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QUICK RECOVERY OF FLIGHT RECORDER DATA (wireless transmission)

Report D2

Overview of Technical Solutions for Automatic Wireless Transmission

An Agency of the European Union

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REPORT D2

Overview of technical solutions for automatic wireless transmission

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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 24]).

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

The aircraft considered for the study are modern commercial air transport aircraft with a maximum take-off mass of over 27 tons, equipped with redundant combined flight data recorder (FDR) -cockpit voice recorder (CVR) capable of recording flight data, flight crew and flight deck audio, data link messages as well as, depending on the type certificate, flight crew – machine interface recordings (ICAO Annex 6 Part I, Section 6.3, [Ref 1]), and mandated to have a Flight Recorder Data Recovery (FRDR) means on-board.

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

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

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

1. **Task 1 - Accident conditions relevant for wireless flight recorder data transmission:**
   - **Objective**: Identify and describe the technical and environmental factors which might affect the aircraft, its engines and its systems during the accident flight, and which need to be taken into account for maximizing the chances of successful wireless transmission of flight recorder data.
   - **Outcome**: A report (D1) of accident conditions which might affect the successful wireless transmission of flight recorder data (e.g. loss of power or equipment, excessive roll or pitch angles, in-flight fire, ditching …), and explaining the impact of such factors.
2. **Task 2 - Overview of technical solutions for automatic wireless transmission of flight recorder data:**
   - **Objective**: perform a screening of possible technical solutions for automatic wireless transmission of flight recorder data (flight data, audio and flight-crew interface recordings, data link messages…) in case of an accident (or serious incident) in a remote land area or an oceanic area.
   - **Outcome**: A solution overview report (D2) identifying the necessary technologies and capabilities of the communication infrastructure, as well as aspects not yet mature, and

discussing the potential effects of factors listed in D1 on the presented solutions. In addition, D2 will recommend the 2 most relevant technical solutions for further investigation to be performed under Task 3.

3. **Task 3 - Technical investigation of two technical solutions for automatic wireless transmission of flight recorder data:**
   - **Objective**: perform a technical investigation of the two most relevant technical solutions as identified in Task 2 and assess their performances for the automatic and wireless transmission of the data required to be recorded and retained by crash-protected flight recorders.
   - **Outcome**: A study report (D3) presenting technical solutions and detailing the two selected technical solutions (concept of operation, data transmission trigger logic (e.g. continuous or triggered), airborne functions and equipment, performance, communication infrastructure…).
4. **Task 4 – Assess challenges and limitations of two technical solutions:**
   - **Objective**: Assess the challenges and limitations of both technical solutions presented in Task 3 and comparison of their expected performance.
   - **Outcome**: An evaluation report (D4) of challenges and limitations addressing main technological enablers and their respective levels of maturity, reliability of main functions, impacts on flight crew procedures, ground handling and maintenance, as well as airline operations…
5. **Task 5 – First consultation of the stakeholder's group:**
   - **Objective**: Obtain the feedback of a group of stakeholders (accident investigation authorities, aviation regulators, operators of large commercial aircraft, associations of commercial pilots) on works performed under Tasks 1 to 4, with a view to incorporate this feedback into the analyses and assessments and to update the corresponding reports.
   - **Outcome**: A stakeholder feedback report (D5) containing the composition of the group of stakeholders, comments and questions raised by the stakeholders and replies as well as changes made to the different reports (D1 to D4).
6. **Task 6 – Simulation of technical solutions:**
   - **Objective**: Prepare an experimental set-up for the performance assessment of the two solutions investigated in Task 3, in particular for the comparison of the respective transmitted dataset (volume, accuracy, completeness, consistency) including reliability and robustness to factors identified in Task 1.
   - **Outcome**: A simulation report (D6) containing the detailed description of the performed simulations, as well as graphics showing the variation in performance when parameters (pitch and roll angles/rates, altitude, location of the aircraft…) are varied.
7. **Task 7 - Scenario-based study of legal aspects:**
   - **Objective**: Assess the legal aspects of data transmission over assets located on the territories of several countries or in space, in order to identify possible inconsistencies with ICAO Annex 13, legal uncertainties and risks for the protection of flight recorder data.
   - **Outcome**: A legal study report (D7) describing the legal framework applicable to the various assets of the communication infrastructure by which data will be transmitted or processed or recorded, scenarios of accidents in various places and with various setups, the potential issues for the protection and the transmission of data to the competent safety investigation authority, as well as proposals to ensure that the transmission service provider and the recipient of the flight recorder data are legally responsible for the preservation and the protection of transmitted flight recorder data.
8. **Task 8 – Second consultation of the stakeholder's group and additional simulation work:**

- **Objective**: Obtain the assessment of a group of stakeholders on the report resulting from Tasks 6 and 7, with a view to incorporate this feedback, to run where necessary complementary simulations and to update the simulation report.
- **Outcome**: A stakeholder feedback report (D8) containing the composition of the group of stakeholders, comments and questions raised by the stakeholders and replies as well as changes made to the different reports (D6 and D7), and possibly simulations and code.

9. **Task 9 – Conclusions and way forward:**
    - **Objective**: Conclude on the concept of automatic wireless transmission of flight recorder data in case of an accident and propose a way forward.
    - **Outcome**: A final report (D9) containing a general reflection on the works performed during the project, the feedback and recommendations received during the stakeholder meetings, the aspects of the concept of automatic wireless transmission of flight recorder data remaining to be explored or showing very challenging issues, a proposed approach for the development of compliance means and material in order to facilitate the performance demonstration to competent authorities, as well as practical recommendations to progress the maturity of this concept and prepare their implementation.

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

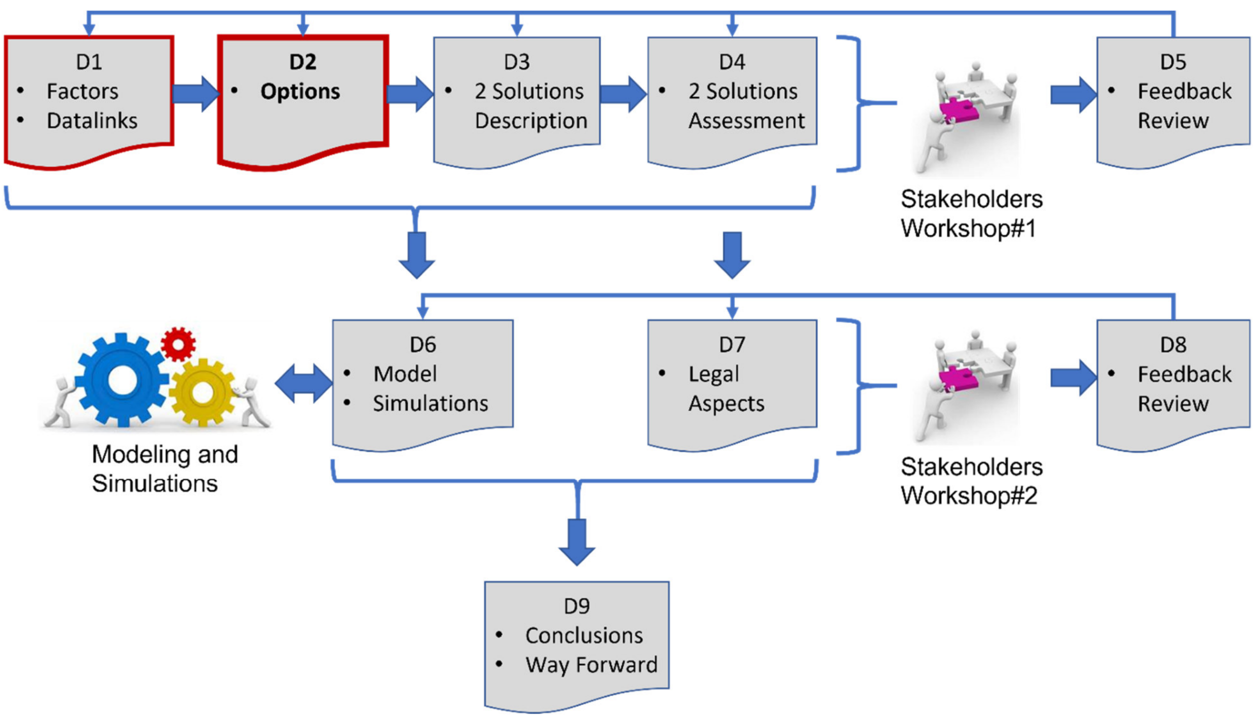

Figure 1: QR-FRD Study Approach and Deliverables Relationship

1.2 Scope of This Report

The present document corresponds to D2 as depicted Figure 1. It summarizes analysis and findings from Task 2 "Overview of technical solutions for automatic wireless transmission of flight recorder data" of the QR-FRD study.

It aims at discussing options for the wireless transmission of flight recorder data based on functional blocks defined in ARINC Project Paper 681 ([Ref 13]). These functional blocks indeed address the different stages of an end-to-end solution, starting with the collection of data to be recorded onboard the aircraft and ending with the recovery of these data by the investigation authorities.

Options discussed at high level within this document include:

- Streaming and triggered transmissions
- Prioritization schemes
- Transmission technologies and strategies
- Location of repositories on the ground and access to the data

Together with the findings from Task 1 “Accident conditions relevant for wireless flight recorder data transmission” summarized in D1 [Ref 14], an assessment of possible solutions ranked after establishment of criteria or requirements to be met is documented. This ranking will allow the selection of the two most promising solutions that will be analyzed more deeply within Task 3 “Technical investigation of two technical solutions for automatic wireless transmission of flight recorder data” and subsequent activities.

This document also presents the form used for a survey of data link service providers, as well as the results from that survey that were made available for the study.

1.3 Organization of the Document

This document is part of Task 2 “Overview of technical solutions for automatic wireless transmission of flight recorder data” 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, “HIGH-LEVEL TECHNICAL DISCUSSIONS”, is composed of two parts discussing several technical topics at high level.

The first part, “Assumptions”, describes the assumptions and dimensioning factors for the study among which:

- Aircraft generation on which QR-FRD solutions could be installed
- Aircraft equipage for these aircraft in terms of flight recorders and communication systems
- Flight crew composition as it may influence audio recording solutions and is likely to evolve over time
- Accident taxonomy identifying most relevant accident types for the study
-
- Flight recorder data transmission schemes and possible trigger events
- Flight recorder data transmission criticality non foreseen as safety-critical but rather subject to privacy, integrity and authenticity
- Stakeholders and participants identified as having an active role related to QR-FRD functions

The second part, “High Level Constraints”, describes the constraining factors for the study among which:

- Data types, amounts and priorities depending on the flight recorders and data they provide for the benefit of investigators. These factors will later be used to assess the required performance of the QR-FRD data collection and data transmission functions
- Data compression that should be considered carefully as it may impact the overall performance of the system
- Data protection that should also be considered carefully as it may impact the not only the overall performance of the system but also the overall concept of operations
- Datalink service requirements that will be used to select the most promising solutions, or highlight limitations for the QR-FRD solutions

Chapter 5, "POTENTIAL SOLUTIONS", is composed of three parts discussing different system architectures and options to be considered and evaluated in order to finally select the most promising ones.

The first part, "Baseline Functional Architectures", describes fielded solutions based on a set of predefined functional blocks that will be used throughout the document. The fielded solutions described include flight recorders, flight operations and maintenance applications, and aircraft tracking - abnormal operations applications. These solutions provided as illustration are indeed relevant to QR-FRD since they are either closely related to ICAO's Global Aeronautical Distress and Safety System (GADSS) concepts of operations [Ref 6] (i.e. flight recorders and aircraft tracking - abnormal operations applications), or very similar in their functional architecture (i.e. flight operations and maintenance applications).

The second part, "Proposed Solutions and Options", discusses different options with advantages and drawbacks for the different predefined functional blocks for QR-FRD solutions, i.e. Data Collection, Start Condition Detection, Data Transport, Off-Aircraft Storage and Data Recovery. Topics such as impact on existing installation, design considerations, feasibility, impact on performance or operations as well as limitations are addressed.

The third part, "Candidate Solutions", discusses impact to flight crew workload and to existing architectures, based on a rough assessment of the options defined in the previous part. It then establishes criteria for the assessment of the different options before scoring the options in an applicability matrix. That matrix summarizes the ranking of the different alternatives and provides rationales for the adopted scoring.

Chapter 6, "SOLUTIONS ASSESSMENT", discusses the two most promising solutions selected by the scoring and rankings performed in the previous section. These solutions, "AISD-based" and "FDAU/FDIU&ACMS-based", will be detailed and modeled in further activities of the QR-FRD study.

The "AISD-based" solution is articulated around an AISD router that will perform a major part of the data processing and part of the transmission. The "FDAU/FDIU&ACMS-based" solution is articulated around FDAU/FDIU&ACMS units that will perform the major part of the data processing and rely on datalink systems (incl. AISD) for the transmission

ANNEX A: DATA LINK SERVICE PROVIDER SURVEY FORM, provides the form used for a survey of datalink service providers as well as a summary of the information collected from that survey.

ANNEX B: DATA LINK SERVICE PROVIDER SURVEY FORM, provides a summary of the information collected from that survey.

2 REFERENCE DOCUMENTS

[Ref 1] [R01] ICAO Annex 6 Operation of Aircraft Part I, International Commercial Air Transport - Aeroplanes, 2018
[Ref 2] [R03] ICAO Doc 10054-1, Manual on Location of Aircraft in Distress and Flight Recorder Data Recovery, 2019
[Ref 3] ICAO Annex 10 Aeronautical Communications Volume II Communication Procedures including those with PANS status, July 2016
[Ref 4] ICAO Annex 13 Aircraft Accident and Incident Investigation, July 2020
[Ref 5] ICAO Circular 347 Aircraft Tracking Implementation Guidelines, 2017
[Ref 6] [R10] ICAO Global Aeronautical Distress & Safety System (GADSS), Concept of Operations V06 June 2017
[Ref 7] ICAO Location of an Aircraft in Distress Repository (LADR) Functional Specification, August 2019
[Ref 8] EUROCAE ED-93, Minimum Aviation System Performance Specification for CNS/ATM Message Recording, July 1998
[Ref 9] EUROCAE ED-111, Functional Specifications for CNS/ATM Recording, July 2002 (incl. Amendment 1, July 2003)
[Ref 10] [R04] EUROCAE ED-112A, Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems, 2013
[Ref 11] EUROCAE ED-202A, Airworthiness Security Process Specification, June 2014
[Ref 12] [R05] EUROCAE ED-237, Minimum Aviation System Performance Specification for Criteria to Detect In-flight Aircraft Distress Events to Trigger Transmission of Flight Information, 2016
[Ref 13] [R09a] ARINC PROJECT PAPER 681 TIMELY RECOVERY OF FLIGHT DATA (TRFD), Draft 5, 2021
[Ref 14] QR-FRD Study D1: “Accident conditions relevant for wireless flight recorder data transmission”, June 2021
[Ref 15] North Atlantic Data Link Mandate (NATDLM), ICAO, February 2021
[Ref 16] FAA AC 20-160A, Onboard Recording of Controller Pilot Data Link Communication (CPDLC) In Crash Survivable Memory, Sept. 2016
[Ref 17] FAA AC 90-117, Data Link Communications, Oct. 2017
[Ref 18] EASA ETSO-2C123c, Cockpit Voice Recorder Systems, 2020
[Ref 19] EASA ETSO-2C124c, Flight Data Recorder Systems, 2020
[Ref 20] EASA ETSO-2C176a, Aircraft Cockpit Image Recorder Systems
[Ref 21] EASA ETSO-2C177a, Data Link Recorder Systems
[Ref 22] EASA Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex IV Commercial air transport operations [Part CAT], Mar. 2019
[Ref 23] Regulation (EU) 996/2010 Investigation and prevention of accidents in civil aviation, Nov. 2010
[Ref 24] [R00] EN-EASA.2020.HPV.06, Quick Recovery of Flight Recorder Data Call for Tender

Other applicable documents:

ARINC 620-10, Datalink Ground System Standard and Interface Specification (DGSS/IS), July 2020
ARINC-717-15, Flight Data Acquisition and Recording System, June 2011
ARINC-767-1, Enhanced Airborne Flight Recorder, May 2009
ICAO Annex 11 – Air Traffic Services, 2018

3 DEFINITIONS AND ACRONYMS

Term	Definition
Aircraft	Equivalent to "*Aeroplane*" in the context of this study, and defined as "*A power-driven heavier-than-air, deriving its lift in flight chiefly from aerodynamic reactions on surfaces which remain fixed under given conditions of flight.*" ICAO Annex 6, Part I [Ref 1]
Controlled Flight Into Terrain (CFIT)	Inflight collision or near collision with terrain, water, or obstacle without indication of loss of control
Chunk	Portion of a bulk of data, of a file, etc. to be processed (e.g. compressed and/or encrypted) and/or transmitted.
Flight recorder	"*Any type of recorder installed in the aircraft for the purpose of complementing accident/incident investigation.*" ICAO Annex 6, Part I [Ref 1]. Flight recorders addressed in the present document include: • Flight data recorders • Cockpit voice recorders • Data link recorders • Flight crew-machine interface recorders
Flight recorder data	Any type of data recorded by the flight recorders that would be used for the purpose of complementing accident/incident investigation. Flight recorder data may include: • Mandatory and optional flight parameters recorded by flight data recorders • Audio recordings between the flight crew members and any other station • Audio recordings of the acoustic environment of the cockpit • Messages and information exchanged over data link • Imagery from displays inside the cockpit and interactions of flight crew members with instruments and displays
Historical flight recorder data	Flight recorder data that has been stored prior to the trigger condition for possible transmission.
Loss of control – in flight (LOC-I)	Loss of aircraft control or deviation from intended flight path while in flight. It is an extreme manifestation of a deviation from the intended flight path, in which the pilot has temporarily, or completely, lost the ability to maintain control of the aircraft in flight. …
Midair Collision (MAC)	Collision between aircraft in flight.
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
ACARS	Aircraft Communication Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACD	Aircraft Control Domain
ACMS	Aircraft Condition Monitoring System
ADS-C	Automatic Dependent Surveillance - Contract
ADPCM	Adaptive Differential Pulse-Code Modulation
ADT	Autonomous Distress Tracking
AeroMACS	Aeronautical Mobile Airport Communication System
AES	Advanced Encryption Standard

Acronym	Definition
AIA	Accident Investigation Authority
AIR	Airborne Image Recorder
AISD	Airline Information Services Domain
aka	Also Known As
AOC	Airline Operations Center
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATN/IPS	ATN over IPS
ATN/OSI	ATN over OSI
BRLOS	Beyond Radio Line Of Sight
CAST	Commercial Aviation Safety Team
CCITT	CAST/ICAO Common Taxonomy Team
CFIT	Controlled Flight Into Terrain
CMU	Communication Management Units
CONOPS	Concept of Operations
CPA	Closest Point of Approach
CPDLC	Controller-Pilot Data Link Communications
CSP	Communication Service Provider
CVR	Cockpit Voice Recorder
DAL	Design Assurance Level
DAR	Digital ACMS Recorder
DLR	Data Link Recorder
DSP	Datalink Service Provider
ELT	Emergency Locator Transmitter
ESASI	European Society of Air Safety Investigators
EST	Enrollment over Secure Transport
FADEC	Full Authority Digital Engine Control
FCMIR	Flight Crew-Machine Interface Recorder
FDAU	Flight Data Acquisition Units
FDIU	Flight Data Interface Unit
FDIMU	Flight Data Interface and Management Unit
FDR	Flight Data Recorder
FF-ICE	Flight & Flow Information for a Collaborative Environment
FMS	Flight Management System
FOQA	Flight Operations Quality Assurance
GADSS	Global Aeronautical Distress and Safety System
GANP	Global Air Navigation Plan
GPWS	Ground Proximity Warning System
HAP	High Altitude Platform
HD	High Definition
HF	High Frequency
HFDL	HF Data Link
ICAO	International Civil Aviation Organization
IFE	In Flight Entertainment
IFEC	In Flight Entertainment & Connectivity
IOC	Input / Output Concentrator
IP	Internet Protocol
IPS	Internet Protocol Suite
ISASI	International Society of Air Safety Investigators
LADR	Location of an Aircraft in Distress Repository
LDACS	L-band Digital Aeronautical Communication System

Acronym	Definition
LDACS A/G	LDACS Air-Ground
LDACS A2A	LDACS Air-to-Air
LOC-I	Loss of Control – In flight
LTE	Long Term Evolution (aka 4G LTE)
LZMA2	Lempel-Ziv-Markov chain Algorithm, version 2
MAC	Mid Air Collision
NA	Not Applicable
NM	Nautical Mile
NTSC	National Television System Committee
OEM	Original Equipment Manufacturer
OFDM	Operational Flight Data Monitoring
OSI	Open System Interconnection
PIESD	Passenger Information and Entertainment Services Domain
QAR	Quick Access Recorders
RF	Radio Frequency
ROV	Remotely Operated underwater Vehicle
SATCOM	Satellite Communications
SPO	Single Pilot Operations
SWIM	System Wide Information Management
TAWS	Terrain Avoidance Warning Systems
TBD	To Be Determined
TFD	Transmission of Flight Data
TRFD	Timely Recovery Of Flight Data
UTC	Universal Time Coordinated
VCR	Video Cassette Recorder
VDL2	VHF Data Link Mode 2
VHF	Very High Frequency
VPN	Virtual Private Network

Table 2: Acronyms

4 HIGH-LEVEL TECHNICAL DISCUSSIONS

4.1 Assumptions

4.1.1 Aircraft Generation

It is anticipated QR-FRD solutions based on wireless transmissions will equip modern aircraft fitted with next generation avionics and communication means, the latter including secure and high speed data links.

Nevertheless, retrofit of current generation (legacy) aircraft may be considered, unless performance requirements are such that they are unlikely to be met, or cost for retrofitting appear to be unaffordable by the airlines.

4.1.2 Aircraft Equipage

Aircraft with a maximum take-off mass of over 27,000 kg shall be equipped with one or more of the following recorders: a flight data recorder (FDR), a cockpit voice recorder (CVR), and shall be able to record data link communications messages as well as, depending on the type certificate, flight crew-machine interface and interactions on a crash-protected flight recorder. (ref. ICAO Annex 6 Part I, Section 6.3 [Ref 1]).

The new aircraft mandated to have a flight recorder data recovery means on board will be equipped with redundant combined FDR-CVR, one at the front, the other at the rear of the aircraft (ref. ICAO Annex 6 Part I, Section 6.3 [Ref 1]). It will hence be unlikely flight recorder data cannot be recovered from at least one combined FDR-CVR in case of an accident occurring over land.

Also, 6.3.5.1 states that "*All aeroplanes of a MCTOM of over 27,000 kg and authorized to carry more than 19 pax for which the application for TC is submitted to a Contracting State on or after 1 January 2021, shall be equipped with a means approved by the State of the Operator, to recover flight recorder data and make it available in a timely manner*." This statement leads to solutions such as automatic deployable flight recorders (ADFR) as well as transmission of flight recorder data, this latter being the focus of the QR-FRD study.

Concerning communication systems, mandates such as the North Atlantic Data Link Mandate ([Ref 15]) require (though with some exceptions) aircraft flying between FL290 and FL410 to be equipped with Controller-Pilot Data Link Communications (CPDLC) and Automatic Dependent Surveillance - Contract (ADS-C) solutions based on FANS 1/A options. This means aircraft are equipped with VHF Data Link (Mode A or Mode 2) and SATCOM (Iridium or Inmarsat), as well as data link recorders. In order to increase availability of the beyond radio line of sight communications (i.e. SATCOM), airlines often also equip their aircraft with HF Data Link (HFDL) solutions. HFDL is indeed considered a backup datalink solution to SATCOM since it is part of the Aeronautical Telecommunication Network (ATN) sub-networks for Aircraft Communication Addressing and Reporting System (ACARS) and Airline Operations Center (AOC) communications, transmission costs are cheaper than those of SATCOM, and [worldwide] coverage slightly larger than that of SATCOM which is currently limited to 80° north and south of the Equator (cf. D1 [Ref 14]). Dual SATCOM solutions (e.g. Iridium plus Inmarsat) are not common yet.

4.1.3 Flight Crew Composition

Considering the time horizon of the study (5 years from now), it can be assumed a 2-pilot crew will still[1] be flying the aircraft and communicating verbally with air traffic controllers, aircraft occupants and other

[1] Single Pilot Operations (SPO) and Trajectory-based Operations (TBO) as well as Remotely Piloted Aircraft Systems (RPAS) would slightly reduce voice communications with the use of high level of automations and extensive use of data link communications

stations. As a result, a minimum of 4 CVR separate channels would be required (ref ICAO Annex 6 Part I, Appendix 8 [Ref 1]) for captain, first officer, cockpit area and passenger address system microphones.

4.1.4 Accident Taxonomy

Figure 2 below depicts the occurrence of accidents categorized per CAST/ICAO Common Taxonomy Team (CICTT) over the 2010-2019 period for commercial air transport aircraft (source https://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf).

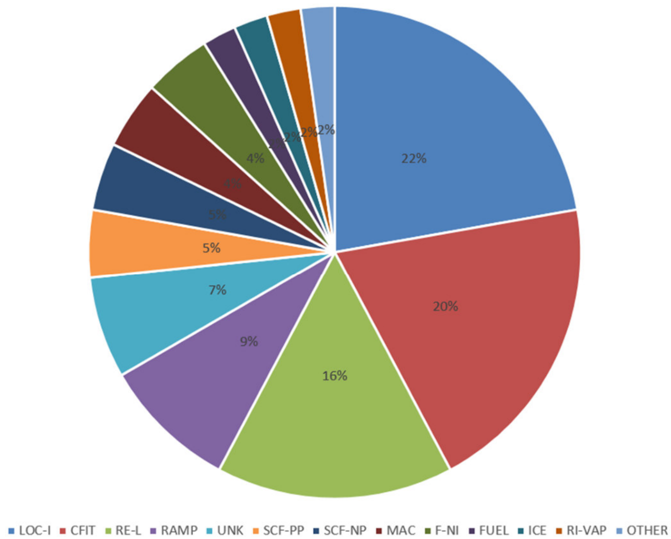

Figure 2: Accident occurrence per category 2010-2019

As can be seen, in a total of 45 accidents catalogued over the period, 22% of the accidents (10 cases) result from loss of control in flight (LOC-I) and 20% (9 cases) result from controlled flight into terrain (CFIT). Midair collision (MAC) represented only 4% with 2 cases over the period. Other cases such as fuel (FUEL), or icing (ICE) are very seldom (2 % each).

Note: LOC-I, CFIT, and MAC would clearly be in the scope of the study when considering triggered transmission of flight recorder data over remote or oceanic regions. All may nevertheless be considered for flight recorder data streaming that will address all phases of flight, or triggered transmission over land or continental regions.

Figures from literature and databases show that recovery of crash-protected recorders may take time (couple of days to several months), hence be expensive, even when the crash/ditching site is known. Also, there are cases for which one or both crash-protected recorders were difficult to recover or never recovered though the accident occurred a few miles from the coast. Sea floor depth, underwater visibility and weather conditions, for instance, are factors influencing the search and recovery of the crash-protected recorders.

The QR-FRD solutions would help in those cases for which recovery of the crash-protected recorders are delayed or eventually not achieved, both for the safety aspects (new aircraft lost a few years after their entry in service) and the public perception aspects. Early conclusions on the accidents may limit fleet grounding as well.

(typically controller-pilot datalink communications (CPDLC)). These operations are not foreseen to be largely deployed within the timeframe considered by the QR-FRD study.

4.1.5 Flight Recorder Data Transmission

ICAO Doc 10054-1 [Ref 2] addresses flight recorder data transmission as a means to recover flight recorder data in a timely manner, and considers continuous transmission starting automatically as soon as fixed flight recorders start recording as well as triggered transmission starting automatically, at minimum as soon as[2] a distress event is detected. Each of the two transmission schemes have pros and cons that are discussed in §5.2.2.4 and §5.2.2.5 respectively.

As recommended by Doc 10054-1, if triggered transmission is used, the activation logic (trigger) "*should be designed so as to ensure successful transmission as early as possible in the accident or incident sequence*". Indeed, as discussed in D1 [Ref 14], the duration of a distress phase statistically lasts only a couple of minutes[3] limiting time for transmitting historical flight recorder data. Also, flight conditions during this critical phase (e.g. excessive attitude angles and variation rates) may make transmissions difficult (e.g. data link communications disconnection due to antenna pointing performance).

ED-237 [Ref 12] can be used as a guidance to define triggers and customize them for each aircraft type. Nevertheless, these being limited to the detection of in-flight distress events, Doc 10054-1 recommends to also consider additional events beyond those described in ED-237 to ensure that an adequate amount of flight recorder data are transmitted. As a result, a preliminary list of events to be considered as flight recorder data transmission triggers would be the following:

- Unusual attitude and variation rates
- Unusual speed
- Flight conditions that could lead to collision with the surface
- Total loss of thrust/propulsion on all engines
- Cabin depressurization
- Fire on board the aircraft
- Aircraft component failure or malfunction
- Shortage of fuel (starvation or exhaustion)
- Flight situation that could lead to collision with other traffic or penetration of adverse weather
- Significant deviation from the operational flight path

The set of events and the trigger logic will be further analyzed and documented in Task 3 of the QR-FRD study.

4.1.6 Flight Recorder Data Transmission Criticality

Information and its transmission are non-safety critical. This should facilitate the design of the solutions, as well as their implementation, and limit acquisition and installation costs. Non-safety critical avionics including computers and communications means (e.g. in-flight entertainment communication suites) can be considered as part of the end-to-end solution, provided they comply with the required performance.

Note: Flight recorders are designed to comply with a design assurance level (DAL) D, the failure classification (i.e. minor failure condition) being driven by the use of flight data recorders in accident investigations (ref. ETSO-2C123c [Ref 18], ETSO-2C124c [Ref 19], ETSO-2C176a [Ref 20], and

[2] No later than five seconds.

[3] Cf. D1 [Ref 14]: when considering loss of aircraft after distress in cruise, only 27% of the cases last more than 3 minutes, 50% more than 2 minutes, 64% more than 1 minute. Conditions permitting the airframe to float upwards for instance would provide extra bonus time for transmission before it sinks should transmissions still be possible (power and equipment available…). Aircraft are designed to float a minimum of 90 seconds to allow passenger evacuation after ditching. An aircraft can float a couple of minutes depending on damages and sea conditions. It shall be noted that solutions based on automatic deployable flight recorders are considered to take over in this specific case by facilitating the physical recovery of the recorders and their data.

ETSO-2C177a [Ref 21]). Such DAL should be an objective for the QR-FRD overall solution, and likely a requirement should it ultimately become a replacement to flight recorders.

The main issues to address with the transmission of flight recorder data (on top of the available throughput out of the aircraft) will be:

- Privacy: guarantee that no unauthorized people/application… have access to the flight recorder data at any stage of the process, from data acquisition to their recovery by investigation authorities and airline operators
- Integrity: guarantee that no or no noticeable/perceptible modification is introduced by the process when comparing the data recovered and made available to the investigators and, the original data having been recorded onboard the aircraft
- Authenticity: guarantee that the data recovered were actually transmitted by the distressed aircraft
- Availability: guarantee that the system and data can be accessed by authenticated users when needed

Note: The level of protection of flight data or data link messages may not be the same as for audio data or images because these latter have a privacy content (ref. Part-CAT [Ref 22], CAT.GEN.MPA.195, point (f)).

4.1.7 Stakeholders and Participants

Several organizations transmit, collect and/or analyze routinely aircraft originating data, many of which are part of flight recorder data. These organizations basically include the airline (flight operations, maintenance, operations control center), the aircraft manufacturer, the communication service provider (CSP, aka datalink service provider (DSP)) (ref. AC 90-117 [Ref 16]), and air traffic services (ref. ICAO Annex 10 Vol. II [Ref 3]).

Nevertheless, flight recorder data belong to the airline and special agreements are often set in place for other organizations (typically the aircraft manufacturer) to use these for their own purpose (typically flight data monitoring programs and preventive maintenance) and share the cost of their transmission.

Accident Investigation Authorities (AIA) are entitled to collect flight recorder data in the framework of an official accident or incident investigation (ref. ICAO Annex 13 [Ref 4] and Regulation (EU) 996/2010 [Ref 23]). They may be supported in the analysis of the recovered data by personnel from the airline as well as from the aircraft manufacturer.

4.2 Constraints

4.2.1 Data Types, Amounts and Priorities

ED-112A [Ref 10] defines minimum performance specifications for the different types of airborne recorders, i.e. flight data recorders (FDR), cockpit voice recorders (CVR), airborne image recorders (AIR) and data link recorders (DLR), and define the contents of the recordings:

- Flight data recorders basically record at least essential parameters that reflect the state and performance of an aircraft. These parameters typically include altitude, speed, attitude, engine power, flight control surfaces and systems configuration and operation. The specific parameters nevertheless depend upon aircraft complexity and data sources available.
- Cockpit voice recorders basically record voice communications between flight crew members as well as between the flight crew and any other station, and the acoustic environment of the cockpit.
- Airborne image recorders basically record images depicting the ambient conditions in the cockpit, as well as flight crew activity and interactions with instruments and control panels.

- Data link recorders basically record messages relayed over data link rather than by voice communications authorizing, directing or controlling the flight path of the aircraft (typically, controller-pilot data link communications (CPDLC)). Recordings also include, besides data link initiation capabilities, surveillance related data, typically the aircraft position transmitted over automatic dependent surveillance - contract (ADS-C), as well as messages provided by flight information services (FIS).

Note: At the time of the drafting of the present document, EUROCAE WG-118 (Crash Protected and Lightweight Flight Recorders) SG-2 is working on next ED-112B revision to include flight crew-machine interface recorder (FCMIR), which are slightly different from AIR. FCMIR "*record the information displayed to the flight crew from electronic displays, as well as the operation of switches and selectors by the flight crew*" (ICAO Annex 6 Part I [Ref 1]).

The data set to recover should include as a minimum "*flight recorder data from the time the aircraft enters the distress conditions to the end of the flight*" (ref. ICAO Doc 10054-1 [Ref 2]), or to the time the aircraft leaves the distress conditions. To the extent possible, the data set should also include "*historical data prior to the time the flight enters distress conditions, with the most recent data being given the highest priority*." (ref. ICAO Doc 10054-1 [Ref 2]). The objective being to recover the "*complete contents of flight recorder data, as defined in Annex 6, Part 1, Section 6.3, in a timely manner*." (ref. ICAO Doc 10054-1 [Ref 2]), hence:

- The complete set of required flight parameters recorded by the FDR during up to the last 25 hours of operation. Mandatory FDR parameters to be transmitted are listed in ICAO Annex 6, Part I [Ref 1].
- The complete contents of audio recordings recorded by the CVR during up to the last 25 hours of operation.
- The complete contents of data link messages recorded by (e.g.) the DLR during up to the last 25 hours of operation.
- The complete contents of flight crew-machine interface recordings during up to the last 2 hours of operation.

A minimum of 20 minutes of buffered historical flight recorder data should be accommodated with (ref. ICAO Doc 10054-1 [Ref 2])

The following table provides rough estimates of the amount of raw data generated by the flight recorders over time. This will serve as a basis to later discuss required transmission throughputs and possible transmission media, or, expected data storage (buffer) for triggered transmissions for instance.

The table is divided into two parts: a first part for flight data, voice communication and audio signals and data link communication messages, and a second part for the flight crew-machine interface recordings.

Data Type	**Data Rates (kbit/s)**	**Amount 1 min (kbyte)**	**Amount 20 min (Mbyte)**	**Amount 2 hours (Mbyte)**	**Amount 25 hours (Mbyte)**
Flight data	7[4]	53	1.1	6	79

[4] As discussed in ARINC Project Paper 681 [Ref 13]: 6-8 kbps for ARINC 717 FDR using 1024 wps data frames. ARINC 767 FDR would double the figure.

Data Type	Data Rates (kbit/s)	Amount 1 min (kbyte)	Amount 20 min (Mbyte)	Amount 2 hours (Mbyte)	Amount 25 hours (Mbyte)
Voice communications (3 mic. audio)	48[5]	360	7.2	43	540
Flight deck audio environment	64[6]	480	9.6	58	720
Data link communications messages	0.2[7]	1.5	0.030	0.18	2.25
Subtotal	***119.2***	***894***	***17.9***	***107***	***1,341***
Flight crew-machine interface recordings	1733[8]	13,000	260	1,559	19,496
Total	**1852,2**	**13,894**	**277.9**	**1,666**	**20,837**

Table 3: Rough estimates of amounts of flight recorder data generated over time

ICAO Doc 10054 [Ref 2] has established priorities for the transmission of flight recorder data due to their relative value to investigations should these data not be available, or the transmission capabilities be limited. Based on the prioritization defined by ICAO, ARINC Project Paper 681 [Ref 13] discusses the prioritization schemes as well as possible transmission distribution schemes for the different flight recorder data types, both real-time and historical. The following table provides cumulative data rate figures for streaming (continuous transmission) and triggered transmission schemes according to priorities defined by ICAO. The figures provide a rough estimate of the bandwidth necessary for the radio communication media to transmit the different data sets. For instance, a datalink system with a 200 kbit/s throughput would be able to transmit priority 1 to 6 data in the continuous transmission scheme, but only priority 1 to 4 in the triggered transmission scheme.

Priority	Flight Recorder Data Type	Data Rate (kbit/s)	Cumulative Data Rate for Continuous Transmission (kbit/s)	Cumulative Data Rate for Triggered Transmission (kbit/s)
1	Real-time flight data	7	7	7
2	Real-time flight deck environment audio	64	71	71

[5] As discussed in ARINC Project Paper 681 [Ref 13]: compressed audio (8-bit samples at 8 kHz) for 3 crew members.
[6] As discussed in ARINC Project Paper 681 [Ref 13]: compressed audio (16-bit samples at 16 kHz) for 1 cockpit area microphone.
[7] As discussed in ARINC Project Paper 681 [Ref 13]: estimation based on ARINC 747 and ARINC 757 CMU outputs.
[8] 1080p Full HD (1920x1080p), instead of NTSC VCD (352x240p) as discussed in ARINC Project Paper 681 [Ref 13].

Priority	Flight Recorder Data Type	Data Rate (kbit/s)	Cumulative Data Rate for Continuous Transmission (kbit/s)	Cumulative Data Rate for Triggered Transmission (kbit/s)
3	Historical flight data	7 x ratio[9]	NA	78 (*)[10]
4	Real-time voice communications (3 mic. audio)	48	119	126 (*)
5	Historical voice + audio (3 mic. + envir.)	112 x ratio	NA	238 (*)
6	Real-time + historical data link communications messages	0.2 x (1 + ratio)	119.2	238.4 (*)
7	Flight crew-machine interface recordings	1733	1852.2	1971.4 (*)

Table 4: Cumulative data rates for continuous and triggered transmission schemes according to priorities

Note: Should it be possible to stream the historical flight recorder data backwards, based on the cumulated data rates in Table 4, an available throughput for the transmission of flight recorder data of 1 Mbit/s would enable approx. 30 Mbyte (240 Mbit) of uncompressed data to be transmitted within 4 minutes[11]. This would basically[12] correspond to the last 20 minutes of flight recorder data, excluding flight crew-machine interface recordings, or:

- Last 30 minutes of flight data + cockpit environment audio + flight crew voice communications.
- Last hour of flight data + cockpit environment audio
- Last 9.5 hours of flight data only

Note: Hardware installations of the flight crew microphones can allow mixing the 2 to 3 audio inputs on a single channel, hence significantly reducing the necessary data rate (16 kbit/s for real-time audio signals (66% reduction), 87 kbit/s cumulative streaming (27% reduction), 94 kbit/s cumulative triggered (25% reduction) for down to priority 4 transmissions). Nevertheless, mixing several audio sources on a single channel has been problematic for recorder specialists at investigation authorities. Discussions with working groups (e.g. EUROCAE WG-118) are ongoing and the general trend is not to mix channels and have their number increased beyond four.

Note: As discussed in §4.1.7, it is likely flight recorder data are also recorded in a "distributed" manner on the ground by several organizations. Priority schemes could be revised to first transmit flight data, cockpit environment audio and flight crew-machine interface recordings, should voice (audio

[9] As discussed in ARINC Project Paper 681 [Ref 13]: ratio (0.0 - 1.0) is a variable rate determined by the transmission method of historical flight data. This value will typically depend on the available transmission throughput, as well as the strategy implemented for the distribution of data within the transmission throughput allocated to the transmission of historical flight data.

[10] Assuming ratio = 100%, i.e. best transmission capability case

[11] Illustrative value of the distress duration as discussed in D1 [Ref 14] and §4.1.5

[12] Figures are provided for illustration and comparison purposes only, without any consideration of possible compression and transmission issues generated by the distress situation and location, protocols…

controller/pilot communication) and datalink communications be retrieved from recordings by ground-based systems. Typically, voice and data link communications with air traffic services could be recovered from ANSP, these latter being required to perform such recordings (ref. ICAO Annex 10 Volume II [Ref 3]). AIA will use all data available including the ones from ground-based sources. However, communications recorded on the ground may not necessarily reflect what the cockpit crew has transmitted or attempted to transmit (e.g. part of it could be blocked or garbled as was the case in Tenerife in 1997 when two simultaneous critical communications have been blocked just before runway collision). However, flight recorder data recordings are subject to ICAO Annex 13 [Ref 4], EU Reg 996/2010 [Ref 23] and policy restrictions. As such, a "distributed" type of transmission should consider any applicable legal restrictions with regard to the receiving entity of each type of data transmitted. Off-aircraft storage of flight recorder data will be discussed in §5.2.4.

4.2.2 Data Compression

Special care will have to be taken when considering compressing files in order to reduce their size for transmission and/or storage. Compression and associated decompression algorithms may provide a resulting file slightly different from the original. Also, processing time increases significantly with the compression ratio. The impact of the delay introduced by compression on the transmissions of flight recorder data will have to be assessed in further activities (e.g. modeling) of the study, with regards to delay related figured provided in ED-112A [Ref 10]. Introducing a delay at transmission level for instance may compromise the transmission of the data.

There is no unique lossless compression algorithm applicable to any file. One could compress very efficiently some files and conversely not compress at all other files depending on their contents (data).

It is recommended not to use lossy compression techniques on flight data and data link communications recordings. Lossy compression techniques may be acceptable on audio[13] and images recordings provided they meet ED-112A requirements. Indeed, audio files are not just listened to and transcribed by safety investigation authorities. They often are submitted to audio spectrum analysis and other advanced audio signals analysis to extract information that is not easily audible or confirm assumptions. Investigation authorities may similarly want to zoom in images and apply advanced image analysis techniques to extract more information from image recordings.

Use of a single lossless compression algorithm for all types of flight recorder data, incl. audio recordings, will have to be evaluated further in the study.

Note: As an example, an ARINC 717 file from an FDR can be compressed with a ratio of approx. 3:1 using the LZMA2 lossless compression algorithm.

Note: ED-112A [Ref 10])allows compression (and provides related performance requirements and recommendations) for both digital (data) and analog (voice) information being recorded. AC 20-160A [Ref 16] recommends not employing any data compression methods on data link communications recordings.

Note: The compression ratio is higher with larger data “chunks”. Nevertheless, the right balance needs to be found with the allocated duration for that “chunk” in order to increase its chances of successful transmission. An optimal size, e.g. equivalent to 4 seconds of recording, will be discussed with investigation authorities.

[13] Lossy compression techniques may introduce important modifications on audio/video files that are not perceptible by humans. ICAO Doc 10054-1 [Ref 2]recommends the use of 3-bit adaptive differential pulse-code modulation (ADPCM) algorithms should lossy compression be considered for cockpit environment audio.

4.2.3 Data Protection

Flight recorder data shall be protected over the whole end-to-end process, from their recording onboard the aircraft to their recovery by the accident investigation authorities and airline operators, via the transmission over the air and through ground networks.

Two common techniques may be considered: use of Virtual Private Networks (VPN) to protect transmissions and use of encryption to protect the data themselves.

Virtual Private Networks (VPN) are commonly used in aviation as a means of securing point-to-point digital communications between the aircraft and the airline. VPN indeed use tunneling protocols and encryption techniques to prevent disclosure of private information. They provide confidentiality, authentication and message integrity mechanisms. New generation communication means such as VHF Data Link Mode 2 (VDL2) and IP-based SATCOM (e.g. Inmarsat and Iridium Next) support VPN.

Note: VPN provided at the transmission level will only ensure data integrity/authenticity of the air-to-ground segment (aircraft to storage destination), hence need to be extended / complemented to cover other transactions on the ground segment as well (storage to users implied in the data recovery and exploitation activities, e.g. airline, AIA…).

Encryption may be considered as well in order to protect flight recorder data recordings, as well as their transmission, from unauthorized / malicious replays. Different encryption techniques can be applied either at recording stage or at transmission stage, if not both. The stage at which it is best suited will depend on the end-to-end architecture being retained after assessment of the solutions detailed further in the present document. Moreover, the brand-new operational concepts for recovering flight recorder data for investigation purposes may also influence the proposed solutions, typically the generation, ownership and exchange of private/public keys.

Note: Encryption ensures confidentiality but not authenticity. Signature of the data should be considered for authentication of the source.

Common standards include X.509 (definition of the format of public key certificates) and Advanced Encryption Standard (AES) (specification for encryption of electronic data) that are used for encryption as well as authentication and integrity assurance in several internet protocols and electronic signatures.

Note: If encryption is considered, it should occur after compression. Indeed, the size of an encrypted file is larger than the size of the original, and compressing an encrypted file is not efficient at all.

Note: On-the-fly Encryption is possible but quite demanding in terms of processing power and operations. Trade-offs should be evaluated when applying these techniques onboard, depending on the stage at which they are applied. Encryption may be performed, if required, either on files (recording level) or on packets (transmission level), if not both. Partially received files/packets cannot be deciphered. Further analysis will need to be conducted to determine the proper balance in the file/packet size to be transmitted depending on transmission performance (especially continuity and integrity aspects).

ED-112A [Ref 10] addresses encryption only for AIR[14] (crew privacy aspects) with the provision of a dual password/encryption key protection capability, both passwords/encryption keys being required for replay of the image recordings. It is envisioned in ED-112A that the passwords/encryption keys be delegated to the airline and its pilot representative, whereas official investigation authorities would have

[14] As mentioned in §4.1.5, images and audio recordings are similarly sensitive in their contents so that encryption and securing requirements should be much higher than for flight data and data link communications.

access to a specialized playback capability that does not require the use of these passwords/encryption keys.

Figure 3 below depicts an overall system architecture and tentatively highlights possible cybersecurity breaches. As can be seen, these may occur at all stages of the process, i.e. on board the aircraft, during over the air transmission, during on ground transmission, at the final repository[15].

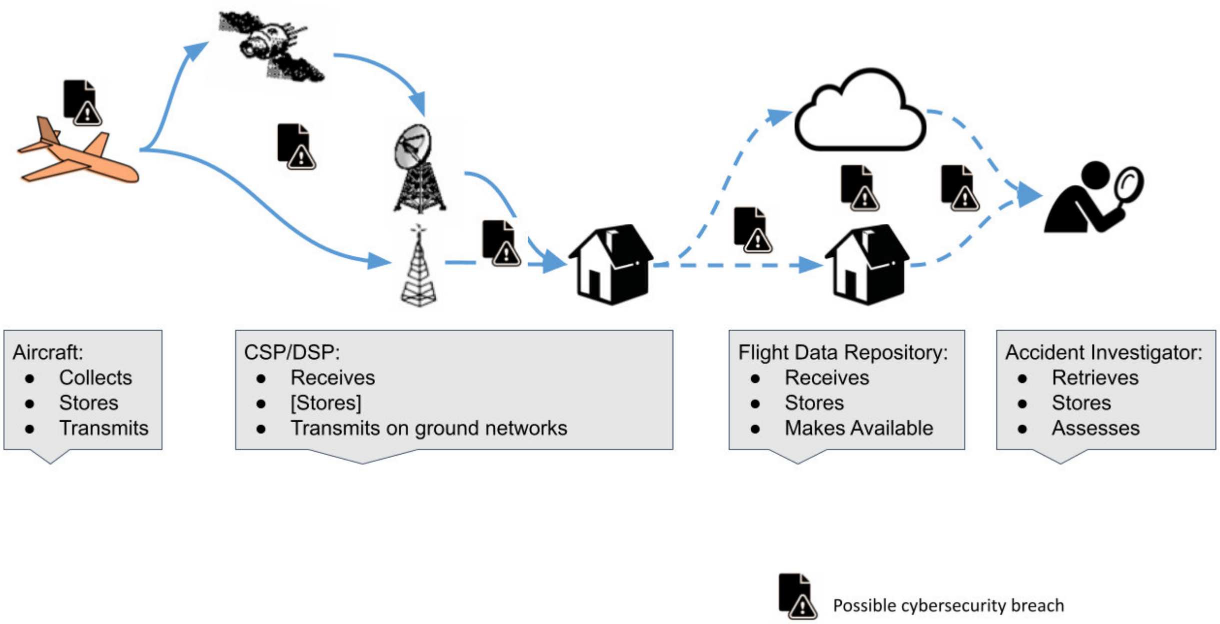

Figure 3: Possible cybersecurity breaches over the end-to-end function

It is recommended that cybersecurity objectives be defined, and risk-cost-benefit analysis be undertaken, pinpointing dreaded risks and their possible impacts before identifying mitigation measures and finally assessing gaps, overlaps and minimum requirements. ED-202A [Ref 11] should be considered as a security methodology. Cybersecurity should not include only corruption/interception of the data sent from the aircraft but also prevent the hacking of the aircraft using the QR-FRD link.

Also, an analysis should be conducted to identify ownership and access rights to the data for the different stakeholders, possible interactions between the different actors, as well as identifying which bear the costs associated with data protection, transmission, and storage[16]. There is for instance a cost associated with the generation of authentication certificates and their renewal (periodic or after revocation) as well as operational costs related to their logistics. The results from this analysis should be summarized in a concept of operations (CONOPS) as mentioned earlier in this section.

Figure 4 below depicts an overall functional architecture based on the functional blocks identified in ARINC Position Paper 681 [Ref 13] and proposes a first draft of end-to-end data protection with

[15] At this stage of the study, the actual location of the flight data repository on the ground is unknown. As discussed later in the document (cf. §5.2.4), several options can be considered incl. the airline, investigation authorities and system wide information systems ("clouds").

[16] Flight recorder data ownership is essential, and their storage location may be regulated (restricted) as discussed later in the study (D4 and D7). In some countries data coming off the aircraft is typically owned by the operator, and rules prohibit data on citizens to be stored outside the country of citizenship.

encryption and a VPN to secure transmissions between the aircraft and the flight recorder data repository on the ground.

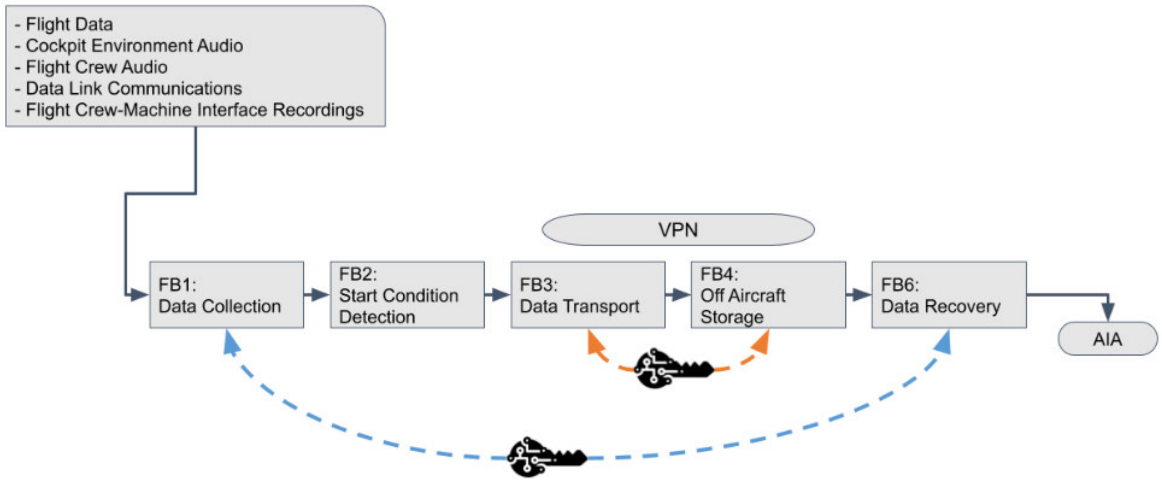

Figure 4: Possible data protection schemes with VPN and encryption keys

The outcomes from the recommended analysis, or CONOPS, could influence this baseline either by simplifying it, e.g. show that use of a single VPN could be sufficient, or by complexifying it, e.g. show a need for multiple layers of data protection associated with both generation and distribution of several keys (private and public).

It is important for an AIA to ensure that the flight recorder data were not tampered. For their mission, but also to reassure the stakeholders (other States in the case of an international investigation, the aircraft manufacturer, the aircraft operator, flight crew associations, relatives of injured persons, general public, etc.) that they have got un-tampered data.

Data tampering is even more a topic for the administration of justice. A judicial investigation may be launched in parallel to the AIA investigation (which is often the case for commercial air transport accidents with fatalities).

Today, the designs of fixed flight recorders limit the risk of tampering, so that it is considered sufficient to quickly recover the flight recorders after an accident or serious incident and to maintain safe custody of them, to prevent a risk of tampering. With a QR-FRD system, AIA will also need to trust that the data they recover were not tampered. Clear rules will need to be established that govern how flight recorder data is stored and how a chain of custody is set up after an accident occurred.

Signature is another data protection mean, primarily meant for authentication purposes though the processing also helps ensuring integrity of the signed data as well. Indeed, a digital signature is a mathematical scheme (aka hash value or message digest) that can be used for verifying the authenticity of digital messages. A valid digital signature gives a recipient (AIA) very strong reasons to believe that the message (flight recorder data) was:

- Created by a known sender (the aircraft): authentication
- Not altered since it was signed (by the aircraft): integrity.

The signature process typically involves four operations:

1. Key generation: Creation of private and public key pairs.

2. Key distribution: Publication by the signer of the public key via a reliable, but not necessarily secret, mechanism. The signer keeps the private key secret.
3. Signing: Use of the signer's private key to generate a digital signature with a secure hash function for the message.
4. Signature verification: Use of the signer's public key by the recipient to verify the signature, usually by recalculating the hash value.

Note: From an investigation perspective, once cross checked and validated, flight recorder data should have the same value regardless of the way it has reached the AIA (transmitted to the ground or extracted from crash-protected recorders). AIA may start to work earlier on the data transmitted to the ground.

The actual means to generate, distribute, and manage cryptographic keys in the QR-FRD context will be documented during Task 3 of the study.

4.2.4 Datalink Service Requirements

The transmission of flight recorder data in anticipation of a possible loss of the recorders after an accident poses a number of requirements on the system architecture (cf. D1 [Ref 14]) as well as on datalink services. Requirements for the latter would typically include:

- Coverage, i.e. ideally worldwide incl. polar regions, at minimum common transcontinental/transoceanic routes
- Availability, i.e. ideally "100%"[17]
- Continuity, same as for availability, in order to minimize loss of data / records during the transmission
- Latency, to be minimal, especially for connection and possible reconnections during the transmission[18]. Reception of the data at final destination could indeed occur minutes after it has been transmitted with no impact on the data recovery and investigation start.
- Throughput available per aircraft, especially from the aircraft to destination (basically the ground segment), the higher the better (especially for triggered transmissions) as discussed in §4.2.1 above
- Cybersecurity / transmission protection mechanisms, both in the air and on the ground

[17] The higher the better. The authors of this document recognize "100%" does not exist for radio communications, though 99.9% is achievable for safety services.
[18] ED-112A [Ref 10] defines requirements for recording interruption recovery after a power interruption. Further assessment of data link communication performance with respect to interruptions (power, reconnection…) will be needed (cf. §ANNEX A: DATA LINK SERVICE PROVIDER SURVEY FORM).

5 POTENTIAL SOLUTIONS

5.1 Baseline Functional Architectures

The baseline functional architectures presented hereafter are based on the functional blocks defined in ARINC Project Paper 681 [Ref 13] for the following deployed systems relevant to the transmission of flight recorder data:

- Flight recorders
- State of the art flight operations and maintenance applications
- Aircraft Tracking - Abnormal Operation applications

These systems, provided as illustration, are indeed relevant to QR-FRD since they are either closely related to ICAO's Global Aeronautical Distress and Safety System (GADSS) concepts of operations (i.e. flight recorders and aircraft tracking - abnormal operations applications), or very similar in their functional architecture (i.e. flight operations and maintenance applications).

The baseline functional architectures will later be used to discuss options and tradeoffs for future QR-FRD installations.

The functional blocks discussed in the present document are the following:

- FB1 Data Collection will consist in collecting the required flight recorder data from the aircraft data sources and storing it in preparation for transmitting it off the aircraft.
- FB2 Start Condition Detection will consist of continuously monitoring data (or a logical combination of data) provided by aircraft systems and/or sensors for detecting a condition to initiate the transmission of the data off the aircraft.
- FB3 Data Transport will consist of transmitting the data off the aircraft and transporting it on the ground until it reaches its storage destination.
- FB4 Off-Aircraft Storage will consist in storing the data in an off-aircraft location with the required access restrictions and protection against modification and corruption.
- FB6 Data Recovery will consist in retrieving the data from the off-aircraft storage and making it available to accident investigators and other authorized users for analysis.

Note: The optional FB5 Locate End of Flight functional block defined in ARINC Project Paper 681 [Ref 13] is not considered part of the QR-FRD study as it is currently handled by Autonomous Distress Tracking (ADT) airborne applications already deployed. Nevertheless, the Aircraft Tracking - Abnormal Operation application functional architecture is provided for information to highlight similarities and differences with QR-FRD.

5.1.1 Flight Recorders

Figure 5 below depicts a generic flight recorder functional architecture. Basically, functional blocks covered are:

- FB1 Data Collection: Data (provided by several avionics systems, computers and dedicated sensors (e.g. microphones for CVR and accelerometers for FDR) using different protocols) are collected and stored on high capacity solid state disks by the different flight recorders (FDR, CVR, combined FDR/CVR…)[19]. In order to facilitate the replay, recordings among the different recorders are meant to be time synchronized (ref. ED-112A [Ref 10]).

[19] The FDR records flight data that have been collected and formatted by Flight Data Acquisition Units (FDAU). CVR acquire audio lines directly. CVR may also record data link communications messages.

- FB2 Start Condition Detection: Recording automatically starts the aircraft still on ground, prior to the aircraft moving under its own power. Ideally, recordings should start as early as possible at the gate during pilots' checks prior to engine start (ref. ED-112A [Ref 10]).
- FB6 Data Recovery: The flight recorders recovered, possibly dismounted from aircraft remains, are handed to the investigation authorities for replay of the recordings and analysis of the retrieved data in safe and secure premises.

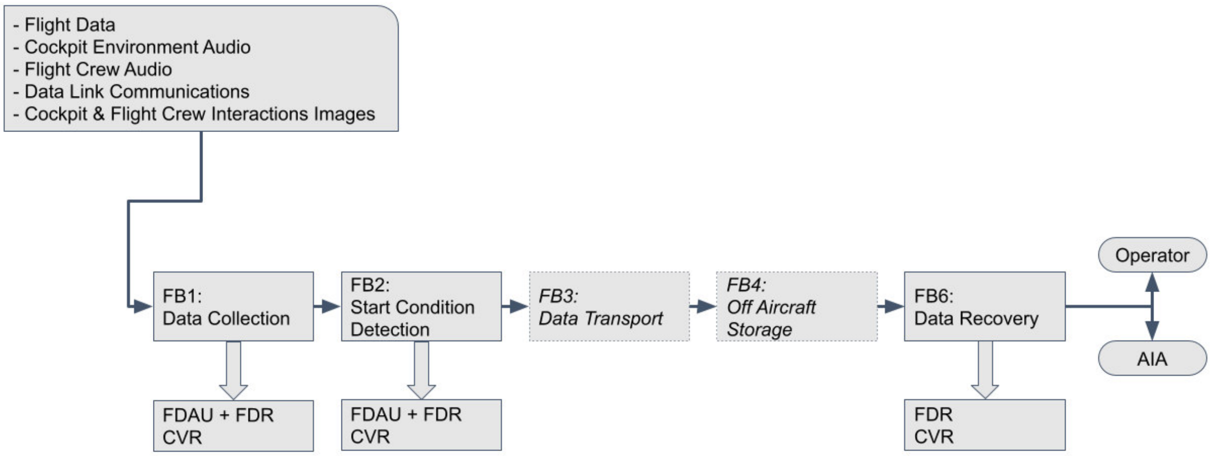

Figure 5: Functional allocation for flight recorders solutions

5.1.2 Airline Information Services Domain Router

Figure 6 below depicts a generic Airline Information Services Domain (AISD) router functional architecture. Basically, functional blocks covered are:

- FB1 Data Collection: Data (provided by several avionics systems, flight recorder data interfaces, flight computers and cockpit displays) are collected and recorded on high capacity solid state disks depending on data types and end users (typically, the airline and the aircraft manufacturer). The different ARINC-717, ARINC-767 and other formats files can be compressed and encrypted.
- FB2 Start Condition Detection: The different recorded files are sent periodically or on event to communication systems for secure transmission off the aircraft at the destination of their respective end-users. Files may be prioritized for transmission depending on different criteria such as their objectives, final destinations, etc.
- FB3 Data Transport: End-to-end Internet Protocol (IP) file transfers, secured using Virtual Private Network (VPN) for instance, and ACARS for short alert messages as well as routing (RF media selection) are performed depending on a set of pre-established rules (e.g. availability, cost …). Common sub-networks include WiFi[20] and LTE (at the airport), as well as cockpit (ATS communications) and cabin (in-flight entertainment) SATCOM while in cruise.
- FB4 Off-Aircraft Storage: Received files are stored on secure servers by the end users (basically the airline and the aircraft manufacturer).
- FB6 Data Recovery: End users recover data from files stored on their respective servers for on purpose analysis (typically operational flight data monitoring (OFDM) and preventive maintenance, e.g. Aircraft Condition Monitoring System (ACMS)).

[20] Current trend is that WiFi Gatelink is going out of considered solutions.

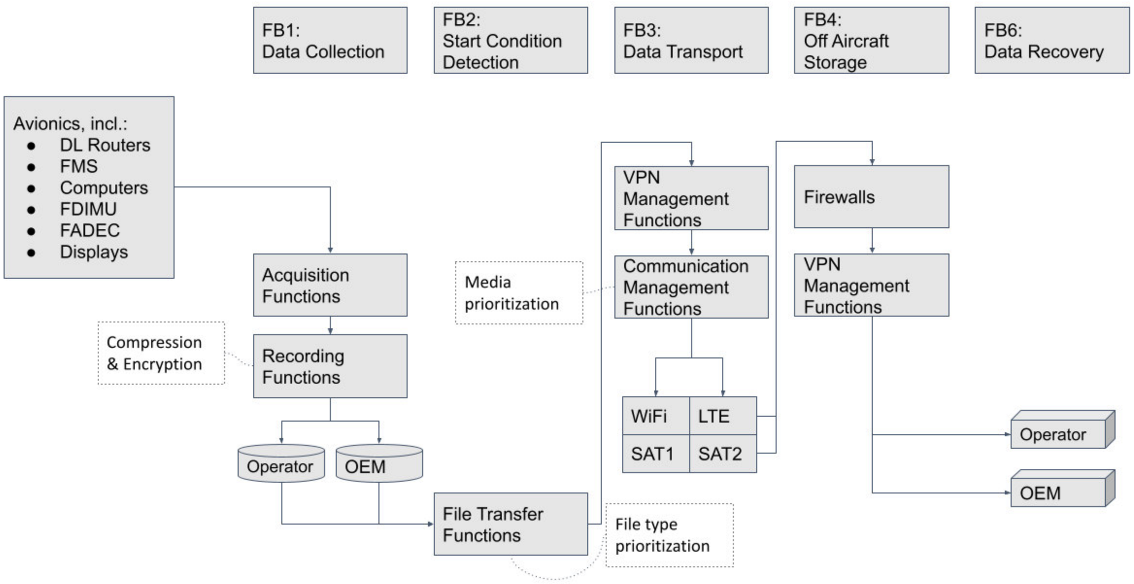

Figure 6: Functional allocation for Airline Information Services Domain Router solutions

5.1.3 Aircraft Tracking - Abnormal Operations Applications

ICAO Circular 347 [Ref 5] provides guidelines for implementing solutions for aircraft tracking under normal conditions as well as monitoring aircraft experiencing an abnormal operation or event. The abnormal events, which might be precursors to accidents or serious incidents, are carefully defined by the operator that wish to further exploit and/or expand their flight monitoring capabilities to trigger subsequent and related monitoring activities. Examples of abnormal events include deviations from flight plan, aircraft-initiated emergency reporting, engine exceedance alerting, abnormal aircraft state… After an abnormal event is detected, increasing the automated position-reporting rate associated with aircraft tracking under normal conditions is recommended in order to provide the relevant ATSU with the most accurate position data available should an escalation to an emergency phase occur.

Figure 7 below depicts a generic aircraft tracking - abnormal operations application. Basically, functional blocks covered are:

- FB1 Data Collection: Data (provided by several avionics systems and computers (typically Terrain Avoidance Warning Systems (TAWS), Airborne Collision Avoidance Systems (ACAS), Flight Management Systems (FMS), Flight Data Interface and Management Units (FDIMU), Full Authority Digital Engine Control (FADEC)) are collected by an I/O Concentrator (IOC) and monitored by an Aircraft Tracking[21] application, part of Airline Operations Center (AOC) applications, in order to build and periodically transmit 4D position reports.
- FB2 Start Condition Detection: Predefined trigger conditions, tailored to the aircraft type, are assessed by the Aircraft Tracking - Abnormal Operations application in order to notify the airline that a trigger is raised and to accelerate the position report transmission period up to once per minute.

[21] In nominal flight conditions, the Aircraft Tracking application periodically (every 10-15 minutes) transmits a 4D position report over ACARS.

- FB3 Data Transport: Based on a set of dedicated Aircraft Communication Addressing and Reporting System (ACARS) messages[22], the trigger conditions and 4D position reports are transmitted off the aircraft using available subnets according to rules/criteria predefined by the airline.
- FB4 Off-Aircraft Storage: Aircraft Tracking - Abnormal Operations reports are received by the airline and stored on secure servers.
- [FB5 End of Flight Localization]: Ultimately, the last reports received by the airline can be used to refine the location of the aircraft in case of loss.
- FB6 Data Recovery: Aircraft Tracking - Abnormal Operations reports are retrieved by the airline, analyzed and help in the decision making corresponding to the detected abnormal situation.

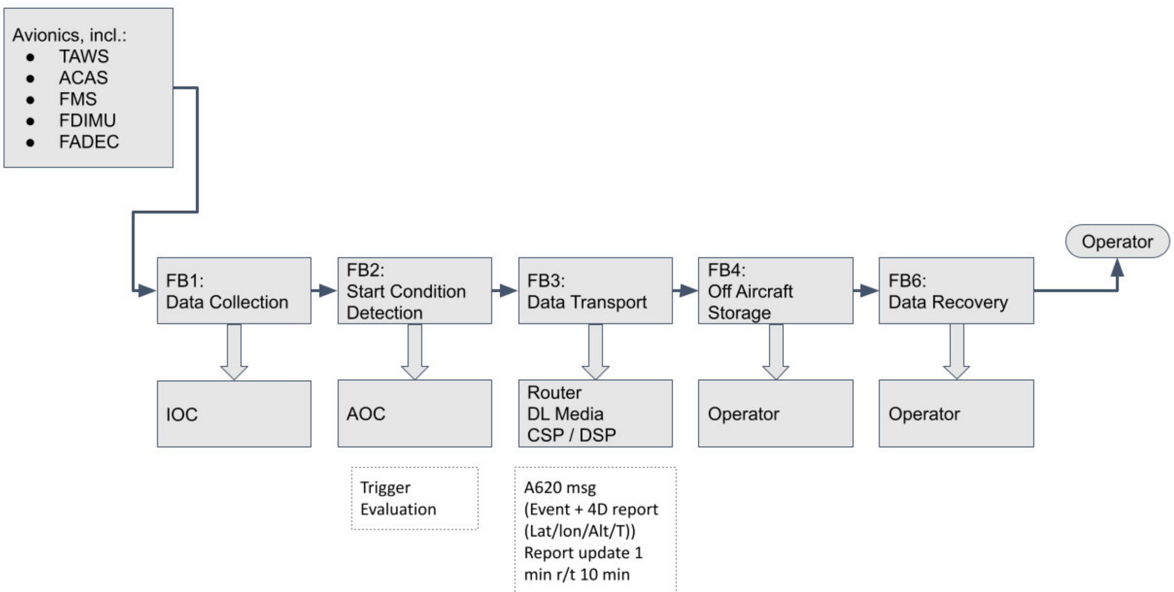

Figure 7: Functional allocation for Aircraft Tracking - Abnormal Operations applications

5.2 Proposed Solutions and Options

The following table lists different options for the end-to-end transmission of flight recorder data based on the functional decomposition proposed in ARINC Project Paper 681 [Ref 13].

Pros and cons of the different options are later discussed.

[22] If ACARS is used presently, ATN should be considered in the future, with ATN/OSI and ATN/IPS.

Functional Block	Options
FB1: Data Collection	Hosting options: • FB1-1: By Flight Recorders only • FB1-2: By Flight Recorders and Secure Mass Storage • FB1-3: By FDIU/FDAU or ACMS unit • FB1-4: By AISD router
FB2: Start Condition Detection	Hosting options: • FB2-11: By “AOC” application • FB2-12: By FDIU/FDAU or by ACMS unit • FB2-13: By AISD router Transmission options: • FB2-21: Streaming transmission • FB2-22: Triggered transmission
FB3: Data Transport	Prioritization options: • FB3-11: Prioritization by data type • FB3-12: Prioritization on time intervals (data correlation) Datalink technologies options: • FB3-21: By current aeronautical data link technologies • FB3-22: By future aeronautical data link technologies (a/g data link) • FB3-23: By alternatives to SATCOM Smart routing options: • FB3-31: By data type • FB3-32: By flight phase • FB3-33: By multi-link • FB3-34: File / packet size Secured transmissions options: • FB3-41: Internet Protocols Hosting options: • FB3-51: By CMU • FB3-52: By FDIU/FDAU or by ACMS unit • FB3-53: By AISD router

Functional Block	Options
FB4: Off-Aircraft Storage	Hosting options: • FB4-1: By the airline / aircraft OEM • FB4-2: By ATS • FB4-3: By CSP/DSP • FB4-4: By AIA • FB4-5: By SWIM
FB6: Data Recovery	AIA recovers the protected flight recorder data recordings from the repository identified in FB-4 Off-Aircraft Storage.

5.2.1 FB1: Data Collection

Options identified for Data Collection defined in §5.1 are described in the following sections.

5.2.1.1 FB1-1: By flight recorders only

Flight recorder systems collect data for recording and later retrieval. An option could be to extract data in-flight from the recorders and push it for transmission off the aircraft.

Pros for that option include:

- No need to duplicate data collection and temporary storage.

Cons for that solution include:

- Need to modify (hence recertify) flight recorders since they are protected and not designed for real-time replay while they are recording.

5.2.1.2 FB1-2: By the flight recorders plus dedicated mass storage

This option would consist in collecting the data by the flight recorders (as of today for physical recovery of the recorders ultimately) as well as by an additional dedicated secure mass storage for wireless transmission of quick recovery flight recorder data.

Pros for that option include:

- No modification of current flight recorder systems.
- The QR-FRD function not being safety critical, and neither meant to replace physical flight recorders, its design assurance level (DAL) may be lower than the ones of flight recorders[23]. This may add to the cost efficiency/acceptance by airlines for equipping.

Cons for that solution include:

- Need to duplicate, possibly introducing integrity issues, recorded data, especially if data are recorded with different (higher) compression algorithms than the ones used by the recorders.

[23] If, in the future, the QR-FRD capability is required for some categories of aircraft as prescribed by a standard in ICAO Annex 6 Part I, the minimum DAL would probably be D, i.e. not lower than current flight recorders (cf. §4.1.5).

5.2.1.3 FB1-3: By the FDIU/FDAU or ACMS unit

This option would consist in collecting the data by a new model of Flight Data Interface / Acquisition Unit (FDIU / FDAU) capable of interfacing also with audio and data link communication and flight crew machine interface recording sources or by the ACMS unit, which already implements functions for acquisition, recording and transmission of data.

Pros for that option include:

- No modification of current flight recorders. No modification of the wiring
- Reduced certification effort (the FDIU/FDAU is DAL C compliant, the ACMS unit is DAL D compliant)
- The FDIU/FDAU and the ACMS unit are configurable (connected to the data loading system), facilitating update of the security elements.

Cons for that solution include:

- Need to duplicate recorded data, possibly introducing deviation between the two storages.

5.2.1.4 FB1-4: By the AISD router

This option would consist in collecting the data by the Airline Information Services Domain (AISD) router, which already implements functions for acquisition, recording and transmission of data oriented to airline operations.

Pros for that option include:

- No modification of current flight recorders. No modification of the wiring
- Reduced certification effort (the AISD router unit is DAL D/E),
- The AISD is fully configurable (connected to the data loading system), easy to update security elements.

Cons for that solution include:

- Modification of AISD router depending on connections to FDAU/FDIU
- Need to duplicate recorded data, possibly introducing deviation between the two storages.

5.2.2 FB2: Start Condition Detection

Options identified for Start Condition Detection defined in §5.1 are described in the following sections.

5.2.2.1 FB2-11: By AOC applications

Many Airline Operation Center (AOC) applications hosted by communication management units (CMU) are interfaced with avionics systems and computers. These applications or extensions thereof can host the start condition detection logic or be modified to do so (typically, the Aircraft Tracking - Abnormal Conditions or Flight Operations and Maintenance applications described above).

Pros for that option include:

- Little to no aircraft cabling modification.
- Little software updates to existing AOC

Cons for that solution include:

- [Yet to be determined] Integrity figures may be too high for the DAL commonly used for AOC applications. Nuisance alerts could hence be generated or events not detected at all.

5.2.2.2 FB2-12: By the FDIU/FDAU or ACMS unit

Detection of triggers, based on flight parameters, are one of the ACMS unit functions. This function can be ported on FDAU/FDIU easily, the two units having knowledge of the flight parameters recorded in the FDR.

Pros for that option include:

- No aircraft wiring modification.
- Little modification of the existing ACMS unit. Easy to be ported on FDAU/FDIU.
- ACMS is easy to be updated, for adaptation of trigger detection.
- Are able to trig in less than 1 seconds (units with real-time operating system)
- Reduced certification effort (the FDIU/FDAU is DAL C compliant, the ACMS unit is DAL D compliant)

Cons for that solution include:

- None identified.

5.2.2.3 FB2-13: By the AISD router

Detection of triggers, based on flight parameters can be performed by the AIDS router, the unit already having flight parameters as an input.

Pros for that option include:

- No aircraft wiring modification.
- Little modification of the existing AISD router.
- AISD can easily be updated with adaptations of trigger detection.
- Is able to trig transmissions timely

Cons for that solution include:

- AISD routers are only DAL E compliant. Nuisance alerts could hence be generated or events not detected at all.

<u>**Note**</u>: The Aircraft Tracking - Abnormal Conditions function is mandatory on air transport aircraft since 1st Jan. 2021. It is designed according to DAL E.

5.2.2.4 FB2-21: Streaming transmissions

Streaming transmissions of real-time flight recorder data can start on very simple conditions, basically as soon as the aircraft is powered on at the gate (cf. §5.1.1).

Pros for that option include:

- Could be promoted as an “add-on” application to airlines who are already interested in receiving periodic reports from the aircraft (e.g. OFDM program, ACMS, trend monitoring…)
- Very simple start condition detection logic to implement
- Full history of the flight can easily be recovered afterwards, or assessed with slight delay offline
- Flight recorder data prioritization can be refined according to flight phase (e.g. voice and data link communications as well as flight crew-machine interface recordings only while at the gate, flight data and cockpit environment audio added once the aircraft is moving …)[24]

[24] These examples of prioritization according to the flight phase are provided for illustration purposes only. They would need more maturity should that scheme be retained. Doc 10054-1 [Ref 2] would accept flight data and data link communication messages to be transmitted when the aircraft is in flight, and voice communications and cockpit environment audio only when the aircraft is in distress.

- More data link subnetworks available (along with different cost) across the flight phases

Cons for that solution include:

- Transmissions and off-aircraft data storage for the full duration of the flight and basically all of the flights, hence generating excessive recurring costs to the airline[25].
- Not an "eco-friendly" / "green" solution: exchanging and storing on servers large quantities of data for long periods of time is presently energy-consuming. Aviation may once again be finger-pointed as not eco-responsible.

Note: Data retention policies to be set in place, possibly burdening the organization responsible for the off-aircraft storage (cf. §5.2.4 below). Part-CAT [Ref 22] CAT.GEN.MPA.195 requires retaining flight recorder data for at least 60 days in case of an accident/serious incident. Otherwise, equivalent to 25h recordings (eq. crash protected recorders) or a couple of (TBD[26]) days. AIA can use data from previous flights during investigations.

Note: A concept of operations based on flight recorder data streaming could be envisioned by which (e.g.) the airline would analyze the data in real-time and provide an early warning to the flight crew that something is going wrong on board that may possibly lead to an accident. An alternative could be to stream only part of the flight recorder data, e.g. flight data and possibly cockpit environment audio, the analysis of which would trigger, from the ground then, the transmission of the full set of flight recorder data should the situation degrade. A weakness of this concept is that it would not work if the connection from the ground to the aircraft were lost. These concepts also raise issues that would need to be further investigated, such as notifying the pilots of possible voice and image recordings remotely initiated, erasure of recorded voice and image recordings afterwards[27]…

5.2.2.5 FB2-22: Triggered transmissions

Triggered transmission of real-time flight recorder data and as much historical data as possible will start as soon as a trigger condition is detected (cf. §Flight Recorder Data Transmission).

Pros for that option include:

- Transmission occurs only for aircraft that experience troubles (abnormal situation) and may be in distress in the short term, and only during a shorter period of time than the whole flight (transmissions will stop when the aircraft recovers nominal flight conditions, lands safely after the incident or is unfortunately lost). This would limit transmission costs as well as the amount of data to be securely stored off-aircraft.

Cons for that solution include:

- Start condition detection logic to be implemented, and possibly tailored/tuned to the aircraft type, as each has its own flight envelope.
- The amount of historical flight recorder data that can be transmitted and recovered afterwards will be a function of the amount of data buffered before the trigger, time left to transmit after the trigger, available transmission throughput that may degrade after the trigger (cf. §4.2.1).

[25] In accordance with usual practice, OFDM data and other ground program data are transmitted after the aircraft is landed, using a low-cost channel (like cellular network). Flight data are overqualified and are only a subset of the necessary avionic data A/L use for they maintenance and quality program. In addition, there no real time requirement for those programs.
[26] Value to be defined in CONOP (D9) later in the study.
[27] The audio and image recordings on fixed flight recorders can be erased by flight crew after a flight with no incident. This capability needs to be adapted to the respective transmitted flight recorder data.

5.2.3 FB3: Data Transport

Options identified for Data Transport defined in §5.1 are described in the following sections.

5.2.3.1 FB3-11: Prioritization by data type

Especially true for triggered transmissions, historical flight recorder data will need to be transmitted "rewinding" time from the detection of the trigger condition, prioritizing some data types among others as discussed in §4.2.1. Same considerations can be ensured for "real time data", (i.e. post trigger flight recorder data, transmitted as generated). Pros for that option include:

- Increased probability to recover full history (entire recording) per data type

Cons for that solution include:

- Limited time to transmit after the trigger is detected could lead to receiving a limited set of data files, e.g. only part of flight data history or full flight data history plus last minutes of cockpit environment audio.
- Risks that the ground tools are not able to resynchronize the different flight recorder data. Indeed, in case of loss of the UTC time reference, there is no guaranty that the buffered flight recorder data, when provided in separated files, can be resynchronized. This would not be the case if the different types of flight recorder data were provided in the same file.

Note: Integration of an absolute time reference at multiplex data level would ensure a more precise exploitation and increase the possibility to rebuild data collection in case of partial data reception at ground level.

5.2.3.2 FB3-12: Prioritization by data type on time intervals

Especially true for triggered transmissions, historical flight recorder data will need to be transmitted "rewinding" time from the detection of the trigger condition, prioritizing data types on time intervals ("chunks" of [yet] TBD duration), allowing correlation of the different data during their analysis. Same considerations can be ensured for "real time data", (i.e. post trigger flight recorder data, transmitted as generated). Pros for that option include:

- Better "mix" of data once recovered
- Recovery of partial history (cf. §4.2.1) but for all data types (hence time correlated data) on a number of time intervals
- Guarantees flight recorder data synchronization, even in case of time function loss on board, and even in case of partially corrupted or failed recording/transmission (robustness to failure).

Cons for that solution include:

- Decreased probability of recovering the full history of a single data type

5.2.3.3 FB3-21: Current Aeronautical Data Link Technologies

Current Aeronautical Data Link Technologies[28] basically include VHF Data Link Mode 2 (VDL2), HF Data Link (HFDL) and Satellite Communications (SATCOM) subnetworks for cockpit communications (Aircraft Control Domain (ACD)), over ACARS or Aeronautical Telecommunication Network (ATN) networks, as well as Wi-Fi and cellular telephony (e.g. 4G) for large file transfers (e.g. OFDM) over IP at the gate (Airline Information Services Domain (AISD)). Long range air transport aircraft are also equipped with In Flight Entertainment & Connectivity (IFEC) SATCOM for the cabin (Passenger Information & Entertainment Services Domain (PIESD)).

Pros for that option include:

[28] These technologies are thoroughly detailed in D1 (ref. [XXX]).

- Networks and ground infrastructure already deployed
- Protected aeronautical spectrum (cockpit communication means)
- Multiple links to ensure coverage and availability at different cost

Cons for that solution include:

- Low throughput available for new applications, except for SATCOM which may be relatively expensive for non-safety critical applications

5.2.3.4 FB3-22: Future Aeronautical Data Link Technologies

Future Aeronautical Data Link Technologies[29] will basically include Aeronautical Mobile Airport Communication System (AeroMACS) for communications in airports, L-band Digital Aeronautical Communication System Air-Ground (LDACS A/G) for air-ground communications over regions with infrastructure and Satellite Communications (SATCOM) subnetworks for cockpit communications (ACD), over Aeronautical Telecommunication Network over Internet Protocol Suite (ATN/IPS) networks. WiFi, cellular telephony (AISD) and IFEC SATCOM (PIESD) as listed previously will also be available.

Pros for that option include:

- Networks and ground infrastructure already deployed (slight adaptations nevertheless required, e.g. antennas and receivers typically for AeroMACS and L-DACS)
- Protected aeronautical spectrum (cockpit communication means)
- Multiple links to ensure coverage and availability at different cost
- High throughput available for ever more demanding Air Traffic Management (ATM) applications

Cons for that solution include:

- New aircraft installations / modifications required (e.g. antennas, receivers, communication routers)
- Standardization by international standardization bodies (e.g. EUROCAE) still required / in progress

5.2.3.5 FB3-23: Alternatives to SATCOM

Alternatives to SATCOM already include HFDL and future Wideband HFDL (cf. D1 [Ref 14]), both considered in the previous paragraphs, as well as beyond radio line of sight (BRLOS) solutions foreseen for unmanned systems and/or internet provision in regions with poor terrestrial infrastructures. These alternatives include use of high altitude platforms (HAP), aka “pseudo-satellites”, and air-to-air relays.

Pros for that option include:

- HAP: meant to be cheaper and faster to deploy than satellites as taking the form of large solar-powered unmanned aircraft or balloons, they allow an augmentation of the coverage of communication means with lower power consumption than traditional SATCOM
- Air-to-Air Relay: aeronautical radio technologies such as VDL Mode 4 and LDACS A2A allow relaying data from an aircraft to another in addressed mode as well as in network mode, hence enabling range extension for communications. When flying in-trail over remote/oceanic regions, follower aircraft could relay the data transmitted by the aircraft experiencing the distress situation. The distressed aircraft can then transmit using short range communication means, and followers retransmit to the ground using relays or air-to-ground communications means they are connected with but in nominal conditions.

[29] These technologies are thoroughly detailed in D1 [Ref 14].

Cons for that solution include:

- HAP: Not deployed yet
- Air-to-Air Relay: Not deployed yet
- Air-to-Air Relay: Data protection (cybersecurity as well as privacy) issues raise with the relaying aircraft, burdening airlines. Nevertheless, the "navigator" and "solidary" spirits of airlines can overcome the issue should protocols and procedures be agreed upon and set in place.

Note: It may be worth considering "solidarity schemes" in which aircraft sharing the same communication channel would temporarily stop [part of][30] their transmission, and free bandwidth for the aircraft in distress.

5.2.3.6 FB3-31: Smart routing by data type

Smart routing by data type, cf. discussion in §4.2.1, will enable historical data to be prioritized by data type in the triggered transmission case:

Pros for that option include:

- More chances to transmit full/deepest possible history of the highest priority data (i.e. flight data according to Table 4)

Cons for that option include:

- Less chance to transmit a time correlated set of historical flight recorder data incl. flight data and voice communications audio for instance

Note: An alternative discussed in §5.2.3.2 above, would be "smart routing by time intervals", with pros and cons opposite to those identified in the previous option. From initial discussions with some safety investigators, this option would be their favorite. It matters more for them to have both flight data and audio (voice communications and cockpit environment) covering the last 30 minutes preceding an accident than 25 hours of flight data only. Integrity checks of the flight data recordings for instance are also performed using the associated audio records. Sometimes, the cockpit environment audio confirms voice conversations or actions from the flight crew. Further discussions on the topic with safety investigation authorities will occur during the study.

5.2.3.7 FB3-32: Smart routing by flight phase

Smart routing by flight phase, cf. discussion in §4.2.1, will enable real-time data to be prioritized by data type relevant to the flight phase in the streamed transmission case:

Pros for that option include:

- Only subsets of real-time flight recorder data are transmitted, also taking benefit of transmission means available during the flight phase

Cons for that option include:

- Time synchronization of the replays may be more difficult
- Assumption that the flight crew will observe non-recorded events and react to these or report them ("indirect reporting" of smoke in the cockpit at the gate for instance).

[30] It is likely ATC communication would still remain.

5.2.3.8 FB3-33: Smart routing with multi-link

Use of multi-link routing techniques offers many advantages among which:

- An increase of transmission link availability figures depending on the flight phase (especially for streaming), or location of the aircraft (though the number of means is reduced when considering oceanic/remote regions, cf. D1 [Ref 14]). It may also be possible to use “non-cockpit” / “safety communication” means, incl. IFEC-purposed high bandwidth SATCOM. Indeed, airlines now agree to use IFEC media when necessary to increase available throughput for the benefit of safety/cockpit related applications, shutting down passenger apps temporarily.
- Redundancy increasing chances data be transmitted and/or increasing integrity should related requirements be too stringent
- Load balancing (e.g. small files on low throughputs means, larger files on higher bandwidth capable means) optimizing simultaneous transmissions on different media

Pros for that option include:

- Maximization of chances of successful transmissions, including resilience to jammers and interferers
- Optimization of transmission costs for the airline

Cons for that option include:

- Implementation of complex routing algorithms
- Possibility of having “holes” (discontinuities) in the recovered flight recorder data or having to re-order the received files. Further analysis should be carried out to assess whether or not the order of packets/files matters as long as they are transmitted, as well as if it is better to have some missing data rather than a small amount of continuous data.

5.2.3.9 FB3-34: File / packet / chunk size

File size, packet size and chunk size have an influence on the amount of successfully recovered data especially when compressed and encrypted. Indeed, the file/packet/chunk shall entirely be successfully transmitted in order to be deciphered and uncompressed (cf. §4.2.2 and §4.2.3). Further analysis will need to be conducted to assess the best balance between transmission of larger amounts of data and transmission of several smaller amounts of data. Results may influence the allocation of the encryption and compression sub-functions in the functional architecture.

Note: Depending on the overhead introduced by the successive layers of protocols as well as encryption, the ratio between the overhead and the payload (useful flight data recordings) should be assessed. It may be worth waiting for a certain amount of flight recorder data to be recorded, especially in the streaming case, before transmitting it. This might result more in a “scheduled transmission” scheme than in an actual streaming of real-time flight data.

5.2.3.10 FB3-41: Internet Protocols

Transmission protocols will influence the performance of the transmission, and their implementation will impact the cost of the solution. Internet Protocols (IP) may be a good candidates for implementing QR-FRD solutions compared to other aeronautical or proprietary solutions. IP indeed provides among other benefits:

- Efficient routing
- Quality of Service
- Built-in authentication and privacy support

5.2.3.11 FB3-51: By CMU

Communication Management Units (CMU) are designed to handle multiple threads of datalink communications, primarily for air traffic services and airline operations applications, feeding radios (presently VDL, HFDL and SATCOM) with information to be transmitted according to different protocols (e.g. ACARS) and predefined sets of rules (e.g. priority, availability, cost…) in one direction, and bridging the radios and the applications in the other direction. CMU are connected to different computers and displays but can also host applications.

Pros for that option include:

- Increases operational assurance in critical cases (the CMU is DAL C compliant)
- Manages protocols addressing the different communication means
- Configurable sets of rules for routing different information types over different communication media
- Already present onboard all aircraft

Cons for that option include:

- Requires an ATN/IPS compliant communication stack to be implemented.

5.2.3.12 FB3-52: By FDIU/FDAU or by ACMS unit

The FDIU/FDAU or ACMS units includes a transmission function, which is interfaced with the communication means through the CMU or the AISD router. This function enables transmission of different data flow, today dedicated to maintenance purpose, to different ground user, based on predefined rules (e.g. priority, availability, cost…). For this purpose, the communication media is managed by the onboard router (CMU or AISD Router)

Pros for that option include:

- Choice in certification effort and cost (choice between DAL C, D or E compliant)
- IP-oriented communications
- Leaves the onboard router manage protocols addressing the different communication means
- Easily configurable/upgradeable (for DAL D or E)

Cons for that option include:

- Requires an update of the interface between the two units: FDIU/FDAU/ACMS unit. The CMU/AISD router need to be updated too.

5.2.3.13 FB3-53: By AISD router

Similarly to the CMU, Airline Information Services Domain (AISD) routers interface computers/avionics and displays supporting dedicated airline applications (e.g. flight and maintenance operations) with wireless communications means, including gatelink WiFi, cellular connections and SATCOM (e.g. Iridium).

Pros for that option include:

- IP-oriented communications
- Manages protocols addressing the different communication means
- Affordable asset
- Scalable and easily configurable/upgradeable

Cons for that option include:

- Not present onboard all aircraft.

5.2.4 FB4: Off-Aircraft Storage

As mentioned above in §4.1.7, several organizations among which the airline and the aircraft manufacturer presently collect and store securely aircraft-originating data for their own purpose, typically flight operations and predictive maintenance analysis.

Note: Flight data belong to the airline and special agreements are in place with the aircraft manufacturer that authorize their use for the aircraft manufacturer's benefits.

Note: Though flight recorder data belong to the airline, Accident Investigation Authorities (AIA) are entitled to recover them from the flight recorders as soon as they are retrieved after an accident or a serious incident. The airline and/or the aircraft manufacturer are later invited to support the investigations. Flight recorders are then made available to the AIA which are able to retrieve data from much damaged recorders and have tools to retrieve more data than the normal replay tools used by operators. The flight recorders recovery described in ICAO Annex 13 [Ref 4] and Regulation (EU) 996/2010 [Ref 23] are also set to avoid possibilities for the airline and/or the aircraft manufacturer to tamper the recordings before investigations start. Such concepts of operation will need to be replicated on the "virtualized" flight recorders. Generation, ownership and distribution of necessary encryption keys as discussed for data protection in §4.2.3 above will influence (or be influenced by) the concepts of operations, which may in turn impact the overall end-to-end system architecture.

Note: The amount of data to be stored for a flight that was subject to an accident is negligible compared to the amount of data collected routinely from nominal flights by the airline and/or aircraft manufacturer. For instance, recordings of flight recorder data over a year for all transatlantic flights entering and leaving the EUROCONTROL pan-European network (approx. 1,700 in 2018)[31], would only occupy a couple of tera-octets should the data be streamed. This amount is significantly reduced if the recordings are deleted periodically. Recordings of flight recorder data from an accident flight and transmitted after a distress condition trigger would only occupy a couple of mega-octets (cf. §4.2.1 above).

Note: Statistical analysis seems to be difficult if not impossible to perform as accidents are too few and present too different cases. The need for storing (and maintaining securely) accidents historical data on dedicated servers/repositories for years may be questionable.

Note: False-positive triggering will generate transmission of flight data, their storage and hence an analysis that can be possibly canceled afterwards. The analysis and decision that the data resulted from false-positive triggering should result in revising the trigger detection algorithms (by AIA) and/or revisiting their implementation (by airline, aircraft manufacturer and QR-FRD system manufacturer).

Options identified for Off-Aircraft Storage defined in §5.1 are described hereafter.

5.2.4.1 FB4-1: By the airline / aircraft OEM

The airline and/or the aircraft manufacturer already collect and store flight data originating from the aircraft for their own purposes (respectively flight operations quality and predictive maintenance).

Pros for that option include:

- Most of the infrastructure and processes are already in place, limiting cost for implementing the QR-FRD aspects
- Facilitated access to recordings for the operator to perform periodic inspections to ensure the different recordings are of acceptable quality (ref. Part. CAT [Ref 22] CAT.GEN.MPA.195(b) and ICAO Annex 6 Part I [Ref 1] Annex 8).

Cons for that option include:

[31] Source: https://www.eurocontrol.int/news/celebrating-100-years-transatlantic-flights

- Ethical issues raised by the possibility of tampering with the data prior to making it available to investigators. Even if the data is encrypted and authenticated, doubts will remain in general public minds.

Note: In order to perform periodic quality inspection of the recordings, the operator (or a contracted service) will have to be able to access to flight recorder data. If this should be relatively easy should flight recorder data be streamed, this may not be feasible should flight recorder data be transmitted after detection of a trigger condition discussed in §4.1.5. A specific transmission trigger, e.g. manual / test condition would be required, likely initiated by the flight crew with their consent. Triggering the transmission from the ground (e.g. uplink request), though technically feasible, will need to be addressed cautiously as it may introduce a cybersecurity breach and the flight crew will have to be notified upfront.

5.2.4.2 FB4-2: By ATS

Air Traffic Services (ATS) are other organizations used to collect and store data (typically voice and data link communications) as well as surveillance data for their own purposes.

Pros for that option include:

- Most of the infrastructure and processes are already in place, limiting cost for implementing the QR-FRD aspects

Cons for that option include:

- Several air traffic services are in charge of the aircraft along its flight. This may result in multiple data destinations (impact on end-to-end transmission, typically routing) and storage location (impact on data recovery from multiple locations)[32].
- It is not a mission of ANSP to store and protect the whole set of flight recorder data. This would require a change to the regulatory framework of ATS at global scale, starting with a change to ICAO Annexes 10 and/or 11. Also, ATS combine many aircraft on the same frequency and store a lot less data compared to recording from each aircraft. ATS does not record the flight deck audio channel of a CVR nor communications between crew members through the aircraft audio system.

5.2.4.3 FB4-3: By CSP/DSP

Communication Service Providers (CSP) and Data link Service Providers (DSP) are other organizations used to collect data exchanged by aircraft for their own purposes. Some DSP already provide services incl. secure data storage and analysis to airlines.

Pros for that option include:

- Most of the infrastructure and processes are already in place, limiting cost for implementing the QR-FRD aspects

Cons for that option include:

- Several CSP/DSP are in charge of the aircraft along its flight. This may result in multiple data destinations (impact on end-to-end transmission, typically routing) and storage location (impact on data recovery from multiple locations).

[32] These issues are mitigated when using IP-based transmissions and networks.

5.2.4.4 FB4-4: By AIA

Storage by Accident Investigation Authorities (AIA) would obviously be an option since the flight recorder data are primarily meant for their purpose, i.e. accident and serious incident investigations.

Pros for that option include:

- Storage and later recovery by the principal stakeholder

Cons for that option include:

- The designated AIA is not known in advance (prior to take-off) as this depends on several factors among which the location of the accident.
- If processes could readily be in place, most of the required infrastructure is not, impacting cost for implementation
- Ownership of the data and the governance model are still issues to be solved (cf. §4.2.3). These issues will be discussed in D4, D7 and D9 later in the study. This may nevertheless be an option for triggered transmission as continuous transmission would put the legal and financial burden of ensuring the preservation of non-accident related data on AIA, which is disproportionate with regards to their mission.

Note: An international / global or regional network of AIA could be envisioned in the future that would set the required infrastructure in place, act as a single destination for the flight data received after triggered transmission typically, manage storage and access rights with the AIA in charge of the investigations. Nevertheless, very few States would be ready to give up their prerogatives regarding safety investigations, as this corresponds to surrendering part of their States' core powers. The concept of a state-owned repository has been brought up in discussions with the consortium and should be further investigated[33].

5.2.4.5 FB4-5: By SWIM

A System Wide Information Management system, aka "aviation cloud", as being considered for Collaborative Decision Making (CDM) applications, could be an option for storage as it already addresses reception and sharing of aircraft-originating data, as well as management of access rights to these data by stakeholders, incl. airlines, aircraft manufacturers, air traffic services, etc.

Pros for that option include:

- Principles and mechanisms already deployed locally, which could be instantiated for AIA purposes (cf. note in §5.2.4.4), QR-FRD would be seen as yet another application

Cons for that option include:

- SWIM is meant for "open sharing" of information among the ATM stakeholders. Protecting flight data recordings for the sole sake of accident investigations should be added to the scope.

Note: The Location of an Aircraft in Distress Repository (LADR) specified by ICAO ([Ref 7]) lies on the same principles as SWIM, i.e. a centrally managed data repository accessible to appropriate stakeholders among which air traffic control, search and rescue organizations, and aircraft operators. Nevertheless, it is dedicated to the collection, storage and sharing of aircraft in distress position information, and unlikely to be expanded to managing flight recorder data even if their transmission is triggered after a distress condition is detected. A similar central repository of flight recorder data may

[33] Storage of flight recorder data and especially audio recordings (due to their private contents) by organizations like EASA was also brought up during discussions. There could then be a problem of independence, AIA having to be independent from national aviation authorities according to EU Regulation 996/2010, Article 4.

be envisaged, provided it is operated in accordance with the EU legislation for accident and incident investigations.

5.2.5 FB6: Data Recovery

AIA recovers the protected flight data recordings from the repository identified in FB-4 Off-Aircraft Storage (cf. §5.2.4).

Note: At the time the present document was drafted, the need for a CONOPS describing roles and responsibilities as well as interactions between the QR-FRD stakeholders was identified (cf. discussions in §4.2.3). At this stage, it is unclear how simple it will be for the AIA to remove the protections set in place and get access to the data.

5.3 CANDIDATE SOLUTIONS

5.3.1 Impact to flight crew workload

Transmission of flight data, whether by streaming, "scheduling" or triggering, cf. §5.2.3, will be automated, hence will not impact the flight crew workload negatively. This should obviously be a requirement, especially for solutions based on distress conditions triggering.

5.3.2 Impact to existing airborne architectures

Impact resulting from the introduction of this new capability onboard modern long-haul air transport aircraft should be limited since most of the components (avionics) foreseen in its implementation already exist, or will be existing (e.g. next generation communication means). Globally, cf. discussions in §5.2 above:

- There should not be modifications to existing flight recorders
- There should be (depending on the solution) hardware modifications to units hosting the data collection function (FB1) (e.g. addition of interfaces for microphones to FDAU/FDIU/ACMS/AISD routers)
- There should be software adaptations for units hosting the trigger logic function (e.g. CMU/AISD router or FDAU/FDIU)
- There should be software adaptations for units hosting the data transport function (FB3) with data packing and packing prioritization logics (e.g. CMU/Communication Router/AISD router)
- There should possibly be tuning/configuration of the multi-link routing function for the unit hosting the data transport function (FB3) (e.g. CMU/Communication Router/AISD router)
- There could be major modifications to the installation should new radios be required to support the data transport function (FB3)
- There should be, depending on the concept of operations, configuration of the units hosting the required encryption keys and authentication certificates (e.g. CMU/Communication Router/AISD router/FDIU/FDAU/ACMS) as well as certificate renewal management by, e.g., Enrollment over Secure Transport (EST) protocols.

Once the two most promising solutions are selected, their architecture will be refined and impacts detailed as part of Task 3 "Technical investigation of two technical solutions for automatic wireless transmission of flight recorder data" of the study.

Note: ICAO Annex 6 Part I ([Ref 1]) requires that an alternate power source powers the CVR and its associated cockpit area microphone components automatically and for at least 10 minutes when all other power sources are lost. Use of batteries[34], provided the requirement is met, is acceptable if

[34] Most battery backups are nowadays transitioned to Li-batteries. These require cautious installations compliant with Special Conditions (cf. EASA SC-F25.1353-01 / CS 25.1353 Amendment 18, Apr. 2021) since they are associated with known potential hazards such as self-sustaining fire and/or explosion.

electrical power to essential and critical loads is not compromised. This requirement, when transposed to the QR-FRD solutions, will impact the airborne architecture in terms of wiring (connecting the full QR-FRD airborne suite, from units collecting the flight recorder data to the SATCOM antenna, to emergency power sources) and provision of extra storage capacity should batteries be used. The induced increase in weight and power consumption will be discussed during activities undertaken within Task 4.

5.3.3 Impact to existing ground-based infrastructures

Impact resulting from the introduction of this new capability to existing ground-based infrastructures would be limited to the introduction of new antennas and transceivers required by the future aeronautical datalinks (FB3), assuming they come in replacement ("plug-ins") on existing terrestrial infrastructures and networks.

The most noticeable impact would be for the off-aircraft function storage (FB4) should the AIA option (FB4-4) be retained. Nevertheless, the cost of the deployment for the solution is relatively inexpensive with current networks, servers and other customer off-the-shelf (COTS) products.

5.3.4 Impact to current operations

Impact resulting from the introduction of this new capability to current operations will depend on the concepts of operations set in place for storing, securing and accessing the flight data in view of investigations after an accident (typically encryption key management) as discussed in sections above.

5.3.5 Criteria for the evaluation of solutions

The following criteria were identified to assess the candidate solutions:

Category	Definition / Scoring Rule
Factors[35]	Resilience to loss of power while aircraft is in-flight (Factor 1) 0: No 1: Yes
	Resilience to loss of main electric power (Factor 2) 0: No 1: Yes
	Resilience to significant or unusual attitude (Factor 3) 0: No 1: Yes
	Resilience to significant or unusual attitude variation rate (Factor 4) 0: No 1: Yes
	Resilience to in-flight fire or loss of physical integrity (Factor 5) 0: No 1: Yes
	Resilience to collision with terrain or the water (Factor 6) 0: No 1: Yes
	Resilience to post impact fire (Factor 7) 0: No 1: Yes
	Resilience to sinking into water after ditching (Factor 8) 0: No 1: Yes
	Resilience to missing terrestrial infrastructure (Factor 9) 0: No 1: Yes
	Solution maximizing the bandwidth in distress situation (Factor 10) 0: No 1: Yes
	Solution extending the duration of the transmission in distress situation (Factor 11) 0: No 1: Yes
	Solution performance not degraded by the aircraft location (Factor 12) 0: No 1: Yes
	Solution minimizing loss of data during transmission (Factor 13) 0: No 1: Yes
	Solution maximizing transmission performance (Factor 14) 0: No 1: Yes
Performance and Quality of Service	Coverage 1: Continental 2: Continental + oceanic 3: Worldwide, incl. polar regions
	Throughput 1: < 100 kbit/s 2: 100 - 500 kbit/s 3: > 500 kbit/s

[35] The factors listed are part of those addressed in D1 (Ref []), known as "factors which affect the wireless transmission of flight data".

Category	Definition / Scoring Rule
	Service availability %
	Service continuity %
	Service reconnection time seconds
	Service cybersecurity/data protection offering 0: none 1: Air-Ground 2: End-to-end
Maturity Level	Deployment horizon 0: > 5 years 1: 1-5 years 2: Already available
Costs	Subscription – Communication 0: €€€ 1: €€ 2: €
	Subscription – Off-aircraft storage 0: €€€ 1: €€ 2: €
	Subscription – Certificates renewal 0: €€€ 1: €€ 2: €
	Equipment – Recurring costs (RC) 0: €€€ 1: €€ 2: €
	Equipment – Non Recurring Costs (NRC) 0: From scratch (full design and development) 1: From baseline (adaptation / reuse existing solutions)
	Equipment –Supplemental Type Certificate (STC) 0: Major modifications 1: Minor modifications 2: Not needed
	Probability of QR-FRD use by AIA %

Table 5: Criteria for the assessment of candidate solutions

5.3.6 Selection Matrix

The following table summarizes the findings from an applicability matrix, provided as a separate Microsoft ® Excel spreadsheet, for criteria defined in Table 5 with regards to options proposed in §5.2. The resulting scores are used to assess the different options and decide whether or not to consider the option as part of the selected solution.

Option	*Score*	*Comment*
FB1: Data Collection (Hosting options)		
FB1-1: By flight recorders only	*16*	*Higher scores due to factors other options will not be resilient to (e.g. fire, crash/ditching). Recovery of the data for transmission may show impractical.*
FB1-2: By flight recorders and Secure Mass Storage	*13*	*Introduction of a new equipment that would only address part of the solution*
FB1-3: By FDIU/FDAU or ACMS unit	*15*	*Already part of flight recording solutions / installations*
FB1-4: By AISD router	*13*	*Lower score than FB1-3 due to factors (i.e. electric power) in current installations.*
FB2: Start Condition Detection (Hosting options)		
FB2-11: By "AOC" application	*14*	*Already receiving flight data, and hosting trigger logics (AT-AC).* *A good option if routing is by CMU (FB3-51) and datalink media (FB3-21/22) are part of ACD medias.*
FB2-12: By FDIU/FDAU or by ACMS unit	*13*	*Already receiving flight data, and hosting trigger logics (ACMS)*
FB2-13: By AISD router	*13*	*Already receiving flight data, and hosting trigger logics (OFDM)* *A good option if routing is by AISD (FB3-53) and datalink media (FB3-21/22) are part of AISD / PIESD medias.*
FB2: Start Condition Detection (Transmission options)		
FB2-21: Streaming transmission	*7*	*High exploitation costs for "seldom" usage*
FB2-22: Triggered transmission	*11*	*Lower exploitation costs than FB-22, but performance highly dependent on trigger definition* *Performance to be evaluated by simulations.*
FB3-32: By flight phase FB3: Data Transport (Prioritization options)		
FB3-11: Prioritization by data type	*4*	*Scheme already in use for other purposes.* *Performance to be evaluated by simulations.*

Option	Score	Comment
FB3-12: Prioritization on time intervals	*3*	*Less mature than FB3-12* *Performance to be evaluated by simulations.*
FB3: Data Transport (Datalink technologies options)		
FB3-21: By current aeronautical data link technologies	*16*	*Pending survey results* *Performance to be evaluated by simulations.*
FB3-22: By future aeronautical data link technologies (a/g data link)	*12*	*Pending survey results* *Performance to be evaluated by simulations.*
FB3-23: By alternatives to SATCOM	*NA*	*Too low TRL*
FB3: Data Transport (Smart routing options)		
FB3-31: By data type	*4*	*Cf. FB3-11*
FB3-32: By flight phase	*5*	*Low maturity* *Performance to be evaluated by simulations <u>if time permits</u>.*
FB3-33: By multi-link	*NA*	*Little opportunities to multiple links available everywhere at the same time*
FB3-34: File / packet size	*NA*	*Common to any solution.* *Performance to be evaluated by simulations.*
FB3: Data Transport (Secured transmissions options)		
FB3-41: Internet Protocols	*NA*	*Common to any solution.*
FB3: Data Transport (Hosting options)		
FB3-51: By CMU	*17*	*Present on all aircraft, but not "IP ready" and less flexible than an AISD router.*
FB3-52: By FDIU/FDAU or by ACMS unit	*17*	*The FDIU/FDAU / ACMS unit is an option covering several FB Options.* *Necessitates a CMU/AISD router controlling the data link media.* *Functional architecture to be evaluated by simulations*
FB3-53: By AISD router	*17*	*The AISD router is an option covering several FB Options.* *Functional architecture to be evaluated by simulations*
FB4: Off-Aircraft Storage (Hosting options)		
FB4-1: By the airline / aircraft OEM	*13*	*Obviously the most efficient option.*

Option	Score	Comment
FB4-2: By ATS	*10*	*“Not their job” unless Annexes are updated, which may not happen for long.*
FB4-3: By CSP/DSP	*13*	*An option for airlines that cannot afford the tasks / infrastructure / … (basically do not own OFDM capabilities) and prefer to outsource the QR-FRD service.*
FB4-4: By AIA	*9*	*Political issues rather than technical issues.*
FB4-5: By SWIM	*10*	*Not really meant to share sensible data.*

Table 6: Solutions selection matrix

6 SOLUTIONS ASSESSMENT

From analysis of the scorings provided in Table 6 and further technical solutions that will be documented during Task 3, two hardware solutions emerge:

1. An "AISD-based" solution, articulated around an AISD router that would perform a major part of the data processing and possibly rely on other domain communication systems (i.e. ACD and PIESD)
2. An "FDAU/FDIU&ACMS-based" solution, articulated around FDAU/FDIU&ACMS units that would perform the major part of the data processing and rely on transmission systems, incl. the AISD router

On the ground side, the flight recorder data would be securely stored by the airline or a contracted organization, and made available to the designated accident investigation authority.

Figure 8 presents the two solutions and the functional allocations on the different hardware and assets.

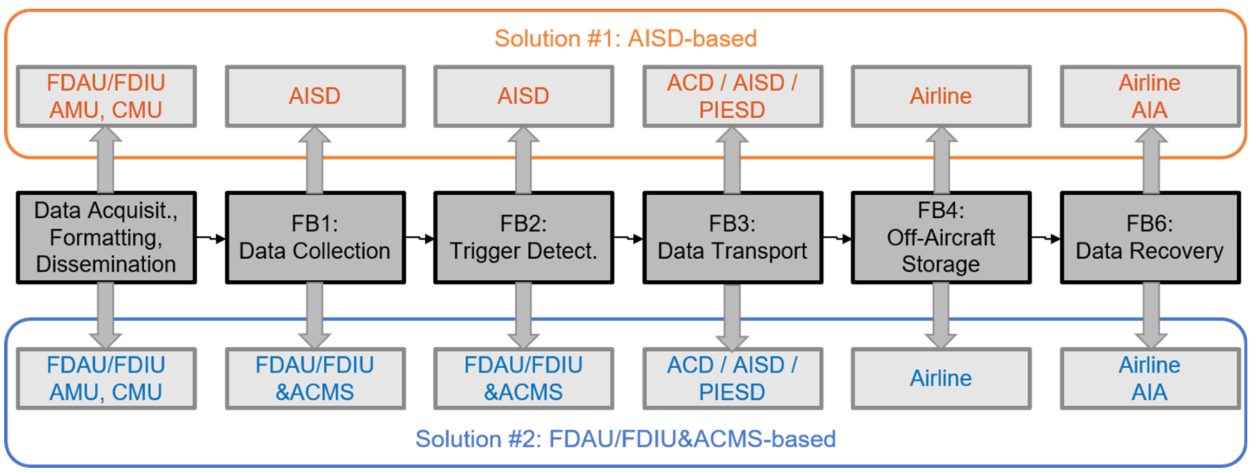

Figure 8: Presentation of the two solutions: "AISD-based" (top) and "FDAU/FDIU&ACMS-based" (bottom)

As can be seen, the two solutions are quite similar and basically rely on the same hardware, difference being in the distribution of functions.

From a functional standpoint, features such as transmission schemes (continuous or triggered), trigger conditions, data processing and data protection schemes (compression, signature, encryption, secure end-to-end transmission…), data link management (multi-link or SATCOM only), prioritization schemes (merged fixed-size chunks or per data type)… need further analysis including modeling and simulations.

The combinations of these features, which can be hosted by any of the two hardware solutions, are multiple. As a starting point for follow on activities within the QR-FRD study, these features have been distributed among two possible solutions as listed in Table 7.

Function/Topic	Solution #1	Solution #2	Comment
Transmission Scheme	Continuous	Triggered	
Merging	TBD	Yes	
Chunking	Adaptive (TBC)	Fixed	
Compression	TBD	Lossless	
Encryption	Audio only	Global	
Signature	Yes	Yes	
Storage	Limited	20 minutes min	Onboard buffer
E2E Secure Connection	https / sftp	VPN	
Data Link Media Mgt	Cellular + SATCOM	SATCOM	TBC by survey

Table 7: Distribution of functions among the two solutions

Note: The order in which the functions are listed does not reflect the actual order in which they will be implemented. This order will be further refined in D3.

ANNEX A: DATA LINK SERVICE PROVIDER SURVEY FORM TEMPLATE

SERVICE PROVIDER SURVEY

Precisely understanding the circumstances that lead to an accident is key to improving flight safety for the entire aviation industry and the flying public. In order to address the issue of late or non-availability of flight recorder data, EASA initiated a study titled "Quick Recovery of Flight Recorder Data" (ref. EASA.2020.HVP.06) aiming at identifying and assessing technical solutions for automatic wireless transmission of flight recorder data. Our consortium, composed of Collins Aerospace, Safran Electronics and Defense and Bertrand de Courville Consulting, has been selected by EASA to conduct it.

The aim of this survey is to gather information related to Data Service Provider capabilities such as link coverage / continuity / latency, throughput performance capability / capacity, quality of service (QoS), modalities of services delivery and pricing policy, in order to evaluate the candidate solutions for automatic wireless transmission of flight recorder data against measurable criteria. A simulation of the transmission chain model will also be implemented at a later stage of the study, based on these inputs.

Your input is critical to the quality and relevance of this study. In addition, we would like to draw your attention to the importance of providing feedback in order for us to take your service into consideration for the selection of solutions.

We understand that some information is business-sensitive and may not be communicated without restrictions. If needed, a Non-Disclosure Agreement (NDA) can be put in place between your organization and Collins Aerospace.

Should this be deemed insufficient, EASA could be the only recipient of the survey response and would only communicate to the consortium what you will have selected according to a dissemination level:

- PU = Public, can be used as input for simulation purpose and be part of the public report
- RE = Restricted to EASA and the consortium in charge of this study, can be used as input for simulation purpose, not part of the public report
- CO = Confidential, only EASA

To help us get a better understanding of the benefits of your solution, any complementary information is welcome.

Please return the survey form to Stephane Lelievre at stephane.lelievre@collins.com.

Should you be willing to respond to EASA directly, please let us know and we will provide you with the contact details.

Thank you for participating in our survey!

SURVEY QUESTIONS

Questionnaire	**Dissemination Level**		
	PU	**RE**	**CO**
Contact information • Date: • Name: • Company: • E-mail:			
Questions may concern several communication media. If relevant, please provide information for each. *If a characteristic is identified as a parameter in the data transmission model then it will be followed by the play symbol (▶) meaning it is necessary for relevant simulation results from our perspective.*			
Provider/service general information • Provider name: • Service name: • Supported communication media: *i.e.: L-Band, Satcom, safety and non-safety SBB, VHF-HF…* • Applicable MOPS / TSO: • Traffic type for which this media is best suited: *i.e.: data safety/non-safety, voice…*			

Questionnaire	Dissemination Level		
	PU	RE	CO
Network information • Do you provide connections to all ANSPs, AACs? • If yes, do you provide worldwide coverage? • Is there a Traffic Priority Management? • Do you have specific limitations that could have an impact on the performance (Aircraft position, altitude, environmental condition …)? • Please provide a coverage map if possible, information such as lat/long versus signal attenuation or at least something like “Worldwide without polar pole lat +80N and -80S”			

Questionnaire	**Dissemination Level**		
	PU	**RE**	**CO**
Quality of service (QoS) for uplink and downlink What is the average throughput per aircraft (kbps)? ▶ What is the average latency (ms)? ▶ What is the availability rate (%)? ▶ In case of loss of connection, what is the reconnection time? ▶ Do you provide authentication? Do you provide integrity checks? Do you provide confidentiality?			

Questionnaire	Dissemination Level		
	PU	RE	CO
<u>Deployment status and service roadmap</u> ☐ Fully deployed infrastructure ☐ Partially deployed infrastructure Date of full deployment: ___ / ___ / ______ ☐ Not deployed yet Date of availability: ___ / ___ / ______ Are there any changes in the coming 5 years that would affect your service (increased data rates, new services…)? If yes, can you provide information about it?			
● <u>Price related information</u> What kind of subscription do you propose (fixed prices on a monthly basis, according to the amount of data consumed...) and their prices (catalog price, price range...)? Is there a Supplemental Type Certificate (STC) available? Does it require a system that is not an aircraft basic system?			

Questionnaire	Dissemination Level		
	PU	RE	CO
• Other information that could be useful for the study *We are interested in any information that we may have missed and that could be very important in the context of this study. Please feel free to add additional information or attach documents.*			

ANNEX B: DATA LINK SERVICE PROVIDER SURVEY FORM

All the survey forms are protected by a Non-Disclosure Agreement and cannot be shared for the moment.

Current status:

Sept 2sd, 2021: OneWeb

Sept 9th, 2021: IntelSat

Oct 14th, 2021: SES ASTRA

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