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RESEARCH PROJECT EASA.2020.C43

QUICK RECOVERY OF FLIGHT RECORDER DATA (wireless transmission)

Report D9

Conclusions and Way-forward

An Agency of the European Union

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REPORT D9

Conclusions and Way Forward

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ABSTRACT OF THE PROJECT

The Quick Recovery of Flight Recorder Data (QR-FRD) research project assesses technical solutions and legal challenges for the automatic wireless data transmission to quickly understand the causes and contributing factors of an accident.

The first part of the project assessed candidate technologies and analyzed different options for the collection, secure transmission, and off-aircraft storage of flight recorder data. Two solutions were selected addressing continuous and triggered transmissions respectively.

The second part assessed the technical feasibility of the two solutions through modelling and simulations of the overall airborne suite and refined the definition of triggers to be used to initiate the transmission of the data. The legal aspects and possible impacts on existing standards and regulations were addressed in detail in this second part.

All analysis and findings covering both the technical and legal aspects were documented and shared with stakeholders including airlines, pilot associations, accident investigators and regulators. Their feedback helped maturing the study outcomes.

All these steps allowed us to identify the main legal issues and, from a technical point of view, to determine that a mix of continuous and triggered transmission of specific data types would probably be the most optimal solution.

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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 9]).

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 large 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 has addressed the technical feasibility and maturity, the performance, the related constraints, the legal aspects 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 flight data recorder (FDR) - cockpit voice recorder (CVR) capable of recording 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 10]), and mandated to have a Flight Recorder Data Recovery (FRDR) means on-board.

A further investigation of the performance levels achievable has been 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 has been investigated.

The results of the feasibility project, together with the practical recommendations for the implementation of the candidate solutions, has been 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.
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 with a large aeroplane 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.

Figure 1 depicts the overall approach taken for the QR-FRD study and the relationship between the different deliverables.

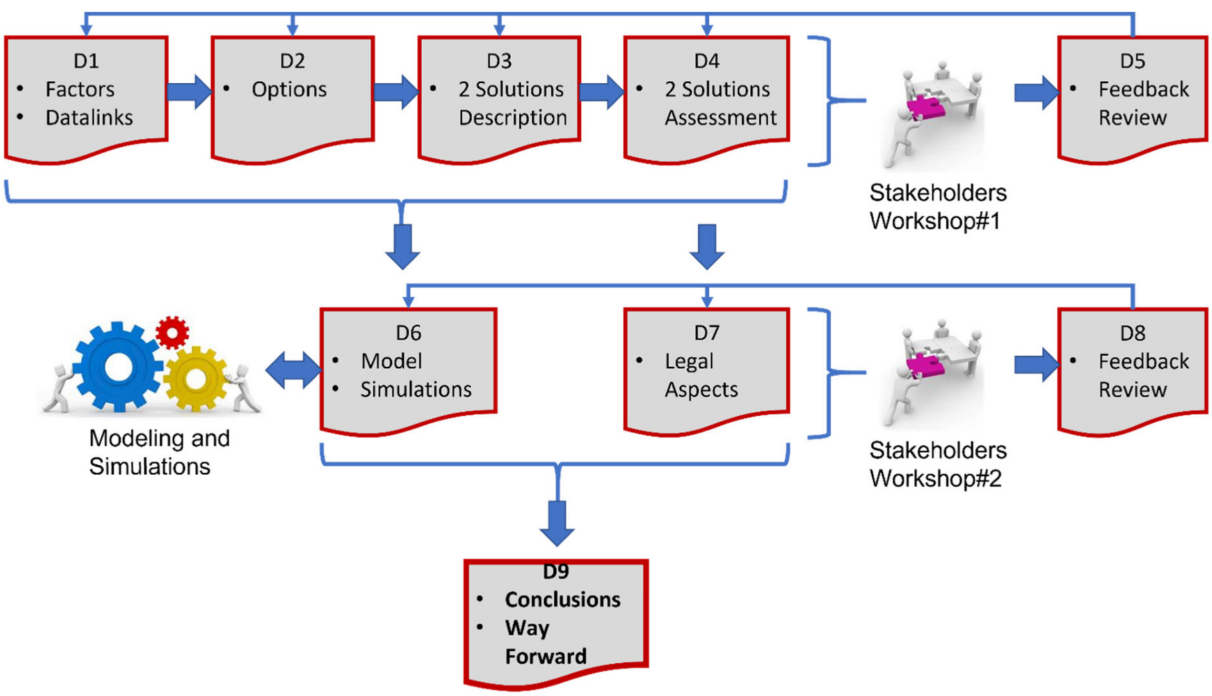

Figure 1: QR-FRD Study Approach and Deliverables Relationship

1.2 Scope of This Report

The present document corresponds to D9 as depicted Figure 1. It summarizes analysis and findings from Task 9 “Conclusions and Way Forward” of the QR-FRD study.

It aims at:

- providing a general reflection on the activities performed during the project, as well as findings collected during these activities,
- providing conclusions and recommendations to progress the maturity of the concept of wireless transmission of flight recorder data to prepare its implementation

1.3 Organization of the Document

This document is part of Task 9 "Conclusions and Way Forward" 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, "EXECUTIVE SUMMARY", a publishable executive summary

Chapter 5, "RETROSPECTIVE OF THE WORK PERFORMED", provides a general reflection on the works performed during the project

Chapter 6, "STAKEHOLDERS' FEEDBACK AND RECOMMENDATIONS", provides the feedback and recommendations received during the two stakeholder's consultations

Chapter 7, "REMAINING AND CHALENGING ASPECTS", provides remaining aspects to be explored including the challenging issues

Chapter 8, "SIMULATION LESSONS LEARNED", provides lessons-learnt regarding the methodology used and the conduct of the simulations

Chapter 9, "PROPOSED APPROACH MEANS TO DEMONSTRATE COMPLIANCE", proposes approach for the development of means and material, in order to facilitate the performance demonstration to competent authorities

Chapter 10, "CONCLUSION AND WAY FORWARD", addresses practical recommendations to progress the maturity of this concept and prepare their implementation

2 REFERENCE DOCUMENTS

[Ref 1] QR-FRD Study D1: "Accident conditions relevant for wireless flight recorder data transmission", Aug 2021

[Ref 2] QR-FRD Study D2: "Overview of Technical Solutions for Automatic Wireless Transmission", Ed 00, Nov 2021

[Ref 3] QR-FRD Study D3: "Technical investigation of the two solutions", Ed 00, Dec 2021

[Ref 4] QR-FRD Study D4: "Assess challenges and limitations of the two solutions", Ed 00, Dec 2021

[Ref 5] QR-FRD Study D5: "First consultation of the stakeholder's group", Ed 00, March 2022

[Ref 6] QR-FRD Study D6.1: "Simulation of technical solutions", Ed 00, July 2022

[Ref 7] QR-FRD Study D7: "Legal Aspects", Ed 00, June 2022

[Ref 8] QR-FRD Study D8: "Second consultation of the stakeholder's group", Ed 00, Jan 2023

[Ref 9] EN-EASA.2020.HPV.06, Quick Recovery of Flight Recorder Data Call for Tender

[Ref 10] ICAO Annex 6 – Operation of Aircraft – Part I – International Commercial Air Transport – Aeroplanes, Ed. 11, July 2018

[Ref 11] ICAO Annex 10 – Aeronautical Telecommunications, 7th Edition, July 2018

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

[Ref 13] ICAO Annex 19 – Safety Management, 2nd Edition, July 2016

[Ref 14] ICAO Doc. 9756 – Manual of Aircraft Accident and Incident Investigation

[Ref 15] ICAO Doc. 9859 – Safety Management Manual (SMM)

[Ref 16] ICAO Doc. 10053 – Manual on the Protection of Safety Information

[Ref 17] ICAO Doc 10054 – Manual on Location of Aircraft in Distress and Flight Recorder Data Recovery

[Ref 18] EU 996/2010 – REGULATION (EU) No 996/2010 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing

[Ref 19] Directive 94/56/EC – Council Directive 94/56/EC of 21 November 1994 establishing the fundamental principles governing the investigation of civil aviation accidents and incidents

[Ref 20] EU 965/2012 – COMMISSION REGULATION (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council

[Ref 21] EU 679/2016 – REGULATION (EU) 2016/679 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC

[Ref 22] EU 1148/2016 – DIRECTIVE (EU) 2016/1148 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union

[Ref 23] EU 881/2019 – Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act)

[Ref 24] EUROCAE ED-203A – Airworthiness Security Methods and Considerations, June 2018

[Ref 25] EUROCAE ED-237 – MASPS for Criteria to detect In-Flight Aircraft Distress Events to trigger Transmission of Flight Information, February 2016

[Ref 26] EASA AMC & GM to Part CAT

[Ref 27] ISO 2700x:2022, Information Security, Cybersecurity and Privacy Protection, ISO/IEC, 2022

[Ref 28] BEA, Technical Document, Triggered Transmission of Flight Data Working Group, March 2011

[Ref 29] COMMISSION IMPLEMENTING REGULATION (EU) 2015/1018 - of 29 June 2015, “[…] occurrences in civil aviation to be mandatorily reported […]”

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 which is 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 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 result of a scientific test that appears to show something exists or is present, when this is not correct" (Cambridge dictionary) (a serious incident or accident in our case)
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

Term	Definition
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
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).

Table 1: Definitions

Acronym	Definition
AIA	Accident Investigation Authorities
AIR	Airborne Image Recording
ANSP	Air Navigation Service Provider
BEA	Bureau Enquête Accidents
CONOPS	Concept of Operations
CRI	Certification Review Item
CSP	Communication Service Provider
CVR	Cockpit Voice Recorder
DAR	Digital ACMS Recorder
DLP	Datalink Provider
DSP	Datalink Service Provider
EASA	European Union Aviation Safety Agency
ETSO	European Technical Standard Order
FB	Functional Block
FCC	Federal Communications Commission
FCMIR	Flight Crew Machine Interface Recordings
FDM	Flight Data Monitoring

Acronym	Definition
FDR	Flight Data Recorder
FMS	Flight Management System
FOQA	Flight Operational Quality Assurance
FRDR	Flight Recorder Data Recovery
GDPR	General Data Protection Regulation
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IP	Internet Protocol
ITU	International Telecommunication Union
LEO	Low Earth Orbit
MOPS	Minimum Operational Performance Standards
NA	Not Applicable
NDA	Non-Disclosure Agreement.
OEM	Original Equipment Manufacturer
PIESD	Passenger Information and Entertainment Services Domain
PKI	Public Key Infrastructure
QoS	Quality of service
QR-FRD	Quick Recovery of Flight Recorder Data
SME	System Matter Expert
SMS	Safety Management System
TBC	To Be Confirmed
TBD	To Be Defined
TC	Type Certificate
TRL	Technology Readiness Level
VPN	Virtual Private Network

Table 2: Acronyms

4 EXECUTIVE SUMMARY

The Quick Recovery of Flight Recorder Data (QR-FRD) research study funded by European Union's Horizon 2020 Programme was undertaken by Collins Aerospace, SAFRAN, Bertrand de Courville Consulting and Courrégé-Foreman for EASA.

The goal of this study was to assess technical solutions for automatic wireless data transmission in a remote land area or oceanic area in order to understand more quickly the causes and contributing factors of an accident from a technical and legal aspects point of view, involving organizations (aka stakeholders) such as regulators, investigation authorities, pilot associations and airlines through the review of the documents produced:

- D1: Accident conditions relevant for wireless flight recorder data transmission
- D2: Overview of Technical Solutions for Automatic Wireless Transmission
- D3: Technical investigation of the two solutions
- D4: Assess challenges and limitations of the two solutions
- D6.1: Simulation of technical solutions
- D7: Legal Aspects

A screening of possible technical solutions for automatic wireless transmission of flight recorder data (including flight data, audio and flight-crew interface recordings and data link messages) is conducted and documented in D1 [Ref 1]. Medias covering the overall spectrum used for communication means were assessed in terms of usage, range, coverage, and bandwidth as well as applicable industry standards among other criteria. A survey performed with SATCOM service provider is used as inputs to the assessment matrix.

Also, resilience to factors that could affect the transmission (typically, excessive attitude and attitude rates of the aircraft, loss of power on all engines, fire, collision and crash or ditching) is addressed.

Similarly, factors that would affect the transmission of flight recorder data prior to the accident are identified and assessed. Indeed, a preliminary analysis of data provided by the BEA shows how little time is left for the system to transmit before an accident once a distress situation is detected onboard.

A systematic approach is taken to identify candidate solutions for each of the functional blocks of the QR-FRD chain and analyses their relevance and drawbacks. The analyses and conclusions are documented in D2 [Ref 2]. The functional blocks are those defined in D2 [Ref 2] and cover the airborne, space and ground segments of an overall QR-FRD system: collection of flight recorder data onboard the aircraft (FB1), detection of a condition to start transmission for either continuous or triggered modes (FB2), transport of the flight recorder data over the air and on the ground from the aircraft to the final recipient system (FB3), secure storage on the ground (FB4), and recovery of the flight recorder data by the accident investigation authorities as well as the airline (FB6).

Different technologies (e.g., datalinks) and state of the art aeronautical systems (e.g., aircraft tracking) that are relevant and/or perform similar functions are described as baselines. Then different options for technologies, system architectures, QR-FRD features, are identified and analyzed in the light of constraints (e.g., volume of data to be transmitted and stored, impact on existing avionics and on aircraft installation) and expected performance. The several options are ultimately benchmarked based on a set of defined criteria. These criteria include resilience to factors identified in D1 [Ref 1], performance and quality of service (e.g., coverage and transmission throughput), maturity level and costs figures. Two most promising solutions result from the ranking of the different options for the different functional blocks and have served as baselines for the next activities of the QR-FRD study.

The first solution, designated as "AISD-based solution", is articulated around an airline information service domain (AISD) router, and is arbitrarily allocated the continuous transmission mode. The second solution, designated as “FDAU/FDIU&ACMS-based” solution, is articulated around flight data acquisition units (FDAU) and aircraft condition monitoring system (ACMS), and is arbitrarily allocated the triggered transmission mode. Both solutions rely on airborne high bandwidth communication means.

A generic QR-FRD system functional architecture encompassing the airborne, space and ground segments is first detailed in D3 [Ref 3], describing the different sub-functions they will embed. These sub-functions basically include digitization, timestamping, merging, chunking, compression, encryption, signature, buffering, trigger condition evaluation, point-to-point secure connection, and secure storage, along with necessary counterparts.

The two solutions identified in D2 [Ref 2] are then presented through a) their respective hardware architecture depicting the avionics arrangements, and b) their respective operational concepts for management of cryptographic keys and organization of the above listed sub-functions. Specificities, as well as expected performance and limitations, are also identified and documented. These findings set the baseline for deeper analysis and comparisons of the two solutions in subsequent QR-FRD study activities and reports.

Additional background information is provided in different annexes of D3 [Ref 3] including usage of flight data for trigger condition evaluation, draft formulas for trigger condition evaluation, description of a flight warning system, accident categories coverage by the proposed trigger conditions as well as European safety occurrences coverage [Ref 29] by the proposed trigger conditions.

The two proposed solutions are then compared, and challenges and limitations are identified, assessed, and documented in D4 [Ref 4]. Technology readiness levels (TRL) for the different options and enablers, functional design assurance levels (FDAL), impacts on existing operational procedures, resilience to factors identified in D1 [Ref 1], and benefits, constraints and technical feasibility issues are criteria used in the comparisons.

Also, legal aspects are identified for each functional blocks and an initial assessment added to the comparison. A more thorough analysis of the legal aspects and their impacts is later conducted and documented in D7 [Ref 7].

Based on the two best candidate solutions provided in D3 [Ref 3] and detailed more in depth in D4 [Ref 4], simulations are conducted to assess the performance of the QR-FRD system such as data volume, data completeness, required throughput and transmission protocol.

The model covers the functional blocks involved in the data transmission chain including the trigger logic to detect potential flight anomalies and takes into account environmental factors identified in D1 [Ref 1] as well as the dynamic conditions the aircraft undergoes. The receiver/transmitter performances and characteristics of the satellite constellations come from satellite provider surveys that the consortium performed. They are used to model satellite constellations as parameter values and contribute to computations of the aircraft/satellite intervisibility conditions.

Representative flight data samples provided by the BEA are used to consolidate the throughput of the flight data input stream that is injected in the model during the simulation. The influence of model parameters such as QoS, file transfer protocol, false-positive ratio, and compression is examined.

The simulation tool that was developed for the study comes with a graphical user interface enabling the user to update model parameters through widgets, run the simulation and display the results in a graphical way. Playing with the model parameters allows to confirm trends, to draw conclusions and to identify areas for improvement to optimize the system.

In parallel, a statistical analysis of the trigger conditions is conducted to increase the reliability and the early detection of situations that could possibly lead to accidents (or serious incidents) but also to evaluate the threshold margin versus the false-positive ratio.

These activities and results from the analysis are documented in D6 [Ref 6], and the source code is made available to EASA. The lessons learned from the analysis allows to identify additional factors to be considered such as spurious signals or aircraft computer failures and have completed study recommendations and conclusions that are documented in the present document.

In parallel, a study was conducted on the existing regulations and on whether any amendments or additions are needed to implement the QR-FRD system. This is documented in D7 [Ref 7].

ICAO annexes and corresponding manuals already include provisions for the transmission of flight data from the aircraft to the ground (in particular Annex 6 and Manual Doc. 10054). However, the study confirmed the necessity to amend Annexes 13 and 6 of the Chicago Convention to extend the definition of “flight recorder” to any type of system installed to complement investigations including by transmitting data for storage of the aircraft, as already recommended by ICAO’s Accident Investigation Panel (AIGP), to make these texts applicable to the QR-FRD.

Also, the study resulted in several recommendations listed by functional blocks and requiring the addition and/or modification of several provisions in the ICAO standards. These recommendations are mainly aimed at strengthening the protection of transmitted data, especially as some of them are personal data protected by existing national laws and in particular by the GDPR, which has a broad scope of application. The study recommends extending to all flight data (even purely technical) the level of protection that is currently provided for personal data only. To ensure a sufficient level of data protection as well as trust in the QR-FRD system, the study recommends to mandate compliance with ISO standards that cover the GDPR requirements (see ISO/IEC 27000 series) and rely on contractual clauses.

Concerning EU legislation, the relevant text is the Regulation EU 996/2010. The study recommends amending some provisions but highlights the fact that, contrary to ICAO Annex 13, the provisions already refer to “recordings” and not only to “recorders”, which could allow to interpret them as already applying to QR-FRD data.

Finally, the study has also identified risks of conflicts of interests that could alter the trust and implementation of the QR-FRD. It is therefore recommended to transfer the data to one or a few independent dedicated central repositories and to define a key retention policy for the decryption keys.

There is no showstopper from technical standpoint and the proposed solutions rely on existing equipment minimizing the avionics architecture impacts. Nevertheless, as the transmission chain requires new interfaces at hardware level for the acquisition of new signals such as imagery (FCMIR) and audio, modifications are necessary. Modifications are also needed to be robust to factors like the loss of power for example. The hosting of functional blocs (FB) identified in the software solutions will be allocated to hardware components before their implementation.

A new standard to define a set of trigger logic needs to be written while leaving the possibility for the OEM to set the threshold according to their aircraft performance and characteristics. Sending a large volume of flight recorder data within a few minutes in triggered mode remains a challenge and an early detection is better on the condition that the ‘false-positive” ratio remains acceptable.

Regarding transmission means, there is currently no other choice than to rely on LEO satellite constellations considering the full set of flight data in remote areas knowing that satellite providers are very active on 5G technology with new emerging market in the aeronautical domain.

The main blocking point remains to decide which entities should be in charge of storing the data or hold and manage the cybersecurity keys. An operational concept could be finalized once this blocking point is solved and agreed upon by the aviation community.

To conclude, the QR-FRD concept is very promising to quickly recover flight recorded data after an accident or serious incident in a remote land or oceanic area for investigation purposes and to contribute to improve safety. However, the road to designing such a system is winding and some questions still need to be answered and complementary studies carried out.

5 RETROSPECTIVE OF THE WORK PERFORMED

We have closely followed the plan proposed in the call for tenders, which describes the natural sequence of the steps of the study and allows for a progressive advance in the level of detail and analysis while covering multiple aspects (technical, legal, organizational, normative, operational, contractual etc...)

In terms of resources and expertise, the following points were important in the execution of the study:

- Identifying as many stakeholders and experts as possible according to the needs of the study
- A guarantee of their availability and responsiveness throughout the study
- The complementarity of the consortium's actors and the means and resources made available

On the organizational side, the key factors favoring a good collaboration of the work were:

- The preliminary establishment of the distribution of the tasks, the rotation of task responsibilities and collaboration/participation in these tasks by each member of the consortium (including proofreading)
- The involvement of the whole consortium from the beginning of the project and not at the time of their intervention (e.g., Bertrand De Courville consulting participated to all meetings and workshops)
- The support of the French Bureau Enquête Accidents (BEA) that we would like to thank greatly and that was able to answer the many questions we had
- Weekly progress meetings, additional workshops as needed and progress meetings with EASA
- Involvement and motivation of all actors

The schedule was globally respected:

- The first draft versions of all documents were delivered on time. The length of the proofreading process varied depending on the complexity of the documents
- The feedback analysis workload is proportional to the number of comments provided by the stakeholder during the review phase and took at least twice as long as expected. Hopefully we were able to anticipate the start of the next tasks to minimize the schedule impact

The interactions with external organizations concerned the surveys, the reviews and support:

- Satellite communication service providers: only three returns out of eleven solicitations (Gogo / Intelsat, SES Astra, Iridium, Inmarsat, Arinc/IMS, Sita, OneWeb, Kuiper project, StarLink, Telesat, Aireon, Iris, Eutelsat) and numerous reminders. Many actors are working on satellite communication, but few are very reluctant to communicate on the subject and this for several reasons:
  i) In the frame of this study some current actors do not want to show their weaknesses in comparison with some others
  ii) Collins can appear as a competitor
  iii) Some want to create a surprise effect with respect to the competition and not to reveal too much
  iv) It is too early to provide details
- Stakeholder's consultations: the review of the studies by the stakeholders was conducted in two steps (D1 to D4 and D6/D7) to get feedback from different perspectives. Two information session (kick-off meeting) were held to address two different time zones and present expectations and give review instructions. Each line of the documents provided was numbered to allow a homogeneous identification of the remarks from the stakeholders. Then, remarks were compiled into a single document and classified by type (comments, improvement, out of scope…) and topic (trigger, data

protection, FCMIR, standards, performance ...), debated within the consortium and with EASA team who validated the responses and processed the feedbacks. At the end of the rollout, a status on the activity was provided to the stakeholders.

On the technical side, the choice of the solutions to be further studied was summarized through an evaluation grid in which we had identified a set of candidate and realistic solutions as described in documents D1 [Ref 1], D2 [Ref 2] and D3 [Ref 3]. The evaluations were done individually by each person in the consortium team and consolidated during a dedicated workshop. The two solutions with the highest scores were retained for the second part of the study from Task 6. The two solutions were then detailed in D4 [Ref 4].

The implementation of the model has been incremental. First a high-level model was presented to EASA at the beginning of Task 6 specifying the scope of the simulation, the probes[1] recorded, the parameters etc... Each one of the functional blocks identified in D2 [Ref 2] and depicted in Figure 2 used as a framework throughout the study has been implemented and tested separately and then assembled to build the final model and perform the simulations.

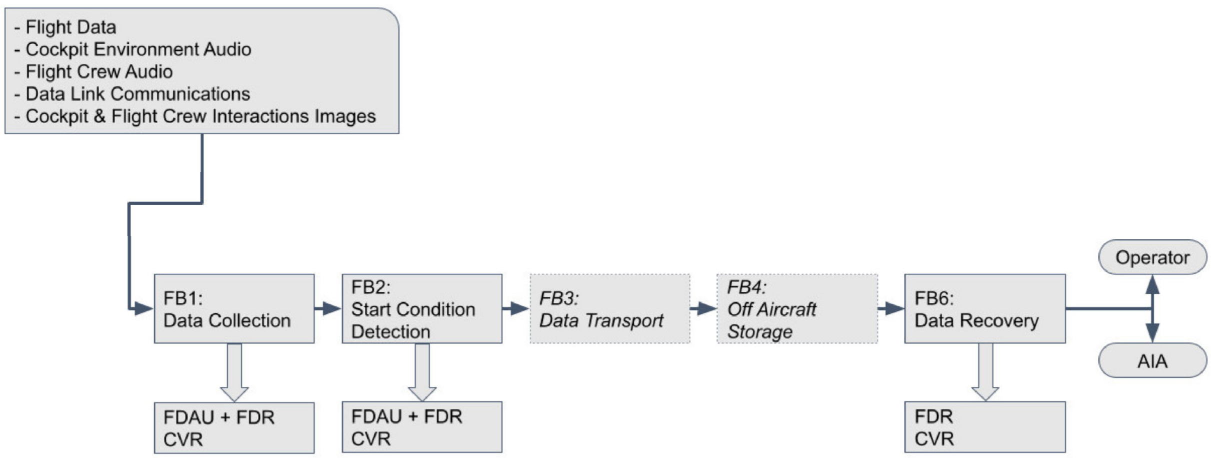

Figure 2: Functional allocation for flight recorders solutions

In the meantime, a statistical study was conducted on triggers previously defined in a BEA study [Ref 28]. The triggers were evaluated on an aircraft model on a large number of flights. More than 6,400 flights, over 6 years (45,500 flying hours) of operation were analyzed, for trigger rate evaluations. Furthermore, additional triggers and trigger conditions were defined, to compare threshold margins including the use of the “Master Warning/Master Caution” signal and the segregation by flight phase. We collected all the results, identified the limits of the system, and made recommendations.

B. de Courville Consulting was in charge of studying the legal aspects of QR-FRD and did so with Courrégé-Foreman, a Paris based law firm specialized in aviation law.

The team studied the functional blocks composing the successive stages of the QR-FRD process as well as the various actors involved in order to identify the relevant legal issues: data ownership and protection, encryption methods, telecommunications infrastructures, data storage and data centers, safety investigations, competent Accident Investigation Authority (AIA), requests from judicial authorities, etc.

[1] Observers (probes) set in place at relevant locations in the model. The observers will reflect metrics to be used for the assessments and evaluations.

For each of these topics, the applicable international and European regulations were studied, and, on some topics, additional research was done in certain domestic legislations (e.g., influence of the US Cloud Act). An analysis of the relevant International Organization for Standardization (ISO) standards was also conducted because of their international scope and the fact that data protection rules strongly encourage certification.

Throughout the study, the legal team regularly monitored the progress of deliverables D1 [Ref 1] to D6 [Ref 6] in order to understand expectations and formulate the most suitable recommendations. Finally, in a case-based approach, the legal team compared these results to known accidents in order to highlight what would have changed with the implementation of the QR-FRD.

6 STAKEHOLDERS' FEEDBACK AND RECOMMENDATIONS

Two stakeholders' reviews were conducted: the first one on the documents D1 to D4 (from factors which affect the wireless transmission of flight data until the challenges and limitations of the two best potential solutions) and the second one on the document D6 (model and simulation) and D7 (legal aspects).

Here is the Stakeholders' groups involved in the project:

Airlines	Bureau of Investigation	Pilot Associations	Regulators
Emirates United British Airways Hawaiian Air Polish Airlines Sprint Air Air France	BEA BFU DSB NTSB SCAAI AAIU	SNPL ALPA-I	ENAV FAA ULC

Table 3: Stakeholders' groups

6.1 First consultation of stakeholder's group

Table 4 below summarizes the recommendations and concerns received from the stakeholders after their review of the first set of deliverables. The feedback is sorted according to the Functional Block (FB) and main feature it relates to. This gives a first idea on the level of concern or interest by the different stakeholders.

FB#	Feature	Recommendation / Concern
FB1	FCMIR	Use screenshots for FCMIR, not AIR (privacy)
FB1	FCMIR	FCMIR likely to include AIR pictures along with screenshots, etc. (technology)
FB1	Combined audio channels	Combined audio channels, though a way to reduce the amount of data to be transmitted, is problematic for investigations. Independent channels to be maintained. (technology)
FB1	Compression	Uncompressed data is too cumbersome to even consider (technology)
FB1	Encryption	Encrypt audio and FCMIR recordings (privacy)
FB1	Encryption	Data to be encrypted, not relying on transmission protection (e.g., VPN) (technology)
FB1	Encryption	Encryption at recording stage is not recommended, and likely not permitted. Only for transmission. (technology)
FB1	Data protection	Adequate key management is of outmost importance, but not an operator business (technology)
FB1	Processing methods	Use state-of-the-art non-proprietary algorithms (technology)
FB1	Processing per data types	Process flight data and audio recordings separately (technology)

FB#	Feature	Recommendation / Concern
FB2	Manual triggering	Manual initiation by flight crew to be stopped automatically, e.g., timer or uplink message (technology)
FB2	Manual triggering	Consider initiation from the ground (engineering) with appropriate permissions from the flight crew governed by processes, e.g., uplink request (technology)
FB2	Manual triggering	Under no circumstances should any of the data transmission increase flight crew workload (concept of operations)
FB2	Trigger events	There is potential to miss the data indicating precursors to the triggering event (technology)
FB2, FB3	Processing per data types	Trigger flight data and audio recordings separately (technology)
FB3	Continuous transmission	Benefits for FDM and real-time maintenance are questionable (cost)
FB3	Continuous transmission	Available satellite bandwidth may be constricted by the number of aircraft simultaneously using same SATCOM (technology)
FB3	Data protection	End-to-end data protection should be ensured, covering all airborne, space and ground segments, from aircraft to end-user. (technology)
FB3	Data protection	Adequate key management is of outmost importance, but not an operator business (technology)
FB3	Cybersecurity	Hacking the aircraft system using the QR-FRD data link shall be prevented. (technology)
FB3	Secure protocols	Use state-of-the-art non-proprietary algorithms (technology)
FB3	Backup batteries	The 10-minute CVR power backup supply does not apply to transmission of flight data (technology)
FB3	Backup batteries	These new recorders would require something similar [to CVR]. However, adding more Li-batteries introduces additional risk to the operation of aircraft. (technology)
FB5	Flight recorder data ownership	AIA will not become a data owner; flight recorder data shall be made available to the AIA for the purpose of investigations (policies)
FB5	Storage location	Possible need for additional requirements for States to protect flight recorder data from being disclosed to the public (policies)
FB5	Storage location	Possible need for additional requirements for States to transfer flight recorder data to the State of occurrence, or to another State (policies)
FB5	Storage location	States may have specific restrictions on what and where data can be stored vs data ownership (policies)
FB5	Storage location	Consider storing accident or serious incident related voice data on servers not belonging to the operator (triggered transmission), or encrypted and only made available to AIA (continuous transmission)
FB5	Storage location	Storage by AIA could be considered for triggered transmissions, which are likely to be investigated. Nevertheless, the operator will likely intend to have a copy of continuous transmissions for their own access (concept of operations)

FB#	Feature	Recommendation / Concern
FB5	Storage location	Storage by Civil Aviation Authority would raise a problem of independence with regards to AIA. However, a central repository may be envisaged, provided it is operated in accordance with regulations for accident and accident investigations (policies)
FB5	Storage location	Storage in extra-territorial data centers or cloud may have serious consequences on data access and protection, undermining data privacy and protection, cf. US Cloud Act (policies)
FB5	Storage location	Off-aircraft storage and data retention by the operator poses serious ethical issues (policies)
FB5	Data protection	The operator storing flight recorder data should leverage on strong access-control policy and mitigate insider threat (policies)
FB5	Data protection	The operator will want the ability to manage the security of flight recorder data (concept of operations)
FB5	Storage per data types	Store flight data and audio recordings separately (technology)
FB6	Flight recorder data handling	Handling of flight recorder data should be same as for FDR and CVR today (policies)
FB6	Use of flight recorder data	AIA will want to use of data recorded on previous flights, not only data recorded prior to serious incident or accident (policies)
FB6	Use of flight recorder data	Flight [recorder] data would have value to the operator if it could be streamed regularly and utilized (cost)
FB6	Use of flight recorder data	Benefit of real time FDM for continuous transmission is minimal over post-flight QAR data transmission. The main benefit would be real time maintenance and troubleshooting (cost)
FB6	Data retention / destruction	Possible need for an operator process to auto-delete audio recordings after a predetermined period and after determined not to be an “incident” flight (policies)
FB6	Data retention / destruction	Retention and deletion of transmitted data on abnormal condition trigger with no further need for investigation, and its governance to be defined (concept of operations)
FB6	Data retention / destruction	Limiting the timeframe of identified data to as little as necessary would add in data protection (policies)
FB6	Occurrence reporting	Possible use of triggers outside of the intended use for investigations (serious incident or accident) to be prohibited (policies)
FB6	QR-FRD and FDR/CVR	QR-FRD processes to co-exist with FDR/CVR processes / definition of flight recorder data to include transmitted data (policies)
FB6	Data protection	Adequate key management is of outmost importance, but not an operator business (technology)
FB6	Data protection	Data protection/security becomes more complicated if the data is held in multiple locations (policies)
FB6	Access to flight recorder data	In some States, operators may not be allowed to access the data from events an AIA is investigating unless they receive specific consent from the AIA (concept of operations)
FB6	Access to flight recorder data	AIA may ask other “better equipped” AIA to process the data for them (concept of operations)

FB#	Feature	Recommendation / Concern
FB6	Data processing and analysis	AIA to be provided with means to process the transmitted flight recorder data and verify its integrity and completeness (technology)

Table 4: Stakeholders' feedback #1 allocated to the Functional Blocks

As can be read, hot topics (those with more than 3 comments) are sometimes subject to debate, i.e., different directions proposed depending on the reviewer organization category. This is typically true for **encryption** for which there is a consensus on the fact that data should be encrypted, though not agreement is reached on where, when, and how the encryption should take place. Also, the recommendation to **process separately flight parameters** (less volume, less privacy critical) **and audio recordings** (greater volumes, highly privacy critical) appears consistently along the functional chain. Finally, the handling of flight recorder data received although no investigation is needed, e.g., **transmission triggered after an abnormal situation was detected but did not lead to an accident or serious incident**, needs to be further refined. It is clear that the expectation is that flight recorder data should be made available to accident investigation authorities as they would from the mass storage device of a recovered combined flight data recorder. It is less clear how this is expected to occur, the physical flight recorders unit being replaced by a virtual and distributed flight recorders.

6.2 Second consultation of stakeholder's group

The recommendations and concerns received from the stakeholders after their review of the second set of deliverables have been divided into two groups, simulation and legal aspects.

Simulation

A total of 51 comments were received from 4 sources including the BEA (8 comments), ECA/BALPA (6 comments), United Airlines (2 comments) and ALPA (35 comments). Most of these comments were addressing the following topics:

- Data transmission performance: throughput, keep alive connection, 5G interference on radio altimeter, data integrity, coverage, bandwidth sharing between passenger wifi and QR-FRD when not in distress and the dataset content
- Costs: direct costs (transmission costs in general and costs in streaming mode) and indirect costs (impact due to the weight of the system for example)
- Representativeness of the tests: only one aircraft type (i.e., Airbus A330) for trigger evaluation seemed not enough
- Triggers: the logic, the parameters involved and the false-positive ratio
- Factors affecting the wireless transmission

Legal Aspects

A total of 73 comments were received from 5 sources including the BEA (8 comments), the NTSB (8 comments), ECA/BALPA (12 comments), United Airlines (2 comments) and ALPA (43 comments). Most of these comments were addressing the following topics:

- Data protection: Practical implementation of protection measures (data erasure, encryption key management); legal risks related to transferring data to non-GDPR compliant States; creation of back up flight data files in separate countries; cybersecurity threats.
- Judicial authorities: Judicial and Accident Investigation Authorities relationship in the context of the QR-FRD processes.
- Airlines Flight Data Monitoring programs: Relevant comments about possible use QR-FRD data by airlines for their FDM programs but these comments were out of the scope of this QR-FRD project.
- In addition, some comments (7) were related to technical aspects which were answered with the support of Collins Aerospace and Safran Electronic & Defense.

27% of these comments and feedback resulted in clarifications and/or additions in their respective documents, i.e., D6 [Ref 6] and D7 [Ref 7], after review of the responses from the consortium with EASA.

7 REMAINING AND CHALLENGING ASPECTS

Context and architecture diagram and brief reminder followed by all additional research or investigation topics needed to mature the QR-FRD, norms, standards, and legislation applicable to update or create…

7.1 Context Diagram

A context diagram is provided Figure 3 below. It identifies the boundary of the QR-FRD system[2] and its "users" on the one hand and depicts their main relationship and interfaces with the system on the other hand.

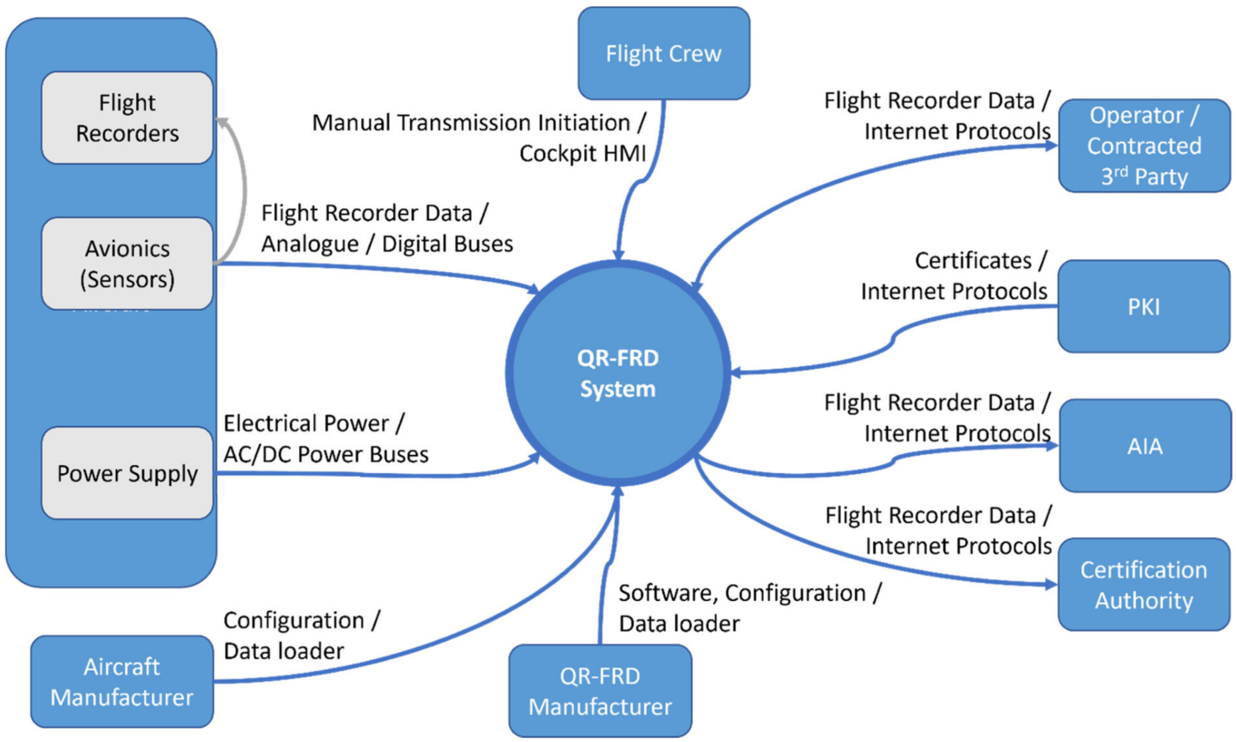

Figure 3: Context Diagram

The following table summarizes the primary usage as sources and/or consumer of the data each "user" of the QR-FRD System, in a counter-clockwise order from Figure 3.

User	Usage
Aircraft / Avionics (Sensors)	• Generates and provides the data and signals to be recorded and ultimately transmitted • Provides the flight parameters for triggers evaluation
Aircraft / Power Supply	• Provides the electrical energy to the components of the system for the duration of flight (starting at the gate) including "Abnormal situation" / "Emergency situation"

[2] Actually, QR-FRD system of systems. As described in previous deliverables and later in the present document, the QR-FRD system encompasses avionic systems onboard the aircraft as well as space-based and terrestrial air-ground communications systems, ground-ground communications systems and networks, secure data storage assets…

User	Usage
Aircraft Manufacturer	• Configures triggers settings (thresholds, hysteresis…) per aircraft type
QR-FRD Manufacturer[3]	• Provides, upgrades, and repairs the related aircraft installation / equipage
Certification Authorities	• Verifies overall performance against specifications / compares flight recorder data stored onboard against flight data recorder data downloaded from the ground-based storage
Accident Investigation Authorities (AIA)	Designated AIA • Accesses flight recorder data for investigation purposes (accident and serious incident cases) • Coordinates flight recorder data retention and/or disposal with the Operator • Provides copy of the data to the other AIAs or their advisors involved in the investigation
Public Key Infrastructure (PKI)	• Provides unique identities for related users, devices, and applications • Governs the generation, revocation, renewal, and secure distribution of related digital certificates
Operator / Contracted 3rd Party	Operator / Flight Operations: • Accesses flight recorder data for SMS purposes • Manages flight recorder data retention and destruction • Manages contracts with related CSP/DSP • Manages contracts with related third parties (if any) Operator / Maintenance: • Accesses flight recorder data for periodic quality inspection purposes • Configures, upgrades, and repairs the related aircraft installation / equipage Operator / Contracted 3rd Party: • Accesses flight recorder data for SMS purposes
Flight Crew	• Provides consent / initiation for transmitting flight recorder data for periodic quality inspection purposes • Allows / prohibits access to audio and imagery recordings

Table 5: Usages of the QR-FRD system by the identified users

7.2 System Architecture

Figure 4 below depicts the QR-FRD system architecture and identifies its main components it comprises, i.e., a flight recorder data collection and processing function as well as a flight recorder data transmission function aboard the aircraft, terrestrial and satellite communication systems along with their respective ground-based infrastructures, a data link service provider network, and a secure storage.

[3] At this stage, the QR-FRD Manufacturer is limited to the organization manufacturing the airborne components (avionics) of the QR-FRD system.

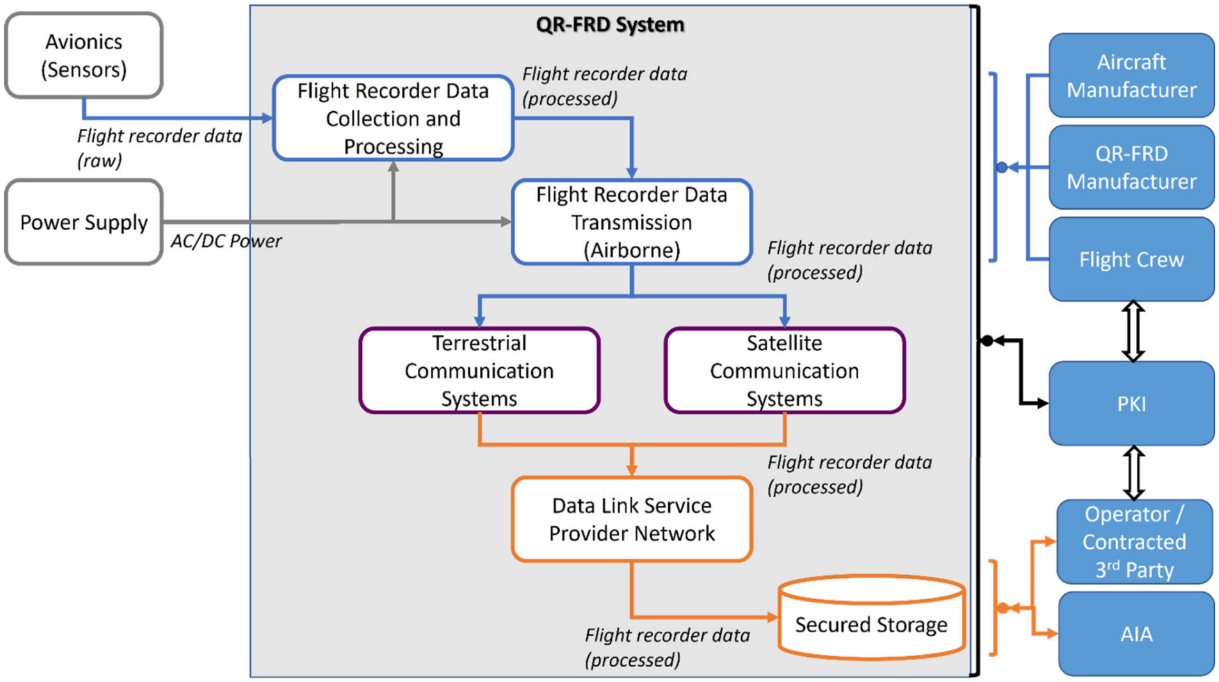

Figure 4: QR-FRD System Architecture

7.3 Identification of gaps and open points

The following table identifies gaps, hence additional research or investigation topics needed to mature the QR-FRD concept and solution(s), norms, standards, and legislations applicable to update or create. Details are provided for most part in D4 [Ref 4] and D7 [Ref 7]. The list of items addressed result from the users listed in §7.1 and systems depicted in §7.2.

Item	Applicable Norms, Standards, Legislations and Guidance documents	Identified Gaps
Overall QR-FRD Concept	ICAO Annex 6 [Ref 10] ICAO Annex 10 [Ref 11] ICAO Annex 13 [Ref 12] ICAO Annex 19 [Ref 13] EU 996/2010 [Ref 18] EU 965/2012 [Ref 20] ICAO Doc. 9756 [Ref 14] ICAO Doc. 9859 [Ref 15] ICAO Doc. 10053 [Ref 16] ICAO Doc 10054[4] [Ref 17]	The overall concept is low TRL (not tested in an operational environment) and requires experimentations and large-scale validations on the operational side before being deployed worldwide.
Aircraft / Avionics (Sensors)	Respective MOPS	-

[4] At the time this document was drafted, the next version of 10054 (10165) was not publicly available

Item	Applicable Norms, Standards, Legislations and Guidance documents	Identified Gaps
Aircraft / Power Supply	-	Without any electrical network changes and/or additional batteries and/or equipment modifications, the system will not be resilient to factor 2 "loss of aircraft power" identified in D1 (cf. D4 [Ref 4] §4.2.4)
Aircraft Manufacturer	ED-203A [Ref 24]	-
QR-FRD Manufacturer[5]	-	MOPS to be created and published for ensuring that all solutions are designed to meet acceptable levels of performance
Certification Authorities	-	ETSO or CRI to be created and published
Accident Investigation Authorities (AIA)	ICAO Annex 13 [Ref 12] ICAO Doc 10054[3] [Ref 17] EU 996/2010 [Ref 18] EASA AMC&GM Part CAT [Ref 26]	Reference document to update (cf. D7 [Ref 7])
Public Key Infrastructure (PKI)	ICAO Annex 13 [Ref 12] EU 679/2016 [Ref 21]	Overall concept to define policies, processes, etc., and their exchanges amongst the identified users.
Operator / Contracted 3rd Party	EASA AMC&GM Part CAT [Ref 26]	Maintenance procedures to be adapted (cf. D4 [Ref 4], §4.5)
Flight Crew	EASA AMC&GM Part CAT [Ref 26]	Flight crew procedures to be adapted (cf. D4 [Ref 4], §4.5)
Flight Recorder Data Collection and Processing	EU 679/2016 [Ref 21] ISO 2700x [Ref 27]	The Overall Processing Sequence for the "Data Collection" function is low TRL (cf. D4 [Ref 4], §4.1)
Flight Recorder Data Transmission (Airborne)	ICAO Annex 6 [Ref 10] ICAO Doc 10054[3] [Ref 17] ED-237 [Ref 25]	Solution #1: The triggers logic for the "Trigger Detection" function is low TRL (cf. D4 [Ref 4], §4.1). Solution #1: A standard for triggers definition covering the abnormal conditions is needed. Solution #1 & 2: Advanced airborne multilink router for the "Data Transport" function are low TRL (cf. D4 [Ref 4], §4.1).
Terrestrial Communication Systems	Respective MOPS ISO 2700x [Ref 27]	-

[5] At this stage, the QR-FRD Manufacturer is limited to the organization manufacturing the airborne components (avionics) of the QR-FRD system.

Item	Applicable Norms, Standards, Legislations and Guidance documents	Identified Gaps
Satellite Communication Systems	EU 996/2010 [Ref 18] Respective MOPS ISO 2700x [Ref 27]	Possible EU 996/2010 amendment (cf. D7 [Ref 7], §5.3.1.4) Satellite constellations offering [cheap] high bandwidth not fully deployed yet. Associated airborne terminals are neither available. Performance of the airborne terminal and antenna in distress conditions (extreme attitude and environmental conditions) needs to be assessed (cf. §8.1.1) and validated with live trials.
Data Link Service Provider Network	EU 1148/2016 [Ref 22] ISO 2700x [Ref 27]	Contracts (cf. D4 [Ref 4], §6.2).
Secured Storage	ICAO Annex 6 [Ref 10] ICAO Annex 13 [Ref 12] ICAO Annex 19 [Ref 13] ICAO Doc 10054[3] [Ref 17] EU 881/2019 [Ref 23] EU 965/2012 [Ref 20] ISO 2700x [Ref 27]	Possible Annex 6 and Doc 10054[3] amendments (cf. D7 [Ref 7], §5.4.2.4) Possible EU 965/2012 amendments (cf. D7 [Ref 7], §5.4.3) Contracts (cf. D4 [Ref 4], §6.2).
Data Recovery	ICAO Annex 13 [Ref 12] ICAO Doc 10054[3] [Ref 17] ISO 2700x [Ref 27]	Possible Annex 13 amendments (cf. D7 [Ref 7], §5.5.1) Possible Doc 10054[3] amendments (cf. D7 [Ref 7], §5.5.3)

Table 6: Summary of gaps identified in concept, solutions, applicable norms, standards, and legislations

At this stage of the study, there are still open points for which no conclusion was agreed upon, or information is yet lacking. These open points here below will require further investigation and/or maturing (cf. §10):

- Possible use of recovered data for routine monitoring (continuous transmission): QR-FRD data is different from FDM data and generally does not meet the needs of FDM program
- Location of the secure storage / under which organization's (recipient) responsibility (cf. D7 §5.4.2.4)
- Flight recorder data transmission scheme / triggered vs continuous or mixed triggered / continuous, bulk vs data type …
- Organization responsible of selecting the QR-FRD technology, in particular the data links and Communication Service Provider (CSP) / Datalink Service Provider (DSP): who bears the costs, OEM vs Operator… The OEM likely aiming for worldwide coverage solutions vs Operator likely aiming for coverage adapted to flights it operates
- Additional triggers definition (typically, "deviation from the planned path" and "flight crew incapacitation" to cover cases such as MH370 (cf. D4 [Ref 4], §6.3)
- Data protection and cyber-security: a risk analysis needs to be conducted once the end-to-end chain of actors is established and objectives are clear. In particular the advantages and

drawbacks of multiple storage locations need to be carefully assessed (cyber risk, judicial risk). That should help defining most suited/cost efficient solution(s) and deciding what data protection mechanisms are required on board the aircraft and at which level.

7.4 Legal aspects

The study of the legal aspects of QR-FRD has allowed to identify relevant regulations and the way in which they would need to be amended or completed to implement this new system.

Annex 13 of the ICAO Convention

Possible inconsistencies regarding the recovery of flight recorder data through systems that transmit data for storage off the aircraft have already been pointed out by ICAO's Accident Investigation Panel (AIGP) in May 2021. They were addressed during AIG/7 in May 2022 and will be reviewed by the Air Navigation Commission.

The Panel noticed that *"data transmission technologies create the potential for scenarios in which the flight recorder or flight recorder data may be held by one or more States not participating in the accident or incident investigation"* and that *"for aircraft equipped to transmit flight recorder data, this data will normally be transmitted to the air carrier through the communication service used by the carrier. In-flight transmission of flight recorder data will likely be involved satellites or/and multiple ground stations, with the received data transmitted and stored in a cloud environment. As a result, there may be full or partial electronical copies of the flight recorder data available in different States, including States not participating in the accident investigation"*.

To address those situations, the panel considers as relevant section 5.14 and 5.16 of ICAO Annex 13:

- 5.14 *"Any State shall, on request from the State conducting the investigation of an accident or an incident, provide that State with all relevant information available to it"*.
- 5.16 *"When an aircraft involved in an accident or a serious incident lands in a State other that the State of Occurrence, that State of Registry or the State of the Operator shall, on request from the State conducting the investigation, furnish the latter State with the flight recorder records and, if necessary, the associated flight recorders"*.

The Panel considers that rather than adding new protections, the modification of ICAO Annex 13 should give similar protection to transmitted flight recorder data. To do so, the Panel recommends the revision of the definition of flight recorders, so that it includes *"systems that transmit data for storage off the aircraft for the purpose of complementing accident/incident investigations"* and the creation of a new Standards that *"must ensure that any full or partial electronic copies of transmitted flight recorder data are provided to the State conducting the investigation without requiring a request"*.

Flight recorders would indeed be defined as *"any type of recording system installed in the aircraft for the purpose of complementing accident/incident investigations, including systems which transmit data for storage off the aircraft"*.

And a new section 5.14.2 would provide that *"If a State has availability to any data from a flight recorder of an aircraft involved in an accident or incident, that State, a) shall, without delay, provide that State conducting the investigation with all such data available to them; and b) shall not divulge such data without the express consent of the State conducting the investigation"*.

If those modifications are to be incorporated in ICAO Annex 13, this will lead to correlative modifications of the ICAO Doc. 9756, Manual of Aircraft Accident and Incident Investigation, as it deals with flight data recorders in its chapters 6 and 7.

Regulation EU 996/2010

At the European Union level, this regulation on the investigation and prevention of accidents and incidents in civil aviation incorporates most of the ICAO Annex 13 Standards and Recommendations.

Some of this Regulation's provisions may need to be revised to take into account the use of QR-FRD data:

- Article 6 on *"Cooperation between safety investigation authorities"* could be amended to specify that the State which has access to the data should provide without delay the data to the State conducting the investigation and should not divulge such data without the express consent of the State conducting the investigation.
- Article 8 on the *"Participation of EASA and national civil aviation authorities in safety investigations"* could include a provision specifying that the participants to a safety investigation (the safety investigations authorities, EASA, national civil aviation authorities of the Member States concerned) are entitled to access to QR-FRD data. It would complete provisions such as the possibility to *"receive copies of all pertinent documents*" (article 8(2)(c)) but should also include the limitation of article 8(2)(d) which entitles them *to "participate in the read-outs of recorded media, except cockpit voice or image recorders"*.

But it also appears that, contrary to ICAO Annex 13, some of Regulation 996/2010 provisions refer to "recordings" and not only to "recorders", which could allow to interpret them as already applying to QR-FRD data:

- Article 11 on the *"Status of safety investigators"* already deals with recordings and is not limited to recorders as it provides that the investigator-in-charge is entitled to*: "…(c) have immediate access to and control over the flight recorders, their contents and any other relevant recordings"*, a wording that seems sufficient to include QR-FRD recordings.
- Article 13 on *"Preservation of evidence"* also refers to recordings*: "any person involved shall take all necessary steps to preserve documents, material and recordings in relation to the event, in particular so as to prevent erasure of recordings of conversations and alarms after the flight"*.
- Article 14 (2) on *"Protection of sensitive information"* provides that *"flight data recordings shall not be made available or used for purposes other than those of the safety investigation (…)".*

Moreover, the definition of *"flight recorder"* in article 2(6) could be amended in a way similar to the AIGP's proposed amendments to ICAO Annex 13.

Data regulation

Finally, the study of the legal aspects of the QR-FRD has concluded that the essential data regulation to be considered for the QR-FRD system will be the EU General Data Protection Regulation (GDPR, Regulation EU 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data).

Indeed, the QR-FRD system allows the collection and transmission of personal data. The legal study revealed that implementing the GDPR, which aims to protect these data, will be unavoidable, even outside of Europe because:

- this regulation has an extraterritorial scope and may apply even when data is stored in a non-EU country (article 3 of the GDPR),
- the definition of personal data (article 4 of the GDPR) is so broad that purely technical data can be regarded as personal data if they allow, by crossing these data with others, to identify flight crew members and their actions.

The study therefore recommends that technical data should be afforded the same level of protection as that afforded to personal data by the GDPR (which is the highest existing legal standard in terms of data protection). This will ensure the data's authenticity and integrity during transmission and storage, as ICAO Annex 13 and European regulation 996/2010 will require.

It should also be noted that the GDPR relies on certification mechanisms set up by accredited certification bodies for the purpose of demonstrating the controller's and processor's compliance (articles 42 and 43). Our study has concluded that certification should be ensured through ISO Standards which are therefore considered in this study as part of the legal framework.

More specially, the study of the legal aspects of QR-FRD resulted in the following reminders and recommendations, listed by functional blocks:

FB1: Data Collection / Acquisition and Digitization

- **To ensure AIA's right of access to data** (versus potential data ownership claims by airlines): ownership claims over data already cannot prevent AIA's access and hinder the investigations. No specific amendment needed.
- **To process personal data**
    - Protection of personal data is a fundamental right although the rights of data subjects on their personal data can be limited in case of accident or serious incident
    - Technical data may be personal too if it allows to identify crew members' actions. For that reason, and because the GDPR provides for the highest existing level of data protection, the study recommends to apply GDPR data protection standards to all QR-FRD data
- **To ensure data protection and integrity**, the study recommends to:
    - Implement encryption techniques coupled with a digital signature in compliance with existing ICAO, GDPR and ISO standards
    - Define a key detention policy for airlines

***FB2: Trigger Detection* - Solution #2**

- **To define an efficient policy of trigger detection**, the study recommends to:
    - Harmonize the selection of events that will activate the transmission of data. This selection of events can be included in the ICAO Standards.
    - Triggers depend on aircraft type characteristics. The aircraft manufacturer should be responsible of setting them for each specific aircraft type

FB3: Data Transport

- **To ensure the availability of telecommunications networks**, the study recommends to:
    - Ensure the availability of dedicated aeronautical frequencies with the ITU
    - Ensure the capacity of the infrastructures: mobile and satellite networks
    - Possible use of the PIESD according to ICAO Manual 10054
- **To ensure data protection**, the study recommends to address cybersecurity risks through ISO certifications that ensure compliance with GDPR requirements
- **To ensure liability of service providers**: through contractual clauses and certification requirement

FB4: Off-Aircraft Storage

- **To permit data transmission to a data center not originally bound by the GDPR**:
  - The GDPR may still apply because of its extraterritorial scope
  - A case-by-case examination of the recipient State's data protection legislation will always be required to stipulate appropriate data protection clauses
- **To ensure data protection**, the study recommends to:
  - Ensure data centers' compliance with the GDPR through ISO 27000 certification and contractual clauses
  - Also, ensure protection of data storage infrastructures through ISO 22237-x certifications
  - Provide a data retention and deletion policy through ICAO standards and contractual clauses
- **To identify the most adequate data recipient:**
  - Possible conflict of interests for the existing actors in the field
  - The study recommends to consider a solution that would not rely on one of the actors in the field but on a third party or a dedicated central repository

FB6: Data Recovery

- **To determine the competent AIA**:
  - The QR-FRD does not challenge the fact that the investigation should be conducted by the State of occurrence AIA
  - The study recommends to complete ICAO standards to require the State of storage to transmit the data to the AIA of the State of occurrence
- **To prevent data withholding by the State of storage**, the study recommends to provide a rule requiring the data holder / data center to store at least one backup copy of the QR-FRD in a different State
- **To ensure timely and efficient transmission of data to the AIA**, the study recommends to:
  - Provide a procedure to quickly identify the data holder and the localization of the decryption key
  - Require the data holder to transmit encrypted data only to the competent AIA
  - Require that third parties legitimately interested in the flight data address their request to the competent AIA and not to the data holder
  - Complete ICAO Manual 10054 to recommend the implementation of efficient procedures
- **To regulate judicial authorities' access**, the study recommends to**:**
  - Review cooperation agreements between AIAs and judicial authorities
  - Strengthen the confidentiality of data in ICAO standards to address data request from foreign judicial authorities
  - Enable the data holder to quickly identify encrypted CVR and AIR data

8 SIMULATION LESSONS LEARNED

Two main activities have been conducted as part of Task 6 "Simulation of Technical Solutions". This aided in providing recommendations for the possible implementation of actual QR-FDR systems.

1. Modeling and Simulations:
    - Implementation of a model reflecting the technical solution, as proposed in D3 [Ref 3] and completed by D4 [Ref 4], with measurement points set at some several key components or interface of the model to generate metrics to be analyzed during the simulation
    - Simulations allowing the assessment of the overall QR-FRD system performance (in D6.1 [Ref 6]), as well as the evaluation of different technical solutions for its main components using interactive graphs based on real and anonymized accident and incident flights scenarios provided by the BEA
    - The model has been designed in such way it can be easily reused

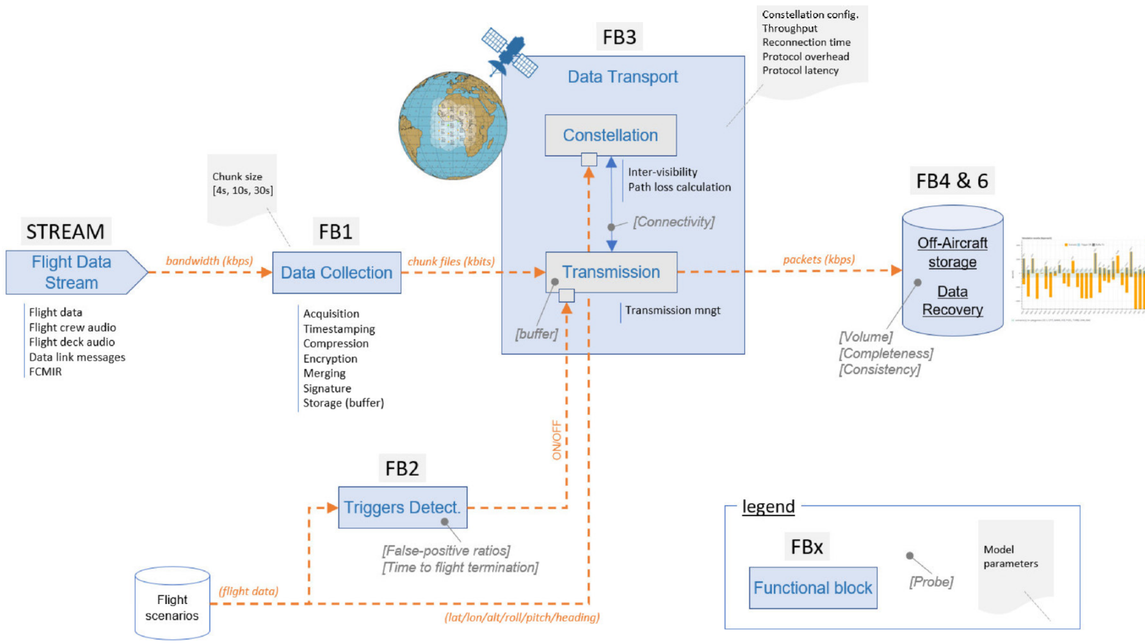

Figure 5: High-level architecture model referencing the QR-FRD functional blocks

2. Statistical analysis of the triggers:
    - A trigger evaluation took place, based on D3 [Ref 3], to evaluate the false-positive ratio and margins for the thresholds used in trigger condition detection

8.1 Model and simulation lessons learned

8.1.1 Results

The results summary below concerns the **triggered transmission** of flight recorder data. In streaming mode, the flight recorder data are transmitted continuously, and the transmission depends mainly on the aircraft attitude.

- Phases of flight
  - Climb and approach:
    - Accidents in such phases are sudden most of the time, and it's often too late to transmit data.
  - Cruise:
    - Trigger condition detection is often concurrent with the loss of datalink connection when related to extreme attitudes
    - The quantity of data sent depends on the throughput, nevertheless the minimum average throughput must be at least 50% greater than the flight recorder data input stream rate to allow sending historical data
- Possible other uses of QR-FRD
  - as a real-time detection of possible serious incident
  - to analyze the recorded flight data without delay when on ground (no need to get the FDR, CVR… from the aircraft)
  - as a redundant mean to get the data (in flight and on ground)

8.1.2 What went well

1. The duration of Task 6 was appropriate (10 months - Sept 2021 to June 2022), which allowed the model to be adjusted and matured in an iterative way
2. The accident and incident database (anonymized flight recorder data) provided by the BEA was essential to have relevant results
3. The evaluation of the input flight recorder data stream based on real samples allowed to verify the assumptions made in D3 [Ref 3] and to adjust the volume of data
4. The modularity of the model allowed to reduce the whole complexity by testing each functional block individually thus reinforcing the confidence in the results of the simulation of the global model
5. We relied on datalink system matter experts (SME) to model the intervisibility and connectivity algorithm that requires a very specific knowledge. Indeed, we have tried to calculate the path loss (loss or attenuation a propagating electromagnetic signal encounters along its path from transmitter to the receiver) but the lack of detailed information did not allow us to go in this direction. The SME suggested to us a simpler way to evaluate the satellite interconnection signal status based on distance and elevation of the satellite
6. We developed the model using Python language and we took advantage of exiting python libraries such as Pandas for data manipulation and Seaborn for data visualization

8.1.3 Main challenges and limitations identified

1. Recorded flight recorder data are data that airlines, OEM and other organizations don't share easily. Even if reports, statistics, or other articles based on recorded flight data are available, raw data are not accessible, whether it is IATA or even SAFRAN, our partner, which have strict Non-Disclosure Agreements (NDA) in place with their airline's customers
2. Only few satellites communication service providers responded to the survey (Task 2) despite numerous reminders. Thus, important input parameters for the model such as detailed roadmap or network architecture are missing resulting in limited technical information

3. We still have a dilemma about the flight recorder data transmission scheme in general. Based on AIA discussions, each accident is unique, and the flight starting point of the accident scenario can be found anywhere in the flight recorder data recordings over the time and in the type of data (flight data, audio, FCMIR…). It's hence a bet to select what type of data to send at a given time, and transmitting continuously is hardly affordable unless the data is used for something else than the QR-FRD purposes
4. Network IP simulation is based on QoS and protocol overhead. Indeed, this aspect requires means which are of a more consequential scale and cost
5. No clear-cut conclusion but recommendations provided (see §8.1.4)
6. The percentage of time this system could be relevant versus the costs of the system knowing that the starting point of the accident scenario can be anywhere has not been evaluated. We could not confirm that the safety benefits brought by a dedicated system overweigh its cost impact

8.1.4 How to improve

1. Introduce new settings of parameters such as:
   - Proportion of operating satellites of the selected constellation (random or regular interval)
   - Transmission period after the end of the scenario (to take into account factor 7 “Post-impact fire, when the crash does not completely destroy the aircraft” and factor 8 “Aircraft sinking into water, after ditching, which does not completely destroy the aircraft”, cf. D1 [Ref 1])
2. Improve the performance of the model. It takes few minutes to execute the 70 incident/accident scenarios provided by the BEA. Optimizing some portions of the code can be useful to run hundreds or thousands of scenarios
3. In case of spurious trigger condition detection or if the flight conditions are back to normal, then a stop transmission condition can be implemented to evaluate the savings on data volume
4. Fine tune the triggers
   - Conditions thresholds can be different according to the flight phase
   - New triggers can be added in the future
     - Significant flight plan deviation (vertical and/or horizontal)
     - Pilot incapacitation
5. Extend the simulation to cover more flights and various type of operations and aircraft types
6. Conduct representative end-to-end tests at file transfer level, using an actual satellite connection. To do so, a new connector can be added to the model to send the data through an IP connection using a specific file transfer protocol (we suggest http3). This could have an impact on the chunk size and could help to determine a good compromise

Points 1 to 5 can be addressed by updating the different functional blocks of the model presented in Figure 5

Point 4 requires a larger flight database to fine tune the trigger based on the methodology presented if D6.1 [Ref 6].

Point 6 is addressed in §8 through by the “Trial (T)” verification type.

8.2 Triggers analysis lessons learned

8.2.1 Context of the simulation

This simulation concerns the assessment of the trigger algorithm described in document D3 [Ref 3] using data collected during actual flights. Triggers have been applied on a subset of the SAFRAN "Cassiopée™" database to perform a false positive analysis, as well as to the identify triggers margins.

"Cassiopée™" is a SAFRAN E&D tool and service, originally used for FDM. To perform this service, it is associated with a large database of flight data records.

The "Cassiopée™" database does not include any flight with "serious incidents" or "accidents". During this assessment, when one algorithm as defined in D3 [Ref 3] is positive during one of these flights, it should trigger the transmission of the flight recorder data. Without any "accident" or "a serious incident" in this database, each triggered event can be considered a "false positive".

The total duration of the flights covered by this analysis is around 45,500 hours, representing 6,040 flights, involving a single aircraft type for a time period of 6 years (2016-2021). The average flight time is around 7.5 hours (the maximum flight duration is 12.5 hours). This aircraft type and type of flights were preferred to cover any situation where Flight Recorder Data transmission via wireless media will be the most efficient way to recover flight data in a timely manner in case of an accident.

However, this analysis is subject to some biases related to the type and region of operations, to the single type of aircraft used and to the limited number of flights when compared to the total worldwide passenger flights. The use of a much larger flight database covering a wide variety of flight operations around the world should help to better simulate triggers performance in real conditions.

Results of the simulation can be found in D6 [Ref 6], section 5.3 and annex D.

8.2.2 Lessons learnt

In accordance with BEA document [Ref 28], the analysis of the 44 fatal flights has provided an average of the time between BEA/Airbus triggers detection and the fatal end of the flight. D3 [Ref 3] concluded that this duration would be too limited to transfer all the data from the various recorders. The first "lessons learned" are:

- The need to improve these triggers to be more efficient as suggested in D1 [Ref 1],
- The "perfect triggers" does not exist, so the present study covers other events than catastrophic accidents.

For this update, several points were noted during the evaluation over a non-accident flight database:

- The triggers threshold should be adapted in accordance with the flight phase. For example, the attitude trigger threshold can be more restrictive during cruise phase versus climb or descend phases,
- The use of cockpit "master warning" as trigger condition has not proved to be relevant for the following reasons:
  - It does not simplify (and reduce) the number of different triggers,
  - It does not reduce the ratio of false detections.
- Some flight data where complex to analyze, due to the invalidity of the parameters. In case of computer failures, some parameters could become invalid. In that case, the result of the computer analyses has been confirmed/released manually. The invalidity of parameters should be considered for the definition of the triggers.

With this analysis, the rate of "false-positive" was evaluated for the "BEA/Airbus triggers algorithms", as described in D3 [Ref 3]. As defined these trigger conditions do not give enough time to transmit all flight recorders data and need to be modified. But such modified triggers will result in a larger number of “false-positive”.

The SAFRAN E&D analysis was performed with FDM data, and not on real FDR data. Today, on board aircraft, the usual practice is to provide two types of recordings: regulatory flight recorder (namely FDR frames) and maintenance / FDM recordings (namely DAR frames). The frequent confusion between the two recording types came from the fact that the format is the same (ARINC 717 or ARINC 767) and the name of the recorder unit is the same (QAR for Quick Access Recorder). Nevertheless, the recorded data have not the same quality level:

- The FDR frames are qualified and certified. It is part of the Type Certificate (TC). There is a guaranty of parameters validity. These frames are used has the first sources of analysis by AIAs
- The DAR frames are reprogrammable by the operators and are only qualified by usage. They are User Modifiable Software (UMS) configurable. DAR frames include the same type of parameters as the FDR ones (recorded at a different sampling rate), plus additional ones, dedicated to maintenance or FDM and programmed by the operators.

Even if the basic flight parameters should be identical, the guaranty of the data validity is not the same(for example, in SAFRAN analysis, the parameter “Cabin Altitude Pressure” - refer to D6 [Ref 6], annex D, section 11.3.12 - may be not valid in the analyzed recorder data).

This analysis has been conducted for only one aircraft type (A330-300) due to flight data availability. To provide better triggers condition, each aircraft type shall be considered independently. The characteristics of each aircraft type are different. Flight data transmission will be more relevant if the trigger conditions are adapted to each aircraft type.

The following actors should be involved in the trigger’s definition:

- The aircraft manufacturers, for there comprehensive knowledge of the aircraft
- The FDM engineers and/or Maintenance engineers, as data users, for their understanding of recorded flight data possibilities and limits
- The operators for their operational experience and their knowledge of safety scenarios

These definitions should be standardized at the appropriate level of details.

9 PROPOSED APPROACHES AND METHODS - MEANS TO DEMONSTRATE COMPLIANCE

Table 7 below summarizes the proposed approaches and methods for main open issues, whether technical, organizational, contractual and/or operational. It identifies the actors (users and assets) involved in assessing the performance and/or verification of the intended function / capability, and indicates possible means of verification, i.e., by analysis (A), simulation (S) and / or trials (T).

Item	Actors Involved	A/S/T
Comms: Coverage	• Data link solution • Infrastructure • CSP/DLP QoS • Contract with CSP/DLP	• A • A • A • A
Comms: Throughput	• Data link solution • Infrastructure • CSP/DLP QoS • Contract with CSP/DLP	• A/S/T • A/-/T • A • A
Comms: Availability	• Data link solution • Infrastructure • CSP/DLP QoS • Contract with CSP/DLP	• A/S/T • A/-/T • A • A
Comms: Continuity	• Data link solution • Infrastructure • CSP/DLP QoS • Contract with CSP/DLP	• A/S/T • A/-/T • A • A
Data: Protection (E2E)	• QR-FRD solution • CSP/DLP QoS • 3rd Party QoS (opt) • Contract with CSP/DLP • Contract with 3rd Party QoS (opt)	• A/-/T • A • A • A • A
Data: Storage	• 3rd Party QoS (opt) • Contract with 3rd Party QoS (opt)	• A • A
System maintenance	• Airline • CSP/DLP • 3rd Party (opt)	• A • A • A
System resilience to external factors	• EASA (New MOPS? New DO160 section?) • QR-FRD Manufacturer • Aircraft manufacturer (Installation, New MOPS?)	• A[6] • T • A/T
Norms compliance	• QR-FRD Manufacturer • OEM • CSP/DLP • 3rd Party (opt) • AIA • Airline	• A • A • A • A • A • A

[6] The expected « environmental qualification » level has to be defined. (ED 112 does not provide a correct level of crash robustness for this system).

Item	Actors Involved	A/S/T
Trigger	• Aircraft Manufacturer (Definition) • AIA • EASA • Aircraft Manufacturer (Simulator) • Aircraft Manufacturer (Flight Tests)	• A • A • A • T • T[7]

Table 7: Summary of means to demonstrate compliance

[7] With restriction, the assumption is: « It is possible to set the Aircraft in « Abnormal situation », with a sufficient safety margin for the aircraft and the test crow. »

10 CONCLUSION AND WAY FORWARD

This project showed it is technically feasible, within 2-5 years, to make flight recorder data available based on a wireless automatic data transmission in order to quickly recover such data after an accident over a remote land or oceanic area for investigation purposes. The geographic zone has been extended to coasts as many airports are located in those areas where the sea can quickly be deep or may include shallow but marshy areas.

The project allowed to converge towards existing solutions that set the technological and legal requirements and identify impacts and challenges to overcome. The volume of flight recorder data actually transmitted may be limited, depending on aircraft attitude and time to transmit before flight termination. Two technical solutions were analyzed, one using a continuous transmission mode and the other triggered transmission mode. The first allows reception of all flight recorder data at the expense of transmission costs and data management (GDPR). The second appears more cost efficient and relevant for the purpose of investigation but may not ensure transmission of sufficient data amount.

A hybrid transmission scheme mixing continuous and triggered transmission seems well adapted. Indeed, triggered mode can be used during the cruise phase as there is more time to transmit and streaming mode can be used during initial climb phase and approach phase when there is very little time to transmit.

Only LEO satellite constellations performances currently fit the QR-FRD transmission of the full set of flight recorder data requirements providing high throughput, low latency, negligible handover and offer a full globe coverage with incoming new ground station and inter-satellite communication capability. Moreover, satellite providers are already interested in the aeronautical domain and some experimentations are already conducted[8] [9] and aviation services will soon be launched[10].

From a legal standpoint, although the existing ICAO standards already provide for the possibility of transmitting flight data from the aircraft to the ground, the project showed the need to adapt certain provisions. In particular, Annexes 13 and 6 and corresponding manuals will need to be amended. At the level of European Union law, the Regulation 996/2010 will also have to be adapted.

Also, to ensure the protection of QR-FRD data, new provisions will have to be introduced in ICAO provisions for regulations. The project revealed the importance of ensuring the protection of all QR-FRD data, both personal and technical. For this purpose, ISO standards would be a good tool to ensure that the actors of the transmission chain guarantee the highest possible level of data protection. It is therefore recommended to introduce in ICAO regulations that all actors of the transmission chain should themselves be ISO certified and use only subcontractors that are also ISO certified. Other provisions are recommended such as the requirement for data centers to delete flight data after 60 days of retention in case they do not correspond to an accident or serious incident and the definition of a policy for decryption keys retention.

Finally, the legal study analyzed the risks for conflicts of interest linked to the handling of QR-FRD data and recommended that one or a few independent dedicated central repositories, be designated

[8] Starlink In-flight Connectivity Service Agreement Reached for Hawaiian Airlines Fleet | https://www.aviationtoday.com/2022/04/25/starlink-flight-connectivity-service-agreement-reached-hawaiian-airlines-fleet/

[9] U.S. Air Force Tests SpaceX's Starlink Internet Aboard F-35 Lightning II Aircraft | https://www.tesmanian.com/blogs/tesmanian-blog/starlink-x

[10] https://www.starlink.com/aviation

to receive the data prior to transmission to the competent AIA and that the decryption keys be kept by a different actor, for instance the airline.

On these different topics, the two stakeholder panel consultations were very informative and beneficial and allowed to highlight major concerns (i.e., costs, data protection, impacts on norms and standards and performance) as well as the level of acceptance of this system by the aeronautical actors.

From a technical standpoint, the transmission triggers (thresholds values) shall be fine-tuned, and new trigger conditions should be added as proposed in this study (e.g., pilot incapacitation and large flight plan deviation). The use of other possible communication means such as AEROMACS, L-DACS or 5G receivers (connection to ground and spec-based networks) should be considered.

Hardware and software avionic interfaces need to be updated to add audio and imagery data acquisition. Also, data streams prioritization should be addressed at on-board router level and at network level (e.g., use of URG TCP flag). Regarding the development of the system, the design assurance level of systems involved in flight recorder data transmission chain on the one hand, and required performance figures (e.g., availability, security level …) will have to be defined. In all cases, full-scale trials will remain necessary to characterize the network connectivity and assess the achieved performance.

Once the QR-FRD concept of operation is finalized, the question that will arise is who will bear the various costs for certification, installation, maintenance (including PKI management), transmission, and storage. The related information will have to be requested to DSP, OEM, other aerospace compagnies and data centers.

Regarding the legal issues that were identified, discussions should be initiated within ICAO with a view to introduce the necessary amendments to Annexes 6 and 13 and the corresponding manuals. Discussions should also be initiated within the European Union to amend Regulation 996/2010.

In this context, discussions will have to be made regarding the organization of the QR-FRD system, including designation of the data recipient and definition of a detention policy for data decryption keys.

Datalink systems are evolving fast: performance of satellite communications continues to increase (throughput up to 50 Mbps – latency down to 20 ms), new satellite provider competitors are coming[11] [12], multi-link routers are under development and seamless 5G[13] is in the pipe.

The emergence of artificial intelligence might facilitate the definition of more robust conditions to trigger the transmission of flight recorder data, for instance by analyzing larger data sets, crew conversations in natural language or video from cockpit cameras.

There will likely be side-benefits collateral effects of such a system, one of which being to avoid grounding a whole fleet of aircraft for a long period of time after an accident occurs as a precautionary measure.

[11] Telesat Lightspeed LEO Network | https://www.telesat.com/leo-satellites/https://www.telesat.com/leo-satellites/
[12] European Union to build its own satellite-internet constellation (IRISS) | https://www.space.com/european-union-satellite-internet-constellation-iriss
[13] Airlines in the EU will Soon Provide 5G Connectivity to Passengers | https://www.aviationtoday.com/2022/12/07/airlines-eu-will-soon-provide-5g-connectivity-passengers/
5G on planes, Wi-Fi on the road – Commission decision opens up new opportunities for innovation | https://digital-strategy.ec.europa.eu/en/news/5g-planes-wi-fi-road-commission-decision-opens-new-opportunities-innovation

Finally, the QR-FRD is a complementary or alternative solution to the automatic deployable flight recorder currently under development. All technological parts are already available, and no blocking point was identified. This system could be added in a first phase to the existing flight recorder systems, and then find its place by combining an actual recorder with the QR-FRD system.

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