European Union Aviation Safety Agency

This project has received funding from the European Union's Horizon 2020 Programme

RESEARCH PROJECT EASA.2020.C43

QUICK RECOVERY OF FLIGHT RECORDER DATA (wireless transmission)

Report D6.1

Simulation of Technical Solutions

An Agency of the European Union

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DELIVERABLE NUMBER AND TITLE:	QR-FRD D6.1 Simulation of Technical Solutions
CONTRACT NUMBER:	EASA.2020.C43
CONTRACTOR / AUTHOR:	Collins Aerospace / Safran E&D / B. de Courville Consulting
IPR OWNER:	European Union Aviation Safety Agency
DISTRIBUTION:	Public

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DATE: 12 July 2022

REPORT D6.1

Simulation of Technical Solutions

Submitted to:

EASA

European Union Aviation Safety Agency

Cologne, Germany

Document Information	
Customer reference	EASA.2020.HVP.06
Project Title	Quick Recovery of Flight Recorder Data
Contract number	EASA.2020.C43
Consortium	Collins Aerospace / Safran E&D / B. de Courville Consulting
Task Number	06
Task Title	Simulation of Technical Solutions for automatic wireless transmission of flight recorder data
Deliverable Name	D6.1 - Simulation of Technical Solutions
Edition	01
Milestone Due Date	July 12th, 2022
Dissemination Level	Public

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1 INTRODUCTION

1.1 QR-FRD Study Presentation

"The overarching objective of the Quick Recovery of Flight Recorder Data (QR-FRD) study is to identify and assess technical solutions for the automatic wireless data transmission to quickly recover flight recorder data after an accident in a remote land area or an oceanic area for the purpose of faster understanding of the causal and contributory factors of an accident" (EASA QR-FRD CFT, [Ref 6]).

The overall objectives of the project are to identify and to assess a series of candidate solutions for the wireless transmission of flight recorder data from commercial air transport aircraft in case of an accident (or a serious incident) in a remote land area or an oceanic area while considering thoroughly the challenges, constraints and limitations of each technical solution and the challenging conditions of an accident (or a serious incident). The evaluation of the candidate solutions will address the technical feasibility and maturity, the performance, the related constraints as well as the cost indicators in comparison to current flight data recorder installations.

The aircraft considered for the study are modern commercial air transport aircraft with a maximum take-off mass of over 27 tons, equipped with redundant combined flight data recorder (FDR) – cockpit voice recorder (CVR) capable of recording flight data, flight crew and cockpit area microphone audio, data link messages as well as, depending on the type certificate, flight crew – machine interface recordings (ICAO Annex 6 Part I, Section 6.3, [Ref 7]), and mandated to have a Flight Recorder Data Recovery (FRDR) means on-board.

A further investigation of the performance levels achievable will be carried out by developing several simulation exercises for two of the candidate solutions, applying representative operational conditions for aircraft accidents (and serious incidents) and aiming at analyzing the options for recovering the most useful data. In addition, the legal implications associated to the wireless transmission of flight recorder data, considering the existing data protection frameworks and the related ICAO Annex 13 provisions will be investigated.

The results of the feasibility project, together with the practical recommendations for the implementation of the candidate solutions, will be presented to a group of stakeholders involved in accident investigations and consolidated with the feedback received.

The activities undertaken within the QR-FRD study, and their respective documented outcomes are the following:

1. Task 1 - Accident conditions relevant for wireless flight recorder data transmission:
    - **Objective**: Identify and describe the technical and environmental factors which might affect the aircraft, its engines and its systems during the accident flight, and which need to be taken into account for maximizing the chances of successful wireless transmission of flight recorder data.
    - **Outcome**: A report (D1) of accident conditions which might affect the successful wireless transmission of flight recorder data (e.g., loss of power or equipment, excessive roll or pitch angles, in-flight fire, ditching …), and explaining the impact of such factors. that describes the considered factors.

2. Task 2 - Overview of technical solutions for automatic wireless transmission of flight recorder data:
    - **Objective**: perform a screening of possible technical solutions for automatic wireless transmission of flight recorder data (flight data, audio and flight-crew interface recordings, data link messages…) in case of an accident (or serious incident) in a remote land area or an oceanic area.
    - **Outcome**: A solution overview report (D2) identifying the necessary technologies and capabilities of the communication infrastructure, as well as aspects not yet mature, and discussing the potential effects of factors listed in D1 on the presented solutions. In addition, D2 will recommend the 2 most relevant technical solutions for further investigation to be performed under Task 3.
3. Task 3 - Technical investigation of two technical solutions for automatic wireless transmission of flight recorder data:
    - **Objective**: perform a technical investigation of the two most relevant technical solutions as identified in Task 2 and assess their performances for the automatic and wireless transmission of the data required to be recorded and retained by crash-protected flight recorders.
    - **Outcome**: A study report (D3) presenting technical solutions and detailing the two selected technical solutions (concept of operation, data transmission trigger logic (e.g., continuous or triggered), airborne functions and equipment, performance, communication infrastructure…).
4. Task 4 – Assess challenges and limitations of two technical solutions:
    - **Objective**: Assess the challenges and limitations of both technical solutions presented in Task 3 and comparison of their expected performance.
    - **Outcome**: An evaluation report (D4) of challenges and limitations addressing main technological enablers and their respective levels of maturity, reliability of main functions, impacts on flight crew procedures, ground handling and maintenance, as well as airline operations…
5. Task 5 – First consultation of the stakeholder's group:
    - **Objective**: Obtain the feedback of a group of stakeholders (accident investigation authorities, aviation regulators, operators of large commercial aircraft, associations of commercial pilots) on works performed under Tasks 1 to 4, with a view to incorporate this feedback into the analyses and assessments and to update the corresponding reports.
    - **Outcome**: A stakeholder feedback report (D5) containing the composition of the group of stakeholders, comments and questions raised by the stakeholders and replies as well as changes made to the different reports (D1 to D4).
6. Task 6 – Simulation of technical solutions:
    - **Objective**: Prepare an experimental set-up for the performance assessment of the two solutions investigated in Task 3, in particular for the comparison of the respective transmitted dataset (volume, accuracy, completeness, consistency) including reliability and robustness to factors identified in Task 1.
    - **Outcome**: A simulation report (D6) containing the detailed description of the performed simulations, as well as graphics showing the variation in performance when parameters (pitch and roll angles/rates, altitude, location of the aircraft…) are varied.

7. Task 7 - Scenario-based study of legal aspects:
   - **Objective**: Assess the legal aspects of data transmission over assets located on the territories of several countries or in space, in order to identify possible inconsistencies with ICAO Annex 13, legal uncertainties and risks for the protection of flight recorder data.
   - **Outcome**: A legal study report (D7) describing the legal framework applicable to the various assets of the communication infrastructure by which data will be transmitted or processed or recorded, scenarios of accidents in various places and with various setups, the potential issues for the protection and the transmission of data to the competent safety investigation authority, as well as proposals to ensure that the transmission service provider and the recipient of the flight recorder data are legally responsible for the preservation and the protection of transmitted flight recorder data.
8. Task 8 – Second consultation of the stakeholder's group and additional simulation work:
   - **Objective**: Obtain the assessment of a group of stakeholders on the report resulting from Tasks 6 and 7, with a view to incorporate this feedback, to run where necessary complementary simulations and to update the simulation report.
   - **Outcome**: A stakeholder feedback report (D8) containing the composition of the group of stakeholders, comments and questions raised by the stakeholders and replies as well as changes made to the different reports (D6 and D7), and possibly simulations and code.
9. Task 9 – Conclusions and way forward:
   - **Objective**: Conclude on the concept of automatic wireless transmission of flight recorder data in case of an accident and propose a way forward.
   - **Outcome**: A final report (D9) containing a general reflection on the works performed during the project, the feedback and recommendations received during the stakeholder meetings, the aspects of the concept of automatic wireless transmission of flight recorder data remaining to be explored or showing very challenging issues, a proposed approach for the development of compliance means and material in order to facilitate the performance demonstration to competent authorities, as well as practical recommendations to progress the maturity of this concept and prepare their implementation.

The figure below depicts the overall approach taken for the QR-FRD study and the relationship between the different deliverables.

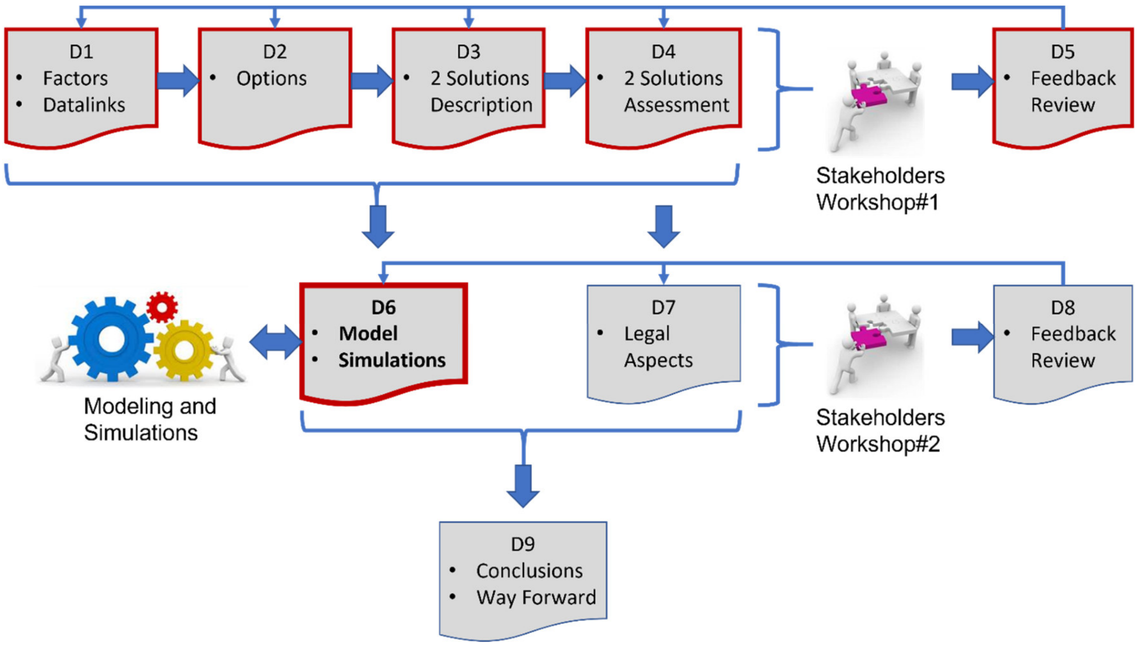

Figure 1: QR-FRD Study Approach and Deliverables Relationship

1.2 Scope of this report

The present report summarizes analysis and findings from Task 6 “Simulation of Technical Solutions of the two solutions” of the Quick Recovery of Flight Recorder Data (QR-FRD) study.

It aims at documenting the modeling and simulations activities undertaken during Task 6 of the study. The model of the QR-FRD solutions is based on findings and conclusions from Task 3 “Technical investigation of the two solutions for automatic wireless transmission of flight recorder data” and Task 4 “Assess challenges and limitations of two technical solutions”, respectively documented in D3 and D4.

The scope of QR-FRD is not the management of distress situations, but recovery of Flight Recorder Data for investigation, so 'search and rescue' services have not been investigated during the project.

1.3 Organization of the document

This document is part of task 6 “Simulation of technical solutions” of the QR-FRD study, and is organized as follows:

Chapter 1, “INTRODUCTION”, (the present chapter), primarily provides background information on the initiation of QR-FRD studies and defines the scope of the present document.

Chapter 2, “REFERENCE DOCUMENTS”, provides the list of reference documents used for the drafting of the present document.

Chapter 3, “DEFINITIONS AND ACRONYMS”, provides definitions of terms and acronyms used in the present document.

Chapter 4, “SIMULATIONS OVERVIEW”, identifies objectives, the assumptions, the limitations and deviation from the proposed solutions in D4, defines metrics to be analyzed through the simulations, and specifies the simulation environment in terms of inputs, outputs, cadencing and human-machine interface.

Chapter 5, "MODEL PRESENTATION", provides descriptions of the model based on the different functional blocks (and related sub-functions) that are detailed and assessed in D3 and D4 respectively.

Chapter 6, "SIMULATION RESULTS", provides the simulations performs and the results obtained

Chapter 7, "CONCLUSIONS AND RECOMMENDATIONS" summarizes main findings from the simulations and provides recommendations and lessons learnt

Annex A, "TESTS SCENARIOS" lists the set of tests performed to test the model

Annex B, "BEA FILES" provides details about the accident and incident avionic data scenario.

Annex C, "IMPLENTED TRIGGERS" provides details about trigger conditions implemented in the model.

2 REFERENCE DOCUMENTS

[Ref 1] QR-FRD Study D1: "Accident conditions relevant for wireless flight recorder data transmission", Ed 02, April 2022

[Ref 2] QR-FRD Study D2: "Overview of Technical Solutions for Automatic Wireless Transmission", Ed 01, April 2022

[Ref 3] QR-FRD Study D3: "Technical investigation of the two solutions", Ed 01, April 2022

[Ref 4] QR-FRD Study D4: "Assess challenges and limitations of the two solutions", Ed 01, April 2022

[Ref 5] QR-FRD Study D5: "First consultation of the stakeholder's group", Ed 01, April 2022

[Ref 6] [R00] EN-EASA.2020.HPV.06, Quick Recovery of Flight Recorder Data Call for Tender

[Ref 7] ICAO Annex 6 – Operation of Aircraft – Part I – International Commercial Air Transport – Aeroplanes, Ed. 11, July 2018

[Ref 8] ICAO Annex 13 – Aircraft Accident and Incident Investigation, Ed. 12, July 2020

[Ref 9] Ed Williams, "Aviation Formulary V1.47", https://edwilliams.org/avform147.htm

[Ref 10] I. del Portillo, B. G. Cameron, and E. F. Crawley, "A technical comparison of three low earth orbit satellite constellation systems to provide global broadband", Acta Astronautica, 2019.

[Ref 11] Nils Pachler, Inigo del Portillo, Edward F. Crawley, Bruce G. Cameron, "An Updated Comparison of Four Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband", MIT, 2021

[Ref 12] Wikipedia, "Spherical coordinate system", https://en.wikipedia.org/wiki/Spherical_coordinate_system

[Ref 13] ARINC Paper 681, "Timely Recovery of flight Data (TRFD), 2021

[Ref 14] BEA Report "Triggered Transmission of Flight Data", 18 March 2011

[Ref 15] EUROCAE ED-112A, "MOPS for Crash Protected Airborne Recorder Systems", Sept. 2013

3 DEFINITIONS AND ACRONYMS

Term	Definition
Abnormal Situation	A situation "*in which it is no longer possible to continue the flight using normal procedures but the safety of the aircraft or persons on board or on the ground is not in danger.*" (https://www.easa.europa.eu/sites/default/files/dfu/EASA_EHEST_HE_11.pdf) Could be assimilated to "*Alert phase: a situation wherein apprehension exists as to the safety of an aircraft and its occupants.*" as defined by ICAO Annex 12. However, this definition, along with the definition of "Distress phase" are from an air traffic controller perspective and are meant to manage search and rescue operations. The QR-FRD perspective, though maybe concurrent, is however different and aircraft oriented.
Aircraft	Equivalent to "*Aeroplane*" in the context of this study and defined as "*A power-driven heavier-than-air, deriving its lift in flight chiefly from aerodynamic reactions on surfaces which remain fixed under given conditions of flight*" (ICAO Annex 6, Part I) and "*of a maximum certificated take-off mass of over 27 000 kg and authorized to carry more than nineteen passengers*"
Chunk	Portion of a bulk of data, of a file, etc. to be processed (e.g., compressed and/or encrypted) and/or transmitted.
Distress Condition	An aircraft is in a distress condition when it is in a state that, if the aircraft behavior event is left uncorrected, can result in an accident.
Distress Situation	"*A situation wherein there is a reasonable certainty that an aircraft and its occupants are threatened by grave and imminent danger and require immediate assistance*." (ICAO Annex 11, "Distress Phase") This situation usually triggers Search and Rescue operations.
Encryption	Process of encrypting (i.e., encoding) data with a cipher or ciphering methods. Cipher or the ciphering methods are the tools used to encode/decode the data. Encryption / decryption and ciphering / deciphering are often considered synonymous.
False-positive	A false positive is an error in binary classification in which a test result incorrectly indicates the presence of a condition (a serious incident or accident in our case)

Term	Definition
FDM	Flight Data Monitoring A process encompassing flight data analysis, the latter being required by ICAO Annex 6 for "*operators of aircraft of a maximum certificated take-off mass in excess of 27,000 kg"* as "*part of their safety management system*" (SMS). Flight data analysis is the "*process of analyzing recorded flight data in order to improve the safety of flight operations.*" (ICAO Annex 6) Operational Flight Data Monitoring (OFDM), aka Flight Operations Quality Assurance (FOQA), is the proactive use of recorded flight data from routine operations to improve aviation safety. It facilitates the tracking and evaluation of flight operations trends, the identification of risk precursors, and the decision making for remedial actions.
Flight recorder	"*Any type of recorder installed in the aircraft for the purpose of complementing accident/incident investigation.*" (ICAO Annex 6, Part I) Flight recorders addressed in the present document include: ● Flight data recorders ● Cockpit voice recorders ● Data link recorders ● Flight crew-machine interface recorders
Flight recorder data	Any type of data recorded by the flight recorders that would be used for the purpose of complementing accident/incident investigation. Flight recorder data may include: ● Mandatory and optional flight parameters recorded by flight data recorders ● Audio recordings between the flight crew members and any other station ● Audio recordings of the acoustic environment of the cockpit ● Messages and information exchanged over data link ● Imagery from displays inside the cockpit and interactions of flight crew members with instruments and displays
Historical flight recorder data	Flight recorder data that has been stored prior to the trigger condition for possible transmission.
Path loss	Loss or attenuation a propagating electromagnetic signal encounters along its path from the transmitter to the receiver
Quality of service (QoS)	Description or measurement of the overall performance of a service, particularly the performance seen by the users of the network. To quantitatively measure quality of service, several related aspects of the network service are often considered, such as packet loss, bit rate, throughput, transmission delay, availability, jitter, etc…

Term	Definition
Real-time flight recorder data	Flight recorder data meant to be transmitted nearly instantaneously as they are collected, either by streaming (all along the flight) or after trigger (abnormal or distress situation is detected).
SMS	Safety Management System "*A systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures.*" (ICAO Annex 6)
Toggling	A rapid / repetitive switching of a parameter between two values. Toggling may come from an instability, resulting in an erratic oscillation between different states or values.

Table 1: Definitions

Acronym	Definition
ACAS	Airborne Collision Avoidance System
ACMS	Aircraft Conditions Monitoring System
ADFR	Automatic Deployable Flight Recorder
AIR	Airborne Image Recording
CFIT	Controlled Flight Into Terrain
DAR	Digital ACMS Recorder
EASA	European Union Aviation Safety Agency
ETOPS	Extended-range Twin-engine Operation Performance Standards
FB	Functional Block
FCC	Federal Communications Commission
FCMIR	Flight Crew Machine Interface Recordings
FMS	Flight Management System
FN-I	Fire/Smoke – Non-Impact
FUEL	Fuel related accident category
FWC	Flight Warning Computer
GUI	Graphical User Interface
HMI	Human-Machine Interface
ICE	Icing related accident category
LEO	Low Earth Orbit
LOC-I	Loss of Control - Inflight
NA	Not Applicable
NMAC	Near Mid-Air Collision
QAR	Quick Access Recorder
QR-FRD	Quick Recovery of Flight Recorder Data
SCF-NP	System/Component Failure – Non-Power plant
SCF-PP	System/Component Failure – Power-plant
TAWS	Terrain Avoidance and Warning System

Acronym	Definition
TBC	To Be Confirmed
TBD	To Be Defined
WSTRW	Windshear or Thunderstorm Warning

Table 2: Acronyms

4 SIMULATIONS OVERVIEW

4.1 Objectives

The objectives of the modeling and simulations activities are to develop a software model of the QR-FRD suite (or relevant parts of it) and run a series of simulations allowing the assessment of its performance, as well as the evaluation of different technical solutions for its main components. This will aid in providing recommendations for the possible implementation of actual QR-FDR systems.

The modeling and simulation approach introduced in D4 is refined hereafter, based on the functional blocks (FB) identified and detailed across the previous tasks of the study. Figure 2 below provides an overview of the models and simulations setup:

- Functional blocks (FB1 to FB6) are depicted in the top row
- Models will primarily be developed for FB1 to FB3[1] and their respective sub-functions. Sub-functions models are detailed in §5.
- A Data Generation model will be developed to feed data from input files and other configuration inputs
- A human-machine interface (HMI, likely a graphical user interface (GUI)) will be provided if necessary for manual inputs and control of the simulations on the one hand, and for online visualization of the results of the running simulation on the other hand
- Offline assessment will be enabled using log files that record the results as well as relevant data generated by the simulations

The results of the simulations to be displayed will be fed by observers (probes) set in place at relevant locations in the model. The observers will reflect metrics to be used for the assessments and evaluations. Metrics are identified and discussed in §4.3.

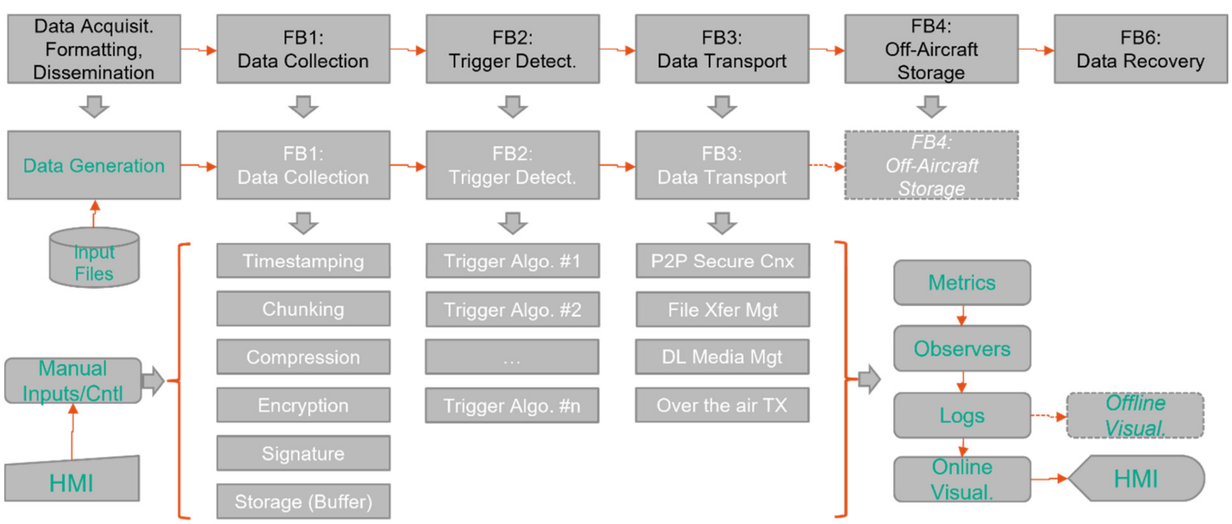

Figure 2: Modeling and simulations overview

[1] Modeling of FB4 is not foreseen in a first step, cf. §4.2.

4.2 Assumptions

Models will be developed to assess the performance of the QR-FRD suite as discussed in §4.1. As such, they are aimed at computing data or enabling the computation of metrics (cf. §4.5) reflecting the performance of the sub-functions architected as they would be in an actual QR-FRD suite. The models will hence not replicate (rehost) actual/prototype pieces of software[2] from a QR-FRD suite, nor will they be fed with actual flight recorder data streams.

Nevertheless, the behavior of the model with respect to the metrics should be close to what could be expected from the QR-FRD solution. This will allow the quantitative and qualitative assessment of the solutions and their respective options.

The following assumptions apply:

- Triggers have been implemented as defined in D3. Only minor adjustments on thresholds or confirmation delays may have been made, based on false-positive trigger condition analysis performed on actual flight data. Moreover, trigger conditions may depend on the aircraft flight envelop or may be specific to an aircraft type.
- Throughput at a given time is definitively impossible to evaluate in an accurate manner. Many factors contribute to its fluctuation over time such as the number of terminals connected to the satellite at a time, the number of satellites connected to a satellite ground relay, the ground server workload, the data transfer protocol, and network protocol to give few examples. An upload bandwidth of 20 Mbps doesn't mean that the system will have such throughput. Hence, an average[3] throughput will be set as a parameter of the model.
- Flight data sources are considered in the model as data streams. These will be characterized with a dedicated throughput and associated with a compression ratio.
- The data collection processing time and latency are negligible as explained in D4. Hence, they have not been modeled.
- LEO satellite handover is generally < 1ms because the constellation has been designed taking into account the orbital period that forces to switch often from one satellite to another. Even if this induces network reconfiguration, this time remains very low and is not taken into account in the model.
- The real flight scenarios kindly provided by the BEA do not quite reflect the latest data 'quality' in terms of accuracy and availability one could expect as output from actual and recent computer units:
    - they are coming from black boxes that could have been partially damaged
    - they have been recorded approximatively between years 1990 and 2010 (so not the latest aircraft)
    - some aircraft are not commercial air transport aircraft

    Also, they are anonymized (do not contain information that could allow to easily recover the flight id and location of the accident/incident).

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[2] There would likely be intellectual property issues doing so.

[3] The throughput is the one made available (or dedicated) to the QR-FRD application. Indeed, other airborne datalink applications may share the same communication media. Priority mechanisms, Quality of service, etc... will influence this figure.

Nevertheless, these data were used to define triggers during other reference studies and are precious to determine the aircraft / satellite intervisibility and path loss based on the aircraft attitude, these factors affecting the most the network connectivity.

- An IP connection is ready to send data at the time trigger condition is detected. This means that a keep-alive mechanism is necessary to maintain the IP link up.

4.3 Limitations and model deviation regarding solutions described in D4

At the time the present document was written, no decision was made concerning the stop of the transmission should triggering conditions no longer be true. Hence, the trigger model does not implement a "trigger reversion" logic. Stop transition is addressed in chapter 7[4].

Not all the flight data (parameters) used in the trigger logics defined in D3 are available in the accident and incident database provided by the BEA. Hence, only a subset of trigger conditions identified in Table 17: Triggers from D3 implemented in the model, is implemented in the model.

The following table identifies limitations and deviations between the model and features assessed in D4 ([Ref 4]).

	Solution #1 "AISD-based"	Solution #2 "FDAU/FDIU&ACMS-based"	MODEL deviation
Tx mode	▪ Streaming ▪ Priority to real-time data	▪ Triggered ▪ Priority to real-time data ▪ Priority on recorder data type	→ Only triggered mode has been implemented as streaming mode can be considered adding a trigger 'begin of flight' → Priority management on data type was not implemented as sending all data type together is a worst-case scenario
FB1: Data Collection	1. Collect flight recorder data and digitize analog audio inputs 2. Gather chunks 3. Timestamp 4. Compress 5. Encrypt the audio chunks 6. Merge (single file) 7. Sign 8. Store the file	1. Collect flight recorder data and digitize analog audio inputs 2. Gather chunks 3. Timestamp 4. Compress 5. Sign 6. Encrypt (all) 7. Store the files	→ Both simulations are possible, but the data volume is the same (delta 0.01%) so only solution 1 is simulated (see §5.1 for flight data size estimation). Moreover, Solution 2 generates more files than Solution 1 which makes the model very complex to implement and maintain even though we can use the chunk size parameter to have more or less files (or small/big files)

[4] The objective of this study is primarily safety investigation oriented, cost reduction technique such as trigger de-activation is not detailed (inverse logic is only considered)

	Solution #1 "AISD-based"	Solution #2 "FDAU/FDIU&ACMS-based"	MODEL deviation
FB2: Trigger Detection	▪ Transmission starts automatically at the beginning of the flight ▪ Transmission stops at the end of the flight	▪ Transmission starts as soon as a singular event is detected ▪ Transmission will automatically stop when no trigger condition exists after a confirmation period or until the aircraft is at the gate (TBC)	Streaming mode maximizes the chance to recover a maximum of data while abnormal/distress trigger event occurs late. Simulation results are based on refined abnormal/distress triggers so that a mixed solution depending on criteria can be depicted.
FB3: Data Transport	▪ Encrypted E2E comm. ▪ Data transfer protocol SFTP ▪ Cellular and LEO satellite ▪ In case of transmission performance degradation, a few retries may be managed	▪ Encrypted E2E comm. ▪ Data transfer protocol SFTP ▪ LEO Satellite ▪ In case of transmission performance degradation, a few retries may be managed	→ Data transfer protocol available within 5 years will be probably more appropriate. No file transfer protocol has been modeled but some parameters allow to tune the model to set different values for the protocol overhead and reconnection time More details in §5.4 → Dual link (Cellular on ground and Satellite in flight) is not implemented
FB4: Off-Aircraft Storage	Flight recorder data is stored on the ground	Flight recorder data is stored on the ground	At simulation level and because flight data sources have been abstracted as data streams, metrics that represent is the amount of data received on ground are generated.
FB6: Data Recovery	N/A for Task 6	N/A for Task 6	N/A for Task 6

Table 3: Model deviation with respect to D4

4.4 Factors of D1 considered in the model

The following table lists which factors identified in D1 ([Ref 1]) are implemented in the model.

Please refer to report D1 §2.2 concerning the possible correlations between accident categories and the factors (D1 §2.1) and refer to D3 annex D for accidents categories versus trigger conditions.

#	Factors Description	Model consideration
Factor 1	"Loss of power on all engines while the aircraft is still in flight"	**YES - Trigger only**
Factor 2	"Loss of equipment that is a non-essential load for electric systems"	Not considered in the model
Factor 3	"Significant [or unusual] pitch and roll attitudes"	**YES**
Factor 4	"Unusual [or excessive] pitch and roll [and yaw] rates"	**YES**
Factor 5	"In-flight fire [or in-flight loss of aircraft physical integrity], which does not completely destroy the aircraft"	**YES - Trigger only (Fire)**
Factor 6	"Collision with land or water, which does not completely destroy the aircraft"	Not considered in the model
Factor 7	"Post-impact fire, when the crash does not completely destroy the aircraft"	Not considered in the model
Factor 8	"Aircraft sinking into water, after ditching, which does not completely destroy the aircraft"[5]	Not considered in the model
Factor 9	"Aircraft out of range of ATC surveillance systems within the 60 minutes preceding the accident and until the accident"	Not considered in the model
Factor 10	"Inappropriate architecture or link solution impacting the bandwidth of the global system in an emergency situation"	Through assumptions and proposed solutions in D4
Factor 11	"Duration of emergency situations"	**YES - Trigger only (False-positive ratios analysis)**
Factor 12	"Location of the aircraft in emergency situations"	**YES**
Factor 13	"Integrity of transmitted data"	Through assumptions and proposed solutions in D4
Factor 14	"Transfer Protocol"	**YES – QoS, overhead and expansion ratio only**

Table 4: Factors considered in the model

4.5 Metrics

The following metrics have been identified at different stages (basically FB boundaries) of the QR-FRD suite. However, as discussed in the following subsections, not all metrics will be measurable as some

[5] Floating duration after ditching is expected to be greater than 90s. This corresponds to 3 min of history based on a throughput twice the input stream and the transmission system operational.

(e.g., accuracy and integrity) would necessitate both actual inputs and actual processing and transmission protocols to be part of the model, which will not be the case (cf. §4.1).

4.5.1 Accumulated Flight Recorder Data

Volume (amount): Though the amount of collected data will be the same for both solutions, the amount of processed and stored (buffered) data will differ. Observers should be set in the Data Collection model (FB1) to be able to assess the performance of the different processing options (e.g., compression and encryption) as well as buffering. Raw and processed data volumes (total and for each type of flight recorder data) could be recorded to evaluate the performance of the suite over time (duration of the flight).

4.5.2 Trigger Logics Performance

False-positive ratios: As discussed in D1 [Ref 1] and D3 [Ref 3], the definition of the different triggers will influence the performance of Solution 2. Globally too stringent triggers will allow short time for transmission, whereas too loose triggers may initiate unnecessary transmissions. Observers should be set in the Trigger Detection model (FB2) to be able to assess the performance of the different triggers and allow the tuning of their respective thresholds and confirmation duration. Triggering time and condition could be recorded for that purpose. The observers should be independent and allow the recording of multiple and/or subsequent trigger conditions.

Time to flight termination: As discussed above, time left to transmit historical flight recorder data after the trigger condition is detected is one of the concerns. Also, the duration of transmissions of real time flight recorder data after the trigger condition is detected is worth assessing. Observers should be set in the Trigger Detection model (FB2) to be able to assess the duration of the transmissions after a trigger condition is detected. Triggering time could be recorded (if not already) for that purpose.

4.5.3 Transmitted/Received Flight Recorder Data

Volume (amount): The amount of data transmitted to the ground differs between the two solutions, and directly drives the operating costs of these. The amount of data being transmitted (at radio level) is not the same as the amount of data having been collected, nor the same as the amount of data having been processed due to the protocols being used. Observers should be set in the Data Transport model (FB3) to be able to assess the performance of the transmission suite (media) as well as the transmission strategy for the two solutions. The amount of real-time flight recorder data successfully transmitted for both solutions, as well as the amount of historical flight recorder data (along with their type) successfully transmitted for Solution 2 could be recorded (total and over time) for that purpose.

Accuracy: NA. It is assumed the processing will not alter the data (e.g., lossless compression techniques) and that the transmission protocols will not reformat the data (e.g., internet protocols).

Completeness: When not all flight recorder data is successfully transmitted, continuity measurements and duration of “gaps” (missing flight recorder data) should be assessed as this may impact the investigations. Observers should be set in the Data Transport model (FB3) model to be able to assess the performance of the transmission suite (routing) as well as the transmission strategy for the two solutions. Timestamps of the successfully received chunks could be recorded for that purpose.

Consistency: Possible time correlation between flight recorder data types is achieved de facto by Solution 1, whereas possibly compromised with Solution 2 should flight recorder data be transmitted per data type and not all historical flight recorder data be transmitted. The data type of the successfully received chunks could be recorded for that purpose.

Latency: Not measured but taken into account during file transfer protocol negotiation.

4.5.4 Transmission Performance

Bit error rate: NA. This will be an input to the Data Transport model (FB3), based on the survey performed during Task 2 of the Study.

***Note**: Modern data link technologies (typically turbo codes) are such that bit error rate can be assumed null when connected.*

Latency: NA. This will be an input to the Data Transport model (FB3), based on the survey performed during Task 2 of the Study.

Connectivity: Whether or not a network connection is possible between the aircraft and a satellite, depending on calculations of the intervisibility between the two antennas and estimation of the path loss will be recorded.

4.5.5 Transmission costs

Transmission costs are assumed directly proportional to the amount of data transmitted and depend on negotiations between the airline or aircraft manufacturer depending on who bears the costs, and the communication/datalink service provider(s)[6].

4.6 Simulation environment

Only fast time simulation mode has been implemented, allowing quick collection of metrics over the 69 files provided by the BEA.

Nevertheless, the architecture of the model could offer the capability to be interfaced to a real-time simulation environment, the result files being available at the end of the simulation or metrics (and their evolutions) displayed in real-time.

4.6.1 Modeling Tools

Python / Jupyter Notebook and the following modules have been used to develop the models and run the simulations:

- Pandas: open-source data analysis and manipulation tool
- NumPy: fundamental package for scientific computing with Python
- Matplotlib: library for creating static, animated, and interactive visualizations
- Seaborn: high-level interface for drawing attractive and informative statistical graphics
- Basemap: map creation
- Pickle: binary protocols for serializing and de-serializing a Python object

[6] The choice of the communication service provider may be made by the aircraft manufacturer when designing the aircraft equipment and not by each individual operator, but this point is unknown for the time being

4.6.2 Human-Machine Interface

The results analysis in done through a responsive HMI developed in python based on:

- Streamlit: open-source app framework to turn data scripts into shareable web apps
- Bokeh: interactive visualizations creation for modern web browsers

The following plots have been identified as a basis for the assessment of the solutions, based on discussions in §4.3:

- Accumulated flight recorder data volume over time (total and per data type)
- Trigger detection(s) over time (incl. set condition identification)
- Transmitted flight recorder data volume over time (total and per data type)
- Transmitted data volume over time

5 MODEL PRESENTATION

The model implements the software solutions as described in D4 and not necessarily the preconized solution.

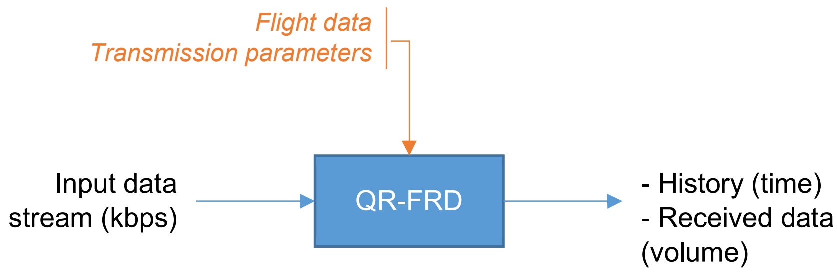


Figure 3: QR-FRD black-box model

The simulations performed with this model allow to learn more about the factors that deteriorate the transmission, the ones that improve the volume of exploitable data on ground and more generally, aid in making propositions and recommendations to improve the system.

As discussed in §4.1, the model is driven by the metrics identified in §4.5, and meant to assess the performance of the solutions through a series of simulations. The model is neither a prototype of a possible solution, nor does it consist in rehosting parts of actual software. Nevertheless, the behavior of the model with respect to the metrics should be close to what could be expected from an actual QR-FRD solution. This will allow the quantitative and qualitative assessment of the solutions and their respective options.

The model has been implemented in a generic and parametric way in order to be able to test various configurations of the system (and not only the ones estimated in the next chapters). The model high-level architecture referencing the QR-FRD functional blocks is presented in Figure 4.

- The “Data Acquisition” block provides a global data stream in kbps based on flight recorder data rates listed in D3 ([Ref 3]). Estimations of these latter have been checked against real data samples
- The “Data Collection” block (FB1) is in charge of creating chunk files following a specific processing order from timestamping to storage in the buffer depending on the two solutions
- The ‘Trigger Detection’ block (FB2) implements trigger conditions listed in Table 17: Triggers from D3 implemented in the model
- The “Data Transport” block (FB3) first computes whether or not a network connection is set based on a given satellite constellation and the position and attitude of the aircraft and then models the “transmission” of the files
- FB4 and FB6 per se are not part of the model. They are identified in the model to provide information on the amounts of data received on the ground using plots

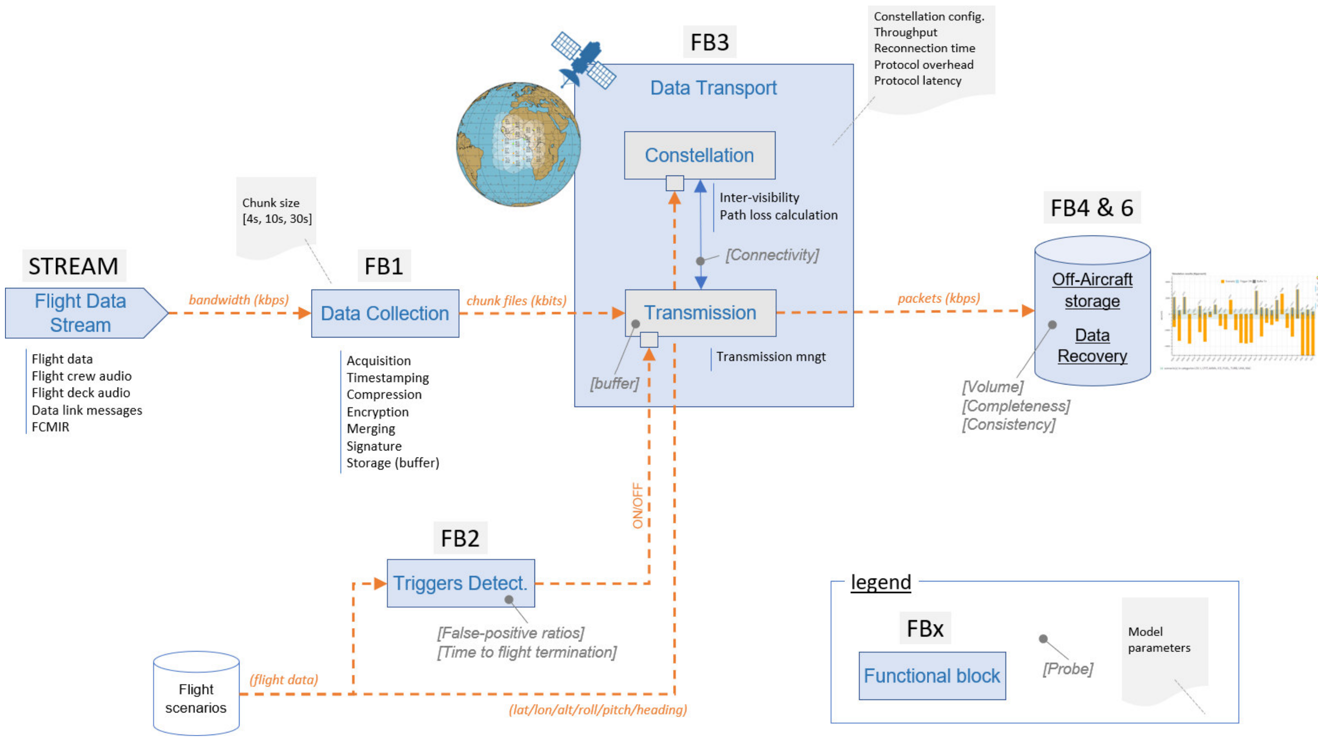


Figure 4: Model overview

5.1 Data Acquisition (Flight Recorder Data Generation)

5.1.1 Flight Data

The minimum set of flight data to consider are the mandatory parameters recorded by Flight Data Recorders (FDR). However, but there are a number of additional FDR/FDM parameters that could also be included. The selection of other relevant parameters could be part of another study.

The flight data throughput was set to 7 kbps in the model to comply with data rates identified in D2 [Ref 2].

Flight data (mandatory parameters) stream = 7 kbps

5.1.2 Flight Crew and Deck Audio

The audio bit depth and sample rate are 8-bit / 8 kHz for the flight crew audio and 16-bit / 16 kHz for cockpit area microphone as defined inD2 [Ref 2].

The audio signals bandwidths are estimated to 48 kbps[7] and 64 kbps respectively for the flight crew audio and the cockpit area microphone audio (without accounting for channel combining or silence editing and with an audio compression of 4:1 based on the Adaptative Differential Pulse-Code Modulation (ADPCM)) as identified in D2 [Ref 2].

Tests have been conducted on representative audio files to confirm or not the estimations of the data rates for these audio channels.

[7] 48 kbps = 8 (bit) * 8 (kHz) * 3 (crew audio channel) / 4 (compression ratio)

The table below summarizes the results of the audio compression using lossy compression (ADPCM) and lossless compression (FLAC):

chunk size (s)	rate (khz)	bit	wav (kbit)	flac (kbit)	adpcm (kbit)	ratio flac	ratio adpcm
4	**8**	**8**	256.352	133.368	131.552	0.520253	0.513169
	16	**16**	1024.352	230.688	258.528	0.225204	0.252382
10	**8**	**8**	640.352	318.800	326.112	0.497851	0.509270
	16	**16**	2560.352	551.104	647.648	0.215245	0.252953
20	**8**	**8**	1280.352	613.208	649.696	0.478937	0.507435
	16	**16**	5120.352	1075.168	1290.720	0.209979	0.252076
30	**8**	**8**	1920.352	964.280	975.328	0.502137	0.507890
	16	**16**	7680.352	1667.104	1933.792	0.217061	0.251784
60	**8**	**8**	3840.352	2029.888	1948.128	0.528568	0.507278
	16	**16**	15360.352	3469.792	3867.104	0.225893	0.251759

Table 5: Estimated audio bandwidth based on real samples (worst-case)

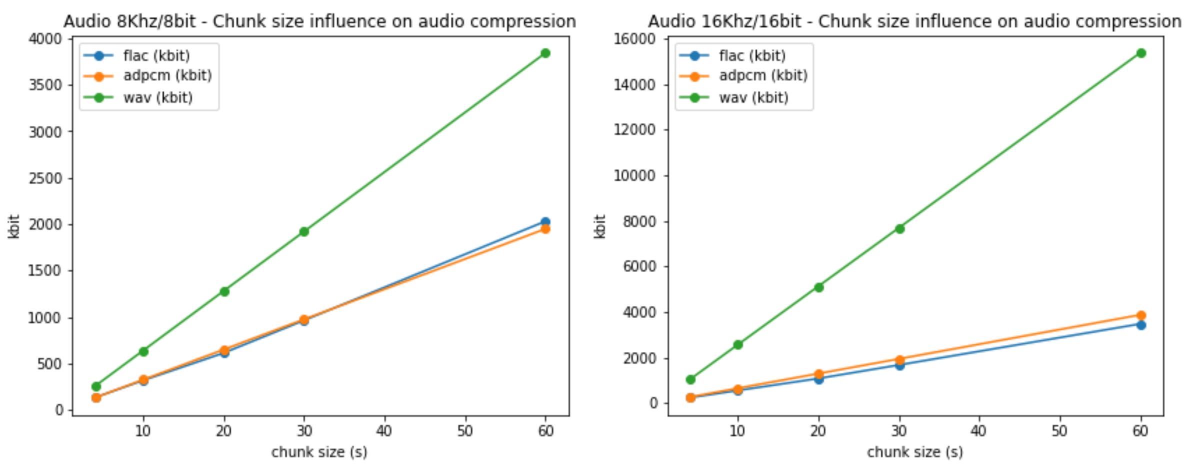


Figure 5: Chunk size influence on audio compression (worst-case)

The audio file size increases linearly so the considered chunk sizes do not have an impact on the compression rate. Audio compression assumption of 4:1 looks good for audio at 16-bit / 16 kHz but is closed to 2:1 for 8-bit / 8 kHz. Moreover, compression ratio is quite the same between ADPCM and FLAC.

Cockpit area microphone audio stream (16-bit / 16 kHz) = 64 kbps

3x Flight crew audio streams (8-bit / 8 kHz) = 100 kbps[8]

[8] ~100 kbps = 133.368 kbit (8bit x 8kHz flac) / 4 (chunk size in s) * 3 (number of microphones)

5.1.3 Data Link Messages

The estimated 0.2 kbps data rate identified in D2 [Ref 2] will used.

Datalink message stream = 0.2 kbps

5.1.4 Flight Crew-Machine Interface Recordings

For the simulation, two mechanisms to fulfill this feature can be considered:

1. A video camera showing the cockpit connected to the AIR
    - a Full HD (1920 x 1080 pixels – 24 bit color) image in JPEG format at 4 Hz as proposed in D2 [Ref 2] which represents around 1.6 MB (based on size of 0.423MB as per ARINC paper 681 [Ref 13] (to be further investigated - in another study - using MPEG-4 video coding format that is more adapted for such stream)

FCMIR Cam image (HD video at 4 images/sec) will not be considered for the following reasons:

- As explain previously, FCMIR displays screenshot and FCMIR Cam image are redundant
- Compression used of 26:1 will probably not be as good because we are closer to a photo than an image (more details, more colors, more color variation etc…)
- Video compression algorithm is more appropriate for FCMIR Cam image and necessitate an evaluation

2. Screenshots performed by the cockpit displays themselves in addition to cockpit event interactions capture
    - 4 main displays SXGA+ (1400 x 1050 pixels) 24-bit color
    - 1 Standby display Q-VGA (320 x 240 pixels) 24-bit color
    - 2 head-up displays S-VGA (800 x 600 pixels) 8-bit color (JPEG does not support monochrome)
    - Control panels events – log user interaction (0.1kbps)

Other displays such as electronic flight bags (EFB) or portable electronic devices (PED) are not considered for the moment because they are not used as navigation display when airborne.

The above listed cockpit displays configuration differs from the one identified in D2 [Ref 2] and seems to be more relevant for the simulations regarding the latest cockpit organization and display performance on the market.

Here is an illustration of the considered cockpit configuration:

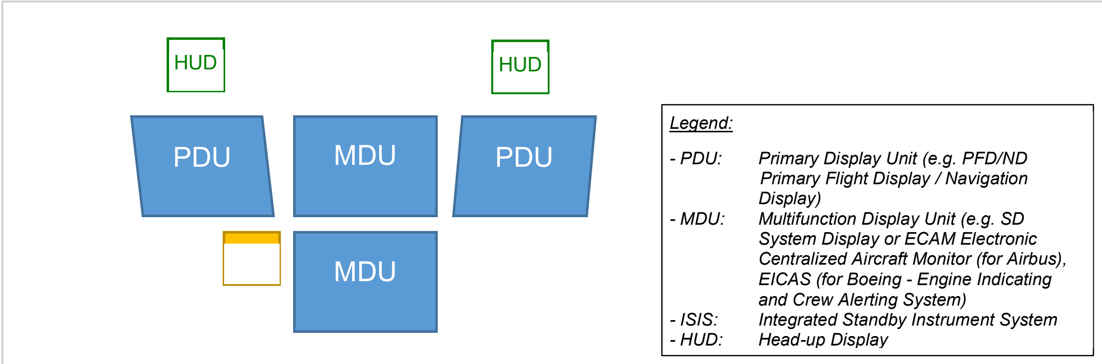


Figure 6: Cockpit displays configuration

Even if there are other ways to store an image like in vector graphics or recording ARINC 661 data exchanges (graphic commands), the choice was made to consider a digital image that represents a worst case in terms of data rate and the simplest way to generate and recover the information.

Also, an image sampling rate of 1Hz is used as identified in document D3. To go further, tests have been conducted on representative PDU, MDU, ISIS and HUD images to confirm that the estimated size can be used in the model. Here are the results:

name	type	display	display count	original size (bytes)	JPG100%	JPG90%	JPG80%	JPG70%	JPG60%	JPG50%	JPG40%	JPG30%	JPG20%
FUSION1.bmp	SXGA+	LD	4	4410054	601222	242963	177452	148573	130326	117376	104835	91739	75301
FUSION10.bmp	SXGA+	LD	4	4410054	694943	253012	182002	150262	130355	117529	105332	91886	74800
FUSION11.bmp	SXGA+	LD	4	4410054	872953	320121	228703	187504	161703	144430	128381	111565	90003
FUSION12.bmp	SXGA+	LD	4	4410054	730582	284671	207283	171970	149291	133932	119468	103180	81472
FUSION2.bmp	SXGA+	LD	4	4410054	460020	186040	136720	113999	100168	90429	80702	70826	57974
FUSION3.bmp	SXGA+	LD	4	4410054	606756	242600	176502	146463	128158	115646	102846	89732	73693
FUSION4.bmp	SXGA+	LD	4	4410054	686880	280825	205351	171701	150286	135465	121259	106278	86834
FUSION5.bmp	SXGA+	LD	4	4410054	560075	226501	166105	138883	121716	109933	98110	85509	69870
FUSION6.bmp	SXGA+	LD	4	4410054	572533	225711	165498	138414	121177	109517	97476	84765	69509
FUSION7.bmp	SXGA+	LD	4	4410054	605818	201301	137823	111211	94142	83044	72845	61970	48613
FUSION8.bmp	SXGA+	LD	4	4410054	1075515	412451	290044	235079	199953	176822	155018	131757	102557
FUSION9.bmp	SXGA+	LD	4	4410054	708741	248740	175024	143325	123108	109979	97351	83275	66345
FUSION_Full_PFD.bmp	SXGA+	LD	4	4410054	409877	159937	114191	93905	81124	72339	64512	56208	45588
FUSION_Half_PFD.bmp	SXGA+	LD	4	4410054	747352	307273	220684	181504	157000	140463	124289	107660	84984
FUSION_MFD.bmp	SXGA+	LD	4	4410054	758949	316088	226382	185980	161109	144365	128744	111608	89967
FUSION_MFD_Chart_MAP.bmp	SXGA+	LD	4	4410054	919604	394132	285999	237272	205508	184110	163883	142014	114239
FUSION_PFD_PULL_UP_WXR2.bmp	SXGA+	LD	4	4410054	747146	307291	220639	181430	157012	140499	124335	107671	84979
HUD_sample1.bmp	S-VGA	HUD	2	1440054	124184	57262	40266	32235	27507	24395	21599	18455	14681
HUD_sample2.bmp	S-VGA	HUD	2	1440054	257566	94043	65146	52274	44226	38929	33624	28425	21623
ISIS_sample1.bmp	Q-VGA	ISIS	1	230454	56086	21904	15765	13046	11304	10195	9092	7813	6230
LD_black.bmp	SXGA+	LD	4	4410054	8996	8996	8996	8995	8995	8995	8995	8995	8995
LD_sample1.bmp	SXGA+	LD	4	4410054	393748	167384	124929	105477	93035	84558	76218	67147	55476
LD_sample2.bmp	SXGA+	LD	4	4410054	868828	276355	177679	137974	113713	98292	84280	70915	55893
LD_sample3.bmp	SXGA+	LD	4	4410054	334364	129144	93286	77167	67240	60727	54487	47916	38766
LD_sample4.bmp	SXGA+	LD	4	4410054	412297	187741	140391	117875	103970	94067	84605	74401	61689
LD_sample5.bmp	SXGA+	LD	4	4410054	703776	248265	173557	141365	120428	105800	91617	76299	57656

Table 6: Estimated image sizes based on real samples (bytes)

In order to estimate the FCMIR data rate for the cockpit displays configuration defined in Figure 6, all compressed images were visually assessed in a first step to select a JPEG quality level (between 100% and 20%) that allows to have an image that still remains of very good readability. JPG with quality 40% is deemed adequate (good sharpness, readability, no confusion possible such as for example ‘6’ instead ‘G’, check small characters and symbols size).

Figure 7: Visual assessment example (from left to right, quality 100%, 40% and 5%)

In a second step, an estimated total size for the display configuration was calculated based on the largest file size of each display type in the JPG40% column as summarized in the following table:

	display	display count	original size (bytes) max	JPG40% max (bytes)	total size (kbits)
0	HUD	2	1440054	33624	537.984
1	ISIS	1	230454	9092	72.736
2	LD	4	4410054	163883	5244.256

Table 7: Largest display image sizes per display type

FCMIR control panels events date has been estimated in report D3 to 0.1 kbps, so it is considered as negligible.

This leads to a total of 5,855 kbits for a snapshot of the considered cockpit displays configuration.

The flight crew interactions with control panels, switches, etc… may hence be considered negligeable within the FCMIR stream.

FCMIR stream (1Hz sampling) = 5,855 kbps

5.2 FB1: Data Collection

The input of FB1 is the data stream data rate expressed in kbps and provided by the “Data Acquisition” block.

The figure bellow summarizes the streams as defined et previous chapter.

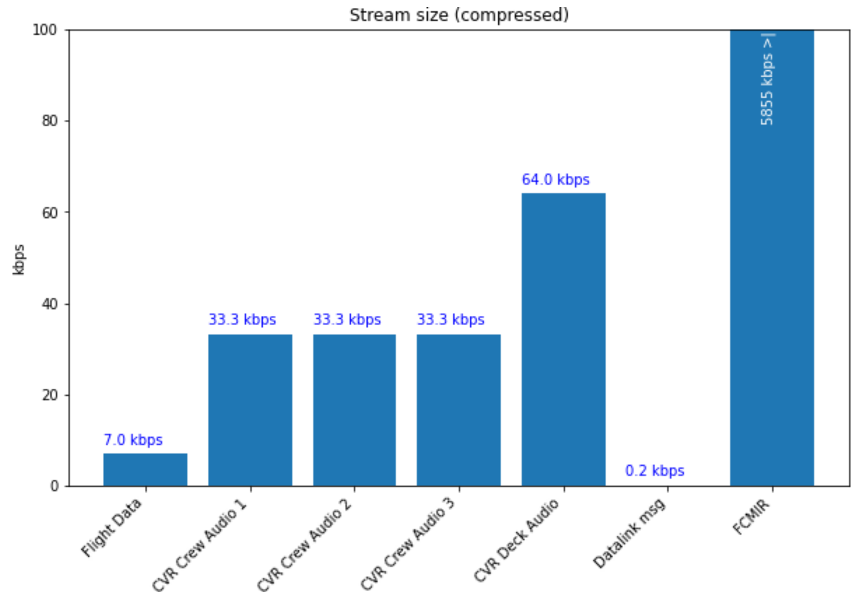


Figure 8: Estimated data streams data rates

Considering a chunk size of 4 seconds, the chunk file size bellow has been calculated for both QR-FRD proposed solutions (cf. D3 and D4) by applying the different processing steps that include overheads and expansion ratios defined in D2. For the given cockpit audio and displays configuration, the size of a file for 4-second chunk for the two solutions are estimated in the following figure:

```
------------ Flight data stream parameters ----------
Streams:
                Flight Data                   7 kbps - compression  1:1 --> 7.00 kbps
                CVR Crew Audio 1           66.6 kbps - compression  2:1 --> 33.30 kbps
                CVR Crew Audio 2           66.6 kbps - compression  2:1 --> 33.30 kbps
                CVR Crew Audio 3           66.6 kbps - compression  2:1 --> 33.30 kbps
                CVR Deck Audio              256 kbps - compression  4:1 --> 64.00 kbps
                Datalink msg                0.2 kbps - compression  1:1 --> 0.20 kbps
                FCMIR                      5855 kbps - compression  1:1 --> 5855.00 kbps

Solution 1:     24110.519 kbit / chunk file of 4 second(s)
Solution 2:     24155.937 kbit / chunk file of 4 second(s)
```

Figure 9: Estimated data rates and 4-second chunk sizes

Whatever the solution, the volume of data is quite the same.

4s chunk file size = ~24.200 Mbits

5.3 FB2: Trigger Detection

This section concerns the real flight assessment of the trigger algorithm described in Document D3. Triggers were assessed for a subset of the SAFRAN "Cassiopée™" database for false positive analysis, as well for the identification of margins at the trigger level.

Note that the triggers conditions implemented in the model are detailed in ANNEX C: IMPLEMENTED TRIGGER.

"Cassiopée™" is a SAFRAN E&D tool and service, originally used for FDM (or FOQA). It is associated with a large database of flight records.

In the "Cassiopée™" database, no "serious incidents" or "accidents" during flight were identified. During this assessment, when one algorithm as defined in the D3 document is positive during one of these flights, it should trigger the transmission of the flight recorder data. Due to the fact that no flights resulted in an "accident" or "a serious incident", each trigger can be considered a "false positive", i.e., a trigger of the transmission of flight recorder data during flight without a fatal outcome/incident.

The purpose of this study is to assess the rate of triggers during standard flights.

Each trigger is independently assessed on a large number of flights. The results of these assessments are presented below.

Note: Since these records are dedicated to FDM or maintenance, they come from ACMS; they are DAR and not FDR records from the FDIU/FDAU. Therefore, the recorded parameters are only qualified through usage (no testing or formal proof that the recorded data are correct).

This study does not aim to redefine the triggers but proposes an assessment of the thresholds used in the formulas of document D3, which will have to be the subject of standardization work (like ED237 for GADSS triggering formulas).

5.3.1 Presentation of analyzed "flight records"

The data analyzed comes from real flights. They result from recording data intended for "FDM" or maintenance purposes.

The aircraft considered are Airbus A330-300s: these are modern medium/long-haul aircraft. They are twin-engine with ETOPS certification.

These aircraft are operated by a reputable European airline.

For reasons related to confidentiality, the name of the airline, the dates and the characteristics of the flights are not disclosed.

The total duration of the flights covered by this analysis is in the order of 45,500 hours, with a total of 6,040 flights, for a time period in the order of 5 years (2016-2021). The average flight time is around 7.5 hours (the maximum flight duration is 12.5 hours). This type of aircraft was chosen to reflect the type of flight where Flight Recorders Data transmission via wireless media will be the only solution: medium/long-haul flights, flights over oceans, etc.

However, this analysis is subject to some biases. Indeed, the flight recordings have the following characteristics:

- They come from a single type of aircraft
- They are from flights with a limited number of pilots, from the same airline
- Although this company provides international flights, these flights do not cover all regions of the world

Note: Since these records are dedicated to FDM or maintenance, they are based on DAR (Digital ACMS Recorder) type of data and not FDR data. Therefore, the recorded parameters are only qualified through usage (no testing or formal proof that the recorded data are correct). These recorded data are not governed by ED 112A compliance. For example, the “cabin pressure altitude” underwent an unexpected variation during flight (it became negative during descent). Furthermore, some parameters are missing (for example, CAS (Calibrated Air Speed) is not recorded, and is replaced in the analysis by IAS (Indicated Air Speed)). Specialists agree that the variation between the two parameters has only minor effects).

5.3.2 Presentation of the analysis

The “Cassiopée™” tool is used to re-run flights based on flight recordings. During these re-runs, procedures are implemented to assess specific conditions throughout the entire flight duration. The tool can be sequenced in batch mode, which enables the launch of a large number of flight analyses.

For the purposes of the project, trigger assessment procedures were written to evaluate the rate of flight recorder data transmission. These procedures are described in document D3. They mainly use the condition provided by the BEA or Airbus in the 2011 report document [Ref TBD]. However, additional triggers are included in document D3 to increase the quality of detections and have more time for the transmission of flight recorder data.

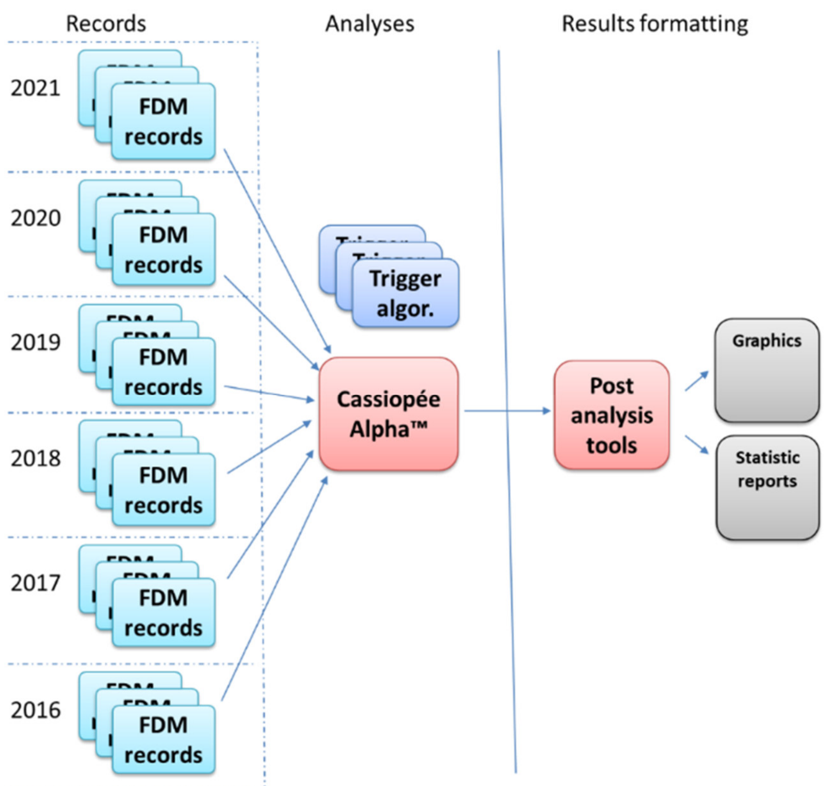


Figure 10: Description of the analysis process

There are two types of assessment, based on the trigger type:

Trigger through the exceedance of a parameter value (“excessive ROLL”, for example)

Some triggers are based on a boundary value. This can be a maximum value or a minimum value.

For this type of trigger, the identified parameters are monitored throughout the flight. The extremes of the parameter value are recorded flight by flight. A histogram of these extremes is constructed and compared to the values that trigger the conditions: each histogram value greater/smaller than the trigger value is a false positive. A margin is then calculated between the histogram values and the trigger value. This margin can be used to assess the best value for this boundary, with the aim of increasing detection quality.

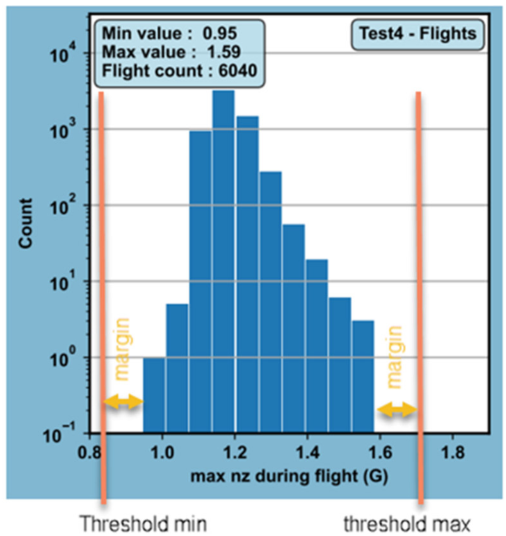


Figure 11: Description of the theshold margin (example)

Trigger through alarms (“STALL”, for example)

Other triggers are based on alarms. These alarms are confirmed by a duration. They can also be confirmed by another alarm.

For this type of trigger, the identified parameters are monitored throughout the flight. The number of alarms and the maximum duration of the alarm are recorded flight by flight. A histogram of these numbers and durations is constructed: each alarm with a duration greater than the confirmation time is a false positive.

5.3.3 False positive ratio and margin analysis

The following table presents the result of the analyses, if the trigger model is complete, the false positive number, and if possible, the margin. These results are provided trigger by trigger:

- The “false-positive” numbers are given if the trigger algorithm given in doc D3 is fully described (no TBD), the parameters use in this trigger algorithm are available in the recorded data.
- The margin is given, if the "false-positive" value can be calculated, if the parameter used in the algorithm is not a discrete signal and there is only one boundary parameter check

Using BEA or Airbus values, provided in document D3 [Ref 3], the analysis detects three or four false positive triggers for 45,000 hours of flight. The ratio of false-positive detection is close to $5e^{-5}$ or $8e^{-5}$. Nevertheless, QR-FRD does not launch SAR activity, so the false-positive rate is only a cost issue.

There is one false positive for:

- Excessive vertical speed, in accordance with the BEA algorithm (during the “Descent” flight phase)
- TAWS alert (during the “Approach” and “Final Approach” flight phases)
- Fire on Board Alert (detector hardware failure suspected)
- Engine Alerts (excessive vibrations, FOD or engine failure suspected)

Name	Source	Duration	Condition	Result	
Excessive Bank	BEA	2 sec	|ROLL| > 50°	FALSE+ 0	Margin 10°
	AIRBUS	2 sec	|ROLL| > 60°	FALSE+ 0	Margin 20°
	BEA/ AIRBUS	2 sec	|ROLL| > 45° AND |ROLLRATE| > 10°/s	FALSE+ 0	Margin N/A
Excessive Pitch	BEA/ Airbus	2 sec	Pitch > 30°	FALSE+ 0	Margin 3°
	BEA/ Airbus	2 sec	Pitch < -20°	FALSE+ 0	Margin -12°
	BEA/ Airbus	2 sec	(Pitch > 20° AND Pitch rate> 3°/s)	FALSE+ 0	Margin N/A
	BEA/ Airbus	2 sec	(Pitch < -15° AND Pitch rate< -3°/s)	FALSE+ 0	Margin N/A
Excessive Vertical Speed	BEA	2 sec	|V/S|> 9,000 ft/min	FALSE+ 1	Margin -472
	AIRBUS	2 sec	|V/S| > 10,000 ft/min	FALSE+ 0	Margin 528 ft/m
Stall Warning	BEA/ AIRBUS	2 sec[9]	STALL Warning = TRUE	FALSE+ 0	Margin N/A

[9] 9 "Stall Warning Events" lasting less than 2 seconds were detected during the flights. These are suspected to be spurious signals and not real warnings.

Name	Source	Duration	Condition	Result
Inappropriate speed for the flight situation (Low CAS[10])	BEA	2 sec[11]	CAS < 100 kt AND Radio altitude > 100 ft	FALSE+ 0 / Margin N/A
Inappropriate speed for the flight situation (Overspeed)	BEA	2 sec	IAS > 400 kt	FALSE+ 0 / Margin 67 kts
	BEA	2 sec	OVERSPEED Warning [12] = TRUE AND Alt < 15,000 ft	FALSE+ 0 / Margin N/A
Excessive Normal and Lateral Accelerations	BEA/ AIRBUS	2 sec	Nz > 2.6g	FALSE+ 0 / Margin 1 g
	BEA/ AIRBUS	2 sec	nz < -1.1g	FALSE+ 0 / Margin -1.2 g
	BEA	2 sec[13]	|ny| > 0.25g	FALSE+ 0 / Margin -
	AIRBUS	2 sec	|ny| > 0.4g	FALSE+ 0 / Margin 0.6
Excessive roll command	BEA	2 sec	|Captain Roll cmd| > 50 AND IAS > 80 kt	FALSE+ 0 / Margin[14] 27.5°
	BEA	2 sec	|F/O Roll cmd| > 50 AND IAS > 80 kt	FALSE+ 0 / Margin[15] 27.5
Excessive use of rudder	BEA	2 sec	|Rudder position| > 6° AND IAS > 240 kt	FALSE+ 0 / Margin -
TAWS Alert	BEA/ Airbus	~~1 sample~~ 2 sec[16]	TAWS/GPWS alert = TRUE/PULL UP	FALSE+ 1 / Margin N/A

[10] The CAS (Calibrated Air Speed) parameter was not recorded in the flight recording. In this analysis, it was replaced by the IAS (Indicated Air Speed) parameter; no major deviation between the two values expected.
[11] For the "Low CAS" event, one IAS and RAlt condition for the 6040 flights, with a duration of less than 2 seconds. It is considered a spurious signal.
[12] In this analysis, the overspeed warning is only considered during flight. The "overspeed warning" with "landing gear extended" or "flap deployed" is not analyzed.
[13] 2 "Ny exceedance events" lasting less than 2 seconds were detected during the flights. However, it seems that these are events related to turbulence, considered as spurious in this context, and not real warnings.
[14] The margin is about the | Captain Roll cmd | parameter, with the condition (IAS > 80 kt).
[15] The margin is about the | F/O Roll cmd | parameter, with the condition (IAS > 80 kt).
[16] There are two spurious signals (with a duration of less than 1 second). One reported event is longer than 2 seconds (3 seconds). It is identified as a false positive trigger.

Name	Source	Duration	Condition	Result
Inappropriate Altitude for the Flight Situation (Too low altitude)	BEA	10 sec	40 < Radio altitude < 100 AND Eng1N1 > 80% AND Eng2N1 > 80%	FALSE+ 0 [17] / Margin [18] 8 sec
TCAS	BEA/ AIRBUS	2 sec[19]	TCAS RA = TRUE	FALSE+ 0 / Margin N/A
Abnormal Value of Cabin Pressure Altitude	D3	5 Minutes	Cabin_Pressure_Altitude#79 > 10,000 ft	FALSE+ 0 / Margin 2,000 ft
Fire on Board Alert	D3	30 sec	Warnings#24 = FIRE_ALERT OR Warnings#24 = SMOKE_ALERT [20]	FALSE+ 1 / Margin N/A
Engine Alerts	D3	2 sec	For each engine: Engine_Vibration_Warning#62 = TRUE	FALSE+ 1 / Margin N/A
	D3	2 sec	For each engine: Engine_OvertemperaturOuie_Warning#63 = TRUE	FALSE+ 0 / Margin N/A
	D3	2 sec	For each engine: Engine_Oil_Pressure_Low_Warning#64 = TRUE	FALSE+ 0 / Margin N/A
	D3	2 sec	For each engine: Engine_Overspeed_Warning#65 = TRUE	FALSE+ 0 / Margin N/A
Low Pressure Warning	D3	2 sec	Low_Hydraulic_Pressure_Warning#30 = TRUE [21]	FALSE+ 0 / Margin N/A
	D3	4 sec[22]	AC_Electrical_Bus_Status#48 = FAIL	FALSE+ 0 / Margin N/A

[17] Due to the recording rate, not all flights were analyzed: for some flights, the duration of the transition from 40 to 100 ft cannot be computed, given the sampling considerations. For these flights, the RAlt transition from 40 to 100 ft is so short that it cannot be measured.
[18] The margin is about the duration time of the condition: 8 sec over the 10 sec.
[19] Several spurious signals (toggling) were filtered, based on the active signal duration.
[20] 21 "fire and smoke" discrete warning signals were recorded, in accordance with the location of the detector.
The "Lavatory Smoke" discrete signal was removed from the study: it is assumed that the 26 activations of this alarm during the 6040 flight were due to passengers. These alarms where cleared, in short delays, without safety impact on the flight. Nevertheless, these conditions can be added to trig the transmission of flight recorders data.
There is also one detection of "Cargo Rest Smoke", with a duration of approximatively 1 and a half hours, starting during the cruise phase and ending at the end of the flight. This may be the result of a detector failure or other failure.
[21] For trigger detection, the loss of two or more hydraulic channels is considered.
[22] The confirmation deadline is set to 4 seconds to eliminate the toggling effect.

Name	Source	Duration	Condition	Result
Electrical Bus Failure Indications	D3	4 sec[23]	DC_Electrical_Bus_Status#49 = FAIL	FALSE+ 0 / Margin N/A
Computer Failure	D3	4 sec	Computer_Failure#52 = TRUE [24]	FALSE+ 0 / Margin N/A
ACAS Alert [25]	D3	2 sec	TCAS_ACAS_Status = ACAS_RA	FALSE+ 0 / Margin N/A
Wind Shear Alert	D3	2 sec	Windshear_Warning = TRUE	FALSE+ 0 / Margin N/A

Table 8: Triggers from D3/implemented in the model/used in false positive analysis

In this study, to eliminate spurious events, a confirmation deadline of two or four seconds is requested for all trigger conditions, including the TCAS/GPWS warning and STALL alerts.

Some trigger conditions cannot be assessed. These cases concern:

- Parameters with spurious values (please refer to the "CABIN ALT WARNING" parameter for example)
- Trigger values that are not defined (for example, minimum engine thrust during flight)

The study only concerns one aircraft type. For other aircraft types, the trigger value may be adjusted, and the number of discrete warning signals (for fire and smoke detection, for example) must be adjusted.

5.3.4 "Master warning events" analysis

During these assessments, a reflection prompted us to look at the FWC's "master warning" parameter: Can we replace all these triggers by monitoring the "master warning" only? It seems it is not a good idea.

The "master warning" alerts are numerous (6,999 alerts over the 45,500 flight hours of the order of one every 10 hours of flight).

On the flights analyzed, the duration of the alert are less than 17 seconds.

[23] The confirmation deadline is set to 4 seconds to eliminate the toggling effect.
[24] In the recorded data, seventeen computer failures are identified in the records. Computers are redundant or triplex. In this analysis, it is considered that the trigger is concerned when the two redundant computers (or the three triplex computers) fail simultaneously.
[25] The flights analyzed took place in airspace that was not very congested, hence this low TCAS-RA alert rate.

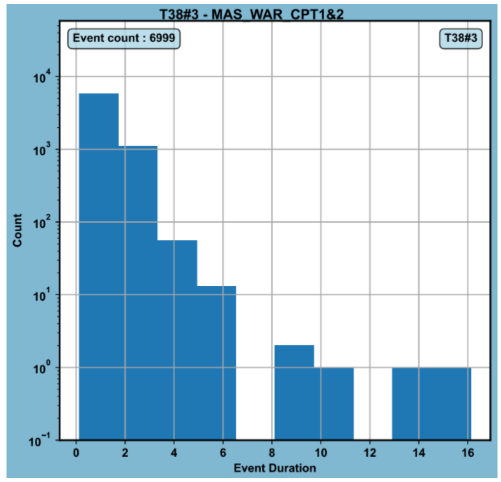


Figure 12: Distribution of the duration of the "Master warning" alert

1,172 events have a duration more than 2 seconds. This would correspond to a rate of 2.5 e^{-2}, per flight hour.

Without further information on the calculation of the "master warning" (algorithm defined by the aircraft manufacturer), a correlation between the triggers defined by document D3 and the "master warning" was carried out: The concomitance was assessed between the "fire/smoke" and "master warning" alarms. No link between these types of alarm could be confirmed or invalidated. The same is true for the other alarms in document D3.

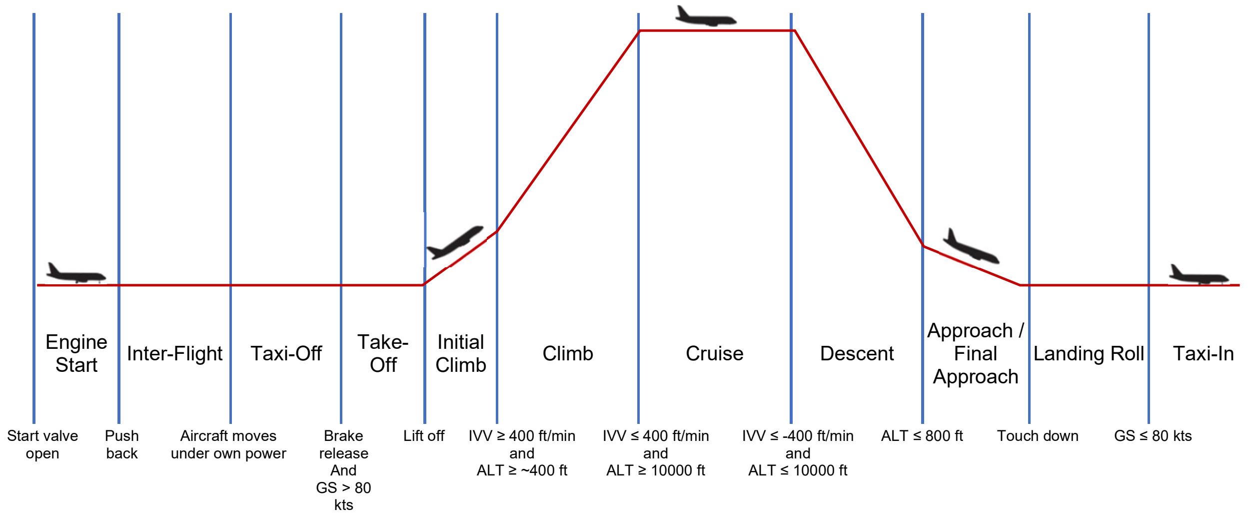
Due to a lot of warning with short duration (83%), it seems this warning are not confirmed before publication. So, a persistence time should be requested, if the "Master Warning" have to be used to trigger the QR-FRD.

We do not know if the use of the "master warning" parameter would improve the quality of detection of the triggers of the D3 document. However, given the number of "master warning" events, it seems that it cannot be used alone to trigger the transmission.

5.3.5 Assessment of trigger margin by flight phase

During a second phase, the analysis was repeated, with discrimination by flight phase.

Note: the “flight phases” criteria are in accordance with FMS broadcast one defined as follow:



IVV: Inertial Vertical Velocity, Alt: Altitude, GS: Ground speed

Figure 13: Flight phases as used for trigger evaluation for A330

During our reflection, it appeared that the attitude should be more stable during the cruise phase, compared to the climb and descent phases. Therefore, a repeat analysis was carried out on the same flights, in particular with respect to the first two criteria, namely "excessive bank" and "excessive pitch". For time-related reasons, it was not possible to perform the same types of analysis on the other criteria[26].

In this second analysis, the values of the extremes of the "ROLL" and "PITCH" parameters were segregated in three cases:

- After the takeoff phase and before the cruise phase (i.e., "Initial climb" and "Climb")
- During the cruise phase
- After the cruise phase, until landing (i.e., "Descent", "Approach" and "Final approach")

[26] The same consideration can be applied to the trigger values of the following conditions: Excessive Vertical Speed / Inappropriate Speed for the flight situation / Excessive Roll command and use of rudder / …

The result of margin assessment for the two first trigger values is presented below.

Name	Source	Condition	Margin / all flight phases)	Margin / flight phase: Climb)	Margin / flight phase: Cruise)	Margin / flight phase: Descent)
Excessive Bank	BEA	|ROLL| > 50°	10°	12°	28°	10°
	AIRBUS	|ROLL| > 60°	20°	22°	38°	20°
Excessive Pitch	BEA/ Airbus	Pitch > 30°	3°	3°	20°	11°
	BEA/ Airbus	Pitch < -20°	-12°	-12°	20°	-12°

Table 9: Assessment of the margin for trigger values by flight phase

The results show that the margin is not constant for all flight phases. For the cruise phase, the trigger levels can be lowered. This optimization could make it possible to make gains in the effectiveness of the triggers, and consequently in transmission time.

To carry out an initial assessment of this observation, a review of the recording data provided by the BEA was carried out. Of the 44 flights "with fatal outcomes", six were identified as concerning:

- Flight phase: Cruise
- Initial detection of the “distress phase”: “Excessive Bank” or “Excessive Pitch”

These are the flights with the following references:

- A011 (ATR 42)
- A022 (B 737)
- A049 (TU 154)
- A030 (IL 18)
- A041 (B 373)
- A044 (MD 82)

On these flights, the "roll" and "pitch" exceedance algorithms were re-run, lowering the trigger thresholds:

	Initial BEA trigger values	Reduced trigger values, during cruise phase
| Roll | exceedance value	50°	30°
Pitch maximum exceedance value	30°	15°
Pitch minimum exceedance value	-20°	-5°

Table 10: Proposal of reduced trigger values for cruise flight phases

With these reduced trigger values, the duration of the "transmission phase" is increased. For the first five flights, the effect is not relevant. However, for the last flight (ref A044), the effect is major:

Flight ref.	"Distress phase" duration, with BEA trigger value	"Distress phase duration", with reduced trigger value
A011	38 sec	38 sec
A022	49 sec	50 sec
A029	161 sec	166 sec
A030	51 sec	56 sec
A041	13 sec	16 sec
A044	**73** sec	**677** sec

Table 11: Evolution of the "transmission phase" duration based on the reduced trigger value during the cruise phase

For the A044 flight, 11 minutes should suffice to transmit all the flight recorder data, versus 1 minute fifteen seconds, which does not.

5.3.6 Lessons learnt for this study

Hereafter are described some "lessons learn" about the study conducted over the flight records.

- Some tests have not been achievable, because trigger algorithm is not known for these events. For example, the algorithm corresponding to "fuel exhaustion", "fuel starvation", "turbulence alert", "deviation from flight plan", "flight crew incapacitation"[27], and other events are not known[28]
- For all trigger condition (even the alarms discrete signal), minimum timing of 2 or 4 sec (for confirmation) to be considered for an event to be relevant. If not a lot of spurious event trigger event. For example, there is up to 32 fire / smoke warning, each one less than1 seconds, over the tested flight records
- For computer failures, consider triggering a transmission only in case all redundant computers (critical / hazardous) are all in failure (for example FADEC1 AND FADEC2), and not on a single computer failure
- Consider evaluation by experts of the different trigger thresholds that have been proposed based on the minimum and maximum observed values. Trigger badly defined may never trigger or trigger too late for a complete transition to occur
- Analysis has been done on only one Aircraft type. Threshold should be analyzed on different aircraft type and validated by manufacture and/or pilots and/or specialists (not only on data). For example, thresholds proposed for engine vibration level must be assessed by engine experts (which level of engine vibration are considered as "critical" by engine experts?). To be generalized on all tests: data and proposed threshold should be validated by experts in the concerned technical domain
- The use of the "master warning" event, as the only trigger of the transmission may not be an efficient algorithm
- The last test session has showed that optimized threshold values can be in accordance with the aircraft condition (flight phase, or equivalent). It makes sense to get different threshold

[27] Some of the causes of flight crew incapacitation are already captured by the trigger conditions defined in Annex C to D6: loss of cabin pressure, smoke, …

[28] During the write of document ED-237, some of these trigger criteria have been considered as "not important criteria" for detection of the "Distress condition". Nevertheless, the purpose of this study was to evaluate the possibility to detect "Abnormal condition", and more trigger thresholds were included in the analysis.

values for the relevant trigger algorithms, to optimize the detection of the "transmission condition"

-

5.4 FB3: Data Transport

The Data Transport functional block is divided into two sub-blocks, respectively dubbed "Constellation" and "Transmission".

The "Constellation" block is in charge of determining if the aircraft and satellite can be connected together, while the "Transmission" block is in charge of sending chunk files when a trigger is raised. This block also takes into account some aspects of the file transfer protocol (e.g., data overhead) and the reconnection time to the satellite network after being disconnected.

5.4.1 Constellation functional block

The purpose of the "Constellation" block is to provide a status on a possible connection with one or more satellites of a constellation.

5.4.1.1 Throughput

It is admitted that when the satellite connection is established, the maximum data throughput is available, but the average throughput may vary according to many other parameters such as the number of terminals connected to the satellite, the number of data transitioning through the satellite ground station, or the internet infra-structure itself until the final data recipient.

So, the simulation will focus on finding the minimum throughput necessary to ensure the QR-FRD function by testing different throughputs.

Based on the provider surveys and on study papers (see [Ref 10] and [Ref 11]), LEO satellites can offer for the moment up to 30 MB/sec uplink bandwidth.

5.4.1.2 Minimum elevation and Maximum Link length

At the time of the study, no detailed link budget analysis on the various constellations being considered could be found. Likewise, the analysis of publicly available FCC licenses was not sufficient to determine a detailed link budget of the various systems. The study was therefore based on the paper "An Updated Comparison of Four Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband" [Ref 11].

This paper provides a recent comparison of the various LEO mega-constellations, including a detailed description of the orbit characteristics of the constellations and the minimum elevation angles necessary for systems to operate. It shall be noted that the paper uses two different sets of minimum elevation angles, one as described in the FCC filing from the various operators, one extrapolated for the final deployments. The latter value was used for the study. The following table summarizes the minimum elevation angles[29] used to determine satellites in LOS:

Constellation	Minimum elevation angle used in the study[30]
One Web	37°
Starlink	25°

Table 12: Constellation minimum elevation angle

[29] Elevation angle depends on antenna aperture
[30] These values are based on REF10 and REF11, this is not the official values.

As the aircraft may not be in its nominal pitch/roll configuration, an estimation of the maximum distance allowable between the satellite and the aircraft is necessary to determine which satellite within the minimum elevation angle requirements can be received properly. As no link budget was available at the time, the maximum link length was estimated considering the worst-case elevation while the aircraft is horizontal.

A satellite that would be within the minimum elevation boundaries while the aircraft is no longer horizontal and would exceed the maximum link length would be considered as no longer connected.

Below is the list of maximum link length considered:

Constellation	Maximum Link length between satellite and Airplane used in the study
One Web	1504 km (for 1200 km orbital altitude)
Starlink	700 km (for 550 km orbital altitude)

Table 13: Constellation maximum link length

5.4.1.3 Model

The principle of the "Constellation" block is the following:

1. A model of a satellite constellation is created through a list of longitude, latitude and altitude values representing the satellite constellation (from provider surveys and documents [Ref 10] and [Ref 11])
2. A list of candidate satellites close to the aircraft is identified and for each of them and the following operations are performed:

a. Calculate azimuth, elevation, and distance of the satellites from their respective geographic coordinates (longitude, latitude, altitude) (see [Ref 9])
b. Perform a rotation according to the pitch, roll and heading angles of the aircraft to place the satellites in the aircraft reference plan (see [Ref 12])
c. And finally check if the elevation angle and the distance between the satellite complies with the communication means specification (antenna aperture, path loss, minimum elevation of the satellite)

Here is an illustration of the system geometry in 2D. On the left, the system with a fixed observer on the surface of the Earth, and on the right, with a flying mobile observer.

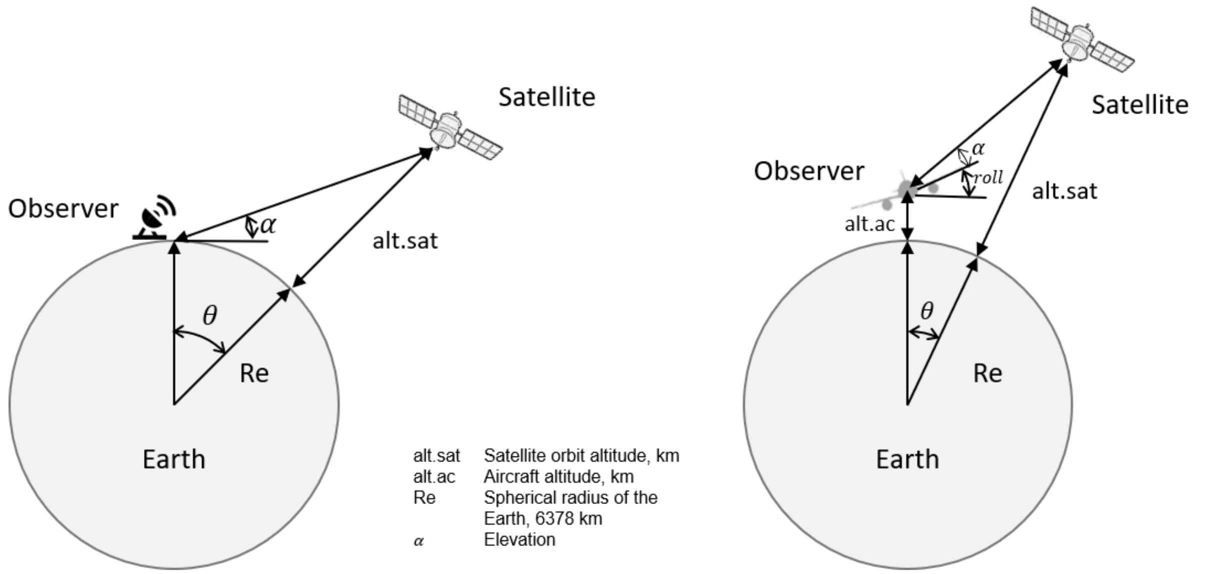


Figure 14: 2D geometry of the system

In the case of the mobile observer, it is necessary the aircraft be placed in the aircraft reference plane to have a correct elevation value.

The figure bellow illustrates the graphical result of the "Constellation" block

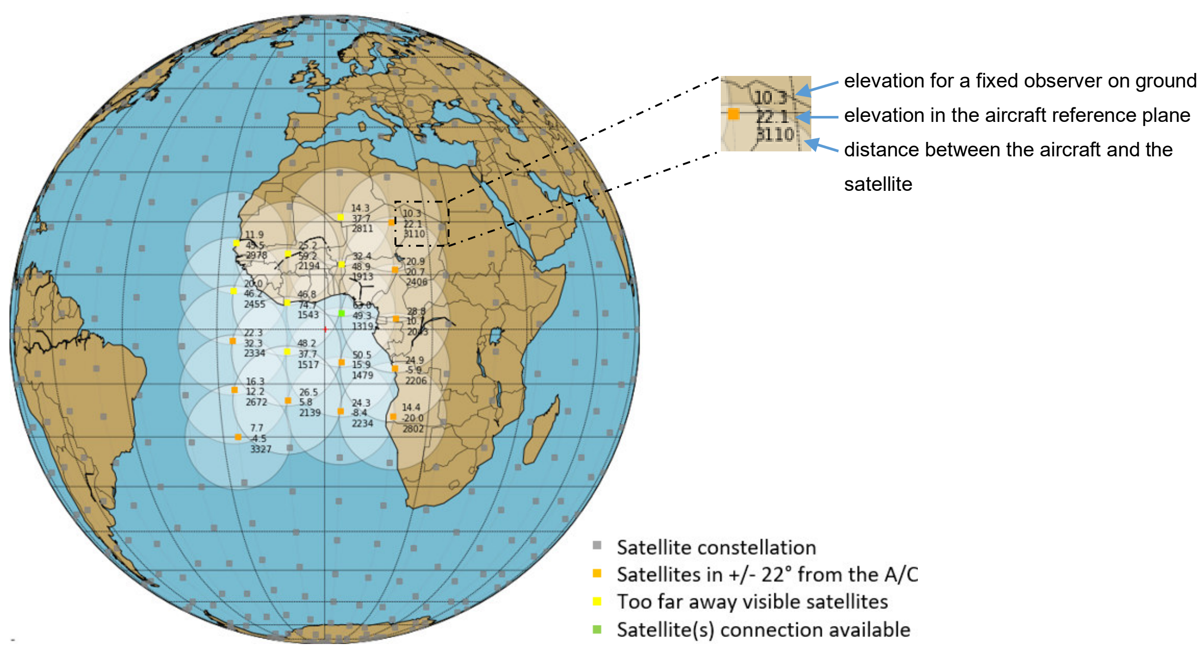


Figure 15: Constellation block results 3D rendering

5.4.2 Transmission block

SFTP and HTTP2 have been identified as file transfer protocols in D3 both using Transmission Control Protocol (TCP). Both necessitate several round trips when negotiating an encrypted connection.

Most of streaming on the internet uses TCP that was designed to ensure delivery of all packets and minimize packet loss. It is a connection-oriented protocol which ensures quality of service by re-transmitting packets until all packets are received.

One of the consequences is that TCP, as a reliable protocol, is extremely sensitive to network latency, which means that significant re-transmission can occur, and this along with the TCP handshake process is made worse by long transmission delays. That is why LEO constellations, unlike GEO constellations, are well adapted (~60-65ms versus >650ms propagation latency). Network latency may be due to transmission delay from the aircraft to the recipient (server) where the data are stored, routing/switching latency, or even Queuing Latency due to congestion for example.

At the moment, a very promising protocol is QUIC-HTTP/3 (quick and secure connection based on UDP - connectionless protocol), so the choice of the file transfer solution at the time the QR-FRD function will be implemented should take this into account.

As the number of packets that can be lost and the impact of this data loss on the file transfer is not known, the model only relies on the Quality Of Service (QoS) provided by the providers. Dedicated tests in a network laboratory and in real condition will be conducted to be more accurate[31].

In summary, the model will rely on average throughput, chunk size and QoS[32] as configurable parameters, the purpose being to find parameter values that take into account potential packet loss and an average throughput that allows to fulfill file transfer requirements such as “the system shall be able to transmit X min historical flight recorder data and Y min real-time flight recorder data after a <specific> event occurs”.

5.5 FB4: Off-Aircraft Storage

Not implemented but graphical representation of the data received on the ground is provided.

5.6 FB6: Data Recovery

Not implemented.

[31] Other consideration should be taken into account. For example, it is admitted that transferring one big file is much faster that a lot of small files that have the same accumulative size.
[32] QoS of 99,9% means 1 file on 1000 lost

6 SIMULATION RESULTS ANALYSIS

6.1 Influence of model parameters

Before performing simulations with the QR-FRD model, here are a series of analysis on the parameters that can impact the volume (thus the recording time) of data received on the ground. Some of them may be obvious or intuitive but computer calculations allow to confirm trends and to draw conclusions.

	Trigger conditions	FCMIR	Chunk file size	Compression	Encryption	Satellite constellation
Coverage						●
Throughput						●
Latency						●
QoS						●
Computation time	●			●	●	
Tx error						●
File transfer protocol			●			●
Time to flight termination	●					
False positive	●					
Fragmentation		●		●		
Latest records			●			
Historical flight recorder data depth received on the ground	●	●		●		●

Table 14: Parameters influence on transmitted flight recorder data

6.1.1 Trigger conditions influence

The sooner the better with an acceptable false positive ratio to be determined/evaluated by aircraft type to take into account their possible flight protection envelop, and other characteristics…

- ⇨ Trigger to be consolidated
- ⇨ Acceptable false positive ratio to determine. Impact on costs and impact on the confidence in the system (nuisance alert).

6.1.2 FCMIR Influence

FCMIR represents 95% of the data volume. Adding a display or a cockpit image camera has a big impact. This drives the choice of the satellite providers. A throughput 50% higher than the flight recorder data input rate is the minimum (for triggered transmissions) to allow to send real-time and historical data.

- ⇨ Images format to be consolidated

6.1.3 Chunk file size

It is a fact; one big file will transfer much faster than thousands of small files that have the same accumulated size. On the other hand, this could have an impact on the last moments of a flight. Indeed, a file that is too big (e.g., a chunk of 60 seconds) may never be received whereas it has been transmitted at 99.9%!

⇨ Dedicated Lab test of file transfer to be conducted in representative environment

6.1.4 Compression

Image and audio compression algorithms were evaluated on representative samples. The type of data has a strong influence and compression performance may vary a lot. Also, lossy compression can be acceptable in some cases (to be defined).

Compression algorithms are generally better when files to compress are large.

Considering the output of a display as a video stream can also be a very good alternative because it can dramatically reduce the size of the data. Indeed, video compression algorithms attempt to reduce redundancy (spatial and temporal) and thus store information more compactly.

⇨ Video compression tests (e.g., MPG-4) to be conducted

6.1.5 Encryption

Encryption can have an impact on computation time, but it is up to future QR-FRD solution provider to correctly size computational resources needed to fulfill the expected performance (meaning encryption time negligible compared to transmission time).

6.1.6 Satellite constellation

The satellite constellation design such as orbital inclination, numbers of planes, satellites per plane, attitudes, ground station's location and satellites inter-communication may not allow a constant network connection.

For example, without ground stations located on high latitude, polar zones may be not covered. This does will not allow satellite communication… unless satellites inter-communication is available. So, ground stations installation may have an impact on connectivity.

Another example with a satellite constellation having an orbital inclination close to zero (crossing at the poles). In that configuration, satellite density is lower near the equator (see example Figure 15: Constellation block results 3D rendering), so the network connection is more easily interrupted with abnormal aircraft attitudes (the pointed satellites are no longer directly above the aircraft and may be too far away to establish a connection).

Impacts on latency and file transfer protocol has been already discussed in §5.4.2 Transmission block.

As internet satellite service providers rely on different constellation designs and technologies, minimal requirements will be defined in D9 to enable QR-FRD function based on model simulation results (QoS, throughput, latency, and coverage).

6.2 Simulation

Based on previous chapter, the simulation parameters settings used are:

- Flight recorder data streams used for this simulation are:
  - 1 x flight data stream (7 kbps) – no compression
  - 3 x flight crew audio streams (100 kbps) – compression ratio 2:1
  - 1 x cockpit area microphone audio stream (64 kbps) – compression ratio 4:1
  - 1 x FCMIR stream (5,855 kbps) – no compression
  - 1 x datalink message stream (0.2 kbps) – no compression
- Average throughput 50% greater than input flight recorder data stream data rate
- 4-second chunk files
- 30 s for the reconnection time after a total connection loss
- QoS = 99,9 %
- Constellation is based on OneWeb constellation characteristics with worldwide coverage.

Figure 16 below depicts the interface of the simulation parameters setting:

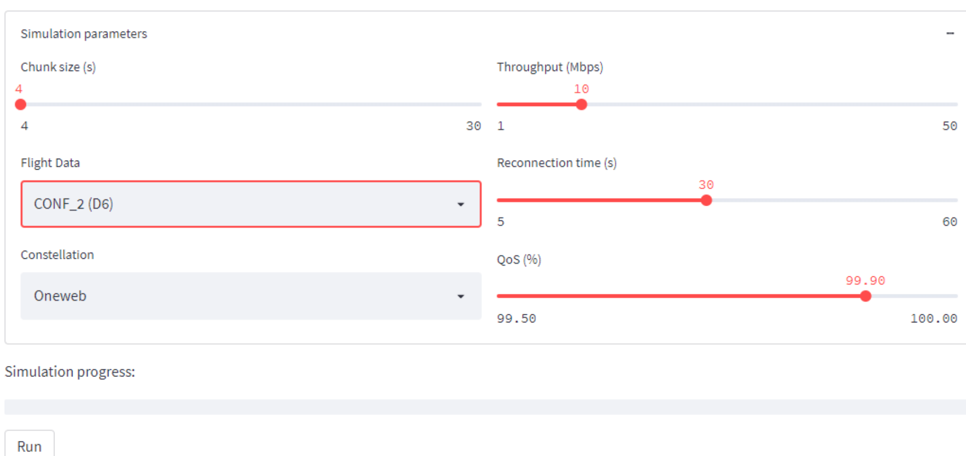


Figure 16: Simulation parameters interface

6.2.1 Data visualization

There are various plots available through the simulation tool.

Scenarios (files provided by the BEA) can be selected using the following filters: phase of flight, occurrence type and occurrence category as depicted in Figure 17

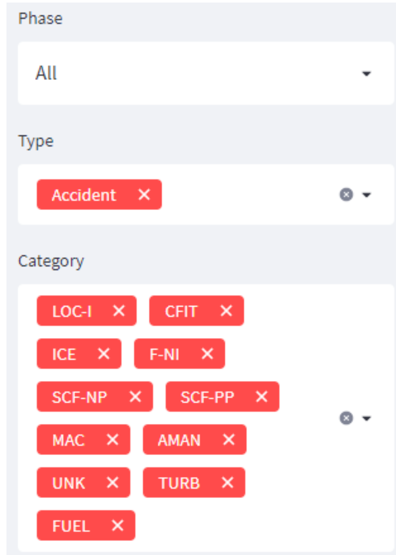


Figure 17: Scenarios filters

Here is a description of the global simulation results view:

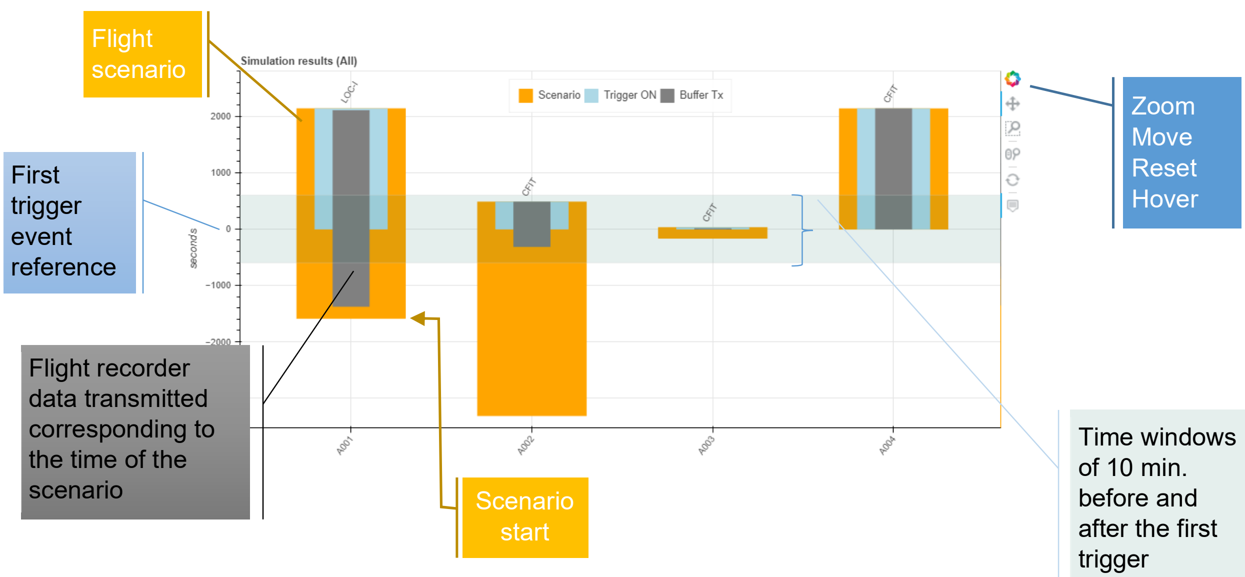


Figure 18: Global simulation results view

Figure 19 bellow depicts the detailed results view for a scenario. The figure displays:

- All-important flight data involved in the trigger logics
- Transmission buffer evolution
- The chunk files transmission delay over time with their status (not send, sent, aborded). Note that real time flight recorder data have precedence over historical flight recorder data. These latter are sent if remaining throughput is available.
- Connectivity status and trigger signal
- Trigger conditions that have been raised over time (only raised conditions are displayed to lighten the figure)

To sum-up, transmission starts when a trigger is raised, and network connection is available. In case of connection loss, connection delay applies to recover the network connection after possible connection condition comes back.

The figure is fully interactive, and zoom are synchronized between the different plots.

Note that “accident” doesn’t mean that the aircraft is destroyed. It may have landed; the scenario doesn't provide the information.

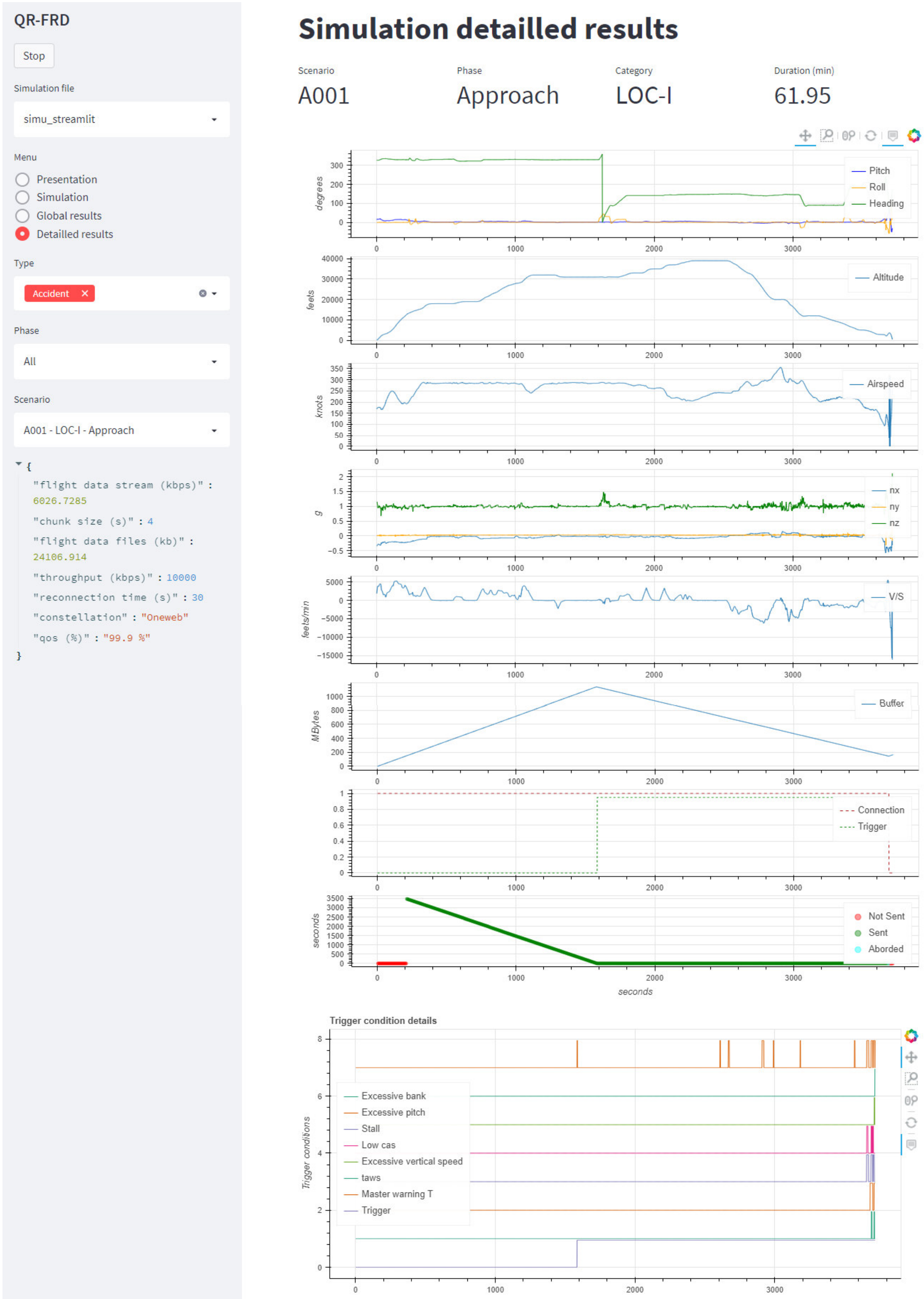


Figure 19: Simulation detailed results view

6.2.2 Climb phase

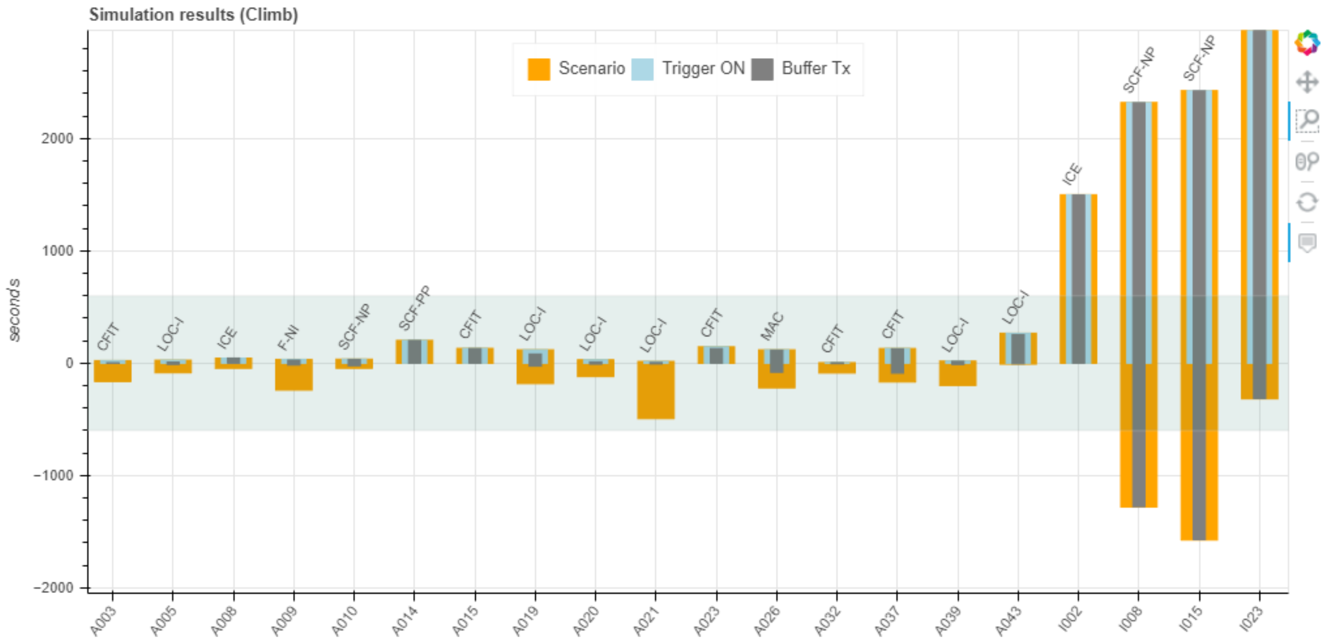


Figure 20: Climb phase – global simulation view

- Flight scenarios categorized as accidents and occurring during the climb phase generally last less than 10 minutes
- For that phase, the first trigger condition event distribution is depicted in the following figure:

trigger1st	Scenarios	trigger1st delay (s)	mean
Excessive bank	A003, A008, A019, A021	163, 45, 181, 493	220.5
Excessive pitch	A020	119	119.0
Excessive used rudder	A039	198	198.0
Low cas	A010, A014, A015, A023, A043, I002	45, 1, 1, 1, 8, 1	9.5
Master warning T	I008	1280	1280.0
Too low altitude	A032, A037	87, 167	127.0
Unusual load factor	I015	1574	1574.0
taws	A005, A009, A026	85, 239, 219	181.0
tcas	I023	317	317.0

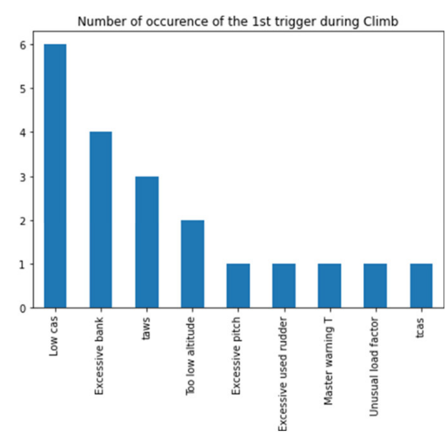


Figure 21: Climb - occurrence of 1st trigger event and its detection time

When occurring first, 'Low CAS' generally triggers very early, and represents 30 % of the first trigger raised (6 out of 20). Other conditions trigger only few seconds before the flight termination.

For A026 and A037, few historical flight recorder data have been sent, respectively due to 'TAWS' and 'Too low altitude' triggers.

- In case of incidents, all flight data are transmitted.
- In case of accidents such as CFIT, LOC-I or MAC accident type, most of the time only real time flight recorder data is transmitted.
- Accidents at take-off look sudden, and it's often too late to send data due to rapid loss of network connection and little transmission time (as observed in detailed views).

6.2.3 Cruise phase

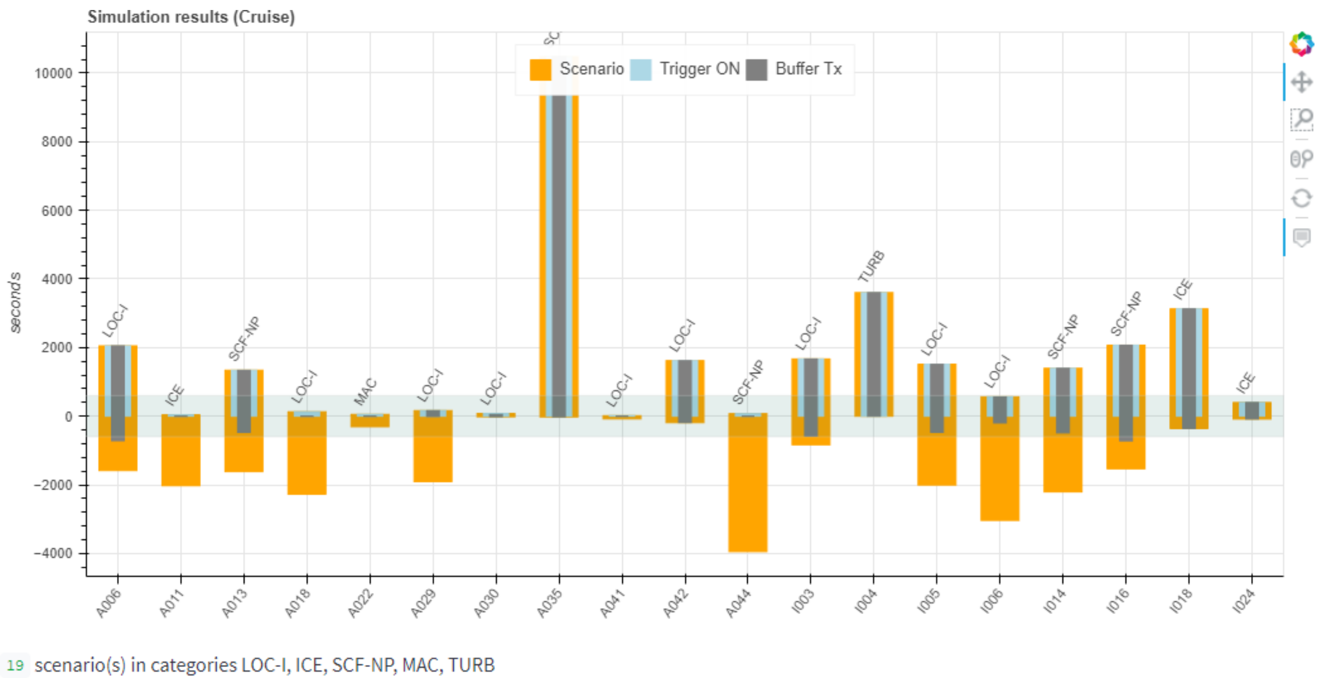


Figure 22: Cruise phase – global simulation view

- Except in case of abrupt descent and extreme pitch/roll angles / angle rates (A011, A018, A022, A029, A041, A044, see related trigger event in Figure 23 below) where the connection is lost almost at the same time the 1st trigger condition is detected, it is possible to transmit flight recorder data. The volume of historical flight recorder data depends on the remaining throughput because real time data have precedence. So, if the available throughput is 30% higher than flight recorder data stream throughput, the historical flight recorder data will represent 30% of the total volume of data. The depth of the historical flight recorder data buffer is not fixed at this stage.

trigger1st	Scenarios
Master warning T	A006, A013, A022, A035, I006, I016
Excessive vertical speed	A029, A030, I018, I024
Excessive bank	A018, A041
Low cas	A042, I004
Stall	A011, I003
Cabin altitude warning	I014
Excessive pitch	A044
Unusual load factor	I005

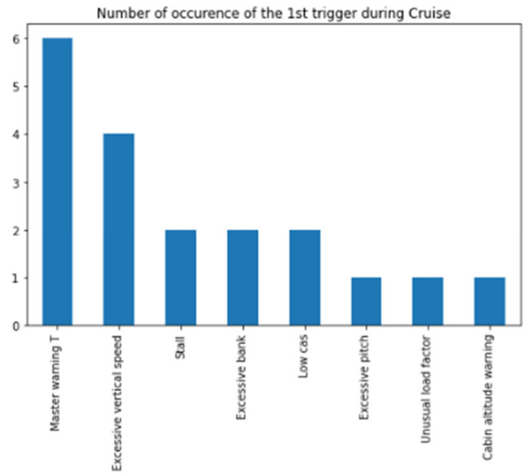
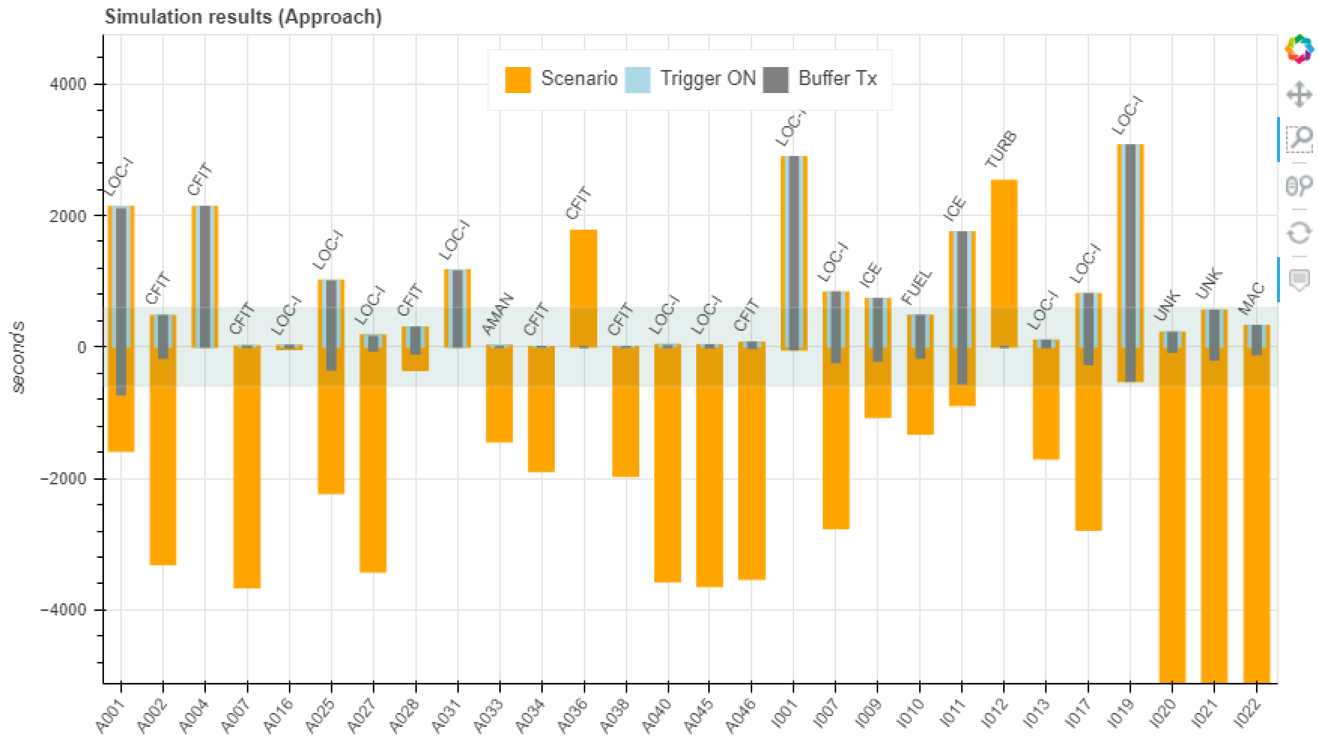


Figure 23: Cruise - occurrence of 1st trigger event

- Note: A number of glitches or missing flight data triggers rely on was noticed in the detailed view of the scenario files provided by the BEA. The actual triggering results should be better with live data.

6.2.4 Approach phase

Figure 24 below summarizes the simulations results for accidents and incidents scenarios that occurred during the approach phase.



28 scenario(s) in categories LOC-I, CFIT, AMAN, ICE, FUEL, TURB, UNK, MAC

Figure 24: Approach phase – global simulation results view

- 13 out of 16 accident scenarios have generated triggers within the last seconds
  - No trigger was detected for A36
  - A016 is very short (1 min) and does not include previous flight phases. This impedes the analysis
  - 8 accident scenarios raised a trigger during the last seconds of the flight (little bit longer for A027)
  - A004 is a complete 35min flight (climb to approach) and the 1st trigger condition has been detected at the beginning of the flight. TAWS trigger is raised during the approach phase, again few seconds before the flight termination
  - Excessive vertical speed has been detected at the beginning of scenario A031 probably due to a wrong initialization of V/S flight data (Same for A025, for glitches reason in the middle of the scenario). Low Cas trigger is raised during the approach phase, again few seconds before the flight termination
- Like for Cruise phase, incidents scenarios show the possibility to transmit flight recorder data with a volume of historical flight recorder data proportional to the remaining throughput once real-time flight recorder data are transmitted. The depth of the historical flight recorder data buffer is not fixed at this stage.
- During Approach phase, the following 1st triggers have been raised:

trigger1st	Scenarios
Master warning T	A001, A002, I017, I019, I020, I021, I022
taws	A027, A028, A034, A038, A045, A046
Excessive bank	A033, I007, I009
Excessive vertical speed	A025, A031, I001
Low cas	A004, A016, I010
Stall	A007, I013
Excessive used rudder	I011
Overspeed	A040

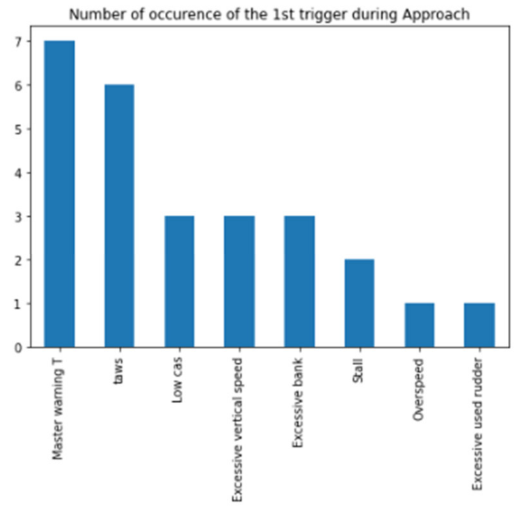


Figure 25: Approach - occurrence of 1st trigger event

- Accidents during approach look sudden most of the time, and it's often too late to transmit data

6.3 Conclusion of the simulation

The analysis of the scenarios shows that each situation is different from one flight to another. The BEA flight scenarios may be incomplete from the standpoint of available flight data to be used for the trigger logics and from the standpoint of the depth of the historical flight recorder data buffer. However, these scenarios are sufficient to draw the first conclusions.

⇨ The available throughput to transmit data through a LEO Satellite is convenient regarding the flight recorder data stream (generally up to 30 Mbit/s - peak). A minimum of 50% more than the flight recorder data stream data rate is preconized (average).

<u>Solution “Triggered mode”</u>

During Initial Climb phase and Approach phase, the sudden occurrence of an event that may lead to an accident or incident does not allow the transmission of sufficient flight recorder data for an analysis of the latter. Trigger condition evaluation doesn’t seem to be appropriate.

During Cruise phase, trigger condition detection is often concurrent with the loss of datalink connection when related to extreme attitudes (half of the accident scenarios). Trigger condition thresholds regarding pitch and roll must be more specific to the aircraft type (e.g., aircraft flight envelop protection) and set according to an acceptable false positive ratio (to be define).

⇨ Except for incidents or accidents where the aircraft can land, data sent to ground does not reach the QR-FRD objectives. Almost all (70% of the time) trigger conditions are detected during the last seconds of the scenario

<u>Solution “Streaming mode”</u>

All flight data of all flights are transmitted until a final loss of connection.

⇨ The cost of this solution may be prohibitive

7 RECOMMENDATIONS

Based on the simulation results and analysis, a hybrid solution is recommended:

- Streaming[33] mode during the Initial Climb phase, with or without FCMIR,
- Streaming mode during the approach phase initiated using altitude, vertical speed and/or distance to the airport for instance (to be further determined)
- Triggered mode during the cruise phase (note that bursts of flight recorder data, perhaps limited to flight data, may be transmitted to maintain the datalink connection)

In addition, it is suggested to add:

- a 'stop real-time flight recorder data transmission' condition such as 'no trigger raised since <to be defined> minutes' (Xa minutes after trigger drops). Basically, it could be the inversed current trigger logic, or a more sophisticated de-activation trigger defined by matter experts.
- a 'stop historical flight recorder data transmission' condition such as <to be defined> minutes' of historical flight recorder data sent (Xb minutes before trigger raises). The real-time flight recorder data still have the highest priority, and a new trigger will reset the timers.

Figure 26 below illustrates the different transmission windows according to the 'stop' mechanisms.

[33] Many airports are close to the coast with significant depths, marecages or silty soils so flight recorder data is necessary during climb and approach.

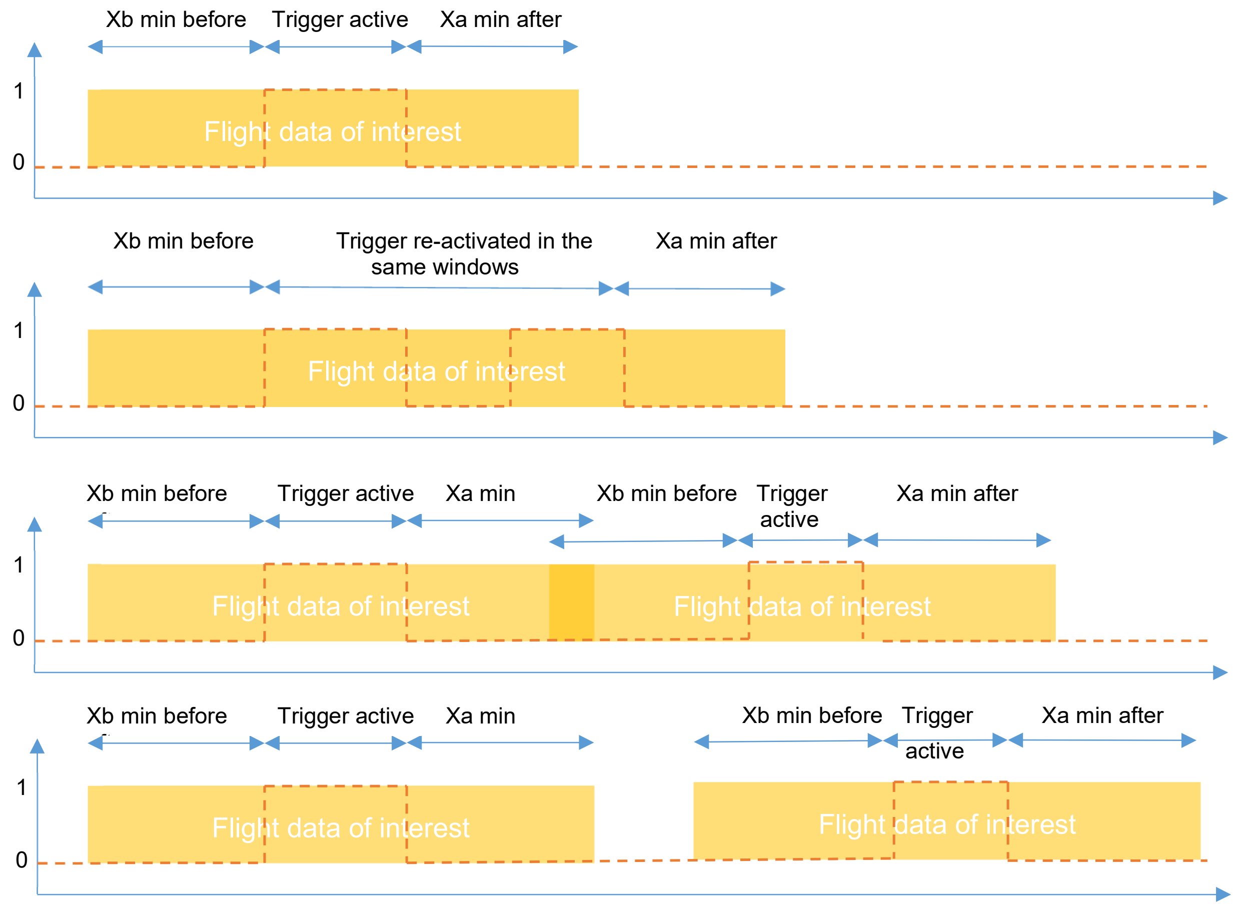


Figure 26: Transmission windows scenarios

Note: A chunk transmitted will not be transmitted twice, there is no overlap.

Other options may be considered:

- Use of Wi-Fi or/and cellular communications during taxi phases to minimize satellite data transmission costs (to the maximum extent possible)
- Stream only flight data and audio recordings during Initial Climb and Approach phases and transmit FCMIR only in triggered mode while in cruise.

8 ANNEX A: BEA FILES

8.1 List of accidents and incidents in database

#	A/C Type	Flight Phase	Occurrence Category ID	Comments
A001	A320	Approach	LOC-I	All the scenarios listed here do not concern necessarily CS-25 or are too old but it is interesting from a flight profile point of view
A002	A320	Approach	CFIT	
A003	B737	Climb	CFIT	
A004	CRJ100	Approach	CFIT	
A005	A310	Climb	LOC-I	
A006	MD-82	Cruise	LOC-I	
A007	B737	Approach	CFIT	
A008	F100	Climb	ICE	
A009	Concorde	Climb	F-NI	
A010	DHC-6	Climb	SCF-NP	
A011	ATR72	Cruise	ICE	
A013	B737	Cruise	SCF-NP	
A014	Shorts360	Climb	SCF-PP	
A015	B747	Climb	CFIT	
A016	F27	Approach	LOC-I	
A018	A310	Cruise	LOC-I	
A019	B737	Climb	LOC-I	
A020	A300	Climb	LOC-I	
A021	Saab340	Climb	LOC-I	
A022	B737	Cruise	MAC	
A023	B737	Climb	CFIT	
A024	CRJ200	Takeoff	ICE	
A025	A300	Approach	LOC-I	
A026	A320	Climb	MAC	
A027	A310	Approach	LOC-I	
A028	Bae146	Approach	CFIT	
A029	Tupolev-154M	Cruise	LOC-I	
A030	Ilyushin-18V	Cruise	LOC-I	
A031	Tupolev-154M	Approach	LOC-I	
A032	Ilyushin-76TD	Climb	CFIT	
A033	B737	Approach	AMAN	
A034	Yakovlev-42	Approach	CFIT	
A035	B737	Cruise	SCF-NP	
A036	Ilushin-76TD	Approach	CFIT	
A037	Ilyushin-76MD	Climb	CFIT	
A038	Tupolev-134	Approach	CFIT	
A039	A300	Climb	LOC-I	
A040	ATR72	Approach	LOC-I	
A041	B737	Cruise	LOC-I	

#	A/C Type	Flight Phase	Occurrence Category ID	Comments
A042	B757	Cruise	LOC-I	
A043	B757	Climb	LOC-I	
A044	MD-82	Cruise	SCF-NP	
A045	A330	Approach	LOC-I	
A046	A321	Approach	CFIT	
A047	UNK	UNK	UNK	
I001	A310	Approach	LOC-I	
I002	DHC-8	Climb	ICE	
I003	CRJ705	Cruise	LOC-I	
I004	A319	Cruise	TURB	
I005	Falcon900	Cruise	LOC-I	
I006	A330	Cruise	LOC-I	
I007	B737	Approach	LOC-I	
I008	A330	Climb	SCF-NP	
I009	Saab340	Approach	ICE	
I010	Embraer120	Approach	FUEL	
I011	Saab340	Approach	ICE	
I012	Saab340	Approach	TURB	
I013	B717	Approach	LOC-I	
I014	B737	Cruise	SCF-NP	
I015	B777	Climb	SCF-NP	
I016	B747	Cruise	SCF-NP	
I017	A320	Approach	LOC-I	
I018	BAe146	Cruise	ICE	
I019	B737	Approach	LOC-I	
I020	B777	Approach	UNK	
I021	B777	Approach	UNK	
I022	A330	Approach	MAC	
I023	A330	Climb	MAC	
I024	B717	Cruise	ICE	

Table 15: BEA Accident and Incident database

8.2 List of parameters

All datasets were provided as Microsoft Excel files (.xls) at a sample rate of 1 Hz (1 data point per second).

Not all parameters are available in the datasets. Parameters involved in trigger conditions and not available have been recalculated from other when possible (i.e., vertical speed from altitude).

Missing values (i.e. N/A) and lower refresh rate (½ Hz or ¼ Hz) where intermediate unavailable data are marked with "-", or blanks have been filled using interpolation method when appropriate[34].

Glitches and spurious value are "filtered" using confirmation delay of the trigger conditions.

#	Definition	Units	Description/Comments
-	Timestamp (FDR time counter)	s	Timestamp sample rate at 1 Hz
1	Barometric altitude (AMSL)	ft	Pressure altitude Combined parameter (Altitude Coarse + Altitude fine)
2	Indicated airspeed	kt	Can be Indicated Airspeed, Calibrated Airspeed or Computed Airspeed
3	Ground speed	kt	
4	Pitch angle	deg	Positive sign=nose-up
5	Roll angle	deg	Positive sign=right wing down
6	Magnetic heading	deg	1 to 360°
7	Engine #1 (of 2) power level (N1)	%, RPM	N1 or EPR or Torque
8	Engine #2 (of 2) power level (N1)	%, RPM	N1 or EPR or Torque
9	Radio altitude (height)	ft	Can be coming from radio-altimeter 1 or 2 or both combined into one parameter.
10	Vertical speed	ft/min	Is either recorded or will be derived from Altitude
11	Longitudinal acceleration (Nx)	g	Longitudinal acceleration Positive sign=deceleration
12	Lateral acceleration (Ny)	g	Lateral acceleration Positive sign=right turn
13	Normal acceleration (Nz)	g	Normal acceleration Positive sign=up
14	Flaps or slats configuration	0-2	0=Clean; 1=Take-off configuration; 2=Approach configuration
15	TAWS warning	discrete	GPWS or EGPWS Alert or Warning, whatever the mode. (0=No Warning;1=Warning)
16	Stall warning	discrete	Can be stick shaker activation Can be information coming from CVRs. 0=No Stall; 1=Stall
17	Cabin altitude warning	discrete	0=No Warning; 1=Warning
18	Master warning	discrete	0=No Warning/Caution; 1=Warning/Caution
19	Left angle of attack	deg	Left True Angle of Attack (or AOA1) Positive sign=up
20	Right angle of attack	deg	Right True Angle of Attack (or AOA2) Positive sign=down
21	Autopilot engagement status	discrete	0=Autopilot disconnected 1=Autopilot engaged
22	Eng. #1 (of 2) ice detection warning	discrete	0=No Ice; 1=Ice
23	Eng. #2 (of 2) ice detection warning	discrete	0=No Ice; 1=Ice

[34] This doesn't change the data volume because the FDR data (A717) already contains data sampled at a greater rate.

#	Definition	Units	Description/Comments
24	Eng. #1 (of 2) intermed. / high pressure spool speed (N2)	%	
25	Eng. #2 (of 2) intermed. / high pressure spool speed (N2)	%	
26	Wing anti-ice system status	discrete	0=OFF; 1=ON
27	Engine #1 (of 2) anti-ice system status	discrete	0=OFF; 1=ON
28	Engine #2 (of 2) anti-ice system status	discrete	0=OFF; 1=ON
29	Total fuel quantity	lb	Sum of quantities of all tanks
30	Gross weight	lb	
31	Center of gravity	%	Center of Gravity
32	Fuel flow engine #1 (of 2)	lb/min	
33	Fuel flow engine #2 (of 2)	lb/min	
34	Engine #1 (of 2) bleed status	discrete	0=OFF; 1=ON
35	Engine #2 (of 2) bleed status	discrete	0=OFF; 1=ON
36	Landing gear selector position	discrete	0=UP; 1=DOWN
37	True airspeed	kt	
38	Captain pitch command position	deg	Positive sign=nose up
39	First officer pitch command position	deg	Positive sign=nose up
40	Captain roll command position	deg	Positive sign=right
41	First officer roll command position	deg	Positive sign=right
42	Rudder pedal position	deg	Positive sign=right
43	Left aileron position	deg	Positive sign=up (turn left)
44	Right aileron position	deg	Positive sign=up (turn right)
45	Rudder position	deg	Positive sign=turn right
46	Left elevator position	deg	Positive sign=Nose down
47	Right elevator position	deg	Positive sign=Nose down
48	ACAS resolution advisory	discrete	0=No Advisory; 1=Advisory
49	Engine #1 (of 2) fire alert	discrete	0=No Fire;1=Fire
50	Engine #2 (of 2) fire alert	discrete	0=No Fire;1=Fire
51	Overspeed (VMO/MMO) warning	discrete	VMO/MMO OVERSPEED 0=No Warning; 1=Warning
52	Left spoiler 1 out status	NA	As many parameters as there are spoilers. May vary with aircraft type. 0°=retracted.
53	Right spoiler 1 out status	NA	
54	Left spoiler LH2 out status	NA	
55	Left spoiler LH3 out status	NA	
56	Left spoiler LH4 out status	NA	
57	Left spoiler LH5 out status	NA	
58	Right spoiler RH2 out status	NA	
59	Right spoiler RH3 out status	NA	
60	Right spoiler RH4 out status	NA	
61	Right spoiler RH5 out status	NA	

Table 16: BEA parameters

9 ANNEX B: TIME TO FLIGHT TERMINATION ON BEA DATABASE

This figure bellow displays in orange the portion of the scenario after the trigger condition was (first) detected (in blue, the portion of the flight prior to trigger detection):

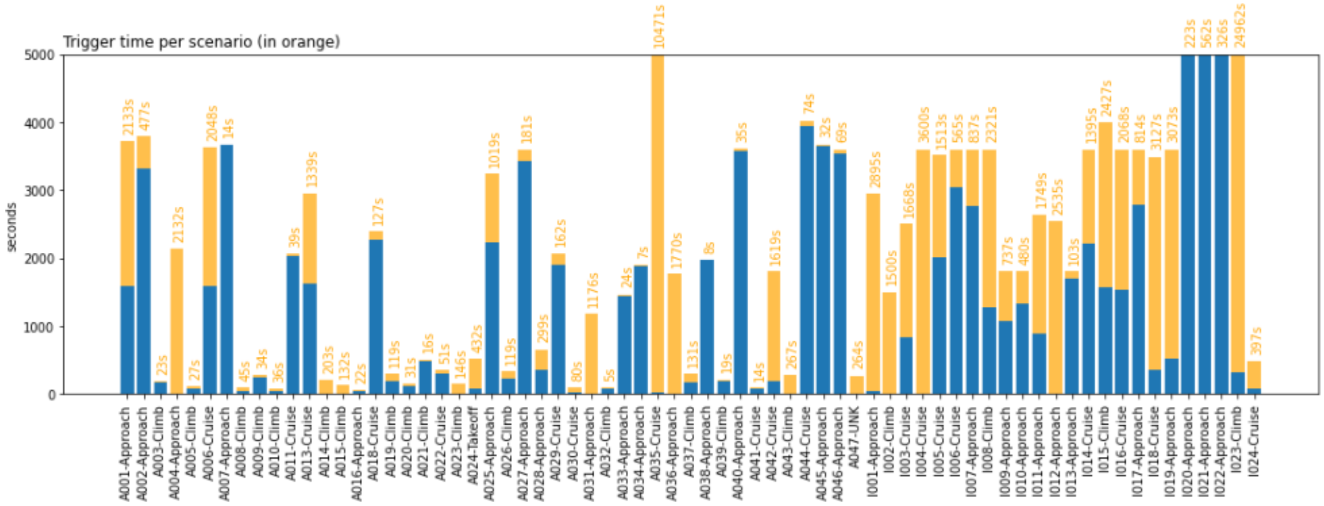


Figure 27: Time to flight termination on BEA scenarios

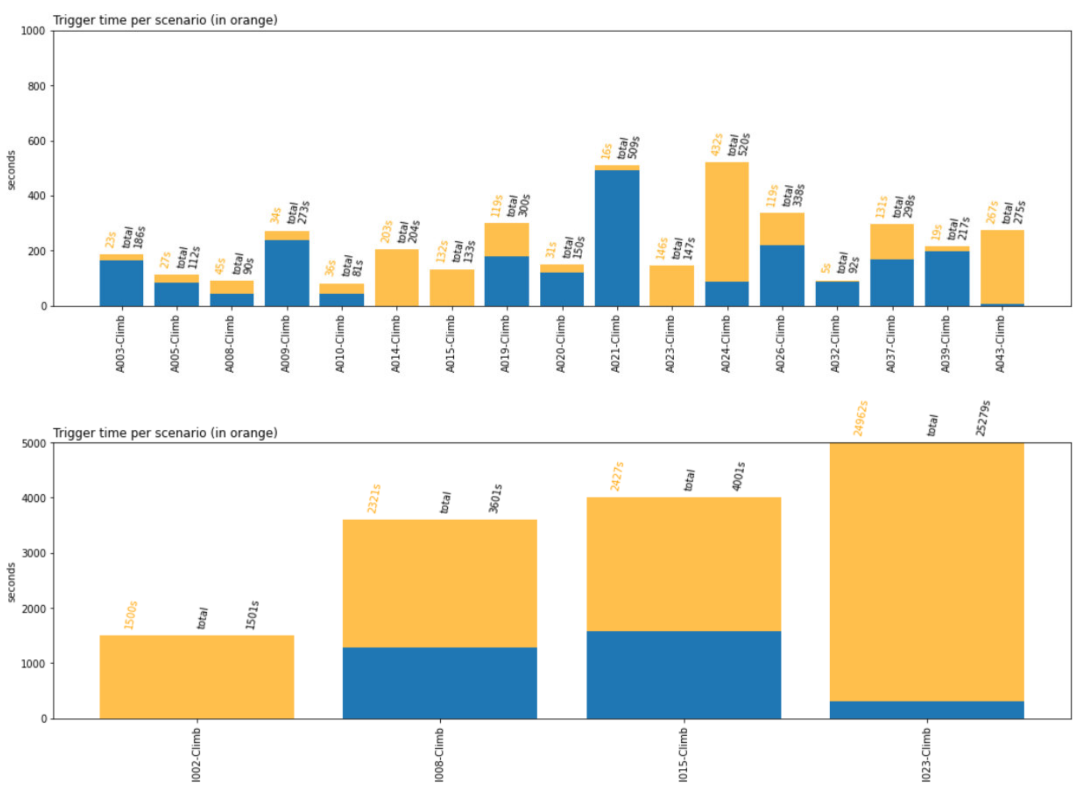


*Figure 28: Time to flight termination on BEA scenarios in Climb phase (**A**ccident then **I**ncident)*

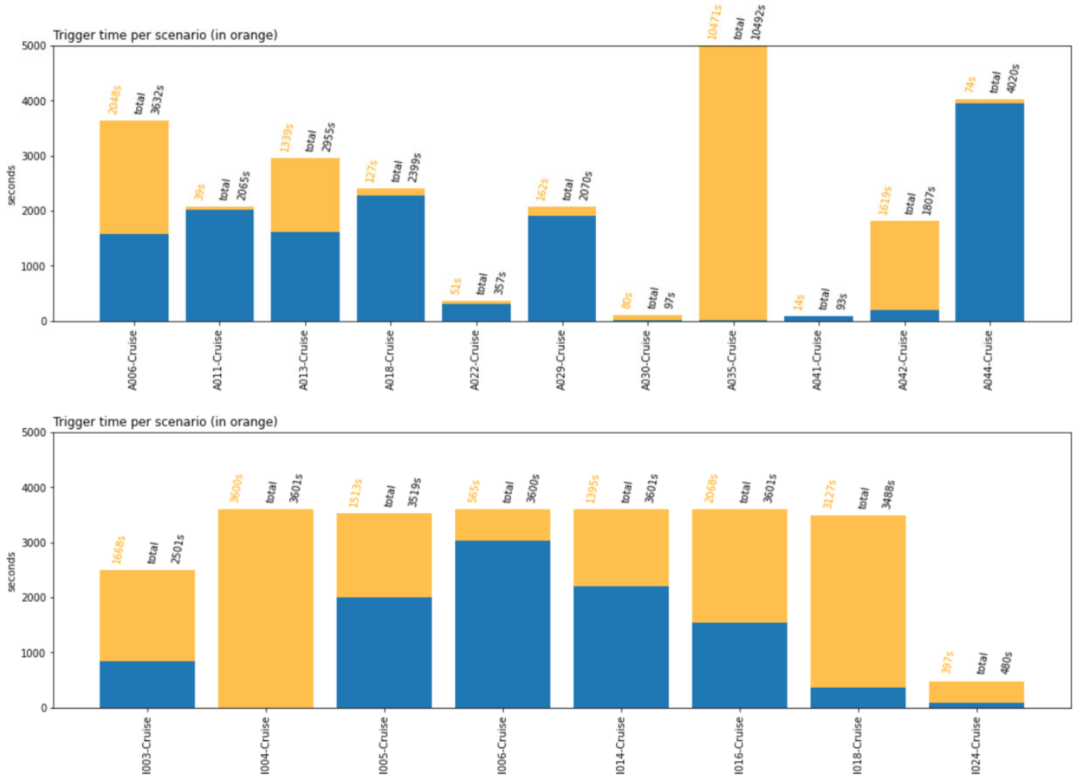


*Figure 29: Time to flight termination on BEA scenarios in Cruise phase (**A**ccident then **I**ncident)*

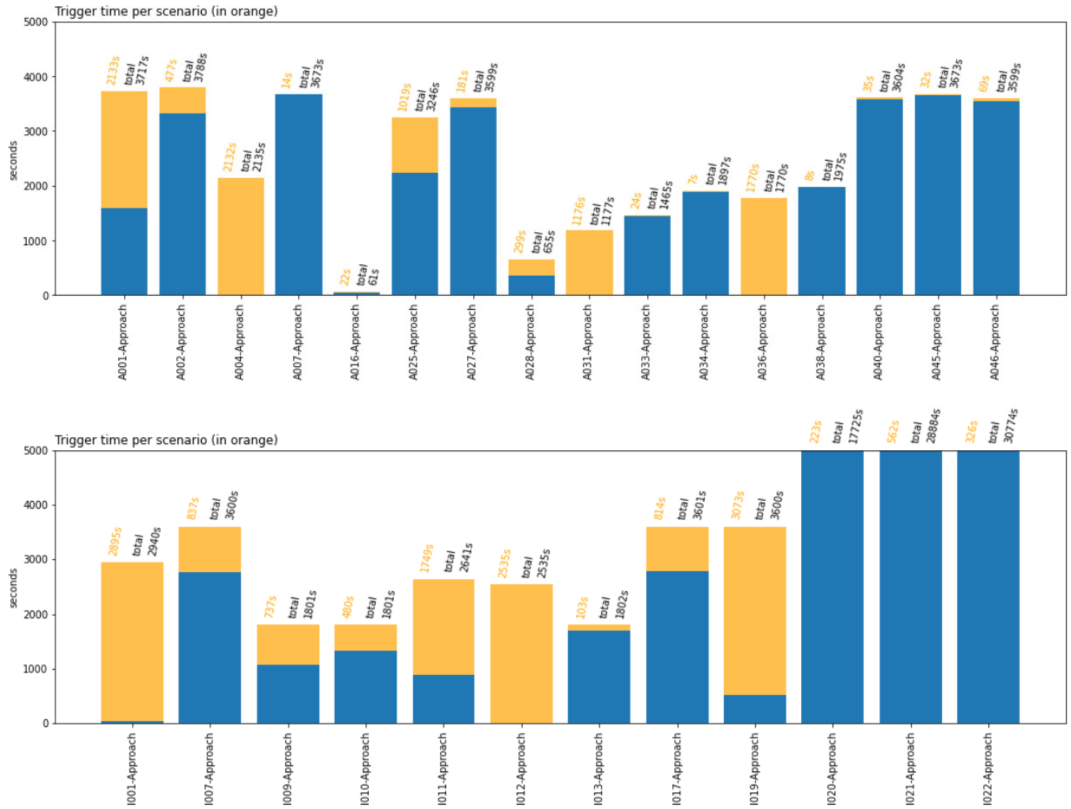


*Figure 30: Time to flight termination on BEA scenarios in Approach phase (**A**ccident then **I**ncident)*

The figure after represents the trigger duration in seconds before the flight termination for each trigger condition that was detected. It allows to determine which trigger was raised and when.

For example, the trigger duration for scenario A001 shown in Figure 27 is 2133 seconds (35 minutes and 33 seconds’). Figure 31 shows that this corresponds to the Master Warning trigger (which was the first raised).

Orange lines identify scenarios where no trigger was raised.

Figure 31: Detailed time to flight termination on BEA scenarios

10 ANNEX C: IMPLEMENTED TRIGGER

The table below recaps the triggers conditions available from various sources and identifies D3 triggers conditions that have been implemented in the model. When no duration is specified, the trigger condition is considered immediately else a delay during which the condition must be set applies.

If a trigger condition is implemented in the model, the mention YES is added else a NO is added.

Condition	Source	Formula	Model implementation
Unusual Attitude			
Excessive roll angle and roll angle rate	D3 / BEA	|ROLL| > 50° OR |ROLL| > 45° AND |ROLLRATE| > 10°/s DURING 2 Sec	YES
	AIRBUS	|ROLL| > 60° OR |ROLL| > 45° AND |ROLLRATE| > 10°/s AND ROLL*ROLLRATE > 0	
Excessive pitch angle and pitch angle rate	D3 / BEA / AIRBUS	Pitch > 30° OR Pitch < -20° OR (Pitch > 20° AND Pitch rate> 3°/s) OR (Pitch < -15° AND Pitch rate< -3°/s) DURING 2 Sec	YES
Unusual Speed			
Excessive Vertical Speed	D3 / BEA	|V/S|>9000 ft/min DURING 2 Sec	YES
	AIRBUS	|V/S| > 10000 ft/min	
Excessive Normal and Lateral Accelerations	D3 / BEA	Nz > 2.6g OR nz < -1.1g OR |ny| > 0.25g DURING 2 Sec	YES
	AIRBUS	Nz > 2.6g OR nz < -1.1g OR |ny| > 0.4g	
Stall Warning	D3 / BEA	STALL Warning = TRUE	YES
Inappropriate speed for the flight situation	D3	CAS < 100 kt OR IAS > 400 kt OR OVERSPEED Warning = TRUE AND Alt < 15000 ft DURING 2 Sec	YES

	BEA	CAS < 100 kt AND Radio altitude > 100 ft DURING 2 Sec OR IAS > 400 kt OR OVERSPEED Warning = TRUE AND Alt < 15000 ft DURING 2 Sec	
	AIRBUS	CAS < 100 kts AND A/C in flight OR CAS > Diving speed OR MACH > Diving Mach	
Near CFIT			
Terrain Avoidance and Warning System	D3 / BEA	TAWS warning/alert = TRUE	YES
	AIRBUS	TAWS/GPWS alert = PULL_UP	
Inappropriate Altitude for the Flight Situation (Too low altitude)	D3 / BEA	40 < Radio altitude < 100 AND Eng1N1 > 80% AND Eng2N1 > 80% DURING 10 Sec	YES
Total loss of thrust/propulsion on all engines			
Engine performance parameters indicating a loss of thrust	D3	For each engine: Engine_Thrust#9 < TBD	NO **(no data)**
Cabin depressurization			
Loss of Cabin Pressure Alert	D3 / BEA	CABIN ALT WARNING = TRUE DURING 10 Sec	YES
Abnormal Value of Cabin Pressure Altitude	D3	Cabin_Pressure_Altitude#79 > 10,000 ft DURING 5 min	NO **(no data)**
Fire on board the aircraft			
Fire on Board Alert	D3	Warnings#24 = FIRE_ALERT OR Warnings#24 = SMOKE_ALERT DURING 2 minutes	NO **(no data)**
Aircraft system failure or malfunction			
Abnormal Engine Parameters	D3	For each engine: Engine_Pressure_Ratio#35 > TBD OR Engine_Indicated_Vibration_Level#35 > TBD	NO **(no data)**

Engine Alerts	D3	For each engine: Engine_Vibration_Warning#62 = TRUE OR Engine_Overtemperature_Warning#63 = TRUE OR Engine_Oil_Pressure_Low_Warning#64 = TRUE OR Engine_Overspeed_Warning#65 = TRUE	NO **(no data)**
Low Pressure Warning	D3	Low_Hydraulic_Pressure_Warning#30 = TRUE OR Low_Pneumatic_Pressure_Warning#30 = TRUE	NO **(no data)**
Electrical Bus Failure Indications	D3	AC_Electrical_Bus_Status#48 = FAIL OR DC_Electrical_Bus_Status#49 = FAIL	NO **(no data)**
Computer Failure	D3	Computer_Failure#52 = TRUE	NO **(no data)**
Low fuel or fuel system anomaly			
Abnormal Values of Fuel Quantities for the Flight Situation	D3	Fuel_Quantity_CG_Trim_Tank#56 < TBD	NO **(no data)**
Fuel Exhaustion	D3	No trigger condition → TBD	NO **(no formula)**
Fuel Starvation	D3	No trigger condition → TBD	NO **(no formula)**
NMAC			
Airborne Collision Avoidance System	D3	TCAS_ACAS_Status#36 = ACAS_RA	YES
	BEA	TCAS RA = TRUE	
Possible penetration of severe weather			
Wind Shear Alert	D3	Windshear_Warning#37 = TRUE	NO **(no data)**
Turbulence Alert	D3	No trigger condition → TBD	NO **(no formula)**
Deviation from Planned Flight Path			

Abnormal values of cross-track error or estimated time of arrival	D3	`No trigger condition` → `TBD`	**NO** **(no formula)**
Flight Crew Incapacitation			
TBD	D3	`No trigger condition` → `TBD`	**NO** **(no formula)**
OTHER TRIGGERS			

Excessive roll command	BEA	`(|Captain Roll cmd| > 50`
		`OR |F/O Roll cmd| > 50)`
		`AND IAS > 80 kt`
		`DURING 2 Sec`
			YES

Excessive use of rudder	BEA	`|Rudder position| > 6° AND`
		`IAS > 240 kt`
		`DURING 2 Sec`
			YES

Table 17: Triggers from D3 implemented in the model

11 ANNEX D: TRIGGER DETECTION ANALYSIS DATA

This section provides the results of Cassiopée™ database analysis. These data are the result of the flight records read back. They are also the sources of the conclusion provided section 5.3.

11.1 Description of the results given in this section

In accordance with the section 5.3, the following process was applied to get the following result.

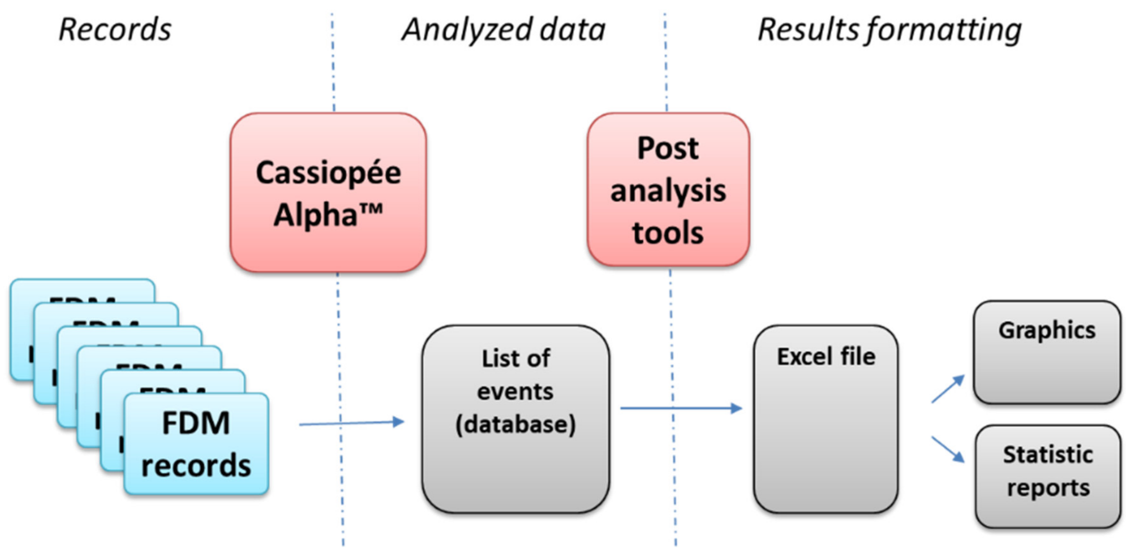


Figure 32: Duration of flight records

The Cassiopée Alpha™ analysis (first part of the process) needs around 72 non-stop hours' workings. The second phase is shorter (less than 6 hours). The CSV excel file with the result is 30 megabytes long,

Several types of graphics are provided:

1. Graphical with analogue value distribution (example the maximum of |Roll| during each flight)

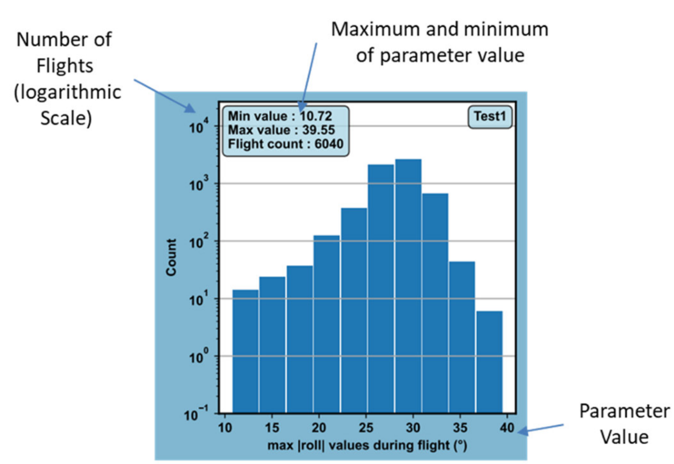


Figure 33: Figure with distribution of Max or Min value of a parameter

2. Graphical with positive Boolean parameter duration distribution (evens, alarms, warning, …)

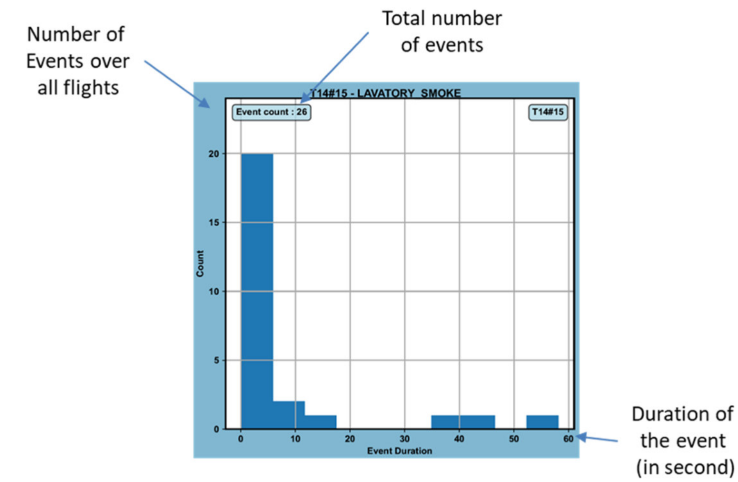


Figure 34: Figure with distribution of duration of event

3. Graphical with positive Boolean parameter flight phase distribution (evens, alarms, warning, …)

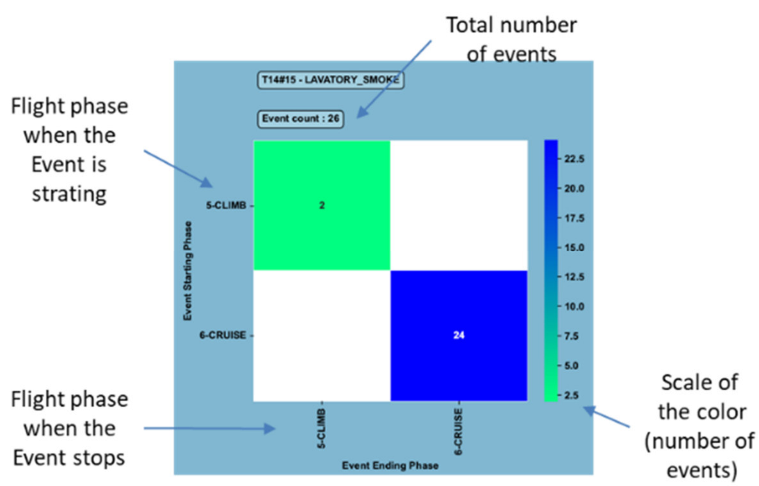


Figure 35: Figure with distribution of event by flight phase

Main remark: the analysis reports a great number of events with a duration of less than 2 seconds. Because the parameters are read out at a rate of one sample per second, the events are only on one or two successive sample. These events are considered as spurious. The main hypothesis is that these events result of energy network switching (transient) or redundant computers commutations. They are not considered in this study. Furthermore, Flight with toggling values (management of parameter validity) are removed from the analysis.

11.2 Characteristics of flights, which records have been analyzed

6040 flights have been analyzed, for a total duration of 45 500 hours. The average of the flight duration is 7h30min, the longer flight is 12h50min.

The aircrafts considered are 2 Airbus A330-300s: these are modern medium/long-haul aircraft. They are twin-engine with ETOPS certification.

The flight considered are from January 2016 to December 2021. These flights address a total of 39 Airports and 102 Air Routes (same from-to parameters)

Among these flights, around 300 have a duration less than 2 hours. These flights are not in accordance with the scope of the study, (I.E medium/long haul, over the ocean). However, the ratio is very low (less than 1%) and does not have impact on the results.

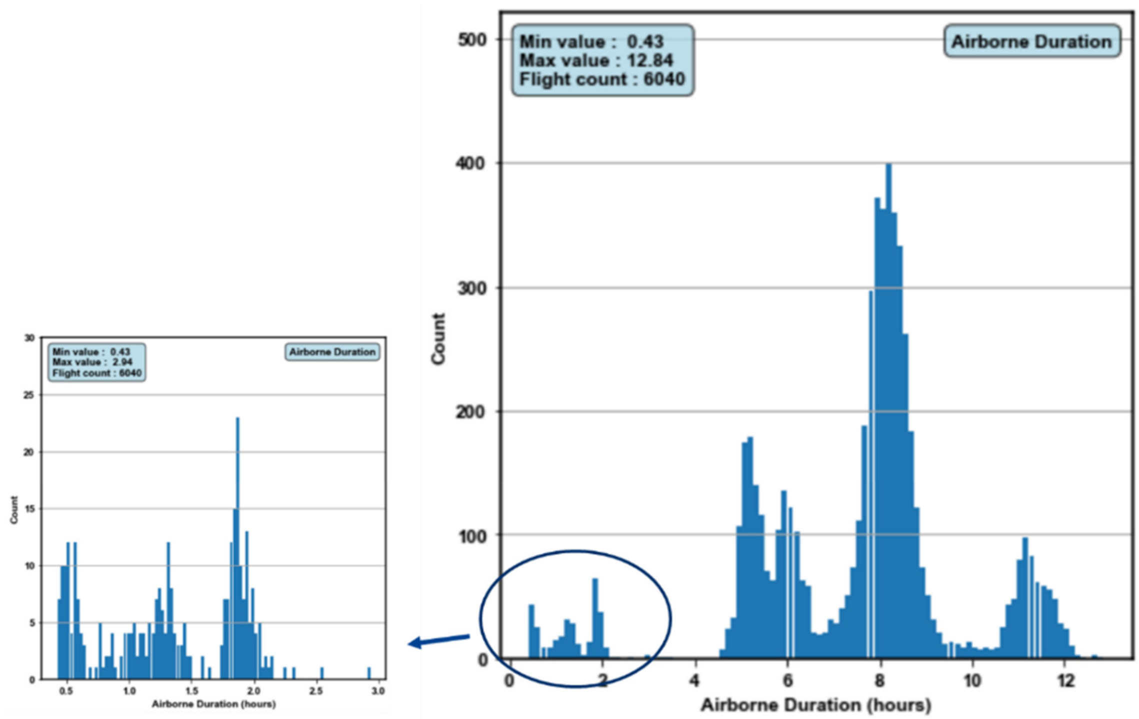


Figure 36: Duration of flight records

11.3 Initial analysis

11.3.1 Test 1: Criteria: Excessive roll angle and roll angle rate

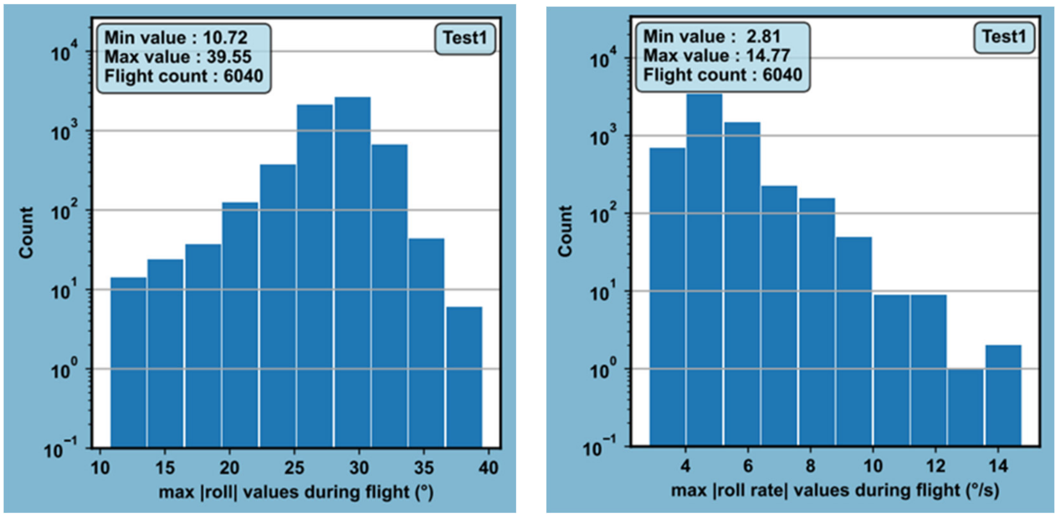


Figure 37: Distribution of Max |roll| and max |roll_rate| values for all flights

(Note: Min values are 0 for |roll| and |roll_rate| for all flights)

Event	Triggers
EVENT T2A: |Roll| >= THR_2A THR_MAX_T2A = 50°	0 event for 6040 flights (+10° margin)
EVENT T2A: |Roll| >= THR_2B THR_MAX_T2A = 60°	0 event for 6040 flights (+20° margin)
EVENT T1: |Roll| >= THR_1 AND |Roll_Rate| >= THR_RATE_1 THR_1 = 45° and THR_RATE_1 = 10°/s	0 event for 6040 flights

11.3.2 Test 2: Criteria: Excessive pitch angle and pitch angle rate

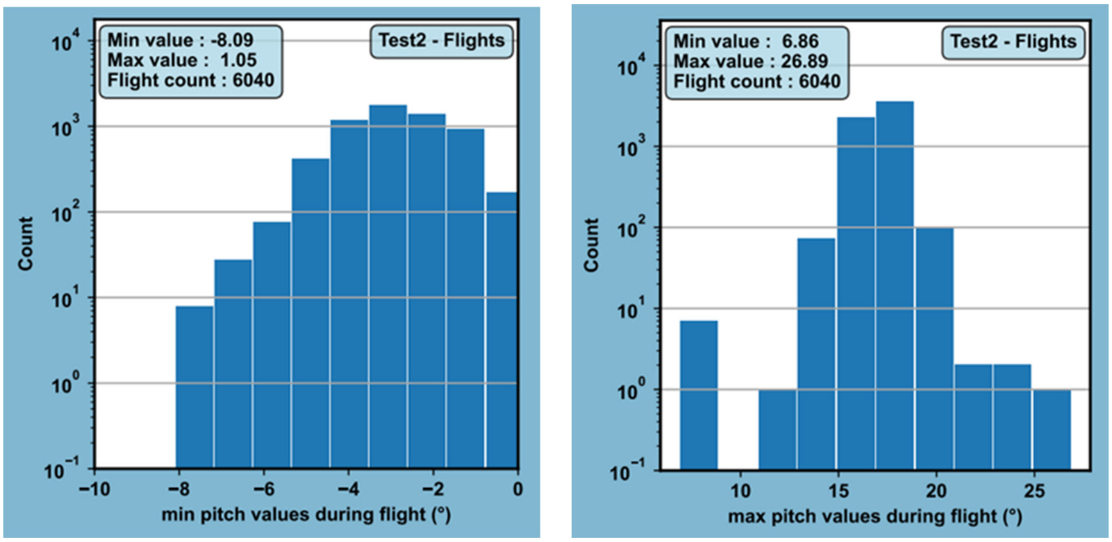


Figure 38: Distribution of Min and max pitch values for all flights

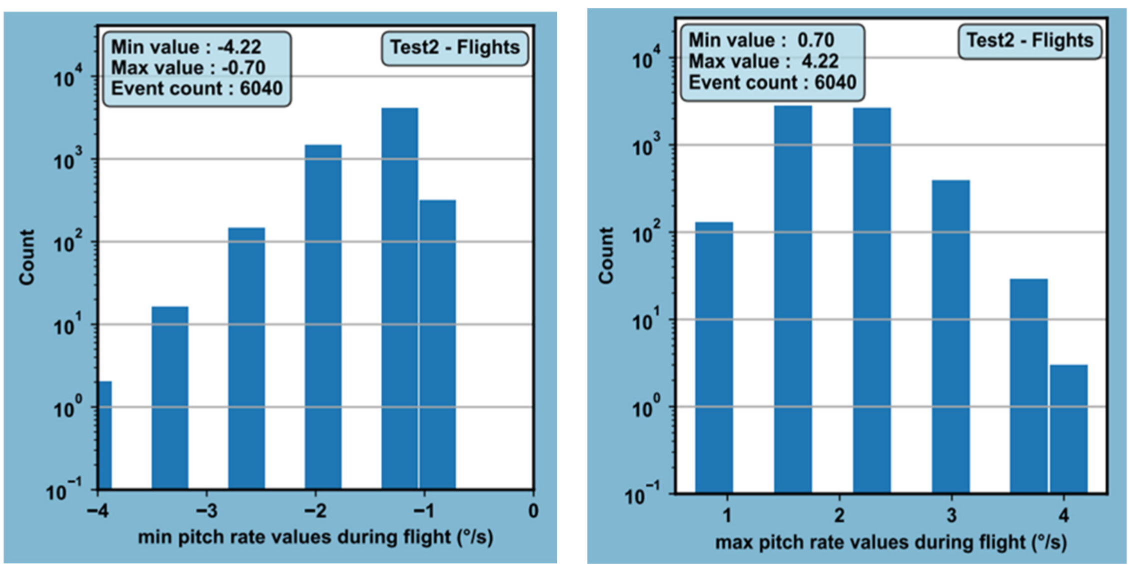


Figure 39: Distribution of Min and max pitch rate values for all flights

Event	Trigger
EVENT T1: Pitch >= THR_1 THR_1 = +30°	0 event for 6040 flights (+3° margin)
EVENT T2: Pitch <= THR_2 THR_2 = -20°	0 event for 6040 flights (-12° margin)

EVENT T3: Pitch >= THR_3 and Pitch Rate >=THR_RATE_3 THR_3 = +20° and THR_RATE_3 = +3°/s	0 event for 6040 flights
EVENT T4: Pitch <= THR and Pitch_Rate <=THR_RATE THR = -15° and THR_RATE=-3°/s	0 event for 6040 flights

11.3.3 Test 3: Criteria: Excessive Vertical Speed

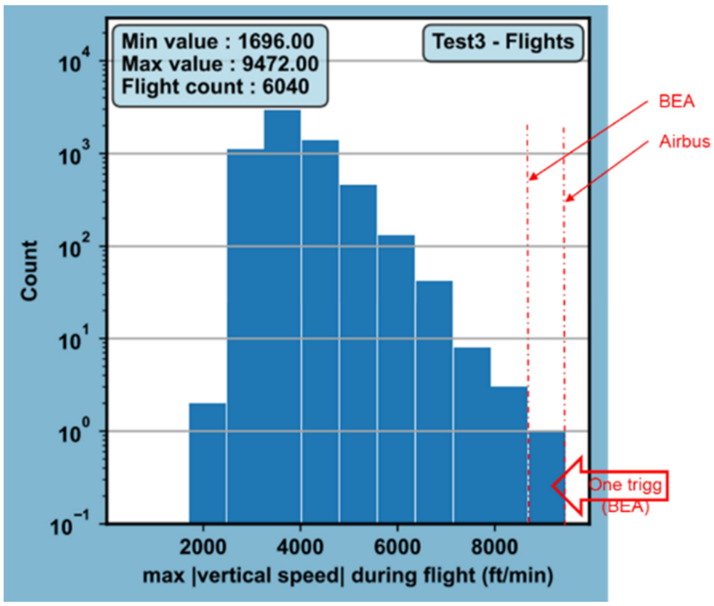


Figure 40: Distribution of Max |vertical speed| for all flights

Event	Result
EVENT T1A: |vertical speed| >= THR_1A THR_1A = +9000 ft/min BEA	1 event for 6040 flights Duration: 8s (+/-1s) Max vertical speed during event: 9472 feet/min Flight Phase: Descent
EVENT T1B: |vertical speed| >= THR_1B THR_1B = +10000 ft/min Airbus	0 event for 6040 flights (+528 ft/min margin)

11.3.4 Test 4: criteria: Excessive normal and lateral accelerations

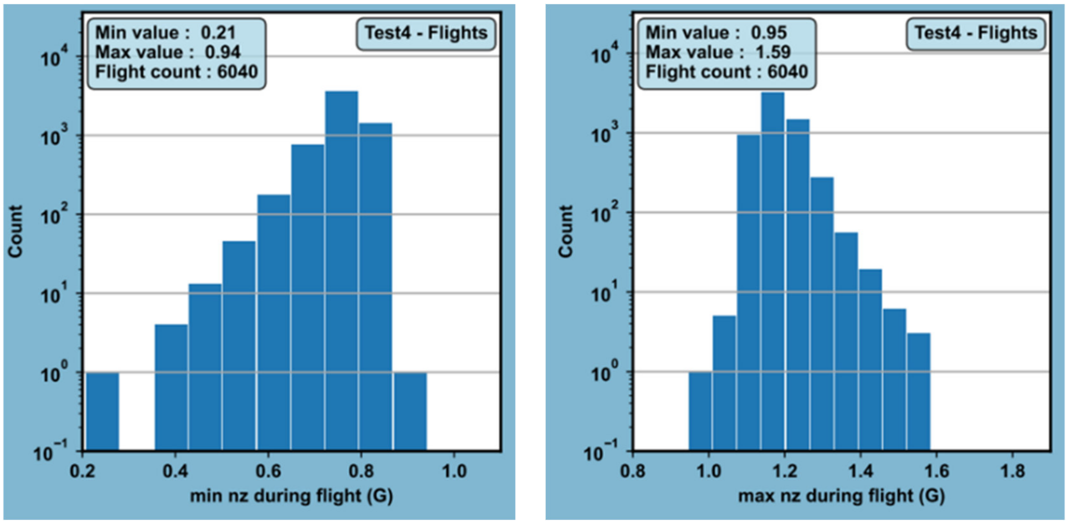


Figure 41: Distribution of Min and Max Nz for all flights

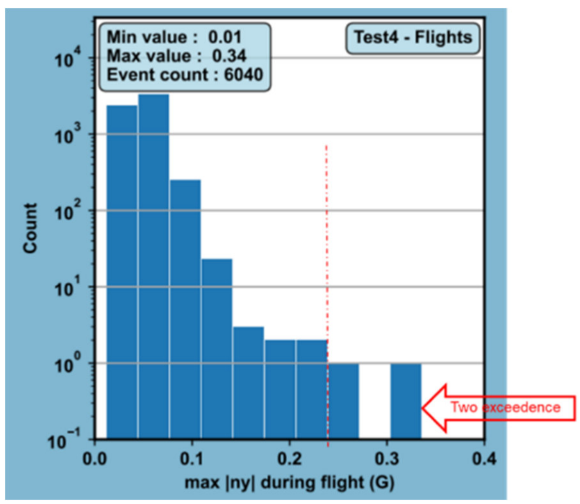


Figure 42: Distribution of Max |Ny| for all flights

Event	Trigger
EVENT T1: Nz >= THR_1 THR_1= +2,6G	0 event for 6040 flights
EVENT T2: Nz <= THR_2 THR_2 = -1,1 G	0 event for 6040 flights
EVENT T3A: |Ny| >= THR_3A THR_3A= +0,25G	2 events for 6040 flights Less than 2s ➔ should be filtered Flight Phase: • Cruise • From Approach to Final Approach

11.3.5 Test 5: Criteria: Stall WARNING

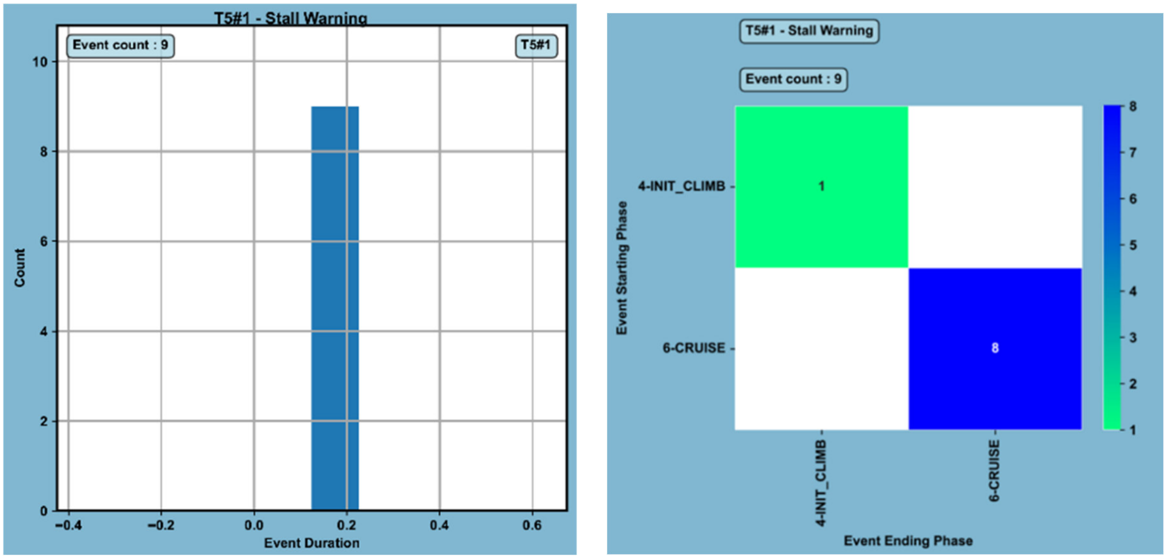


Figure: Distribution of “Stall warning” duration and flight phase

Note: in this figure, a “duration of 0.2 second” means “only one sample recorded” (a “glitch”). The hypothesis of such spurious recorded parameter is a “transient” (switching of redundant computers).

Event	Trigger
STALL event	9 events for 6040 flights Less than 2s ➔ should be filtered (only on sample) Flight Phase: - Init Climb (1 event) - Cruise (8 events)

11.3.6 Tests 6 and 7: criteria: inappropriate speed for the flight situation - CAS

Note: CAS parameter is not present in the recorded parameters, replaced in this analysis by IAS parameter.

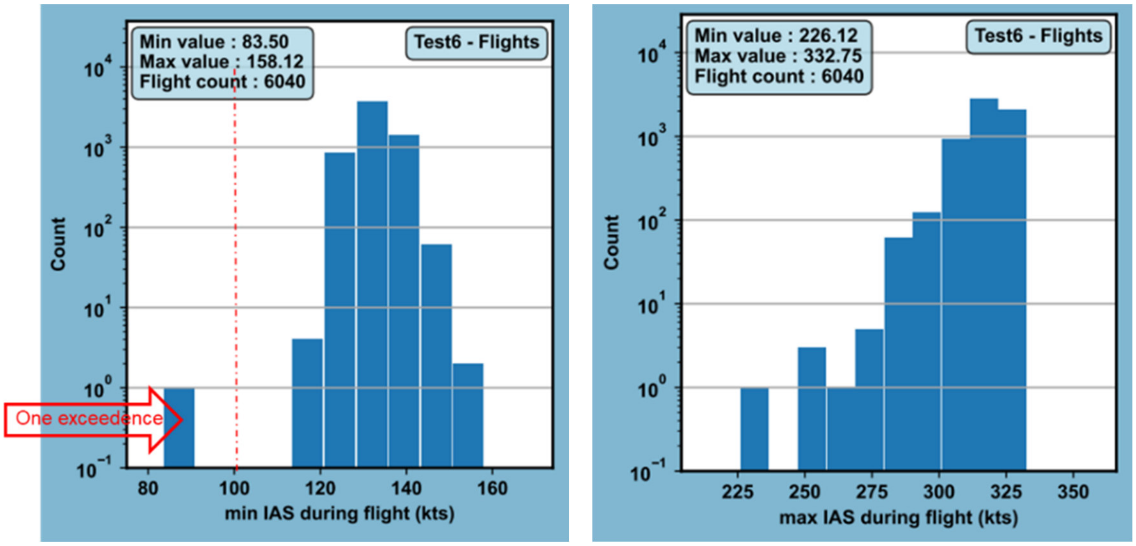


Figure 43: Distribution of Min and Max IAS for all flights

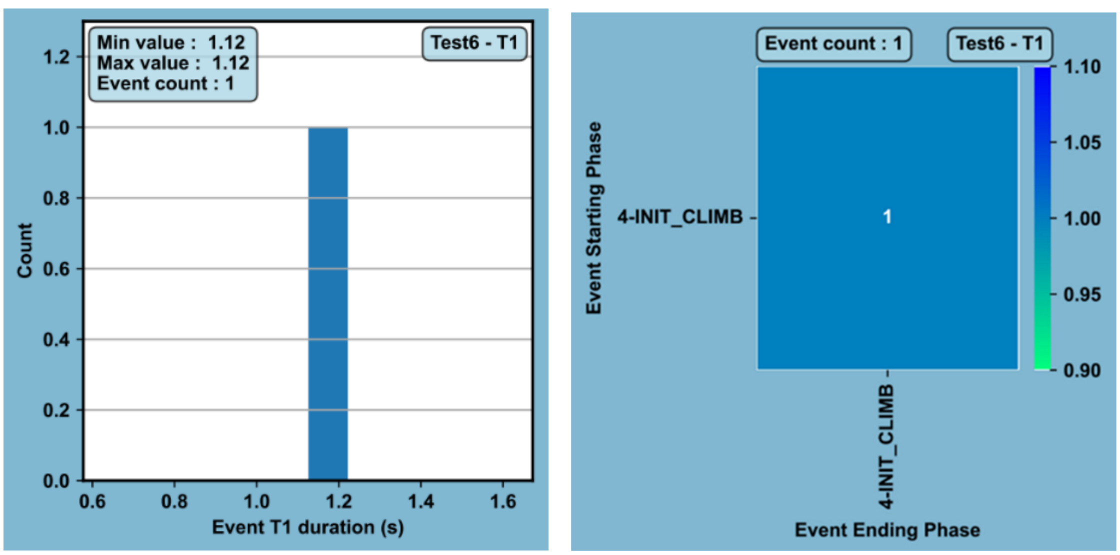


Figure 44: Distribution of duration of the event: IAS <= +100 kts With RALT >= 100 feet

Event	Result
EVENT T1: IAS <= THR_1 With RALT >= 100feet THR_1= +100 kts	1 event for 6040 flights Less than 2s ➔ should be filtered Min IAS during event: 93kts Flight Phase: Init Climb
EVENT T2: IAS >= THR_2 THR_2= +400 kts	0 event for 6040 flights (+67kts margin)

11.3.7 Test 8: Criteria: inappropriate speed for the flight situation – overspeed

(no graphical, due to no event detected)

Event	Result
EVENT T1: OVERSPEED WARNING And ALT_STD <= THR_1 THR_1= +15000 feet	0 event for 6040 flights

11.3.8 Test 9: Criteria: Terrain avoidance and warning system (TAWS) alerts

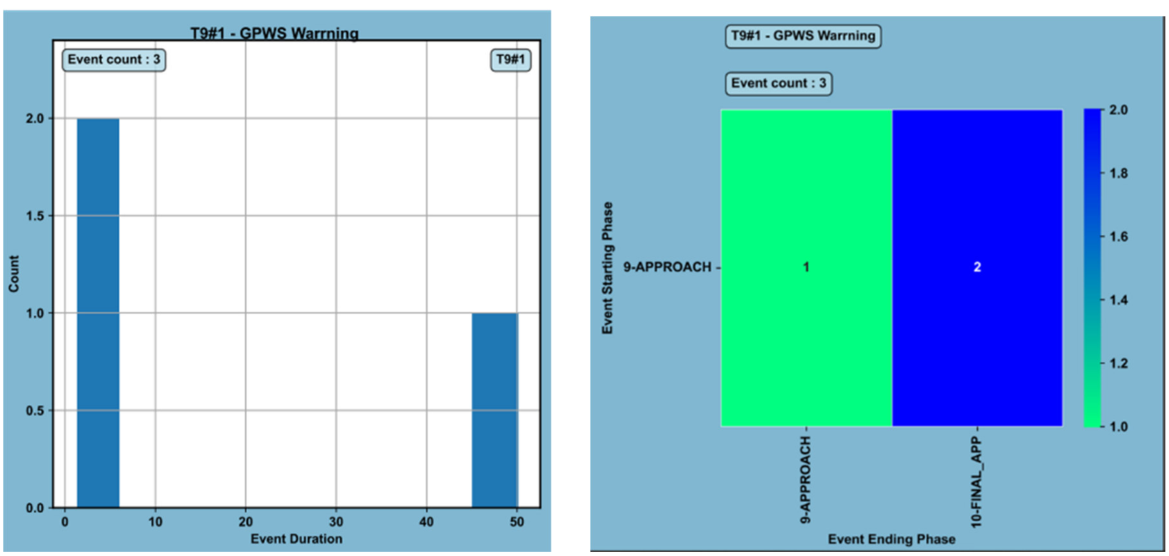


Figure 45: Distribution of GPWS warning duration and flight phase

Event	Result
EVENT T1: TAWS WARNING	3 events for 6040 flights (for 3 different flights) 1 event lasting 50s (+/-1s) from Approach to Final Approach 2 events lasting less than 3s during Approach ➔ should be filtered

11.3.9 Test 10: Criteria: poor altitude gains after take-off

The event “test 10 -T3” is:

(40feet <= RALT <= 100feet)
And Engine 2 N1 >= 80%
And Engine 1 N1 >= 80%

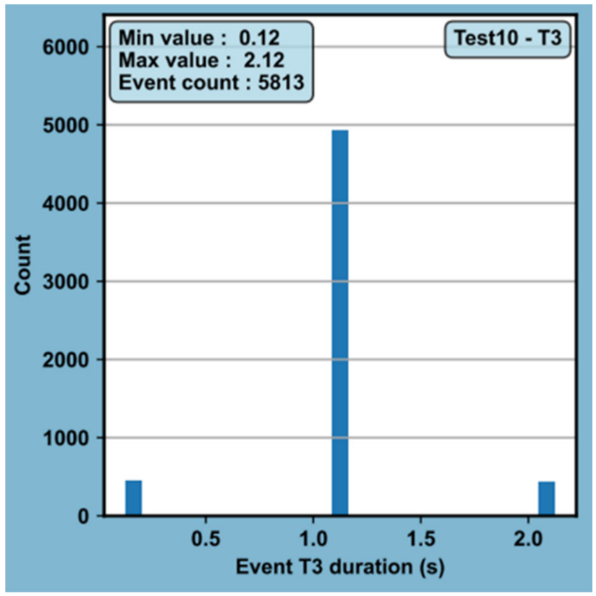


Figure 46: Distribution of duration of event T3

Remark: There are only 5 813 events for 6 040 flights. For 227 records, the sampling rate does not enable to detect this event: on takeoff, the radio altitude parameter jumps from “less than 40 feet” to “more than 100 feet”, in less than one seconds, and is not recorded.

The value of 100 feet may be adjusted to get a better diagnostic.

Event	Result
EVENT T3: (Engine 1 N1 >= 80% And Engine 2 N1 >= 80% And 40feet <= RALT <= 100feet) longer than 10 sec	0 events for 5813 flights Not evaluated on 227 flights (duration cannot be measured)

11.3.10 Test 11: Criteria: loss of thrust

Engine thrust parameter considered is “engine N1” parameters.

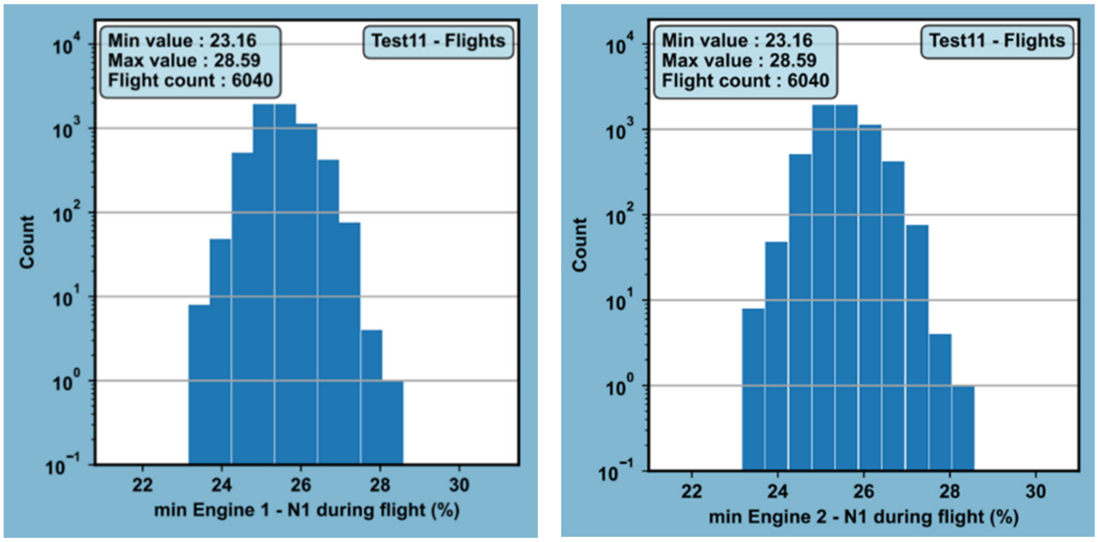


Figure 47: Distribution of engine N1 parameter during flight

No boundary value has been proposed in document D3

11.3.11 Test 12: Criteria: Cabin pressure alert

The analysis reports 59001 events “cabin pressure alert” for 6040 flights. These events are detected during all flight phases (mainly during climb and descent).

These events are not considered in the result of the analysis, identified as an erroneous information.

One assumption, for such great number of events, is that the recorded information is not correct. Another hypothesis is that this "warning" does not have the required severity, to trig data transfer.

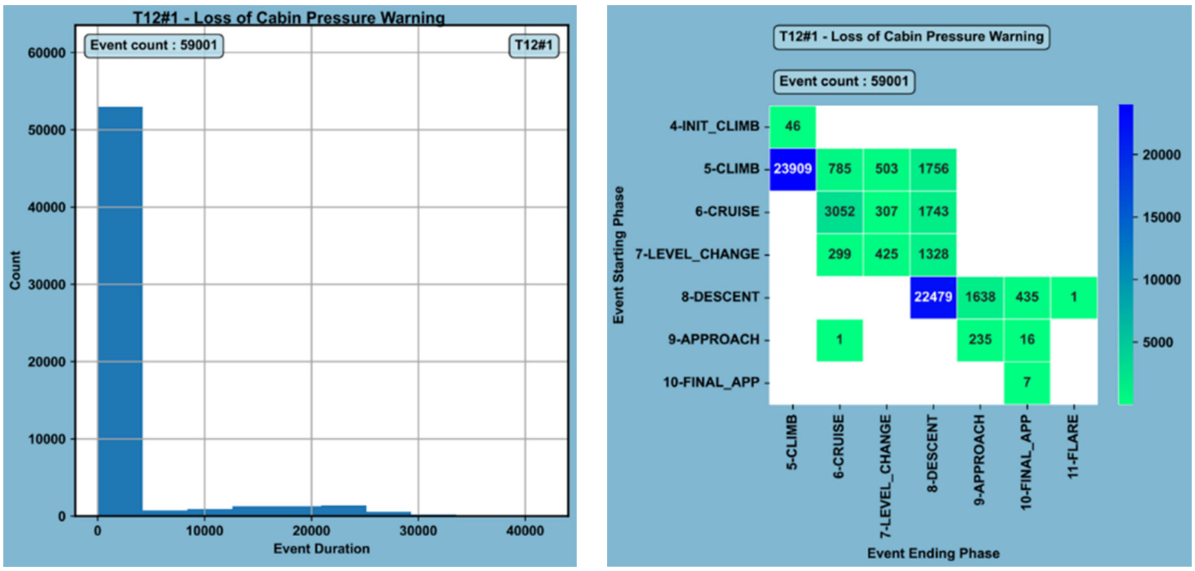


Figure 48: Distribution of Cabin pressure alert (durations and flight phase)

11.3.12 Test 13: criteria: abnormal value of cabin pressure altitude

The analysis of this specific parameter reports erroneous value (negative value during Descente). Nevertheless, the exceedance of "cabin pressure altitude" have been check.

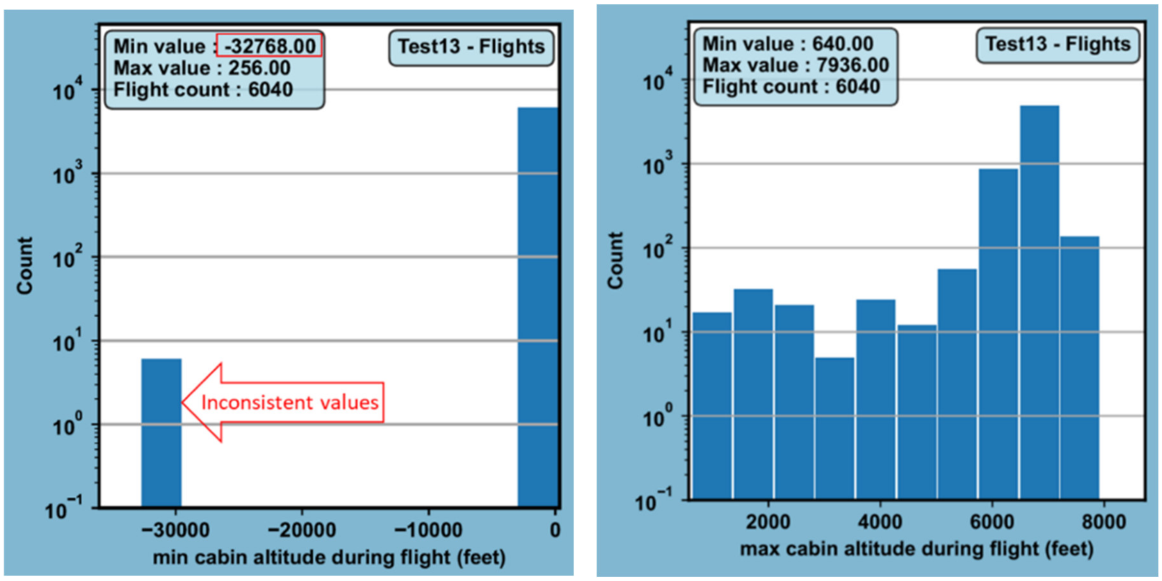


Figure 49: Distribution of Cabin altitude pressure

Event	Result
EVENT T1: Cabin Altitude Pressure >= THR_1 THR_1= +10000 feet	0 event for 6040 flights (margin 2064 feet)

11.3.13 Test 14: Criteria: Fire on board the aircraft

Inside the records, 21 fire/smoke warning signal was identified.

Some of them are grouped (potentially each group manages by the same computer or going through the same communication link). 3 groups are identified, which have the same fire/smoke warning distribution

- The activation duration is only reduced to 0.25 sec (one sample),
- The warnings activation of each signal of the same group are synchronized

These activations are spurious event.

For group 1, there are 13 spurious events, for group 2, 19 spurious events, and for group 3, 15 spurious.

Only 5 other fire/smoke warning are different behavior:

Engines (and APU) fire warnings (3 warnings):

These warning signals support also spurious events (all of them have a duration of less than 2 sec), but these spurious events are not synchronized, between them and with the other spurious event...

The "lavatory smoke" warnings

There are 2 smoke warning signals recorded: LAVATORY_SMOKE and LAVATORY_SMOKE_ ALERT.

- On the LAVATORY_SMOKE warning, there are 26 activations, with a duration up to 1 minutes.
- On the other hand, the LAVATORY_SMOKE_ALERT, there is no activations.

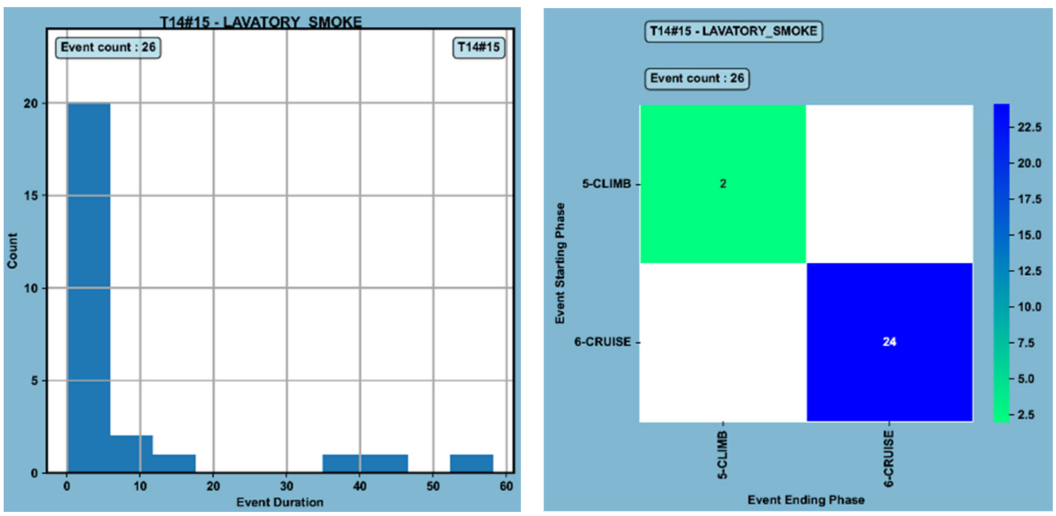


Figure 50: Distribution of "lavatory smoke" activation duration and flight phase

An analyze shows that the "LAVATORY_SMOKE" is the row signal, coming from the detectors and the "LAVATORY_SMOKE_ALERT" is the warning (when confirmed) reported to the warning system.

So "LAVATORY_SMOKE" warning is not considered for our analysis.

The CARGO_REST_SMOKE warning.

Like the other smoke warning, this signal support also spurious activations (13). But this signal support also one even with a duration about 5100 sec (1 hour and 40 minutes), starting during cruise phase, ended after landing.

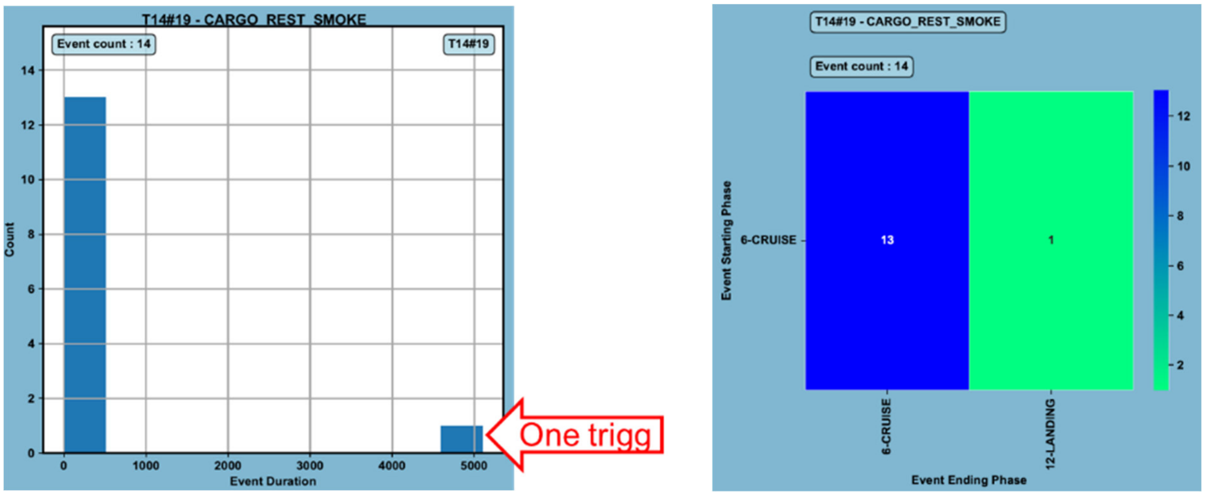


Figure 51: Distribution of "Cargo rest smoke" activation duration and flight phase

As no onboard fire has been declared by the airline, the diagnostic is a failure of the smoke detectors. This even should trigger the transmission of the Flight Recorder Data.

Event	Result
GROUP 1 ALERT	13 events for 6040 flights Less than 2s ➔ should be filtered
GROUP 2 ALERT	19 events for 6040 flights Less than 2s ➔ should be filtered
GROUP 3 ALERT	15 events for 6040 flights Less than 2s ➔ should be filtered
APU_FIRE_WARNING	12 events for 6040 flights Less than 2s ➔ should be filtered
FIRE_ENGINE_1_WARNING	5 events for 6040 flights Less than 2s ➔ should be filtered
FIRE_ENGINE_2_WARNING	13 events for 6040 flights Less than 2s ➔ should be filtered
LAVATORY_SMOKE	*Not part of analysis*
LAVATORY_SMOKE_ALERT	0 event for 6040 flights
CARGO_REST_SMOKE	for 6040 flights 1 event lasting 5100s; Event started during Cruise, ended by landing condition (thus warning present longer than 5100s) Other events less than 2s ➔ should be filtered

11.3.14 Test 15: criteria: Engine abnormal pressure ratio

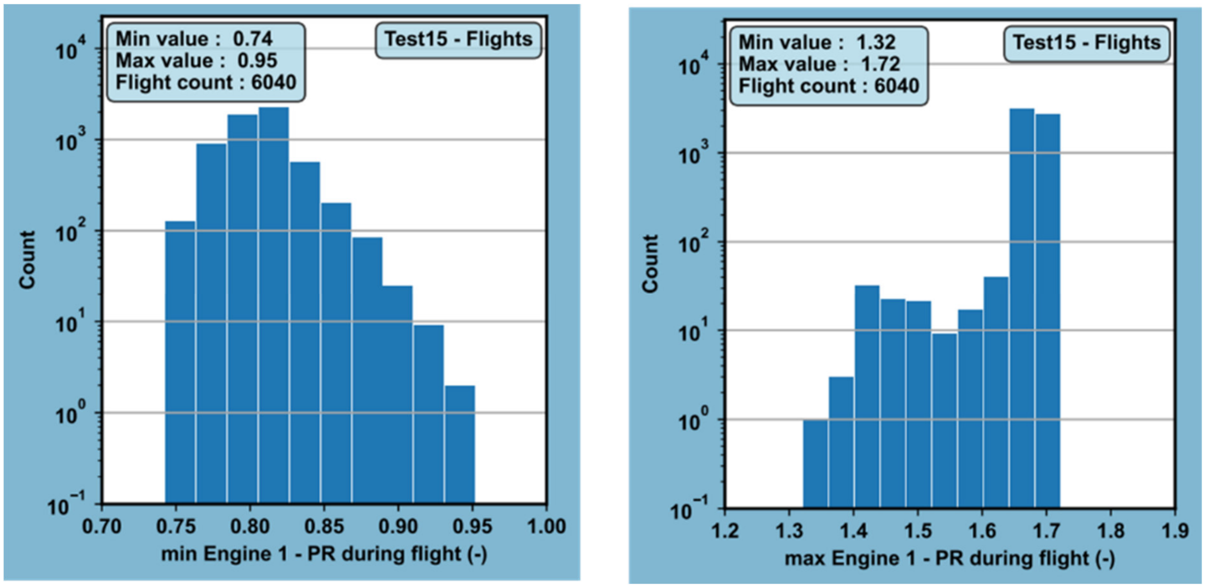


Figure 52: Distribution of engine 1 EPR

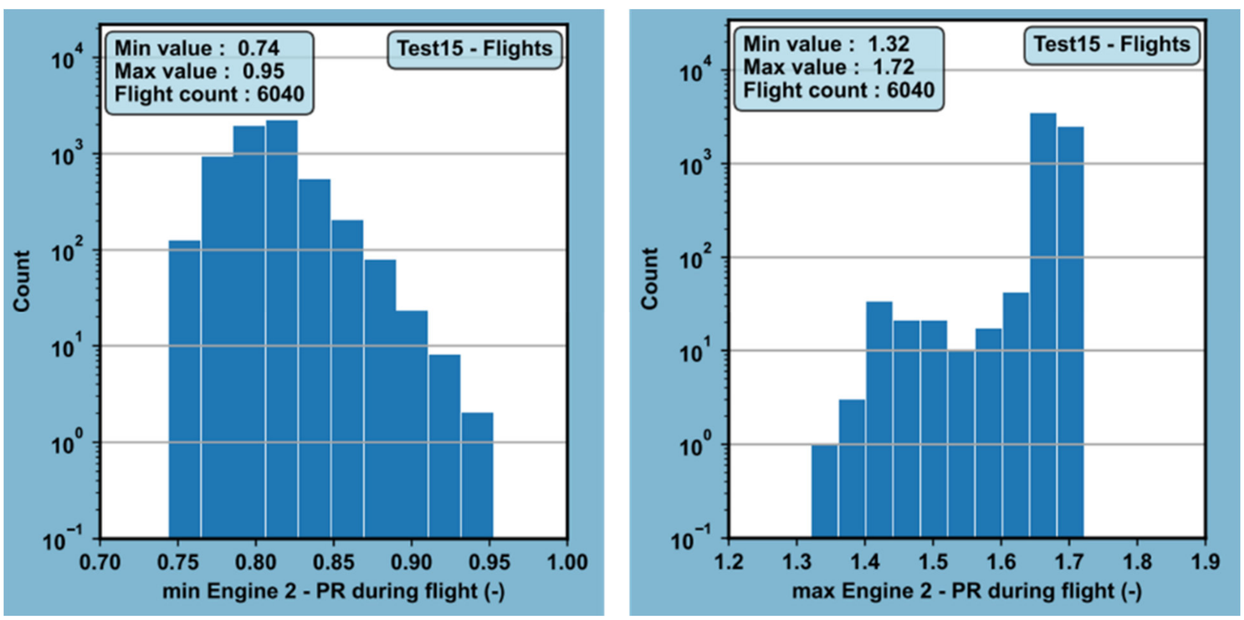


Figure 53: Distribution of engine 2 EPR

No boundary value has been proposed in document D3

11.3.15 Test 16: Criteria: Engine abnormal indicated vibration

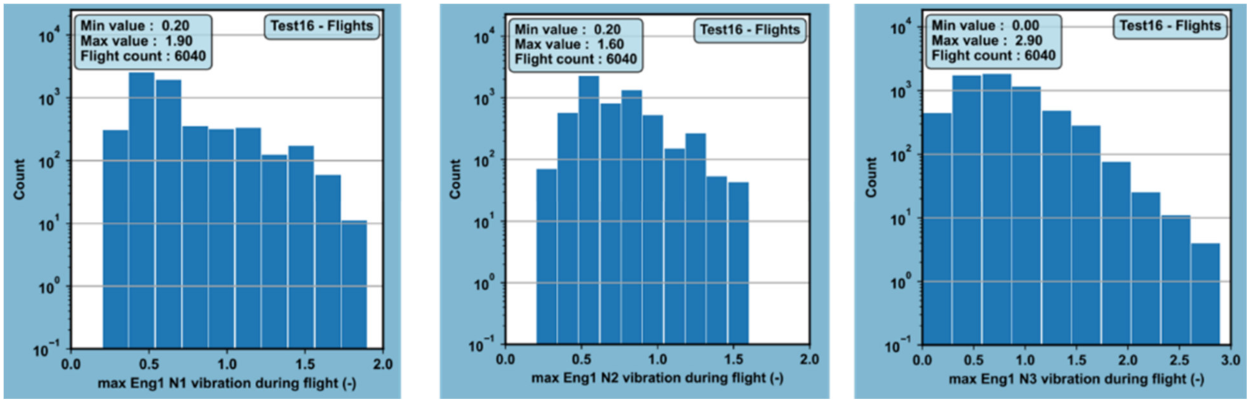


Figure 54: Distribution of engine 1 vibration level

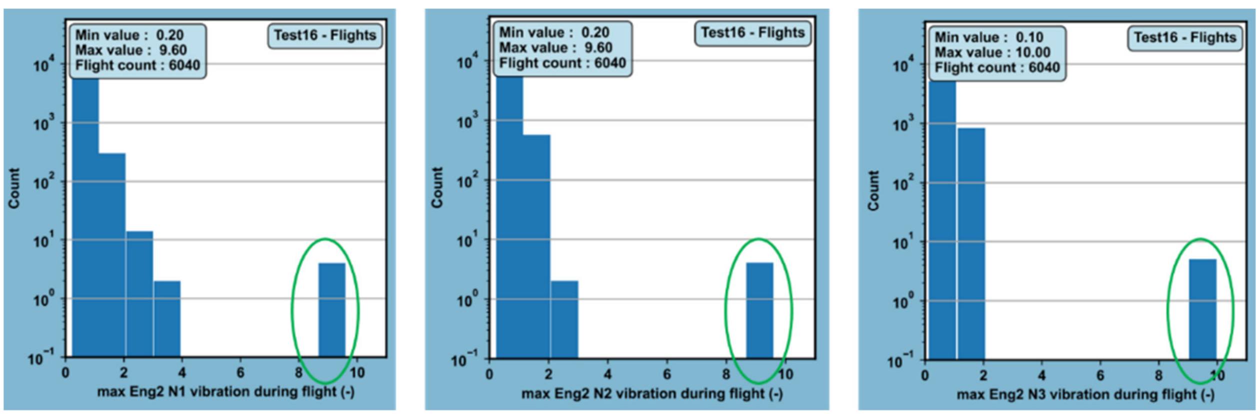


Figure: Distribution of engine 2 vibration level

(Note: in the 3 figures, the flight referenced green ovals are the same)

No boundary value has been proposed in document D3, for these parameters. Nevertheless, a second assessment in done with other parameters, about engine vibration alarms

For investigation purpose only, a boundary value of 4g is taken, for eng 2 N1, eng 2 N2 and eng 2 N3 vibration levels.

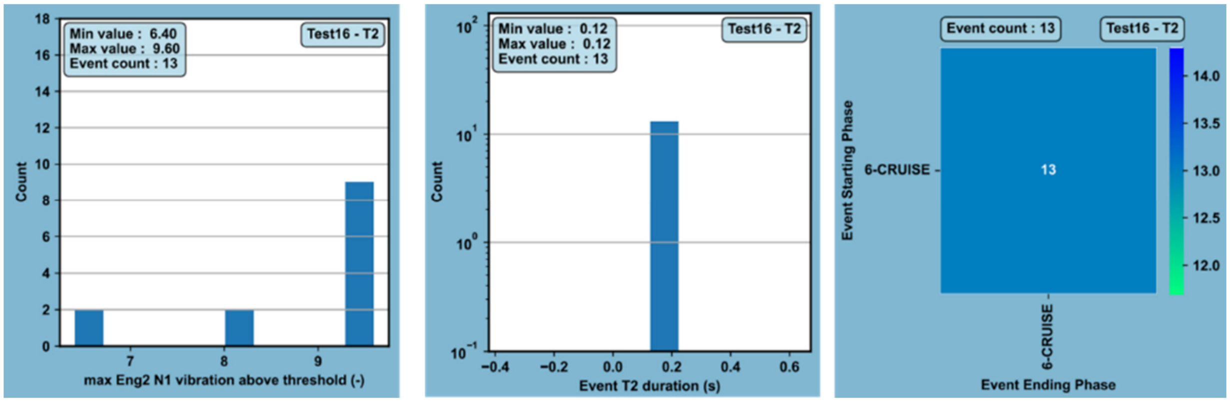


Figure 55: Distribution of VIB_ENG2_N1 above threshold (4g)

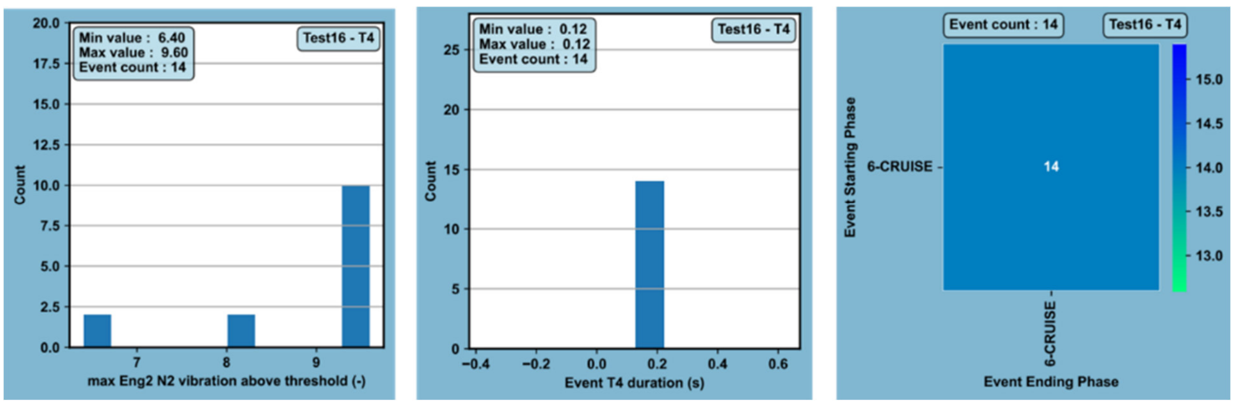


Figure 56: Distribution of VIB_ENG2_N2 above threshold (4g)

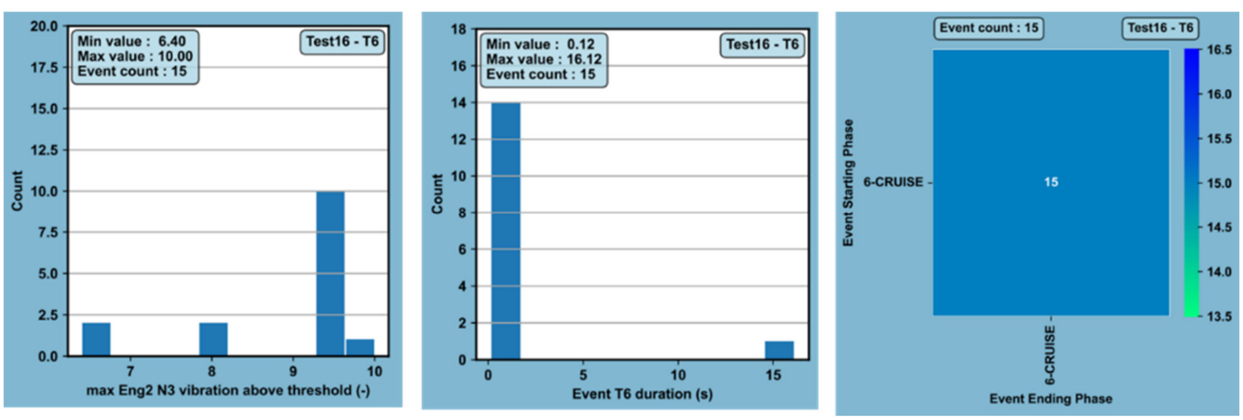


Figure 57: Distribution of VIB_ENG2_N2 above threshold (4g)

No event on VIB_ENG1_N1_ALERT VIB_ENG2_N1_ALERT VIB_ENG1_N2_ALERT VIB_ENG2_N2_ALERT, and VIB_ENG1_N3_ALERT have been reported, but one alert on VIB_ENG2_N3_ALERT is reported during one flight.

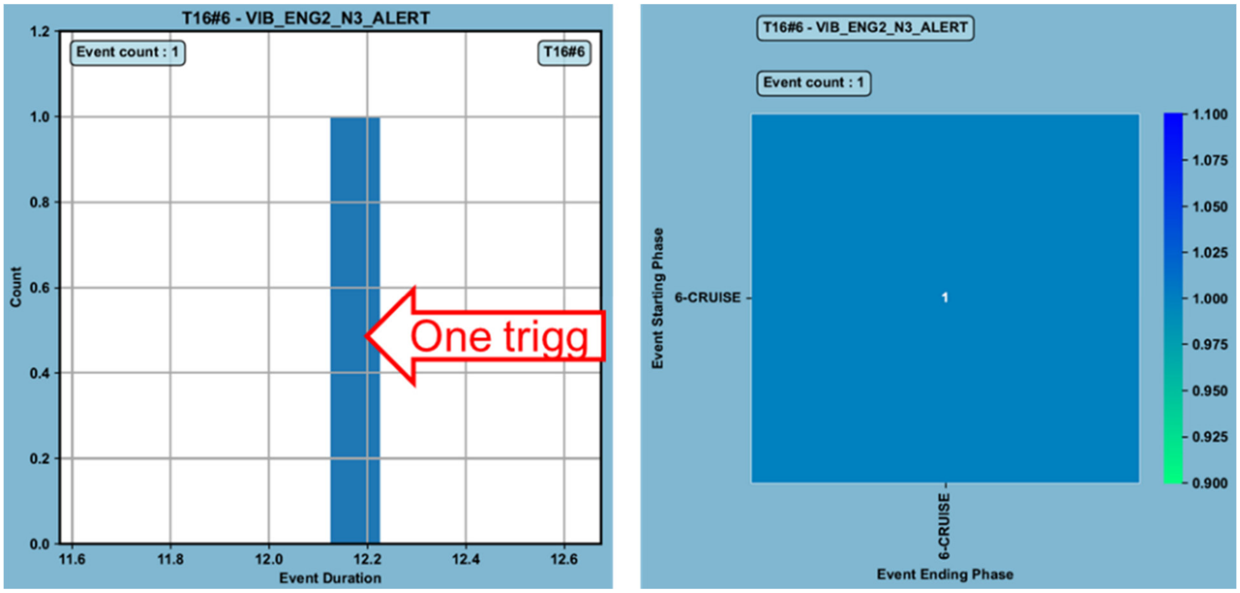


Figure 58: Distribution of VIB_ENG2_N3_ALERT duration and flight phase

The check of date of the vibration exceedances shows that:

- Eng 2 N1 vibration exceedances are synchronized with Eng 2 N2 vibration exceedances
- Eng 2 N2 vibration exceedances are synchronized with Eng 2 N3 vibration exceedances
- VIB_ENG2_N3_ALERT is synchronized with the longer Eng 2 N3 vibration exceedances

Event	Result
T1: Engine 1 N1 Vibration Alert	**0 event for 6040 flights**
T2: Engine 2 N1 Vibration Alert	**0 event for 6040 flights**
T3: Engine 1 N2 Vibration Alert	**0 event for 6040 flights**
T4: Engine 2 N2 Vibration Alert	**0 event for 6040 flights**
T5: Engine 1 N3 Vibration Alert	**0 event for 6040 flights**
T6: Engine 2 N3 Vibration Alert	**1 event for 6040 flights, lasting 12s (+/-1s), during Cruise**

11.3.16 Test 17: Criteria: A/C system failure or malfunction: Engine over temperature (oil temp.)

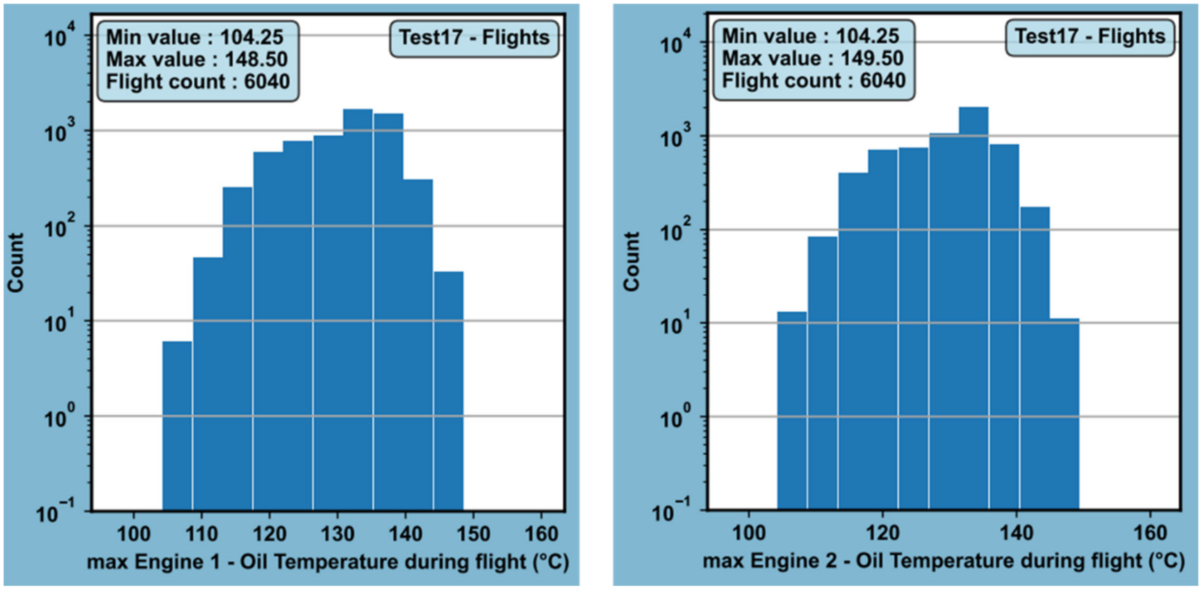


Figure 59: Distribution of engines oil temperature

No boundary value has been proposed in document D3

11.3.17 Test 18: Criteria: A/C system failure or malfunction / Engine low oil pressure

No event on engine 1 low oil pressure

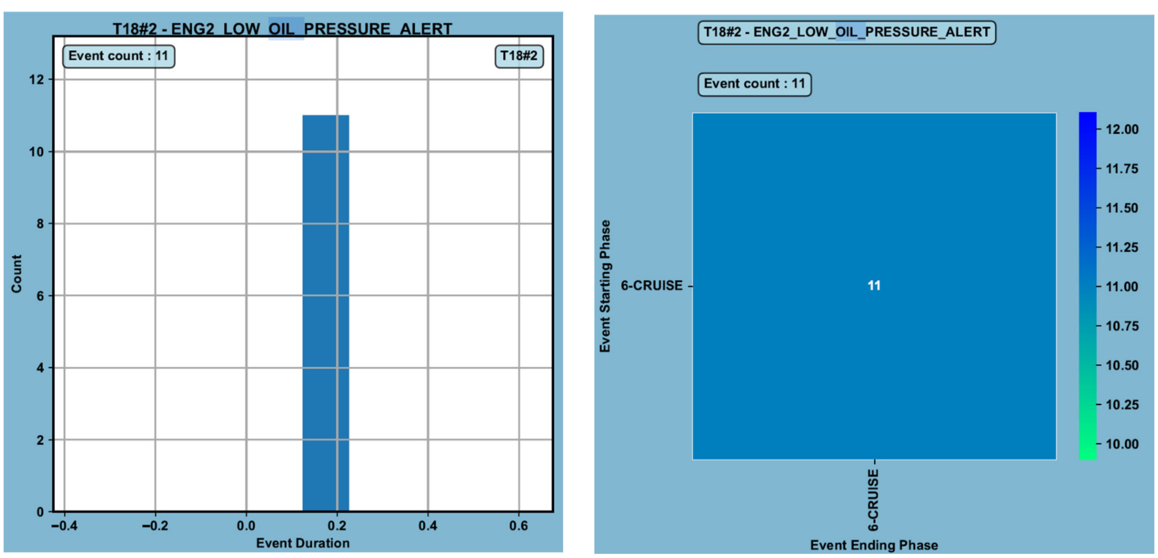


Figure 60: Distribution of engine 2 low oil pressure alert duration and flight phase

Event	Result
EVENT T1: EVENT T1 – Engine 1 Low Oil Pressure Warning	0 event for 6040 flights
EVENT T2: EVENT T2 – Engine 2 Low Oil Pressure Warning	11 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered

11.3.18 Test 19: Criteria: A/C system failure or malfunction / Engine turbine overheat

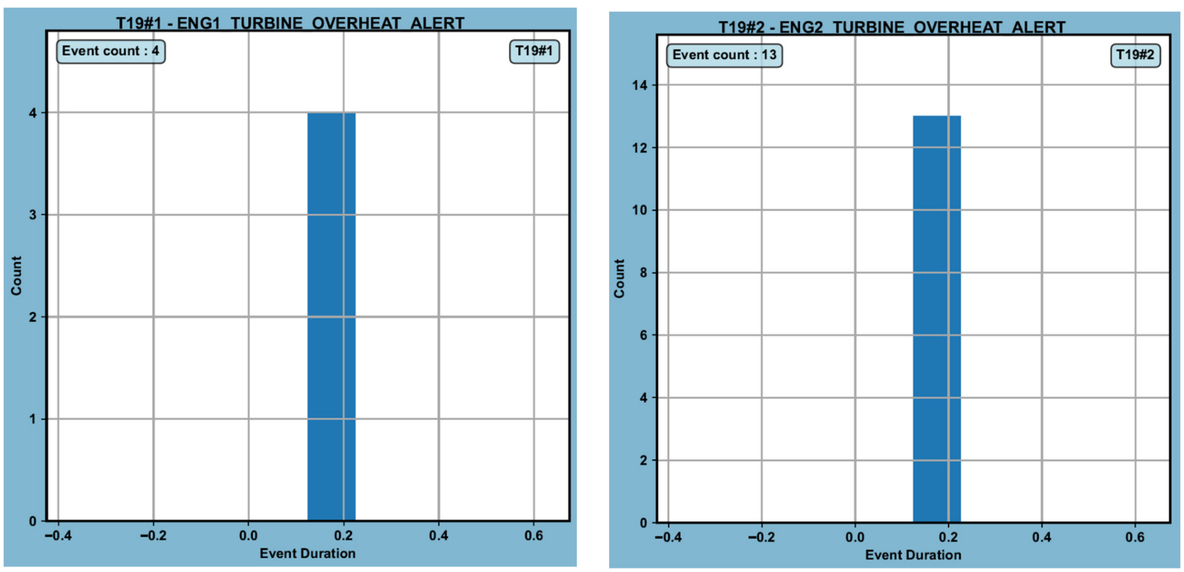


Figure 61: Distribution of engine turbine overheat warning duration

Event	Result
EVENT T1: EVENT T1 – Engine 1 Turbine Over-heat Warning	4 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered
EVENT T2: EVENT T2 – Engine 2 Turbine Over-heat Warning	13 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered

11.3.19 Test 20: Criteria: A/C system failure or malfunction / Engines over-speed

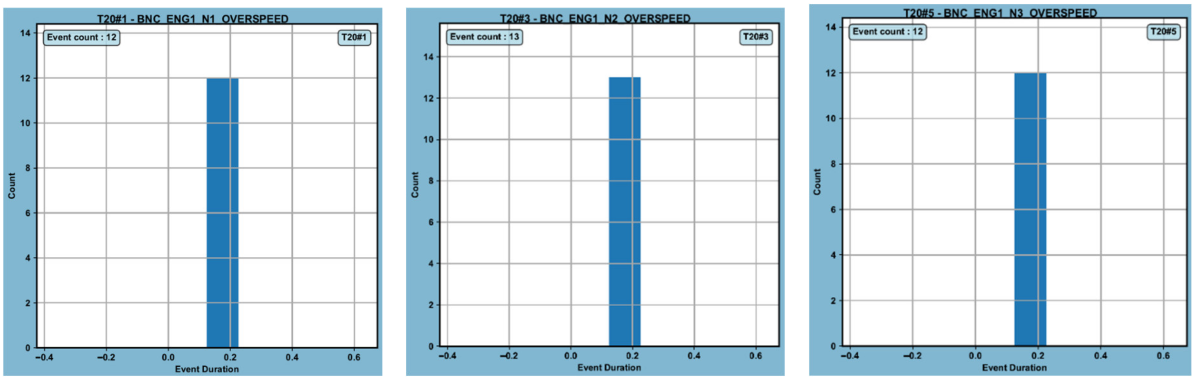


Figure 62: Distribution of engine 1 over speed warning duration

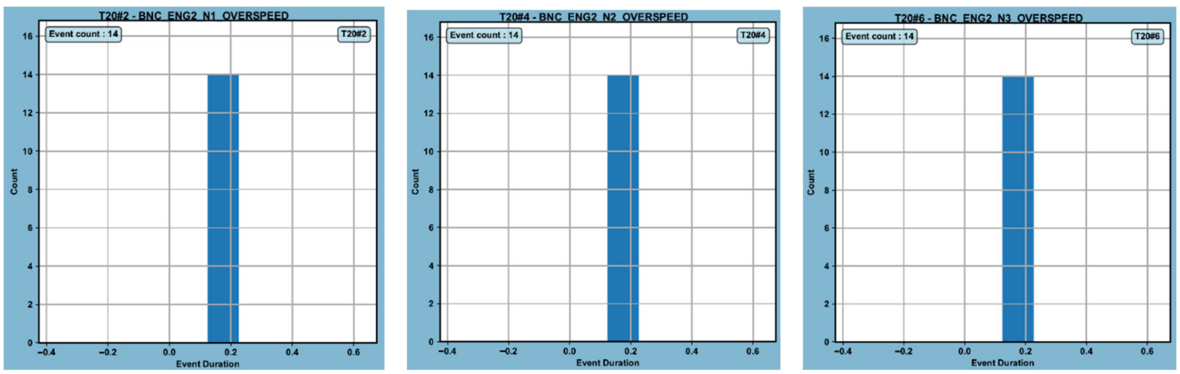


Figure 63: Distribution of engine 2 over speed warning duration

Event	Result
EVENT T1: Over-speed Alert Engine 1 N1	**12 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered**
EVENT T2: Over-speed Alert Engine 2 N1	**14 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered**
EVENT T3: Over-speed Alert Engine 1 N2	**13 events for 6040 flights Less than 2s, during Cruise (12) and Approach (1) ➔ should be filtered**
EVENT T4: Over-speed Alert Engine 2 N2	**14 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered**
EVENT T5: Over-speed Alert Engine 1 N3	**12 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered**
EVENT T6: Over-speed Alert Engine 2 N3	**12 events for 6040 flights Less than 2s, during Cruise ➔ should be filtered**

11.3.20 Test 21: Criteria: A/C system failure or malfunction / Low Hydraulic Pressure Warning

Only the event “2 or 3 hydraulic network fait” is considered in this study. One hydraulic network failure is not considered has critical.

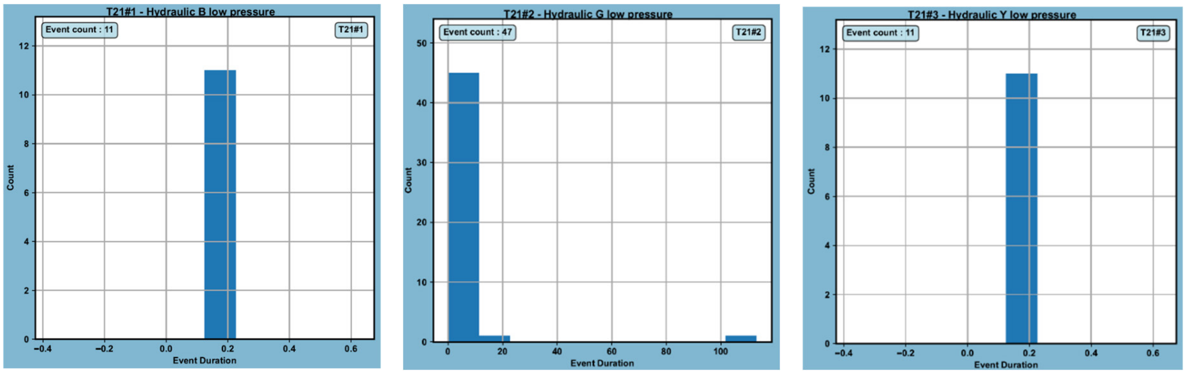


Figure 64: Distribution of Low Hydraulic Pressure warning duration

Event	Result
Simultaneous B+G+Y Hydraulic failures	**11 events, during Cruise for 6040 flights** **Less than 2s ➔ should be filtered**
Events on G Hydraulic failure only	**2 consecutive events on same flight lasting 14s then 113s (with a short time interruption less than 2s) for 6040 flights** **Event interrupted by on-ground condition (thus alert lasting more than 113s)** **Triggered during final approach** **23 other events lasting less than 2s ➔ should be filtered**

11.3.21 Test 22: Criteria: A/C system failure or malfunction / Low Pneumatic Pressure Warning

No parameter about “Pneumatic Pressure” provided in the records, no analysis conducted.

11.3.22 Test 23: Criteria: Electrical AC/DC bus failure indications

5 parameters are recorded: ACV_B_1XP_NV, ACV_B_9XP_NV, DC_ESS_NO_V, DC1_NO_V and DC2_NO_V

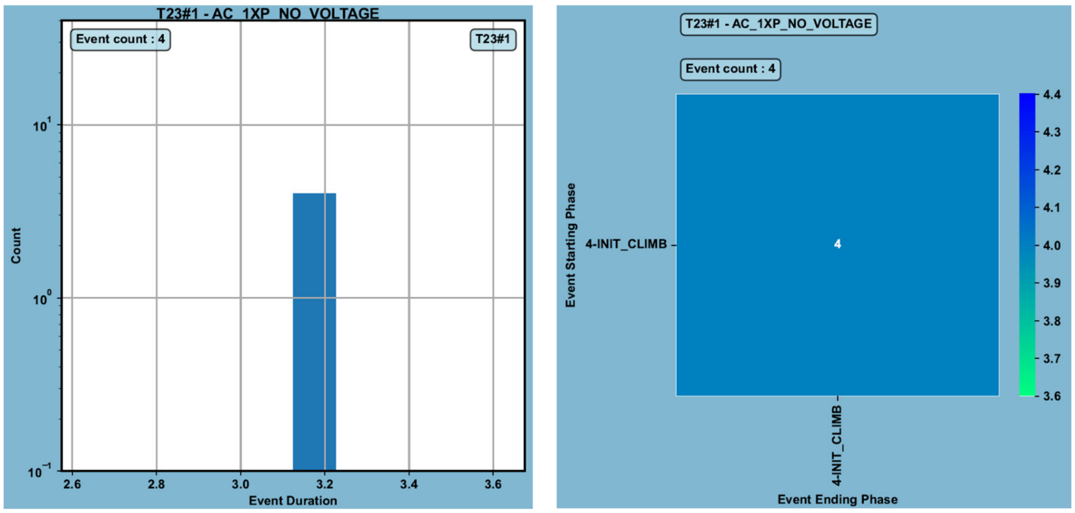


Figure 65: Distribution of AC No Voltage alert duration and flight phase

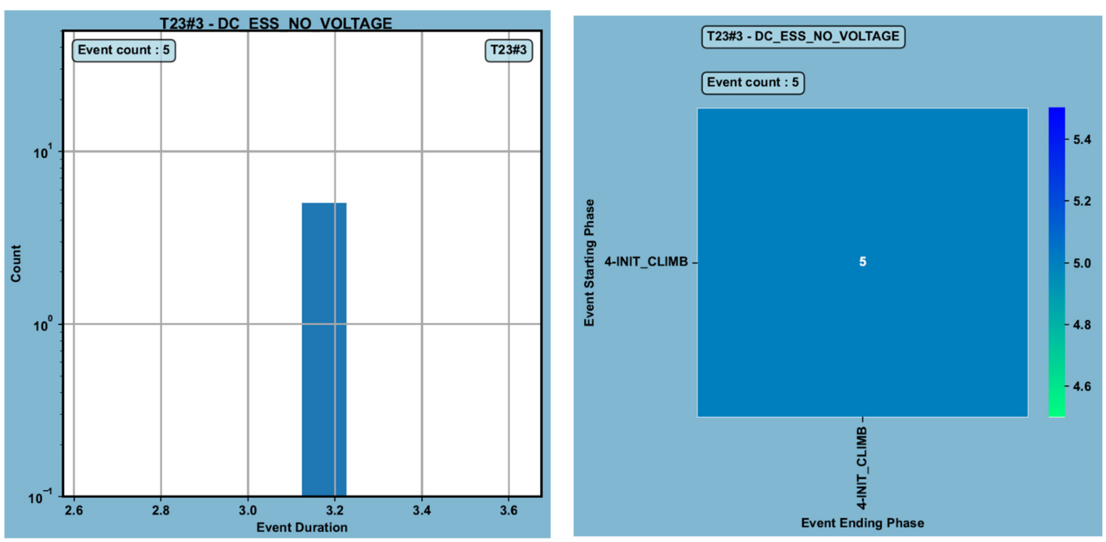


Figure 66: Distribution of DC Essential No Voltage alert duration and flight phase

Event	Result
Event T1: AC_1XP_NO_VOLTAGE	**4 events for 6040 flights Less than 4s, same flight, during Init Climb ➔ should be filtered**
Event T2: AC_9XP_NO_VOLTAGE	**0 event for 6040 flights**

Event	Result
Event T3: DC_ESS_NO_VOLTAGE	4 events for 6040 flights Less than 4s, during Init Climb ➔ should be filtered 3 events simultaneously with Event T1 2 other events on different flights
Event T4: DC1_NO_VOLTAGE	0 event for 6040 flights
Event T5: DC2_NO_VOLTAGE	0 event for 6040 flights

11.3.23 Test 24: Computers failures

17 different events, about computers failures are recorded: BSCU 1 and 2 fault, FADEC 1 and 2 _faults, FCMC 1 and 2 faults, FCPC_1, 2 and 3 faults, FCSC_1 and 2 faults, FWC 1 and 2 faults, GPWS SYS and TERR faults and SDAC 1 and 2 faults.

The following assumption is taken: The situation requires the transmission of Flight Recorder Data if the 2 critical redundant computers (or the 3 triplex ones) are failed.

Note:

- SAFRAN E&D supposes that FWC, GPWS and SDAC are not Critical computers.
- Other failures are recorder, but not addressing computers: it is SLAP and SLAT faults, not taken in account in this study.

Single events:

Event	Result
Event T1: BSCU1 FAULT	21 events for 6040 flights Lasting up to 35000s, involving all flight phases Some events are lasting the whole flight duration
Event T2: BSCU2 FAULT	9 events for 6040 flights Lasting up to 26000s, involving all flight phases
EventT3: FADEC1 FAULT	1 event for 6040 flights Lasting 3s (+/-1s), during Cruise
EventT4: FADEC2 FAULT	3 events for 6040 flights Lasting 3s (+/-1s), during Cruise
EventT5: FCMC1 FAULT	5 events for 6040 flights Lasting 3s (+/-1s), during Cruise
EventT6: FCMC2 FAULT	5 events for 6040 flights Lasting 3s (+/-1s), during Cruise
Event T7: FCPC1 FAULT	9 events for 6040 flights

Event	Result
	All event during different flights 1 event lasting 19228s, started during cruise, ended by ground condition (failure being potentially still present) During this particular event, FCPC2 and FCPC3 were not faulty other events lasting between 26s and 40s
Event T8: FCPC2 FAULT	0 event for 6040 flights
Event T9: FCPC3 FAULT	13 events for 6040 flights All event during different flights Some events (9) during the whole flight duration, up to 30000s 3 events lasting between 39s and 52s, during Cruise 1 event starting during cruise and ended by ground condition (14256s)
Event T10: FCSC1 FAULT	8 events for 6040 flights 1 event lasting 20000s, during whole flight Other events lasting between 24s and 108s, during Cruise or Descent
Event T11: FCSC2 FAULT	5 events for 6040 flights Lasting between 30s and 48s, during Cruise
Event T14: FWC1 FAULT	2714 events for 6040 flights Less than 4s, all flight phases involved
Event T15: FWC2 FAULT	1333 events for 6040 flights 1 event lasting 312s, during Cruise Other events lasting less than 4s, during Cruise and Level Change
Event T16: GPWS SYS FAULT	22 events for 6040 flights Lasting up to 30000s (some lasting during the whole flight)
Event T17: GPWS_TERR_FAULT	30 events for 6040 flights Lasting up to 35000s (some lasting during the whole flight)
Event T18: SDAC1 FAULT	0 event for 6040 flights
Event T19: SDAC2 FAULT	0 event for 6040 flights

Simultaneous events:

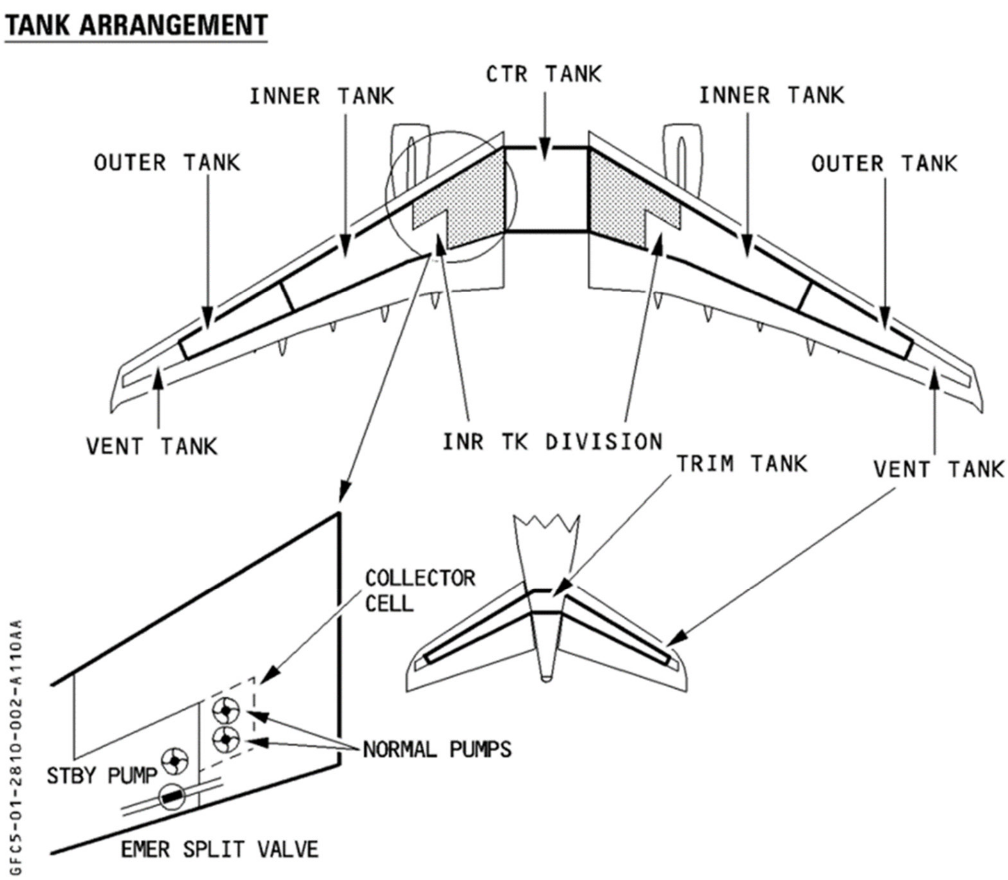
Event	Result
BSCU1 FAULT + BSCU2 FAULT	3 events, lasting less than 4s
FCMC1 FAULT + FCMC2 FAULT	5 events, lasting less than 4s

Note: The faults STAP and FLAP do not modify the final result, if they should be added to the analysis.

11.3.24 Test 25: Low fuel or fuel system anomaly / Abnormal values of fuel quantities

5 parameters are founded, about fuel quantity: Left inner tank, right inner tank, Left outer tank, right outer tank and trim tank. Total fuel is the sum of these 5 parameters.

(Central tank parameter not valid)



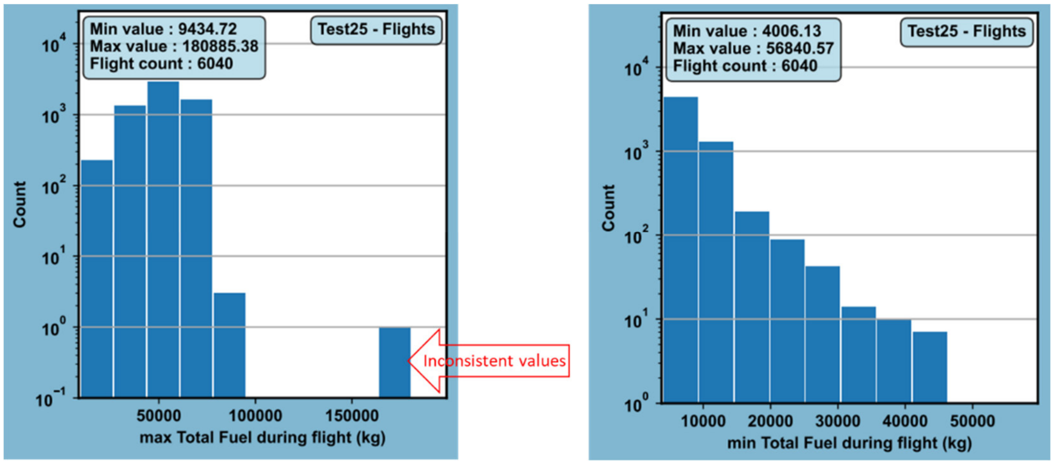


Figure 67: Distribution of max total fuel and residual total fuel value

No boundary value has been proposed in document D3

11.3.25 Tests 26 and 27: Low fuel or fuel system anomaly / fuel exhaustion and fuel starvation

No algorithms given in document D3.

11.3.26 Test 28: Airborne collision avoidance system (ACAS) alerts

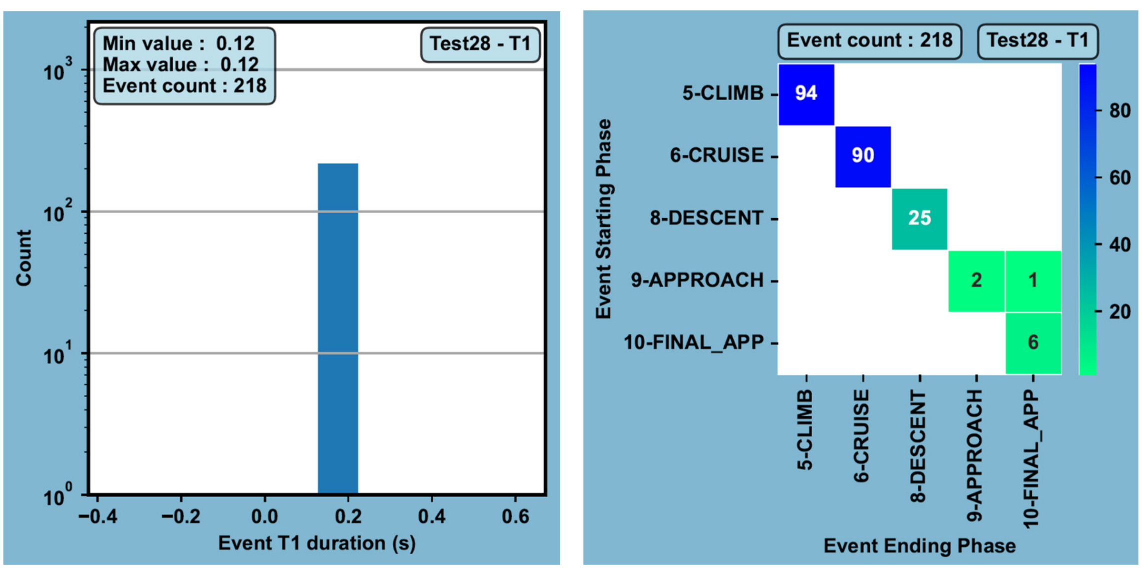


Figure 68: Distribution of ACAS alert duration and flight phase

Event	Result
Event T1: TCAS RA > 0	**218 events for 6040 flights** **Less than 2s ➔ should be filtered** **Max TCAS RA of 6 observed during events** **During all flight phases**

11.3.27 Test 29: Criteria: Possible of penetration of severe weather / wind shear alert

(No graphical, due to no event detected)

Event	Result
Event T1: Wind Shear Alert	**0 event for 6040 flights**

11.3.28 Tests 30, 31 and 32: Possible of penetration of severe weather / turbulence alert, Deviation from planned flight paths / Abnormal values of cross-track error or estimated time of arrival and Flight crew incapacitation

No algorithms given in document D3.

11.3.29 Tests 33: criteria: Excessive roll command

Excessive roll command - ((|CPT_ROLL| > 50° or |FO_ROLL| > 50°) AND (IAS > 80kt))

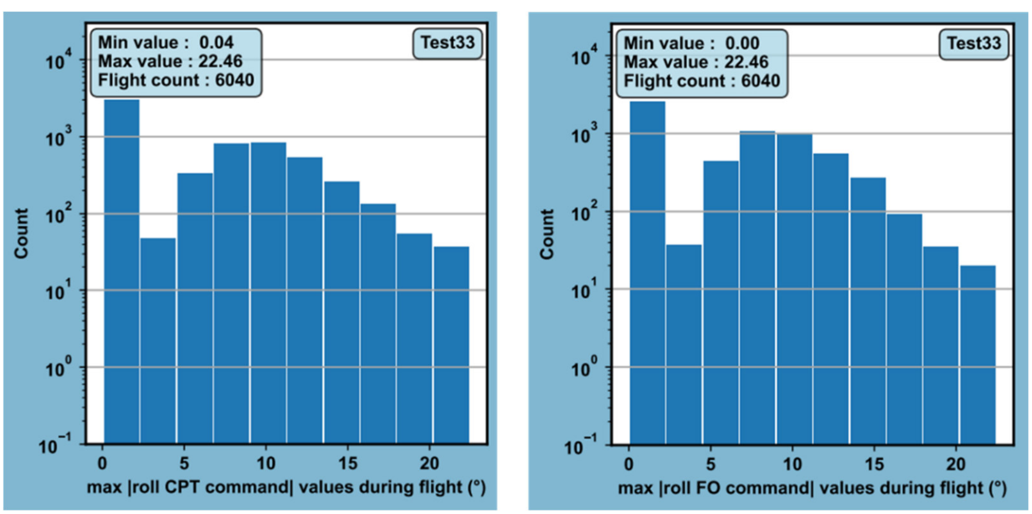


Figure 69: Distribution of Cpt and F/O |roll command| values

Note: No filtering done by IAS conditions (as IAS > 83.5kts for all flights)

Event	Result
Event T1: **|Roll CPT command| >= 50°** **And** **|IAS| >= 80 kts**	**0 event for 6040 flights** **(+27,5° margin)**
Event T2: **|Roll FO command| >= 50°** **And** **|IAS| >= 80 kts**	**0 event for 6040 flights** **(+27,5° margin)**

11.3.30 Tests 34: criteria: Excessive pitch command

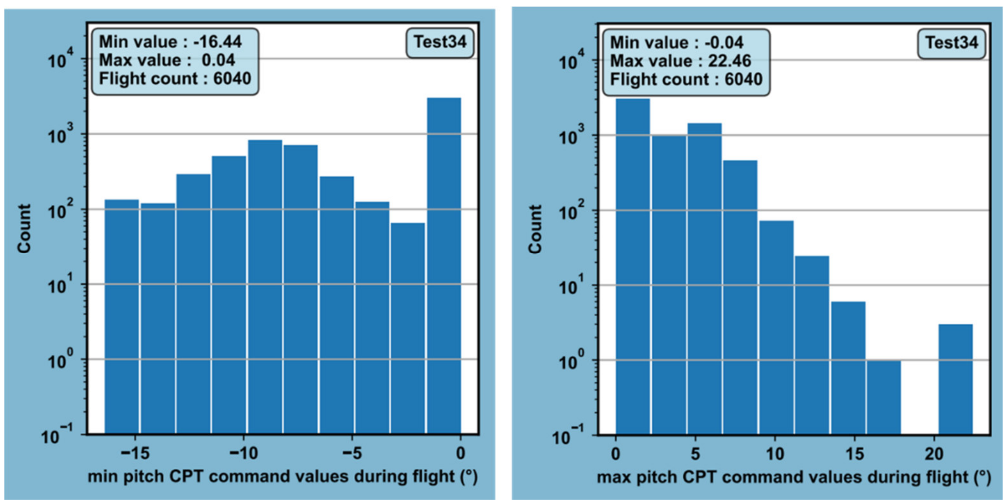


Figure 70: Distribution of Max and min Pitch Cpt command values

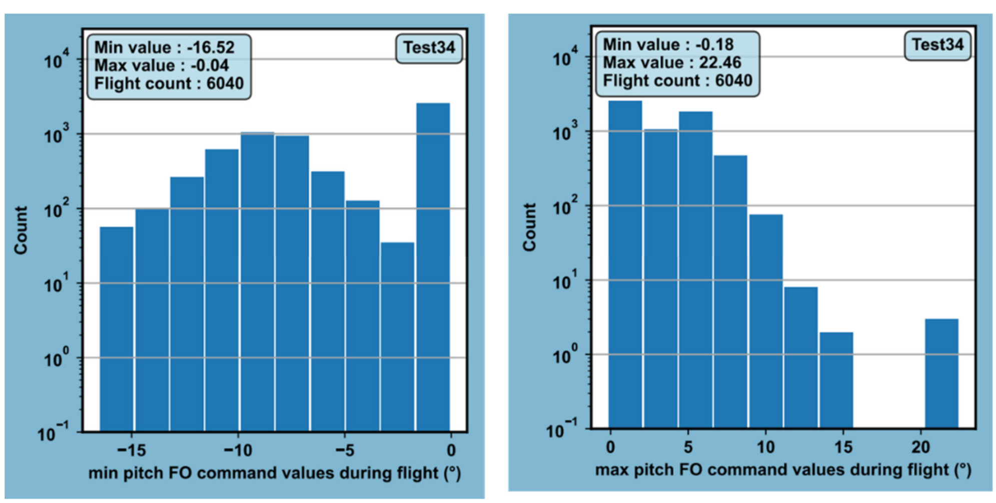


Figure 71: Distribution of Max and min Pitch F/O command values

Note: No filtering done by IAS conditions (as IAS > 83.5kts for all flights)

Event	Result
EVENT T1: **Pitch CPT command <= -20°** **And** **IAS >= 80 kts**	**0 event for 6040 flights** **(-3.5° margin)**
EVENT T2: **Pitch CPT command >= +25°** **And** **IAS >= 80 kts**	**0 event for 6040 flights** **(+2.5° margin)**
EVENT T3: **Pitch FO command <= -20°** **And** **IAS >= 80 kts**	**0 event for 6040 flights** **(-3.5° margin)**
EVENT T4: **Pitch FO command >= +25°** **And** **IAS >= 80 kts**	**0 event for 6040 flights** **(+2.5° margin)**

11.3.31 Tests 34: criteria: Excessive pitch command

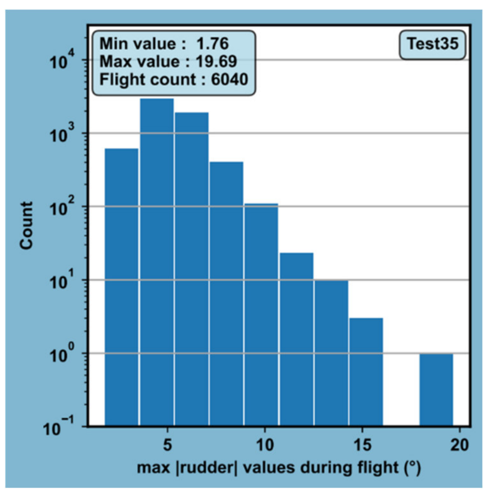


Figure 72: Distribution of Max |rudder| values

Event	Result
|Rudder| >= +6° **And** **IAS >= +240 kt**	**0 event for 6040 flights**

11.3.32 Tests 35 and 36: criteria: ineffective roll command and ineffective pitch command

No algorithms given in document D3.

11.3.33 Complementary analysis: the master warning conditions

The objective of this analysis is to check the number of the events previously analyzed in the initial study can be replaced by the check of the master warning signal.

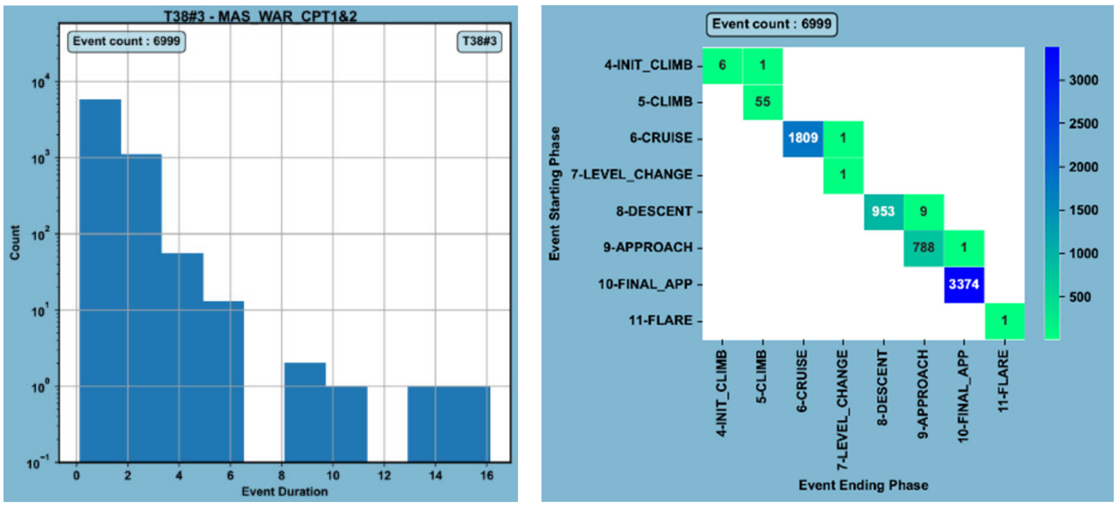


Figure 73: Distribution of "master warning" duration and flight phase

"Master Warning" events with a duration of less than 2 seconds are considered as spurious and are not considered for the analysis. 1,172 events have a duration more than 2 seconds.

A correlation between the triggers defined by document D3 and the "master warning" was carried out: The concomitance was assessed first between the "fire/smoke" and "master warning" alarms.

Fire/smoke events	Number of "Master warning" correlated event	Total number of events	Duration of the smoke / fire events (in sec)
EVENT T14#15 - BNC_LAVATORY_SMOKE	12	27	0,2 à 58
EVENT T14#19 - BNC_CARGO_REST_SMOKE	3	14	0,2 et 4800
EVENT T14#01 - BNC_APU_FIRE_WARNING	2	12	0,2
EVENT T14#03 - BNC_FIRE_ENGINE_2_WARNING	2	13	0,2 et 2
EVENT T14#04 - BNC_BULK_AVIONICS_SMOKE	1	14	0,2
EVENT T14#05 - BNC_LOWER_DECK_STORAGE_SMOKE	1	14	0,2
EVENT T14#06 - BNC_AFT_CARGO_SMOKE	1	13	0,2
EVENT T14#07 - BNC_AUTONOMOUS_VCC_SMOKE	1	18	0,2
EVENT T14#08 - BNC_AUXILIARY_AREA_1_SMOKE	1	18	0,2
EVENT T14#09 - BNC_AUXILIARY_AREA_2_SMOKE	1	18	0,2

Fire/smoke events	Number of "Master warning" correlated event	Total number of events	Duration of the smoke / fire events (in sec)
EVENT T14#10 - BNC_AUXILIARY_AREA_3_SMOKE	1	18	0,2
EVENT T14#11 - BNC_AVIONICS_SMOKE	1	13	0,2
EVENT T14#12 - BNC_BULK_CREW_REST_ COMPARTMENT_SMOKE	1	18	0,2
EVENT T14#17 - BNC_PAX_BROADBAND_SMOKE	1	14	0,2
EVENT T14#18 - BNC_CABIN_REST_SMOKE	1	13	0,2
EVENT T14#20 - BNC_VCC_1_SMOKE	1	18	0,2
EVENT T14#21 - BNC_VCC_2_SMOKE	1	18	0,2
EVENT T14#02 -BNC_ FIRE_ENGINE_1_WARNING	0	4	0,2 et 1
EVENT T14#13 - BNC_FWD_CARGO_SMOKE	0	13	0,2
EVENT T14#14 - BNC_INFLIGHT_ENTERTAINMENT _CENTER	0	14	0,2
EVENT T14#16 - BNC_LAVATORY_SMOKE_ALERT	0	0	

Figure 74: Correlation between "master warning" alarms and fire/smoke detection

The value of "Number of "Master warning" correlated event" is the number event, when a "master warning" alarm raise during the time that a fire/smoke event is active.

No correlation between these types of alarm could be confirmed or invalidated. The only link is "the more there are fire / smoke alarms, the more there are correlated "Master warning" "Fire / Smoke" alarms

Same conclusion with the other alarms in document D3.

11.3.34 Complementary analysis: the determination of the margin, by flight phases, for the aircraft attitude

The objective of this analysis is to measure the margin of the Roll and Pitch, in accordance with flight phase:

- After the takeoff phase and before the cruise phase (i.e., "Initial climb" and "Climb")
- During the cruise phase
- After the cruise phase, until landing (i.e., "Descent", "Approach" and "Final approach")

The final values of the margins are given section 5.3.4.

Hereafter are the graphics.

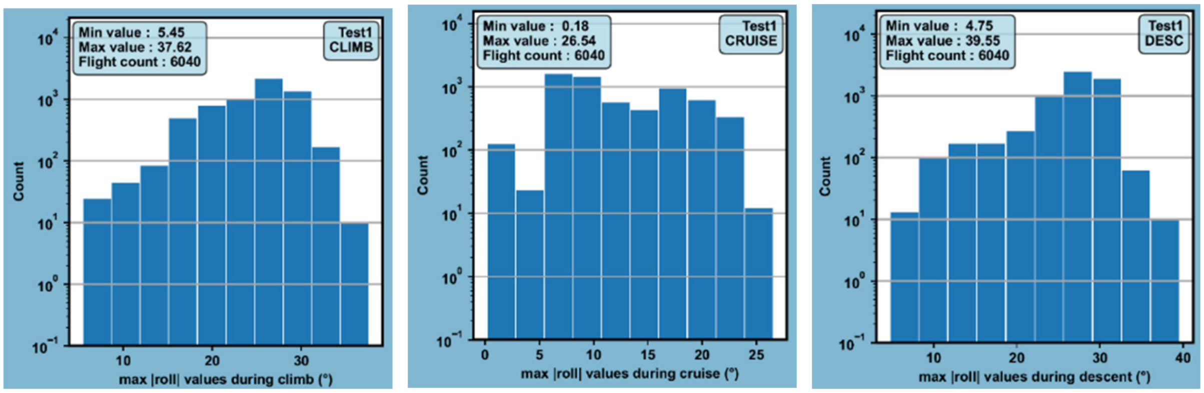


Figure 75: Distribution of Max |roll| values by flight phases

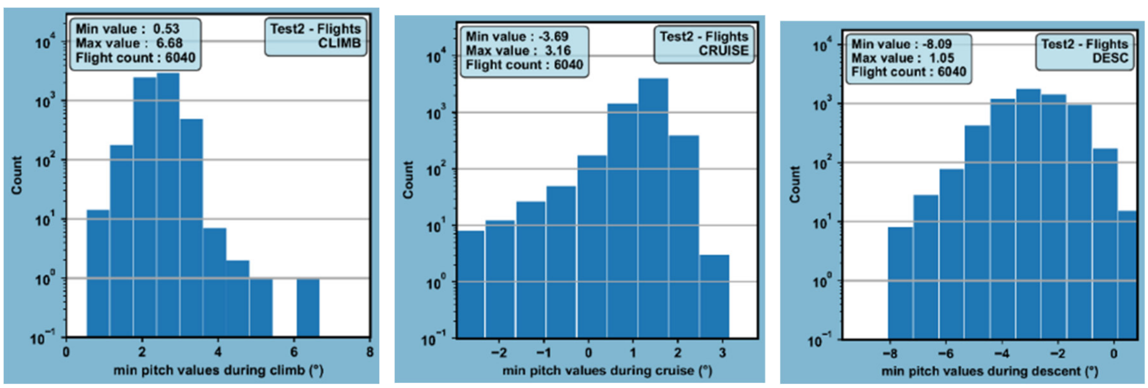


Figure 76: Distribution of Min Pitch values by flight phases

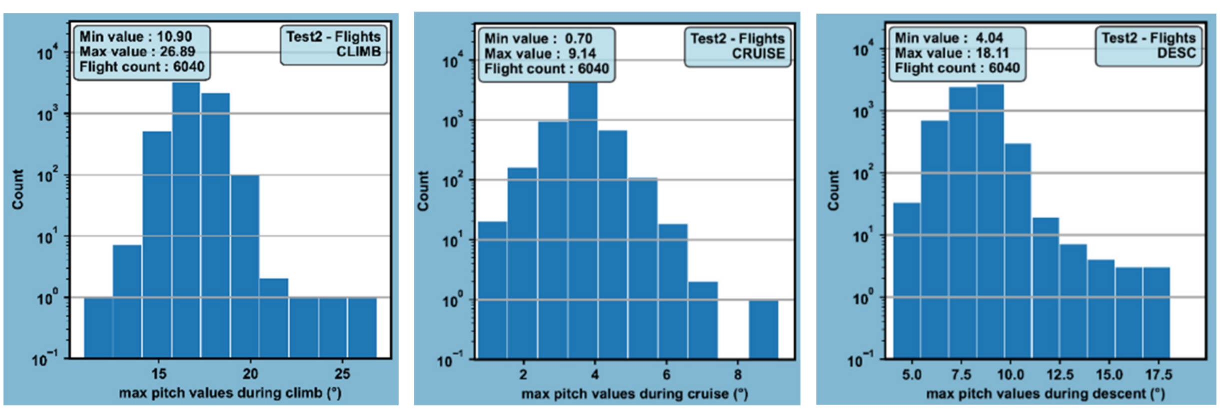


Figure 77: Distribution of Max Pitch values by flight phases

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