fleets other than Airbus.
- 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 position	Analogue
HGG/TRK P/B selection (VS/FPA)	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold	Maturity
TDB	TBD	TBD	TBD	TBD

LOC30 — Abnormal flight control inputs

Summary

Develop means to identify situations of abnormal inputs into 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 flight crew proficiency and human factors are present when the pilot is flying manually the aircraft. Flight crews of modern airliners do not conduct flights 'manually' or in raw data, in compliance with safety standards, company policies and environmental protection issues (noise abatement). However, these practices may lead to unexpected consequences — flight crew proficiency may be degraded during manual flying, which may lead to incorrect flight control inputs, thus increasing the risk of suffering an UPSET condition at any altitude (problem also addressed in LOC29 'Mismanagement of automation'). The typical scenarios where these values can appear are the following:

- Adverse weather and high wind speeds during departure or arrival; wind shear.
- Change of runway at very short notice (localiser 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 that the operators conduct some studies to determine the most extreme inputs applied. These studies should be performed for each flight leg operated, so that the flight control inputs that are normal for one specific flight leg are not considered as abnormal if all flight legs are considered together. If 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 in 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 into 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 aircraft configuration'. To complement the proposals on this precursor, some assessments should be carried out by the operators 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 the landing gear extension should be correlated with this sequence. Out of this assessment, a normal pattern should be identified. To document this recommendation, please refer to the AAIB UK report on the serious incident of the landing gear retraction at the same time with the reduction of the flaps/slats (AAIB Bulletin: 9/2017, G-EZEW, dated 30 June 2016).

The deployment of speed brakes should be also closely monitored. There are flight phases, such as during climb and cruise, where it is expected that these surfaces are retracted. 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 and heading excursions during flight as well as during take-off and landing rolls need to be monitored since full control inputs into the rudder pedals can lead to runway veer-off.

Summary of the WGB recommendations for this precursor:

- Assessment of the extreme flight controls applied for each flight leg (using either the flight commands or control surfaces).
- Dual input.
- The correct sequence for the deployment of flaps/slats (landing) and retraction (take-off) 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
Speed brake (*)	Discrete
Main landing gear (MLG)(*)	Discrete
Flap angle	Analogue
Slat angle	Analogue
Spoilers	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
Whole flight	n/a	'Dual input'	Raise event if dual input was applied.
Excessive pitch/roll inputs	n/a	'Excessive inputs'	Opposing direction control inputs within a short span, e.g. side-stick value change above N deg within X seconds. (Note 1)
Full rudder pedal inputs	n/a	'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'	Raise event if the spoiler is activated during the climb phase.

Note 1: Possible value for Airbus fleets is 4 degrees within 2 seconds.

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

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 in terms of legal requirements or company procedures.

The second event considers the comparison between the actual fuel quantity remaining at touchdown and the planned fuel quantity remaining 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 that planned'	Raise event if ***FuelRemaining – FuelPlanned*** < Threshold (Notes 2 and 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 I — *International Commercial Air Transport — Aeroplanes*. There, the final reserve fuel is indicated as a remaining time to fly. Depending on factors including aircraft type, mass, and environmental factors, this time constraint can be transformed into a fuel quantity constraint. Depending on the aircraft type, in ICAO Annex 6, the final reserve fuel is indicated to be 30 to 45 minutes.

Note 2: The value of the planned fuel remaining at touchdown might not be available in the FDM data and needs 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 type);
- 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 'Incorrect aircraft configuration');
- the incorporation of the expected fuel remaining at the end of the flight leg from the flight plan; this would allow a direct comparison with the actual fuel quantity on board from the flight data;
- the previous bullet point can be extended to the whole flight plan, creating the basis for a 'fuel monitoring programme'.

LOC32 — Incorrect aircraft configuration

Summary

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

Rationale

The correct configuration of an aircraft is essential for its safe operation. Unintended or inappropriate aircraft configuration is a significant causal factor in documented LOC-I incident reports.

The identification of incorrect aircraft configuration in the FDM can be achieved by monitoring the 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 made 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
Speed brake (*)	Discrete
Main landing gear (MLG) (*)	Discrete
Static air temperature (SAT) (Note 1)	Analogue
Indicated airspeed (IAS)	Analogue

Note 1: If not available on the data stream, it can be obtained from the total air temperature (TAT).

Note 2: If the flap lever is not available, it can be derived from the flap angle.

Measurements and events

Search window	Measurements	Event	Event threshold
'Start of flight' (engine start and taxi out)	n/a	'Taxi without take-off flap set'	Raise event if **GroundSpeed** > 8 kt, **FlapLever** ≠ take-off position **SAT** > 0 (deg) (see Notes 1 and 2)
Whole flight (from unstick to landing)	n/a	'Airspeed low for configuration'	Raise event if **CAS** < Threshold (see Note 3)
Whole flight (from unstick to landing)	n/a	'Flap placard exceedance'	Raise event if **CAS** > Threshold + 5 kt (see Note 4)
Whole flight (from unstick to landing)	n/a	'Gear down speed exceedance'	Raise event if **GearDown** = True, **CAS** > VLE
Take-off; initial climb	n/a	'Early configuration change after take-off'	Raise event if **FlapLever** selection change, **AAL** < 1 000 ft (see Note 5)

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

- A319/320/321: Flap lever ≠ 1, 2 or 3 (take-off position)
- Boeing 777: Flap lever = 0 or 1

Note 2: De-icing procedures may permit initial taxi without take-off flap set. The FDM test for SAT (static air temperature) > 0 diminishes false positive events being detected in icing conditions.

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

- A319/320/321: Calibrated airspeed (CAS) < VLS – 3 kt
- Boeing 747: Calibrated airspeed (CAS) < V_{REF} at touchdown + *constant*, where *constant* depends on current flap lever setting

Note 4: The value of the threshold is fleet specific and defined in the flight crew operating manual (FCOM). Based on an operator's implementation, its FDM system event adds a constant 5-kt buffer (allowance) to the defined placarded threshold value to diminish the appearance of false events.

Note 5: This event captures the unintentional early flap retraction in the take-off and initial climb phases.

Future developments and recommendations

Proposal for definitions of new events:

1) Speed brake deployed with high thrust setting

Search window	Measurements	Event	Event threshold
Whole flight (from unstick to landing)	n/a	'Speed brake in use with high thrust'	See Note 1

Note 1: No specific event defined to detect *speed brake deployed with high thrust settings*. Based on an operator's implementation, *speed brake usage* with *land flap and speed brake usage* below 1 000 ft are events that are both defined in the 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)	n/a	'Inappropriate trim inputs'	See Note 2

Note 2: Based on an operator's FDM implementation, no specific events are defined to detect trim changes in critical flight phases. For example, trimming during the 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 type).
- — The detection of incorrect aircraft configuration along the flight inducing increased drag (related to LOC31 'Fuel exhaustion').

CONTROLLED FLIGHT INTO TERRAIN (CFIT)

Controlled flight into terrain (CFIT) is defined in the document 'Aviation Occurrence Categories'[23] developed by the CAST/ICAO Common Taxonomy Team.

Each recommendation identified by Working Group A (WGA) corresponds to a possible precursor for an incident or accident related to CFIT. The current chapter presents the algorithms proposed by Working Group B (WGB) to address each of the recommendations identified by WGA.

The frequency of CFIT accidents has decreased over the last decades due to the terrain awareness and warning systems (TAWS) that have been incorporated into the aircraft as a result of studies performed on CFIT accidents. The carriage of a TAWS on board the aircraft has 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 state-of-the-art assessments 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 upon these databases.

[23] The document can be accessed at http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf.

Table 1 — Incorporation of external databases in the FDM programme

CFIT precursors				
Precursor	**Description**	**External data sources**		
		Terrain	**Weather**	**Navigation**
CFIT01	Poor visibility conditions	No	Yes	No
CFIT02	Wrong altimeter settings	No	Yes	No
CFIT03	Flight below minimum sector altitude (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 approach/unstable approach	No	No	No
CFIT12	Inadequate response to wind shear warning	No	No	No
CFIT13	Reduced horizontal distance to terrain	Yes	No	No
CFIT14	Reduced time to terrain impact	Yes	No	No

In order to maximise the benefit from the proposed precursors, WGB recommends the following:

1) To record at least one accurate position from the best navigation system available on board (FMS, GPS or IRS). Figures that have one assessment of the degradation of the position signals should be also be recorded (such as the *figure of merit* and/or dilution of precision (DOP) signals from the GNSS).

2) All the TAWS modes should be recorded separately and not only a discrete parameter indicating when the TAWS has produced a warning.

CFIT01 — Poor visibility conditions

Summary

Develop means to identify present visibility conditions (e.g. instrument meteorological conditions (IMC) or visual meteorological conditions (VMC)).

Rationale

Using the current technology available on board aircraft and the existing data frames, 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:

— The METAR information provides some information about the visibility. The data in METARs reflects the average conditions close to the aerodrome. Although this can be used as guidance, it is not a direct measurement of the real visibility conditions.

— FDM systems may rely on the number of landings performed with both autopilots (APs) engaged at the moment of touchdown (TD)[24] to have one assessment of landings performed in CATIII conditions. This depends on the number of flights analysed over a 1-day period by the FDM system and may be only one indication of poor visibility conditions. The capture of consecutive TDs with both APs engaged over a limited period of time may be an indication of poor visibility conditions.

Future developments and recommendations

New developments in this area are dependent on the integration of new technologies on board aircraft, 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 evaluating the visibility can be conducted if the equipment is available in the future.

[24] This may be fleet dependent. Operators should check what are the conditions for CATIII landings for their 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 QNH value can be taken from the METARs and it is useful to use as reference value at a specific time and location. This measurement does not change significantly for 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 – StdPres	'Wrong altimeter setting'	Raise Abs(DestQNH – StPress) > Threshold

Future developments and recommendations

CFIT accidents may happen in remote locations away from aerodrome areas. The solution provided only includes the landing and departure phases since there is the need for a valid reference value to compute the measurement.

The integration of aerodrome database data allows checking whether 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 a need to integrate meteorological data from external data sources both for CFIT01 'Poor visibility conditions' and CFIT02. 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 in METARs. The meteorology science has been increasingly developing during the last decades and an evaluation of what is available in this area that can be integrated with the FDM analysis is of great interest.

CFIT03 — Flight below minimum sector altitude (MSA)

Summary

Develop means to identify situations of aircraft that fly below the minimum sector altitude (MSA).

Rationale

The MSA provides a minimum clearance from terrain obstacles. The definition for 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 offer a representation of the minimum altitude corresponding to each geographical location. This is useful information if incorporated in the FDM system (see 'Future developments and recommendations' of this section).

The most direct way to address this precursor is to monitor the radio altitude (RA) clearance from the ground and verify that this value is always above or equal to 1 000 ft. This point can be determined by using the runway threshold position and assuming a 3-degree descent slope. This will determine the point until which the 1 000-ft RA 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 the 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 RA 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 perform the calculations for this precursor (see Annex 1 'Accurate position computation'). This precursor should take into consideration RE34 'Erroneous guidance' to determine whether or not the aircraft is on the expected flight path.

Aircraft parameters

Parameter	Type
Radio altitude (RA)	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
All flight phases except cruise up to 2 500 ft (Note 1)	***Terrain_Clearance = Radio altitude value for the current location***	'Insufficient terrain clearance'	Terrain_Clearance < 1 000 ft (Note 2)

Note 1: Validity of the radio altitude (RA) parameter.

Note 2: If the aircraft is not on 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 into 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 (RA) measurements which are just below the aircraft;
- the navigation database integration; this will allow to fine-tune which is the correct flight path for each approach and the published altitude limitations.

CFIT04 — Deviation below the glideslope

Summary

Develop means to identify (severe) deviations below the glideslope that increase the CFIT risk.

Rationale

The deviation from the glideslope was already addressed in this document under RE26 'Unstable approach'. All instrument approaches should be stable by 1 000-ft radio altitude (RA) (assuming that the RA indicates the height above the aerodrome elevation) and instrument landing system (ILS) approaches should be stable when intercepting the glideslope well above 1 000 ft. The criterion used was:

- more than 1-dot glideslope deviation.

A large deviation from the glideslope below 1 000-ft 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 on deviation below the glideslope will focus on RA < 1 000 ft.

Aircraft parameters

Parameter	Type
Radio altitude (RA)	Analogue
Flight phase	Discrete
Flight mode annunciator (FMA) mode	Discrete
Glideslope deviation	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
FMA mode or flight phase is either in 'Final approach' or 'Land', and RA is below 1 000 ft	***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)

CFIT05 — Flight management system (FMS) incorrectly set

Summary

Develop means to identify errors in the flight management system (FMS) settings, especially those associated to close-to-terrain operations (e.g. approach in a mountainous area).

Rationale

Wrong FMS inputs are addressed in this document in LOC10 on 'Incorrect performance calculation', and in LOC08 'Centre of gravity (CG) out of limits'. These inputs may also have CFIT consequences, and it is useful to emphasise that the accurate take-off speeds (V_1, V_R and V_2) 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 of 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 in the FDM system navigation information about standard instrument departures (SIDs) and standard terminal arrival routes (STARs) so that deviations from the standard paths to be followed can be identified.

Future developments and recommendations

Any recommendation for this precursor relies on data to be made available to the FDM system, such as:

- automatic measurement of the weight of the aircraft on the ground (initial GW);
- automatic measurement of the centre of gravity on the ground (initial CG);
- 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 bullet points.

CFIT06 — Inadequate vertical mode selections of the aircraft flight control system (AFCS)

Summary

Develop means to identify inadequate vertical mode selections of the aircraft flight control systems (AFCS), especially those associated to close-to-terrain operations (e.g. approach in a mountainous area).

Rationale

The possible misuse of the vertical modes in automatic systems on the aircraft is a subset of the LOC29 precursor, which is dedicated to the *mismanagement of automation*. In the current precursor, it is emphasised that studies should be conducted based on historical data, internal investigations or published accident reports in order to perform an assessment of the abnormal patterns of the autopilot (AP) and the autothrust / autothrottle (AT) modes during take-off and landing. The correct use of the AP and AT modes and their sequence should be taken into account.

The procedure should consist of the following:

- Limit the altitude for this analysis to below 1 000 ft AGL, so that the focus is close to terrain.
- Identify the modes that are abnormal (e.g. climb mode during the approach flight phase).
- Flight crew operation manual (FCOM) / aircraft flight manual (AFM) limitations.
- General standard operating procedures (SOPs) which preclude certain modes (e.g. prohibited use of VS during certain phases of flight).
- Particular RWY-specific procedures.

CFIT07 — Incorrect descent point

Summary

Develop means to identify incorrect descent points.

Rationale

This precursor is closely related to CFIT03 'Flight below minimum sector altitude (MSA)'. The rationale of CFIT03 can be used to overcome the difficulties associated with the accurate determination of the top-of-descent point. This is not a fixed position in the map — it can be rather variable during the day due to ATC constraints or any military activity in the area.

Due to the difficulties associated with the accurate determination of the top-of-descent point, it is not possible to classify in a clear way whether or not it is correct. In this way, this precursor reverts to the minimum terrain clearance considered in CFIT03 'Flight below minimum sector altitude (MSA)'.

CFIT08 — Inadequate terrain awareness and warning system (TAWS) escape manoeuvre

Summary

Develop means to identify escape manoeuvres, after a triggered TAWS alert, which are non-compliant with the correct manoeuvre or airline standard operating procedures (SOPs). Apart from that, approaches with repeated TAWS soft warnings (or just one TAWS warning) should be monitored. Repeated TAWS soft warnings during an approach can evidence that either the aircraft was not safe with regard to the terrain potentially due to the approach procedure design, or that the TAWS needs to be adjusted for that particular approach.

Rationale

The TAWS is composed of a set of modes that identify how close to the ground the aircraft is. 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 (RA) measurement. More recent systems, other than these basic modes, incorporate a terrain database comprising natural terrain elevations and man-made obstacles. These systems can monitor both the proximity to the ground as well as the forward risk collision in the path direction. Each warning has its appropriate flight crew response which can vary with the fleet and/or the 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 perform 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 flight crew are avoided. A proper evaluation of the risk involved in these cases should be performed. It is also recommended that these conclusions be shared with the equipment vendor so that a fine-tuning of the envelope can be performed, when justified.

CFIT09 — Inadequate missed approach and go-around flight path

Summary

Develop means to identify missed approach and go-around flight paths that are non-compliant with published information or airline standard operating procedures (SOPs).

Rationale

For this precursor, we should firstly identify the start point of the missed approach or the go-around. 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 airline procedures 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 the 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. The radio altitude (RA) is also an important parameter caused by the terrain. In the low-altitude situation, the change of the RA should also be greater than the predetermined threshold value. The climb rate and the climb gradient should be positive and greater than the predetermined threshold value.

However, the real flight path can be changed based on ATC instructions. The desired flight path should be known before monitoring.

Required parameters

Parameter	Type	Data sources
Longitude position	Analogue	Aircraft
Latitude position	Analogue	Aircraft
Climb rate	Analogue	Aircraft
Radio altitude	Analogue	Aircraft
Desired heading true	Analogue	SOPs
Desired course	Analogue	SOPs
Climb gradient	Analogue	SOPs
Navigation fix position	Analogue	Navigation database
Terrain height	Analogue	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 height	'Height decrease'	Raise event if ***ChangeOfH*** < Threshold
Missed approach Go-around	***ChangeOfRA*** = Change of radio attitude	'Terrain'	Raise event if ***ChangeOfRA*** < Threshold1 and radio attitude < Threshold2

Note 1: This lateral deviation can also be obtained from the course deviation indicator (CDI). Air traffic controllers (ATCOs) play a big role as regards 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 ATCO instructions.

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 2-engine aeroplanes, not less than 2.4 % for 3-engine aeroplanes, and not less than 2.7 % for 4-engine aeroplanes in the approach phase according to CS 25.121. The climb gradient limit depends on the aircraft configuration and number of engines.

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'. Aircraft declaring an emergency are given priority over other aircraft (provided that a more serious emergency does not occur with 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 practicably possible. If VFR conditions do not exist, the pilot will then continue the route last assigned by the ATC.

Speech communication includes high frequency (HF) and very high frequency (VHF) communication, where HF is a long-range communications system between aircraft, or between aircraft and ground stations, and the VHF communications system supplies two-way voice and data communications between aircraft as well as 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	n/a
VHF_2_FAIL	CAS Caution VHF 2 FAIL	Discrete	n/a
VHF_3_FAIL	CAS Caution VHF 3 FAIL	Discrete	n/a
ATC_CODE	Selected ATC Transponder Code	Decimal	n/a

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

CFIT11 — Low-energy state during approach / unstable approach

Summary

Develop means to identify low-energy states during approach and unstable approach.

Rationale

Energy management per flight phase is covered in LOC13 'Inadequate aircraft energy' and in RE26 'Unstable approach'. This precursor can be considered as a specific case of LOC13 for flight phases close to the ground.

An 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 above-mentioned states could lead to a short or hard landing and there may not be sufficient engine response to counteract any late downdraft in the final approach.

Therefore, this event concerns the following three types of aircraft states:

1. continuously low altitude during the final approach,
2. continuously speed slow during the final approach,
3. Thrust low in the final approach.

Aircraft parameters

Parameter	Type
Glideslope deviation	Analogue
Radio altitude	Analogue
Indicated airspeed	Analogue
Approach target speed (V_{APP})	Analogue
Engine 1/2 N2	Analogue
Flight phase	Discrete
Flight mode annunciator (FMA) mode	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
FMA mode or flight phase is either in 'Final approach' or 'Land', and radio altitude (RA) is below 1 000 ft (500 ft for thrust low)	***GS_Max_Dev_Down*** = Glideslope maximum deviation below the beam ***IAS_Deficit*** = Indicated airspeed deviation from V_{APP} ***THR_Deficit*** = N2_1 and N2_2 deviation from a preset threshold	'Deviation below glideslope' 'Deviation from approach speed' 'Thrust low on final approach'	Raise event if ***GS_Max_Dev_Down*** > Threshold for a certain period of time (e.g. 3 seconds) Raise event if ***IAS_Deficit*** > Threshold Raise event if ***THR_Deficit*** > Threshold for a certain period of time (e.g. 3 seconds) and ***RA*** < 500 ft

CFIT12 — Inadequate response to wind shear warnings

Summary

Develop means to detect inadequate response 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 the on-board avionics systems and indications or crew-assessed scenarios of wind shear based on the changes of wind speed and direction with inputs ranging from weather warnings to other reports related to wind shear conditions. Secondly, it involves the response/actions of the flight crew once they identify wind shear in order to mitigate the risks associated with that condition.

System wind-shear detection: most of the modern aircraft have two types of wind-shear detection systems — the 'predictive wind shear' and the 'reactive wind shear'. The warnings outputs vary so that the flight 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 the wind speed, direction and aircraft attitude and heading excursions point towards wind-shear conditions.

Correct response based on the phase of flight and the wind-shear detection. The main element is the application of maximum thrust available to counter with the onset of loss of speed, monitor the speed trend, and not change the flap or landing gear configuration. When out of wind shear, retract the landing gear and the flaps and increase the airspeed.

Aircraft parameters

Parameter	Type
Wind speed, direction	Analogue
Predictive wind shear warning	Discrete
Reactive wind shear warning	Discrete
Eng (*) Thrust lever position	Analogue/Discrete
Autothrust disconnect discrete	Discrete
Flap lever AND/OR flaps position	Analogue/Discrete
Landing gear lever or landing gear position	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
Take-off / Initial climb	WSHR (wind shear) warning duration Wind speed Wind direction	WSHR detected (time t), check post-response (see Note 1)	Raise event if below conditions are not met. If (WSHR = TRUE), Thrust = Max available Flaps @ WSHR = Flaps @ t + x (s) Gear @ WSHR = Gear @ t + x (s)
Approach / Landing	WSHR warning duration Wind speed Wind direction	WSHR detected (time t), check post-response (see Note 1)	Raise event if below conditions are not met. If (WSHR = TRUE), Thrust = TOGA Flaps @ WSHR = Flaps @ t + x (s) Gear @ WSHR = Gear @ t + x (s)

Note 1: Changes to the thrust are immediate; however, not changing the flaps and landing gear configuration can be dynamic, i.e. based on time or a level-off past a go-around execution.

CFIT13 — Reduced horizontal distance to terrain

Summary

Develop means to identify scenarios of reduced horizontal distance to terrain.

Rationale

This precursor relies on the comparison of the distance between consecutive positions recorded on board the aircraft with respect to the respective altitude from the nearby terrain on the same horizontal plane (Figure 19).

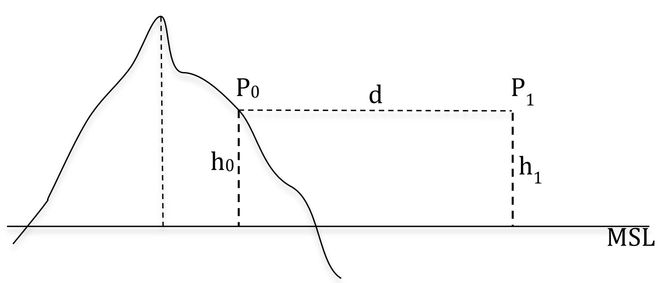

Figure 19 - Terrain position (fixed point P0) and aircraft position (moving point P1)

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 using an external terrain database. The altimetry reference from both aircraft and terrain must be the same. The altitude h_1 from Figure 19 has to reflect the altitude to the mean sea level (MSL), i.e., with the QNH baro correction (ALT_QNH).

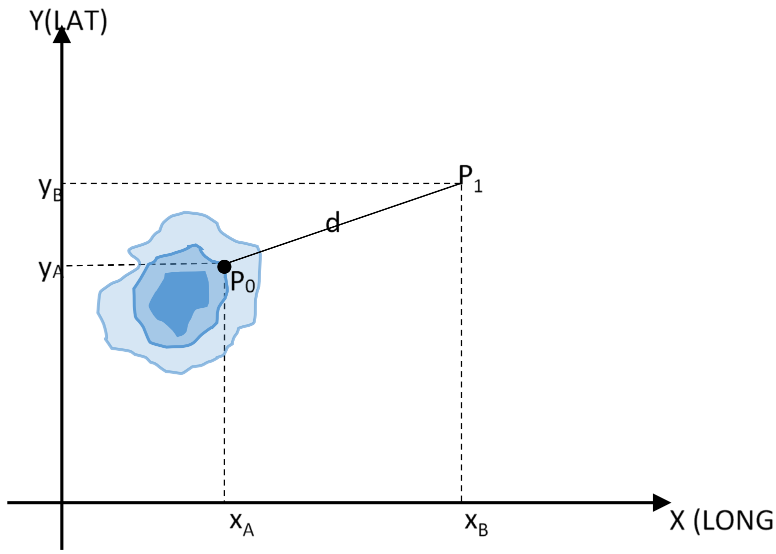

Figure 20 - Terrain and aircraft positions, horizontal view

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[25]. This formula calculates the great circle distance, which approximates the distance between two latitude and longitude points assuming that the Earth is a perfect sphere. However, if we are 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.

For each flight path close to one elevation, one will conduct the calculations for one value for a minimum distance (d_{min}). 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 10 NM[26] of the aircraft position. This can be used to assess the closest proximity to the terrain (Figure 21).

25 See https://en.wikipedia.org/wiki/Haversine_formula.

26 This distance can change according to the air operator's experience.

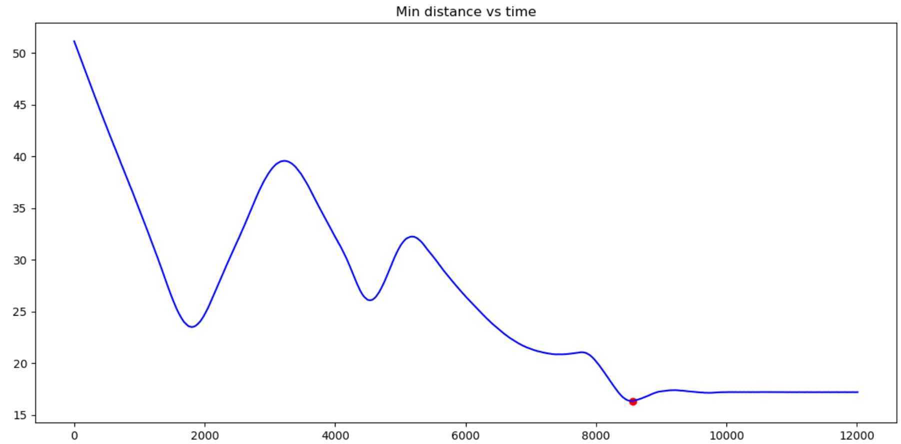

Figure 21 - Minimum distance versus time

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
Altitude standard	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}		

Future developments and recommendations

The values recorded for the 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 the 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 into flight data, which provide more advanced concepts on this area. The first was performed by the Technical University of Munich (TUM)[27] and the second by Instituto Superior Técnico[28].

[27] Technical University of Munich (TUM), Controlled Flight into Terrain Analyses in Flight Data Monitoring, Niclas Bahr (https://mediatum.ub.tum.de/1403391), 2017.

[28] Instituto Superior Tecnico, *Development of a Terrain Awareness Warning System Tool for Aircraft Operation Monitoring*, Miguel Melo Mata, 2018 (https://fenix.tecnico.ulisboa.pt/cursos/meaer/dissertacao/1409728525632609).

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 'Reduced horizontal distance to terrain') from the university studies presented, will be used to develop the rationale for this precursor. The following definitions introduce the concepts that will be used in this precursor.

Definitions[29]

'Map': In the current context, map refers to the set of grid terrain cells, each one with a corresponding altitude. This is available through a terrain database[30].

'Flight path map': The set of all the terrain cells that are necessary to cover the flight path completely (Figure 22).

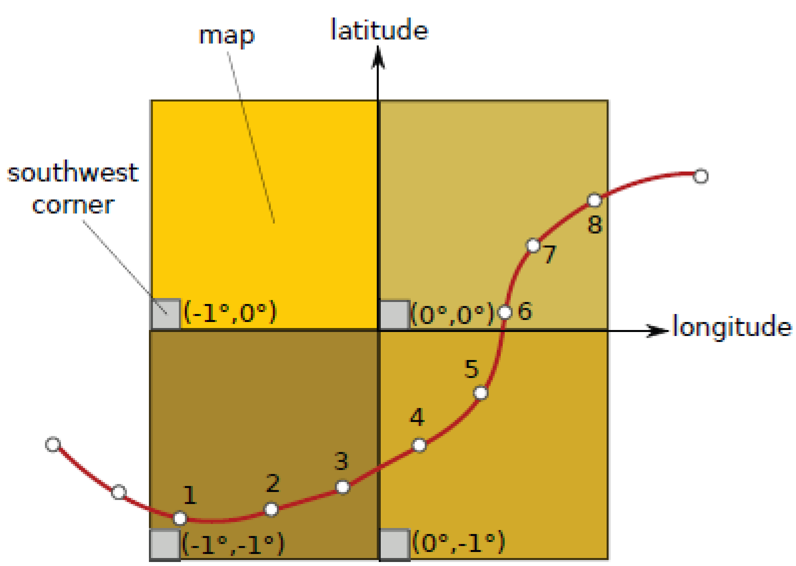

Figure 22 - Flight path map

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[29] Credit for the images used in this section: Technical University of Munich (TUM), *Controlled Flight into Terrain Analyses in Flight Data Monitoring*, Niclas Bahr, 2017 (https://mediatum.ub.tum.de/1403391).

[30] A comparison between the different terrain databases can be found in the WGA document 'Review of controlled flight into terrain (CFIT) precursors from an FDM perspective'.

'CFIT trajectory': Defined as the trajectory tangent to the flight path in the direction of the speed vector. This is the escape trajectory if there was no aircraft control.

'Time to impact': The shortest time during 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 address this precursor (see
Table 2 — Sequence of procedures).

Table 2 — Sequence of procedures

Procedure	Description	Input	Output
#1	Extract the cells from the terrain database to determine the flight path map	Aircraft position (LAT, LONG)	Set of cells from the terrain database that are covered by the flight path
#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 (LAT, LONG) Speed vector	CFIT trajectory
#5	Calculate the CFIT trajectory altitudes (Note 3)	CFIT trajectory	CFIT trajectory altitudes
#6	Determine the CFIT trajectory terrain cells	CFIT trajectory	CFIT trajectory cells
#7	Extract the CFIT terrain cells altitudes	CFIT trajectory cells	Altitudes from the CFIT trajectory cells
#8	Check whether 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:

$$\mathbf{v} = GS * \begin{pmatrix} cos(track\ angle) \\ sin(track\ angle) \\ tan(fligh\ path\ angle) \end{pmatrix}$$

Note 2: The CFIT trajectory is a tangent line to each new position on the flight path. This line is determined using the speed vector to calculate the next position for the CFIT trajectory. This is a potential trajectory corresponding to the escape path from the real aircraft trajectory (flight path). In the formula below, P_n is the next position (LAT, LONG), P_{n-1} is the previous position, and the function tau (τ) is to convert the result of v.Δt from metres to degrees (more details can be found in the TUM work).

$$P_n = P_{n-1} + \tau(\mathbf{v.\Delta t})$$

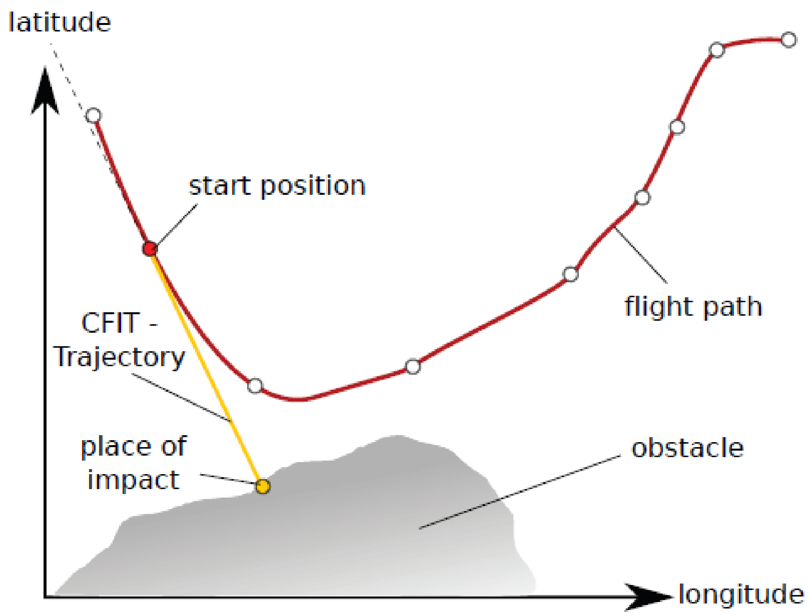

Figure 23 - CFIT trajectory

In order not to extend this calculation indefinitely, it is considered that it can be performed for 60 seconds. This value is a design parameter; the operator may adjust it according to its experience and specific needs.

Note 3: The computation of the CFIT trajectory altitudes is based on a start position. This point is obtained from the position parameters (LAT and LONG) 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's 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 three-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 refers 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
Altitude standard	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. The implementation of this idea can be found in the work developed by Instituto Superior Técnico, 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.

CFIT15 — Low climb gradient

Summary

Develop means to identify scenarios of a reduced climb gradient.

Rationale

The 'Low climb gradient' is proposed to be derived out of the measurement of the time it takes for the aircraft to reach 1000ft,.This is an indirect approach to evaluate the climb gradient with a simple calculation. This will reflect the climb gradient as this time may increase if the aircraft is in one of the possible situations:

- overweighted
- incorrect thrust
- incorrect configuration

In addition, one event can be defined using this measurement. This precursor may be used to complement existing events that monitor weight, thrust and configuration, but in this case, making use of the final outcome, i.e., the climb performance of the aircraft. It also has the potential to monitor the obstacle avoidance during the climb,

Aircraft parameters

Parameter	Type
Altitude standard	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
From Lift-off until Alt STD = 1000ft	**TIME1000** = Elapsed time from lift-off until ALT STD is 1000ft	'Low climb gradient'	Raise event if TIME1000 > Threshold

MID-AIR COLLISION (MAC)

Mid-air collision (MAC) is defined in the document 'Aviation Occurrence Categories'[31] developed by the CAST/ICAO Common Taxonomy Team.

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 pilots. Dealing with MAC incidents in the operators' FDM program relies not only on the data available on the operators' aircraft, but also on external data. The analysis of this type of incidents is greatly enhanced by collecting the data from the second aircraft involved in the incident, which may be normally difficult. The information provided by the air navigation service providers (ANSPs) is also paramount for the correct evaluation of the risk involved in one of these incidents. Another source of complementary information for this type of incident is the one inside the memories of the TCAS avionics boxes, which contain the log of each event with information that is not normally available on the recorded data, such as:

- intruder altitude / altitude rate,
- intruder range / range rate,
- intruder bearing,
- position,
- advisory type,
- both own and intruder displayed and aural warnings,
- vertical speed limits,
- intruder Mode S address,
- minimum approach point (also known as 'closest point of approach').

This information is indicative and different TCAS systems may provide parameters equivalent to those provided in the list above.

[31] The document is available at http://www.intlaviationstandards.org/Documents/OccurrenceCategoryDefinitions.pdf.

MAC01 — Incorrect altimeter setting or incorrect transition timing

Summary

Develop means to detect incorrect altimeter settings or incorrect transition timing, which could lead to situations of increased mid-air collision (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.

Where possible, the operator should have access to the altitude recordings from different sources, i.e. all the systems that can provide the altitude, typically the captain (system 1), the first officer (system 2) and standby (system 3). 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 Europe, no specific altitude is prescribed for this transition to occur. It is expected to happen within the 5 000 to 8 000-ft range. This information can be used as a base to search for this transition until the top of climb (ToC) and from the top of descent (ToD). This procedure excludes the cruise flight phase and concentrates the search on the climb and descent phases.

For US operations, the search can be simplified, starting after the ToD at 18 000 ft ± 500 ft where the reference should change from STD to QNH.

To tackle this precursor, some external data has to be made available to the FDM, so that the weather data is available. These can be:

- METARs,
- Flight plan.

Aircraft parameters

Parameter	Type
Altitude standard	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

MAC02 — Lateral deviation

Summary

Develop means to detect situations where the actual flight trajectory deviates from the published, cleared or intended trajectory.

Rationale

Deviations from the flight path may occur without consequences in most regions of the globe, except for dangerous or temporarily 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 be available in order to compare the path from the aircraft and with that 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 the lateral deviation is a way to verify compliance with SIDs and STARs.

Aircraft parameters

Parameter	Type
Latitude	Analogue
Longitude	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
TBD	TBD	TBD	TBD

Future developments and recommendations

TBD

MAC03 — Flight level bust

Summary

Develop means to identify flight level busts, i.e. situations where the cleared and intended altitude or flight level is overshot during climb or undershot during descent.

Rationale

Relying only on the FDM to achieve a wide-ranging solution for identifying level busts presents 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 flight crew is the intended clearance altitude or flight level, 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 the climb, cruise and descent flight phases. The proposal from WGB is 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 flight crew in the autopilot control panel[32] while monitoring the corresponding altitude of the aircraft during climb or descent.

Example 1: *Situations of increased MAC risk. While climbing to cruise altitude, the flight crew selects FL380 in the autopilot control panel. If the aircraft overshoots the selected altitude by 500 ft, it is considered a level bust.*

The second type of precursors monitor unexpected aircraft behaviour with regard to altitude selection (for example, crew not following changes to altitude selection).

Example 2.1: *After top of descent at FL380, the flight 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 flight crew selects FL360 and maintains altitude during a threshold period after the selection of the new altitude.*

Note that these apparently unexpected behaviours may be legitimate reactions to external factors, for example ACAS warnings or ATC requests. If this is the case, the event should be invalidated. Also, the altitude reference used by the flight crew should be the altitude being monitored, either STD/QNH/QFE. Changes in the barometric reference or in the flight level (FL) 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.

[32] In the Airbus terminology, this refers to the 'flight control unit (FCU)'.

Aircraft parameters

Parameter	Type
Altitude STD/QNH/QFE	Analogue
Barometric reference selection (STD/QNH/QFE)	Analogue
Altitude selected	Analogue
Inertial vertical velocity	Analogue

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 and 2)
Descent	***ALT*** = Altitude ***ALT_SEL*** = Altitude selected ***IVV*** = Inertial vertical speed	'Flight level undershoot'	Raise event if (***ALT*** – ***ALT_SEL***) < Threshold ***AND*** abs(IVV) < Threshold (see Notes 1 and 2)
Climb Cruise Descent	***ALT*** = Altitude ***ALT_SEL*** = Altitude selected ***IVV*** = Inertial vertical speed ***DeltaALT* = abs(*ALT* – *ALT_SEL)***	'Altitude misbehaviour during climb/descent'	Raise event if ***DeltaALT*** increases over time ***AND*** abs(IVV) > Threshold ***DURING*** Threshold (see Notes 1, 2 and 3)
Climb Cruise Descent	***ALT_SEL*** = Altitude selected ***IVV*** = Inertial vertical speed	'Altitude misbehaviour after altitude selection change'	Raise event if ***ALT_SEL*** changes ***AND*** abs(IVV) < Threshold ***DURING*** Threshold (see Notes 1, 2 and 4)

Note 1: The 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 be triggered 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 already, the major challenge in monitoring flight level busts via the FDM is not having access to the ATC clearance given and relying only on the altitude selection by the flight crew. However, as the FDM develops technologically, it might be possible in the near future to have such data and monitor these types of events with more sources of information. As a final note, one should take into consideration the fact that there are external occurrences during aircraft operation, such as TCAS warnings or severe turbulence, which may trigger one of these level bust events. While they are not directly related to aircraft attitude misbehaviour, each airline should treat these events according to its own internal policies and EOFDM recommendations.

MAC04 — High rate of climb/descent

Summary

Develop means to identify climbs and descents with high rates. Due to the trigger logic of ACAS alerts, high rates can lead to the generation of nuisance alerts (see MAC08 'Airborne collision avoidance system (ACAS) alerts').

Rationale

Some information regarding the control of the rates of descent or climb to avoid unnecessary resolution advisories (RAs) is presented at 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 levelling of the aircraft. The use of the vertical speed mode to approach a flight level depends both on the 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 flight 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 1 000 ft before the level is attained. Any abnormal level should be identified.

Aircraft parameters

Parameter	Type
Vertical speed (Note 1)	Analogue
Latitude	Analogue
Longitude	Analogue
Altitude standard	Analogue

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 1 000 ft)	'High rate of climb/descent'	Vertical speed > Threshold

MAC05 — Inadequate use of automation

Summary

Develop means to identify situations of inadequate use of automation related to the aircraft trajectory.

Rationale

The mismanagement of automation is already addressed in LOC29 in the context of 'loss of control in-flight (LOC-I)'. The same kind of analysis is applied in the case of mid-air collision (MAC).

In addition to the LOC29 text, it is important to assess to what extent the flight crew follows the indications in the flight director bars. For manual manoeuvres supported by the flight director, the divergence from the indications may lead to MAC events.

If the flight mode annunciator (FMA) parameters are recorded (usually only the ACTIVE modes, not the ARMED modes), then the comparison between the modes and the other air data is possible.

e.g.: FMA says CLIMB but vertical speed is – 1 000 fpm for > 3 seconds.

e.g.: FMA says TOGA but THR LVR is at 22 degrees for > 3 seconds.

Aircraft parameters

Parameter	Type
Flight Director — Pitch (FDPITCH)	Analogue
Flight Director — Roll (FDROLL)	Analogue
Pitch (Note 1)	Analogue
Roll (Note 1)	Analogue
Flight Director status (Note 2)	Discrete
FMA modes	Discrete

Note 1: Alternatively, the pitch and roll command parameters from the side stick or column can be used.

Note 2: The parameter providing the information whether the flight director is ON or OFF.

Measurements and events

Search window	Measurements	Event	Event threshold
Flight director status ON	DeltaPitch = FDPITCH – PITCH DeltaRoll = FDROLL – ROLL	'Pitch flight director not followed' 'Roll flight director not followed'	DeltaPitch > Threshold DeltaRoll > Threshold

MAC06 — Automatic altitude control system OFF in reduced vertical separation minima (RVSM) conditions

Summary

Develop means to identify situations of inappropriate settings of the automatic altitude control system in reduced vertical separation minima (RVSM) conditions.

Rationale

RVSM-defined altitudes are between FL290 and FL410.

Detailed information can be found at:
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 address this precursor, it is proposed to set the altitude at 20 000 ft to detect whether the autopilot disengages above that flight level. This includes all the flight levels from the RVSM.

Aircraft parameters

Parameter	Type
Altitude standard	Analogue

Measurements and events

Search window	Measurements	Event	Event threshold
Altitude > 20 000 ft (Note 1)	Autopilot disengaged	'Autopilot disengaged above 20 000 ft'	n/a

Note 1: Using the triggering altitude down to 20 000 ft, then the precursor is not only linked to RVSM altitudes, but to all cruise altitudes.

MAC07 — Last-minute changes to standard instrument departures (SIDs) and standard arrival routes (STARs)

Summary

Develop means to identify last-minute changes to standard instrument departures (SIDs) or standard arrival routes (STARs) (possibly in combination with MAC02 'Lateral deviation').

Rationale

Last-minute changes to SIDs or STARs could be due to reasons that are independent of the flight crew (ATC, traffic advisories (TAs)) and may be performed to prevent hazardous situations such as mid-air collision (MAC). Therefore, the monitoring of the change to the SID and the STAR alone may not be enough and should be linked with other monitoring such as of TA alerts (MAC08).

All the possible solutions identified by WGB had serious limitations and leave no space for the proposal of a solid one. The possible ways and limitations are as follows:

1. Some fleets allow the recording of the waypoints from the FMS. This is data that could be compared with the messages from the control–pilot data link communications (CPDLC). The names of SIDs and STARs are present in this system.

   Limitations:

   - Recording of the FMS parameters[33];
   - Capture of the CPDLC messages[34].

2. Reverse engineer from the flight path to identify a possible SID/STAR by the NAV charts.

   Limitations:

   - Requires one database of SIDs and STARs to be maintained in the FDM system (all the updates incorporated).

Aircraft parameters

Parameter	Type
TBD	TBD

Measurements and events

Search window	Measurements	Event	Event threshold
TBD	TBD	TBD	TBD

33 The normal contents of the data frames do not include the FMS parameters that are necessary to address this precursor.

34 Despite the identified advantage of using the CPDLC parameters to address this precursor, these parameters are not normally available in the data frames from the WGB members' fleets.

Future developments and recommendations

It is recommended, in order to address this precursor, that the maximum information from the FMS be included in the data frame, in particular the parameters from the flight plan (waypoints, etc.).

MAC08 — Airborne collision avoidance system (ACAS) alerts

Summary

Monitor every safety-relevant information with respect to the airborne collision avoidance system (ACAS) that is available within the FDM. In particular, resolution advisories (RAs) shall be identified and further investigated in detail.

Rationale

When an ACAS warning is detected by the FDM system, it is assumed that the operator will proceed with a post-analysis of each event in order to observe the expected behaviour as a reaction to each warning. In this case, the support for this analysis is maximised if the information presented in the bullet points below is available to the analyst.

- All the ACAS modes are part of the recorded parameters.
- Support information should be produced for the analysis of RAs, such as:
  - RA warning duration,
  - RA reaction delay,
  - RA-to-AP disengagement time,
  - RA direction,
  - RA acceleration,
  - RA change of vertical speed,
  - compliance with the vertical speed band margins,
  - RA warning and AP not disconnected,
  - TA warning and FD not switched off.

Also, the TAs should be monitored, more specifically if there was inadvertent command from the pilot as a result of this warning.

In addition, for the operator to assess the hotspots for its operations, it is recommended to monitor the TCAS warning locations, both for TAs and RAs, through the use of the position parameters and plot those parameters on a map, so that all the locations on the globe are clearly identified.

Aircraft parameters

Parameter	Type
All ACAS modes	Discrete
Latitude	Analogue
Longitude	Analogue
AP (*) engaged	Discrete
Flight director	Discrete

Measurements and events

Search window	Measurements	Event	Event threshold
After the RA warning was issued	RA warning duration	n/a	n/a
After the RA warning was issued	RA reaction time (Note 1)	'High reaction time to RA warning'	RA reaction time > Threshold (Note 2)
After the RA warning was issued	Time from RA to AP disengagement	'High AP disengagement time after RA warning'	AP disengagement time > Threshold
After the RA warning was issued	AP1, AP2, FD1, FD2 @ time the RA was issued	'ACAS-AP' (Note 3)	n/a
After the RA warning was issued	AP1, AP2, FD1, FD2 @ time the RA was issued	'ACAS-FD' (Note 3)	n/a

Note 1: Calculated as the difference between the time at which the RA was issued and the first input from the pilot as a reaction to it.

Note 2: Expected reaction time is typically 3 seconds (may be SOP or fleet dependent).

Note 3:

ACAS — AP NOT DISENGAGED

ACAS — FD NOT SWITCHED OFF

Once an ACAS event is detected, check within 10 seconds whether the autopilot (AP) is disengaged or whether the flight director (FD) is switched off. If not, raise an ACAS-AP or an ACAS-FD event.

If the ACAS ALERT value can be accessed, you can decode it and check the *vertical speed* for a CLIMB OR DESCENT OR NO_CHANGE value after '5 seconds'.

MAC09 — Inappropriate airborne collision avoidance system (ACAS) settings

Summary

Develop means to monitor the settings of the airborne collision avoidance system (ACAS) and to verify their suitability.

Rationale

The precursor LOC27 'Hardware failure' already contemplates the case when the ACAS unit is in failure. Although this is important to monitor, the current precursor directs us to inappropriate ACAS control panel selections that disable the ACAS system to perform the due protection of the aircraft, in particular the detection of the selections:

- ACAS mode standby,
- ACAS mode TA only,
- altitude reporting OFF,
- transponder SWITCHED OFF.

Depending on the fleet or the ACAS system installed on the aircraft, the range selection can also be inappropriate for the surrounding traffic to be properly displayed.

The detection of these configurations and ranges provides information to the analyst to realise in which circumstances the configuration was disabling some functionalities of the ACAS system and decide about its proper use.

Aircraft parameters

Parameter	Type
ACAS panel selections (Note 1)	Discrete

Note 1: If these parameters are not available in the data frame, this can be left for future developments and identification of the missing parameters required for the FDM analysis. Alternatively, for fleets that have this capability, this can be part of the data frame customisation.

Measurements and events

Search window	Measurements	Event	Event threshold
Whole flight	n/a	Any of the ACAS panel selections SBY TA ONLY ALT RPT OFF XPDR OFF (Note 1)	n/a

Note 1: The selections may differ depending on the ACAS system installed on the aircraft.

Annex 1 — Accurate position computation

Summary

Many monitoring algorithms are linked to a good estimation of the aircraft position. Depending on what 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** has led Working Group B (WGB) to create this specific annex in order to present some ideas on the 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 the geographical position data.

Possible sources for the position parameters are:

- IRS[35],
- 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 figures, which show the position parameters from the same flight from each of these systems.

[35] In most recent fleets, it is associated with the air data computer (ADC) and is named 'ADIRS'.

IRS

Figure 24 - IRS Position (Illustration for a specific aircraft)

GNSS

Figure 25 - GNSS Position (Illustration for a specific aircraft)

FMS

Figure 26 - FMS Position (Illustration for a specific aircraft)

For capturing any geographical position data, it is recommended that the relevant parameter (i.e. latitude or longitude) be 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:

$$0.001^{o} \approx 111M\ resolution$$
$$0.00001^{o} \approx 1M\ resolution$$

Some developments of these concepts are available in the presentation from Joachim Siegel, Lukas Höhndorf, on EOFDM Conference 2016, named '**Landing Trajectory and Touchdown Point Reconstruction**'[36].

[36] This presentation can be found in the 'EVENT PROCEEDINGS' section at 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 recommended parameters presented in this Annex 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
- **Units:** 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 (AMC) and Guidance Material (GM) to point CAT.IDE.A.190 'Flight data recorder'[37] of Annex IV (Part-CAT) to the Air Operations Regulation[38]. It is important to note that the FDR and its contents are mainly to be used by safety investigation authorities (SIAs) in case there is an accident or a serious incident. The table provided in this annex should not be confused with the list of mandatory parameters as provided in the applicable regulations; the purpose of the parameters described here is to support the FDM programmes, in particular the precursors described in this document.

Despite the fact that the FDR was not originally intended to support flight data monitoring (FDM), some operators rely on it to perform their daily FDM analyses. Due to the fact that this data frame was conceived initially for accident investigation purposes, it has some limitations in terms of existence, sampling rate and resolution of some of the parameters. The goal of the FDM analysis is different, i.e. it uses the data to detect precursors from unsafe situations and avoid in this way that accidents happen again. In order to achieve this goal, and for operators to be able to rely on data frame customisation to adapt their data, the FDM needs to use other on-board recorders such as the 'quick access recorders (QARs)' or similar. In this case, the FDR data frame should always be used as a baseline and any customisation should be built on top of this set of data to increase its contents. All the performance specifications in the tables below are as stringent or more stringent than the FDR parameters performance specifications contained in the AMC and GM to CAT.IDE.A.190 'Flight data recorder'.

For those fleets that do not allow this kind of customisation, aircraft manufacturers should keep in mind the dual use of the data recorded in the FDR and may use the list of parameters of this annex as a reference when creating the FDR's data frame. This is especially valid for new aircraft which also benefit from the new technologies available for sensor data transmission and recording of parameters.

The parameters described in this annex are recommendations that result from the Best Practices identified by the EOFDM members to support all the precursors described in this document. They are not intended to be prescriptive.

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[37] https://www.easa.europa.eu/regulations#regulations-air-operations

[38] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (OJ L 296, 25.10.2012, p. 1) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1585563757916&uri=CELEX:32012R0965).

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	n/a	n/a	D
Excessive cabin altitude warning	1	n/a	n/a	D
Excessive high differential pressure warning	1	n/a	n/a	D
Excessive negative differential pressure warning	1	n/a	n/a	D
Mode SEL P/B MAN	1	n/a	n/a	D

Autoflight — ATA 22

Description	Rate Hz	Units	Resolution	Type
Altitude selected	1	ft	64	A
FMS_Temp[39]	1	°C	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	2	n/a	n/a	D
Speed brakes armed	1	n/a	n/a	D
Pitch trim position	1	deg	0.09	A
Flap/slat lever angle	1	deg	0.04	A
Flap/slat lever position	1	n/a	n/a	D
Flap angle	1	deg	n/a	A
Slat angle	1	deg	n/a	A
Rudder	8	deg	0.09	A
Rudder pedal	4	deg	0.09	A
Angle of attack (*)	1	deg	0.09	A
Envelope protection system	1	n/a	n/a	D
Pitch command (column or side stick)	8	deg	0.09	A
Roll command (column or side stick)	8	deg	0.09	A
Control column force	TBD	TBD	TBD	TBD
Control column	TBD	TBD	TBD	TBD

[39] The temperature that is inputted in the FMS before take-off. It can be OAT or FLEX, or other, depending on the fleet.

Control wheel force	TBD	TBD	TBD	TBD
Elevator actuator/quadrant	TBD	TBD	TBD	TBD
Elevator surface	8	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	n/a	n/a	D
Icing AoA	1	n/a	n/a	D
Icing detected	1	n/a	n/a	D

Instruments — ATA 31

Description	Rate Hz	Units	Resolution	Type
Master warning	1	n/a	n/a	D
Master caution	1	n/a	n/a	D
Acceleration longitudinal	4	g	0.004	A
Acceleration lateral	4	g	0.002	A
Acceleration normal	8	g	0.004	A
Smoke avionics (*) warning	1	n/a	n/a	D
Smoke cargo (*) warning	1	n/a	n/a	D
Smoke lavatory (*) warning	1	n/a	n/a	D
Wind shear warning	1	n/a	n/a	D
Wind shear caution				
HGG/TRK P/B selection (VS/FPA)	1	n/a	n/a	D

Landing gear/wheels and brakes — ATA 32

Description	Rate Hz	Units	Resolution	Type
Brake (*) temperature	1	°C	1	A
Brake (*) pressure	1	psi	1	A
Brake (*) pedal position	1	deg	1	A
Autobrake selection	1	n/a	n/a	D
Main landing gear (*)	4	n/a	n/a	D
Nose landing gear	4	n/a	n/a	D
Nose-wheel steering fault	1	n/a	n/a	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 (GW)	1	kg	18.14	A
Indicated airspeed (IAS)	1	kt	0.25	A
Ground speed (GS)	2	kt	1	A
Airspeed true	1	kt	0.5	A
Approach target speed (VAPP)	1	kt	0.25	A
V_1	1	kt	0.25	A
V_2	1	kt	0.25	A
V_R — Rotation speed	1	kt	0.25	A
Pitch rate	4	deg/s	0.06	A
Latitude	1	deg	1.7e-4	A
Longitude	1	deg	1.7e-4	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[40]	0.2	A
Glideslope deviation	4	dots[41]	0.4	A
Vertical speed	4	ft/min	16	A
Pitch	4	deg	0.09	A
Roll	4	deg	0.09	A
Radio altitude (RA)	4	ft	0.5	A
Landing elevation (FMC)	1	ft	8	A
Centre of gravity (CG)	1	%MAC	0.01	A
Mach number	1	MACH	0.001	A
Total air temperature (TAT)	1	°C	0.25	A
Static air temperature (SAT)	1	°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 wind shear warning	1	n/a	n/a	D

Note 1: Alternatively, the barometric correction can be recorded and applied to the altitude standard parameter to derive either the ALT_QNH or the ALT_QFE.

Oxygen — ATA 35

Description	Rate Hz	Units	Resolution	Type
Oxygen low pressure	1	n/a	n/a	D

Auxiliary power unit (APU) — ATA 49

Description	Rate Hz	Units	Resolution	Type
APU fire	1	n/a	n/a	D

[40] Alternatively, mDDM.

[41] Idem.

Power plant — ATA 7X / 8X / 9X

Description	Rate Hz	Units	Resolution	Type
Eng (*) thrust lever angle	2	deg	0.04	A
Eng (*) thrust lever position	1	n/a	n/a	D
Eng (*) engine pressure ratio	1	n/a	TBD	A
Eng (*) N1	1	%	0.06	A
Eng (*) N2	1	%	0.13	A
Eng (*) N3	TBD	TBD	TBD	TBD
Eng (*) fire warning	1	n/a	n/a	D
Eng (*) oil temperature	1	°C	1	A
Eng (*) oil pressure	1	psi	2	A
Eng (*) oil quantity	1	quart	0.25	A
Eng (*) exhaust gas temperature	1	°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	n/a	n/a	D
FADEC system fault warning	1	n/a	n/a	D
Eng (*) Nh	TBD	TBD	TBD	TBD
Eng (*) Np	TBD	TBD	TBD	TBD
Eng (*) torque	TBD	TBD	TBD	TBD