European Union Aviation Safety Agency

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

RESEARCH PROJECT EASA.2020.C43

QUICK RECOVERY OF FLIGHT RECORDER DATA (wireless transmission)

Report D1

Accident conditions relevant for wireless flight recorder data transmission

An Agency of the European Union

DELIVERABLE NUMBER AND TITLE: QR-FRD D1 Accident conditions relevant for wireless flight recorder data transmission
CONTRACT NUMBER: EASA.2020.C43
CONTRACTOR / AUTHOR: Collins Aerospace / Safran E&D / B. de Courville Consulting
IPR OWNER: European Union Aviation Safety Agency
DISTRIBUTION: Public

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DATE: 31 May 2021

REPORT D1

Accident conditions relevant for wireless flight recorder data transmission

Submitted to:

EASA

European Union Aviation Safety Agency

Cologne, Germany

Document Information	
Customer reference	EASA.2020.HVP.06
Project Title	Quick Recovery of Flight Recorder Data
Contract number	EASA.2020.C43
Consortium	Collins Aerospace / Safran E&D / B. de Courville Consulting
Task Number	01
Task Title	Accident conditions relevant for wireless flight recorder data transmission
Deliverable Name	D1 - Accident conditions relevant for wireless flight recorder data transmission
Edition	02
Milestone Due Date	May 31st, 2021
Dissemination Level	Public

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1 Introduction

1.1 QR-FRD Study Presentation

"*The overarching objective of the* Quick Recovery of Flight Recorder Data (QR-FRD) *study is to identify and assess technical solutions for the automatic wireless data transmission to quickly recover flight recorder data after an accident in a remote land area or an oceanic area for the purpose of faster understanding of the causal and contributory factors of an accident*" (EASA QR-FRD CFT [R0].

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, [R1]), and mandated to have a Flight Recorder Data Recovery (FRDR) means on-board.

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

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

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

1. **Task 1 - Accident conditions relevant for wireless flight recorder data transmission:**
    - **Objective**: Identify and describe the technical and environmental factors which might affect the aircraft, its engines and its systems during the accident flight, and which need to be taken into account for maximizing the chances of successful wireless transmission of flight recorder data.
    - **Outcome**: A report (D1) of accident conditions which might affect the successful wireless transmission of flight recorder data (e.g. loss of power or equipment, excessive roll or pitch angles, in-flight fire, ditching …), and explaining the impact of such factors. that describes the considered factors.
2. **Task 2 - Overview of technical solutions for automatic wireless transmission of flight recorder data:**
    - **Objective**: perform a screening of possible technical solutions for automatic wireless transmission of flight recorder data (flight data, audio and flight-crew interface recordings, data link messages…) in case of an accident (or serious incident) in a remote land area or an oceanic area.

- **Outcome**: A solution overview report (D2) identifying the necessary technologies and capabilities of the communication infrastructure, as well as aspects not yet mature, and discussing the potential effects of factors listed in D1 on the presented solutions. In addition, D2 will recommend the 2 most relevant technical solutions for further investigation to be performed under Task 3.

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

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

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

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

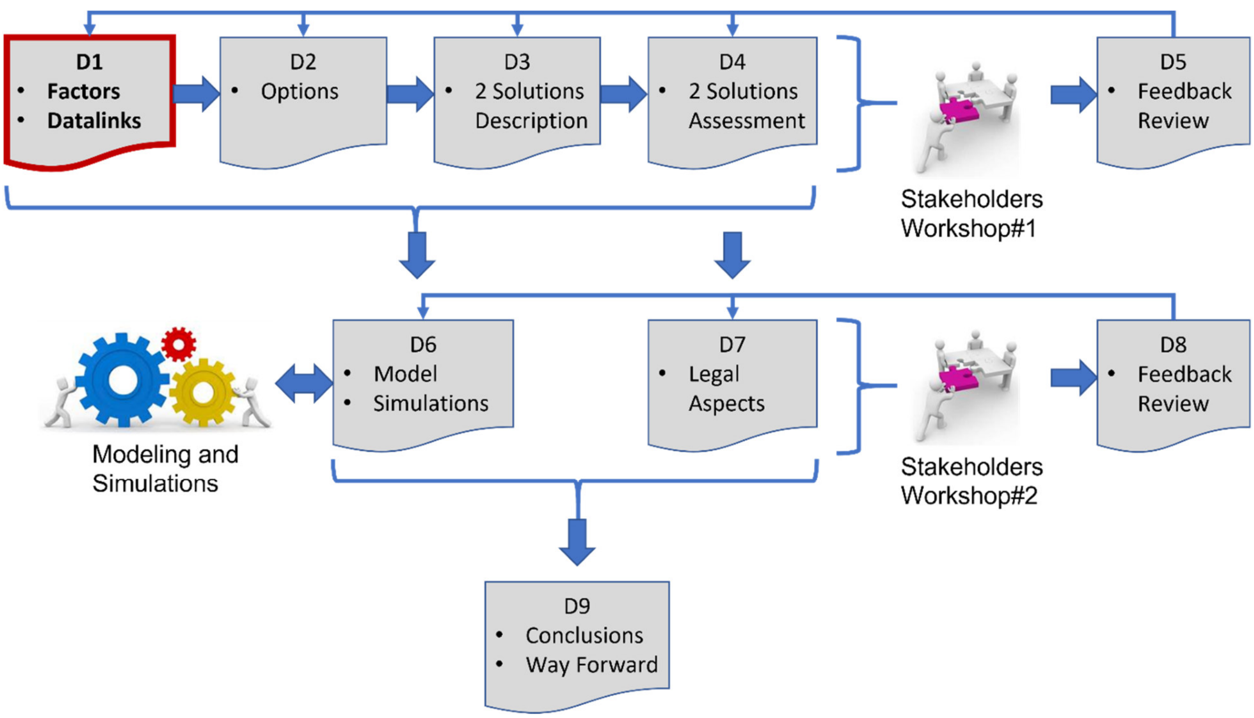


Figure 1: QR-FRD Study Approach and Deliverables Relationship

1.2 Scope of this report

The present document corresponds to D1 as depicted Figure 1. It is the Consortium result of the analysis of the technical and environmental factors that may affect an aircraft, its engines and its systems during a flight distress phase that is likely to lead to an accident. The objective is to analyze the chances of the successful wireless transmission of flight recorder data.

The analysis performed is mainly based on the initial work carried out by the BEA in 2011. In particular, the "Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile" (BEA) provides a report on the study (Ref [R6]) and a database with 44 flight data recordings with a final accident outcome.

1.3 Background

The event considered in the task described hereafter is an accident (as defined in ICAO Annex 13) involving an aircraft with a Maximum Certified Take-Off Mass (MCTOM) of over 27,000kg and operated for commercial air transport in a remote land area or an oceanic area (unlawful interference crashes are not part of the study).

2 Factors which affect the wireless transmission of flight data

The following is the list of the factors identified as possibly affecting the wireless transmission of flight recorder data, especially in the event of an emergency. The list is supplemented with a description of the effect, and, where possible, a quantified evaluation of the effect of the factors.

Note: In accordance with the meeting of 11 June 2021 between the EASA experts and the consortium members, it has been specified that transmission may include three use cases:

- The Timely Recovery of Flight Data (TRFD);
- The continuous transmission of flight recorder data;
- The transmission of the location of the aircraft in the event of an emergency.

This list is based on the experience of the European Union Aviation Safety Agency (EASA) (please refer to procurement document [R0]). It has been supplemented by the knowledge of BEA experts and the experience of the companies who are members of the consortium.

Quantification has been computed using the BEA flight database (please refer to BEA document [R6]).

2.1 Factors

2.1.1 Factor 1: "Loss of power on all engines while the aircraft is still in flight"

<u>Classification</u>: This factor is a "general scenario".

This factor is identified by EASA (and confirmed by aviation history).

This factor was not encountered within the BEA flight database (even though US Airways Flight 1549 and the ditching in the Hudson River is in everyone's mind).

Note: This event is also scenario #4 identified in document ED-237 [R2].

<u>Effect on the wireless transmission of flight data</u>

There are two major effects:

1) When there is no thrust, the flight will quickly terminate. The duration of possible flight data transmission is mainly linked to the altitude at which the engines failed. It can be up to several minutes, especially during the cruise flight phase (up to 30 minutes, please refer to Air Transat A330. The final diagram of the "Factor 11: Duration of emergency situations" chapter of this document provides a distribution of "emergency situation" durations).
2) Loss of the non-essential electric power network. Data transmission units are powered by this network.

- <u>Three cases that lead to this condition have been identified:</u>
    - 2.1) Fuel starvation or fuel exhaustion (for example, Tuninter flight 1153, August 2005). In this case, the power will not recover. In this example, the aircraft is an ATR72 with MTOW < 27t.
    - Note: This effect is the same as the following factor described below (Factor 2: "Loss of equipment that is a non-essential load for electric systems"). As described in this next section, today, communication units (routers, ACARS antenna, (except VHF dedicated to ATC), etc.) are not "essential" systems, and are not powered by the uninterrupted electric network.
    - 2.2) Engine shutdown is due to an external factor (volcanic ash, for example, please refer to the British Airways flight on 9 June 1982). In this case, the electric power network can be recovered by switching to the Auxiliary Power Unit (APU). In this case,

the effect is an interruption of transmission system power. At the very least, this interruption may be in the order of several dozen seconds.

- 2.3) Engine shutdown is due to a fuel leak (for example, Air Transat A330). In this case, the effect is an interruption of transmission system power with no solution (the APU cannot be switched on in this case).

2.1.2 Factor 2: "Loss of equipment that is a non-essential load for electric systems"

Classification: This factor is a "general scenario".

This factor is identified by EASA (and perhaps confirmed by the BEA flight database).

This factor is encountered once within the BEA flight database. If we consider the flight data referenced A008, some flight parameter recordings are stopped 14 seconds before the end of the recording. This event is synchronized with the non-availability of some data for engine 2. It would appear that engine 2 has shut down, also causing the shutdown of its electrical production, leading to the electrical load shedding of non-essential systems.

Effect on the wireless transmission of flight data:

Today, FDR systems (data and voice recorders, combo recorders, FDAU/FDIU, etc.) are powered by the uninterrupted electric network and/or may include additional self-power storage (please refer to Recorder Independent Power Supply or RIPS, described in the Arinc 777 document). Nevertheless, with the exception of the VHF communication unit, used for ATC (triplex system), the other units involved in ground/flight communication are considered non-essential. These units include the router, the ACARS, the antenna, and any other dedicated units. Taking this consideration into account, these communication units are not powered by the uninterrupted electric power network.

Therefore, when the power is shut down, transmission is stopped.

If transmission is requested when a non-essential load for electric systems has failed, the communication system may be powered by the uninterrupted electric network, or may include internal power storage.

2.1.3 Factor 3: "Significant [or unusual] pitch and roll attitudes"

Classification: This factor is a "general scenario".

This factor is identified by EASA and the consortium.

For the majority of the flight data provided by the BEA database, the pitch and roll of the aircraft are recorded until the end of flight. These recordings are precious data for the evaluation of the aircraft attitude before the final outcome.

Note: This event is also scenario #1 identified in document ED-237 [R2].

Effect on the wireless transmission of flight data

In order to be able to communicate, the communication relay (satellite, VHF station) must be visible and addressable from the aircraft antenna. Depending on the characteristics of the antenna, in the event of excessive pitch/roll, the link is interrupted.

Directional antennas have a limited angular beam weight and it is necessary beam point them to a satellite through an antenna positioner or to beamform the beam of an antenna to ensure inter-visibility between the aircraft and the satellite with an optimum link budget.

Qualification of this effect

Using the BEA 44 accident flight database, the evaluation of the impact of this factor is as follows:

- If transmission is only possible when the aircraft pitch/roll value is between -90° and +90°, transmission is only possible for 85% of the "Warning time[1]" given by the BEA. (This value corresponds to a mechanical SATCOM antenna, vertically connected to a satellite from the aircraft, or to a VHF antenna, connected to a ground station exactly under the aircraft).
- If transmission is only possible when the aircraft pitch/roll value is between -60° and +60°, transmission is only possible for 75% of the "Warning time" given by the BEA. (This value corresponds to an electronic SATCOM antenna, vertically connected to a satellite from the aircraft).

Note: The BEA flight database does not provide the position of the aircraft. For this analysis, it has been decided that the wireless communication relay (satellite, VHF station, etc.) is located vertically with regard to the aircraft.

An additional parameter may be included in this analysis: when communication is interrupted and the aircraft has returned to a standard attitude, the resumption of the transmission service is not instantaneous. A delay of 10 seconds (typical average value) has been added for this analysis. In this case, the percentage changes:

- For the first case (-90°/+90°), transmission is only possible for 79% of the "Warning time" given by the BEA;
- For the second case (-60°/+60°), transmission is only possible for 67% of the "Warning time" given by the BEA.

During this interruption of communication, a buffer is requested to memorize the data (i.e., flight parameters, voices, datalink and images) that cannot be transmitted, especially for the continuous transmission of flight data. When communication is reestablished, the content of the buffer is transmitted at the same time as the real-time data.

Additional limitations to DO262E regarding antennas may be added to increase the success of transmission.

2.1.4 Factor 4: "Unusual [or excessive] pitch and roll [and yaw] rates"

Classification: This factor is a "general scenario".

This factor is identified by EASA and the consortium.

For the majority of the flight data provided by the BEA database, the pitch, roll and heading of the aircraft are recorded every second until the end of the flight. Through the difference between two samples, it is possible to evaluate the rate of the attitude modification. These recordings are precious data for the evaluation of aircraft attitude modification before the loss of the aircraft.

Note: This event is also scenario #1 identified in document ED-237 [R2].

[1] In accordance with the BEA 2011 document, "Warning time" is the duration between the "Emergency situation" trigger and the "time to impact".

Effect on the wireless transmission of flight data

In the case of a directional antenna, the acquisition and tracking dynamics of the antenna must be compliant with the movement of the aircraft. Otherwise, the link is interrupted.

Directional antenna, acquisition and tracking pointing performances (speed rate) must be greater than the aircraft attitude (pitch, roll, heading) speed rate to ensure continuous satellite tracking with no datalink interruptions.

Qualification of this effect:

Using the BEA 44 accident flight data, the evaluation of the impact of this factor is as follows:

- If the antenna is only compliant with DO262E (dynamic: 6°/sec), transmission is only possible for 54% of the “Warning time” given by the BEA;
- If the antenna has a dynamic of 12°/sec, transmission is only possible for 71% of the “Warning time” given by the BEA. (This value corresponds to a standard mechanical SATCOM antenna);
- If the antenna has a dynamic of 20°/sec, transmission is only possible for 79% of the “Warning time” given by the BEA. (This value corresponds to an efficient mechanical SATCOM antenna).

An additional parameter may be included in this analysis: when communication is interrupted and the aircraft attitude returns to a standard speed, the resumption of the transmission service is not instantaneous. A delay of 10 seconds (order of magnitude of Inmarsat 4, Iridium Next or SATCOM in L band) has been added for this analysis. In these cases, the percentage changes:

- For the first case (6°/sec), transmission is only possible for 40% of the “Warning time” given by the BEA;
- For the second case (12°/sec), transmission is only possible for 60% of the “Warning time” given by the BEA;
- For the third case (20°/sec), transmission is only possible for 67% of the “Warning time” given by the BEA.

Note: For directional antenna, it is important that the motion sensors are located inside the antenna, and that the antenna does not use aircraft navigation computer data. In an “emergency situation”, if the antenna is autonomous, this increases the quality of position control.

Additional limitations to DO262E regarding antennas may be added to increase the success of transmission (increase of the minimum antenna speed).

2.1.5 Factor 5: "In-flight fire [or in-flight loss of aircraft physical integrity], which does not completely destroy the aircraft"

Classification: This factor is a "general scenario".

The "in-flight fire" factor was initially identified by EASA. It was increased during analysis by an additional factor (in-flight loss of aircraft physical integrity), with the same effect. This concerns the "in-flight loss of aircraft physical integrity" (referring, for example, to Turkish Airlines Flight 981-Hernemonville).

It is not possible to provide information concerning this factor with regard to transmission systems from the BEA flight database.

Effect on the wireless transmission of flight data

With respect to "in-flight fire" factors, three cases must be considered:

1) Cabin fire: This has no effect on the wireless transmission system (computer in the electronics bay, antenna outside)[2];
2) Cockpit or electronic bay fire:
    1. If the fire affects the computers and/or the wiring of the transmission system, the performance of the transfer is degraded and all transmissions possibly aborted.
    2. If the fire does not affect the transmission system computers/wiring, there is no effect on wireless transmission.
3) Cargo bay fire (examples: UPS Boeing 747 near Dubai Airport in 2010 or Asiana Boeing 747 in 2011 lost at sea. Both were cargo aircraft.):
    1. If the fire affects the wiring of the transmission system, the performance of the transfer is degraded and all transmissions possibly aborted.
    2. If the fire does not affect the transmission system wiring, there is no effect on wireless transmission.

With respect to the "in-flight loss of physical integrity" factor, two cases must also be considered:

1) The loss of physical integrity concerns the wireless transmission system and its wiring (example: tearing off of the SATCOM antenna): in this case, the performance of the transfer is degraded and all transmissions possibly aborted.
2) The loss of physical integrity does not affect the wireless transmission system: in this case, there is no effect on wireless transmission.

Note: Until the advent of the latest aircraft, the flight recorder system had no redundancy. The communication system (with the exception of the ATC system) also had no redundancy. On new generation aircraft, flight recorders (combo recorders) are redundant and located one at the front and one at the rear of the aircraft.

Note: Until the advent of the latest aircraft, the location of the flight recorders in the aircraft implied long-length wiring. This increases the risk of "loss of the flight recording function" through "cable tearing" in the event of mechanical effects occurring in-flight.

In accordance with current knowledge and data, it is not possible to quantify the effect of these two factors.

[2] The only possible effect concerned the wiring running along the fuselage. If the cabin fire destroys the antenna wiring, the effect is the same as "cable tearing"

To increase the robustness against these factors, the redundancy of the communication system (computer, antenna, wiring), is requested.

Note: Today the communication system is not redundant.

2.1.6 Factor 6: "Collision with land or water, which does not completely destroy the aircraft"

Classification: This factor is an "issues of survivability".

This factor is identified by EASA and is confirmed by the analysis.

Not all crashes completely destroy the aircraft. Following a hard landing that does not destroy the aircraft, but which causes severe damage to the aircraft's structure, recorder data transmission may be possible.

Effect on the wireless transmission of flight data:

Following a crash that does not completely destroy the aircraft, three points must be considered with regard to flight recorder data transmission:

- In the scope of the transmission of flight recorder data, are all units involved in the transmission still powered?
- In the scope of the transmission of flight recorder data, are all units involved in the transmission still connected (cable tearing)?
  - What is the situation with respect to the robustness of the unit (especially the antenna) following a "hard landing", which causes severe damage to the structure of the aircraft?

Note: The SATCOM antenna (dedicated to transmission) is a directional antenna, with an accuracy of a few degrees. It is difficult to imagine that it would be operational following the acceleration of an impact.

If transmission is requested, following a crash, which does not completely destroy the aircraft:

- In the scope of the transmission of flight recorder data, all user units may be powered by the uninterrupted electric network, or may include internal power storage;
- The wiring between the user units in the scope of the transmission of flight recorder data may be redundant and reduced in size;
- In the scope of the transmission of flight recorder data, all user units may be qualified to survive a crash (especially acceleration/impact, please refer to the EUROCAE ED12/RTCA DO160 document).

2.1.7 Factor 7: "Post-impact fire, when the crash does not completely destroy the aircraft"

Classification: This factor is an "issues of survivability".

This factor is identified by EASA and is confirmed by the analysis.

In all BEA flight database cases, when the aircraft reaches the ground, all recordings are stopped.

In the event that the crash does not completely destroy the aircraft, the post-impact fire will stop the transmission. The following section will analyze the possibility of increasing transmission time.

Effect on the wireless transmission of flight data

Following a crash that does not completely destroy the aircraft, in the event of a post-impact fire, three points must be considered with respect to flight recorder data transmission:

- In the scope of the transmission of flight recorder data, are all user units still powered?
- In the scope of the transmission of flight recorder data, are all user units still connected (cable tearing)?
- What is the situation with respect to the robustness of the unit (especially the antenna) following a "hard landing" and fire, which cause severe damage to the structure of the aircraft?

Note: The SATCOM antenna (dedicated to transmission) is a directional antenna, with an accuracy of a few degrees. It is difficult to imagine that it would be operational following the acceleration of an impact.

If transmission is requested, following a crash, which does not completely destroy the aircraft:

- In the scope of the transmission of flight recorder data, all user units may be powered by the uninterrupted electric network, or may include internal power storage;
- The wiring between the user units in the scope of the transmission of flight recorder data may be redundant and reduced in size;
- In the scope of the transmission of flight recorder data, all user units may be qualified to survive a crash (especially acceleration/impact and fire resistance, please refer to the EUROCAE ED12/RTCA DO160 document).

2.1.8 Factor 8: "Aircraft sinking into water, after ditching, which does not completely destroy the aircraft"

Classification: This factor is an "issues of survivability".

This factor is identified by EASA and is confirmed by the analysis.

In all BEA flight database cases, when the aircraft reaches the water and sinks, all recordings are stopped.

Effect on the wireless transmission of flight data

Following ditching, which does not completely destroy the aircraft, five points must be considered with regard to flight recorder data transmission (it is assumed that the communication antennas used for transmission are located on top of the aircraft fuselage:

- Are the antennas in the water?
- Is the floating aircraft stable or not (is the sea rough?
- In the scope of the transmission of flight recorder data, are all user units still powered?
- In the scope of the transmission of flight recorder data, are all user units still connected (cable tearing)?
- What is the situation with respect to the robustness of the unit (especially the antenna) following a "hard landing" and fire, which cause severe damage to the structure of the aircraft?

Note: The SATCOM antenna (dedicated to transmission) is a directional antenna, with an accuracy of a few degrees. It is difficult to imagine that it would be operational following the acceleration of an impact.

If transmission is requested, following a ditching, which does not completely destroy the aircraft:

- The antenna is located on top of the aircraft fuselage;
- Additional limitations to DO262E may be added to increase the success of transmission (increase in the minimum antenna speed);
- In the scope of the transmission of flight recorder data, all user units may be powered by the uninterrupted electric network, or may include internal power storage;
- The wiring between the user units in the scope of the transmission of flight recorder data may be redundant and reduced in size;
- In the scope of the transmission of flight recorder data, all user units may be qualified to survive a crash (especially acceleration/impact and fire resistance, please refer to the EUROCAE ED12/RTCA DO160 document).

2.1.9 Factor 9: "Aircraft out of range of ATC surveillance systems within the 60 minutes preceding the accident and until the accident"

Classification: This factor is a "general scenario".

This factor is identified by EASA.

This case could not be identified in the BEA flight database.

The analysis conducted is as follows: currently, the ATC surveillance system is not available when the aircraft is over the ocean or unpopulated land. In these locations, SATCOM communication is mainly used. The VHF link is partially possible and the HF link is not guaranteed.

This factor also addresses flight over mountainous terrain. This might limit or obstruct wireless transmission, but for other reasons, such as signal bouncing. The effect on the wireless transmission is identical.

In other words, factor 9 concerns the fact that the accident may take place in a remote or oceanic area. The initial name of the factor 9 was given in the project "Part II: Tender specification", nevertheless, the factor 9 title can be reformulated into "Accident take place in a remote, oceanic area or over a mountainous terrain". The name is not modified for traceability purpose.

Note: The means of communication used for long-range transport are VHF, HF and SATCOM.

Effect on the wireless transmission of flight data:

- VHF communication not possible;
- HF communication not guaranteed.

The main communication link for the transmission of flight recorder data is based on those of satellites.

2.1.10 Factor 10: "Inappropriate architecture or link solution impacting the bandwidth of the global system in an emergency situation"

Classification: This factor is a "general scenario".

This factor is identified during the analysis and is dependent on the architecture of the solution.

This case could not be identified in the BEA flight database.

This factor concerns the availability of data transfer in the context of the TRFD. When the "emergency condition" trigger is activated, the on-board units have to transmit flight recorder data as fast as possible.

Several architecture solutions will be proposed and analyzed in subsequent activities of the study. The objective is to identify the architecture that maximizes data transmission (refer to Document D2, D3 and D4, of this project).

The architecture may optimize transfer speed, in order to reduce the latency induced by standard transmission: compression, negotiation of cybersecurity key, etc. To this end, the solution must provide:

- The largest bandwidth possible;
- The most in-depth history possible;
- Optimized data preprocessing (encryption, compression, etc.), in order to limit latency before transmission.

Effect on the wireless transmission of flight data:

- Optimal transmission in distress situations.

Within a given period of time, the volume of data is proportional to the bandwidth: the larger the bandwidth, the greater the volume of data transmitted. On the contrary, for a given volume of data, the larger the bandwidth, the shorter the transmission time.

Note: The fact that the frequency is protected is mitigated by the guarantee of link availability factor and the fact that a protected spectrum offers better link availability, for example, with safety services in Inmarsat IV Swift Broadband with 99.9% as required in ICAO Gold.

The architecture of the solution may optimize data transfer.

2.1.11 Factor 11: "Duration of emergency situations"

Classification: This factor is a "general scenario".

This factor was identified during the analysis.

In this initial study, the "emergency situation" trigger is based on BEA algorithms provided in the BEA 2011 document. This document also provides the duration of "warning times", i.e., the time between the "emergency situation" trigger and the "time to impact".

This factor concerns the availability of data transfer in the context of the TRFD.

It is possible to transmit a larger volume of data if this duration is increased. If it is possible to detect the "emergency situation" earlier, it may be possible to transfer more data. The volume of data is directly proportional to the transmission time.

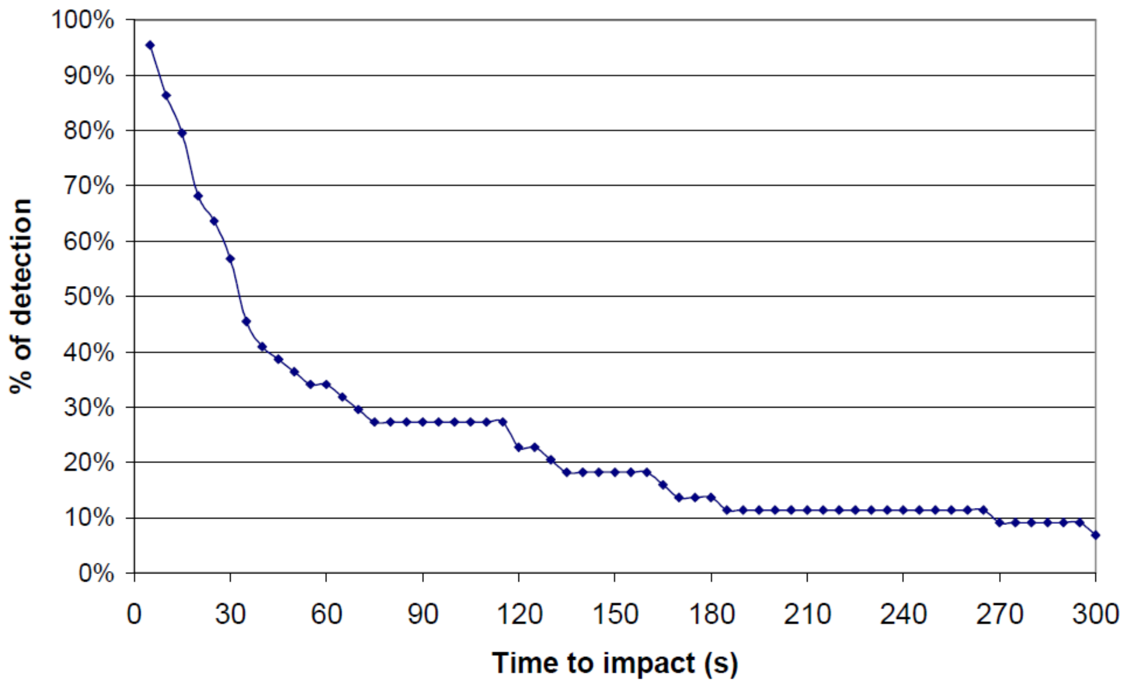
Note: In this initial analysis, "emergency" detection is based on BEA work (please refer to [R6]).

Effect on the wireless transmission of flight data:

- A longer time to transmit flight data.

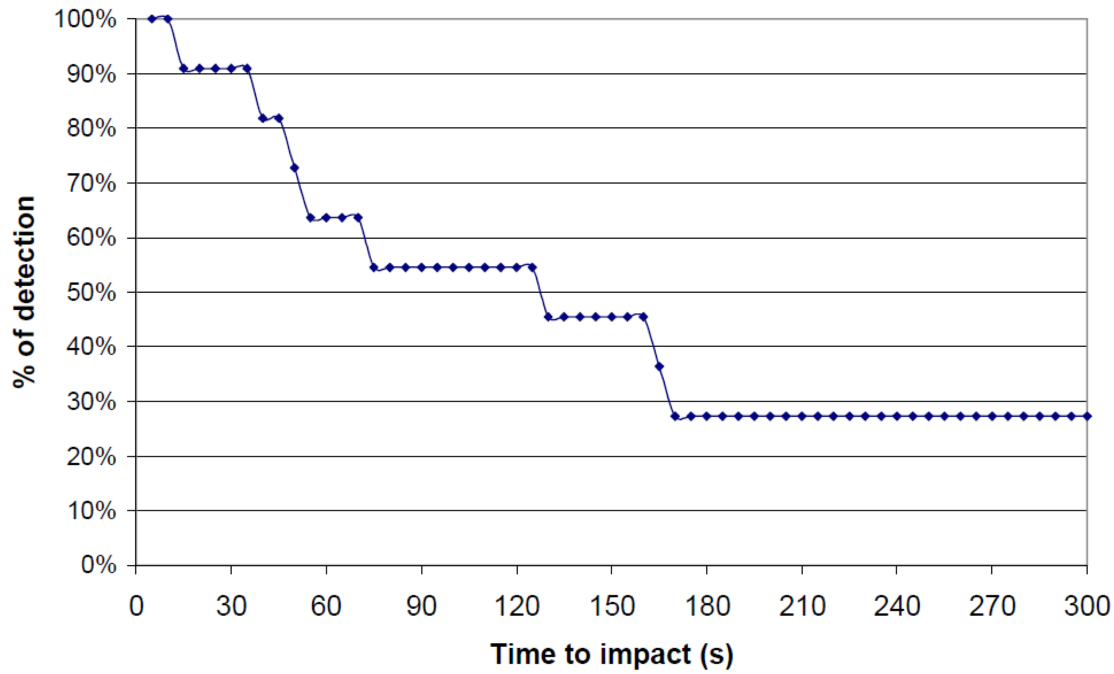
The following data are extracted from the 2011 BEA document (ref [R6]).

The following diagram presents the distribution of the "flight accident" percentage versus the "warning time" (or the duration between the "Emergency situation" trigger and the time to impact).



The results indicate warning times greater than 15 seconds in 80% of cases, greater than 30 secs in 57% of cases, greater than 60 seconds in 34% of cases and greater than 120 seconds in 23% of cases.

The BEA document also provides a diagram restricted to accidents during the cruise phase.



Warning times:

- *Greater than 15 seconds in 91% of cases;*
- *Greater than 30 seconds in 91% of cases;*
- *Greater than 60 seconds in 64% of cases, and;*
- *Greater than 120 seconds in 55% of cases.*

2.1.12 Factor 12: “Location of the aircraft in emergency situations”

Classification: This factor is a “general scenario”.

This factor was identified during the analysis.

It is not possible to provide information concerning this factor from the BEA flight database

The aircraft location affects the quality and the bandwidth with LEO, MEO or GEO satellites. The aircraft position on Earth relative to the satellite position induces a relative distance that could be affected by free space propagation and attenuation effects due to meteorological effects, gas effects, or reflective or refractive radio electric propagation. Consequently, link budget and link availability are affected. In this case, datalink management to mitigate these effects decreases the bandwidth and consequently the data rate to increase the link budget margin to ensure no interruption of the datalink.

Effect on the wireless transmission of flight data:

- Aircraft located at high latitudes (> 60° latitude) are dependent on satellite systems (less availability of communication).

Note : In case of polar flight, the communication with GEO satellites are not possible when the Aircraft are located at high latitude. Nevertheless, communication still possible with MEO and LEO constellations.

2.1.13 Factor 13: “Integrity of transmitted data”

Classification: This factor is a “general scenario”.

This factor was identified during the analysis.

It is not possible to provide information concerning this factor from the BEA flight database.

In distress conditions, due to possible aircraft attitude and vibration conditions, data transfer is likely to be interrupted. The proposed solution should minimize data losses; conventional protocol mitigations (message repetition, time-out detection, etc.) may not be suitable, due to the short duration allowed for transmission.

Effect on the wireless transmission of flight data:

- Risk of data loss.

The solution must challenge the flow efficiency and integrity of the transferred data.

2.1.14 Factor 14: "Transfer Protocol"

Classification: This factor is a "general scenario".

This factor was identified during the analysis.

It is not possible to obtain information concerning this factor from the BEA flight database.

In accordance with the protocol chosen for the transfer, an analysis must be conducted to select the best format for the transmission of the data package per media solution: one large file, several short files, files with all the recorded data mixed, etc.

Note: This factor mainly concerns the air/ground protocol (possibly with an impact on-board), while factor 10 concerns on-board architecture (to optimize the performance of the data flow).

The data format (xml vs binary) and file size affect the performance of data transmission.

For example, one large file versus several short files: the transmission rate is affected by the communication protocol when the ratio (or percentage) between the useful data and the data required for the protocol is high. By way of illustration, when transmitting small UDP packets (in this example, Ethernet II frame), Header and FCS/CRC are 14 + 4 bytes, payload from 14 bytes to 1,500 bytes. The smallest packet in this case is 18 bytes (synchronization plus protocol) for 14 bytes of payload, for a ratio of payload to total bytes of only 43% (i.e., 14 bytes of payload against 14+18 bytes for the frame size).

Effect on the wireless transmission of flight data:

- Non-optimal data quantity upon reception (large overhead compared to payload).

The solution must challenge the flow efficiency and integrity of the transferred data.

2.2 Accident categories (CICTT) and possible factors affecting wireless transmission

The following table presents the possible correlations between accident categories as chartered by the CAST/ICAO Common Taxonomy Team (ref. [R15]), and the above listed factors (§2.1). Its purpose is not to “weight” these factors regarding accident categories.

ACCIDENT CATEGORIES (CICTT) AND POSSIBLE FACTORS AFFECTING WIRELESS TRANSMSSION															
Accident Categories (CICTT) 2010 to 2019	**Comments**	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
ARC (Abnormal Runway Contact)	Out of scope (on aerodrome)														
CFIT (Controlled Flight Into Terrain)							X	X				X			
F-NI (Fire/Smoke - No Impact)	May lead to LOC-I		X	X		X	X	X	X						
FUEL (Fuel-related)	May lead to LOC-I		X	X			X	X	X						
ICE (Icing)	May lead to LOC-I			X	X		X	X	X						
LOC-I (Loss of Control – In-flight) (Note 1).	May result from another Category			X	X		X	X	X						
MAC (Mid-air/Near Mid-air Collision)	May lead to LOC-I	X	X	X	X	X	X	X	X			X			
OTHR (Other)															
RAMP (Ground Handling)	Out of scope (on ramp)														
RE (Runway Excursion)	Out of scope (on aerodrome)														
RI-VAP (Rwy Inc - Vehicle/Acft/Person)	Out of scope (on aerodrome)														
SCF-NP (Syst/Compnt Failure - Non Pwr Plant)	May lead to LOC-I		X	X	X		X	X	X						
SCF-PP (Syst/Compnt Failure - Pwr Plant)	May lead to LOC-I		X	X	X		X	X	X						
UNK (Unknown or Undetermined)															
USOS (Undershoot/Overshoot)	Out of scope (on aerodrome)														
WSTRW (Windshear or Thunderstorm)	May lead to LOC-I			X	X		X	X	X			X			
Others Accident Categories (CICTT)															
ADRM (Aerodrome)	Out of scope (on aerodrome)														
AMAN (Abrupt Maneuver)	See: SFC-NP or SFC-PP														
ATM (Air Traffic Management)	See: MAC														
BIRD (Bird)	See: SFC-NP or SFC-PP														
CABIN (Cabin Safety Event)	See: F-NI or SFC-NP														
CTOL (Collision with obstacle - Take Off/Ldg)	Out of scope (on aerodrome)														
EVAC (Evacuation)	Out of scope (on aerodrome)														
EXTL (External load-related occurrences)	Out of scope (type of operation)														
F-POST (Fire/Smoke post-impact)	See other accidents leading to F-POST														
GCOL (Ground Collision)	Out of scope (on aerodrome)														
LALT (Low Altitude Operations)	Out of scope (type of operation)														
LOC-G (Loss of control - Ground)	Out of scope (on aerodrome)														
RI-A (Runway Incursion - Animal)	Out of scope (on aerodrome)														
SEC (Security-related)	Out of scope (security excluded)														
TURB (Turbulence encounter)	See: LOC-I, SFC-NP or SFC-PP														
WILD (Wildlife)	See: SFC-NP or SFC-PP														

Factors affecting wireless transmissions:

- F1 " Loss of power on all engines while the aircraft is still in flight "
- F2 “Loss of equipment that is a non-essential load for electric systems”
- F3 “Significant [or unusual] pitch and roll attitudes”
- F4 “Unusual [or excessive] pitch and roll [and yaw] rates”
- F5 “In-flight fire [loss of aircraft physical integrity]"
- F6 “Collision with land or water.”
- F7 “Post-impact fire”
- F8 “Aircraft sinking into water, after ditching”
- F9 “Aircraft out of ATC range within the 60 minutes preceding the accident”
- F10 “Inappropriate architecture or link solution impacting the bandwidth of the global system in an emergency situation”
- F11 “Duration of emergency situations”
- F12 "Location of the aircraft in emergency situations"
- F13 "Integrity of transmitted data"
- F14 "Transfer protocol"

- Note 1: LOC-I is seen here as a loss of control of the aircraft and/or of the flight path when a plane cannot be landed safely at an airport (fuel exhaustion etc.). F-NI, FUEL, ICE, MAC, SCF-NP/PP, AMAN, WSTRW, BIRD, CAB, TURB may lead to LOC-I.
- Note 2: X F11 when the duration might be too short for optimal data transmission.

3 Transmission Solutions

Several datalinks can be used for the transfer of recorder data.

Existing and future datalink capabilities on aircraft will be compared to recorder data transfer requirements.

An overview of the media communication capabilities to support data transfer trigger conditions is given in the following tables.

Note: Incompatibility or coexistence between proposal solutions will be the subject of a second delivery document after the selection of a short-listed solution, due to the complexity of the studies of all combinational interoperability solutions in the D1 document.

As an example, L band SATCOM Iridium and Inmarsat in close frequency bands could be used on the same aircraft, due to different locations on this aircraft.

3.1 Transmission sheet solutions

3.1.1 HF/WHF/VHF/UHF Solutions

Frequency band	HF	WHF (gen3, gen4)	VHF		UHF		UHF, S to C bands
Frequency	2.85MHz – 22MHz	2.85MHz – 22MHz	117.975MHz – 137 MHz		960-975 MHz	960 to 1,164 MHz	700MHz – 3.8GHz
Cyber	Could be added	Could be added	Could be Added		Could be Added	Included	Service operator
Network/operator	Free	Free	VDL4	VDL2	LDACS 2	LDACS 1	2G/3G/4G/5G Terrestrial Network
Service	ACARS Messages	TBD	Mode A	Mode 2	TBD	TBD	2G/3G/4G/5G
Primary usage (ATC/AOC/IFE/etc.)	ATC/AOC	TBD	ATC/AOC	ATC/AOC	TBD	ATC	Voice in cellular network
Secondary usage (ATC/AOC/IFE/etc.)	ATC/AOC	TBD	ATC/AOC	ATC/AOC	TBD	N	Data in cellular network (Internet)
Primary operation (Surface/Climb-Desc/Cruise)	All	All	All	All	All	All	Surface/Climb-Desc TBC/Up to 1km altitude
Air-Ground/Air-Air Capabilities	Y	Y	A-G/A-A	A-G	A-G	A-G/A-A	A-G
Full/Half Duplex	TBD	TBD	Half (STDMA)	Full Duplex	Full Duplex	Full Duplex	Full Duplex
Protected Aeronautical Spectrum (Y/N)	N	N	Y	Y	Y	Y	N
Range (Nm) at 30,000 ft or above (Air-Ground)	1,600NM	1,600NM	150NM to 200NM	150NM to 200NM	200NM	200NM	Cellular coverage up, below 1km
Coverage (Continent/Worldwide/World+Polar)	World+Polar	World+Polar	Continent (lim'd)	Continent (*)	-	-	Cellular coverage up, below 1km
Throughput (kbps) - Aircraft Tx → Uplink for SAT	1.8Kbps	120Kbps (gen3) to 240Kbps (gen4)	19.2Kbps	31.5Kbps	270.833Kps/Channel	291kbps to 1.3MBPS	10Kbps 2G, 384Kbps 3G, 4Mbps 4G, ~10 to 50Mbps 5G (TBC)
Guaranteed bandwidth							
Antenna type (Omni/Directional)	Omni	Omni	Omni	Omni	Omni	Omni	Omni
Antenna location (Top/Bottom/Diversity)	Top	Top and Bottom	Bottom	Top and Bottom	Top (TBC)	Top (TBC)	Top and bottom diversity
Limitations (e.g., atmospheric)	Atmospheric Ionospheric layer	Atmospheric Ionospheric layer	TBD	TBD			Cellular network coverage and altitude
MOPS	TBD	TBD	ED-108A	ED-92C	TBD	TBD	N
MOPS antenna tracking							
MOPS time re-acquisition			few s	few s			
Coverage	1,600NM	1,600NM	150NM to 200NM	150NM to 200NM	200NM	200NM	Local TN coverage
Nominal throughput	1.8Kbps	120Kbps (gen3) to 240Kbps (gen4)	19.2Kbps	31.5Kbps	270.833Kps/Channel	291kbps to 1.3MBPS	10Kbps 2G, 384Kbps 3G, 4Mbps 4G, ~10 to 50Mbps 5G (TBC)
Guaranteed availability	Fluctuating due to Ionospheric layer	Fluctuating due to Ionospheric layer	99.00%	TBD	TBD	TBD	TBD
Max altitude	No (under ionospheric layer)	No (under ionospheric layer)	No	No	No	No	200m to 1km max
Protocol	No	No	TBD	TBD	Dedicated	Dedicated	UDP/IP
Antenna coverage	Omni	Omni	Omni	Omni	Omni	Omni	Omni
Antenna tracking speed	-	-	-	-	-	-	-
Acquisition time, Re-acquisition time	-	-	-	-	-	-	-

TBD &TBC will be discussed during the survey with communication solution providers.

3.1.2 SATCOM Solutions

Frequency band	SATCOM L band		S band SATCOM		SATCOM Ku Band	SATCOM Ku			SATCOM Ka Band				SATCOM Ka
Frequency	1,616.0-1,626.5 MHz	1,525 to 1,559 MHz, 1,626.5 to 1,660.5 MHz	1.98GHz to 2.2GHz (in 3 ITUs regions) in future	1.98GHz -1.995GHz (Downlink) and to 2.17GHz – 2.185GHz (Uplink)	12GHz to 18GHz	10-14 GHz	10-14 GHz	10-14 GHz	17.3GHz to 30GHz	26.5GHz to 40GHz	20GHz -28GHz	20-30 GHz	20-30 GHz
Cyber	Service Operator	Service operator	Service operator	Service Operator	Service Operator	Service Operator			Service Operator	Service Operator	Service Operator	Service Operator	Service Operator
Network/operator	Iridium Next (66xSAT LEO)	Inmarsat IV (3xSAT GEO)	5G NTN (SATCOM LEO/GEO)	Multi operator 4G/5G aerial dedicated Network	Viasat KU (TBC)	Gogo 2Ku	Global Eagle	Panasonic	5G NTN (LEO/GEO)	Inmarsat V (4xSAT GEO)	Viasat KA	SES Astra O3B and Mpower (MEO)	New GDC/Taqnia
Service	Certus safety (2026 - TBC)	Swift Broadband, Swift Broadband Safety	5G releases 17, 18	Based on 4G LTE (aero) with modifications and 5G	Viasat KU (TBC)	Gogo 2Ku	Global Eagle	Panasonic	5G releases 17, 18	Global Xpress	TBD	TBD	TBD
Primary usage (ATC/AOC/IFE/etc.)	ATC/AOC	ATC/AOC	Voice in cellular network	IFE/IFC In-Flight Entertainment or connectivity	IFE	IFE	IFE	IFE	IFE (TBC)	IFE	IFE	IFE	IFE
Secondary usage (ATC/AOC/IFE/etc.)	ATC/AOC	ATC/AOC	Data in cellular network (Internet	IFE/IFC In-Flight Entertainment or connectivity	IFE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Primary operation (Surface/Climb-Desc/Cruise)	All	All	All	Cruise phase and between 10km to 12km altitudes	Cruise and potentially all	Cruise and potentially all	Cruise and potentially all	Cruise and potentially all	Cruise and potentially all				Cruise and potentially all
Air-Ground/Air-Air capabilities	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G	A-G
Full/Half Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex	Full Duplex
Protected Aeronautical Spectrum (Y/N)	Y	Y	N	N	N	N	N	N	N	Y	N	N	N
Range (Nm) at 30,000 ft or above (Air-Ground)	Worldwide including Polar	Global coverage between -/+ 80°N/S	NTN coverage Worldwide	Limited to dedicated network coverage up to 150km and 12km maximum altitude	Regional to Worldwide	Regional to Worldwide (TBC)	Regional to Worldwide (TBC)	GEN1: Worldwide 98% commercial air traffic; GEN2: Worldwide 80% commercial air traffic; GEN3: Worldwide 50% commercial air traffic.	NTN coverage Worldwide	Worldwide without polar pole lat +80N and -80S, Mobile spot	Regional to Worldwide	Worldwide polar included	TBD
Coverage (Continent/Worldwide/World+Polar)	350Kbps up to 524Kbps (in future) 704 kbps with HLA antenna	Global coverage between -/+ 80°N/S	NTN coverage Worldwide	Dedicated network coverage	Regional to Worldwide	TBD	TBD						TBD
Throughput (kbps) - Aircraft Tx ➔ Uplink for SAT	350Kbps up to 524Kbps (in future) 704 kbps with HLA antenna	2.4Kps to (1x to 4x) 432Kbps SBB, 1x432Kbps Safety	150Mbps up max	4G LTE 100Mbps and up to 1Gps 5G in uplink	2.5Mbps to 20Mbps up	70Mbps up (TBC)	100Mbps up	GEN1: 12Mbps down, up TBD; GEN2: 80Mbps down, up TBD; GEN3: 250Mbps down, up TBD.	200Mbps up (TBC)	1Mbps min to 4.7Mbps up	1Mbps min to 50Mbps	1Mbps min to 15Mbps	TBD
Guaranteed bandwidth	Circuit Mode	Yes/Dynamic (SBB)		4G LTE reserved bandwidth depends on user number on base station, 5G allocated bandwidth could be guaranteed for dedicated usages and services by operator									
Antenna type (Omni/Directional)	Dir Elec	Dir Elec	Dir Elec	Semi omnidirectional on aircraft, zenithal sectorial antenna on ground dedicated eNode	Dir Mechan/Elec	Dir Elec	Dir Mechan	Dir Mechan	Dir Elec	Dir Mechan/Elec	Dir Mechan/Elec	Dir Mechan/Elec (future)	TBD
Antenna location (Top/Bottom/Diversity)	Top (Front)	Top (Central)	Top	Aircraft on bottom	Top	Top	Top	Top	Top	Top	Top	Top	Top
Limitations (e.g., atmospheric)			Available SATCOM in LEO/GEO for coverage	Limited to dedicated network coverage and between 10km and 12km maximum altitude	SATCOM coverage	SATCOM coverage, Ku band	SATCOM coverage, Ku band	SATCOM coverage, Ku band	SATCOM coverage, Ka band	SATCOM coverage, Ka band	SATCOM, Ka band and Worldwide coverage	Ka band coverage	Ka band coverage
MOPS	DO-262	DO-262	5G NTN releases 17, 18	No MOPS	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
MOPS antenna tracking	6°/s pitch, roll, azimuth	6°/s pitch, roll, azimuth		No omnidirectional antenna on aircraft side and sectorial antenna on ground-based eNode									
MOPS time re-acquisition	10s	10s		No MOPS	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Coverage	Worldwide including Polar	Worldwide without polar pole lat +80N and -80S	NTN coverage Worldwide	Dedicated network coverage	Regional to Worldwide	Regional to Worldwide	Regional to Worldwide	Regional to Worldwide	NTN coverage Worldwide	Worldwide without polar pole lat +80N and -80S, Mobile spot	Regional to Worldwide	Worldwide polar included	Regional (TBC)
Nominal throughput	350Kbps up to 524Kbps (in future) 704 kbps with HLA antenna	2.4Kps to (1x to 4x) 432Kbps SBB, 1x432Kbps Safety	150Mbps up max	100Mbps max with 4G LTE and 1Gbps max with 5G	2.5Mbps to 20Mbps up	70Mbps up (TBC)	100Mbps up	GEN1: 12Mbps down, up TBD; GEN2: 80Mbps down, up TBD; GEN3: 250Mbps down, up TBD.	1Mbps min (TBC)	1Mbps min to 4.7Mbps up	1Mbps min to 50Mbps	1Mbps min to 15Mbps	TBD
Guaranteed availability	> 99	99.9	TBD	Services dependent	TBD	98%	TBD	TBD	TBD	TBD		99.8	TBD
Max altitude	No	No	No	12 km	No	No	No	No	May be affected by propagation under cloud				
Protocol	UDP/IP, streaming	UDP/IP, streaming	UDP/IP	UDP/IP, streaming	UDP/IP (TBC)	UDP/IP (TBC)	UDP/IP (TBC)	UDP/IP (TBC)	UDP/IP	UDP/IP	TBD	UDP/IP	TBD
Antenna coverage	8,2°to 90°El/360 Az (Flylink Thalès)	0°to 90°El/360 Az (Cobham HGA-7001) 0° to 75° if LGA SB200 (to be checked)	TBD	Omnidirectional	0°90°el/360az KuKarray-2L, G-18L, -10°/90°G30L Ku Viasat	7.5°to 90°El/360 Az Ku 3030 ThinKom antenna	0°to 90°El/360 Az ER-6000A	-10°to 90°El/360 Az	10°to 90°El/360 Az (TBC)	-8° to 90° El AZ 360° (GETSAT milli) or 7.5°to 90°El/360 Az KA 2517 ThinKom antenna	0°to 90°El/360 Az Viasat antenna GM-40L and G18-L, G12-L	0° to 90° El AZ 360° (GETSAT microsat)	TBD
Antenna tracking speed	TBC (ditto Inmarsat IV 1,000°/s)	1,000°/s	TBD	No	100°/s KuKarray-2L, G-18L, G30L Ku	Up to 1,000°/s	> 30°/s RAYSAT ER-6000A Wavestream	12°/s FT310 Astronics	200°/s	200°/sec (mechan GETSAT milli) or 1000°/s KA 2517 ThinKom	95°/s GM-18L antenna Viasat and 100°/s G18-L, G12-L	200°/sec (mechan GETSAT microsat)	TBD

Acquisition time, Re-acquisition time	-	Init TBD, re-acquisition time < 30 milliseconds in any direction of beam steering	TBD	TBD	< 30s and LEO reacquisition < 2s, KuKarray-2L, G-18L	TBD	TBD	TBD	TBD	TBD	< 30s, 2s LEO Handover time	< 20s, < 100ms	TBD

TBD &TBC will be discussed during the survey with communication solution providers.

3.1.3 Impact of abnormal conditions on communication media

	HF	WHF (gen3, gen4)	VHF	UHF	UHF, S to C bands	SATCOM L band	S band SATCOM	SATCOM Ku Band	SATCOM Ku	SATCOM Ka Band	SATCOM Ka
F1 - Loss of power on all engines while the aircraft is still in flight	Inoperative due to the lack of emergency power		ATC: Speech today (on backed up network) - in the future digital solution (if on backed-up network)	Reserved for ATC and location	Operative only if powered by emergency network.			Inoperative due to the lack of emergency power			
F2 - Loss of equipment that is a non-essential load for electric systems											
F3 - Significant [or unusual] pitch and roll attitudes	Loss of 3dB if angle> 45°					• Risk of no link if antenna opening angle < 0°. • Function of satellite inter-visibility and antenna coverage.	• Risk of no link if antenna opening angle is too small (Angle TBD). • Function of satellite inter-visibility and antenna coverage.	• Risk of no link if antenna opening angle < 0° for G-18L or -10° for G-30L. • Function of satellite inter-visibility and antenna coverage.	• Gogo 2Ku: Risk of no link if antenna opening angle < 7.5° for 3030 ThinKom. • Global Eagle: Risk of no link if antenna opening angle < 0°. • Panasonic: Risk of no link if antenna opening angle- < -10°. • Function of satellite inter-visibility and antenna coverage.	• 5G NTN: Risk of no link if antenna opening angle < 10°. • Immarsat V: Risk of no link if antenna opening angle < -8°. • Viasat KA or SES Astra O3B and Mpower: Risk of no link if antenna opening angle < 0°. • Function of satellite inter-visibility and antenna coverage.	• Risk of no link if antenna opening angle is too small (Angle TBD). • Function of satellite inter-visibility and antenna coverage.
F4 - Unusual [or excessive] pitch and roll [and yaw] rates	No impact					No impact if speed rate < 1,000°/s.	No impact if speed rate is not too excessive (max speed rate TBD).	No impact if speed rate < 100°/s.	• Gogo 2Ku: No impact if speed rate < 1,000°/s. • Global Eagle: No impact if speed rate < 30°/s. • Panasonic: No impact if speed rate < 12°/s.	• 5G NTN, Immarsat V or SES Astra O3B and Mpower: No impact if speed rate < 200°/s. • Viasat KA: No impact if speed rate < 95°/s for GM-18L or < 100°/s for G18-L.	No impact if speed rate not too excessive (max speed rate TBD).
F5 – In-flight fire [or in-flight loss of aircraft physical integrity], which destroys the aircraft	Depending on system redundancy		If future digital solution is on backup network	Depending on system redundancy	No redundancies - depending on equipment and wiring status.						
F6 - Collision with land or water, which destroys the aircraft	Loss of transmission systems.										
F7 – Post-impact fire	Depending on transmission system status.										
F8 - Aircraft sinking into water, after ditching											
F9- Aircraft out of range of ATC surveillance systems within the 60 minutes preceding the accident and until the accident	TBD		Inoperative transmission	TBD	Communication available						
F10 - Inappropriate architecture or link solution impacting the bandwidth of the global system in emergency situations	Impact on quantity of data transmitted.										
F11 - Duration of emergency situations	Impact on quantity of data transmitted.										
F12 - Location of the aircraft in emergency situations	Impact on transmission in the case of inter-visibility between transmitter and receiver.										
F13 - Integrity of transmitted data	Impact on quantity of data transmission depending on transmission redundancy solution.										
F14 – Transfer protocol	Impact on quantity of data transmitted depending on data packet size.										

TBD &TBC will be addressed during survey elaboration.

3.2 Overview of the candidate's datalink and services

Datalink characteristics are presented by ascending order of frequency band.

3.2.1 Datalink in HF frequency bands

The HFDR (High Frequency Data Radio) System comprises one or two HF radios (and associated couplers) sharing one HF shunt-type antenna.

Note: Encryption functions could be added to HFDL, outside of ACARS or cockpit services messages usages. Data rate is too limited to be considered for data transfer usage in this case.

<u>HFDR Data Mode:</u>

Used for long-range communications between aircraft and ground stations;

Operates between 2.000 MHz and 29.999 MHz for data;

Only one HFDR available for datalink at any given time.

Note: Service Provider requirement for data mode transmissions.

<u>Automatic selection of data rates</u>

HFDL allows data transmission rates of 300, 600, 1,200 and 1,800 bits/s. The HFDL function uses the highest possible data rate available to support the message size of the downlink transmission.

At any time, each link between the aircraft and the ground station will have a maximum downlink and uplink data rate.

The maximum uplink rate is determined by the aircraft and provided to the ground station, whereas the maximum downlink rate is determined by the ground station and provided to the aircraft.

These data rates are determined based on the signal received. An insufficient or marginal signal-to-noise ratio will cause the aircraft to search for a new frequency from the same or a different ground station, which provides a sufficient signal-to-noise ratio for the establishment and use of the datalink.

<u>Protocol</u>

This may be described as a sort of HF ACARS:

- Transmissions on HF are in USB on a 1,440Hz sub-carrier with a symbol speed of 1,800 baud.
- Modulation is 2-PSK, 4-PSK or 8-PSK with effective bit rates of 300, 600, 1,200 or 1,800 bits/s, based on signal quality.
- The protocol consists of a combination of frequency division multiple access (FDMA) and time division multiple access (TDMA).
- HF radio transceivers operate in half duplex mode.
- HF frequency spectrum: 2 to 30 MHz.
- M-PSK modulation centered on carrier upper sideband (1,440Hz) and modulated at a rate of 1,800 Hz.
- Protocol fully supports character (ACARS Messages) or bit-oriented data.

HFDL is still the only datalink technology that works over the North Pole, providing continuous, uninterrupted datalink coverage on the popular polar routes between North America and Eastern Europe and Asia.

<u>Advantages of HFDL:</u>

- Wide coverage due to the extremely long range of HF signals;
- Simultaneous coverage on several bands and frequencies;
- Multiple ground stations at strategic locations around the globe;
- Relatively simple avionics using tried and tested technology;
- Rapid network acquisition;
- Exceptional network availability.

Disadvantages of HFDL:

- Very low data rates (making the system unsuitable for high-speed wideband communications);
- HFDL transmission quality depends on solar activity.

As a result of the above, the vast majority of HFDL messages are related to airline operational control (AOC); however, HFDL is also expected to play an important role in Future Air Navigation Systems (FANS), where it will provide an additional means of datalink with an aircraft, supplementing VDL, GPS and SATCOM systems.

Overview of the HF datalink solution

- Frequency band: HF;
- Frequency: 2.85MHz – 22MHz;
- Network/operator: Free;
- Service: ACARS messages;
- Primary usage: ATC/AOC;
- Secondary usage: ATC/AOC;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground and Air-Air Capabilities;
- Half Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: 1,600 Nm at 30,000 ft or above (Air-Ground);
- Coverage: World+Polar;
- Throughput: 1.8 kbps;
- Antenna type: Omnidirectional;
- Antenna location: On top of the aircraft;
- Limitations (e.g., atmospheric): Atmospheric ionospheric layer;
- MOPS: No;
- MOPS antenna tracking: No;
- MOPS time acquisition: No;
- Guaranteed availability: No guarantee;
- Max altitude: Under ionospheric layer;
- Protocol: No;
- Antenna coverage: Omnidirectional;
- Antenna tracking speed: No due to omnidirectional antenna;
- Acquisition time: Unpredictable.

3.2.2 Wideband High Frequency solution

HF communications are currently used for LOS/BLOS communications with the use of ionospheric atmospheric layers as a reflector. The range can be up to several thousand kilometers (16,000km).

Note: Additional encryption functions could be used to data transfer services in this band. Data rate is too limited to be considered for data transfer usage in this case.

Third and fourth generation HF radio communications could offer up to 240Kbps in 48KHz channels in the 1MHz to 28MHz HF band. However, data rate offers are in accordance with data rate requirements. Several modulation orders and channel coding are used but not defined in a dedicated norm.

The use of this channel HF bandwidth could be limited due to limited availability arising from radio meteorological ionospheric effects. Progress in automatic allocation algorithms could counterbalance this, such as the ALE algorithm (ALE: Automatic Link Establishment).

The HF bandwidth is also very widely solicited due to intensive use by amateur radio and military applications.

<u>Overview of the Wideband WHF datalink solution</u>

- Frequency band: HF;
- Frequency: 2.85MHz – 22MHz;
- Network/operator: Free;
- Service: No dedicated services;
- Primary usage: Voice communication;
- Secondary usage: Data transfer for amateur radio;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground and Air-Air Capabilities;
- Half Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: 1,600 Nm at 30,000 ft or above (Air-Ground);
- Coverage: World+Polar;
- Throughput: 120Kbps third generation to 240Kbps fourth generation;
- Antenna type: Omnidirectional;
- Antenna location: On top of the aircraft;
- Limitations (e.g., atmospheric): Atmospheric ionospheric layer;
- MOPS: No;
- MOPS antenna tracking: No;
- MOPS time acquisition: No;
- Guaranteed availability: No guarantee;
- Max altitude: Under ionospheric layer;
- Protocol: No;
- Antenna coverage: Omnidirectional;
- Antenna tracking speed: No due to omnidirectional antenna;
- Acquisition time: Unpredictable.

3.2.3 VHF Datalink (VDL)

The VDR System (Very High Frequency Data Radio) on aircraft:

- Comprises three identical transceivers and three antennas (ARINC 716 for voice and ARINC 750 for data radio);
- Allows short-range communications: 118 to 136.975MHz with 8.33 kHz spacing;
- For data communications, only VDR 3 is interfaced with the ATSU.

Note: Additional encryption functions could be used to data transfer services in this band. Data rate is too limited to be considered for data transfer usage in this case.

VDL modes: overview of characteristics:

- Mode A:
  - Carrier Sense Multiple Access (CSMA);
  - Amplitude Modulated Shift Keying (AM-MSK);
  - 2,400 bits per second;
  - Connection-oriented;
  - Lacks support for priority;
  - ACARS blocks.

- Mode 2:
  - Carrier Sense Multiple Access (CSMA);
  - Differential 8-Phase Shift Keying (D8PSK);
  - 31,500 bits per second;
  - Connection-oriented;
  - Lacks support for priority;
  - AVLC frames;
  - ARINC 429 HS digital bus.

- Mode 0:
  - Carrier Sense Multiple Access (CSMA);
  - Amplitude Modulated Shift Keying (AM-MSK);
  - 2,400 bits per second;
  - Connection-oriented;
  - Lacks support for priority;
  - ACARS blocks;
  - Analog modem audio.

<u>Overview of the Wideband VHF datalink solution</u>

- Frequency band: VHF;
- Frequency: 117.975MHz – 137 MHz;
- Network/operator: VDL4 and VDL2;
- Service: Mode A (VDL4), Mode 2 (VDL2);
- Primary usage: ATC/AOC;
- Secondary usage: ATC/AOC;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground and Air-Air Capabilities in VDL4 and Air-Ground in VDL2;
- Half Duplex (STDMA) in VDL4, Full Duplex in VDL2;
- Not a Protected Aeronautical Spectrum;
- Range: 150 Nm to 200NM at 30,000 ft or above (Air-Ground);
- Coverage: Continent (limited);
- Throughput: 19.2Kbps in VDL4 and 31.5Kbps in VDL2;
- Antenna type: Omnidirectional;
- Antenna location: On the top and bottom of aircraft in VDL2, on the bottom of aircraft for VDL4;
- Limitations (e.g., atmospheric): Atmospheric ionospheric layer;
- MOPS: in VDL4: ED-108A, in VDL2: ED-92C;
- MOPS antenna tracking: No;
- MOPS time acquisition: A few seconds;
- Guaranteed availability: 99% exceed annual time in VDL4;
- Max altitude: Above 30,000ft;
- Protocol: TBD;
- Antenna coverage: Omnidirectional;
- Antenna tracking speed: No due to omnidirectional antenna;
- Acquisition time: Unpredictable.

3.2.4 UHF datalink

In the UHF frequency band, the LDACS2 and LDACS1 services can be used.

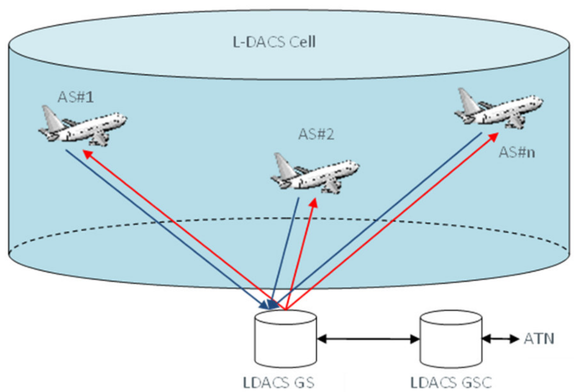
LDACS is a wideband terrestrial system with line-of-sight coverage intended to work alongside VDL2 for new and more demanding services.

Note Additional encryption functions could be used to data transfer services in this band. Data rate is too limited to be considered for data transfer usage in this case.

It operates in the L band (around 1 GHz), which has excellent propagation characteristics.

- LDACS2 is in the 960MHz to 975 MHz band;
- LDACS1 is in the 960MHz to 1164 MHz band.

Operational compatibility (spectrum interference) with existing L band systems (Navigation DME, GNSS, Military LINK16, mobile telephony) remains an important subject, and desirable technology features have been identified, which could make LDACS spectrally compatible.



LDACS is a modern communication system with scalability for aeronautical datalink applications. The advantage is that it also features additional capabilities that are considered in the framework of "Integrated CNS and Spectrum" developments.

Studies and flight trials performed by the SESAR program have demonstrated that LDACS is able to support Alternative Positioning Navigation and Timing (APNT) and navigation backup to GNSS.

LDACS is a frequency division duplex (FDD) configuration using orthogonal frequency division multiplexing (OFDM) modulation techniques, reservation-based access control and advanced network protocols.

L band Digital Aeronautical Communications System (LDACS) is the future ground-based communications link within the FCI.
Two proposals: the LDACS1 and LDACS2 datalink solutions.
L band is heavily used by aeronautical navigation services and aeronautical military communications systems.

Various deployment configurations are possible:

- Use only the lower part of the L band, 960-978 MHz (LDACS2);
- Use the lower and upper parts of the L band, 960-978 MHz/1,150-1,157 MHz;
- Slight reorganization of L band assignments for radar navigation;
- Inlay scenario (preferred approach for LDACS1).

Comparison of LDACS1 and LDACS2:

- LDACS1 can use more spectrum in the L band due to the inlay approach, and no reorganization of spectrum assignments is required;
- LDACS1 is the Broadband LDACS proposal (fivefold bandwidth) that provides considerably more capacity;
- LDACS1 uses OFDM;
- LDACS1 is considerably more mature than LDACS2;
- Detailed evaluations of PHY and MAC layer LDACS1 show improved robustness with respect to LDACS2;
- LDACS1 receivers have improved robustness against interference.

Achievements and status of LDACS and Potential of LDACS1:

- LDACS1 enables high-capacity aeronautical communications;
- Minimum useful data rate (Forward Link +Return Link = overall): 291 kbps +270 kbps = 561 kbps;
- Maximum useful net data rate (Forward Link +Return Link = overall): 1.32 Mbps +1.27 Mbps = 2.59 Mbps;
- Well suited to serve modern ATM applications and future needs;
- Comparison with LDACS2 (overall): 70kbps to 115 kbps;
- LDACS1 is highly flexible and scalable, and enables long-term evolution;
- OFDM-based physical layer rather than GSM;
- Scalability towards higher data rates;
- LDACS1 provides for quality-of-service;
- Fast access to resources and low delays for application;
- Different priorities available for different applications;
- LDACS1 enables the integration of the navigation functionality.

Overview of the UHF LDACS1 & 2 datalink solutions

- Frequency band: UHF;
- Frequency: 960MHz – 975 MHz LDACS2 and 960MHz – 1,164MHz LDACS1;
- Network/operator: LDACS1 and LDACS2;
- Service: TBD;
- Primary usage: TBD;
- Secondary usage: TBD;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground and Air-Air Capabilities in LDACS1 and Air-Ground in LDACS2;
- Full Duplex;
- Protected Aeronautical Spectrum;
- Range 200NM at 30,000 ft or above (Air-Ground), relay between aircraft could be used in LDACS1;
- Coverage: Currently TBD;
- Throughput: 291Kbps to 1.3Mbps in LDACS1 and 270.833Kbps/channel in LDACS 2;
- Antenna type: Omnidirectional;
- Antenna location: On top of the aircraft;
- Limitations (e.g., atmospheric): Range coverage up to 200NM without aircraft-to-aircraft relay;
- MOPS: Not currently defined;
- MOPS antenna tracking: No;
- MOPS time acquisition: Not currently defined;
- Guaranteed availability: TBD;
- Max altitude: Above 30,000ft;
- Protocol: Dedicated (TBC);
- Antenna coverage: Omnidirectional;
- Antenna tracking speed: No due to omnidirectional antenna;
- Acquisition time: Unpredictable.

3.2.5 SATCOM L Band

Two SATCOM L band systems are currently used in aircraft for cockpit and cabin services and could be used to record data transfer.

The selection criteria are as follows:

- Integration and aeronautical service deployment approval for considered aircraft (A320/A321) certification available;
- System coverage (includes possibilities for transpolar flight) must include complete Earth coverage;
- Latency (geosynchronous system or low-orbit constellation system, better than geosynchronous);
- Existing or mid-term deployment;
- Aircraft cost impact (airborne terminal cost) and cost of services;
- Data rate and service availabilities;
- Service guarantees upon datalink establishment by SATCOM operators;
- Secure communication (e.g.: could be used with VPN, and other cybersecurity services).

The two SATCOMs selected are as follows:

- INMARSAT, Swift Broadband services, already in service and upcoming SB-S Swift Broadband Safety service;
- IRIDIUM NEXT, Certus services in mid-term deployment and Safety services (potential availability ~2026).

The two systems are in the L frequency band, which is the best choice in terms of link budget versus data rate. Only these two systems can support complete or best Earth coverage with the same SATCOM system.

For safety, high availability and diversity, the two SATCOM systems and services (INMARSAT SB-S and Iridium Next) could be used in redundancy mode.

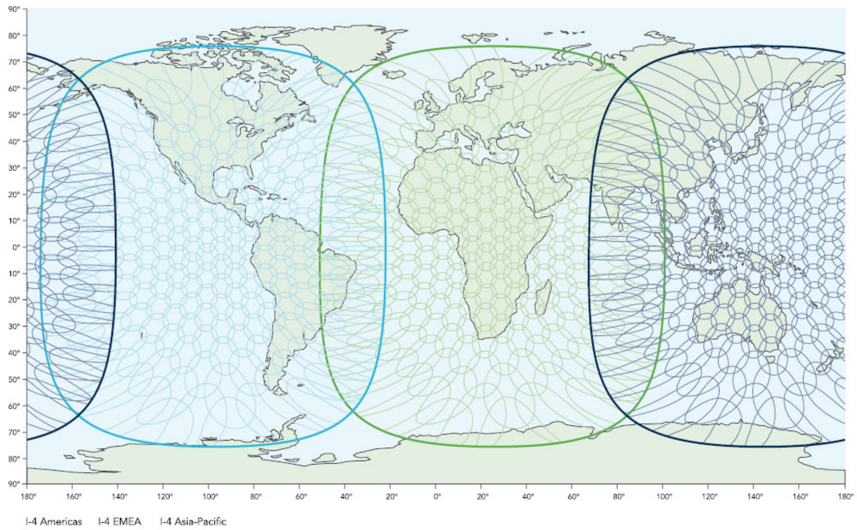
Note: Inmarsat Swift Broadband Safety (SB-S) services and Future Iridium Next Certus Safety services (not available before 2026) could also be used to meet requirements but this is reserved to dedicated safety services in ICAO Gold.

The oldest Iridium services are still available, but data rate performances do not meet requirements (only 2,400 bauds).

3.2.5.1 INMARSAT IV solution

Swift Broadband services

Four geostationary satellites (36,000km) in L band (1.6GHz) to cover the Earth between the +/-80° North and South latitudes.



Inmarsat IV Swift Broadband coverage

Within Swift Broadband, several levels of service are available:

- Swift Broadband Safety (SB-S) services are currently the only services that could offer 99.9% L Band availability in gate-to-gate mode. This SB-S service guarantees at least one channel at a 432Kbits/s IP data rate with high priority and a second channel with lower priority.
  - Multi-channel prioritized voice and data communications over IP;
  - High-speed, secure IP connectivity for the cockpit;
  - More than 99.99% L band availability gate-to-gate worldwide coverage in the ICAO GOLD standard;
  - Subscription-based monthly data package service, ensuring cost effectiveness.
- The Swift Broadband HGA class (class 6 terminal) delivers the full capabilities of Swift Broadband top-of-the-range communications services for general aviation (up to 432Kbps/channel and up to four channels, 1,728Kbps). This HGA service offers the best solution in terms of data rate and services, and is selected for C2 BLOS solutions on Inmarsat Swift Broadband;
- The Swift Broadband IGA class delivers high quality voice communications and a symmetrical, background data connection (up to 332Kbps/channel and up to four channels);
- The Swift Broadband 200 class, single channel, offers high quality voice and guaranteed rates of 8Kbps, 16Kbps or 32Kbps (up to 200Kbps/channel and up to four channels);
- Swift Broadband SB_UAV dedicated services to UAV are provided for low altitude and long endurance (up to 332Kbps 1 channel).

Swift Broadband (HGA) service features:

- The Swift Broadband HGA (Class 6 terminal) delivers the full capabilities of up to 1,728Kbps;
- Up to four channels per aircraft deliver simultaneous voice and data communications, always-on data up to 432kbps per channel, HDR data rates up to 700kbps on demand, and full-channel streaming with Swift Broadband X-Stream;
- Contended IP data: Over a high-gain antenna (HGA), Swift Broadband delivers a symmetrical, always-on data connection of up to 432kbps per background channel;
- Satellite telephony: High-quality voice with the full functionality of terrestrial fixed phone services. Each Swift Broadband channel provides a circuit-switched voice channel to the aircraft, with an option to add up to eight more with the multi-voice capability, using the in-built VoIP functionality. All voice services can be used in parallel to the packet data services;
- Streaming IP/Swift Broadband X-Stream;
- Swift Broadband (HGA) provides guaranteed connection rates per channel of 8, 16, 32, 64 and 128kbps symmetrical and HDR streaming services (Full or Half on symmetrical connection and a combination of Full HDR, Half HDR and 64kbps on an asymmetrical basis) on demand, as well as full-channel streaming with Swift Broadband X-Stream;
- Multi-channel: Up to four channels per aircraft, enabling up to 1.728Mbps over a high-gain antenna delivering simultaneous voice and data communications;
- Enhanced data: Allows simultaneous users concurrent access to applications. Data compression enables the optimization of channel usage by conveying larger amounts of data in the same timeframe;
- Global coverage: Swift Broadband is accessible globally, except in the extreme Polar regions;
- Secure connections: compatible with government-grade encryption and secure communications standards, and VPN.

Overview of the Inmarsat Swift Broadband datalink solution

- Frequency band: L;
- Frequency: 1,525 MHz to 1,559 MHz, 1,626.5 MHz to 1,660.5 MHz;
- Network/operator: Inmarsat IV;
- Service: Swift Broadband, Swift Broadband Safety;
- Primary usage: ATC/AOC;
- Secondary usage: ATC/AOC;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Protected Aeronautical Spectrum;
- Range limited Earth coverage between -/+ 80°N/S;
- Coverage: Global Earth coverage between -/+ 80°N/S;
- Throughput: 2.4Kps to (1x to 4x) 432Kbps SBB, 1x432Kbps Safety;
- Guaranteed bandwidth: Yes in safety services and dynamically in Swift Broadband (allocated upon access request, depends on channel availability);
- Antenna type: Electronic directional;
- Antenna location: Central position on top of the aircraft;
- Limitations: Earth coverage between -/+ 80°N/S, aircraft attitude and antenna beam coverage;
- MOPS: DO-262;
- MOPS antenna tracking: 6°/s pitch, roll, azimuth;
- MOPS time acquisition: 10 seconds;
- Guaranteed availability: 99% of Swift Broadband and 99.9% of Safety services exceed annual time;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP, streaming;
- Antenna coverage:
    - 0°to 90°El/360 Az (Cobham HGA-7001);
    - 0° to 75° if LGA SB200 (to be checked);
- Antenna tracking speed: 1,000°/s (Cobham HGA7001 antenna);
- Acquisition time: < 30 milliseconds in any direction of beam steering.

3.2.5.2 Iridium Next solution

SATCOM 2018 deployment, operational services: Q3 2019

Sixty-six satellite constellation at an orbit altitude of 780km (in L band: 1.616-1.6265 GHz).

Iridium Next complete global coverage services

Two classes of Certus services are proposed in Iridium Next:
“Peak” data rate services: (to be confirmed once deployment has been completed)

- Certus BLK1: 134kbps up and 176kbps down, “peak” data rate;
- Certus 100: 88kbps up and 88kbps down, “peak” data rate;
- Certus 200: 176kbps up and 176kbps down, “peak” data rate;
- Certus 350: 352kbps up and 352kbps down, “peak” data rate;
- Certus 350 is the service that most closely meets our requirements with all services, including weather radar video or map or panoramic video;
- Certus 700: 352kbps up and 704kbps down, “peak” data rate;
- Certus 1400: 512kbps up and 1.408Mbps down, “peak” data rate.

Streaming services and available data rates:

- Certus 4.8: 4.8kbps up/down data rates;
- Certus 9.6: 9.6kbps up/down data rates;
- Certus 14.4: 14.4kbps up/down data rates;
- Certus 28: 28kbps up/down data rates;
- Certus 56: 56kbps up/down data rates;
- Certus 96: 96kbps up/down data rates;
- Certus 128: 128kbps up/down data rates;
- Certus 168: 168kbps up/down data rates;
- Certus 256: 256kbps up/down data rates. In data streaming, this service most closely meets the project requirements, with the exception of panoramic video;
- Global coverage: Iridium Next will be accessible globally, including Polar regions;
- Secure connections: Compatible with government-grade encryption and secure communications standards, and VPN;
- COTS services in terms of $/hour/data rate to be consulted with the SATCOM operator service;
- Lower latency than Inmarsat Swift Broadband due to lower altitude orbit (LEO);
- Redundancy through several satellites at a time for a terminal.

Overview of the Inmarsat Iridium Next datalink solution

- Frequency band: L;
- Frequency: 1,616 MHz to 1,626.5 MHz;
- Network/operator: Iridium Next (66 LEO Satellite constellation);
- Service: Iridium Next and Iridium Next Safety services (~2026);
- Primary usage: ATC/AOC;
- Secondary usage: ATC/AOC;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Protected Aeronautical Spectrum;
- Range: Unlimited Earth coverage;
- Coverage: Global Earth coverage include polar;
- Throughput: 350Kbps up to 524Kbps (in future) in uplink and 704 kbps to 1.4 Mbps with HLA antenna in downlink;
- Guaranteed bandwidth: Circuit mode;
- Antenna type: Electronic directional;
- Antenna location: Front position on top of the aircraft;
- Limitations: Earth coverage including polar;
- MOPS: DO-262;
- MOPS antenna tracking: 6°/s pitch, roll, azimuth;
- MOPS time acquisition: 10 seconds;
- Guaranteed availability: 99% of Iridium Next and 99.9% (TBC) of Iridium Next (2026) Safety services exceed annual time;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP, streaming;
- Antenna coverage: 8.2°to 90°El/360 Az (Thalès Flylink);
- Antenna tracking speed: 1,000°/s (TBC);
- Acquisition time: TBD.

3.2.6 Terrestrial cellular network UHF to S bands

Terrestrial cellular network for 2G, 3G, 4G or 5G 3GPP standards.

The 2G, 3G, 4G or 5G terrestrial cellular networks could be used for recorder data transfer. The available data rate services could be up to 10Mbps in uplink and downlink for 4G and up to 100 Mbps in future 5G, with a latency of 10ms in 4G and 1ms in the 5G standard. Reserved services and data rates could be possible with the use of dedicated telecom operator base stations.

Currently, a study must be conducted to establish the usability, or limitations, of the 4G and 5G networks for aeronautical applications in airport environments and in aircraft take-off, landing, taxiing and cruise phases.

The datalink range will be limited to Base Station coverage (up to 30km) and at ground or low-level altitude (under 1km).

The Base Station antenna beam is dedicated to ground coverage and not to high elevation angles (up to 10°). With high-level altitudes, aircraft could be linked to several Base Stations, which must be separated to limit interference cancelation. In the 4G standard, the speed limit between the ground station (Base Station) and the aircraft is 350km/h, and it will be 500km/h in 5G, with a limited data rate (not currently known).

Aeronautical certification aspects must be considered; 4G or 5G aeronautical services are currently not defined and this solution is not currently proposed for aeronautical usages by the EASA or the FAA.

Overview of the terrestrial cellular datalink solution

- Frequency band: UHF to S bands;
- Frequency: 700 MHz to 3,800 MHz;
- Network/operator: Multi-operator around the globe for the 2G/3G/4G/5G Terrestrial Network;
- Service: 2G/3G/4G/5G (3GPP standards);
- Primary usage: Digital voice in cellular network;
- Secondary usage: Data in cellular network (e.g.: Internet);
- Primary operation: Surface/Climb-Desc up to 1km altitude;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited to cellular network coverage and 1km maximum altitude;
- Coverage: Limited to cellular network coverage and 1km maximum altitude;
- Throughput: 10Kbps 2G, 384Kbps 3G, 4Mbps 4G, ~10 to 50Mbps 5G in uplink;
- Guaranteed bandwidth: 2G to 4G depending on the number of users on the base station; 5G allocated bandwidth could be guaranteed for dedicated usages and services by operator;
- Antenna type: Omnidirectional;
- Antenna location: Top and bottom diversity on aircraft;
- Limitations: Limited to cellular network coverage and 1km maximum altitude;
- MOPS: No MOPS;
- MOPS antenna tracking: No omnidirectional antenna;
- MOPS time acquisition: No;
- Guaranteed availability: Service-dependent, only 5G could offer guaranteed availability in future;
- Max altitude: 200 meters up to 1km;
- Protocol: UDP/IP, streaming;
- Antenna coverage: Omnidirectional;

- Antenna tracking speed: No;
- Acquisition time: TBD.

3.2.7 5G Non-Terrestrial Network (5G NTN), SATCOM in S Band

For the 5G NTN, two solutions in SATCOM could be used in future, one in S band at the same frequency as the terrestrial network with LEO satellite constellations, and the second in Ka band with geostationary satellites.

Currently, no S band or Ka band satellites are deployed in orbit for 5G services; only the 3GPP standard 5G release 17 is promulgated and release 18 is currently under discussion.
Fifth generation (5G) telecommunication systems are expected to meet world market demands in terms of accessing and delivering services anywhere and anytime.
Non-Terrestrial Networks (NTNs) are able to meet the requirements of anywhere and anytime connection by offering wide-area coverage and ensuring service availability, continuity and scalability.
In the next chapter, we will review 3GPP NTN features and their potential in satisfying user expectations in 5G networks & beyond. State of the art, current 3GPP research activities and open issues are investigated to highlight the importance of NTNs in wireless communication networks.
An NTN may have different deployment options according to the type of NTN platform involved. Platforms are grouped into two main categories: space-borne and airborne.
Currently, only SATCOM are considered but aircraft-to-aircraft relay could also be considered in future.

The classification of space-borne platforms typically depends on three main feature parameters, such as altitude, beam footprint and size. Orbiting space-borne platforms can be classified as:

- Geostationary Earth Orbiting (GEO), which have a circular and equatorial orbit around the Earth at an altitude of 35,786 km, and whose orbital period is equal to the Earth's rotation period. A GEO platform appears fixed in the sky to the observers on the ground. The GEO beam footprint size ranges from 200 to 3,500 km.
- Medium Earth Orbiting (MEO), which have a circular orbit around the Earth, at an altitude varying from 7,000 to 25,000 km. The MEO beam footprint size ranges from 100 to 1,000 km.
- Low Earth Orbiting (LEO), which have a circular orbit around the Earth, at an altitude of between 300 and 1,500 km. The LEO beam footprint size ranges from 100 to 1,000 km.
- LEO and MEO are also known as Non-GEO (NGSO) satellites, due to their motion around the Earth within a lower time period than the Earth's rotation; in fact, this varies from 1.5 to 10 hours.

In the context of 5G & beyond, NTNs support all three usage scenarios defined by the International Telecommunication Union (ITU), which are as follows:

- Enhanced Mobile Broadband (eMBB);
- Massive Machine Type Communications (mMTC);
- Ultra-Reliable and Low Latency Communications (URLLC).

Since providing URLLC services may be a challenging task due to the satellite propagation delay and stringent URLLC requirements of reliability, availability and very low latency, the NTN mainly considers eMBB and mMTC as the main 5G service enablers for the definition of use cases.

With regard to eMBB services, the NTN aims to bring benefits to provide Broadband connectivity in unserved/under-served areas, on moving platforms (i.e., aircraft) and to offer network resilience by combining terrestrial networks and NTNs.

Furthermore, the NTN is also used to offload terrestrial networks, by making available the broadcast channel to deliver broadcast/multicast contents or wide/local area public safety messages to handheld or vehicle-mounted UEs on home premises or on-board moving platforms.

With respect to mMTC, the NTN supports connectivity for both wide and local area IoT services. In the case of a wide-area IoT service, connectivity between IoT devices and the NTN platform is ensured, as well as service continuity, through satellites and terrestrial gNBs for telematics applications (i.e., automotive and road transport, energy, agriculture).
In the case of a local area IoT service, the NTN provides connectivity between the mobile core network and gNBs serving IoT devices, by gathering information belonging to groups of sensors deployed under the coverage of one or more cells.

Therefore, the NTN is relevant in 5G NR systems because it aims to offer benefits in aircraft usage areas in terms of 5G targeted performance (i.e., tried and tested data rate and reliability), and to provide connectivity in unserved/under-served areas for both users and mMTC devices and for traveling users.

<u>NTN Architectures:</u>

In the Next Generation Radio Access Network (NG-RAN), new interfaces and protocols are added to support NTNs.
An NTN platform may act as a space mirror or gNB in the sky. Consequently, two satellite-based NG-RAN architectures are distinguished: transparent and regenerative. In the latter case, the NTN platform may implement partial or full gNB functionalities depending on whether the gNB functional split (i.e., the gNB consists of central and distributed units) is considered or not.
Another classification of the NTN architecture can be made based on the type of access. Hence, in satellite access architecture, the NTN terminal is directly served by the NTN platform, whereas in relay-like architecture, the NTN terminal and the NTN platform communicate with each other through a relay node (this could be another aircraft in the same area).

<u>Overview of the Non-Terrestrial 5G in S band datalink solution</u>

- Frequency band: S band;
- Frequency: 1.98GHz to 2.2GHz (in three ITU regions in future);
- Network/operator: Multi-operator around the globe for the 5G Non-Terrestrial Network (not currently deployed);
- Service: 5G releases 17, 18 (3GPP standards);
- Primary usage: Digital voice and data transfer across the Non-Terrestrial Network and the Terrestrial Network in continuity;
- Secondary usage: Data transfer (e.g.: Internet);
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited to Non-Terrestrial Network and Terrestrial Network satellite constellations;
- Coverage: Limited to Non-Terrestrial Network and Terrestrial Network satellite constellations;
- Throughput: Up to 150Mbps (to be confirmed) 5G NTN in uplink;
- Guaranteed bandwidth: In future, 5G NTN allocated bandwidth could be guaranteed for dedicated usages and services by operator;
- Antenna type: Electronic directional;
- Antenna location: On top of the aircraft;
- Limitations: Limited to Non-Terrestrial Network and Terrestrial Network satellite constellations;
- MOPS: No MOPS;
- MOPS antenna tracking: Currently no MOPS and no requirements defined;
- MOPS time acquisition: No;
- Guaranteed availability: Service-dependent, 5G NTN could be offered availability in future;
- Max altitude: > 30,000ft;
- Protocol: UDP/IP, streaming;
- Antenna coverage: 0° to 90° elevation and 360° azimuth (TBC);
- Antenna tracking speed: Currently not available, potentially up to 1,000°/s;
- Acquisition time: TBD.

3.2.8 Air 2 Ground IFE in S bands

This system uses 4G LTE standards with limited modification to support IFE services on aircraft.

The Air to Ground (A2G) IFE services proposed by Skyfive could be used for recorder data transfer. The available data rate services could be up to 100Mbps in uplink and downlink for 4G and up to 1Gbps in future 5G, with a latency of 1ms in the 4G aero LTE and 5G standards. This system uses dedicated services and a dedicated operator with a reserved frequency band.

A dedicated eNode with vertically pointing antennas placed at ground level are used throughout the flight trajectory to ensure continuous services for IFE/IFC services. On aircraft, a dedicated palm size antenna enables connection with the ground.

Only the cruise flight phase is covered throughout the flight trajectory.

Currently, a study must be conducted to establish the uses, or limitations, of the 4G and 5G networks for aeronautical applications in airport environments and in aircraft take-off, landing, taxiing and cruise phases.
The datalink range will be limited to Base Station (eNode) coverage (up to 150km or 3,000km2 to 6,000km2 and an aircraft altitude up to 12km).

This system includes modifications to share Doppler effects between the aircraft and the ground station and latency in systems. A dedicated network in 4G LTE is used to ensure this service.

Overview of the A2G Skyfive datalink solution

- Frequency band: S band;
- Frequency: 1,980 MHz -1,995 MHz (Downlink) and up to 2,170 MHz – 2,185 MHz (Uplink);
- Network/operator: Multi-operator 4G/5G aerial dedicated network;
- Service: Based on 4G LTE (aero) with modifications and 5G;
- Primary usage: IFE/IFC In-Flight Entertainment or connectivity;
- Secondary usage: IFE/IFC In-Flight Entertainment or connectivity;
- Primary operation: Cruise phase and between 10km and 12km altitudes;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited to dedicated network coverage up to 150km by eNode and 12km maximum altitude;
- Coverage: Dedicated network coverage;
- Throughput: 4G LTE up to 100Mbps and up to 1Gps 5G in uplink;
- Guaranteed bandwidth: 4G LTE reserved bandwidth depends on the number of users on the base station; 5G allocated bandwidth could be guaranteed for dedicated usages and services by operator;
- Antenna type: Semi-omnidirectional on aircraft, zenithal sectorial antennas on ground-dedicated eNode;
- Antenna location: On the bottom of aircraft;
- Limitations: Limited to dedicated network coverage and between 10km and 12km maximum altitude;
- MOPS: No MOPS;
- MOPS antenna tracking: No omnidirectional antenna on the aircraft side and sectorial antenna on ground-based eNode;
- MOPS time acquisition: No MOPS;
- Guaranteed availability: Service-dependent;
- Max altitude: 12km;
- Protocol: UDP/IP, streaming;
- Antenna coverage: Omnidirectional;
- Antenna tracking speed: No;
- Acquisition time: TBD.

3.2.9 SATCOM in Ku Band

3.2.9.1 Notes on SATCOM In-Flight Entertainment services

In-flight entertainment (IFE) refers to the entertainment available to aircraft passengers during a flight.

The services currently available are as follows:

- A moving-map system is a real-time flight information video channel broadcast through to cabin project/video screens and personal televisions (PTVs);
- Audio entertainment covers music, as well as news, information;
- Video entertainment is provided via a large video screen at the front of a cabin section, as well as smaller monitors situated every few rows above the aisles;
- In-flight movies and personal on-demand videos are stored in an aircraft's main in-flight entertainment system, from which a passenger can view them on demand over the aircraft's built-in media server and wireless broadcast system;
- Video games;
- IFE has been expanded to include in-flight connectivity services, such as Internet browsing, text messaging, cell phone usage (when permitted) and emailing. In fact, some players in the airline industry have begun referring to the entire in-flight entertainment category as "IFEC" (In-Flight Entertainment and Connectivity or In-Flight Entertainment and Communication).

Several SATCOMs in Ku and Ka bands on aircraft offer In-Flight services to passengers, and additional services in some cases for cockpit services.

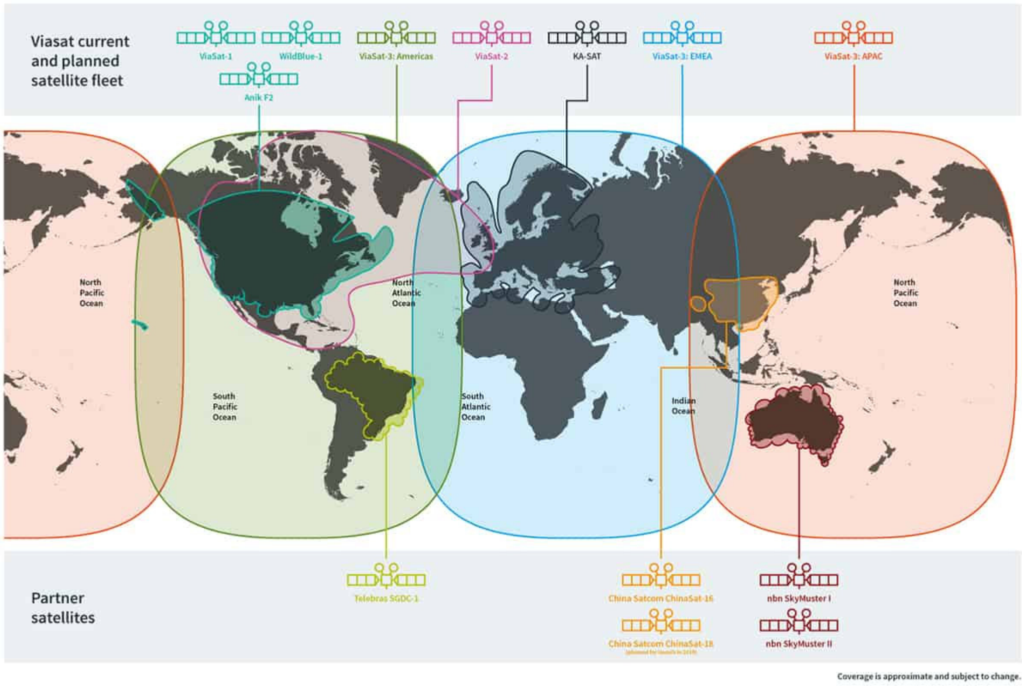
These services are not covered by any MOPS because the main usage is passenger services and not critical services.

In-Flight Entertainment uses a SATCOM terminal datalink with a significant data rate (a few Mbps) in uplink that could be re-used to transmit air flight recorder data.

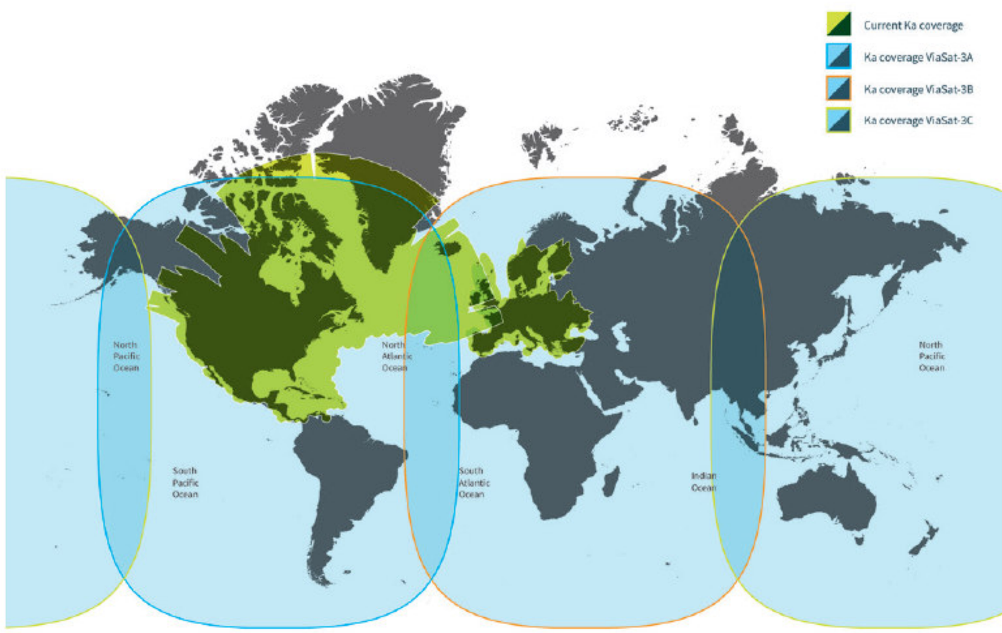
Many of these IFE SATCOM solutions use the DVB standardization waveform and protocol.

These solutions are not guaranteed in terms of data bandwidth and link availability.

3.2.9.2 VIASAT aeronautical services in Ku/Ka Bands



VIASAT Ku and Ka band service coverage in 2019



VIASAT Ka band service coverage in future

Viasat aeronautical services in Ku/Ka bands are dedicated to cabin services and In-Flight Entertainment.

These services are not currently dedicated to cockpit services but could be used to record data transfer.

There is no guarantee in terms of availability throughout the flight, nor with regard to the data rate.

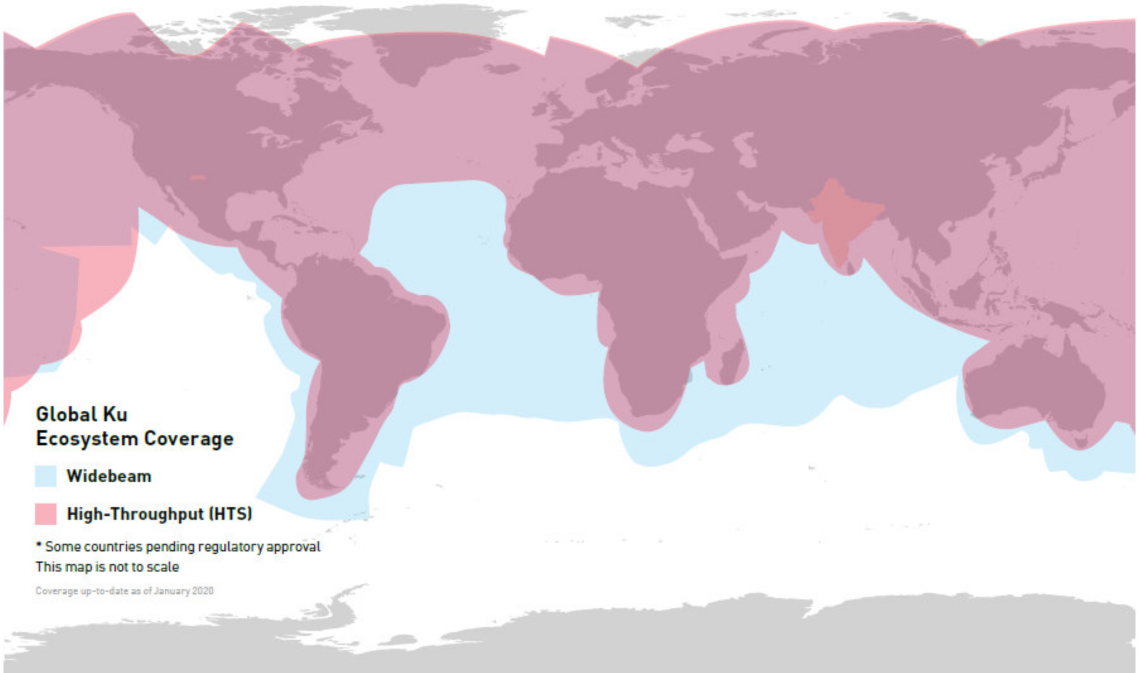
Viasat Ku/Ka band description:

- VIASAT in Ku/Ka bands use proprietary standards for SATCOM transmission and protocol;
- Several geostationary SATCOMs in Ku and Ka bands are used by VIASAT to cover the Earth.

Overview of the VIASAT in Ku/Ka band datalink solution

- Frequency band: Ku band and Ka band (VIASAT KA, KA SAT SATCOM);
- Frequency: 12 GHz to 18 GHz in Ku band and 20GHz -28GHz in Ka band;
- Network/operator: VIASAT;
- Service: VIASAT;
- Primary usage: In-Flight Entertainment;
- Secondary usage: In-Flight Entertainment;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited Earth coverage between -/+ 80°N/S;
- Coverage: Global Earth coverage between -/+ 80°N/S;
- Throughput: 2Mbps in Ka band, up to 2.5Mbps in Ku band;
- No guaranteed bandwidth;
- Antenna type: Electronic directional or hybrid electronic and mechanical;
- Antenna location: Central position on top of the aircraft;
- Limitations: Earth coverage between -/+ 80°N/S, aircraft attitude and antenna beam coverage;
- No MOPS;
- No MOPS antenna tracking:
- No MOPS time acquisition;
- Guaranteed availability: 99% of Swift Broadband and 99.9% of Safety services exceed annual time;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP, streaming;
- Antenna coverage:
  - 0°90°El/360az KuKarray-2L, G-18L, -10°/90°G30L Ku Viasat;
  - 0°to 90°El/360 Az Viasat antenna GM-40L and G18-L, G12-L in Ka band.
- Antenna tracking speed: 100°/s KuKarray-2L, G-18L, G30L Ku, 95°/s GM-18L Viasat antenna and 100°/s G18-L, G12-L in Ka band;
- Acquisition time: < 30s and LEO reacquisition < 2s, KuKarray-2L, G-18L in Ku band and < 30s, 2s LEO handover time in Ka band.

3.2.9.3 GOGO aeronautical services in Ku Band



GOGO Ku band service coverage in 2019

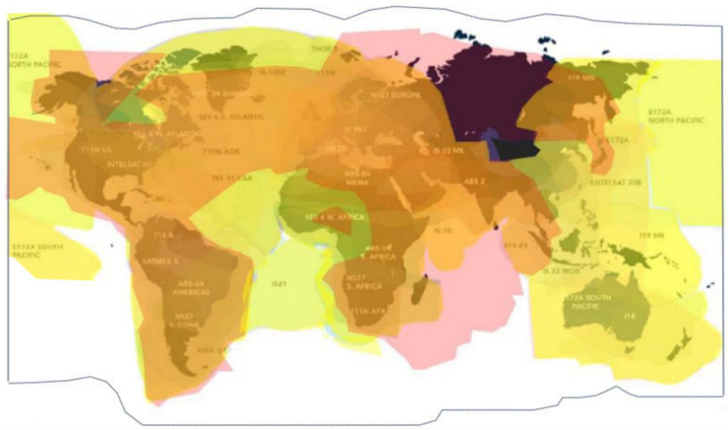
Gogo aeronautical services in Ku band are dedicated to cabin services and In-Flight Entertainment. These services are not currently dedicated to cockpit services but could be used to record data transfer.

There is no guarantee in terms of availability throughout the flight, nor with regard to the data rate. Several geostationary SATCOMs in Ku band are used by GOGO to cover the Earth.

Overview of the Gogo in Ku band datalink solution

- Frequency band: Ku band;
- Frequency: 10 GHz to 14 GHz;
- Network/operator: GOGO2Ku;
- Service: GOGO2Ku;
- Primary usage: In-Flight Entertainment;
- Secondary usage: In-Flight Entertainment;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited between -/+ 80°N/S with regional areas for continental coverage;
- Coverage: Partial Earth coverage between -/+ 80°N/S with regional areas for continental coverage;
- Throughput: Up to 2.5Mbps (TBC) and down up to 70Mbps in Ku band;
- No guaranteed bandwidth;
- Antenna type: Electronic directional or hybrid electronic and mechanical;
- Antenna location: Central position on top of the aircraft;
- Limitations: Range limited between -/+ 80°N/S with regional areas for continental coverage;
- No MOPS;
- No MOPS antenna tracking;
- No MOPS time acquisition;
- Guaranteed availability: 98%;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP;
- Antenna coverage: 7.5°to 90°El/360 Az Ku 3030 ThinKom antenna;
- Antenna tracking speed: Up to 1,000°/s;
- Acquisition time: TBD.

3.2.9.4 Global Eagle aeronautical services in Ku Band



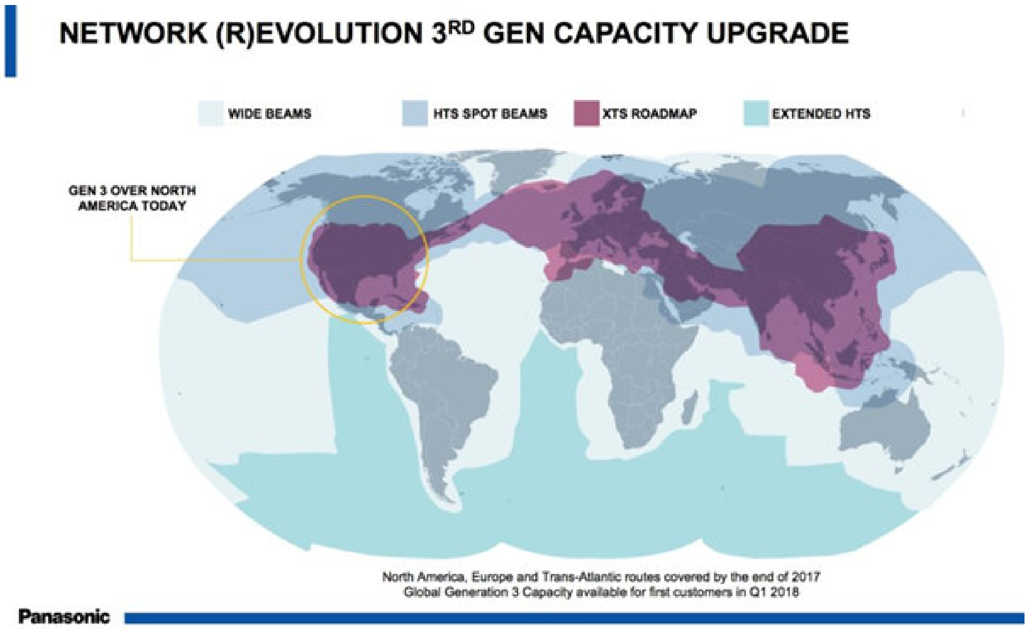
Global Eagle Ku band service coverage

Global Eagle aeronautical services in Ku band are dedicated to cabin services and In-Flight Entertainment
These services are not currently dedicated to cockpit services but could be used to record data transfer.
There is no guarantee in terms of availability throughout the flight, nor with regard to the data rate.
Global Eagle uses several geostationary SATCOMs in Ku band to cover the Earth.

Overview of the Global Eagle in Ku band datalink solution

- Frequency band: Ku band;
- Frequency: 10 GHz to 14 GHz;
- Network/operator: Global Eagle;
- Service: Global Eagle;
- Primary usage: In-Flight Entertainment;
- Secondary usage: In-Flight Entertainment;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited between -/+ 80°N/S with regional areas for continental coverage;
- Coverage: Partial Earth coverage between -/+ 80°N/S with regional areas for continental coverage;
- Throughput: Up to 1Mbps (TBC) and down up to 100Mbps;
- No guaranteed bandwidth;
- Antenna type: Directional mechanical;
- Antenna location: Central position on top of the aircraft;
- Limitations: Range limited between -/+ 80°N/S with regional areas for continental coverage;
- No MOPS;
- No MOPS antenna tracking;
- No MOPS time acquisition;
- Guaranteed availability: No;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna coverage: 0°to 90°El/360 Az ER-6000A RAYSAT;
- Antenna tracking speed: > 30°/s RAYSAT ER-6000A Wave stream;
- Acquisition time: TBD.

3.2.9.5 Panasonic aeronautical services in Ku Band



Panasonic Ku band service coverage

Panasonic aeronautical services in Ku band are dedicated to cabin services and In-Flight Entertainment.
These services are not currently dedicated to cockpit services but could be used to record data transfer.
There is no guarantee in terms of availability throughout the flight, nor with regard to the data rate.

<u>Panasonic description:</u>
Panasonic In-Flight Entertainment services have been deployed across the third generation.

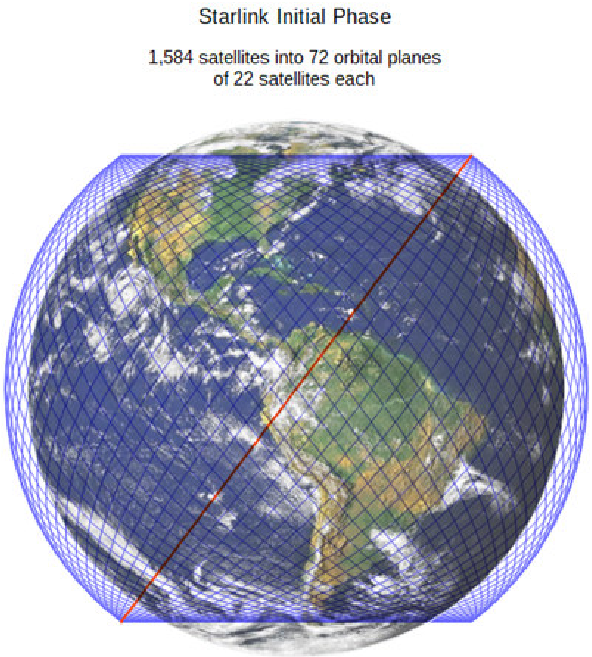
- First generation or GEN1: Worldwide 98% commercial air traffic;
- Second generation or GEN2: Worldwide 80% commercial air traffic;
- Third Generation or GEN3: Worldwide 50% commercial air traffic.

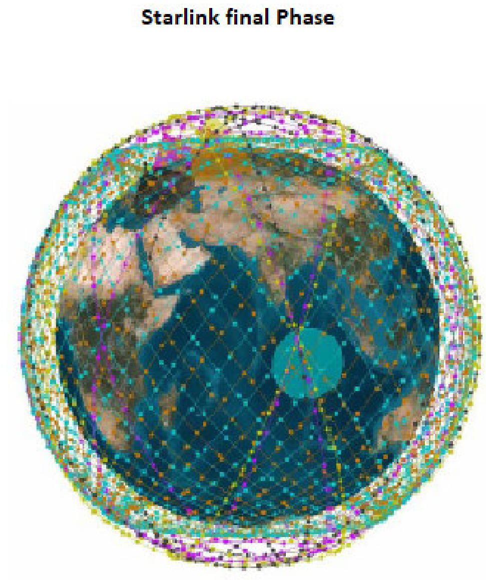
Overview of the Panasonic in Ku band datalink solution

- Frequency band: Ku band;
- Frequency: 10 GHz to 14 GHz;
- Network/operator: Panasonic;
- Service: Panasonic;
- Primary usage: In-Flight Entertainment;
- Secondary usage: In-Flight Entertainment;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground usage;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range: Limited between -/+ 80°N/S with regional areas for continental coverage;
- Coverage: Partial Earth coverage between -/+ 80°N/S with regional areas for continental coverage;
- Throughput: GEN1: 12Mbps down, up TBD; GEN2: 80Mbps down, up (TBC); GEN3: 250Mbps down, up (TBC);
- No guaranteed bandwidth;
- Antenna type: Directional mechanical;
- Antenna location: Central position on top of the aircraft;
- Limitations: Range limited between -/+ 80°N/S partial with regional areas for continental coverage;
- No MOPS;
- No MOPS antenna tracking;
- No MOPS time acquisition;
- Guaranteed availability: No;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna coverage: -10°to 90°El/360 Az Astronics;
- Antenna tracking speed: 12°/s FT310 Astronics;
- Acquisition time: TBD.

3.2.9.6 Starlink in Ku band

Starlink is a satellite internet constellation being constructed by SpaceX, providing satellite Internet access. The constellation will consist of thousands of small mass-produced satellites in Low Earth Orbit (LEO), which communicate with designated ground stations.





Starlink constellation coverage in 2021 and in the final phase

<u>Starlink Ku band description:</u>

The Starlink satellite constellation uses 4,425 satellites (currently) in 83 inclination planes and polar orbits, and in future, will use up to 42,000 satellites.
The architecture of the Starlink satellite constellation network is as follows:

- First shell: 1,440 in a 550 km (340 mi) <u>altitude</u> shell at 53.0° inclination;
- Second shell: 1,440 in a 540 km (340 mi) shell at 53.2° inclination;
- Third shell: 720 in a 570 km (350 mi) shell at 70° inclination;
- Fourth shell: 336 in a 560 km (350 mi) shell at 97.6°;
- Fifth shell: 172 satellites in a 560 km (350 mi) shell at 97.6°.

In 2020, users experienced download speeds from 11 <u>Mbit/s</u> to 60 Mbit/s, and upload speeds from 5 Mbit/s to 18 Mbit/s in the beta version, with 50ms to 100ms latency.
These services are not currently dedicated to aeronautical services but could be used to record data transfer.
In 2019, Starlink and the United States <u>Air Force Research Laboratory</u> (AFRL) conducted aircraft datalink trials through a multi-year contract.
Currently, Starlink services are not guaranteed in terms of availability throughout the flight, nor with regard to the data rate.
This system is in the satellite constellation deployment phase and only beta services are available.
In future, Starlink could also be used on aircraft for In-Flight Entertainment and data transfer recording.
Performances and availability for aircraft usage are still unknown at this time.

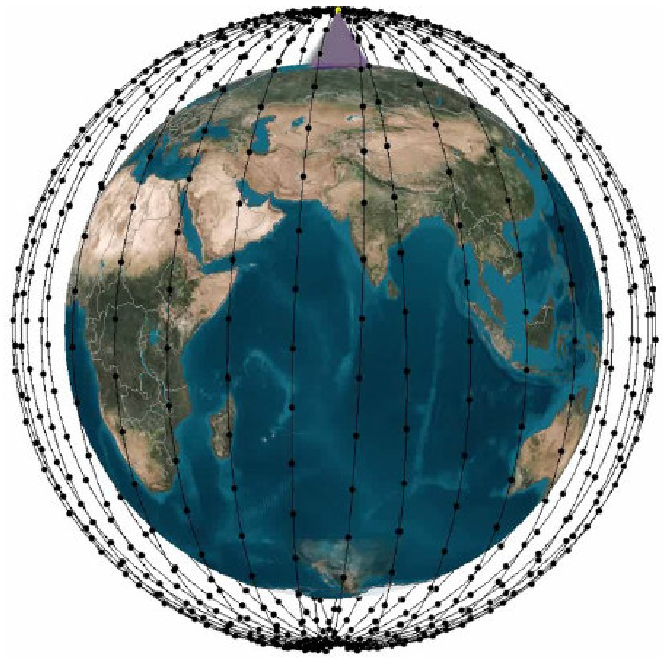
Overview of the Starlink in Ku band datalink solution

- Frequency band:
- Frequency:
- Network/operator: STARLINK;
- Service: STARLINK;
- Primary usage: Internet services;
- Secondary usage: Internet services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground): the Earth worldwide in future (including polar);
- Coverage: World+Polar;
- Throughput (kbps) - Aircraft Tx → Uplink for SAT: 10Mbps to 150Mbps in future;
- Directional electronic antenna;
- Antenna location: On top;
- Limitations (e.g., atmospheric):
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Coverage: potentially 0° to 90°;
- Nominal throughput: 10Mbps to 150Mbps, 20ms to 40ms in future;
- No guaranteed availability with current services;
- Max altitude: above 30,000ft;
- Protocol: UDP/IP and TCP/IP;
- Antenna coverage: Not defined;
- Antenna tracking speed: Not defined;
- Acquisition time, Re-acquisition time: Not defined.

3.2.9.7 Oneweb in Ku band

Oneweb primary services in Ku band are dedicated to residential internet and alternative GNSS services.

These services are not currently dedicated to aeronautical services but could be used to record data transfer.



OneWeb 720 satellites constellation

Oneweb constellation coverage in the final phase

<u>Oneweb Ku band description:</u>

The Oneweb satellite constellation uses 720 satellites in 18 polar planes at 1,200km in an 86.4° inclination plane with 40 satellites per plane.

This system is in the satellite constellation deployment phase and no services are currently available.

In future, Oneweb could also be used on aircraft for In-Flight Entertainment and for data transfer recording.

Some performances and availability for aircraft usage are still unknown at this time.

In future, potential download speeds will go up to 195Mbps, and upload speeds will range from 5 Mbps to 10 Mbps, with 50ms latency.

Overview of the Oneweb in Ku band datalink solution

- Frequency band: Ku band;
- Frequency:
- Network/operator: Oneweb;
- Service: Oneweb;
- Primary usage: Internet services;
- Secondary usage: Internet services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground):
- Coverage: World+Polar;
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SAT 10Mbps to 150Mbps;
- Antenna type: Electronic directional;
- Antenna location: Top;
- Limitations (e.g., atmospheric):
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Coverage:
- Nominal throughput: 10Mbps to 195Mbps;
- No guarantee of availability;
- Max altitude: above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna coverage: Not defined;
- Antenna tracking speed: Not defined;
- Acquisition time, Re-acquisition time: Not defined.

3.2.10 SATCOM in Ka Band

3.2.10.1 5G NTN aeronautical services in Ka Band

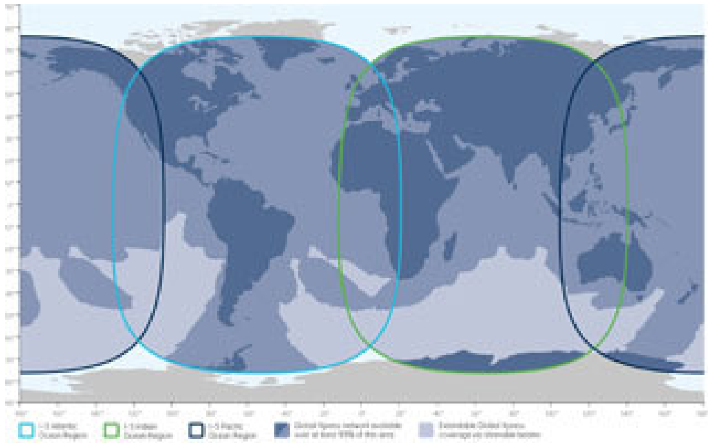
For 5G NTN, two solutions in SATCOM could be used in future, with geostationary and low orbit satellites.

Currently, no Ka band satellites are deployed in orbit for 5G services; only the 3GPP standard 5G release 17 is promulgated and release 18 is currently under discussion.

Overview of the 5G NTN (Non Terrestrial Network) in Ka band datalink solution

- Frequency band: Ka Band;
- Frequency: 17.3GHz to 30GHz;
- Network/operator: Not currently defined;
- Service operator: Dependent, in the 5G release 17 and 18 standards, NTN (LEO/GEO);
- Primary usage: Internet and throughout similar cellular services;
- Secondary usage: Internet and throughout similar cellular services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground): Worldwide in future;
- Coverage: World+Polar;
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SATCOM: Up to 200Mbps (TBC);
- Antenna type: Electronic directional;
- Antenna location: Top;
- Limitations (e.g., atmospheric): Ka band channel propagation limits;
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Antenna coverage: Not defined;
- No guarantee of availability;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna tracking speed: Not defined;
- Acquisition time, Re-acquisition time: Not defined.

3.2.10.2 Inmarsat V aeronautical services in Ka Band



Inmarsat V Global Xpress Ka band service coverage

<u>Inmarsat V Global express Ka band description:</u>

INMARSAT Global Xpress services in Ka band have similar Earth coverage to Swift Broadband services, but with a higher data rate, up to 10Mbps in uplink and downlink. This service uses a bigger antenna.

Airborne antenna systems need a mechanical positioner or electronic antenna scanning with lower availability than the L band antenna.

The Global Express constellation is composed of three GEO satellites, which provide near-complete global coverage (with the exception of the poles and high latitude regions). Performances depend on the antenna type. Two types of antennas are currently considered for aeronautical applications:

Fuselage-mounted antenna:

- Downlink data rate: 42 Mbps Max, 18 Mbps Min;
- Uplink data rate: 3.8 Mbps Max, 450 kbps Min.

Tail-mounted antenna:

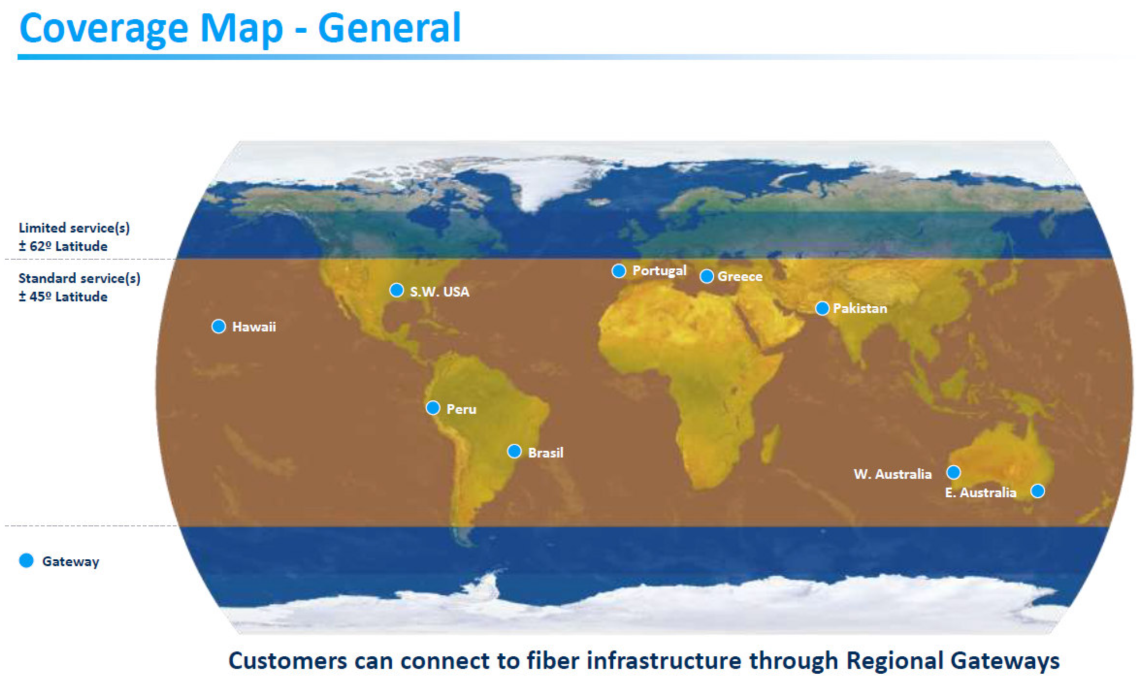
- Downlink data rate: 35Mbps Max, 15 Mbps Min;
- Uplink data rate: 2.1 Mbps Max, 400 kbps Min.

Manufacturer	Inmarsat		Model		Added by	Astrium
Used Technology 1	GlobalExpress (Inmarsat V)					
Type	Command&Control		Payload		Air Traffic Integration	
Standards/Protocols	Downlink DVB-S2/Uplink proprietary iDirect (MF-TDMA)					
Frequency	DL: 19.7 to 20.2 GHz and 19.2 to 19.7 GHz (high-capacity beam) UL: 29.5 to 30.6 GHz and 29 to 29.5 GHz (high-capacity beams)					
Bandwidth	32 MHz					
Transmission power	Up to 55dBw					
Data rate	Up to 42 Mbps DL Up to 3.8 Mbps UL					
Modulation	QPSK, 16QAM, 32 QAM, 64 QAM					
Range	Worldwide					

Overview of the Inmarsat V Global Xpress in Ka band datalink solution

- Frequency band: Ka Band;
- Frequency: 26.5GHz to 40GHz;
- Network/operator: Inmarsat V;
- Service operator: Global Xpress;
- Primary usage: Internet and In-Flight Entertainment services;
- Secondary usage: Internet and In-Flight Entertainment services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground): Worldwide without polar pole lat +80N and -80S, Mobile spot;
- Coverage: World+Polar;
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SATCOM: 2.1Mbps to 3.8Mbps;
- Antenna type: Electronic directional;
- Antenna location: On top of fuselage or tail-mounted;
- Limitations (e.g., atmospheric): Ka band channel propagation limits (may be affected by propagation under cloud);
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Antenna coverage: -8° to 90° El AZ 360° (GETSAT milli) or 7.5°to 90°El/360 Az KA 2517 ThinKom antenna;
- No guarantee of availability;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna tracking speed: Not defined 200°/sec (mechan GETSAT milli) or 1,000°/s KA 2517 ThinKom;
- Acquisition time, Re-acquisition time: Not defined.

3.2.10.3 SES Astra aeronautical services in Ka Band



O3B and Mpower KA band service coverage

SES Astra O3B and Mpower aeronautical services in Ka band are dedicated to mobile internet and other mobile services in the aeronautical, maritime and terrestrial fields.

These services are not currently dedicated to cockpit services but could be used to record data transfer.

<u>O3B and Mpower Ka band description:</u>

O3B Mpower is a communications satellite system currently under construction and due to be launched in Q3 2021. Owned and operated by SES, O3B Mpower initially comprises 11 high-throughput and low-latency satellites in a Medium Earth Orbit (MEO), along with ground infrastructure and intelligent software, to provide multiple terabits of global Broadband connectivity for applications including cellular backhaul to remote rural locations and simultaneous international IP trucking.

The O3B Mpower satellites use fully-shapable and steerable spot beams that can be shifted and scaled in real-time to suit individual users, and will join SES' existing constellation of 20 first generation O3B satellites in MEO.

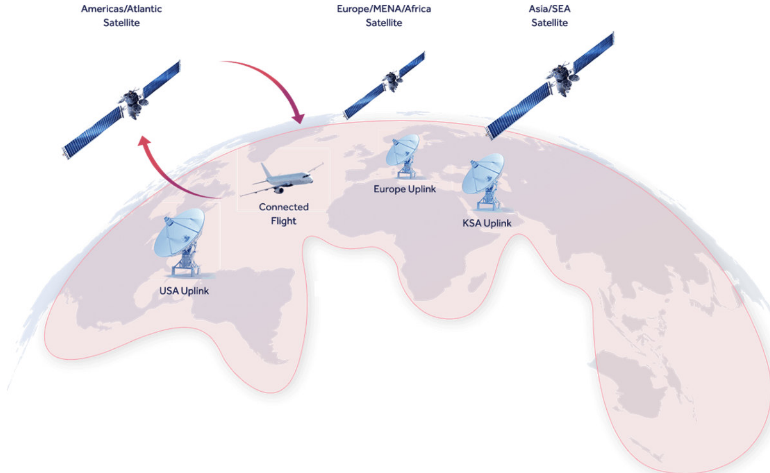
From MEO, the O3B Mpower satellites can deliver high-bandwidth connectivity between latitudes 50°N and 50°S (covering 96% of the global population) to mobile and/or remote terminals.

Additional satellites operating in a second medium Earth orbit at an inclination of 70° would give near-complete global coverage.

Overview of the O3B and Mpower in Ka band datalink solution

- Frequency band: Ka Band;
- Frequency: 20GHz to 30GHz;
- Network/operator: SES ASTRA;
- Service operator: SES ASTRA;
- Primary usage: Internet and In-Flight Entertainment services;
- Secondary usage: Internet and In-Flight Entertainment services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground): Worldwide;
- Coverage: World+Polar (O3B + Mpower);
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SATCOM: 1Mbps to 15Mbps;
- Antenna type: Electronic and mechanical directional;
- Antenna location: Top of fuselage;
- Limitations (e.g., atmospheric): Ka band channel propagation limits (may be affected by propagation under cloud) less affected due to MEO satellite altitude around GEO Ka band SATCOM;
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Antenna Coverage: 0° to 90° El AZ 360° (GETSAT milli);
- No guarantee of availability;
- Max Altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna tracking speed: 200°/sec (GETSAT milli);
- Acquisition time, Re-acquisition time: < 100ms.

3.2.10.4 GDC/Taqnia aeronautical services in Ka Band



GDC/Taqnia KA band service coverage

GDC/Taqnia aeronautical services in Ka band are dedicated to IFE/IFC services.
These services are not currently dedicated to cockpit services but could be used to record data transfer.
There is no guarantee in terms of availability throughout the flight, nor with regard to the data rate.
Satellite coverage is limited to regional areas.
<u>Overview of the GDC/Taqnia in Ka band datalink solution</u>

- Frequency band: Ka Band;
- Frequency: 20GHz to 30GHz;
- Network/operator: New GDC/Taqnia;
- Service operator: GDC/Taqnia;
- Primary usage: Internet and In-Flight Entertainment services;
- Secondary usage: Internet and In-Flight Entertainment services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground): Regional;
- Coverage: Partial world;
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SATCOM: 1Mbps (TBC);
- Antenna type: TBD;
- Antenna location: Top of fuselage;
- Limitations (e.g., atmospheric): Ka band channel propagation limits (may be affected by propagation under cloud);
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Antenna coverage: (TBD);
- No guarantee of availability;
- Max Altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna tracking speed (TBD);
- Acquisition time, Re-acquisition time: (TBD).

3.2.10.5 Kuiper in Ka band

Kuiper Systems LLC is a subsidiary of Amazon that was set up in 2019 to deploy a large Broadband satellite internet constellation to provide Broadband internet connectivity.

Kuiper primary services in Ku band are dedicated to residential internet and alternative GNSS services.

These services are not currently dedicated to aeronautical services but could be used to record data transfer.

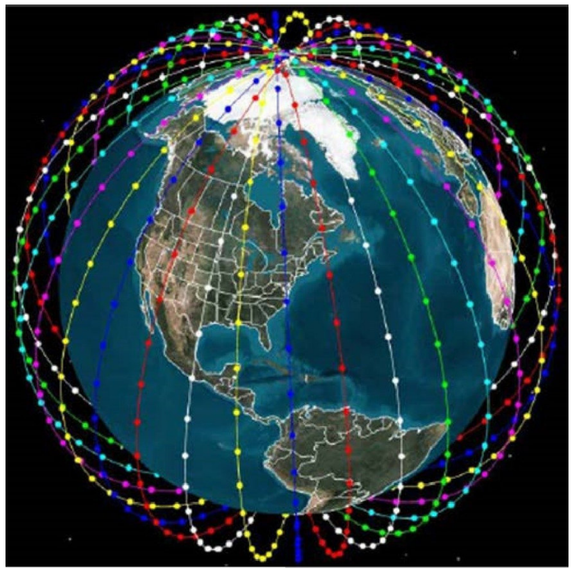


Figure: Kuiper constellation coverage in final phase

Kuiper Ka band description:

The Kuiper System plans to use 3,236 satellites operating in 98 orbital planes in three orbital shells, one each at 590 km (370 mi), 610 km (380 mi), and 630 km (390 mi) orbital altitude.

The Kuiper user terminal is expected to support up to 400Mbps in downlink; the uplink data rate is currently unknown.

The user terminal uses low-cost flat-panel antennas. It is a Ka-band phased-array antenna that is much smaller than traditional designs for antennas that operate at 17–30 GHz. The antenna will be ~30 cm (12 in) in width and is expected to support up to 400 megabits per second (Mbps) of data bandwidth.

This satellite constellation system is planned but not deployed.

In future, Kuiper could also be used on aircraft for In-Flight Entertainment and for data transfer recording.

Some performances and availability for aircraft usage are still unknown at this time.

Overview of the Kuiper in Ka band datalink solution

- Frequency band: Ka band;
- Frequency: downlink 17.7-18.6 GHz, 18.8-20.2 GHz, Uplink 27.5-30.0 GHz;
- Network/operator: Kuiper;
- Service: Kuiper (TBC);
- Primary usage: Internet services;
- Secondary usage: Internet services;
- Primary operation: Surface/Climb-Desc/Cruise;
- Air-Ground;
- Full Duplex;
- Not a Protected Aeronautical Spectrum;
- Range (Nm) at 30,000 ft or above (Air-Ground):
- Coverage: World+Polar;
- Throughput (kbps) - Aircraft Tx ➔ Uplink for SAT: Not currently known, only downlink at 400Mbps;
- Antenna type: Electronic directional;
- Antenna location: Top;
- Limitations (e.g., atmospheric):
- No MOPS;
- MOPS antenna tracking: Currently not defined;
- MOPS time acquisition: Currently not defined;
- Coverage;
- Nominal throughput Tx (TBC): 400Mbps in downlink;
- No guarantee of availability;
- Max altitude: Above 30,000ft;
- Protocol: UDP/IP (TBC);
- Antenna coverage: Not defined;
- Antenna tracking speed: Not defined;
- Acquisition time, Re-acquisition time: Not defined.

3.3 Datalink transmission criteria

Several transmission parameters and performances must be considered to select the best recorder data radio transmission solutions.

The link budget of each link between the aircraft and a ground station or between the aircraft and a satellite or between aircraft must be studied and calculated throughout a flight trajectory, and everywhere on Earth, to be sure that propagation effects do not degrade performances with sufficient link margin.

Some data radio transmission links are greatly affected by propagation effects due to their high frequency band use (e.g.: Ka band or HF band).

Each datalink transmission is limited in geographic coverage and range.

Another parameter is the availability of the transmission link as a percentage of annual time exceeded in relation to link budget analysis (official definition for statistical link availability guarantee throughout a year).

The inter-visibility (with Fresnel Ellipsoid) of each link between the aircraft and ground station/satellite/other aircraft must be studied and calculated throughout a flight trajectory.

This studied inter-visibility could be impacted by different situations.

For example, antenna masked due to fuselage, antenna beam limitation due to aircraft attitude or antenna tracking speed in relation to excessive aircraft attitude.

Some datalink transmissions are already used for safety services and could be re-used for the specific purpose of QR-FRD but with the limitation of switching them during the airborne phase and during the ground phase (furthermore, aircraft to aircraft or services across SATCOM must be considered).

Note: Current safety services are dedicated systems with dedicated ground infrastructures. These systems could be re-used to transmit recorder data but with modifications on the airborne side and on the ground side to split or switch the data flow between safety service data and data coming from the recorder and to redirect it to a dedicated system.

These solutions impact current safety normalization standards and infrastructures.

For existing datalink dedicated cockpit services, some MOPS are available to guarantee operational requirements and services.

For IFE datalink services, no MOPS are available, performances are not guaranteed, and each datalink must be studied to validate current performances. IFE solutions nevertheless present complementary and possible redundancy solutions. The benefit of IFE solutions is to offer more bandwidth than other solutions but with limited or no link availability and guarantee of data rate services.

4 Wireless media possibility for FDR data transmission

Integrating the results of the "Factors" and "Communication solutions" chapters, the possible communication solutions are as follows:

Based on existing communication media:

- Most recommended communication media solution:
  - UHF L Band – 960 to 1,164MHz – LDACS1 network. LDCAS1 expected throughput is up to 1.3Mbps;
  -
  - SATCOM L Band – 1,616.0-1,626.5 MHz - Iridium Next (66xSAT LEO) network. SATCOM L Band Iridium Next Certus service expected throughput is up to 350Kbps (now) and 524Kbps (in future).

- Recommended communication media solution:
  - SATCOM L Band – 1,525 to 1,559 MHz, 1,626.5 to 1,660.5 MHz - Inmarsat IV (3xSAT GEO) network. SATCOM Inmarsat IV Swift Broadband services offer up to four (channel) x432Kbps=1.728Mbps;
  -
  - SATCOM Ka Band – 26.5GHz to 40GHz - Inmarsat V (4xSAT GEO) network. SATCOM Inmarsat V Global Express services offer up to 3.8Mbps.

- Alternative communication media solution:
  - WHF (gen3, gen4) - 2.85MHz to 22MHz;
  -
  - S band SATCOM – 1.98GHz to 2.2GHz (in 3 ITU regions) in future - 5G NTN (SATCOM LEO/GEO) network.

Note: The LDACS1 and SATCOM L band solutions would be considered as redundant and in parallel media to optimize link availability.

Note: LDACS1 is terrestrial and a line-of-sight datalink but could also be used as a relay between aircraft in line-of-sight between us and terrestrial.

Integrating future communication media:

- SATCOM – Starlink Ku network solution;
- SATCOM – Oneweb Ku network solution;
- SATCOM – Kuiper Ka network solution.

Note: Financial considerations have not yet been evaluated.

5 References

Reference	Title	Date
[R0]	Quick Recovery of Flight Recorder Data - Procurement Documents, EASA.2020.HVP.06	10 June 2020
[R1]	International Commercial Air Transport - Aeroplanes (dated July 2018 or later), ICAO Annex 6 part I, Operation of Aircraft	July 2010
[R2]	Aircraft Accident and Incident Investigation, ICAO Annex 13	2019
[R3]	Manual on Location of Aircraft in Distress and Flight Recorder Data Recovery, ICAO Doc 10054	
[R4]	Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems (September 2013), EUROCAE ED-112A	September 2013
[R5]	Minimum Aviation System Performance Specification for Criteria to Detect In-Flight Aircraft Distress Events to Trigger Transmission of Flight Information, EUROCAE ED-237	February 2016
[R6]	Triggered transmission of flight data working group report, BEA	March 2011
[R7]	Flight data recovery working group report, BEA	3 September 2020
[R8]	Aircraft Autonomous Distress Tracking (ADT), ARINC Report 680	26 August 2016
[R9]	Timely Recovery of Flight Data (TRFD), ARINC Report 681 draft 4	31 July 2020
[R9 bis]	Timely Recovery of Flight Data (TRFD), ARINC Report 681 draft 5	26 March 2021
[R9 ter]	Timely Recovery of Flight Data (TRFD), ARINC Report 681	August 6th, 2021
[R10]	Global Aeronautical Distress Safety System (GADSS) – Concept of Operations, ICAO, Version 6.0	7 June 2017
[R11]	BEA study “Aircraft Tracking and Flight Data Recovery via Satellite Constellations”	06/03/2018
[R12]	EUROCAE ED-237, MASPS for Criteria to detect in-flight aircraft distress events to trigger transmission of flight information	01/02/2016
[R13]	Location of an Aircraft in Distress Repository, Functional Specification, Draft	03/05/2019
[R14]	ED-62B/DO-204B, MOPS for new generations of ELTs	
[R15]	Statistical Summary of Commercial Jet Airplane Accidents – worldwide Operations 1959 – 2019	December 2020

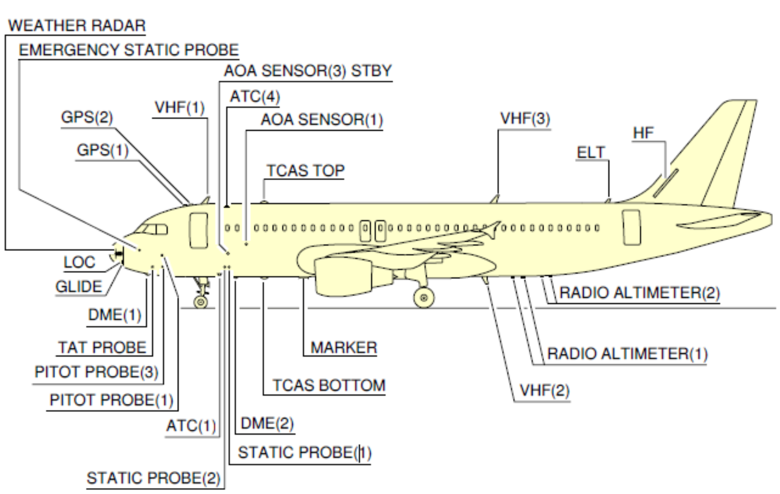
6 List of Abbreviations

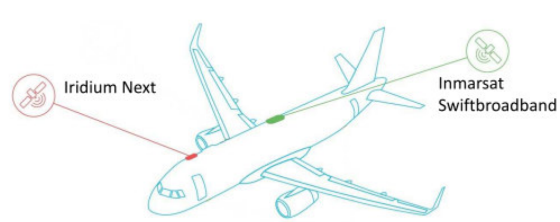
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
CICTT	CAST/ICAO Common Taxonomy Team
CFIT	Controlled Flight into or Toward Terrain.
FDR	Flight Data Recorder
FOMAX	Flight Operations and MAintenance eXchanger (™ Airbus)
FTP	File Transfer Protocol
GADSS	Global Aeronautical Distress & Safety System
GNSS	Global Navigation Satellite System
GPWS	Ground Proximity Warning System
GSA	European GNSS Agency
HAPS	High Altitude Pseudo Satellite
HF	High Frequency
HFDL	High Frequency Data Link
HFN	HF Next (© Collins)
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Associations
IM	Information Management
IP	Internet Protocol
KOM	Kick-Off Meeting
LOC-I	Loss of Control – In Flight
MCTOW	Maximum Certificated TakeOff Weight
MDDU	Multipurpose Disk Drive Unit
MOPS	Minimum Operational Performance Specification
NATO	North Atlantic Treaty Organization
OAT	Onboard Aircraft Tracking
OEM	Original Equipment Manufacturers
OSI	Open System Interconnection
PIESD	Passenger information and Entertainment Service Domain
PM	Program Manager
PMP	Project Management Plan

QA	Quality Assurance
QR	Quick Recovery
QSR	Quality State Report
R&O	Risk and Opportunity
RCF	Rockwell Collins France, a Collins Aerospace Company
SCI	Secure Centralized Interface
SED	Safran Electronics & Defense
SME	Subject Matter Expert
SNPL	Syndicat National des Pilotes de Ligne
SSR	Secure Server Router (© Collins)
TBC	To Be Confirmed
TBD	To Be Defined
TCP	Technical Consistent Process
TPM	Technical Project Manager
TPQM	Technical Performance & Quality Measures
TRL	Technical Readiness Level
TS	Tender Specification
UN	United Nations
VDL	VHF Digital Link
VHF	Very High Frequency
WBS	Work Breakdown Structure

APPENDIX A: Communication equipment

ATA	System	Qty of antennas	Operating Frequency Band	Comment
34	ADF		190 - 1750 Khz	Could be removed? Expected to be still in use in third world countries
23	HF	0 or 1	Analog Voice: 2-30 Mhz HF Datalink:	At least 1 + SatCom or 2 to fly outside VHF coverage
34	MARKER BEACON		75 Mhz	Part of VOR
34	LOC/DGPS		108 -118 Mhz	Part of ILS / xLS
23	VHF	3	118 – 136.975 Mhz	2 are mandatory (CS 25.1307); most a/c are equipped with 3 – the 3rd one is usually devoted to cockpit data-link (but can be used for Voice as necessary)
34	GLIDE SLOPE		328.6 – 335.4 Mhz	Part of ILS
46	EICU			Replaces Gatelink
23	ELT		121.5; 243 and 406 MHz	Emergency Locator Transceiver
34	DME		962 - 1213 Mhz	
46	GATELINK		VARIOUS [WiFi 2.4 GHz / LTE / UMTS]	Used for ATA 46 Open World – could be removed
34	ATC TRANSPONDER RECEIVER	Top x 2 + Bottom x 2	1030 RX 1090 TX Mhz	Used for ATC and ADS-B Out Fully redunded system; one unit can be shared with TCAS and share antennas as well
34	TCAS	Top x 1 + bottom x1	1030 TX 1090 RX Mhz	Traffic Collision Avoidance System
23	SATCOM INMARSAT	tbc (optional)	1525 - 1660,5 Mhz	
23	SATCOM IRIDIUM	tbc (optional)	1616 - 1626,5 Mhz	



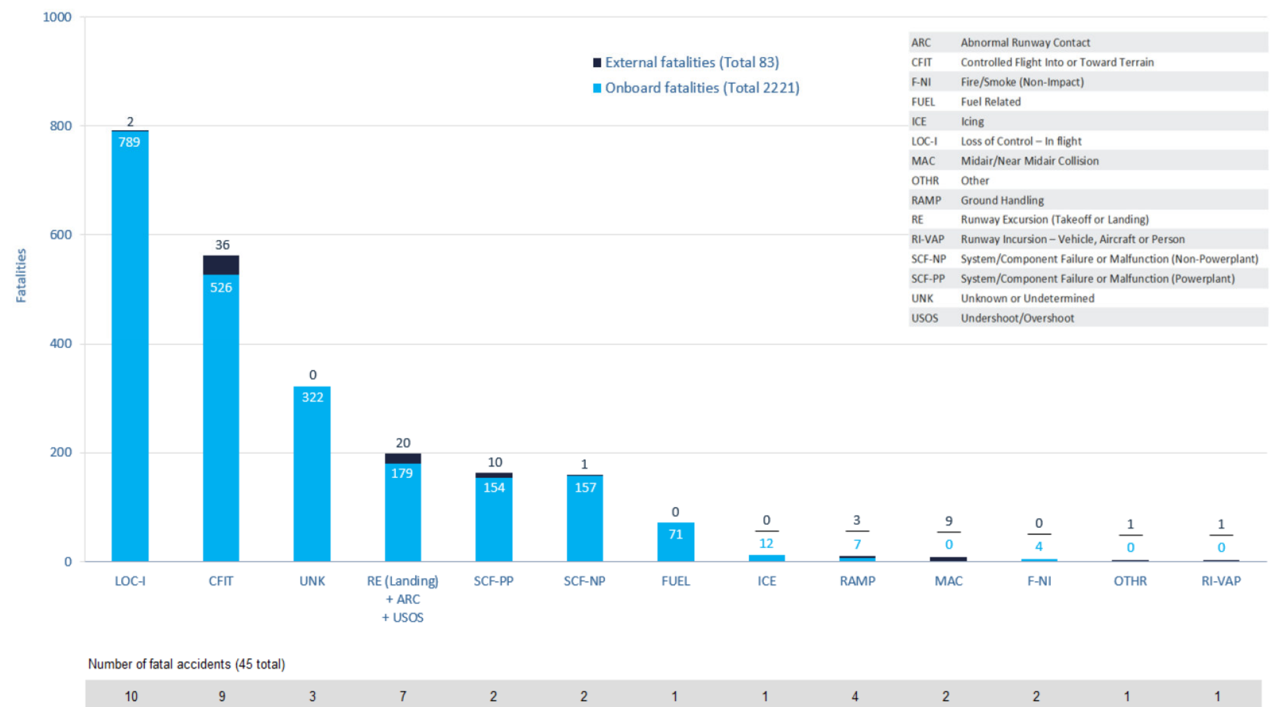


APPENDIX B: Fatal accident categories

Extract from the Boeing Statistical Summary document. This annually published document presents accidents involving commercial jet aircraft with a maximum take-off weight of over 60,000 lbs (27t). The accident categories used here refer to CAST/ICAO taxonomy.

Please see https://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf

Fatal Accidents | Worldwide Commercial Jet Fleet | 2010 through 2019



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